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ABSTRACT BOOKLET

COAL - ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT



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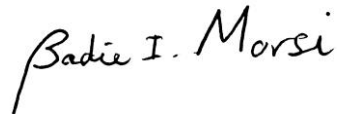
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On behalf of the Twenty-Seventh Annual International Pittsburgh Coal Conference, we wish to express our sincere appreciation to Ms. Heidi M. Aufdenkamp for her dedication and professionalism; and Mr. Yannick Heintz and Mr. Laurent Sehabiague for their invaluable assistance in preparing this Abstracts Booklet.

Thank you,

A handwritten signature in black ink that reads "Badie I. Morsi". The signature is written in a cursive style with a large, sweeping initial 'B'.

Badie I. Morsi, Editor
Professor and Executive Director of the Conference

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SESSION 1
Combustion: Oxy-Coal Development – 1

1-1
Development of Oxycoal™ Technology Resulting from Testing Conducted at Doosan Power Systems' Clean Combustion Test Facility (CCTF)

Peter Holland-Lloyd, David Fitzgerald, Doosan Power Systems, UNITED KINGDOM

Oxyfuel combustion technology is one of several Carbon Abatement Technologies (CATs) currently being developed. The technology offers a means of generating carbon dioxide rich flue gas requiring minimal treatment prior to sequestration or beneficial application. Doosan Power Systems are aiming to develop a competitive oxyfuel firing technology suitable for full plant application post 2015, and is taking a phased approach to the development and demonstration of oxyfuel technology. Doosan Power Systems is leading a number of collaborative projects that are investigating 'Oxyfuel Combustion Fundamentals and Underpinning Technologies', the 'Demonstration of an Oxyfuel Combustion system', the 'Modelling and Testing of the 40 MWt OxyCoal™ Burner', and the 'Optimisation of Oxyfuel PF Power Plant for Transient Behaviour'. This paper outlines progress on the 'Demonstration of an Oxyfuel Combustion system' project, which is demonstrating an oxyfuel combustion system of a type and size (40MWt) applicable to new build and retrofit advanced supercritical boiler plant. Installation and commissioning are complete and testing is in progress. Preliminary results have shown safe and smooth transitions between air firing and oxyfuel operation, with economiser outlet CO₂ concentrations greater than 85% v/v dry being achieved.

1-2
Co-Firing of Coal and Wood Biomass in Oxy-Fuel Combustion

Seong Yool Ahn, Jae woo An, Yon Mo Sung, Cheor Eon Moon, Gyung Min Choi, Duck Jool Kim, Pusan National University, SOUTH KOREA

The characteristic such as ignition, maximum, burn-out temperature, heat-flow and gas component of co-firing biomass with coal in various oxy-fuel combustion conditions were investigated to provide useful information about applying technique to existing power plant in this study. Wood biomass is more efficient than sub-bituminous coal for cost and has many advantages for environmental regulations. Though wood biomass is CO₂ free fuel and it has a little amount of sulfur comparing with coal, the heating value of wood biomass is much lower than coal fuels. This makes it hard to use at existing power plants. In this study, we explored the thermo gravimetric analysis in air and oxy-fuel atmospheric conditions with three kinds of coal (wira, adaro, shenhua). The thermo gravimetric analyzer (DSC TGA, TA instrument Q600) ran under non-isothermal and co-firing biomass with coal in oxy-fuel conditions. Heating rate was 30 K/min at temperature up to 1300 K and also we investigate the syngas composition to provide coal reactivity under low heating rate condition. The size of selected coals and wood biomass in this report were filtered by a 200 mesh sieve. 15 mg weight of sample was used at one time and 100 ml/min of oxidant (air, O₂ and CO₂ mixture) was supplied to TGA continuously. SRI 8610C which has HID and TCD detector was used for gas analysis (H₂, CO, CO₂). The temperature of ignition, maximum and burn-out from the TG and DTG curve indicate volatile and carbon reactivity at various atmospheres. The higher rate of biomass was mixed, the lower ignition temperature was appeared due to high content of volatile matters. The burn-out temperature was affected more than ignition temperature by changing atmospheric condition. Heat flow profile means actual heat transfer in combustion process; this heat flow is important information to apply co-firing in oxy fuel condition to existing power plants. The results of syngas analysis are useful to investigate the chemical reaction in reaction process. The results obtained show that specific condition of co-firing coal and wood biomass in oxy-atmosphere has very similar tendency with air condition.

1-3
NO_x Reburning in Oxy-Fuel Combustion – An Experimental Investigation

Daniel Kühnemuth, Fredrik Normann, Klas Andersson, Filip Johnsson, Bo Leckner, Chalmers University of Technology, SWEDEN

This work investigates the reburning reduction of nitric oxide (NO) in a 100 kW propane-fired oxy-fuel flame. The conducted experiments include a comprehensive parameter study: NO was injected into the recycled flue-gas, the inlet oxygen concentration was varied between 25 and 37 vol. % and the stoichiometric ratios at the burner inlet ranged from 0.7 and 1.15. The respective influence of inlet oxygen concentration and burner stoichiometry on once-through and total reduction of NO was measured. Furthermore, concentration and temperature in the furnace were mapped to

identify important differences between oxy and air-fired conditions. The furnace measurements show that the peak concentration of carbon monoxide may be more than twice as high as in air-fired conditions. The formation paths of CO and its influence on the NO_x chemistry are therefore discussed. The results of the parameter study show that reburning is favored by decreased burner stoichiometry. The effect of inlet oxygen concentration on once-through NO reduction is of minor importance. Changes in stoichiometry and oxygen inlet concentration are associated with changes in recycle ratio. The influence of the recycle ratio on the NO reduction is of great importance and is investigated as separate parameter.

1-4
Oxy-Combustion of Pulverized Coal: Modeling of Char-Combustion Kinetics

M. Geier, C. R. Shaddix, Sandia National Labs, USA; B. S. Haynes, University of Sydney, AUSTRALIA

In this study, char combustion of pulverized coal under oxy-fuel combustion conditions was investigated on the basis of experimentally observed temperature-size characteristics and corresponding predictions of numerical simulations. Using a combustion-driven entrained flow reactor equipped with an optical particle-sizing pyrometer, combustion characteristics (particle temperatures and apparent size) of pulverized coal char particles was determined for combustion in both reduced oxygen and oxygen-enriched atmospheres with either a N₂ or CO₂ bath gas. The two coals investigated were a low-sulfur, high-volatile bituminous coal (Utah Skyline) and a low-sulfur subbituminous coal (North Antelope), both size-classified to 75–106 μm. A particular focus of this study lies in the analysis of the predictive modeling capabilities of simplified models that capture char combustion characteristics but exhibit the lowest possible complexity and thus facilitate incorporation in existing computational fluid dynamics (CFD) simulation codes. For this purpose, char consumption characteristics were calculated for char particles in the size range 10–200 μm using (1) single-film, apparent kinetic models with a chemically "frozen" boundary layer, and (2) a reacting porous particle model with detailed gas-phase kinetics and three separate heterogeneous reaction mechanisms of char-oxidation and gasification. A comparison of model results with experimental data suggests that single-film models with reaction orders between 0.5 and 1 with respect to the surface oxygen partial pressure may be capable of adequately predicting the temperature-size characteristics of char consumption, provided heterogeneous (steam and CO₂) gasification reactions are accounted for.

1-5
Study on Thermodynamic Calculation for O₂/CO₂ Flue Gases Recycled Combustion Boiler

Li-Qi Zhang, Can-Zhi Li, Fang Huang, Ji-Hua Qiu, Chu-Guang Zheng, Huazhong University of Science and Technology, CHINA

Oxy-fuel combustion technology is considered as an effective approach to capture CO₂ from the combustion of fossil fuels. The traditional boiler must be retrofitted in order to adapt to this new technology and the conventional thermodynamic calculation method also needs to be modified for obtaining higher accuracy. A 50MW traditional pulverized coal boiler was calculated in this paper, which adopts modified thermal calculation method to calculate the thermodynamic in the different O₂/CO₂ recycle mode and in different recycle rate, compares the results with that of traditional air and optimizes the recycle rate in O₂/CO₂ recycle mode. The results indicated that the best operation condition will be achieved when the oxygen volume of oxidant is 30% (recycle rate 0.633) in hot recycle mode.

SESSION 2
Gasification: General Session - 1

2-1
Coal: Biomass Gasification - A Pathway for New Technology Development of Oxygen Blown Co-fired Gasification with Integrated Electrolysis

Tana Levi, R. Witney, Y Iwasaki, Tony Clemens, CRL Energy Ltd.; S Pang, Q Xu, University of Canterbury; AI Gardiner, Industrial Research Limited, NEW ZEALAND

This paper describes new research that builds on the air blown gasification of lignite for hydrogen production technology that has been developed over the past several years. The new technology package is designed to assist New Zealand meet the challenges of peak oil and global climate change. The programme uses the results from gasifying a range of pellet blends of lignite or sub-bituminous coal with P.radiata or

E.nitens, in either a bench scale gasifier or a 50 kW gasifier, to develop a fundamental understanding of the chemical processes underpinning gasification behaviour of coal/biomass blends. Significant attention is given to the development of a new technology comprised of oxygen blown co-fired gasification with integrated electrolysis for production of low carbon footprint syngas, syngas and hydrogen from New Zealand's coal and biomass resources. Syngas produced can be used for Fischer Tropsch production of liquid transport fuels. If shown to be successful the new technology would offer: i) Low carbon footprint transport fuels for the present and hydrogen for future transport fleets, ii) Increased flexibility in tailoring syngas for Fischer Tropsch production, and iii) A new option for matching the uptake of New Zealand intermittent renewable generation (including wind, marine and hydro) with a new deferrable load in the form of stored hydrogen.

2-2

Hydrogen Generation from Water by Using Plasma

Beycan Ibrahimoglu, Ibrahim Ibrahimoglu, Anadolu Plazma Teknoloji Merkezi; Fırat Şen, Vestel Defence Industry R&D Department; Şahika Yürek, Türkiye Kömür İşletmeleri; Orhan Demirel, Turkish Coal Enterprises (TKI), TURKEY

Plasma is the key to the development of new advanced technologies of producing hydrogen from different sources – water, hydrogen sulfide, a variety of hydrocarbons (including natural gas) and even coal. Plasma processes are characterized by extremely high specific productivity (more than 100 times in comparison with catalytic processes), low metal capacity and absence of inertia, they are ecology friendly. 21st era's the new energy carrier hydrogen can be produced from different sources. Today though different methods have been used for hydrogen production from water; it has not been produced in great amount and cheaply. Recently, to produce hydrogen from water, plasma method is used.

2-3

Technology and Operational Experience – The Shell Perspective

Jay Wang, Shell Global Solutions International BV, THE NETHERLANDS

In our presentation we will discuss Shell's experience of deploying SCGP in China, and how learning from our experience has enabled new levels of operational excellence. Up to date, Shell has sold nineteen licences in China, some of which are repeat customers. We will illustrate how we have learnt from experience on the ground and were able to make a wave of several start-ups a success: in one plant less than 12 hours elapsed between initial coal feeding and actual production of methanol products. We will show that we are not just focusing on deployment enablers for today, but continue to invest in both R&D and deployment capabilities that will enable the growth of coal gasification over the coming decades. We're harnessing excellence in technology and design – especially in India and China – while constantly seeking out new opportunities to deploy gasification.

2-4

Controlling the Synthesis Gas Composition from Catalytic Gasification of Hypercoal and Coal by Changing the Gasification Parameters

Atul Sharma, Toshimasa Takanohashi, National Institute of Advanced Industrial Science and Technology, JAPAN

Catalytic gasification of coal is an efficient way to achieve high gasification rates at as low as 700°C temperatures. The problem of deactivation of catalyst due to the interaction of catalyst with mineral matter in the coal was overcome by using HyprCoal, an ash less product of solvent extraction process as feed coal for catalytic process. Synthesis gas is the main desirable product and its composition H₂/CO ratio is important for its use in the downstream FT process. However, in a catalytic gasification process it is difficult to control the gas composition because of the effect of catalyst on water-gas shift reaction. Effect of temperature and gasifying agent composition on gasification rate and synthesis gas composition were investigated. Experiments were carried out with pure steam, pure CO₂ and mixture of steam and CO₂ as gasifying agents in the 600–700°C temperature range to investigate the effects. Results showed that by adjusting the steam to CO₂ ratio of the gasifying agent it is possible to control the synthesis gas composition. Effect of CO₂ addition on reaction kinetics was discussed along with the calculated gas compositions. A new single step process to produce a desired synthesis gas from catalytic gasification has been proposed.

2-5

A Technico-Economical Feasibility Study of Plasma Assisted Coal Gasification Compared to a Reference Auto-Thermal Gasification Process

Nazim Merlo, Iskender Gökalp, ICARE-CNRS, FRANCE

The paper explores the technical and economic feasibility of a plasma assisted coal gasification facility. Allothermal gasification processes provide higher gas mass yield compared to auto-thermal processes but their relevancy in terms of energy balance, global economics and environmental, namely CO₂, impact remains still to be demonstrated.

In this work, we first select a reference auto-thermal process of coal gasification compatible with plasma generator integration. The concept chosen is based on the NETL study entitled *Baseline Technical and Economic Assessment of a Commercial Scale Fischer-Tropsch Liquids Facility* (2007). The coal of reference in this study is an Illinois No. 6 bituminous coal. The gasifiers studied concern two-stage, oxygen-blown, entrained flow, refractory-lined gasifiers with continuous slag removal. Dedicated air separation units supply 95 % purity oxygen to the gasification process. Gasification units are the heaviest investment part with 41 % of the total investment for the considered plant. The commercial aim of the modeled plant is to produce 50 000 barrels per day of commercial-grade diesel (56 %) and naphtha liquids (44 %).

In a second step, we design a new gasification process where plasma generators are integrated, as realistically as possible, to the reference process. For this work we essentially use the AspenPlus software. Plasma torches chosen belong to the non-transferred arc technology with a hot cathode up to 200 kWe and a cold one beyond. Generally, the power range of plasma torches selected for industrial uses is 200-4000 kWe. Basically, current technological constraints concern cathode materials in relation to the plasma gas and the gasifier pressure range which is 0.1-0.5 MPa for these plasma torches. We also define the operating conditions of syngas for a Fischer-Tropsch synthesis: with iron catalyst, the H₂/CO ratio required being between 0.7 and 1.5 with the temperature range 493-613 K and the pressure range 1.5-3 MPa. Note that the quality of syngas is also determined by the content of tars usually accepted as < 0.1 mg / Nm³. This upper limit could be tightened if the generated syngas should be compressed for Fischer-Tropsch treatment.

Several studies about coal gasification in hydrogen, air and steam plasmas were carried out since 1990's [1-3]. Plasma generators integration in a coal gasification process is considered in [4,5], especially for coal ignition assisted by plasma generators. Equilibrium thermodynamic models and chemical kinetics approaches were also developed in [6,7]. A similar study conducted for liquid biomass gasification with a plasma assisted process has shown an improved ratio of H₂/CO but of course at the expense of electric power consumption [8].

Using all this available information, a comparison of the mass and energy balances with an assessment of carbon footprint for both autothermal and allothermal coal gasification processes are presented. The additional energy consumption should not ideally exceed the equivalent of energy released by coal combustion to entertain the auto-thermal gasification in the reference process. We also compare investment and operating costs for the two processes including the Fischer-Tropsch units, compression units and the gas cleaning systems.

Acknowledgments: This work is supported by the General Directorate of Turkish Coal Enterprises

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SESSION 3

Carbon Management: GHG Management Strategies and Economics – 1

3-1

Processes to Produce Value Added Products from CO₂

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The possible ways to convert CO₂ to valuable products are (1) catalytic conversion, (2) electrocatalytic/electrochemical process, (3) plasma processes, (4) photocatalytic/photochemical process, and (5) enzymatic/biochemical process. Hydrocarbon, hydrogen and oxygenates are mainly produced by the catalytic conversion of CO₂ at

the temperature and pressure of 250-1000°C and 140-3500 psi, respectively. On the other hand, carbon monoxide, syngas, hydrocarbons and alcohols are the main products produced at low pressure and high temperature from plasma process. CO₂ is converted to hydrogen and hydrocarbons by photocatalytic/ photochemical process at the temperature and pressure of 5-400°C and 485-1,470 psi, respectively. Electrocatalytic/electrochemical process produces alcohol, aldehydes, ketones, other oxygenated, alkenes and alkanes at very low temperature (room – 150°C). Furthermore, bi-carbonate and alcohols are also produced from CO₂ at low temperatures and pressures using enzymatic/biochemical process. Successful implementation of the above mentioned processes could be a possible solution to reduce the amount of CO₂ emission into the atmosphere.

3-2

Design and Operational Strategies for IGCC with CO₂ Capture

Chris Higman, Higman Consulting GmbH, GERMANY; George Booras, Electric Power Research Institute; Dan Kubek, Gas Processing Solutions LLC; Jim Sorensen, Sorensenergy LLC; Doug Todd, Process Power Plants, LLC, USA

In Europe, Japan, Australia, the USA and other countries actively developing plans for CO₂ capture, transport, and geological storage, specifications for the purity of the CO₂ are still in the development stage. Specifications for existing CO₂ pipelines in the USA vary according to the history of individual systems and CO₂ usage. The EU directive on CCS calls for the CO₂ stream to consist overwhelmingly of CO₂ and addresses the makeup of the remainder in terms of outcomes to avoid, rather than in any specific detail. In addition to meeting CO₂ specifications for transport and storage, designers of CO₂ capture systems must address the environmental and safety impacts of low-concentration components in the CO₂ when it must be vented during startup, shutdown, and situations when send-out to transport and storage is interrupted. Specifications for impurities such as sulfur species, CO, H₂, acid gas removal solvent, etc. may be dictated by environmental regulations and safety requirements, rather than by pipeline materials compatibility and considerations related to underground storage or use for enhanced oil recovery (EOR). IGCC possesses inherent advantages in meeting varying CO₂ purity requirements, and offers flexibility and optimization potential for mitigating the cost of satisfying these requirements. This paper presents the results of the Electric Power Research Institute (EPRI) CoalFleet-for-Tomorrow Program's technical review of the impact that these issues have on the design and operation of IGCC units with CO₂ capture.

3-3

Envisioning CO₂ Distribution Networks for Carbon Capture and Storage (CCS) in the United States: Strategies for CO₂ Pipeline Deployment at a Regional Scale

Nils Johnson, Joan Ogden, University of California, Davis, USA

If CO₂ emissions are regulated in the future to address climate change, technologies for reducing the emissions associated with coal use must be implemented. The leading approach for achieving reductions is carbon capture and storage (CCS), where CO₂ is captured at the source, compressed, and transported for storage in onshore or offshore underground geologic reservoirs. CCS infrastructure will require large financial investments and research is needed to identify cost-effective deployment strategies.

This paper uses a CO₂ pipeline optimization tool and regional geographic data to examine the viability of regional CO₂ disposal networks for various CCS adoption scenarios in the United States. Geographic specific case studies are conducted for each of the U.S. Regional Carbon Sequestration Partnership territories and aggregated into a national assessment. We examine several approaches for building up regional CO₂ sequestration systems. In one case we look at independent pipelines, connecting individual CO₂ sources with sinks. In the other case we look at the development of interconnected regional CO₂ pipeline networks. Regional networks have been proposed as a means for reducing transportation costs through scale economies. However, it is unclear when and if these regional networks will be competitive with independent pipelines connecting individual sources and sinks.

The CCS adoption scenarios will specify the adoption of capture technologies at different types of point sources over time (e.g., sites with low cost capture will adopt CCS first). The pipeline optimization tool will use the location of sources and sinks within each region, the scale of CO₂ flows, and the capacity and type of geologic disposal sites to identify the CO₂ pipeline network that minimizes both transport and injection costs. Not only will the proximity of sources and sinks impact the viability of regional networks, but also the capacity and type of available disposal sites. For example, it is possible that a more extensive regional network will be developed to take advantage of low-cost disposal sites (e.g., enhanced oil recovery sites) in cases where the reduction in injection costs exceed the increase in transport costs. Our optimization tool is uniquely capable of examining the trade-offs between transport and disposal costs in designing CO₂ distribution networks in real geographic regions.

It is important to determine whether and when an organized regional pipeline network will become economically viable in order to identify whether there is a business case for regional CO₂ disposal services. Potential cost advantages of a regional disposal network are scale economies in CO₂ pipeline transport, and the ability to utilize a variety of higher quality disposal sites, rather than just the closest sites. This study will

provide maps showing optimal strategies for the deployment of CO₂ disposal infrastructure in the United States over time and quantify the cumulative required capital investment, levelized cost of disposal (\$/tonne CO₂), cumulative CO₂ stored, and regional limits on CO₂ storage capacity.

3-4

Linking Economic and Technological Modeling of CCS and Legislative Policy for Coal Mining Companies

Pratt Rogers, Sean Dessureault, University of Arizona, USA

The combustion of coal releases the greatest percentage of CO₂/kWh of all fossil fuels used in the generation of electricity. According to the Energy Information Agency (EIA), under proposed carbon legislation, the cost of coal steam generation increases dramatically. CCS will be one component of the energy generation options within this highly complex regulated energy sector and will be an integral part of coal's future as a source of electricity generation. There are a multitude of economic models projecting the impact of proposed legislation targeted at reducing carbon emissions. These models offer broad generation projections based on macroeconomic, supply, demand, and conversion assumptions. Due to the effects of these different legislative proposals and CCS technology developments, coal mining companies will need to understand the price and fuel product (mineralogical) implications. An integration of these many different economic models would be needed. The first step in designing an integrated model is to characterize the existing models by determining their inputs, outputs and feedback loops. The proposed paper will review model characterization results from the key existing public, and to the degree permitted, private economic models. Development of an integrated economic and technological model targeted for coal-mining companies will help them develop investment strategies under the different proposed legislation and mineralogical requirements of CCS technology.

SESSION 4 Coal Science: Coal Chemistry – 1

4-1

Carbonaceous Emissions Reflected in Deposits on Building Stones: Case Study in Prague Castle

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The formation of thin black surface layers or black-coloured gypsum crusts can be observed on stones of many buildings and sculptures around the world. Such black surfaces not only change an aesthetic aspect of the (historic) sights, but they also initiate destructions stone surfaces by exfoliation. Therefore, the principal aim of this study was to identify the carbonaceous particles and isolate the organic compounds present in the black weathered stone surfaces from chosen parts of Prague Castle. Samples were collected by Department of Conservation of the Office of the Head of State of the Czech Republic. This heritage is located in the centre of Prague – the capital of the Czech Republic – and is exposed to natural weathering influences, such as rain, wind, temperature or pressure. However, the main factors accelerating stone decay processes are miscellaneous pollutants to which stone surface is exposed. The approach applied on sandstone surfaces used here was a combination of non-destructive (optical microscopy) and destructive (gas chromatography and pyrolysis-gas chromatography/mass spectrometry, Py-GC/MS) analytical techniques. Two samples of black layers were collected from Saint Vitus's Cathedral and one sample from a balcony of the historical building on the 3rd ward in Prague Castle.

Microscopically, we found an authigenic gypsum formation (thickness up to 1 mm) at the surface of porous sandstone with the upper layer formed by admixtures of fine grains of quartz, clay minerals, bricks, fly ashes and organic particles. High reflecting combustion residues, namely soot and chars, prevail in all samples and contain a lower portion of the low reflecting modern organic matter such as wood tissues, plant remains, pollen grains, algae and fungal spores.

Total organic carbon content (TOC) varied from 0.08 % to 4.28%. GC/MS data of the dichloromethane extract did not show any significant amount of the organics typical of pollution such as polycyclic aromatic hydrocarbons or other organic compounds. The only substances found were phthalates. They are used in a large variety of industrial products and they are being released in the environment. Pyrolysis-GC/MS analysis was also used as a technique to determine organic substances. The pyrograms of the samples showed a range of alkenes, polyaromatic hydrocarbons and other molecular markers. Benzonitrile was the most abundant compound in the analyses. It is a product of vulcanization or asphalt processing, but this substance is also a marker for Black Carbon – a kind of carbonaceous particles released into the atmosphere mainly from an incomplete combustion of fossil fuels and biomass. Black Carbon particles are resistant in the environment and are able to absorb other organic particles, for example polycyclic aromatic hydrocarbons, styrene or dibenzofuran. These organic compounds were identified in the pyrolysates of the analysed samples and served as an

evidence of fuel-burning pollution. The most disaster sample was from the south part of Saint Vitus's Cathedral.

Samples from weathered surfaces of sandstones from Prague Castle contained organic particles and compounds, which are known to result from human activities, particularly from combustion processes and others, which may partly come either from such sources or from biological production.

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4-2

Visualization of Coal Conversion Using X-Ray Computed Tomography QP Campbell, HWJP Neomagus, North-West University, SOUTH AFRICA

Coal conversion processes, specifically pyrolysis and gasification, are often characterized on a laboratory scale using thermogravimetric analysis (TGA) methods. From these experiments, information about kinetics, conversion, and even structural features may be deduced. When using kinetic models, some assumptions have to be made about the structure and mechanisms of conversion. These assumptions should always be confirmed with information about the coal structure, like porosity, pore structures and surface area. Still, it remains difficult to visualise the conversion process spatially in a coal particle, which is in any event almost never homogenous.

Three dimensional X-ray computed tomography is a technique traditionally associated with the medical field, but industrial tomography is already a mature technique. With more sophisticated equipment, resolutions of images have increased to such an extent, that when the technique is used for scanning coal particles, a wealth of information can be gained about the structure of the individual particles. Features like lithotype layering, structures and extent of mineral distributions, crack distributions and cleat orientations can clearly be observed.

In this study, both vitrinite- and inertinite rich coal particles were selected and these particles (approximately 20 mm) were first individually subjected to 3D X-ray CT scanning, and then subjected to pyrolysis. The same particles were then scanned again after complete pyrolysis, to determine any structural changes due to the process. These particles were then subjected to CO₂ gasification. The process was interrupted a number of times, and after cooling in an inert atmosphere, the individual particles were scanned again. The remaining particles, after complete conversion, were scanned for a final time.

The data obtained from the TGA were then compared with structural information from the CT images, to obtain a better description of the conversion process.

4-3

Organic Sulphur Functionality Changes in Biotreated Coals

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During the late century, rising global concerns over the effects of acid rain led to the development and utilisation of technologies to reduce SO₂/NO_x emissions. The formation of SO₂ occurs during the combustion of sulphur containing coals and can lead to acid rain but also acidic aerosols (extremely fine air-borne particles). A number of technologies, collectively known as a desulphurization, have been developed to reduce SO₂ emissions. Recently, biological approaches – biodesulphurization, becomes more popular, in view of the fact that processes are performed under mild conditions with no harmful reaction products and the characteristics of coal are hardly affected. Since there are sufficient chemical, physical and biological desulphurization methods for inorganic sulphur removal, the aim of the present study is to apply biodesulphurization treatments with a desulphurization potential toward organic sulphur functional forms in coal. Another target of the study is to trace the changes in sulphur. Two Bulgarian high sulphur containing coal samples, sub-bituminous (Pirin) and lignite (Maritza East), and one Turkish lignite (Cayirhan-Beyazari) are used in the experiments. In order to concentrate our efforts on a deeper research on organic sulphur, samples are preliminary demineralized and depyritized. The white rot fungi "*Phanerochaeta Chrysosporium*" – ME446 and the thermophilic and acidophilic archae "*Sulfolobus Solfataricus*" – ATCC 35091 are the microorganisms applied in the biodesulphurization processes.

A requirement of any research on desulphurization is an availability of accurate method for sulphur functional forms tracing. It is important to evaluate the effect of the treatment and to select proper coals for sulphur specific desulphurization processes. Temperature programmed reduction at atmospheric pressure (AP-TPR) together with its variation in detection mode proves to be an effective technique. To specify the organic sulphur forms in coal and to assess the changes in organic sulphur that occurs as a result of applied biotreatments AP-TPR coupled "on-line" with mass-spectrometry (AP-TPR-MS) in different gas media, i.e. H₂ and He, is used. The sulphur volatile organic compounds, neither reduced in the AP-TPR condition nor captured in the tar fraction, are quantitatively determined by "off-line" TD-GC/MS technique applying deuterated sulphur compounds as inner standards. Oxygen bomb combustion followed by ion chromatography is used to evaluate quantitatively organic sulphur compounds captured in the tar and char residue.

4-4

Surface Coal Mine Planning Against Large Landslides

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Can Lignite Surface Mine of Turkish Coal Enterprises (TKI) is located on the northwestern Turkey. Lignite with about 9.3 billion tons of reserve is a major source for energy production in Turkey. Turkish Coal Enterprises produces about 60% of the country's yearly production. Can Surface Lignite Mine which is planned to produce approximately 2.5 million tons of 3000 kcal/kg coal, will be one of the main production areas of TKI. Slope failures in the form of large landslides can cause serious interruptions in production of lignite. Major landslides commonly occur in TKI Can Lignite Mine. Back analysis of such slides can provide information about the mechanisms of such slides, so that preventive measures can be taken to reduce the future risks of landslides in the lignite basin.

A large slide in Panel Can 5 involved movement of a mass of overburden extending about 1.5 km from the slope face. Production activities were stopped here. To provide information for slope planning in the other important panels such as Panel Can B, analyses were carried out in order to determine the mechanisms of this slope failure. Using a 2D limit equilibrium method of slices program SLIDE and FLAC 2D finite difference program, it was found that very low friction angle associated with a weak clay layer underneath the coal seam triggered this large slide. Using overall slope angles as low as 17° did not prevent slides in the basin, since this layer was found to have a much lower friction angle and dominate the sliding mechanism. Towards the edges of this lignite basin, inclination of the sedimentary units including this weak layer and local fault formations increase, and this situation contributes to the occurrence of landslides. In designing production slopes especially around the edges of the basin, new production advancement directions and slope stability improvement alternatives were to be considered.

Another major landslide interrupted the production at the southern part of the open pit lignite mine. Landslide was back analyzed by numerical modeling in order to determine mobilized shear strength parameters during the slide. This information was believed to be useful in planning the safe slope angles for future production areas and safe production advancement directions in developing new production panels in the mine considering the inclined nature of the coal bed and the basin especially around lignite basin edges.

In numerical modeling efforts, a 2D limit equilibrium method of slices program SLIDE and a 3D finite difference program were used to determine the shear strength parameters that were mobilized during the slide. After the slide natural slope of the loose material that moved on the foundation rock of the basin was around 13°. This friction angle was assumed to be the natural trend of the mechanical behavior of the weak material on the base rock, and thus it was kept constant during the analysis. In order to assign a cohesion value which was active during the slide, a circular failure was initiated, and the cohesion for the sliding material was determined first with 2D method of slices. Accepting that even a few degrees improvement in the overall pit slope angles can bring significant savings in stripping costs, further back analysis modeling was carried out with a 3D program FLAC 3D program. 3D modeling effort resulted in an activated cohesion value almost twice as much compared to the 2D back analysis results. Using this value in designing the overall slope angles future production plans is obviously going to lead to significant savings.

4-5

Clean Coal Strategies for Feed Coal for Power Plants: A Case Study of North Karanpura Coalfields (NKCF) Coal, India

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The modern industrial and agricultural activities depend largely on electric power for their growth and sustenance. More than 70% of India's Power generation comes from Thermal Power Plants (TPPs), out of which more than 90% are coal based. In India, out of the total coal production 78% coal is utilized for thermal power generation. Indian coal mining organizations has a target of 500 MT annual coal production by next three years and their subsequent utilization in TPPs would lead to severe stress on environment by production of 150 MT of fly ash as well as large amounts of suspended particulate matter (SPM). The Indian Gondwana coals are characterized by high percentage of inertinite and high mineral matter content, due to its allochthonous origin (Stach et al., 1982), but they can burn satisfactorily to give high heat value (Clove and Lester, 1994; Choudhury et al., 2004). Generally, the reactive macerals, vitrinite and liptinite and also reactive inertinite participate in the burning activity (Choudhury et al., 2007, Mandal and Kumar, 2009). All these organic constituents are associated with the inorganic constituents or mineral matters which are in the form of carbonates, sulfates, sulphides and silicates. The trace elements in Gondwana coal are mostly associated with mineral matter such as silicates, oxides, sulfides, sulfates, and carbonates many of which are concentrated in coal more than their Clarke Value. The combustion of such coal leads to further enrichment of trace elements in various components of ash, many of which are potential health hazards. As per the US EPA Clean Air Act Amendment 1990, Trace Elements namely Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Nickel,

Selenium, Thorium, Uranium and Zinc falls under the category of Hazardous Atmospheric Pollutant (HAP). The high concentration of trace element affect our biological system by their cytotoxicity or genotoxicity. The trace elements associated with inorganic fraction of coal can be partially removed by conventional coal preparation techniques.

North Karanpura Coalfield (NKCF), situated between latitudes 23° 38'N - 23° 56'N and longitudes 84° 46'E - 85° 23'E covering an area of 1230sq km is a storehouse of noncoking coals. The area is gradually becoming a major coal supplier to Thermal Power Plants of north India. The study area includes four adjoining blocks of NKCF, which are Ashok, K D Hesalong, Karkata and Piparwar (Fig.1). The area covers about 100 sq km. where the mining operation is active at present. In the three blocks viz. Ashok, K D Hesalong and Piparwar, Seam I to Seam IV are present, while Seam V is present along with the other four in Karkata Block. All these seams, in this area are termed as Seam I = Dakra, Seam II = Bukbuka, Seam III = Bisrampur, Seam IV = Karkata and Seam V = Raniganj.

The present paper is aimed at a brief petrographic study to know about the mineral-maceral association along with a detail study of trace elements present and its environmental impact.

SESSION 5 Sustainability and Environment – 1

5-1

A Solution to Water Crisis in Energy Production: Feasibility of Using Impaired Waters for Coal-Fired Power Plant Cooling

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The freshwater demand has increased globally due to rapid population growth and economic expansion. According to the U.N. Environment Program, the global freshwater withdrawal reached 4430 km³ in 2000, and was projected to reach 5240 km³ in 2030, a 38% increase from year 1995. Simultaneously, the global energy demand will increase by 77% from 2006 to 2030. Of the total energy production, thermoelectric power generation accounts for 80-90%. To operate a thermoelectric power plant, such as a coal-fired power plant, a great amount of water is needed for cooling system. Since 2005, thermoelectric energy generation has become the number one freshwater use in the U.S. With the growing demand for freshwater and water shortages in many parts of the U.S., a number of proposed power plants were terminated or suspended due to the lack of freshwater for cooling. Use of alternative water sources will inevitably be a critical solution to ensure sufficient power production in the future. Many types of nontraditional water sources already exist, with drastically varying availability and quality. This study, sponsored by the U.S. Department of Energy, demonstrated the feasibility of using nontraditional water sources, many of which are of impaired quality, for cooling in coal-fired power plants. Three types of impaired water were evaluated: secondary-treated municipal wastewater, passively-treated abandoned mine drainage, and ash settling pond effluent from coal-fired power plants. A systematic review of the existing regulations in the U.S. revealed that using impaired waters for power plant cooling is generally allowed by the state/local governments, with some environmental quality control requirements. A national statistical analysis showed that secondary-treated municipal wastewater is a very promising alternative in terms of its quantity and geographical proximity to power plants. The effluent from only 1 or 2 fairly large publicly owned wastewater treatment facilities will satisfy the total cooling water needs of a coal-fired power plant that is located within a 10-mile radius. Half of the existing coal-fired power plants in the U.S. can benefit from their proximity to secondary effluent discharge points. Despite its widespread availability for use in power plant cooling, municipal wastewater can pose several technical difficulties in cooling systems, including corrosion, scaling, and biofouling. Results from both bench-scale and pilot-scale tests showed that the appropriate chemical treatment regimen can address the problems of corrosion, scaling, and biofouling in cooling systems when secondary-treated municipal wastewater is used as makeup water.

5-2

Leaching Characteristics of Waste from PF Utilities and Transitional Technologies using Australian Coal

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Australia produces approximately 13 million tonnes per annum of pf-combustion wastes (ash) from coal-fired power stations. A small proportion is utilised but most is deposited in wet ash dams or dry repositories. The nature of this waste stream is expected to change with adoption of transitional power generation technologies such as fluidised bed combustion, oxy-fuel combustion and integrated gasification combined-cycle processes using slagging gasifiers. The leaching properties of the major solid waste streams from each of these (transitional) processes have been compared with

those of typical fly ashes from conventional pf power stations burning Australian bituminous thermal coals. Batch leaching tests were done at two liquid:solid ratios (3.5:1 and 20:1) and the results compared to similar pf ash studies. It is concluded that most trace elements were leached from the fly ash and bottom ash of FBC systems at similar concentrations to those present in equivalent leachates from ash of conventional power stations (lower concentrations of Cd, Co, Ni and Zn were leached from the waste of two FBC power stations). Trace elements were also leached in similar proportions from fly ashes derived from the same coals fired under air-fired (conventional) and oxy-fuel combustion conditions. Some of the trace elements (e.g. B, Cr, Mn, V and Zn) in the gasifier slags were not leached as readily as those in fly ash from conventional power stations; others (e.g. As and Se) were leached at similar concentrations from both types of ash materials.

5-3

Borovac Coal Cleaning Process

Branislav Grbovic, Borovac International Pty Ltd, AUSTRALIA; Miloljub Grbovic, Borovac International Pty Ltd; Jelenko Micic, Mining Basin Kolubara d.o.o.; Miroslav Spasojevic, "Nikola Tesla" Power Plants, SERBIA

The western parts of Serbian Kolubara coalfields contain significant quantities of interlayer waste that is causing considerable operational difficulties and inefficiencies at the mine and power plants. Future development of open pits will further worsen these issues as pits are expanding into the areas of lower quality coal, while at the same time the coal supply demand will increase due to construction of new power plant units. Testwork and investigations focused on Kolubara's Tamnava coal have been conducted over the years aimed at developing a process capable of removing interlayer waste from complex coal seams typically present in most of Serbian lignite deposits.

The results have confirmed that „Borovac“ coal cleaning process is capable of breaking the bonds between coal and waste and subsequently separating the waste from ROM coal. The implementation of the process will enable more efficient operation of existing plants and better utilisation of available coal reserves.

The process has a potential to contribute significantly to reduction in overall environmental pollution caused by the products of combustion. This new Technical–Ecological–Commercial–Ethical concept is aimed to resolve the actual cause of the problem and prevent or minimize its chance of reoccurring in future, rather than attempting to heal the consequences once the problem has already been created.

5-4

Reducing Greenhouse Gas Emissions from Coal Combustion by Adding Micro-Algal Biomass

Jaco Brink, Sanette Marx, North-West University, SOUTH AFRICA

Each year millions of tons of greenhouse gases are released during combustion of coal in coal-fired power plants. Supplementing the coal feedstock to these power plants with micro-algal biomass, could maintain energy production, while decreasing the net contribution of greenhouse gases to the atmosphere, with resultant improvements to the environment.

The research project compared the calorific value and the elemental composition of low-grade Highveld coal, one of the major coal types mined in South Africa and one of the main types used for power generation in South Africa, against two sources of micro-algal biomass. One of the sources of micro-algal biomass was the dominant species in the Hartbeespoort Dam (37 km west of Pretoria, South Africa), *Microcystis aeruginosa*, which was harvested directly from dam. The second source of micro-algal biomass, *Cyclotella meneghiniana*, was cultivated in 4-liter Erlenmeyer bioreactors, using a modified growth medium. The low-grade Highveld coal had a calorific value of 21.65 MJ/kg, and a carbon, hydrogen, nitrogen and sulfur content of 56.06, 2.33, 1.51 and 0.78 mass %, respectively. In comparison, micro-algal biomass from the Hartbeespoort Dam had almost a similar calorific value of 21.02 MJ/kg compared to the low-grade coal's; and a carbon, hydrogen, nitrogen and sulfur content of 42.00, 6.75, 8.87 and 0.72 mass %, respectively. The cultivated micro-algal biomass, *Cyclotella meneghiniana*, had a lower calorific value of 17.30 MJ/kg; and a carbon, hydrogen, nitrogen and sulfur content of 38.80, 6.49, 6.41, 0.33 mass %, respectively. Supplementing coal feedstock to coal-fired power plants with micro-algal biomass holds great potential for minimizing the net production of greenhouse gases.

5-5

The Creation of Georeactor Global Scientific Network

Jan Rogut, Jozef Dubinski, Aleksandra Tokarz, GIG, Central Mining Institute, POLAND; Marc Steen, Institute for Energy, Joint Research Centre; Hans Bruining, Delft University of Technology, THE NETHERLANDS; Hema J. Siriwardane, West Virginia University; Tomasz Wiltowski, Southern Illinois University; Elizabeth Burton, Lawrence Livermore National Laboratory; Subhas K. Sikdar, US EPA, USA; Thomas Kempka, German Research Centre for Geosciences (GFZ), GERMANY; Sohei Shimada, University of Tokyo, JAPAN

Sustainable, responsible and eco-friendly exploitation of geological space and resources requires gathering, ordering and integrating an enormous amount of scientific knowledge that has been generated in separate, different fields of

geosciences. Critical, target-oriented evaluation, unification and utilization of data, models and approaches of geology, geophysics, geochemistry and related scientific geo-disciplines are required for setting up a trustworthy geo-technology platform aimed at facilitating low-emission production of energy and raw materials in-situ. Underground coal gasification, geothermy, enhanced oil and coal-bed methane recovery, long term safe storage of nuclear and hazardous wastes, CO₂ storage in deep geological formations and most recently methane extraction from gas shale are examples of key industrial technologies and processes that should benefit from such an initiative. Overcoming the present lack of sound, science-based, reliable and timely response by engineers and decision makers to growing societal concerns about environmental, technical and economic risks which could delay or fully stop the development of geo-technologies is imperative to realise their considerable potential to provide energy and materials for the growing human population in a clean, low-emission way.

Because of their multi-disciplinary character and of the very limited number of tools available for controlling in-situ operations, geo-technologies rank among high risk engineering activities. Access to their supporting science and engineering base is limited because the major part of the knowledge has been generated in the frame of proprietary research by oil or mining technology giants or in highly classified nuclear weapons testing programs. Current increasing attention to climate change and to tightened environmental regulations opens new and additional opportunities and challenges for geo-research. The interdisciplinary nature of geo-technologies generates a set of important questions but at the same time provides driving forces for research in a variety of emerging fields such as nano-geo-technology, biotechnology, chemical reaction engineering, dynamics of complex systems, reactive transport in multiphase systems, process intensification and integration. Last, but not least, the future of geo-technologies critically depends on a rational, objective socio-economic and environmental analysis of their strengths and weaknesses.

The presentation, prepared by a voluntary team of authors is the first public presentation of the initiative to establish a global scientific network focused on excellence and effective exchange of knowledge of geo-sciences and geo-engineering that is presently dispersed across various fields of geo-technologies. An up-to-date curriculum on clean technologies for the production of energy and materials in situ for the coming generation of mining and energy professionals will be the key educational target of the network. Financial and managerial support of the network will be sought from the People programme of 7th EU Framework Programme for RTD and in the context of collaboration agreements with countries such as US, China, Japan, India, Australia, South Africa.

SESSION 6

Coal-Derived Products: Chemicals/Materials

6-1

Converting Brown Coal into Chemicals and Hydrogen by Steam Cracking and Gasification

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Chemical products are derived primarily from petroleum, while coal and natural gas remain minor feedstock. The balance of supply and demand of crude oil inevitably strongly affects the prices of many chemical products. To stabilize their prices, it is necessary to diversify of the sources of these chemicals. Low-rank coals, such as brown coals and lignites, are not usually exploited because of their low calorific values, high moisture and oxygen contents, and propensity for spontaneous ignition.

We will propose a process converting Loy Yang coal into hydrogen and chemicals such as mono-aromatic hydrocarbons and oxygenated compounds by using steam as hydrogen source. Loy Yang coal was pyrolyzed and separated into char and tar. The char was gasified for hydrogen production and the tar was cracked catalytically for chemical production. This presentation will show the activities of iron oxide catalysts for cracking the tar and an integrated process with pyrolysis, gasification, and cracking.

We experimentally determined a pyrolysis condition for the process. Loy Yang coal was performed in a moving bed reactor and pyrolytic products were collected in char and tar traps and a gasbag. At a temperature in the range of 853 to 873 K, char contained traces of tar that was an inhibitor of gasification and the amount of tar including oxygenated compounds was obtained in the range of 12.7 to 14.7 wt.%. We considered that the temperatures were advantageous for gasification and cracking.

Developing a catalyst for tar conversion is important. The catalyst was required to convert the tar into the chemicals with producing less gaseous product so as to obtain the chemicals that were more valuable than hydrogen. Catalytic cracking of pyrolytic oil was performed in a fixed bed reactor with an iron oxide catalyst in a steam atmosphere. Cracking with Ce-Zr-Al-FeO_x yielded the more amounts of mono-aromatic hydrocarbons, phenols and ketones than the oil. The total yield of chemicals was up to about 40 mol-C% on an oil basis.

We investigated the potential and the optimum condition of the process on the basis of the experimental results for pyrolysis of Loy Yang coal and cracking of the tar. The autothermal condition for the process was determined by calculating an energy and mass balances of the process. The energy efficiency of the process was affected by not only the amount of steam, but also the rate of char conversion. The variations in the autothermal conditions were predicted against the amount of steam and the rate of char conversion.

6-2

A Peat-Based Natural Absorbent for Sewage Purification

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Peat from the LEIPI deposit (Murmansk region, Russia) was used to obtain a natural absorbent. Wastewaters from mining and processing integrated works contained increased amounts of both cations (manganese and strontium) and anions (sulfates). Peat from this deposit was selected as a candidate absorbent because it is rich in humic acids (62%), which are known to be capable of actively binding cations to form stable, insoluble complexes.

Solutions of alkali (sodium and potassium hydroxides) were used to activate the humic acid components of peat. These alkalis were found to activate fulvic acids, which had also a high affinity for anions. However, interaction of metal cations with fulvic acids yielded soluble salts; i.e., metals remained in the purified water. The use of dry calcium hydroxide as an alkaline reagent led to activation of humic acids, with the fulvic acid content remaining insignificant.

An original technology that included the stages of mixing the reagents in a special disperser and subsequent formation in an extruder was used to obtain the peat-based natural absorbent.

Sewage purification using the natural absorbent was tested in the static and dynamic modes. Purification in the static mode was found to be more efficient. The procedure resulted in a considerable decrease in the manganese and strontium contents of water (with purification rates of 98 and 88%, respectively), as well as the sulfate content (with a purification rate of 80%).

6-3

Pilot Scale Production of Humic Substances from Turkish Leonardites

Bekir Zühtü Uysal, Ufuk Gündüz Zafer, Ö. Murat Dogan, Duygu Öztan, Gazi University; Zeki Olgun, Mustafa Ozdingis, Selahaddin Anac, Turkish Coal Enterprises (TKI), TURKEY

A large number of organic humic substances are increasingly being applied worldwide especially in agricultural applications. Turkish Coal Enterprises (TKI) has been producing humic acid and other humic containing substances from Turkish lignites and leonardites since 2008. A number of methods for the extraction of humic substances using sodium hydroxide solution in laboratory scale have been published. Potassium hydroxide and different acids (hydrochloric acid, sulfuric acid, nitric acid and phosphoric acid) were used for the production of humic acid in our laboratories before pilot plant was designed and pilot scale production was started. Humic substances were first extracted to the alkaline medium at 85°C for 6 hours and then these extracted substances were precipitated with the acid. Experimental results showed that phosphoric acid resulted in the highest extraction efficiency of humic acid. The extraction efficiencies of Göynük leonardite were found as 61.4, 66.9, 79.0 and 91.2 % for studies with hydrochloric acid, sulfuric acid, nitric acid and phosphoric acid, respectively.

6-4

Heavy Metal Removal by Using Chemically Crosslinked Turkish Coal Based Humic Acid

Tulay Inan, Hacer Dogan, Murat Koral, TUBITAK Marmara Research Center; Selahattin Anaç, Zeki Olgun, TKI(Turkish Coal Enterprises), TURKEY

Chemically crosslinked humic acid was synthesized by using epichlorohydrin as cross-linking reagent. Humic acid was obtained from TKI (Turkish Coal Enterprises). The reaction was optimized and the products were analysed by the Fourier transform infrared (FTIR) spectroscopy, thermal gravimetric analyser (TGA) and scanning electron microscopy (SEM). The efficiency of these samples as adsorbent has been studied as a function of amount, contact time and initial heavy metal concentration by a series of batch experiments. The study showed that crosslinked humic acid could be used as an effective sorbent for the removal of heavy metals.

Analysis of the Effect of Internal Defect on Coke Fracture Behavior by Rigid Bodies-Spring Model

Kenichi Hiraki, Hayashizaki Hideyuki, Yoshiaki Yamazaki, Tetsuya Kanai, Xiaoping Zhang, Masakazu Shoji, Hideyuki Aoki, Takatoshi Miura, TOHOKU University, JAPAN

In this study, to investigate the effect of internal defect in coke, fracture analyses using RBSM (Rigid Bodies-Spring Model) which is applied to fracture analysis of brittle materials such as concrete are carried out for coke. First, in case of taking no account of internal defect, the fracture analyses with RBSM assuming 4-point bending tests are carried out. As a result, analytical results reproduce the fracture behavior well. Next, it is known that internal defect such as non-adhesion region boundaries in coke influences coke strength, so in case of taking account of non-adhesion region boundaries, the fracture analyses with RBSM assuming 4-point bending tests are carried out. To investigate the location of non-adhesion region boundaries in coke, 3 percent non-adhesion region boundaries are randomly located in the coke and fracture analysis of two cases are carried out. Analytical results show that fracture load decreases when non-adhesion boundaries are located under region of high stress and microcracks happen at around non-adhesion region boundaries. It is supposed that these microcracks cause surface breakage. Analytical results also show that the fracture starts at non-adhesion region boundaries when non-adhesion region boundaries are located under region of high stress. In particular, fracture progresses at the location of continuous non-adhesion region boundaries. To investigate the fraction of non-adhesion region boundaries in coke, 3, 5 and 10 percent non-adhesion region boundaries are randomly located in coke. As a result, fracture loads decrease with an increase of non-adhesion region boundaries in the coke.

SESSION 7

Combustion: Chemical Looping Development – 1

Ilmenite as an Oxygen Carrier in a Chemical Looping Combustion System: Reaction Kinetics and Fluidized Bed Performance

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In order to better classify potential oxygen carriers for a Chemical-Looping Combustion system, a lab-scale bubbling fluidized bed reactor has been designed and built at the University of Utah. In order to simulate a dual-fluidized bed system, the reacting gas is cycled between the oxidizing gas (Air) and the fuel gas (CH_4/N_2 or $\text{H}_2/\text{CO}/\text{N}_2$ mixture). Volume percentages of CH_4 , CO , CO_2 and O_2 are analyzed in real time by a CAI NDIR/ O_2 gas analyzer. Ilmenite, a naturally-occurring and relatively low cost titanium-iron oxide mineral (FeTiO_3) is an interesting potential oxygen carrier for chemical looping combustion. Tests to characterize performance of ilmenite as an oxygen carrier and to measure oxidation and reduction kinetics have been conducted at temperatures ranging from 750°C to 950°C. One test was conducted for 24 hours in order to determine the long term performance of ilmenite over several cycles. Such data is important when considering applicability in industrial systems where attrition resistance and long-term reactivity are important. Results compare favorably with thermogravimetric (TGA) studies of reaction kinetics conducted at the University of Utah. This paper describes the experimental approach, data analysis and assessment of the potential for ilmenite as a carrier in full-scale systems.

Application of Inorganic Remains Originating from Water Purification and Sewage Sludge Ashes in Chemical Looping Combustion Process

Ewelina Ksepko, Grzegorz Łabojko, Marek Sciazko, Institute for Chemical Processing of Coal, POLAND

The presented paper contains results of research on chemical looping combustion (CLC). The objective of paper was to prepare new low cost materials [1] used as oxygen carriers and investigate their reactivity in terms of applicability to energy systems. Multi cycle CLC tests in atmospheric TGA with oxygen carriers utilizing H_2 were conducted. Stability and oxygen transport capacity were described. Chemical phase composition was investigated by XRD technique. Three cycle test at 600 °C, 700 °C and 800 °C showed that proposed materials as oxygen carriers showed stable performance during the 3-cycle test at each temperature. The oxygen transport capacity has varied from 4 to 13.9 wt %, depending on temperature.

The fractional reduction, fractional oxidation and global rates (dX/dt) of reactions were calculated. It was found, that thermal treatment of wastes did not affect reduction/oxidation reaction rate. Oxidation reaction was much faster than reduction for all oxygen carriers within time of 1.5 minute. High melting temperature in reducing atmosphere of 1180 °C was observed. Small particle size below 59 μm was detected.

XRD pattern after multi-cycle test showed stable crystalline phase and confirmed that complete regeneration after multi-cycle tests was achieved.

Acknowledgement: Work supported by the Polish Ministry of Education and Science, Grant № 11.10.009. The authors are gratefully to Upper Silesian Enterprise of Water Supply Joint Stock to make samples available. [1] Application for the patent No P390127.

Chemical Looping with Oxygen Uncoupling: Design Calculations and Process Engineering Simulations Using Kinetic Data

JoAnn S. Lighty, Adel F. Sarofim, Asad H. Sahir, Edward Eyring, Gabor Konya, University of Utah, USA

Chemical Looping with Oxygen Uncoupling (CLOU) is a process which is being researched as a potential candidate for combustion of solid fuels facilitating effective CO_2 capture. An engineering analysis has been developed using data from in-house experiments on copper oxide as an oxygen carrier and utilizing global coal char oxidation kinetics reported in literature. Insights from the experimental study of Lewis and Gilliland on carbon gasification with metal oxide along with the developed engineering analysis have been incorporated to develop scenarios to study the impact of the residence time of air and fuel reactors and the recirculation rate of oxygen carrier on the process. The analysis has been extended by employing an ASPEN PLUS simulation of stoichiometric reactor models to develop relevant material and energy balances in the formulated scenarios.

In-house experiments for gathering the kinetic data on unsupported and supported copper oxide have been conducted using a Thermo-gravimetric analyzer (TGA). From these experiments conducted on CLOU, supported copper oxides have emerged as promising candidates and they are being explored further. The experimental data are currently being evaluated for kinetic parameters to be incorporated into the simulations.

The results of the order-of magnitude engineering analysis based on gas-solid reaction kinetics, and global coal char oxidation kinetics are presented in this paper. Design aspects of importance in identifying suitable conversions for the fuel and air reactors have been investigated as well as the role and impact of oxygen carrier recirculation rate on the energy balance of the process.

Chemical Looping Combustion and Gasification – A Novel Technique to Produce Concentrated Stream of Hydrogen and Carbon Dioxide from Victorian Lignites

Chiranjib Saha, Ali Akhavan, Sankar Bhattacharya, Monash University, AUSTRALIA

Chemical-Looping combustion and gasification is a novel technique where an oxygen carrier is used to transfer oxygen from the combustion air to the fuel, thus avoiding direct contact between air and fuel. This technology is an alternative to conventional combustion and gasification where oxygen needs to be supplied from air or air separation plants which are energy intensive. This new methodology prevents CO_2 from being mixed with combustion gases. Chemical looping concept has been widely studied for combustion of natural gas; however its application to solid fuel, such as coal, is being studied only recently. From literature it is evident that limited number of studies has been performed on chemical looping using lignites. Victoria has large resources of lignites (>500 years at current consumption rate) and therefore there is a strong incentive for development of efficient technologies, such as chemical looping, for power generation from lignites. Oxide of metals such as Nickel, Copper, Cobalt, and Manganese are good oxygen carrier candidates and have been studied extensively to be used in chemical looping process. Iron oxide is an inexpensive mineral in Australia and when used in chemical looping, it is expected to generate concentrated stream of CO_2 and H_2 . However, much is unknown about the yield of products such as H_2 , CO_2 , CO , Char etc. from this process as a function of time, temperature, particle size and type of lignites. Present literature also lack information regarding the fate of the externally added Fe_2O_3 particles through their interaction with the constituents of lignites and their prospects for regeneration. This paper explores the possibility of using lignite in chemical looping with iron oxide as oxygen carrier. The reduction and reoxidation properties of Fe_2O_3 are investigated using thermogravimetric analyzer (TGA). Scanning electron microscopy (SEM) along with EDX of fresh solid reactants is compared with used reactants to understand the changes in surface morphology and mineral composition. Surface elemental information of agglomerates as a function of temperature and time are also being investigated. This paper presents preliminary results from this ongoing study.

SESSION 8
Gasification: Underground Coal Gasification – 1

8-1
Bloodwood Creek UCG Pilot 2008 – 2010
Cliff Mallet, Carbon Energy Pty. Ltd., AUSTRALIA; Burl E. Davis, Carbon Energy Pty Ltd, USA

In October, 2008 Carbon Energy PL installed their next generation commercial version of a parallel UCG CRIP module at their site at Bloodwood Creek, 50 km west of Dalby, Queensland Australia. They demonstrated the commercial feasibility of their UCG process at Bloodwood Creek with a 100-day field trial with both air and oxygen/steam injection. The single module is capable of accessing 200,000 tonne of coal during its operational life. The UCG syngas was flared for over a year, and is now used to feed a 5 MW of electricity plant, with power being sold into the local electricity grid. This demonstrates commercial application of fuel gas generated by the Carbon Energy Parallel CRIP UCG process. The next phase of the program will involve installation of a 20 MW facility for sale into the electricity grid.

8-2
Studies on Gasification of Turkish Lignite via Underground Coal Gasification
Şahika Yürek, Kıvanç Het, Directorate of Turkish Coal Enterprises (TKİ), TURKEY

It is known that with nearly 12.3 billion tons of reserve coal, Turkey produces nearly 22% of its electricity needs via the burning of these reserve fuels. TKI, Turkey's largest mining organization and the sixteenth largest national company, owns a nearly 2.5 billion ton share of this reserve. TKI, engaged in extracting coal from mines for heating and thermal purposes, is also engaged in studies directed towards utilizing coal for alternative purposes, following the latest technological advances in the world. One of the spearheading studies is geared towards obtaining synthetic gas via the underground gasification of coal.

The process of underground coal gasification is an operation in which steam, composed of air and water, is directed with the assistance of injection wells into underground coal deposits and the resulting gas from this reaction is directed to the surface by conduction channels. This technique aims to render feasible what has been a difficult and costly means of production for accessing reserves in the sea and at great depths. Furthermore, this technique would render possible the above-ground processing of obtained gas into H₂, CH₄, NH₃, CO, and CO₂ for a variety of applications. However, these are not the only advantages of underground gasification of coal; this process also aims to contain CO₂, one of the key factors in the level of greenhouse gases, within the areas from which coal is extracted from beneath the surface of the earth. It has been widely accepted that the process of underground coal gasification is a means of clean coal production which minimizes environmental impacts with low costs and high productivity.

Within the scope of these studies TKI has carried on contacts with both local and foreign firms, and the most rigorous study in this area has been conducted under the guidance of the leading expert in the field, the American firm Lawrence Livermore Laboratories. If a suitable site replete with the necessary conditions for an experimental initial run involving the underground gasification of coal in Turkey is identified by the advising firm, then plans will be laid for the undertaking of larger scale underground gas production domestically.

In conclusion, without a doubt this technique could once again bring to the fore those lignite coal resources of ours which are currently unexploited, which entails the financial inactivity of those sites. Within the scope of Clean Coal Technology, this technology would be an important step in ensuring a prudent means of meeting of our future energy needs.

8-3
Underground Coal Gasification and Applicability to Thrace Basin Lignite in Turkey
Ayşe Yildirim, Serdar Dogan, Turkish Petroleum Company, TURKEY

As it is known that, hydrocarbon reserves have been declined rapidly and with other problems for energy demand, there have been expanded and renewed interests in new alternative technologies in worldwide. Underground Coal Gasification (UCG) is the one of those technologies for new energy sources. UCG is a gasification process carried on low calorific value, non mined or no minable coal seams due to the geological conditions (high fracture frequencies, volcanic, complex storage/tectonic structures). UCG process converts coal in situ into product gas (syngas) by using oxygen/ steam mixture (air, enriched air, oxygen/water and carbon dioxide/oxygen). Here the coal beds react as a chemical reactor, thus gasification process is maintained underground rather than conventional gasification methods. In this process; coal, steam and oxygen are brought together to the combustion temperature for coal by adjusting the amount of oxygen carefully, the coal is not completely burned but decomposed chemically. The process is a partial oxidation rather than combustion. The resulting

mixture (carbon monoxide, hydrogen, carbon dioxide, methane) is UCG gas (syngas) can be used Integrated Gasification Combined Cycle (IGCC) configuration as a supplement and substitute fuel for electricity generation and chemical synthesis resulting in manufacturing of synthetic liquid fuel or chemicals by Fisher-Tropsch process.

Turkish Petroleum Company (TPAO), has a vision being an energy company and taking in the commission to assess the low calorific value lignite reserves in Turkey by clean coal technologies under the roof of Ministry of Energy and Natural Resources (ETKB) conjunction with General Directorate of Mineral Research and Exploration (MTA), Turkish Coal Enterprises (TKİ), Electric Power Resources Survey and Development Administration (EİEİ), Electricity Generation CO.İNC (EUAS), ETİ MINE Works General Management (ETİ Maden), Turkish Hard Coal Enterprises (TTK) and General Directorate of Mining Affairs (MİGM). In this review, geological, geophysical and chemical studies have been done on the lignite beds, which were determined during natural gas drilling in Thrace Basin in Turkey and their applicability is being discussed to UCG processes.

SESSION 9
Carbon Management: GHG Management Strategies and Economics – 2

9-1
CO₂-Reduction through Biomass Co-Firing in Coal Fired Power Plants
Klaus-Dieter Tigges, Roland Jeschke, Alfred Gwosdz, Alfons Leisse, Hitachi Power Europe GmbH, GERMANY

Facing the threatening background of global warming the impetus for more and more activities to reduce CO₂ emissions is given. Biomass co-firing, being regarded as CO₂ neutral, has a potential to reduce CO₂ emissions generated by mankind. This particularly applies for power generation based on fossil fuels. Besides that operators of utility boilers are always interested in reducing production cost with a special focus on fuels. Biomass is deployed increasingly in power stations as wood pellets, chips and others. Moreover most of the new power stations being under construction right now envisage biomass combustion in the short or mid term. Hitachi Power Europe has been involved in co-firing for a couple of years starting with grinding of wood pellets. In consequence the development of biomass firing technology was extended to cover the entire value chain from storing and grinding up to firing a wide range of biomass products. This technology can be applied for both lignite and hard coal fired steam generators. It is based on HPE's well proven firing technology for hard coal and lignite and was refined under full scale conditions in a 35 MW test facility. The combustion tests provided a comprehensive set of operating data to evaluate the technology and validate the combustion models especially adapted to biomass firing conditions. This paper outlines the biomass technology for co-firing woody biomass in hard coal or lignite fired steam generators up to an amount of 100% and shows possible applications taking different biomass features into account. Results of combustion tests are described and calculated and measured data are shown.

9-2
Ventilation Air Methane Abatement at CONSOL Energy's Enlow Fork Mine
Richard A. Winschel, Deborah A. Kosmack, William P. Fertall, CONSOL Energy Inc.; Jerry Gureghian, Green Holdings Corp., USA

CONSOL Energy Inc. and Green Holdings Enlow, Inc. (a subsidiary of Green Holdings Corp.), are developing one of the largest coal mine ventilation air methane (VAM) emission abatement project in the United States at CONSOL's Enlow Fork Mine in southwestern Pennsylvania, USA. The status of the project is discussed herein.

9-3
Novel Methods of Coal Seam Gas Content Determination for Estimation of Greenhouse Gas Emissions from Mining
Abouna Saghafi, CSIRO Energy Technology, AUSTRALIA

Coal seam naturally contains greenhouse gases, dominantly methane but also carbon dioxide and to a lesser extent higher hydrocarbons. With coal mining most gas volumes trapped in coal seams and strata are liberated which mostly end up in atmosphere. In order to assess fugitive emissions from mining new methods are devised. In situ gas content of coal seams is a primary parameter required in these methods.

Traditionally the purpose of gas content determination in coal mines has been the safe operation of mining and workers. Over the years various methods of measurement have been developed for ungrounded mining. However, these methods are not always adequate for requirement of emissions assessment for greenhouse gas inventory and new definition of gas content and more accurate measurement methods are required. The liability of the coal producer or coal user or both in relation to the emitted and remaining gas in coal can be a major factor for the way gas content is defined and measured.

In order to accommodate the future emission trade scheme (ETS), one of the first steps is to debate the definition of gas content and developing more adequate methods of measurement. In this paper the authors look at possible definitions of gas content in relation to the purpose of its use and suggests novel methods of its determination.

9-4

Swelling of Moist Coal in Carbon Dioxide and Methane

Richard Sakurovs, Robyn Fry, Stuart Day, CSIRO Energy Technology, AUSTRALIA

The possibility of injecting CO₂ into coal seams for enhanced coalbed methane (ECBM) recovery while simultaneously providing long-term carbon sequestration is an active area of research. It is now well known that coal swells in the presence of water and gases, which in turn may affect the permeability of the coal. If the swelling of the coal matrix by each component can be quantified, it may be possible to make better predictions about the suitability of particular seams for ECBM and carbon sequestration. Although there have been numerous studies where coal swelling has been measured in gases or water, there is relatively little information relating to how swelling of coals by gases is affected by water.

In this paper we report on the gas-induced swelling behaviour of four moist Australian coals. Blocks of coal, nominally 30 × 10 × 10 mm, were cut parallel and perpendicular to the bedding plane from larger lumps. Samples were moisture-equilibrated at 97 % relative humidity before being exposed to CO₂ or CH₄ at pressures up to 16 MPa and a temperature of 55 °C. Swelling of each sample was measured directly using an apparatus where digital cameras monitored the change in length of the block as a function of pressure.

Results show that swelling was greater in CO₂ than CH₄, with lower rank coals swelling more than high rank material. The presence of moisture significantly reduced the amount of additional swelling by the gas compared to dry coals, however, the degree to which the swelling of the coals was affected by moisture depended on the rank of the coal. It was also found that, proportionally, CH₄-induced swelling was more affected by the presence of moisture than CO₂-induced swelling. Although moist coals swelled less in CO₂ than dry coals, if the swelling due to moisture is included, the total swelling is more than that induced by CO₂ in the dry coal.

9-5

Evaluation of Total Porosity and the Amount of Inaccessible Pores in Coal Using Small-Angle Neutron Scattering

Yuri B. Melnichenko, L. He, Oak Ridge National Laboratory; M. Mastalerz, Indiana University, USA; R. Sakurovs, CSIRO Energy Technology; T. Blach, Griffith University, AUSTRALIA

Carbon sequestration in geological formations such as deep unminable coal seems is one of the proposed measures for arresting the rising concentration of atmospheric carbon dioxide. The efficiency of CO₂ sequestration and enhanced coalbed recovery depends crucially on the ability to predict sorption capacity of green house gases in coal, which may vary significantly depending on the total porosity of the coal as well as on the amount of pores that are actually accessible to a specific fluid. Due to the high penetration power and relatively short wavelength of neutrons, small-angle neutron scattering (SANS) as well as ultra small-angle scattering (USANS) techniques are ideally suited for assessing the phase behavior of various fluids in engineered and natural porous systems including coal. SANS and USANS offer a number of advantages for evaluating the total coal porosity, as all pores both accessible and inaccessible to the fluid contribute to the scattering at ambient conditions. One of the most important advantages is that scattering experiments can be performed with samples saturated by non- or weakly adsorbed supercritical fluids at pressures corresponding to the zero average contrast (ZAC) condition. At this condition the neutron contrast between solid matrix of coal and all pores accessible to a fluid is annulled and any residual scattering may be attributed to the scattering from inaccessible pores which do not belong to the interconnected porous channels and therefore cannot be filled with the fluid.

In this talk we will discuss the results of the USANS and SANS studies of four bituminous coals from the Illinois Basin (USA) and Bowen Basin (Australia) saturated with CO₂ and methane at pressures up to 8000psi (53MPa) including pressures corresponding to the ZAC condition. The scattering patterns at different pressures are used to demonstrate that the scattering length density of different coals, the parameter crucial for calculating ZAC condition can be accurately predicted from evaluated based of the chemical composition of a particular coal obtained by ultimate analysis. Scattering patterns at the ZAC are compared with SANS and USANS measured at ambient conditions and all studied coals reveal non-zero residual scattering, which shows that there are pores in coal inaccessible to methane and CO₂ on the timescale of the experiment (days). Scattering patterns from pores with sizes greater than ~ 100 Angstrom are analysed using a newly developed approach which is used to determine the amount of pores accessible to CO₂ and methane in each coal as a function of pore sizes. We demonstrate that the way the volume of accessible pores changes as a function of pore sizes is unique for each of the examined coals and the volume fraction of accessible pores may vary between 90 % (macropore region) to 30 % (mesopore region). We also analyse scattering from micropores, which reveals strong condensation effects of CO₂ and methane in all for coals. The developed

methodology may be applied for evaluating the volume of accessible pores in other natural porous materials of interest for CO₂ sequestration, such as saline aquifers, shales, and sandstones.

SESSION 10 Coal Science: Coal Fires

10-1

Early Stage Detection of Coal Spontaneous Combustion in View of Pretreatment of the Coal

Boleslav Taraba, Zdenek Pavelek, Jiri Janek, Ostrava University, CZECH REPUBLIC

The main aim of the investigations was to elucidate possible changes in oxidation behaviour of coal from the mine district that had to be sealed off because of fire incident. With this respect, two samples of bituminous coal were studied to describe changes in evolution of the gases indicating early stage of spontaneous combustion process (namely carbon monoxide, ethylene, propylene). Three types of coal pre-treatment procedures were used to simulate *in situ* conditions of the coal lying near the „spon-com“ site in the sealed off area: i) pre-oxidation of coal (200, 250°C), ii) pre-heating of the coal under inert gas (200, 250°C), and iii) extinguishing of pre-heated coal (200, 250°C) by liquid water. After the pretreatments, amount and composition of gases evolved from the coal during aerial oxidation at temperatures 40 – 200°C were measured at continuous flow reactor. Irrespective of type of the pre-treatment, oxidation of the pre-treated coal was found to be accompanied by increased CO evolution in comparison with not-treated coal (up to temperature 100°C). Opposite to it, evolution of ethylene and propylene was ascertained to be somewhat lowered by the coal pre-treatment procedures. However, experiments proved that *threshold* temperature for the unsaturated hydrocarbons (*i.e.* minimal temperature when evolution of the indication gas is obviously detected) is not depended on the coal pre-treatment procedure.

Obtained results thus indicate that carbon monoxide and unsaturated hydrocarbons have their relevance as spontaneous combustion indicators even for mine areas that had been sealed off because of coal fire incident, and that are to be re-opened.

10-2

Scope of Using Fly Ash for Reclamation and Control of Fire in Coal Mines

R. V. K. Singh, G. Sural, V. K. Singh, Central Institute of Mining & Fuel Research, INDIA

The disposal of Fly Ash is regulated by different countries as a waste. It is categorised as Non-hazardous waste. In a recent report, Riley identified those International agreements applicable to the disposal of coal ash. These regulations are administered by United Nations (UN), the European Union (EU) or the Council of the Organisation for Economic Co-operation and Development (OECD). Fly ash is being used for construction of roads, embankment and building components, besides this it may be used to control mine fires through underground and surface sealing, to reclaim mine land, to restrict subsidence, to fill abandoned mine pits, to minimise or eliminate ash discharge to the rivers and reservoirs and to fabricate light weight blocks for rapid construction of mine stoppings in fire area for isolation.

Fire in coal mines is one of the serious problem of the Mining Industry. Huge quantity of valuable natural resources like coal is being lost and environment is badly affected due to release of noxious and green house gases. During the process of extraction of coal by opencast mining method, firstly the industrial waste like soil, sand stone and overburden material is being extracted and it is not being utilised in the proper manner. Particularly in India, 75 - 85 Million tones of fly ash per annum is being generated by coal based Thermal Power Station which will cross 100 million tones per year in the next two/ three years and will go up further with expansion of thermal generation. Production of fly ash from thermal power station has now become a matter of great concern for the utilisation. Most of the places after extraction of overburden material & coal, the remaining portion is being left idle for the longer time, thus spontaneous heating/ fire occurs and it creates a very danger problem. This extracted portion should be filled up with waste like fly ash for proper filling material using the techniques like surface sealing (blanketing) and making the incombustible barrier (stoppings). The purpose of this paper is to present the different scope for using fly ash for reclamation and control of fire in coal mines.

10-3

SEM Study of Some Indian Natural Cokes (Jhama)

Ashok K. Singh, Nandita Choudhury, Central Institute of Mining & Fuel Research, CSIR; Mamta Sharma, National Metallurgical Laboratory, CSIR; Mahendra P. Singh, Banaras Hindu University, INDIA

Scanning Electron Microscopy (SEM) is an indispensable tool for studying the mineral and organic matrix, particularly in the baked coals or natural cokes, which form due to

magmatic intrusion (dykes and sills) in coal seams. In this paper this tool has been used to demonstrate the relationship between morphology and genesis of natural coke or jhama samples derived from Damodar Valley Coalfields of India. The SEM studies were carried out using JEOL-840A JSM under magnifications ranging from 200X to 50000X on selected heat altered coal/natural coke, CPC and graphite samples to decipher the microstructures of these samples and comparative studies. The chips of coal lithotypes, heat altered coal/natural cokes, CPC and graphite, of about 1cm size were isolated from the coal blocks using hammer, chisel and forceps and were washed with alcohol to remove the superficial dust and mounted on brass stubs using silver paste as glue and coated with gold (thickness about 400 Å).

SEM photographs reveal some textural features of natural coke which would not be detectable using optical microscopy. The similarity between images of natural and artificial coke and also the mineral assemblages present in the natural coke matrix is proof that temperatures over 350°C were experienced during contact metamorphism. Due to its greater depth of focus compared to optical microscopy, SEM provides information on textures in unpolished samples complementary to microscopic data. The main findings include identification of carbonized matrix, mosaics and flow structures of various dimensions, nature and dimensions of the micro, meso, macropores and cracks formed due to escape of volatiles and relationship and association of mineral matter or their altered products (glassy matrix) with the generated pores. The system thus permits a combined maceral-mineral analysis, which can be used to advantage in coal geology studies.

10-4

Examination of Low Temperature Air Oxidation Mechanism of Brown Coal for Suppressing Self Ignition Tendency

Kouichi Miura, Ryota Okajima, Mitsunori Makino, Ryuichi Ashida, Kyoto University, JAPAN

Low rank coals including brown coal and lignite are valuable energy resources in this century. For the storage and transportation of the low rank coals, suppression of self ignition tendency as well as dewatering is essential. The self ignition tendency is closely related to the rate of oxidation of the coals. Therefore it is very important to examine the rate and mechanism of the oxidation of the coals at low temperatures.

In this paper the mechanism of air oxidation of an Australian brown coal, Loy Yang, was investigated at less than 300°C. The coal was heated up to an oxidation temperature of 260, 280, or 300 °C at the rate of 10 K/min in an helium stream containing oxygen by either 11 % or 22 %, and kept for 0, 30, or 60 min at the oxidation temperature. Weight change, gas formation rate, and fate of surface functional groups during the oxidation were investigated using thermogravimetry, gas chromatography, and *in-situ* FTIR spectrometry. The amount of gas phase oxygen consumed, ξO_2 , was estimated from the weight change and the gas formation rate. The oxidized coal was cooled to 65°C in the oxygen atmosphere and then heated up to 700°C at the rate of 10 K/min in the helium stream containing oxygen by 22 % to estimate the gasification rate of the oxidized sample. The self ignition tendency was characterized by the temperature, T_g , at which 10% of the oxidized coal is gasified. The higher heating value (HHV) of the oxidized coal was estimated by the Mottot-Spooner equation with the ultimate analysis of the oxidized sample.

10-5

Beneficiation Prospects of Baked Coking Coals from Seam XV, Jharia Coalfield, Damodar Valley, India

Ashok K Singh, N. K. Shukla, N. Choudhury, Central Institute of Mining & Fuel Research, CSIR; Mamta Sharma, National Metallurgical Laboratory, CSIR, INDIA

Baked coals in the Jharia Coalfield, due to its irregular physical and chemical characteristics such as hardness, loss in caking property and slow in burning due to loss of volatile matter, have got very poor response from utilization point of view in industry. In this attempt the baked coals from seam XV, lying mostly unused in Jharia coalfield, have been beneficiated through F & S in the laboratories at CIMFR, Dhanbad, India. The washability investigations were carried out at the size fractions 50-25, 25-13, 13-06, 06-03 and 03-0.5 mm and at the specific gravity range of 1.4 to 1.8 at a difference of 0.05 and 0.1. The washability data developed on the size 50-0.5 mm has been presented through conventional washability curve and Mayer's curve and it is observed that at 11.9% ash level 25.8% cleans may be used for carbon artifact industry and the rejects (74.2%) at 23.7% ash level may be used in Indian Power Plants after judicious blending with high VM power coals.

11-1

Emissions from Cofiring Coal with Renewable Materials Such as Biomass and Sewage

Lesley Sloss, IEA Clean Coal Centre, UNITED KINGDOM

The practice of co-firing biomass with coal in full-scale coal utility plants is increasing due to the benefits with respect to reduced fossil fuel-based CO₂ emissions. Biomass also tends to have a lower sulphur content than coal and therefore emissions of SO₂ are reduced. The same is true for NO_x emissions from lower fuel nitrogen content. Further, the lower flame temperatures and different combustion stoichiometry of biomass can result in lower thermal NO_x production. The exception to this is the combustion of sewage sludge which may contain significantly more nitrogen than coal. However, co-firing of coal with sewage sludge helps to reduce overall NO_x emissions.

A reduction in ash, especially when co-firing wood, is another advantage of co-firing. Increased chlorine and/or changes in ash particle adsorbency can help reduce trace element emissions such as mercury and arsenic. However, some biomass materials, such as straws and grasses, can have higher potassium and chlorine than coal which may lead to problems such as slagging and fouling. There are also potential issues with respect to changes in the operation of pollution control technologies. For example, in some situations, the formation of dioxins can result from co-firing biomass in less than optimal conditions. Phosphorus in sewage sludge can react with lime to reduce sulphur capture in fluidised bed systems. Sewage sludge tends to have higher concentrations of several trace elements such as Cr, Cu, Ni, Pb, Zn and Fe than coal. It has been shown that these elements tend to end up in the fly ash and it is important to ensure that this has no detrimental effects on the intended use of such ash.

In most cases, the balance between the characteristics of the coal and biomass and the plant operation can control any detrimental plant effects. In practice, full-scale coal-fired plants such as Drax in the UK and Fiume Santo in Sardinia note little or no detrimental change in trace element emissions following the introduction of biomass as a co-fuel.

It would appear that, for the most part, the benefits of co-firing biomass far outweigh any negative effects. In fact, it would seem that the majority of environmental impact assessments regard the production, transport and preparation of the biomass fuels more important than changes in the stack emissions from the plant as a result of the co-firing. Detrimental effects, however, can be an issue for ash management.

11-2

Element Leaching from Coal Stockpiles – Case Studies from the Sydney and Collie Basins, Australia

Colin R. Ward, Leanne Stephenson, Zhongsheng Li, University of New South Wales; David French, Ken Riley, Owen Farrell, CSIRO Energy Technology, AUSTRALIA

Laboratory testing has been carried out to evaluate the potential for release of elements from coal in exposed stockpiles, drawing on sample sets from the Sydney Basin in New South Wales and the Collie Basin in Western Australia. Testing in the Collie Basin was further extended to evaluate element leaching from the coastal sand deposits on which the stockpile was constructed, to ascertain whether the stockpile might represent a significant source of contaminants to the associated groundwater system. The mobility of the elements in the coal and sand was evaluated by batch leaching tests; samples of each material were shaken in sealed polyurethane bottles with water or a controlled pH (acid) solution for 18-24 hours, after which the concentrations of major and trace elements in the resulting leachates were determined. For the Collie Basin complementary tests were also carried out in which coal and coal underlain by sand were separately placed in Perspex columns and demineralised water or an acid solution was allowed to permeate through.

The natural pH of the Collie Basin coal in water was shown by the batch tests to be 4.75 to 5.0, while that of the Sydney Basin coals, and also of the Collie Basin sand, was 8.0 to 9.3. Trace elements of environmental concern were mostly released at low concentrations from the coals of both basins. For the Sydney Basin some elements, such as Mn, Co, Ni and Zn, were released at slightly higher levels when the coals were tested with acid rather than water, suggesting a slight influence of pH on element mobility from the coal samples. Other elements, such as Mo and Se, were less mobile from the Sydney Basin coals under acid conditions than at natural (alkaline) pH levels. Element release from the Collie coals, which had a naturally acid pH when tested with water, showed a similar pattern to that displayed by the Sydney Basin coals under acid test conditions.

Trace elements in the Collie Basin study, especially As, Cr, Cu, Mo, Pb, Sb, Th, U, V and Zn, were mostly released in higher concentration from the sand than from the coal. A few elements, such as Ba, Mn and Ni, were released in higher concentrations from the coal (although values were still low), while others, such as Cd and Co, were released in low but approximately equal concentrations from both coal and sand samples.

Column tests on the Collie coal gave similar results to the batch leaching studies, although with slightly higher pH levels. The coal/sand column produced a leachate with a pH of 8.2 to 8.6, consistent with neutralisation of the acidic coal leachate by the carbonate minerals in the sand sample. Flow through the coal/sand column became blocked in the course of the test, apparently due to solution and re-precipitation of calcium carbonate in the sand by the acidic coal leachate. Higher concentrations of most trace elements, including As, B, Ba, Cr, Cu, Mo, Sb, Se, U and V, were released from this column before the blockage compared to the columns with coal alone. Comparison to the batch test results suggests that these elements were mainly derived from leaching of the sand component.

11-3

Economic Evaluation of Sulcis Coal Leaching Process

Elisabetta Fois, Melis Francesco, Carbosulcis S.p.A.; Giampaolo Mura, Antonio Lallai, Agata Pistis, Università di Cagliari, ITALY

Coal is a fossil fuel rich of elements different from carbon; sulphur can compose up to 12% its mass but represents an undesired impurity as its combustion produces SO₂ gases which result in the formation of acid rain.

Sulcis coal is a sub-bituminous coal from the Monte Sinni mine in the South West coast of Sardinia. The ash content of this coal is about 15 wt % as received, whereas the sulphur content is 7-6 wt% (inorganic sulphur is present at about 3%). Since most of the pyritic sulphur is finely disseminated in crystals of micron or sub-micron size, the only remaining possibility of removing sulphur from this coal prior to its utilization is confined to chemical methods.

Leaching is also called solid-liquid extraction; it is in fact a process which aims to separate soluble components from a solid mass by using a proper solvent. Leaching with chemicals may be carried out to reduce ash and sulphur concentration in coal. In coal industry, both biological and chemical leaching are used; the chemical one relies mainly on mineral acids, but efficaciously utilises also some bases in the form of molten caustic mixtures, or combinations of these with oxidising reagents.

The present work shows the economic evaluation of Sulcis coal leaching process. Moreover, this work shows results of the experimental tests which are conducted on Sulcis coal samples by sequential leaching of potassium hydroxide followed by hydrogen peroxide. The tests carried out verify the technical efficiency of the process for desulphurization of that coal. This economic evaluation system has been developed to carry out feasibility studies at the preliminary stages of this project.

The process has been extensively studied at laboratory-scale. Parameters investigated included coal top-size, reagent composition, slurry concentration, reaction temperature, and reaction time. Additional investigations include coal leaching-reagent regeneration, product recovery, product stability on process performance and economics.

The high efficiency of sulphur reduction, on average about 30%, was found to be of special technical relevance for relatively large particle sizes, i.e. -5.60 mm, said efficiency being obtained through tests carried out on different particle size classes of leached samples. At the same time, the calorific value of the sample thus treated has surprisingly shown an appreciably reduced decrease only of 4 to 10%.

11-4

Coal Resource Estimation in Isiklar-Kisrakdere (Soma, Manisa, Turkey)

A. Erhan Tercan, Bahtiyar Ünver, Mehmet Ali Hindistan, Hacettepe University; Perihan Çorbacı, Kıvanç Het, Turkish Coal Enterprises, TURKEY

Isiklar-Kisrakdere is a site that is located in Soma Neocene region and contains lignite coal suitable for underground mining extraction. This paper presents a case study in which coal resource estimation is addressed. For this purpose a data base is constructed using drill hole information such as collar, survey, sample and geology tables. Then solids for coal seams are produced by considering faults and geological layers. The solid models are divided into equal size and shaped blocks. The mean calorific values of these blocks are estimated by geostatistical techniques. Finally quality-tonnage curves are produced.

11-5

Coal Explorations in Turkey: New Projects and New Reserves

İlker Şengül, MTA, TURKEY

Of the primary energy sources, coal, which is regarded as a solid fossil fuel, is very crucial with respect to other primary energy sources since it has an undoubted longer time of reserve and a wider distribution than the other sources. World recoverable coal reserves are 915 billion tonnes, and our country with own lignite reserves is among 10 leading countries in the world.

Tertiary deposits cover a total area of 110.000 km², and they are distinguished as about 2% Eocene, 14% Oligocene, 52% Miocene and 32% Pliocene. Total prospecting area performed by the General Directorate of Mineral Research and Exploration is 205.000 km². 42.000 km² areas of Tertiary, which could be prospective for coalfields, are studied with detail and the coalification is determined in an area of about 1500 km².

Coal exploration studies were about to cease at the beginnings of 1990's years due to the fact that our country exploited more increasingly natural gas. These studies augmented again by the projects, which commenced and co-ordinated by the General

Directorate of Mineral Research and Exploration in 2005. The priority in these studies is given to re-investigate the areas suitable for coal deposition in our country, and so to determine new prospective fields. In this context, new coal deposits are discovered in Thrace, Soma (Manisa), Karapınar (Konya), Dinar (Afyonkarahisar), Alpu (Eskisehir) and Afsin-Elbistan (Kahramanmaraş) basins, there are also reserve increases in the known coal fields. Our lignite reserves, known as 8.3 billion tonnes for a long time, reached to 12.6 billion tonnes due to the exploration and research studies, commenced in 2005 and conducted by General Directorate of Mineral Research and Exploration. However, taking into consideration the exploited amount in the lignite fields is 1.1 billion tonnes so far, it is concluded that lignite reserves in our country is 11.5 billion tonnes. After 2005 an increasing amount of 4.3 billion tonnes of proven+probable+possible reserves is a very crucial source of energy because it is domestic.

The utilization for fuels of coal-powered plants by our coals, which often have been ranked as low-level lignites, is inevitable for a sustainable energy and therefore a sustainable development.

With newly discovered oil and coal fields, the General Directorate of Mineral Research and Exploration pioneered the establishment of TPAO and TKİ, both of which are the most important institutions, and has been constituting a leadership in energy. Today, our institution again took this mission via proposed and conducted projects.

SESSION 12

Coal-Derived Products: Activated Carbon Production-1

12-1

Activated Carbon from Brown Coal by Chemical Activation

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In Victoria, brown coal is a cheap resource, which at current consumption rate has over 500 years of reserves. A possible utilization of these materials is converting them into activated carbon, which has potential for use as adsorbent and catalysts. Activated carbons can be produced by two methods - physical activation and chemical activation. Chemical activation is preferred over physical activation owing to the lower temperatures and shorter time needed for activation. The activation property of activated carbon strongly depends on its surface area.

In this study, we prepared activated carbons from Loy Yang brown coal using chemical activation. The materials were dipped into the solution for 24 h at room temperature, thoroughly washed by distilled water in order to remove the exact chemicals, and then filtered. Then the impregnated materials were pyrolyzed in a furnace at temperatures of 400°C-600°C for 30 mins under flowing N₂ at 20 ml/min. The type of activating reagent (KOH and K₂CO₃) and the effect of carbonization temperature on the texture of activated carbons have been investigated.

The morphologies of activated carbons were observed by SEM. The surface areas of activated carbons were measured by volumetric adsorption analyzer, using N₂ as the adsorption gas at -196°C.

This paper summarises the different chemical activation reagent and the carbonization temperature effects on activated carbons' porous structures and identifies the optimum preparation conditions for activated carbon from Loy Yang coal.

12-2

Low-Temperature Catalytic Graphitization of Carbon Material

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Carbon containing materials are generally classified by their graphitization (crystallization) temperature into two types: hard-to graphitize (3000-3200°C) and more easily graphitized (2200-2800°C). The temperature of graphitization can be lowered to 1900°C by application of a vanadium catalyst [1]. The use of nanoparticles of various metals allows further reduction of the graphitization temperature, but graphite is produced in the form of nanoparticles [2, 3]. In this work, low temperature conversion of carbon materials into graphite was studied by the example of coal-tar pitch transformation into foamed graphite in the presence of d-metals at a temperature of 600-1000°C [4]. The use of metal catalysts was shown to result in considerable reduction of graphitization temperature, suppression of emission of carcinogenic benzopyrenes during the graphitization and an increase of the product specific electrical conductivity. The specific conductivity of the obtained samples measured in a temperature range 4-300 K was close to that of crystalline graphite. The formation of graphite was proved by the study of the products by XRD and Raman spectroscopy. The produced foamed graphite can be pressed to form articles of different shape and size, which can be used, e.g., as material for the manufacture of electrodes.

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12-3

Experimental Research on the Preparation of Activated Carbon with Higher Absorbability from Anthracite

Jian Chang, Qiao-wen Yang, Zhen-hua Hou, Bin-bin Zhao, Dawei Zhao, China University of Mining and Technology, CHINA

This paper studied experimental conditions of making higher absorption activated carbon from Jincheng anthracite, under the action of two additives NaNO_3 and KOH . The result was obtained by using the orthogonal experiment in which four factors were designated: the carbonization temperature, the carbonization time, the activation time as well as the additive types, with the target of iodine value. The optimized parameters had been found out: the carbonization temperature is 600°C , the carbonization time is 1.5h, the activation time is 4h and the additive is NaNO_3 which is better in a weight proportion of 8%. At last, under the optimized parameters, the better activated carbon products could be gained by acid pickling, which has a higher iodine value 1094.8mg/g and low ash content 8.73%.

12-4

Research on the Preparation of Highthermalconductivity Carbon Block by the Ordered Growth of Self-assembled Mesophase

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Highthermalconductivity carbon material is a focus in the new carbon material research field. With few QIs coal tar pitch as raw material in this work, the thermoplastic mesophase pitch was prepared by the thermal polymerization processes. The effect of molding pressure on the development of ordered mesophase was studied. In our experiments, the mesophase pitch containing the same TI was molded respectively at 25°C to 600°C under 6.18 MPa, 9.24 MPa, 13.84 MPa, 20.05 MPa, carbonized at 1000°C and graphitized at 2800°C . The results showed that the graphitization degree of the carbon blocks ranges from 48.8% to 72.1% by graphitized at 2800°C .

With the increase of pressure, the apparent density increased from 1.47 g/cm^3 to 1.58 g/cm^3 and the porosity decreased. It is shown by SEM that the regional mesophase displayed a sort of highly ordered structure with long fiber and the mesophase liquid crystal molecules were aligned perpendicular to the compressing in the molding process. The axial and radial direction of thermal conductivity range of the carbon blocks was 140.5-156 W/m-K, 169.2-219.4W/ W/m-K, respectively. The anisotropic ratio increased as the pressure increased and reached 1.41. It was proved that one-step hot press molding not only increased the density and decreased the porosity of the carbon blocks, but also promoted the growth of mesophase in order, formed the long-range ordered, fibrous structure which was similar to carbon fibers. Consequently, the phonons conducted along the long-range ordered structure, the hindrance of the conduction of phonons was reduced.

SESSION 13

Combustion: Mercury and Trace Elements

13-1

UNEP Coal Combustion Partnership Area Activities Prior to 2013 Global Mercury Treaty

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To address the risk to human health and the environment from anthropogenic mercury releases, the Governing Council (GC) of the United Nations Environment Programme (UNEP) decided in 2003 to establish the UNEP Mercury Programme. The UNEP Mercury Programme currently consists of two main complimentary activities: fulfilling the aims of the Global Mercury Partnership and the negotiation of a legally binding instrument. Negotiations of a legally binding instrument on mercury began in June 2010 and are to be finalized by February 2013. The Global Mercury Partnership is the main mechanism for the delivery of immediate actions on mercury during the negotiation process.

The largest single anthropogenic emission source of mercury is the combustion of coal in power plants and industrial boilers. Practices capable of providing reductions in mercury emissions from coal-fired power plants have been summarized in UNEP's POG (Process Optimisation Guidance) document. These practices include plant efficiency improvement, pre-combustion control/prevention measures, maximization

of plant performance, co-benefit mercury removal by other pollutant emission control technologies and mercury-specific control processes. This document was presented to government agencies in four selected countries: South Africa, Russia, India, and China. When finalized, the document will serve as a tool for individual coal-fired, electricity-generating plants and for individual countries to: evaluating the opportunities to achieve multi-pollutant emission reductions at coal-fired power plants, assessing opportunities to improve energy efficiency of power plants and thus achieving reduction of greenhouse gas (GHG) emissions together with the reduction of mercury emissions, and providing guidance on how to optimize co-benefits of multi-pollutant control systems to reduce mercury emissions.

This paper presents the contents of the POG document, including information on coal usage and typical examples of air pollutant control equipment deployed at coal-fired plants in each of the four countries of interest. Up-to-date progress and future plans for dissemination of the POG document in the four selected countries are also given. Finally, the paper presents the progress achieved in the four focused countries toward the completion of the UNEP background study.

13-2

Direct Measurement of Mercury in Simulated Flue Gas

Bihter Padak, Jennifer Wilcox, Stanford University, USA

Homogeneous oxidation of mercury in the flue gas of coal combustion utility boilers has been studied for many years to understand the speciation of mercury. In spite of a vast amount of experimental studies, supported by modeling efforts, there are still many questions to be answered and the speciation of mercury is not fully understood yet. One needs to be able to make precise mercury measurements to understand its speciation and accurately predict the extents of mercury oxidation. Traditionally "difference" techniques are used which involves the direct measurement of elemental mercury. These techniques do not allow for distinguishing between the two different oxidized forms, Hg^+ and Hg^{+2} which makes it difficult to understand mercury speciation. It has recently been shown that mercury measurements performed with wet chemical conditioning systems are biased, resulting in inaccurate partitioning between oxidized and elemental mercury species. Given the shortcomings of the difference techniques, it is essential to measure oxidized and elemental mercury directly and hence separately to have a complete understanding of mercury speciation. In this study a custom-built electron ionization quadrupole mass spectrometer (EI-QMS) will be used to directly measure mercury species in combustion flue gas.

To accurately measure the low concentrations of different mercury species present in coal combustion flue gases, the EI-QMS must be sensitive to concentrations in the ppb range, which can pose a challenge. To increase the sensitivity, the system has been upgraded to have a supersonic beam and a skimmer is placed after the first orifice that is heated. In such a setup, scattering of the molecular beam is avoided and the amount of gas which reaches the ionization region, and subsequently the ion detector, is maximized, thereby improving the sensitivity of the instrument. Also a tuning fork chopper has been implemented in the system along with a lock-in amplifier to enhance the signal-to-noise ratio.

A benefit of employing a mass spectrometer is, unlike traditional impinge-based methods, the oxidized forms can be isolated and individually identified because it separates the products based on their mass-to-charge ratio. With this custom-built instrument, mercury species will be directly measured for the first time for high temperature combustion applications. By directly measuring mercury species accurately, one can determine the actual extent of mercury oxidation in the flue gas, which will aid in developing mercury control technologies. In addition, not only mercury but also other trace metals in flue gas such as arsenic and selenium can be measured and speciated in flue gas.

13-3

Modeling Trace Element Release from Included and Excluded Pyrite during Pulverized Coal Combustion

Wayne S. Seames, Esam I. Jassim, Steven A. Benson, University of North Dakota, USA

A mathematical model was developed to study the vaporization of trace elements during the combustion of individual coal and pyrite particle. The initial modeling has focused on the release of As, Se and Sb associated with pyrite since it is the host site for these elements. The model considers the release of the trace elements from pyrite included in coal particles and excluded from coal particles. The model predicts the amount of elements vaporized as a function of coal particle size, mineral grain size, mineral grain association, flame temperature, and residence time. The model considers the combustion of the coal char and the decomposition, fragmentation, melting, and coalescence processes of the pyrite particles.

Online Monitoring of Boron in Flue Gas Desulfurization Effluents by Fully Automated Measuring Equipment

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We developed a fully automated measuring equipment for aqueous boron (referred to as the online boron monitor) on the basis of a rapid potentiometric determination method using a commercial BF_4^- ion-selective electrode (ISE). The equipment can measure boron compounds with concentration ranging from a few to several hundred mg/L, and the measurement is completed in less than 20 min without any pretreatment of the sample. In the monitor, a series of operations for the measurement, *i.e.*, sampling and dispensing of the sample, addition of the chemicals, acquisition and processing of potentiometric data, rinsing of the measurement cell, and calibration of the BF_4^- ISE, is automated.

To demonstrate the performance, we installed the monitor in two full-scale coal-fired power plants and measured the effluent from a flue gas desulfurization (FGD) unit. The boron concentration in the effluents varied significantly depending on the type of coal and the load of power generation. An excellent correlation ($R^2 = 0.987$) was obtained in the measurements between the online boron monitor and the conventional measurement (ICP-AES). The online boron monitor revealed long term behavior of boron in the FGD effluent for the first time and thus it can serve as a useful tool for managing boron emission in process effluents.

Mercury Sorption on Brominated Activated Carbon

Erdem Sasmaz, Jennifer Wilcox, Stanford University, USA

EPA estimated that approximately 75 tons of mercury were found in the coal delivered to power plants each year and about two thirds of this mercury was emitted to the air, resulting in about 50 tons being emitted annually. This 25-ton reduction was achieved through existing pollution controls such as fabric filters (for particulate matter), scrubbers (for SO_2) and selective catalytic reduction units (for NO_x). To predict the levels of mercury emissions from coal-fired power plants and determine the best applicable control technologies, it is important to understand heterogeneous mercury reaction mechanisms on activated carbon surfaces.

Experimental studies are conducted using a bench-scale packed-bed system to further understand heterogeneous mercury reaction mechanisms. Methane is combusted in a tubular burner and the effect of combustion products on the sorption of mercury are investigated. Additionally, other flue gas species will be introduced in a controlled manner to the reactor system to understand their effect on mercury adsorption. Activated carbon-based sorbent materials before and after simulated flue gas exposure are analyzed using X-ray photoelectron spectroscopy (XPS). Characterization experiments are conducted to determine the chemical bonds, surface coverage and speciation of mercury. Our XPS results for mercury sorption tests on brominated powder activated carbon surfaces conducted in an air environment suggest that mercury is adsorbed on carbon surfaces in the form of oxidized mercury; however, the identification of the oxidation state of mercury on our samples was limited due to presence of silicon on the surfaces and its subsequent interference with mercury spectral lines.

Effect of Coal Volatile Matter on Emissions of Boiler Combustion

Hasancan Okutan, Nalan Erdöl Aydın, Erhan Böke, İstanbul Technical University, TURKEY

Turkey's most important bituminous coal deposits are located especially in Zonguldak basin on the shores of the Black Sea in the Northern Turkey. Coal obtained from Zonguldak basin by means of underground mining is transferred to various washery plants in districts such as Zonguldak, Çatalağzı, Armutçuk and Amasra, where its sulfur and mineral matter contents are reduced and it is classified as coking, semicoking and noncoking coal. Coking coal is used as feed stock in the coke production, while noncoking coal is consumed as industrial and domestic fuel throughout the country.

Bituminous coals from Zonguldak basin have a considerable amount of volatile matter contents, some of which are easy to desorb from the coal surface during heating and they leave the coal structure without burning.

In this study, effect of coal volatile matter on the combustion efficiency and CO , SO_2 , NO_x and particulate emissions of the bituminous coals and lignite from Turkey and Sibirya are investigated in a 174 kW, half cylindrical hot water boiler. Experiments were carried out for 27,0% volatile matter Zonguldak washery, 27,5% volatile matter Çatalağzı washery, 34,0% volatile matter Armutçuk washery, 35% volatile matter Amasra washery, 0,8% volatile matter Zonguldak coke, 38% volatile matter Soma and 18,9% volatile matter Sibirya coals. Combustion tests were performed according to Turkish Standards (TS) 4040 and 4041, which are equivalent to respective ISO standards. Individual combustion efficiency, particulate and gas emissions profiles and cumulative emissions are determined and the experimental results are discussed.

The Improvement of UCG Processes

Karol Kostur, Technical University of Košice, SLOVAK REPUBLIC

The idea of the transformation of coal in underground into synthetic gas so called syngas has interesting in world more centuries. UCG (Underground Coal Gasification) is an in situ technique to recover the fuel or feedstock value of coal that is not economically available through conventional recovery technologies. Today, less than one sixth of the world's coal is economically accessible. Today, similarly to all other countries in the world also in Slovakia there is an interest in the revival and perfection of the UCG technology. From the viewpoint of content the research is directed toward to increasing heating capacity of syngas. From the standpoint of the methods used one can characterize the research by 2 approaches: experiments in UCG laboratory and mathematical modeling, including of simulation studies. Both approaches have helped to discover complicated relationships during UCG and they will be subject this lecture. Most important are topologies/methods, humidity of coal, heat losses, temperatures in relevant zones, composition of oxidation agents and permeability. Calorific value of syngas is 0.55 – 4.45 MJ.Nm⁻³ on average with maximum 25.51 MJ.m⁻³ if oxidation agent was used air only. In case using mixture air + oxygen have been obtained calorific value from range 0.43- 6.38 MJ.m⁻³ on average with maximum 27.53 MJ.m⁻³. The analysis has been done for these big differences by aim to improve UCG. Therefore in paper is described:

- Structure of thermodynamics model including simulation cases,
- Experimental plant, including measured data,
- Relevant results (the influence of reaction's area).

Modelling of Deep Lignite Seams for Conventional Production and Underground Coal Gasification in Turkey

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Turkish Coal Enterprises (TKI) is the biggest state owned company in Turkish mining industry and has been producing lignite for more than a 50 years period. Majority of TKI's production has been done by surface mining methods. However, the lignite resources suitable for surface mining are to be depleted in about 10 years. This suggests that lignite production in the near future be supplied by underground mining. It is compulsory to develop new underground mines for maintaining safe supply of lignite in the country. TKI and Hacettepe University have been collaborating on 3D modelling of lignite seams and subsequent underground mine design. Soma, Tuncbilek and Yatagan lignite basins are selected for this purpose. Lignite seams in these basins are subject to severe tectonic movement. This will unfortunately lead to loss of some part of the deep seated seam(s) by underground mining methods. Hence, application of underground coal gasification technique to utilize these parts is evaluated as a viable alternative. This paper briefly describes tectonics and general characteristics of lignite seams together with essentials of conventional underground mining and coal gasification.

An Integrated 3-D UCG Model for Predicting Cavity Growth, Product Gas, and Interactions with the Host Environment

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This paper presents recent work from an ongoing project at Lawrence Livermore National Laboratory (LLNL) to develop a comprehensive, integrated simulation tool for underground coal gasification (UCG). This capability will predict cavity growth, product gas composition, and interactions with the host environment. We are developing an efficient approach to integrate four classes of numerical submodels, representing specific processes in their respective spatial domains: (1) UCG cavity, (2) wall zone, (3) rubble zone, and (4) far field. The UCG cavity submodel includes turbulent gas-phase mass and heat transfer, radiative heat transfer, and gasification reactions within the cavity. LLNL has gained considerable simulation experience in the UCG-cavity domain, using STAR-CCM, a commercial computational-fluid-dynamics (CFD) code. Furthermore, in the far-field domain, LLNL possesses expertise and cutting-edge simulation tools such as NUFT (Nonisothermal Unsaturated Flow and Transport) code to model thermohydrological behavior, and GEODYN-L and LDEC codes to model geomechanical behavior. That expertise has been useful in developing our integrated simulation approach. The integrated UCG simulation tool is intended to support UCG design and operations, environmental monitoring, and risk assessments. In this paper we discuss the initial stage of development of our integrated modeling approach, which focuses on the wall-zone submodel (WZM), and the integration of the

WZM with the far-field submodel (FFM). The WZM is a 1-D, multi-phase, multi-species model that includes solid-reaction kinetics for pyrolysis and combustion; methanation and water-gas shift reaction for phase kinetics. The WZM extends far enough into the host coal/rock to encompass the region of thermal effects. Because mechanical effects are assumed not to influence the far-field conditions, it is possible for the FFM to be represented using an isothermal NUFT model. In later stages of model development, we intend to address the influence of geomechanical effects on far-field hydrology. The WZM is executed as a family of 1-D submodels, distributed over the surface of the UCG cavity, with the isothermal NUFT FFM providing the necessary boundary conditions. The initial UCG cavity submodel is a simplified, abstracted model that uses mass- and heat-transfer coefficients to represent turbulent and buoyant gas-phase mixing, includes gas-reaction kinetics, and represents flow through the spalled material on the floor of the cavity. In later stages of model development, the simplified, abstracted UCG cavity model will be replaced by either a CFD model, or an abstracted model, calibrated using CFD models. Later stages of model development will also incorporate the results of geomechanical models to represent spallation behavior and the geomechanical influence on far-field permeability distribution. During the course of model development, we make systematic comparisons with published UCG models to help validate our approach and to improve our knowledge of UCG.

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14-4

Quantification of the Effects of Various Thermal Boundary Conditions in the Underground Coal Gasification Cavities Using a Compartment Model

Sateesh Daggupati, Ramesh Naidu Mandapati, Sanjay M Mahajani, Anuradda Ganesh, Preeti Aghalayam, IIT Bombay; Sapru R.K., Sharma R.K., ONGC, INDIA

The UCG product gas can be used for electricity generation, or as a chemical feed stock, and gas turbine power generation combined with UCG is one of the promising ways of accomplishing clean coal utilization. In the UCG process, a cavity consisting of ash, char rubble and void space is formed and its size increases three dimensionally in a non-linear fashion. Operational control of the UCG process is difficult because of the several phenomena that are occurring simultaneously such as the detachment of coal from the cavity roof (i.e. spalling), water intrusion, chemical reactions, heat and mass transfer, and so on. These phenomena also lead to a complex flow distribution in the cavity. The characterization and quantification of this non-ideal flow field is necessary as it influences the performance of the UCG process. It is affected by several parameters such as the temperature gradients, inlet nozzle position and orientation, and coal properties such as thermal conductivity. The primary objective of this work is to study the effect of temperature gradients and various thermal boundary conditions on the reactant gas flow patterns in an underground cavity, through mathematical simulations. CFD simulations are performed for each case in order to get the flow pattern and residence time distribution curves. The effects of various thermal boundary conditions in the underground coal gasification cavities are quantified by performing the compartment modeling simulations independently. The results presented here may provide good insight of the UCG cavity under different scenarios of the UCG process.

14-5

Estimation of Chemical Reaction Occurred in Underground Coal Gasification

Osamu Yamada, Mamoru Kaiho, National Institute of Advanced Industrial Science and Technology (AIST); Sohei Shimada, The University of Tokyo; Shouji Fujioka, Japan Coal Energy Center; Jie Liang, China University of Mining and Technology, JAPAN

We have proposed a method to derive the gasification reaction formula, from the result of ultimate analysis and composition $CH_mO_n + \alpha O_2 + \beta H_2O \rightarrow \gamma H_2 + \delta CO + \epsilon CO_2 + \eta CH_4$, of gas produced. Since the numerical expressions to determine the value of α to η in above reaction formula were derived without any arbitrary assumption and approximation, we consider that the equations are generally used for the analysis of data obtained by any kind of gasification process.

The characteristics of chemical reaction process of underground coal gasification (UCG) in Fushin coal mine in China was elucidated by our method as presented previously. We have successfully prepared the method to estimate the temperature of gas in UCG reactor based on the heat of reaction hr calculated from reaction formula by following equation;

$$hr = \gamma hH_2 + \delta hCO + \eta hCH_4 - hcoal$$

where hH_2 , hCO , hCH_4 , and $hcoal$ show molar heating value of H_2 , CO , CH_4 , and coal. Since the wall of the reactor of UCG is made of coal, hr seems to be utilized effectively in pyrolysis and drying of coal. The UCG reactor was regarded as adiabatic, therefore, hr agrees with a total of sensible heat of gas exist in the reactor at that temperature.

We compared the reaction processes and gasification temperature of UCG carried out at Xinghe mine, Liuzhuang mine, Ezhaung mine, Xiyang mine, and Fuxin mine. Carbon content of each coal was 81.67, 82.66, 82.87, 92.34, and 79.70% respectively.

Average amount of α in each coal was estimated as 0.333, 0.376, 0.477, 0.171, and 0.347 mol/mol respectively, and that of β was also estimated as 0.688, 0.399, 0.397, 0.717, and 0.247 mol/mol respectively. α and β seemed to correlate to the value of $hcoal$.

14-6

Computational Flow Modeling of Underground Coal Gasification (UCG) Process

Sateesh Daggupati, Ramesh Naidu Mandapati, Sanjay M Mahajani, Preeti Aghalayam, Anuradda Ganesh, IIT Bombay; Sapru R.K., Sharma R.K., UCG Group, IRS, ONGC, INDIA

Underground coal gasification (UCG) is a technique which permits access to coal which either lies too deep underground, or is otherwise too costly to exploit using conventional mining techniques. At the same time, it eliminates many of the health, safety and environmental problems of deep mining of coal. An irregular shape cavity is formed in the coal seam when coal is converted to gaseous products and its volume increases progressively as the coal is consumed. The complexity involved in modeling UCG process thus compels one to adopt a rigorous modeling approach that calls for use of computational fluid dynamics (CFD), which solves all balance equations simultaneously on a high speed computer. The simulation tool developed in the present work is capable of simultaneously predicting temperature distribution in the coal seam and profiles of velocity, temperature and species inside the cavity of a given size and shape. Further, with the help of this simulator we study the effect of various inlet conditions such as steam to oxygen ratio, feed temperature etc., on the product gas compositions. Ultimately, this work would help one to obtain the optimum conditions to produce product gas of high calorific value for a given cavity along with the specified inlet and boundary conditions. A broader objective of this simulation work is to track the growth of cavity and the associated changes in the UCG performance.

SESSION 15

Carbon Management: CO₂ Sequestration

15-1

CO₂ Sequestration in Unminable Coal with Enhanced Coal Bed Methane Recovery: The Marshall County Project

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A pilot test is being conducted in Marshall County, West Virginia, USA, to evaluate enhanced coal bed methane recovery and simultaneous carbon dioxide sequestration in an unmineable coal seam in the Northern Appalachian Basin. Injection of carbon dioxide (CO₂) began in September 2009 and it continues at the time of this writing. This paper describes the project and its current status.

15-2

A GIS-DSS for a CO₂-ECBM Project Feasibility Study: Case of Sulcis Coal Basin (Sardinia, Italy)

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The correct identification of the potential sites for geological storage of greenhouse gases (i.e. CO₂) is the most important operative step to assure the success of the project. It is obvious that, in the CO₂-ECBM technologies field, the success of a geological storage project can be reached only if, in addition to the technical and the economical accomplishment, the safety for the people and the ecosystems directly exposed are always guaranteed.

In the CO₂-ECBM technologies field, the geological reservoir evaluation must consider a great number of parameters, often very heterogeneous, mainly concerning: the coal seams features, the hosting formations properties, the environmental restrictions and the human/administrative constrains. The variety and variability of these parameters make each evaluation unique and, for this reason, it is impossible to give some "universally-valid" guidelines to help the *Decision Maker* in the planning procedure. For these reasons it is not advisable for the *Decision Maker* using only his own experience rather it would be advisable the use of a **Decision Support System (DSS)**.

In the **Carbon Geological Storage (CGS)** field, the combination of DSS and GIS technologies allows the realization of very powerful tools able to identify and solve technical problems (like the location of geological reservoirs able to contain safely large quantities of gases) and to evaluate technically/economically different alternatives (like the environmental monitoring system planning) in order to assure the right balance between the technical/economical success of the project and its environmental sustainability.

This research work concerns the first results accomplished by our research team in the development of a GIS-DSS for the pre-feasibility study of a CO₂-ECBM project within the Sulcis coal basin (Italy, SW Sardinia).

The GIS-DSS has been completely implemented using the ArcGIS Model Builder 9.3. The available data concerning: the basin DTM, the coal bed 3D-model, the geological maps, the aerial photo, the land use data and the environmental constraints have been combined using the Weighted Overlay Process (WOP). The WOP applied (also known as *Multi-Criteria Evaluation - MCE*) produced an output grid by combining the input grids values and weighting them by using a relative importance scale. This operative step allowed to define, within the basin area, the most suitable zones where the next detailed studies should be concentrated ("Basin Suitability Map").

The current version of the GIS-DSS, fully functional although yet under development, can be modified to consider more input parameters and/or to produce different results varying the weighting relative scale.

15-3

Effect of Rock Composition on Mineralization in Sequestration

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The reactive behavior of pure CO₂ with limestone, sandstone, arkose and peridotite was examined in this study. The experimental apparatus consists of series of high-pressure reactors with pure CO₂ as feed gas at 1000C to evaluate the dependence of kinetics and mineralogical changes on rock composition. Arkose was observed to exhibit the highest tendency of participating in these reactions, which can be attributed to the geochemical complexity of its initial mineral assemblage. Layers of calcite were seen growing on the surface of the arkose. Analcime deposits are almost omnipresent either occurring as large connected aggregates or as deposits on surfaces of other minerals. Ankerite and calcite deposition were observed as amorphous mass intergrown with starting minerals.

Continuous dissolution of limestone was seen with the release of CO₂ gas, indicated by the increasing pressure in the reactor (formation of a gas chamber), which occurs due to the lack of any source of alkali to buffer the solution. With sandstone, there was slight increase in pH due to dissolution of feldspars. The rate of carbonation of feldspars is pretty slow compared to the dissolution. Hence the precipitation of carbonates at the measured time scale is not evident. In peridotite experiments, carbonation of peridotite forming calcium and magnesium carbonates along with serpentine was evident. Hence, arkose has the geochemical complexity for permanent sequestration of CO₂ as carbonates and is an ideal choice. Geochemists workbench (GWB) was used for kinetic modeling of these reactions. A full factorial statistical analysis was carried out to identify the most sensitive parameters (kinetic rates and reactive surface areas) in the arkose. The results from simulations indicate much rapid pace of these reactions when compared to experiments. Hence, caution should be exercised when using the calculated rates of reaction for making long-term process predictions. The study provides useful laboratory data (with model comparisons) when considering CO₂ sequestration in different geologic The brine chemistry results for the experiments with different initial rock compositions are presented in this report. These results complement the changes in the rock chemistry.

15-4

Geological CO₂ Storage in Coal-Bearing Formation

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JAPAN

CO₂ geological storage (CGS) has been recognized as an indispensable and cost-efficient abatement measure against the Global Warming due to the CO₂ emission from large-scale energy-related sources. Within the CGS, disposal of CO₂ into deep saline aquifer formation (DSAF) and injection of CO₂ into deep unminable coal seam (UCS) for enhanced coalbed methane recovery (ECBMR) are two promising technologies which have been widely studied. Recently, the interest of geologists and policy-makers in a specific type of subsurface formation called deep coal-bearing formation (DCBF) is booming. DCBF is characterized by the generation of relatively thin coal seam between strata of other subsurface materials, mostly sandstone. It deserves special attentions because of its intrinsic saline-aquifer-like characteristics resulting from the huge amount of storage potential all around the world as well as the presence of coal which may reduce the risk of the leakage and offset the operation cost by ECBMR.

In this study, a non-isothermal multi-phase multi-component fluid dynamics simulator was developed for the comprehensive study on CO₂ migration and assessment on the performance of CO₂ storage in DCBF.

Modeling of the thermophysical properties of fluid and the geological properties are elaborated considering the trade-off between the simplicity and the accuracy required. The newly-built simulator was substantially verified by comparing the result of this simulator with the results calculated by other sophisticated simulation code for the test problems and it shown a good agreement. The simulator was further verified by simulating CO₂ injection into saline aquifer formation and tracing the migration of CO₂ under the consideration of non-isothermal effect.

A reservoir models which are representative in the natural world were set up. Several evaluation indexes considering every aspect of CO₂ storage were introduced.

Sensitivity analysis on several key parameters associated with fluid dynamic in the porous media was conducted on the models.

15-5

Experimental Study on Carbon Dioxide Sequestration by Mineral Carbonation

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Carbon dioxide sequestration by mineral carbonation is a potentially attractive route to mitigate possible global warming on the basis of industrial imitation of natural weathering processes. In the paper, two typical minerals serpentine and wollastonite were selected as feedstock for direct mineral carbonation experiments under low-middle pressure. Abundant experimental studies were performed in the paper to investigate the factors (temperature, pressure, particle size, pre-treatment and gas composition) that influence the conversion rate of carbonation reaction. The products from experiments were analyzed by x-ray diffraction (XRD), field scanning electron microscopy equipped with energy dispersive X-ray analysis (FSEM-EDX). The results show that, after antigorite mineral carbonation, the mainly mineral components include: quartz, and magnesite, few antigorite. Rhombohedra magnesite crystals and rounded particles of serpentine were also identified from SEM image. For the wollastonite carbonation, the mainly mineral in production is calcite, which was also identified by SEM analysis. Few amorphous SiO₂ which can't be identified by XRD has been found around the calcite particles in the SEM image. All of these validate that mineral carbonation is a potential technique for carbon dioxide sequestration. The method of mass equilibrium after heat decomposition was used to calculate the mineral carbonation conversion rate. The conversion rate increases with the increasing of temperature. The conversion rate of wollastonite carbonation is higher than antigorite carbonation. Pressure is also an important factor to mineral carbonation. For both of wollastonite and antigorite, the carbonation conversion rate is increase with increasing reaction pressure. Because carbon dioxide is dissolve in water solution easier in high pressure. The conversion rate of mineral carbonation after pretreatment, such as heat treatment and pulverization, is much higher than the normal mineral. Under the condition of simulated flue gas, the conversion rate of wollastonite mineral carbonation decreased sharply compared with the pure carbon dioxide. And with the addition of SO₂ in the simulated flue gas, the conversion rate of wollastonite mineral carbonation decreased. A carbonation experiment at P_{CO2} =4.0 MPa, T=150°C, dp< 30µm results in a highest carbonation conversion rate of 89.5% for wollastonite. Compared with antigorite, wollastonite is more promising in carbon dioxide mineral sequestration.

15-6

CO₂ Sequestration for the Shenhua DCL Plant in China

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In 2009 the world's 1st modern commercial direct coal liquefaction (DCL) plant was completed in China by the Shenhua Group Corporation (Shenhua), the world's largest coal company. Based on the results obtained from initial start-up operations, the plant has undergone a series of modifications prior to full scale operation that will produce about 24,000 bbl/d of liquid fuels. When in full scale operation, the plant will generate over 3 million metric tons of highly concentrated CO₂ each year, a major issue given current concerns related to the carbon footprint of the energy sector. To address these concerns, Presidents Obama (US) and Hu (China) announced a joint effort to develop a CO₂ sequestration project related to the Shenhua DCL plant in November 2009 that is an initial step in addressing the carbon management issue for the coal conversion industry. The US Department of Energy (DOE) and the China National Energy Administration (NEA) are supporting a cooperative effort by a US team led by West Virginia University (WVU) and a China team supported by Shenhua to analyze the alternatives available and to develop an implementation plan for this project. These collaborative efforts include a feasibility study for the initial project and a broader study of the Ordos Basin to determine the potential for broader implementation and inclusion of other CO₂ sources. Cooperative efforts are expected to address risk analysis, modeling, CO₂ utilization, geoscience research on CO₂ storage and carbon management planning for the Ordos Basin. As a result of initial efforts previously completed, Shenhua is implementing a series of engineering modifications to the DCL plant to increase the concentration of the CO₂ stream from the initial 89% level based on the original plant design to 95% or greater to improve the sequestration efficiency. A pre-feasibility study was completed in 2009. The new effort will support the development of a full feasibility study to extend the initial efforts as well as a pilot demonstration project designed to store approximately 100,000 MT/y of CO₂ in deep saline aquifers near the Shenhua DCL plant. This demonstration project is expected to be implemented during 2010. The data developed for the pilot project including data from test wells and the initial results of the pilot storage test are some of the first steps toward a comprehensive study of a CO₂ sequestration effort for the Ordos Basin. If successful, this broader effort could evolve into the world's largest current sequestration effort with an ultimate goal of sequestering 50-60 million mt/y of CO₂ in the Ordos Basin. This paper provides an overview to the joint efforts between the WVU led US research team and the Shenhua led China research team to explore the potential for such a sequestration effort. The results of these efforts are expected to

provide a better understanding of CO₂ constraints and possible solutions relevant to future coal conversion developments around the world.

SESSION 16
Coal Science: Coking

16-1

Clean Fuel Production Works from Canakkale-Can Coals

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In this study, high sulfur containing Canakkale-Can coals were used to upgrade their calorific and sulfur values, with employing washing, multi gravity separation and flotation methods.

For this purpose, samples were taken from the fields, and then representative samples were prepared to conduct physical, chemical, mineralogic and petrographic analysis, determine grain size distribution, proper ore processing method and suitable working conditions of the chosen suitable devices, for the experimental works.

Sink-float tests were performed on the various sized prepared samples. The received data was evaluated, then concentrated coals with determined densities were obtained, then the briquettes were made out of these coals. The secondary washing cycle products and -0.5mm coals were taken to be tested with a Multy Gravity Separator. Besides, flotation tests were carried out to decrease sulfur content of the coals.

16-2

Study on the Relation between Moisture of Coals and the Coking Process and the Quality of Cokes

Junfang Bao, Gaifeng Xue, Hongbin Chang, Wuhan Iron and Steel (Group) Corporation, CHINA

According to determining the moisture of coals through the water were 0%, 6% and 12% the proportion of coal the bulk density, heating rate and the quality of the crucible coke, the conclusion was educed that the moisture of coals have significant impacted bulk density, heating rate and the quality of the crucible coke. When the moisture is 0%, bulk density, heating rate and the quality of the crucible coke are much better than the moisture at 6% and 12% in both cases.

16-3

Coke Quality Prediction Based on MATLAB Neural Network

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The research aimed to confirm the feasibility of predicting the coke quality by using BP neural network based on MATLAB with Gieseler fluidity data. 60 samples of blended coals were tested with their Gieseler fluidity including softening temperature, plastic range and maximum Gieseler fluidity, the corresponding cokes' CSR and CRI were also tested. 50 samples were trained by BP neural network and 10 samples were simulated, the results show that BP neural network model had an extremely high fitting precision.

16-4

Thermoplasticity Improvement of Coal Blends by Adding Solvent-Extracted Coal

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A coal extract, produced by thermal extraction and solvent de-ashing in 2-ring aromatic solvent, has an excellent thermoplasticity even though the parent coal appears no thermoplasticity. We named it "HPC, High Performance Caking additive", and have been developing to utilize as a thermoplasticity accelerator to make strong coke for blast furnace. This study concerns with the effect of HPC addition to improve thermoplasticity of coal blends.

Significant improvements in the thermoplasticity of coal blends were observed by HPC addition, especially with high blending ratio of slightly caking coals. The thermoplastic phenomenon of coal, softening, fluidizing and re-solidifying, was traced as the quantitative behavior of the molecule mobility of coal. The quantitative behavior of the mobile component was investigated by in-situ high temperature 1H-NMR relaxation time measurement¹). Thermoplasticity appealed with generation of the mobile component, and the fluidity increased with increase in the mobile component, and re-solidified with disappearance of the mobile component. The mobile component was increased by HPC addition, and also the fluidity strongly increased. Each coal, HPC and coal blends were thermally extracted in the 2-ring aromatic solvent. The coal extraction yields were quantitatively related with the mobile component measured by the 1H-NMR relaxation time measurement. The maximum fluidity of coal was also

related with the coal extraction yield. The amount of the solvent extractable component could be regarded as a scale parameter of the mobile component. The maximum fluidity of coal blends with HPC addition can be estimated from the arithmetic mean of each component coal's extraction yield. Thus the optimum condition of HPC addition to make strong coke can be determined by this method.

16-5

Effect of Technical Property of Coking Coal on Optical Texture of Coke

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The optical texture of coke is not only related with the metamorphism of coking coal, but also is related with the technical property of coking coal. In this paper, the effect of technical property of coking coal on optical texture of coke was studied, and the coke was coked by several kinds of coking coal with close rank but different technical property. The results showed that if the coking coal had high caking index and thickness of colloidal matter layer, it was easy to make the coke optical texture transform to higher aeolotropic degree, that was to say, the isotropic structure was easy to transform to the close grained or the close grained was easy to transform to the coarse grained; if the coking coal had low caking index and thickness of colloidal matter layer, the contents of isotropic and inert structure of its coke would become high.

16-6

Research on Coke Microstructure Coked by High Metamorphism Coal of Different Grain Size

Gaifeng Xue, Ru Xiang, Zikui Song, Wuhan Iron and Steel Corp, CHINA

High metamorphism coal used into coking-blending can become leaning agent and center of coking. The coking morphology, size, the state of combing with active component and combing strength has many effects on coke quality. By researching on the coke microstructure coked by meagre-lean coal of G value 0~5, 5~10, 10~20, and lean coal of G value 20~40, 40~65, it finds the coke microstructure and morphology is obviously different if the coal coked at the state of different grain size has different metamorphism and G value. This paper emphasizes on the changes of microstructure and quality of coke coked by the meagre-lean coal of G value 10~20 and the lean coal of G value 40~65 in different grain size, the results show if the thin coal or meager-lean coal is blended at the state of best grain size, the mixture ratio can be increased 20%~25%, and the coke quality can be improved especially the thermal property, the M₁₀ can be improved 1%~1.5%, M40 can be increased 2%, CRI can be improved 3%~6% and CSR can be increased 2%~5%.

SESSION 17
Sustainability and Environment - 3

17-1

Carbon Capture and Integration: An Alternative Perspective to CO₂ Emissions and Carbon Capture and Sequestration

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As carbon dioxide emissions come under greater scrutiny due to being linked with catalyzing the adverse effects of global climate change, high pollution-emitting coal power plants are called to lessen their contribution to rising greenhouse gas levels. However, the international increase in coal usage continues in the world's fastest growing economies, especially China, India, South Africa and Indonesia, despite such criticism (*Coal Information: 2010*; IEA, 2010). The potential for coal power plants to remediate their emissions through subterranean Carbon Capture and Sequestration (CCS) is economically viable, yet it does not correct the potential harm such storage procedures have on the environment or public health. Evidence analyzing harm created from water aquifers acidifying, since they are comprised of carbon-absorbing rock, is slowly bringing to light questions concerning the total human and ecological safety of CCS in the long term (*Economics of geological CO₂ storage and leakage*; van der Zwaan & Gerlagh, 2008). Rather than seeing carbon dioxide as a pollutant, creating a procedure for Carbon Capture and Integration (CCI) can utilize these gaseous byproducts as usable secondary resources. Instead of diverting greenhouse gases from power plant smoke stacks to deep boreholes of porous stone, altering emissions flow directly to a contained environment for growing biomass (namely fast-growing and heavily carbon-dependent algae) provides a circular rather than linear method of carbon storage (Lehmann, 2009). Evidence already provides means of carbon dioxide transportation for other industries, namely industrial and chemical facilities. Grown biomass can be transformed and reintroduced into the energy production economy via two processes: 1) conversion into bio-ethanol using steam generated by excess heat from coal combustion and sold as a secondary output and 2) transformation into dehydrated algae cake and used as a solid fuel supplement should coal resource prices rise beyond sustainable profit-making levels. Outside of the energy economy, these integrative approaches enable future banking of emissions credits when larger carbon cap and trading institutions become regionally established. In both cases, Carbon

Capture and Integration can be environmentally and economically beneficial for meeting the growing demand in energy currently placed on coal-based infrastructures while remaining conscious of the international repercussions from increasing carbon footprint levels.

17-2

Future Coal Production Outlooks in the IPCC Emission Scenarios: Are They Plausible?

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Anthropogenic climate change caused by CO₂ emissions is strongly and fundamentally linked to the future energy production. The Special Report on Emission Scenarios (SRES) from 2000 contains 40 scenarios for future fossil fuel production and is used by the IPCC to assess future climate change. Coal, with its 26% share of world energy, is a major source of greenhouse gas emissions and commonly seen as a key contributor to anthropogenic climate change. SRES contains a wide array of different coal production outlooks, ranging from a complete coal phase-out by 2100 to a roughly tenfold increase from present world production levels. Scenarios with high levels of global warming also have high expectations on future fossil fuel production.

The assumptions on resource availability are in SRES based on Rogner's assessment of world hydrocarbon resources from 1997, where it is stated that "the sheer size of the fossil resource base makes fossil sources an energy supply option for many centuries to come". Regarding the future coal production it is simply assumed to be dependent on economics, accessibility, and environmental acceptance. It is also generally assumed that coal is abundant, and will thus take a dominating part in the future energy system. Depletion, geographical location and geological parameters are not given much influence in the scenario storylines.

This study quantifies what the coal production projection in SRES would imply in reality. SRES is riddled with future production projections that would put unreasonable expectation on just a few countries or regions. Is it reasonable to expect that China, among the world's largest coal reserve and resource holder and producer, would increase their production by a factor of 8 over the next 90 years, as implied by certain scenarios? Can massive increases in global coal output really be justified from historical trends or will reality rule out some production outlooks as implausible?

The fundamental assumptions regarding future fossil fuel production in SRES was investigated and compared with scientific methodology regarding reasonable future production trajectories. Historical data from the past 20 years was used to test how well the production scenarios agree with actual reality. Some of the scenarios turned out to mismatch with reality, and should be ruled out. Given the importance of coal utilization as a source of anthropogenic GHG emissions it is necessary to use realistic production trajectories that incorporate geological and physical data as well as socioeconomic parameters. SRES is underpinned by a paradigm of perpetual growth and technological optimism as well as old and outdated estimates regarding the availability of fossil energy. This has resulted in overoptimistic production outlooks.

17-3

The European Coal Market, a Prosperous Future?

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From the worldwide crisis of finance and economy in 2009 the international coal market was not exempted. Production and demand of coal showed an incising recession. In particular the member countries of the EU 27 were affected. Market forecasts up to that time about the further development of the European coal market, including bituminous coal as well as lignite, became completely worthless in shortest time and need now an intensive revise and actualisation.

The consideration of all important factors and figures, political, economic and technological, only will come to the result that in the long term the EU market will be a shrinking one, whereby at the time being it is not possible to give an exact and approximately reliable forecast about market conditions and a safe evaluation of the various factors. The complexity of the subject will be illustrated and evaluated in the following paper.

17-4

Trace Metals Mobility and Partitioning in Brine Irrigated Weathered Coal Fly Ashes from a Coal Burning Power Station in the Mpumalanga Province, South Africa

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The aging process (weathering) of discarded coal fly ash that is initiated by chemical interaction with ingressed CO₂, atmosphere (O₂) and percolated rain water might lead to eventual release of metals present in different mineral phases or physicochemical forms in coal fly ash. In most cases the mineral forms holding these toxic contaminants in weathered coal fly ash are not identified and quantified. This study was carried out to gain insight into the metal partitioning in different physicochemical forms and different environmental conditions (rain water percolation, ingress CO₂ and ingress O₂) that can cause their eventual release into the ground water system. 8 years old drilled core ash samples collected from the dump at a South African coal burning power station were characterized using X-ray diffraction (XRD). A five step sequential

extraction (SE) procedure was selected to determine the element partitioning in different physicochemical forms in coal fly ash as a function of the ash dump profile. XRD revealed the major fly ash mineral phases to be quartz and mullite. Other minor phases included hematite, lime, calcite, anorthite, mica and enstatite. The carbon content and unburned carbon (LOI) of fly ashes analyzed in the study had low values in general. The brine irrigated weathered ash samples were sialic in chemical composition. The ratio of SiO₂/Al₂O₃ as determined by bulk chemical composition (X-ray fluorescence) classified it as a silico-aluminate class F fly ash. The results of sequential extraction (SE) showed that some major and trace elements are moving in a leaching pathway through the ash in water soluble, exchangeable, carbonate, iron and manganese fractions. Silicon, calcium and magnesium are mainly present in carbonate, iron and manganese and residual fractions of the coal fly ash. Trace element likes Se and As are mainly present in exchangeable, carbonate and residual fractions of 8yrs old brine irrigated fly ash. The order of selectivity of some toxic metals association with specific phases was found to be; Se (Residual > Exchangeable > Water soluble > Carbonate > Iron and manganese), As (Exchangeable > Carbonate > Residual > Water soluble > Iron and manganese) Cr (Carbonate > Iron and manganese > Exchangeable > Water-soluble > Residual), Mo (Carbonate > Iron and manganese > Exchangeable > Water soluble), B (Exchangeable > Water soluble > Carbonate > Iron and manganese > Residual). Results demonstrate preferential adsorption of elements for different physicochemical forms in brine irrigated fly ash; transport of the metals through weathering processes therefore might depend on the association phase and its aqueous behavior. Toxic analytes investigated are present in water soluble, exchangeable and carbonate fractions of brine irrigated fly ash. The release of As, Se, Cr, Mo and B from water soluble fraction is of environmental concern for possible contamination of ground water underneath the brine irrigated ash dump.

17-5

Methane Enrichment from Anaerobic Digestion Gas (ADG) Using Polymeric Hollow Fiber Membrane

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The hollow fiber membrane (HFM) was prepared by the dry-wet phase inversion method using polyethersulfone for recovery of methane from ADG application. The produced fiber was characterized by a scanning electronic microscope (SEM) and single gas permeation measurements using methane and carbon dioxide. The HFM module was manufactured in order to examine mixture gas separation behavior. Separation experiments of ternary mixtures (H₂S/CO₂/CH₄) were carried out to investigate removal of hydrogen sulfide, and carbon dioxide and methane enrichment according to retentate flow rate and operating pressure difference. To improve separation efficiency, simulation of multi-stages separation process with recycle was conducted by numerical analysis using a MATLAB. As a result, recovery ratio of methane increased from 55 % to 90 %.

17-6

Effect of Introduction of Clean Coal Technology on Future Asian Energy Supply

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Dynamic New Earth 21 (DNE21), a long-term energy supply calculation model, was used to estimate the future energy supply up to 2050 when the CCT was introduced in Asian countries under GHG emission regulation. Three scenarios, BAU, Emission Regulation with CCT employment and NO CCT employment, were set. The statements of world main countries' GHG reduction target were used for the CO₂ emission regulation. The results showed that the introduction of CCT combined with CCS is a key technology to establish the stable energy supply for China and India under GHG emission regulation.

SESSION 18

Coal-Derived Products: Activated Carbon Production-2

18-1

Investigation of Carbonization Kinetic of Tunçbilek Lignite Used for the Preparation of Activated Carbon

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The main objective of this study was to investigate the carbonization of Tunçbilek lignite by TG. Thermogravimetric analyses were performed at different conditions such as heating rates of 10 and 30 °C/min, temperatures of 500, 650 and 800 °C, particle sizes of 1700-700 and 150-100 µm, heating mediums of nitrogen and carbon dioxide and gas flow rates of 15 and 40 cm³/min. Based on TG curves, the kinetic parameters of the process were calculated using the methods of Coats-Redfern,

Horowitz-Metzger and Dharwadkar-Karkhanavala in order to illuminate the mechanism of carbonization of Tunçbilek lignite. The carbonization kinetic models of Tunçbilek lignite were set up. The main carbonization stage could be described by the second order global models for Tunçbilek lignite and activation energies varied in the range of 31.7-69.0 kJ/mol.

18-2

Synthesis of Nitrogen-Doped Carbon Materials from Coal-Tar and Petroleum Pitches and Nitrogen Containing Organic Precursors

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Doping of carbon nanomaterials with nitrogen opens possibility of regulation of their functional electrophysical and adsorption properties.

A series of amorphous microporous carbon materials were prepared by chemical and subsequent thermal treatment of various nitrogen containing organic precursors, or their mixtures: o-nitroaniline, 8-oxyquinoline, benzotriazole, etc. The obtained products have nitrogen content in the range of 0.5-20 wt.%. The samples have a very high specific surface area (1000-3100 m²/g) and a large fraction of micropores - over 70%. The effects of the nature of the precursor and the preparation conditions on nitrogen content and product properties were studied. It was shown that the BET area and pore volume generally decrease and the N content increases with lowering of the carbonization temperature.

Another series of nitrogen doped materials were prepared by carbonization of petroleum pitch, coal-tar pitch or coal-tar pitch mixed with polyvinylchloride (PVC) as carbon precursors and polyacrylonitrile (PAN) as a nitrogen precursor. Depending on the conditions of the preparation and the PAN/pitch ratio, materials containing different amounts of nitrogen (from 5.3 to 13.6%) were obtained. The presence of PVC in coal-tar pitch was shown to increase the yield of the nitrogen containing carbonaceous product. As a result of chemical interactions between carbon precursors and PAN the aromatic structures containing nitrogen are formed. IR spectra showed the presence of pyrrole structures in the products. The carbonization of carbon precursors with PAN was shown to be an effective method of preparation of carbon materials with high nitrogen content.

The state of nitrogen species in the prepared N-doped carbon materials was studied by XPS. The results showed that three types of nitrogen are generally present in these materials: with binding energies of 398.5; 400.1 and 400.8 eV. According to literature, these signals correspond to pyridine-like N, pyrrole nitrogen and bridgehead-type N incorporated into graphitic network, respectively.

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18-3

Effect of Mineral Matter of Brown Coals on the Reactivity of Char Steam Gasification and on the Properties of Activated Carbons

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The goal of this paper is to gain a fundamental understanding about steam gasification of different brown coal chars under low temperature and high pressure. The coals from different deposits of Kansk-Achinsk Basin, Lena Basin and from Yalloum Basin (for comparison) were used to study the role of the naturally occurring metals on the physico-chemical properties of the chars and steam gasification reactivity. The data on how the preliminary decationization with solution of hydrochloric acid affects the structural characteristics of brown coal chars and their gasification reactivities are presented. The importance of controlling parameters (such as structural characteristics of carbon and naturally occurring metals) in the physico-chemical properties of the chars, in the gasification reactivity and in the textural properties of gasified chars is considered. The concentration of calcium and catalytic activity of calcium species were found to be a key factor for their reactivity for steam gasification and carbon dioxide formation. Quantitative relations were revealed.

18-4

Study of the Properties of Coal from Mongolian Saikhan-Ovoo Deposit and the Char and Carbons Produced

B.Purevsuren, Ya.Davaajav, Kh.Serikjan, S.Batbileg, Institute of Chemistry and Chemical Technology, Mongolian Academy of Sciences, MONGOLIA; P.N.Kutsnezov, Institute of Chemistry and Chemical Technology of Siberian Branch of Russian Academy of Sciences, RUSSIA

The main performance characteristics of coal from the Saikhan-Ovoo deposit in Mongolia were determined. This coal corresponds to a high metamorphic stage, which corresponds to lean coal transitional to anthracite. It is characterized by high yield of char, high calorific value, and low sulfur content. Iron compounds (60.2 %) predominate in the mineral matter of coal with a small participation of silicon,

aluminum, calcium, and other metal compounds. The concentrations of the toxic metals Sr, Mn, Zn, and Cu are no higher than the maximum permissible concentrations. The supramolecular structure of the organic matter of coal mainly consists of closely packed graphite-like clusters containing on average 6.7 aromatic layers. A small fraction of carbon (about 20 %) is structured as γ -components at the periphery of clusters. Active carbon was obtained by thermal steam activation. Its structural characteristics and sorption capacity for iodine and methylene blue were determined.

18-5

Research on the Preparation of Thermal Conductivity C/C Composites by One-step Hot Press Molding

Jin Ming-Lin, Qingzhong Cheng, Shanghai Institute of Technology; Yan-Wen Zhang, Xiao-Long Zhou, East China University of Science and Technology, CHINA

Along with unceasing development of aerospace technical and national defence industry, introducing C/C composites as thermal conductivity of materials can meet the demands of new technology. Compared with traditional metal materials, C/C composites have the features of light unit weight, high thermal conductivity, corrosion-proofed. This study focused on preparation of C/C composites with SCFs and thermoplastic mesophase pitch by hot press molding and discussion about the influence of SCFs' content and distributed orientation on two-dimensional thermal conductivity and bulk density. The results showed that when TI yield level of thermoplastic pitches was 82.1% and SCFs' mass fraction was 7%, the hot pressed sample had high bulk density. By analysis of SEM morphology, the fiber's distributed orientation was almost perpendicular to hot pressing direction and ordered arrangement of toothlike pitch structure was visibly found after etched with potassium dichromate, which led to thermal conductivity of longitudinal section at 127.51W/(m.K). Reversely, increasing over many SCFs resulted in poor ordering degree and decreasing graphitization degree of matrix carbon.

18-6

Preparation and Characterization of New Adsorbents (AC-COPET)

Zhi-yuan Yang, Peng Liu, Pan Ran, Xi'an University of Science and Technology, CHINA

The new adsorbents, which can be used to concentrate CBM, were studied in the fields of their preparation by SFC/PET co-carbonization and their methane-affinity modification in this paper. We compared the traditional physical and chemical activation methods with microwave chemical process by the preparation of adsorbents and found that the latter had higher iodine adsorption capability, shorter preparation time and higher yield ratio. The optimum conditions for preparing AC-SFC by microwave chemical synthesis were: microwave power 450 W, irradiation time 6.5 hr. Further, we could find that SFC and PET had good carbonized synergies and the AC-COPET, which prepared by w (SFC): w (KOH): w (PET) = 1: 3: 0.4, has high iodine adsorption value, 1837 mg/g, BET's surface area 1590.8 m²/g, micropore's area 456.9 m²/g. The performances of AC-COPET had significantly exceeded active carbon (SPAC) on sale.

According to the special experiment combined with analysis of FTIR, TG and XRD, the formation mechanism of AC-COPET was found that collaborative co-carbonization between coal and PET was mainly about cleavage reaction in early stage, while it became polycondensation in late stage. Under the hot alkali and the free radical attack, PET occurred secondary cracking in pyrolysis, and small molecules such as C₂H₄ and C₆H₆, had appeared. These small molecules were captured by coal macromolecules and participated in the reaction of coal aromatic structure unit dehydrogenation condensation. PET played a positive role in the carbonization process of coal and the formation of pore structure of carbonized products.

SESSION 19

Combustion: Oxy-Coal Development – 2

19-1

Comparative Study of Coal Ash and Deposits from Air and Oxy-Fuel Combustion

Jost O.L. Wendt, Dunxi Yu, William J. Morris, University of Utah; Andrew Fry, Constance L. Senior, Reaction Engineering International, USA

Oxy-fuel combustion is a promising technology used to realize carbon capture and storage (CCS). To retrofit conventional air-fired power plants to oxy-fuel combustion, the effects of switching from air- to oxy-firing on ash deposition must be well understood. A down-fired oxy-fuel combustor was used to generate bulk ash, size-segregated ash and deposit samples under conditions of: (a) air; (b) 27% O₂/73% CO₂; (c) 32% O₂/68% CO₂. Once-through CO₂ was used in oxy-fuel cases to simulate cleaned flue gas without moisture or contaminants. The excess oxygen in the flue gas for all combustion cases was fixed at 3%. For bulk ash collection, the combustion products

were directed into an isokinetic water-cooled probe with a 90 mm filter housing, where ash was deposited on the filter for subsequent examination. No dilution was used. For size-segregated ash collection, the combustion products were extracted by an isokinetic, nitrogen-quenched and water-cooled sampling probe. The combination of a pre-cyclone and a Berner Low Pressure Impactor (BLPI) was used to obtain full particle size distributions and ash samples for further analyses. For ash deposit collection, a water-cooled probe fitted with a detachable tubular deposition substrate was horizontally fixed at a distance from the burner. The exposure time was about 4-5 hours. The obtained bulk ash, size-segregated ash and deposit samples were subjected to chemical analyses. Characteristic data of ash and deposits are used to identify major constituents that contribute to ash deposition. The effects of switching from air- to oxy-firing on ash partitioning between ash and deposits are investigated.

19-2

Oxy-Fuel Combustion: A Technological Option for Retrofitting Existing Pulverized Lignite Fired Power Plants in Turkey

İskender Gökalp, CNRS-ICARE, FRANCE; Mucella Ersoy, Turkish Coal Enterprises, TURKEY

Lignite is one of the major domestic primary energy resources in Turkey. Turkish lignite reserves are estimated to 12 billion tons by 2010. However its quality is quite low and requires promotion of efficient clean coal technologies. Lignite is consumed in three sectors in Turkey: thermal power plants (85%), industry and households. Due to the oil crisis faced during 1970s, lignite gained great importance as a domestic resource and most of the existing pulverized lignite-fired power stations were installed in mid 1980s.

In Turkey, the average annual energy consumption increase rate is 7%. 8079 MW of the total Turkish 44000 MW existing installed capacity concern lignite-fired power stations. While the share of lignite in electricity generation reached its highest value of 47% in 1986, this share declined to 15% in 2004 due to the use of natural gas in electricity generation. Over the last four years it has increased again to 21,1% by commissioning of new lignite-fired power plants. According to the Turkish "Electricity Market and Security of Supply Strategy Paper" issued in 2009, all existing proven lignite reserves will be used for electricity generation by the year 2023.

Except one power plant based on fluidized bed combustion technology, most of the remaining pulverized lignite-fired power plants in Turkey are old and need to be retrofitted to meet environmental commitments. The thermal efficiencies of existing Turkish lignite-fired power plants vary between 28% and 39% in 2008.

This paper consists in two parts. The first part will summarize the past and present situation of electricity generation in Turkey using lignite power plants. This will be done by taking into account the fact that Turkey signed the Kyoto Protocol in 2009 and also is a candidate for EU membership and therefore Turkish legislation should be harmonized with EU coal, electricity and environment related legislations. New investments in the existing lignite-fired power plants to comply with EU legislations and Kyoto Protocol commitments are therefore urgently required.

In the second part of the paper, retrofitting of the existing Turkish pulverized lignite-fired power plants for oxy-firing will be evaluated. Oxy-fuel combustion is a technology which, if optimized, may significantly contribute to the reduction of CO₂ emissions. An important requirement is to demonstrate that this technology can be retrofitted to the many existing power plants already operating in order to prepare for implementation of CCS after 2020. This is necessary to fully evaluate the concept feasibility, address perceived commercial risks, and improve the overall cost and efficiency when the CCS readiness is taken into account. As most work to date on oxy-fuel coal combustion has been applied only at small scale and to bituminous coal, it is necessary to extend the range of fuels and the scale of the technology. Developing oxy-firing for lignite plants should ensure that clean coal technologies can be applied to these plants and should demonstrate the fuel flexibility of lignite, which increases the competitiveness of the technology.

A multi-partnership project is under development in order to retrofit a small lignite-fuelled boiler. A combined RTD/Demonstration approach is developed to validate the feasibility of retrofitting and assessing some innovative options for efficiency improvement of oxy-fuel combustion. RTD goals are to optimize the oxy-fuel combustion process, fuel handling and safety, oxy-fuel burner design, evaluation of retrofitted system, its efficiency and environmental performance, including the quality of the CO₂ stream for various CCS options. Demonstration goals include a full retrofit of a pulverized lignite power plant in operation and validation of its scalability. The details of the project will be presented and discussed in the presentation.

19-3

Oxy-Fuel Combustion Chemistry – Implications on Corrosion Related Issues

Klas Andersson, Daniel Fleig, Fredrik Normann, Filip Johnsson, Chalmers University of Technology, SWEDEN

The present work addresses recent findings on the oxy-fuel combustion chemistry and the related composition of oxy-fuel flames. The two main topics are the sulphur chemistry occurring in coal combustion including SO₂, SO₃ and H₂S formation for different coals and the formation and oxidation of CO in methane, propane and in various coal flames. The implications on corrosion issues in oxy-fuel boiler design are

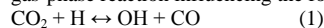
discussed, as well as future research needs. The results presented include experimental work from the literature and results by the oxy-fuel group at Chalmers. The experiments at Chalmers are performed in a 100 kW_n oxy-fuel test facility, which has been used extensively since its commissioning in 2003. In addition, modeling of the gas phase chemistry is discussed and related to the experimental work. All results presented for oxy-fuel combustion are related and compared against air-fired conditions.

The sulphur chemistry in oxy-fuel combustion differ from that under air-fired conditions; the main areas discussed in the paper are the

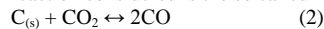
- Conversion of fuel-S to SO₂
- H₂S formation in the flame at (local) fuel rich conditions
- SO₃ formation

The SO₂ concentration increases drastically in oxy-fuel compared to air-fuel conditions. Both experiments and modeling show that the formation of H₂S is promoted by the high SO₂ concentration in the oxy-fuel environment, given sub-stoichiometric conditions. The SO₃ concentration is also expected to increase, due to the elevated SO₂ concentration. Increased concentrations of SO₃ in combination with a high moisture content in the flue gases (when recycling wet flue gases) will lead to a higher acid dew point temperature with corrosion implications at low temperature parts of the boiler.

Both experimental and modeling work indicates that the CO formation is influenced by both homogeneous and heterogeneous reactions occurring in oxy-fuel combustion. Modeling of the homogenous chemistry in methane flames has shown that the main gas-phase reaction influencing the formation is



Reaction 1 gives, besides a direct effect on CO formation, also an effect on the radical pool composition by promoting the formation of OH, which influences the SO₃ formation as is discussed further in the paper. High levels of CO are also found in experimental work on oxy-coal flames where gasification reactions are suggested to contribute to the CO formation, in addition to the homogenous reactions. The main reaction considered is the so called Boudouard reaction



However, there are different opinions on the influence of gasification reactions on the CO formation in oxy-coal combustion, as will be discussed further in the paper. To summarize, high levels of CO and H₂S are observed in the flame and near burner zone as well as higher SO₂ concentrations in the combustion zone in general. As mentioned, the SO₃ levels are expected to increase in oxy-fuel compared to air-fired conditions, but the formation of SO₃ needs to be studied in more detail under oxy-fuel conditions. For corrosion phenomena occurring at combustion temperatures, design principles otherwise employed during reburning and air/fuel staging in air-fired boilers may be adopted in oxy-fuel firing. For coals with a high sulphur content and ashes with low sulphur retention capabilities, the temperature window of low temperature corrosion may be drastically influenced. Thus, oxy-fuel combustion is expected to cause a more corrosive environment than air-firing, due to the elevated concentration of combustion products.

SESSION 20 Gasification: Fundamentals - 1

20-1

Modeling of Coal Char Gasification in Coexistence of CO₂ and H₂O

Satoshi Umemoto, Shiro Kajitani, Saburo Hara, Central Research Institute of Electric Power Industry (CRIEPI), JAPAN

In coal gasifier, carbon dioxide gasification reaction and steam gasification reaction occur at the same time. However, the gasification models which explain the competition between carbon dioxide gasification and steam gasification are few. In this study, coal chars were gasified with carbon dioxide and steam at the atmospheric condition using a thermogravimetric analysis (TGA) at various reactant partial pressures. Langmuir-Hinshelwood type gasification model was modified to explain the char gasification by carbon dioxide and steam. In the proposed model, carbon dioxide gasification and steam gasification share active sites partially. The proposed model can describe the gasification reaction rate of coal chars in the presence of carbon dioxide and steam which was not explained by conventional models.

20-2

Investigation of Component Release During Pressurized, High Heating Rate Devolatilization of Coal and Petroleum Coke

David Wagner, Kevin J. Whitty, University of Utah; Glenn L. Shoaif, Paul Fanning, Eastman Chemical Company, USA

A high pressure wire-mesh heater developed at the University of Utah was used to study devolatilization characteristics of two coals and one petroleum coke. The fuels were pyrolyzed under nitrogen and temperatures ranging from 1000 °C to 1200 °C at pressures to 63 bar and with holding time at maximum temperature to five seconds. Char and volatile yields were quantified using a "design of experiments" approach to

assess the gasification behavior the three fuels. The findings of these data agree with similar wire-mesh studies concerning pressure, hold time, and final temperature trends.

20-3

High Pressure TGA Studies on German Brown Coal under Carbon Dioxide Atmosphere

Abhishek Bhargava, Patrick J. Masset, Freiberg University of Mining and Technology, GERMANY

In this study, a high pressure thermo-gravimetric analyser was used to probe the partial oxidation characteristics of coal to simulate gasification like conditions. A gasification grade, German lignite coal was selected for the HP-TGA analysis at increasing values of total pressures of up to 45 bars in carbon dioxide atmosphere. Three distinct reaction zones were identified and the kinetic constants were calculated using the Coats and Redfern model. It was shown, the accessible porosity responsible for gas transport increases with the temperature and therefore the reaction rate. Computer controlled scanning electron microscope (CCSEM-EDX) was used to probe the surface morphology of coal-char particles recovered from the HP-TGA to validate the transport mechanism of the reactant gas from the surface to the un-reacted core. The evolution of solid phase porosity in coal samples with increasing temperature impacted the diffusivity of reactant gases in coal particle and thus the reaction kinetics.

20-4

Studies on Gasification of Char in Fixed Bed Reactor

Ramesh Naidu Mandapati, Preeti Aghalayam, Sateesh D, Narseh D, Sanjay M Mahajani, Anuradda Ganesh, IIT Bombay; Sharma R.K., IRS, ONGC, INDIA

In the present work, we study gasification of char obtained by pyrolysis of Indian Lignite coal, in a fixed bed reactor. Because of its operational flexibility, the fixed bed reactor (FBR) can be conveniently used to carry out endothermic reactions under controlled conditions. The present work is focused on how various operating parameters such as temperature, flow rate, particle size and pressure affect the extent of the steam and CO₂ gasification reactions. A broad objective of this work is to develop a kinetic model, identify mass and heat transfer limitations, if any, based on this data and further support the results obtained by carrying out independent thermogravimetric analysis.

SESSION 21

Carbon Management: Pre-Combustion CO₂ Capture

21-1

Development of Dry Regenerable CO₂ Sorbent and WGS Catalyst for SEWGS Process

Joong Beom Lee, Tae Hyoung Eom, Jungho Ryu, Jeom-In Baek, Dong-Hyeok Choi, Keun Woo Park, Seong Jegarl, Seug-Ran Yang, Korea Electric Power Research Institute, KOREA

IGCC integrated with CCS has been regarded as a promising option to reduce CO₂ emission under the situation that coal is the dominant source among fossil fuels for the electricity-generating units. Recently, KEPSCO Research Institute proposed the new concept for the pre-combustion CO₂ capture process, which is named as one loop sorption enhanced water gas shift (SEWGS) process consisted of two fluidized bed reactors. Sorption enhanced water gas shift (SEWGS) process is combined the water-gas shift reaction with CO₂ capture at the same time. In this study, Nine MgO-based dry regenerable CO₂ sorbents and Seven CuO-based water gas shift catalysts were prepared by spray-drying technique to evaluate their applicability to a fluidized-bed sorption enhanced water gas shift (SEWGS) process. In these sorbents, MgO-based sorbents satisfied most of the physical requirements for commercial fluidized bed reactor process along with reasonable chemical reactivity. All sorbents had a spherical shape, an average size of 112–148 μm, and a size distribution of 45–250 μm, a bulk density of 0.61–0.83 g/mL. The attrition Index (AI) of all the sorbent was below 15% except P-9 sorbent, compared to about 20% for commercial fluidized catalytic cracking (FCC) catalysts. CO₂ sorption capacity of PC-4 was approximately 17.6 wt% at 200 °C and 21 bar with synthesis gas conditions.

Spray dried CuO-based WGS catalyst showed relatively good physical properties. Most of catalyst had a spherical shape, an average size of 121–157 μm, and a size distribution of 37–250 μm, a bulk density of 0.92–1.06 g/mL. Attrition Indices (AI) of PC-4, PC-12 and PC-13 was below 10%, which is suitable for fluidized SEWGS process.

21-2

High Capacity Regenerable Sorbent for Pre-Combustion CO₂ Capture

Gökhan Alptekin, Ambal Jayaraman, Steve Dietz, Lauren Brickner, Ryon Tracy, TDA Research, Inc, USA

TDA is developing a novel sorbent that removes CO₂ via physical adsorption from synthesis gas and the relatively strong affinity of the sorbent to CO₂ enables effective operation at temperatures up to 300°C (well above the dew point of synthesis gas stream generated by most commercial gasifiers). However, because the sorbent and the CO₂ do not form a true covalent bond, the energy needed to regenerate our sorbent (4.9 kcal per mol of CO₂) is much lower than that observed for either chemical absorbents (e.g., 29.9 kcal/mol CO₂ for sodium carbonate) or amine-based solvents (e.g., 14.2 kcal/mol CO₂ for monoethanolamine). Our sorbent can be regenerated isothermally and CO₂ could be recovered at pressure (~150 psia). Thus, the energy needed to regenerate the sorbent and compress the CO₂ for sequestration is significantly lower than that for any technology reported to date. TDA's CO₂ sorbent could be used to capture CO₂ in a Integrated Gasification Combined Cycle (IGCC) power plant after the water-gas-shift (WGS) reaction when most of the carbon is in the form of CO₂. The high surface area and favorable porosity of the sorbent also provides a unique platform to introduce additional functionality, such as active groups to catalyze the or to remove trace metals (e.g., Hg, As).

We carried out bench-scale evaluations of TDA's CO₂ sorbent in both fixed-bed adsorber and a thermo gravimetric analyzer (TGA). The sorbent achieved high CO₂ capacity, high removal efficiency and excellent durability. The sorbent showed stable performance in both these systems under simulated synthesis gas (180+ cycles in the bench-scale flow system and over 1,644 cycles in the TGA). We also studied the effect of operating parameters like temperature, pressure, and cycle time on the sorbent performance. The results from our on-going sorbent evaluations will be presented at the meeting.

21-3

Fixed-Bed Adsorption of Carbon Dioxide-Nitrogen Mixtures onto Activated Carbon: Characteristics of CO₂ Adsorption and Modeling

Regina F.P.M. Moreira, Tirzha L.P. Dantas, Federal University of Santa Catarina; Francisco Murilo T. Luna, Ivanildo J. Silva Jr., Diana C. S. de Azevedo, Federal University of Ceara, BRAZIL; Carlos A. Grande, Alrio E. Rodrigues, University of Porto, PORTUGAL

The atmospheric content of the most abundant greenhouse gas, CO₂, has risen from preindustrial levels of 280 parts per million (ppm) to present levels of over 365 ppm. The main sources of CO₂ emissions are the combustion of fossil fuels, such as coal, natural gas and petroleum, and industrial processes, such as oil refinement and the production of cement, iron and steel. The reduction of carbon dioxide emissions from flue gases can be achieved using post-combustion technologies such as adsorption. Different adsorbents, such as activated carbon, zeolites, MCM-41, mesoporous silica material SBA-15 and several enriched-amine sorbents, have been tested. Good recovery and product purity have been accomplished with very high energy consumption. An ideal sorbent should offer high adsorption and selectivity for carbon dioxide as well as economically feasible regeneration. However, if the affinity of the adsorbent for carbon dioxide is too high, the regeneration step can negatively affect the cost of the process.

In this paper, we report an experimental and theoretical study on the separation of carbon dioxide and nitrogen on activated carbon in a fixed bed. The breakthrough curves were obtained at different temperatures using CO₂/N₂ mixtures. A model based on the Linear Driving Force (LDF) approximation for the mass transfer was used, taking into account the energy and momentum balances, to satisfactorily reproduce the breakthrough curves.

21-4

Development of Dry Regenerable CO₂ sorbent for Fluidized-Bed CO₂ Capture Process from Coal Power Plant

Chong Kul Ryu, Joong Beom Lee, Tae Hyoung Eom, Bok Suk Oh, Jeom-In Baek, Kyeongsook Kim, Young Ho Wi, Jegarl Seong, Won Sik Jeon, Korea Electric Power Research Institute, KOREA

This paper summarizes the results of performance of dry regenerable sorbent for CO₂ capture at low temperature. Each sorbents was prepared by spray drying techniques to identify potential materials with Na₂CO₃ and K₂CO₃ as active material. The physical properties, particle size distribution and average particle size, bulk density, BET, Hg porosity and shape, of the spray-dried sorbents were investigated by standard methods and the attrition resistance of the sorbents for circulating fluidized-bed application was measured with a modified three-hole air-jet attrition tester based on the ASTM D 5757-95. Sorbent chemical reactivity was measured in low temperature range (carbonation at 50°C~70°C and regeneration at 120°C~140°C) with simulated flue gas containing 10 vol% H₂O and 14.4 vol% CO₂ with simultaneous thermo gravimetric analyzer (TGA). The maximum CO₂ sorption capacity of sorbents was approximately 12wt% and attrition index (AI) reached below 1% in case of K-based sorbents and 35% in case of Na-based sorbent. The results of physical properties and CO₂ sorption

capacities showed excellent characteristics for circulating fluidized-bed process application to capture CO₂ from flue gas condition.

SESSION 22
Coal Science: CBM/Carbon Dioxide

22-1

A Comparison of Experimental and Theoretical High Pressure CO₂ Isotherms on Coals from the Upper Silesian Basin, Czech Republic
Zuzana Weishauptová, Oldřich Přibyl, Martina Švábová, Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, CZECH REPUBLIC

A manometric high pressure sorption apparatus was constructed. Pilot tests of the apparatus were carried out in the subcritical region below 6 MPa pressure and the results were compared with the results of low pressure measurements extrapolated to the same pressure. Both methods provided comparable results.

22-2

Conversion of Ukrainian Low Grade Solid Fuels with CO₂ Capture
O.M. Dudnyk, I.S. Sokolovska, Coal Energy Technology Institute of National Academy of Sciences of Ukraine, UKRAINE

The processes of generation of synthesis gas with high hydrogen content from the Ukrainian low grade solid fuels are studied at the Fuel Cell Test Installation. In case of the use of coals (bituminous coal of Lvov-Volyn coal deposit and brown coals of Alexandria and Zhytomyr deposits), there were studied the processes: steam conversion of volatile to produce high-reactivity char; char steam gasification using lime to produce synthesis gas with high hydrogen content. In case of the use of wood waste (from Kyiv region), there were studied the processes: carbonization of wood waste pre-impregnated with water solutions of H₃PO₄, FeCl₃, and CaCl₂ to produce wood coal; wood coal steam gasification using lime to produce synthesis gas with high hydrogen content and activated char coal. A special technique for determination of CO₂ absorption and desorption degrees in the steam gasifier was developed for experimental evaluation of char steam gasification.

The IGCC circuits with fuel processor, electrochemical fuel cell generator, steam and gas turbines are developed. In case of utilization of bituminous and brown coals, it is proposed to use the batch fuel processor that can operate in the modes of combustion (desorption of CO₂) and steam gasification (absorption of CO₂). In case of biomass utilization, it is proposed to use fuel processor consisting of the system for special preparation of wood waste, carbonizer for wood coal production, gasifier for synthesis gas and activated char coal production, system of CO₂ absorption for an increase in hydrogen concentration in the product gas and CO₂ desorption for absorbent reactivation.

The research work was carried out within the framework of two projects of the Complex Program of Scientific Researches of the National Academy of Sciences of Ukraine "Fundamental Problems of Hydrogen Energy" at the Fuel Cell Test Installation with elaboration of the before prepared approaches for the development of the Fuel Cell IGCC circuits.

22-3

Coalbed Gas Potential in the Miocene Soma Basin (Western Turkey)
Sedat İnan, Aynur Dikbaş, Semih Ergintav, Fırat Duygun, TÜBİTAK Marmara Research Center; M.Namık Yalçın, Kübra Tırpan, Korhan Yaşar, İstanbul University; Ender Okandan, Mustafa Baysal, Middle East Technical University; Yuda Yürüm, Sabancı University; Ruhi Saatçılar, Sakarya University; Murat Yılmaz, Ali Rıza Toygar, Turkish Petroleum Corporation; Ayhan Kösebalaban, Selahaddin Anaç, Hakkı Duran, Mehmet Onbaşı, Mücella Ersoy, Mehmet Atasayar, İsmail Ergüder, Turkish Coal Enterprises, TURKEY

The Neogene Basins of Turkey contain as much as 9 billion tons of lignite-rank coal (Şengüler, 2001; Tuncalı et al., 2002). The Miocene Soma Basin, a rift basin trending NE-SW (approximately 20 kilometers by 5 kilometers) in the Aegean Extensional Province (EAP) of Western Turkey, is estimated to contain at the least one billion tons of lignite and about half of this reserve is present at depths greater than 600 m (Turkish Coal Enterprises, 2006). Miocene marl/limestone units and Pliocene clastics and volcanic tuffs overlie the Miocene coals of the Soma basin. There are several coal seams in the basin but the most economical and thus target seam is known as KM2 with an average thickness of about 20 meter across the basin. In the Soma Basin, Turkish Coal Enterprises (TKİ) has mined this KM2 seam by open cut coal mining and underground mining for several decades in the Northern and Central part of the basin, respectively. Recently, coal exploration activities have been extended to the Southern part of the basin by means of exploratory drillings. Recently, coal exploration activities have been extended to the Southern part of the basin by means of exploratory drillings. In this context, two boreholes encountering a coal seam (KM2) up to 20 m thick were

evaluated. The KM2 coal seam was encountered between 900 and 940 m depth in two boreholes drilled approximately 1 km apart. Wellhead gas content was measured on coal cores following the USBM method (Diamond and Levine, 1981). Additionally, coal was placed in hermetically sealed canister and desorbed gas was analyzed in laboratory for chemical composition (by FTIR gas analyzer) and ¹³C isotope (by GC-IRMS). Coal characterization was completed by means of Rock Eval (RE) Pyrolysis, Proximate and Ultimate analyses, as well as microscopic analyses for typing of macerals and vitrinite (humintite) reflectance measurements.

The wellhead gas content measurements (six core measurements from two boreholes) indicate that as much as 4 m³ gas / ton coal is present in the coal recovered from 900 to 940 m below the surface. The rank of coal based on vitrinite (humintite) reflectance measurements is lignite to sub-bituminous (0.40 to 0.45 % Ro); supported by RE Tmax values of 420 °C. TOC content of the coal samples vary between 53 to 73 %. The composition of the gas is dominantly methane (more than 99.4 %) and the ¹³C/¹²C isotope ratio of methane is 61 to 65 per mil. Considering the chemical composition of the gas and the del ¹³C isotope of the methane, the source of the coal gas is biogenic probably generated by bacteria. The maceral analyses show that coal samples on average contain more than 60 % huminitite(vitrinite). Adsorption on the internal coal surface is considered as the primary mechanism of gas storage in coals and the surface area, which controls the gas adsorption capacity, is in general a function of the micro-pore volume (Levy et al., 1997; Crosdale et al., 1998) which is known to be abundant in vitrinite maceral group. The vitrinite/huminitite maseral content has positive correlation with gas sorption capacity (Levy et al., 1997); meaning that at a given pressure, the higher percentage of micro-pore dominated huminitite/vitrinite the more gas adsorption capacity. In this context, the Miocene Soma lignites have good micro-pore properties in respect to gas adsorption.

Preliminary evaluation, based on limited analyses and results summarized above, on gas potential of the Miocene Soma Basin is encouraging, yet further investigations in the Soma Basin are underway by coal desorption testing of cores received from ongoing coal exploration boreholes.

22-4

Underground Coal Determination by Integrated (Reflection & WVSP) Seismic in the Miocene Soma Basin (Western Turkey)

Ruhi Saatçılar, Sedat İnan, Fırat Duygun, Semih Ergintav, Aynur Dikbaş, TÜBİTAK Marmara Research Center; Murat Yılmaz, Ali Rıza Toygar, Turkish Petroleum Corporation; Ayhan Kösebalaban, Selahaddin Anaç, Hakkı Duran, Mehmet Onbaşı, Mücella Ersoy, Mehmet Atasayar, İsmail Ergüder, Turkish Coal Enterprises; M.Namık Yalçın, İstanbul University; Ender Okandan, Middle East Technical University; Yuda Yürüm, Sabancı University; Emin Demirbağ, İstanbul Technical University, TURKEY

The Neogene Basins of Turkey contain as much as 9 billion tons of lignite-rank coal (Şengüler, 2001; Tuncalı et al., 2002). The Miocene Soma Basin, a rift basin trending NE-SW (approximately 20 kilometers by 5 kilometers) in the Aegean Extensional Province (EAP) of Western Turkey, is estimated to contain at the least one billion tons of lignite and about half of this reserve is present at depths greater than 600 m (Turkish Coal Enterprises, 2006). Miocene marl/limestone units and Pliocene clastics and volcanic tuffs overlie the Miocene coals of the Soma basin. There are several coal seams in the basin but the most economical and thus target seam is known as KM2 with an average thickness of about 20 meter across the basin. In the Soma Basin, Turkish Coal Enterprises (TKİ) has mined this KM2 seam by open cut coal mining and underground mining for several decades in the Northern and Central part of the basin, respectively. Recently, coal exploration activities have been extended to the Southern part of the basin by means of exploratory drillings.

In order to aid fast and economical coal exploration activities of the Turkish Coal Enterprises (TKİ), a collaborative work has been started for development of an integrated seismic method for coal exploration. The aim is to develop a practical seismic method for TKİ to apply in its exploration activities in other Lignite coal basins of Turkey. The information gathered from tens of coal exploration boreholes already drilled in the study area will be used to calibrate the horizons to be mapped by surface seismic and WVSP methods (Tselentis and Paraskevopoulos, 2002). Surface seismic data will be collected on roughly East-West and North-South oriented lines. Furthermore, at the intersect of these lines borehole WVSP data will be collected. The seismic source for both surface and borehole WVSP seismic will be a mini-vibrator and the data will be collected contemporaneously. The seismic study will be conducted between May and July 2010. Soon after, the seismic data processing work will be initiated.

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Study on Grinding Technology of Weakly Caking Coal

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For lower cost and saving the premium resource, People have explored the coking-blending technology and extended the blending proportional of weakly caking coal. In this study, the coal coking properties, coal contractibility, change of coke microstructure and coking-blending experiment of coal are discussed, and the effect of the grinding technology of different metamorphism of weakly caking coal on coking behavior and coke quality are investigated. The results showed that the active components of the meager-lean coal and lean coal, whose vitrinite reflectance is over 1.60%, played the role of inertia during the process of converting coke just like other inertia components, so they only became the center of coking. Moreover, the microstructure could deteriorate the coke quality. So if we adopt the fine grinding technology to destroy the structure default, the blending proportional will increase over 20%, at the same time, the coke quality also increases. If the low rank weakly caking coal, such as gas coal and 1/3 coke coal, have higher activity in the course of coking, they can combine with other kind of coal easily, and even melt each other in the interface, which will result in granule of coal structure and the quality of coke will be influenced, so such coal should not be ultra fine grinding; On the other hand, the interial components of them have lager shrinkage, shrinkage gap will appear in the course of coking, due to the fine particle produced during grinding, and result in the poor coal quality, so the appropriate grinding is necessary. The study proved that high metamorphism weakly caking coal should be adopt the fine grinding technology and the low metamorphism weakly caking coal adopt the selective grinding technology.

SESSION 23

Sustainability and Environment - 4

23-1

Large Scale Use of Pond Ash for Reclamation of Waste/Alkaline Land for Agriculture and Forestry

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In India, presently coal contributing to about 70% of the total energy requirement, produces 118 million tons of fly ash per year from its thermal power plants, which is projected to exceed 170 and 440 million tons per annum by 2012 and 2030, respectively. This huge quantity of fly ash not only being of tremendous environmental concerns but also occupies large areas of land for its dumping, which needs urgent and appropriate measures for its safe disposal and gainful utilization on sustainable basis. Besides reclamation of a vast area of wasteland for agriculture and forestry is another challenge for fast growing population of the country. The Central Institute of Mining and Fuel Research (erstwhile Central Fuel Research Institute), Dhanbad has made detailed study on the bulk utilization of fly ash/pond ash in agriculture and forestry sectors in the vicinity of different TPPs under different agro-climatic conditions and soil types for last two decades. The demonstration studies for the popularization purpose were carried out in the waste/alkaline lands of farmers' fields and the results of such investigations are reported in the present paper. The productivity of various crops grown in the ash amended treatments substantially increased the yield (20 – 45%) over control along with noticeable increase in the nutrient content of crop produce, early maturity of the crops grown and improvement in the nutrients status/biological activity of the soil on sustainable basis.

23-2

The Thermal Treatment Study of Pyrite from South Brazil Coal Mining Industry

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The coal mining have been produced two effects: the region development and the environmental degradation by the pyrite (FeS_2) oxidation and acid mine drainage (AMD) production. Pyrite decomposition produces gases like SO_2 under oxidation conditions and S_2 under inert conditions. This study is developing a system for the capture of the different species of gases for the production of products with major value. The reactions take place in a scrubber for the purification of the gases. For the SO_2 scrubber reactions with a $\text{NaOH}/\text{H}_2\text{O}$ solution is used for the production of Na_2SO_3 that has value for chemical applications at Brazil. Other solution used was: NH_4OH and H_2O that produced ammonium sulphate ($(\text{NH}_4)_2(\text{SO}_4)$) an important raw material for the fertilizer industries. The last way for the purification of the pyrite reducing its sulphur content is to develop a system of catch of the elemental sulphur at the reactor. Characterization steps included chemical analysis with XRF spectrometer and phase analysis with XRD spectrometer. The pyrite for this work was milled under 325 mesh-tyl for the thermal treatment step. The thermal treatment took place at 750

$^\circ\text{C}$ for 1h and the characterization steps showed the phases: Na_2SO_3 ; $(\text{NH}_4)_2(\text{SO}_4)$. In this work are the results of XRD, particle size distribution and the pyrite heating results at different temperatures.

23-3

Pyrolysis of the Various Types of Fuels - Credit Cards

Dagmar Juchelkova, Helena Raclavska, Adela Cízkova, Vaclav Roubicek, VSB-Technical University of Ostrava, CZECH REPUBLIC

The project concerns on the Technologies for pyrolyses processes and quality of fuels. We concern us also on the optimization of technology and the influencing of system and output parameters. According to the experiences of long term test form the small units was redesigned. The new unit allows making tests close to the real conditions. Some interesting information will be present.

SESSION 24

Coal-Derived Products: Direct Coal-to-Liquids

24-1

Alliance DCL Technology for Producing Ultra Clean Transportation Fuels

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A strategic alliance to provide a single-source solution for producing ultra-clean fuels by direct coal liquefaction (DCL) alone or in combination with refinery residues or biomass has recently been formed between Headwaters Inc. and Axens. Depending on the properties of coal of interest, the alliance can apply either slurry or support catalyst system to effectively convert coal or in combination of biomass and petroleum residues into liquid hydrocarbons using a commercial proven back-mixed reactor system. This paper provides recent results of direct liquefaction and refining studies for a bituminous coal and also for a co-feed consisting of a lignite and petroleum resid. Properties of intermediate and finished coal derived liquids as compared to petroleum derived fuels will be discussed. DCL is a hydrogen addition process and its hydrogen usage is substantially more than that for hydroprocessing of petroleum crude. This paper will compare impact of hydrogen generated by various methods, (e.g. steam methane reforming, coal and/or biomass partial oxidation, and electrolysis) on carbon footprint from DCL.

24-2

Direct Coal to Liquids (DCL): High Quality Jet Fuels

W. Weiss, H. Dulot, A. Quignard, N. Charon, M. Courtiade, IFP New Energy, FRANCE

The worldwide demand of fuels has been intensified in recent years and is expected to continue growing. To satisfy these energy requirements and diversify the source of fuels, the energy industry has to face the challenge of using alternative feedstocks in order to produce transportation fuels like jet or diesel. Direct Coal Liquefaction (DCL) process enables liquid yields higher than indirect liquefaction via Syngas and FT process (typically 3.5 bbl/T coal for the best available DCL processes compared to 2.5 bbl/T coal for indirect process, on a dry ash free basis including hydrogen production and upgrading in both cases). In order to obtain high quality transportation fuels, raw coal liquid effluents derived from Direct Coal Liquefaction need to be severely upgraded using hydrotreating and hydrocracking. This work focuses on the characterization of physical and chemical properties and composition of jet fuel cuts obtained by DCL before and after hydroprocessing, and shows that high quality jet product could be obtained using appropriate hydrocracking conditions.

24-3

Extraction of Brown and Sappropelitic Coals with Toluene and Water Containing Fluids under Supercritical Conditions

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The conversion of brown coals from the Borodino and Kangalas deposits and sappropelitic coal in an aqueous medium and in a toluene containing mixture with water and tetralin was studied under supercritical conditions over the temperature range of 375–550 $^\circ\text{C}$ and at pressures from 13 to 40 MPa. It was found that the methanation, hydrolysis, and oxidation reactions of brown coals with the predominant formation of gaseous products (methane, carbon dioxide, and hydrogen) prevailed in an aqueous medium. Liquid substances were formed in an insignificant amount. In the toluene solvent under supercritical conditions at 440 $^\circ\text{C}$, the addition of a small water amount (15 %) stimulated the degradation of coals with the predominant formation of liquid products and moderate gas formation. The use of calcium oxide and sodium hydroxide

as catalysts increased the yields of liquid products. It was noted that the reactivity of Kangalal coal in this process was higher than that of Borodino coal. Much higher conversions were achieved in the extraction of sapropelitic coal. In the supercritical toluene containing media with small amount of hydrogen donor tetralin cosolvent the conversion achieved 79 % at 4000C.

24-4

Research and Development of New Type Reactor for Direct Coal Liquefaction

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At present, bubble column reactor and ebullated bed reactor are applicable to the direct coal liquefaction (DCL) reactor. However, there are more or less some defects in both of them. Loop reactor is applied widely in chemistry industry, biochemical engineering, environmental engineering, petro-chemical industry and other industries for its simple structure and many merits. In order to introduce loop reactor into DCL industry, we have established a world's first large-scale pressurized loop reactor cold-state simulation apparatus. The reactor was 0.6 m in diameter and 6.6 m in height, and its draft tube was 0.4 m in diameter and it 5.75 m in height. It simulates the fluid dynamics behaviors within the DCL reactor by using nitrogen-water system. The effects of superficial gas velocity, superficial liquid velocity, pressure and surface tension on gas holdup in the loop reactor were investigated; the anti-interference ability of the loop reactor also was investigated. The explorative experiment that the loop reactor is applied to the DCL process under actual liquefaction conditions (pressure=19.0 MPa, temperature=455 °C) has been conducted in the 6 ton coal/day process development unit (PDU). The test has set a precedent that loop reactor can be used as DCL reactor. The experiment results show that the loop reactor's coal conversion rate is slightly higher than that of the ebullated bed reactor while the oil yield slightly lower than that of the ebullated bed reactor. Therefore, loop reactor can be used in the coal direct liquefaction process.

24-5

Characterization and Distribution of Phenolics in Direct Coal Liquefaction Oils

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Phenolics are the predominant oxygen-containing components in the direct coal liquefaction oil (DCLO), and account for 15% of DCLO (IBP~350°C) approximately. In a traditional DCL process, DCLO is hydrotreated unexceptionally to produce gasoline, diesel oil or kerosene; and thereby the concentration of phenolic components must be reduced sharply, in course of hydrotreating, to especially low level to come up to the requirement of qualified products. Since phenolic compounds, however, are valuable, even rare raw material or intermediates for lots of fine chemical processes actually, the phenolics should be pre-removed, separated and purified subsequently to produce series of high profitable by-products, instead of being hydrotreated. Qualitation and quantitation of phenolics in DCLO is the fundamental step for choosing by-products and designing separation route on each compound. Because the distribution of phenolics in DCLO has been shown to affect coal degradation and reactivity, upgrading to fuels, and stability, much more attention has been paid to the analysis of these compounds during the last three decades of 20th century, and almost every analytical method available has been applied to the analysis. Limited achievement, however, has been possessed till now, because chromatographic detection technique specific for oxygen-containing compounds in DCLO is deficient at that time, and phenolics are difficult to analyse for their high polarity and strong reactivity.

SESSION 25

Combustion: Chemical Looping Development - 2

25-1

Development of Real-Time Dynamic Simulation of Chemical Looping Process for Advanced Controls

Xinsheng Lou, Hao Lei, Abhinaya Joshi, Carl Neuschaefer, Alstom Power Inc., USA

Alstom Power Inc. (Alstom) is collaborating with the U.S. Department of Energy (DOE) in a multiphase project developing an entirely new, ultra-clean, low cost, high efficiency power plant technology for the global energy market. This new power plant concept is based on a process utilizing high temperature chemical and thermal looping technology. This chemical looping (CL) technology can be configured as a next generation power plant with a controlled stream of CO₂ for use or sequestration. In coordination with the process development project efforts, Alstom is investigating and developing advanced controls for this chemical loop system under an DOE

Advanced research project co-sponsorship. A key part of this controls project is development of a new computational approach to process dynamic simulations for use in the control work. The Phase I project focused on developing an early understanding of the basic transport process and the underlying process control dynamics. The project includes characterization of the chemical looping process, building solid transport process math models, and dynamic simulation software to support control investigations. This first of a kind simulator and Alstom's experimental facilities were used in exploring advanced controls concepts such as model predictive control (MPC) for application to the chemical looping process. A paper was presented at PCC 2009, summarizing the progress of the Phase I R&D project executed by Alstom Power. In order to enable a smooth transition from the current Phase I (simulation and controls of the pilot scale process) project to Phase II (scale-up CL prototype process - 3MW_{th}, to be erected in Windsor, CT, US in 2010-11), a Phase I Extension period was created between DOE and Alstom to focus on preparations for the scale-up modeling, real-time simulation, and control specification development for the Phase 2 efforts to address the forth coming 3MW_{th} CL prototype.

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This paper, in addition to the off-line dynamic process simulator, presents the recent work conducted to develop a Real-time Simulator. First, the paper introduces the technology background and project status. Then, the paper presents the technical approach to first principle modeling of a hot solid multi-loop flow model, model discretization and software and numerical simulation development in the simulation environment. The simulation results and numerical problems resolved during the computational studies are presented at a proper technical level. Next, the paper shares the experiences in using a Real-Time Workshop (RTW) toolbox to convert the models into real-time target files to be used with customer specified user interfaces. The resulting real-time simulator with the basic closed-loop PID controls is then introduced in the modeling and simulation section as well. The results from the testing of Real-time advanced controllers on the simulator are presented as a validation of the real-time simulation platform.

Operational optimization along with advanced controls has been established as a key milestone for this future clean power generation plant research and development project. To conclude this paper, further discussions are extended on the future phases of the project for integrated control and optimization designs along with Alstom's clean fossil power system development.

25-2

Effect of H₂S on Chemical Looping Combustion of Coal-Derived Synthesis Gas over Fe₂O₃ - MnO₂ Supported on ZrO₂/Sepiolite/Al₂O₃

Ewelina Ksepko, Marek Sciazko, Institute for Chemical Processing of Coal, POLAND; Ranjani V. Siriwardane, Hanjing Tian, Thomas Simonyi, James A. Poston Jr, U.S. DOE, USA

The paper contains results of collaborative research work on novel combustion technology known as chemical looping combustion (CLC). The objective of paper was to prepare Fe₂O₃ - MnO₂ supported on ZrO₂/Sepiolite (ICPC, Poland) oxygen carriers and to evaluate the performance (NETL, US DOE) of these for the CLC process with synthesis gas/air. Thermo gravimetric analysis (TGA) and low pressure (10 psi) bench scale flow reactor tests were conducted to evaluate the performance. Multi cycle tests were conducted in an atmospheric TGA with oxygen carriers utilizing simulated synthesis gas with & without H₂S. Effect of H₂S impurities on both the stability and the oxygen transport capacity was evaluated. Multi cycle CLC tests were also conducted in the bench scale flow reactor at 800 °C with selected samples. Chemical phase composition was investigated by X-Ray diffraction (XRD) technique. Five Cycle TGA tests at 800 °C indicated that all oxygen carriers had a stable performance at 800 °C. It was interesting to note that there was complete reduction/oxidation of the oxygen carrier during the 5-cycle test. The fractional reduction, fractional oxidation and global reaction rates of the reactions were calculated from the data. It was found, that support had a significant effect on both fractional reduction/oxidation and the reaction rate. The oxidation reaction was significantly faster than the reduction reaction for all oxygen carriers. The reaction profile was changed by the presence of H₂S but there was no effect on the reaction rate due to presence of H₂S in syntheses gas. Low pressure bench scale flow reactor data indicated stable reactivity, full consumption of oxygen from oxygen carrier and complete combustion of H₂ and CO. XRD data of samples after multi-cycle test showed stable crystalline phases without any formation of sulfides or sulfites/sulfates and complete regeneration of the oxygen carrier after multi-cycle tests.

Effect of Coal Blending Method on Combustion Characteristics and NO_x Emission in a Drop Tube Furnace

Song-gon Kim, Chun-sung Lee, Byoung-Hwa Lee, Ju-Hun Song, Young-June Chang, Chung-Hwan Jeon, Pusan National University, SOUTH KOREA

This paper presents the dependence of combustion characteristics and emission on in-furnace blended method in Drop Tube Furnace (DTF). The experiments were performed with blending of sub-bituminous and bituminous coals (single coals and approximately 25%/75%, 50%/50% and 75%/25% blends) at different blending method under the condition of 1.34 excess air ratio.

In the in-furnace blended method, the distance between injection positions was changed along the axial direction to investigate the interaction between the different rank coals.

The results show that the unburned carbon ratio decreased as the blend ratio of Adaro (subbituminous coal) in Yakutugol (bituminous coal) increase when two coals fed into the furnace simultaneously (out-furnace method). But, at the 75% of sub-bituminous coal blending, emission of unburned carbon was higher than the amount which was emitted from Yakutugol (bituminous coal) burning solely. The NO_x emission increased as blending ratio of Adaro increase. In the case of the 75% Adaro and 25% Yakutugol blending, in-furnace blending method was performed to compare with out-furnace blending method. In-furnace blended method led to a higher combustion efficiency and lower NO_x emission than out-furnace blended method. In other words, it was seen that ignition position in blending influences remarkably combustion efficiency and NO_x emission. The reason was that volatiles burning of Adaro coal which has high volatiles content relatively launches earlier than Yakutugol coal in the out-furnace blending method. It led to increase of unburned carbon in bituminous coal by deficiency of oxygen to be reacted. Different ignition position between bituminous and sub-bituminous coals by in-furnace blended method improves burning rate of bituminous coal and reduce the unburned carbon from bituminous coal at specific blending ratio. Furthermore, NO_x emission also decreased by using in-furnace blending method.

TGA and DTF Studies on Coal Blends to Assess Combustion Performance

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As the practice of utilization of high ash Indian coals for power generation by blending those with low ash coals are growing, uncertainties in resultant combustion characteristics associated with blending practices need to be assessed in depth. For this purpose, two typical blend combinations of Indian coals, representing combinations of similar and different coal rank, were chosen. Combustion studies with blends in Thermo Gravimetric Analyzer (TGA) and in Drop Tube Furnace (DTF) reveal both interactive and non-interactive behaviour of constituent coals. Type and level of interaction varies with constituent coal-type, blend proportion, combustion-conditions and combustion-stages. Both positive and negative deviations from the expected weighted average values of combustion parameters were noticed. In top port (DTF) interactions are high (compared to next ports), carbon burnout values are scattered and inferior than parent coals. TGA showed lowering of activation energy in blends. Characteristic TGA parameters and burn out efficiencies in different ports of DTF' reflected interesting features.

SESSION 26 Gasification: Fundamentals – 2

Effect of Operation Parameters on Gasification for the Production of Synthesis Gas

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The sensitivity of operating parameters on the gasification of different Turkish coals was investigated for the production of synthesis gas. The coal properties were determined by detailed analysis in Turkish Coal Enterprises. The calculations and the analysis were carried out assuming the kinetic equilibrium model for gasification. The higher heating value of the synthesis gas produced was calculated for the evaluation of performance of the process. The effects of steam rate of water gas shift reactor, bypass ratio and coal composition on synthesis gas produced were analyzed. Moreover, integration of the gasifier with water-gas shift reactor was also investigated to obtain the desired H₂/CO ratio using different coals. The model developed in this work can be used for choosing the proper set of operating parameters to produce the synthesis gas with the desired composition suitable for the purpose of its end use.

High-Pressure and High-Temperature Gasification of Upgraded Brown Coal Char Using a Mini Direct Heating Reactor

Kouichi Miura, Ryuichi Ashida, Mitsunori Makino, Xian Li, Kyoto University, JAPAN

We have recently proposed an upgrading method of low rank coal which consists of treatment of coal in non-polar solvent, such as 1-methylnaphthalene, at temperatures below 350°C. The products obtained from the treatment are solvent-soluble fraction (extract) and insoluble fraction which we call "upgraded coal (UC)". It was found that the gasification reactivity of the UC char was much larger than that of the raw coal char for the seven coals out of the nine coals tested, indicating that the proposed upgrading method can be one of the ways of enhancing the gasification reactivity of coal char without using catalyst. In Japan oxygen blown gasification with recycled CO₂ has been proposed to facilitate the CO₂ separation and hence to increase the gasification efficiency under the NEDO "Innovative Zero-emission Coal Gasification Power Generation Project". To realize the gasification concept practically, it is essential to increase the CO₂ gasification reactivity of coal chars under high CO₂ pressure of ~2 MPa at T = ~1200°C. This requests the developments of methods to increase the gasification rate and to measure the gasification rate under such extreme conditions. In this work a mini direct heating reactor (mini-DHR) was successfully constructed to measure the CO₂ gasification rate of coal chars at high temperature and high pressure. The validity and accuracy of the gasification rate measurement by the mini-DHR were well clarified, indicating that the mini-DHR can be a handy apparatus for measuring the gasification rate under extreme gasification conditions. Measurement of CO₂ gasification rate of the UC char using the mini-DHR showed that the gasification rate of UC char was larger than that of the raw coal char by about 2 times even at high temperature and high pressure. This clarified that the proposed coal upgrading method is effective in increasing the CO₂ gasification rate at high temperature and high pressure without using catalyst.

CFD Simulation of Process-driven Particle Fragmentation in a Coal Bed Gasifier

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Good gas-solid contact is essential in a coal bed gasifier such as in a COREX® melter gasifier. The charged particle size distribution and the particle fragmentation behavior inside the slowly moving fixed bed strongly influence the local counter current gas flow and therefore also the rate of heat transfer between gas and coal, the rate of drying, devolatilization and gasification.

COREX® is the first commercially operating smelting reduction process, based on coal instead of coke, as alternative for industrial ironmaking route via the blast furnace. Besides coal the melter gasifier also contains reduced iron ore and additives, which are not subject of this paper.

General multiphase models in commercial CFD codes are not directly applicable to the simulation of moving reactive beds considering changes in particle size distribution. A customized approach based on a combination of Eulerian and Lagrangian formulation is used to describe the flow of gas and solids as well as the physical and chemical processes across the moving bed reactor.

The solids flow and the gas flow are represented by a set of Eulerian equations. So the flow of solids respectively the flow of a granular material is treated as a continuum with appropriate material properties. The balances for solids and gas flow are interconnected via source terms. The energy balance of the solids flow and the models for fragmentation and devolatilization are implemented by means of a Lagrangian formulation. The solids flow consists of a set of particle sizes including dust. This set of particle sizes changes according to local process parameters which are: solids pressure, shear stress, rate of water evaporation (coal drying), rate of devolatilization, rate of gasification and rate of temperature change. To take this into account a fragmentation model has been developed which solves a conservation equation for each particle size. The local source terms within these equations are connected to the above mentioned local process parameters. Due to the fact that the considered moving bed consists of non-uniformly sized particles the temperature of small particles will be different from the temperature of larger particles. However, the temperature of the particles is important for the rate of drying, devolatilization and gasification. Therefore an energy balance for each particle size is implemented within the presented model.

In a first step the model has been used to study the impact of a changing particle size distribution on the gas flow and heat transfer between gas and solids. The effect of fragmentation on the devolatilization process has been simulated too. Next development steps are the integration of models for coal drying and gasification as well as a gas phase reaction model.

Experimental Investigation into Primary Fragmentation of Large Coal Particles

Adam Luckos, Roelof L.J. Coetzer, Ed L. Koper, Sasol Technology R&D, SOUTH AFRICA; Monika Kosowska-Golachowska, Częstochowa University of Technology, POLAND

Thermal fragmentation plays an important role in coal conversion processes because it accelerates devolatilization and affects the kinetics of gasification and combustion. In addition, fragmentation may generate large quantities of fine particles. Elutriation of these un-reacted coal fines lowers carbon conversion and, therefore, the thermal efficiency of the conversion process. Most of the fragmentation tests were conducted with medium-size particles in fluidized beds at temperatures 750–900°C. Little information is available in the open literature on the primary fragmentation of large coal particles typically encountered in coke ovens, smelting furnaces and fixed-bed gasifiers.

In this paper the results of primary fragmentation tests conducted with single particles of three bituminous non-swelling coals in a laboratory-scale reactor at convective conditions are reported. All tests were carried out in inert atmosphere at ambient pressure and superficial gas velocity of 0.2 m/s. The effects of temperature, particle size, and mineral matter content on the fragmentation behaviour were studied. The primary fragmentation process was quantified through the probability of fragmentation and degree of fragmentation. During tests, coal particles were breaking up into pieces producing a few big pieces and a large number of fine fragments. Both particle size and gas temperature significantly influenced the fragmentation process. Only 20-mm particles tested at 400°C did not undergo the primary fragmentation. The most extensive fragmentation was observed for 80-mm particles at 600°C. The degree of fragmentation increased with increasing mineral matter content. The experimental data provide evidence that a 'critical' size exists below which coal particles do not experience primary fragmentation in the convective environment.

26-5

Investigation of the Pyrolysis and Gasification of a Turkish Coal Using Thermal Analysis Coupled with Mass Spectrometry

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Clean conversion of coal into gaseous and liquid fuels and chemicals is of utmost importance along with its direct utilization via combustion in a sustainable manner. Pyrolysis is an important intermediate stage in coal conversion processes such as combustion and gasification. Coal gasification is applied in IGCC systems for power generation as well as for the production of a range of gaseous and liquid fuels from hydrogen to diesel. Thermal analysis results coupled with mass spectrometry (TA/MS) applied to the pyrolysis and gasification of a Turkish coal are presented here. Pyrolysis experiments have been carried out in argon atmosphere while air has been used as the gasification agent. The samples have been heated from room temperature up to 1000°C. The main evolved products have been identified through the on-line recorded mass spectra. The thermolysis behavior of the coal sample has been checked comparatively for selected gas flow rates and heating rates. The gas flow rate has been changed between 5 and 70 mL/min whereas the heating rate range has been selected as 10 to 40 °C/min. Two different sample masses (5 and 10mg) have been used to observe any effect of the mass on the thermal analysis results. Final operation conditions are based on these results. The TG curves, the on-set, shape and off-set of the DTG curves combined with the evolution temperatures of the major gaseous products such as H₂, CO, CO₂, CH₄, H₂S and SO₂ for the selected appropriate operation conditions clearly show differences in the thermolysis behavior at different atmospheres, gas flow rates and heating rates. These differences in thermolysis behavior indicate when and under which conditions pyrolysis and/or partial oxidation (gasification) and/or oxidation might be occurring. The TA/MS results are also indicative of the reactivity of the coal sample to the selected atmosphere at various temperatures.

TG-MS results can be utilized to determine kinetic parameters via various methods. Care should be taken to avoid mass transfer limitations. The results prove that the gasification of coal consists of two major reactions: pyrolysis and gasification of in situ formed char. The rate of the latter reaction is much slower than that of the former reaction. The volume of the gasifier is therefore primarily dependent on the gasification rate of char. For this reason, kinetics of char gasification obtained by TA/MS plays a key role by providing valuable information for the proper design and operation of gasifiers.

27-1

Development of Post Combustion Carbon Capture Technology

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Doosan Power Systems Ltd (DPS) are currently developing post-combustion and oxyfuel carbon capture technologies for early commercialisation. The purpose of this document is to highlight the work that is being carried out by DPS specifically on Post Combustion Carbon Capture.

Post Combustion Capture

DPS licensed an advanced solvent scrubbing technology from HTC Purenergy Inc. back in September 2008. HTC who are based in Regina, Canada, work very closely with the University of Regina who are recognised as one of the leading global research institutes in Post Combustion Carbon Capture. In addition to the licence agreement, DPS acquired a 15% stake in HTC to further cement the bond. DPS are now preparing commercial bids for fullscale solvent scrubbing plants, comprising all equipment from flue gas desulphurization (FGD) plant outlet to CO₂ compression plant inlet. The long-term performance of HTC's proprietary amine-based solvent, RS2, has been assessed in verification runs at the Boundary Dam pilot plant (4 tonnes per day CO₂ capture). Further work is being carried out by DPS at its purpose built solvent scrubbing pilot plant in Renfrew, Scotland. This plant is part of the Emissions Reductions Test Facility (ERTF) with an approx. 1tpd CO₂ capture rate. This paper outlines Doosan Power Systems post combustion capture development and commercialisation activities.

27-2

Lignite Derived Carbons for CO₂ Capture

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A range of carbon adsorbents were prepared from Victorian lignite and investigated for their ability to selectively capture carbon dioxide (CO₂).

Carbons were prepared by steam activation of titania- impregnated Victorian lignite. The titania was removed by acid washing following activation. Pore size analysis (using nitrogen adsorption data and the BJH method) indicated a total pore volume of 0.48 mL/g with a significant volume present as mesopores (0.16 mL/g) and an average pore size of approximately 3.7 nm. X-ray diffraction analysis indicated no ordered symmetry.

This carbon was then further modified to incorporate approx 1% nitrogen. The carbon was nitrated and the resulting nitrate groups were reduced using aqueous ammonia. When nitration was carried out with fuming nitric acid, the pore volume dropped significantly to about half its prior value and the proportion of mesopores was reduced, suggesting that some structural degradation and pore blockage had developed during the modification. When using sodium nitrate as the nitrating agent, this degradation did not occur such that the original pore volume distribution was substantially maintained. The reversible CO₂ adsorption capacities of these materials were measured and compared. Modification of the carbon led to an increase in the amount of carbon dioxide that could be adsorbed from a CO₂-rich stream (90% in Ar) at ambient conditions. As much as 8.3 wt% (1.9 mmol/g or 36 g/L) CO₂ was reversibly adsorbed on the modified carbon. A further 1.4 wt% was irreversibly adsorbed at ambient conditions, but could be quantitatively recovered from the adsorbent by increasing the temperature to 120°C. Modification of the carbon with N also led to small increase in the heat of adsorption from 28.3 to 32.1 kJ/mol CO₂ adsorbed, indicating that CO₂ capture occurred via a physisorption mechanism rather than via a chemisorption as had originally been postulated.

Key drivers for undertaking this investigation were the very low cost and very low mineral content of this lignite as a potential carbon precursor. However, the CO₂ adsorption capacities of the highly mesoporous products described above were not as high as for carbons prepared from other materials or by other routes. Carbons with higher pore volumes, proportionately more microporosity and/or with more extensive modification by N gave better results.

27-3

Physical Properties and Reactivities of Mg-Based Dry Regenerable CO₂ Sorbents Prepared by Spray-Drying Method

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Integrated gasification combined cycle (IGCC) is evaluated as a cost-efficient power generation system when CO₂ capture is considered together. CO₂ capture at a warm temperature and a high pressure will improve the thermal efficiency of IGCC system compared with current low temperature CO₂ capture process. In this work, we presented dry regenerable solid CO₂ sorbents with high CO₂ sorption capacity at warm temperatures and a high pressure and excellent physical properties suitable for fluidized-bed process applications. Mg-based CO₂ sorbents were prepared using spray-

drying technique. The physical properties of the spray-dried sorbents were characterized in terms of shape, particle size, packing density, and attrition resistance etc. The reactivity of the sorbents was measured with a thermogravimetric analyzer (TGA) and with a bubbling fluidized-bed reactor using simulated synthesis gas at 20 bar. TGA weight gain measured at the temperatures of 200 and 400 °C for adsorption and regeneration, respectively, was about 11 wt%. CO₂ sorption capacity measured in a bubbling fluidized-bed reactor at the same condition was around 9 wt%.

SESSION 28
Coal Science: Coal Chemistry – 2

28-1

Carbonaceous Particles from the Incomplete Combustion

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The abundance and composition of emitted products are primarily related to the fuel composition and to the characteristics of the combustion processes. Fuels used in combustion are usually fossil fuels or living or dead vegetation and they are mainly of a carbonaceous nature. The chemical composition of combustion plumes is a complex and as a result of incomplete combustion processes particles enter the atmosphere as well. As combustion whether from motor vehicles, industrial flames, or biomass burning is ubiquitous, carbonaceous particles are found virtually everywhere. Black carbon (BC) is general term used to describe carbonaceous residues produced by incomplete combustion of organic matter. The concept of BC refers to particles which are black when measured by optical techniques.

In this work we characterized the chemical and petrological changes associated with the formation of char from coal, peat, wood and wheat. Since the formation of BC depends on several factors, we prepared series of carbonaceous residues in two environments. The combination of non-destructive (optical microscopy) and destructive (gas chromatography and pyrolysis-gas chromatography/mass spectrometry) analytical techniques was used for the samples characterization. The chemothermal oxidation method was employed to determine the BC content in the samples.

28-2

Trace Element Partitioning and Leaching in Solids Derived from Gasification of Australian Coals

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Energy Technology, AUSTRALIA

Trace element concentrations vary between coals from ppb to ppm levels and can depend on the rank of the coal and its geological origins. During gasification, some of the trace elements are volatilised at high temperatures and may condense and deposit in cooler downstream parts of the system or in quench water streams. Some species may appear in condensed phases such as slag or flyash. Changes in the trace element concentrations in the slag and flyash from that of the parent coal are expected due to the reactions occurring at high temperatures and the different chemical activity of the trace element phases in the slag, flyash and syngas.

Four Australian coals were used in a gasification test program conducted in the Siemens 5 MW_{th} gasification test facility. Solid samples were collected from different points in the gasification process during each test. Compositions of these samples were analysed and the distribution of trace elements was studied.

It was found that the elements can be classified as follows, according to their tendency to appear in the slag and fly ash:

- Non-volatile and no partitioning between slag and flyash: Nb, U
- Partitioned between slag and fly ash: Cu, W, Mo, Cd, Bi, Zn, Sn, Sb
- Partially volatile and depleted from either slag or fly ash: Be, Th, Sc, Y, Li, Mn, Ni, Sr, Ba
- Highly volatile (i.e. were not observed in either slag or fly ash): As, Se, B, Hg, F, Pb, V.

Comparison of these experimental results with equilibrium calculations of trace element appearance in the condensed phases suggests that the modelling approach is suitable only for certain elements. For several of the trace elements of significance in this study, kinetic factors have to be considered in conjunction with thermodynamic modelling.

The leaching behaviour of the trace elements in the slag was also studied. This work shows very low leachability for most of the trace elements except Zn and Sb, which, due to their relatively high volatility, reported in the slag samples in very low concentrations.

28-3

Effect of Coal Rank on Carbon Oxides Formation via the Low Temperature Atmospheric Oxidation Process

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Imported coal travels large distances in ship-holds and is thereafter stored in strategic stockpiles. From the moment the coal is mined it undergoes degradation in a process called weathering. This process involves a series of reactions between atmospheric oxygen and the coal surface which result in several gaseous emissions.

The present research aims at expanding our knowledge of the formation of low temperature (30-150°C) oxidation products and their dependence on coal rank. The coals studied are those which serve for power production, namely lignites and bituminous coals. The focus of this work is primarily on the functional groups that can serve as precursors to the formation of carbon oxides. It is known that the formation of carbon oxides is correlated to the concentration of oxygen in the atmosphere. However, the precise relationship and the specific functional groups at the coal surface that are reactive are still unclear.

It has been observed that coals of different rank react differently to atmospheric oxidation. That is why simulation experiments were carried out with bituminous coals on the one hand as well as lignites on the other hand. From the results of these experiments a comparison of the behavior of variously aged coals has been evaluated. Conclusions drawn from the present research can help to gain a better understanding of the reactions occurring while stored coal undergoes the oxidation process.

28-4

Quantitative Determination of Minerals in Coal by CQPAC Method

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Recently a new method (CQPAC) for the quantitative determination of minerals in coal has been suggested (Klika and Ritz, 2009). This method is based on the recalculation of the elemental bulk chemical analysis on quantitative determination of minerals by optimization procedure. In this contribution the errors of quantitative calculated minerals by CQPAC method are tested using typical analysis of the bituminous coal. These errors can rise from not quite correct input data which are: a) identified minerals, b) wrong determined crystallochemical formulae of minerals and c) error in chemical analysis. The influence of those sources of errors on quantitative determination of minerals in coal by CQPAC method is critically evaluated.

28-5

The Catalytic Effect of Added Sodium- and Potassium Carbonate to an Acid Treated Inertinite Rich South African Bituminous Coal Char

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Alkali salts in the mineral part of coal decompose, react and vaporize as the temperature increases. The degree of vaporization of alkali metals or compounds, as well as other inorganic species, depends on the mode of occurrence of the mineral matter, the temperature and the grain size in the coal. The condensed inorganic species deposit onto the boiler tubes of the furnace at lower temperatures and give rise to a fouling problem. The condensed alkali species also lead to agglomeration of remaining coal and ash particles within the reactors. Potassium and sodium compounds also enhance the gasification rate due to catalytic activity of these compounds. Alkali species react with the coal phenolate- and carboxylic groups and catalyze the formation of ether cross-links within the carbon matrix of coal. The amounts of potassium and sodium species within coal thus change the reactivity of the coal.

A South African inertinite rich bituminous coal, containing 23% ash was treated with HF and HCl to reduce the mineral content to less than 2%. The coal char was prepared by heating the coal samples under nitrogen up to a temperature of 900 °C and constant mass. Between 0.25% and 4% (mass percentages) of Na₂CO₃, K₂CO₃ and a blend of these compounds were added to the coal samples before charring. The same amounts were added to separate charred coal samples. Comparative CO₂ reactivities of the acid treated coal char samples were determined using a thermogravimetric method. The catalytic effects of potassium carbonate and sodium carbonate on the reactivity of the treated coal char samples were investigated. These large percentages of added compounds enhance the influence thereof and lead to clearly identified trends. A substantial increase in the reactivity was observed after addition of these catalysts. SEM analyses of the char that formed indicated changes in char porosity and surface structure. BET surface area analyses were performed and reported. The contribution of the increased surface areas to the increased reactivity was established and the influence of the added catalysts thus validated. The samples were also heated under CO₂ to 900 °C in a tube furnace, and XRD and FTIR analyses performed on the products to analyze the composition of the samples.

SESSION 29
Coal Science: Beneficiation - 1

29-1

Pre-Combustion Cleaning of Pulverized Fine Coal at Power Plant Using Novel RTS Dry Separation Technology

Daniel Tao, Ahmed Sobhy, Qin Li, Rick Honaker, University of Kentucky, USA

Coal cleaning technologies are vitally important for producing clean coal to supply abundant and affordable energy for the nation's economy under the increasingly stringent environmental regulations. They are generally categorized into pre-combustion and post-combustion processes. Coal cleaning prior to combustion is often accomplished using wet physical processes at coal preparation plants. However, the resultant coal product still contains a significant amount of impurities such as ash, sulfur, mercury that are not well liberated from coal particles mostly in the size range of several millimeters to inches. The pulverization of coal prior to combustion at the power plant provides an ideal feed of well liberated fine coal particles for physical cleaning. If a cost-effective dry separation process is developed to further clean pulverized fine coal at the power plant prior to its combustion, the cost of expensive post-combustion chemical cleaning processes such as flue gas scrubbing can be reduced considerably.

In this study, a novel rotary triboelectrostatic separator (RTS) was investigated for dry cleaning of pulverized Illinois fine coal samples. The proprietary RTS technology is characterized by an innovative high efficiency rotary charger, charger electrification, laminar air flow, and specially designed electrodes. The separation performance of this technology was evaluated in terms of ash content reduction as well as mercury and sulfur content reduction. Important process parameters such as charger material, potential and rotation speed, feed flow rate and air flow rate were investigated for their effects on the separation performance.

29-2

The Prediction of Caking Propensity of Gondwanaland Coals Using Petrography

Daniel Van Niekerk, Johan Joubert, Trudie Britz, Sasol Technology R&D, SOUTH AFRICA

The caking propensity of a coal (the extent of agglomeration) is an important factor to consider in coal conversion processes. In general, the caking propensity of Northern Hemisphere Carboniferous-aged coals can be predicted using vitrinite content: The higher the vitrinite content, the greater the caking propensity. Predicting caking propensity for Permian-aged Gondwanaland coal is problematic due to the high inertinite content. Inertinite consists of both a reactive component (exhibit behaviour similar to that of the corresponding vitrinite) and an inert component. Therefore, it is postulated that the amount of reactive macerals will correlate to the caking propensity. Current characterization of reactive inertinite is conducted by visual recognition during maceral point-count analysis. Visual recognition is highly subjective and therefore prone to errors. To reduce the amount of bias from the maceral analysis, a new multi-maceral reflectogram model is proposed. A multi-maceral reflectogram consisting of reflectance values from vitrinite, semifusinite and inertodetrinite were constructed for various coals. From the multi-maceral reflectogram the amount of reactive macerals could be determined. The amount of reactive macerals obtained from the reflectogram exhibited a linear relationship with caking propensity: The greater the caking propensity, the higher the amount of reactive macerals. Therefore, the multi-maceral reflectogram is proposed as a petrographic method to predict caking propensity of Gondwanaland coals.

29-3

Dry Coal Cleaning Using the FGX Separator

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The extraction of coal typically results in the recovery of pure rock that ranges from very small to very large quantities depending on the seam thickness and other characteristics. In the eastern U.S. coalfields, a significant amount of out-of-seam rock is being extracted in order to recover coal from relatively thin seams. As a result, the amount of run-of-mine feed that is rejected as rock material at the coal cleaning plant can range from 50%-70%. The haulage, processing, and storage of the rock represent significant energy inefficiency and high operating costs. Removing the pure rock material near the extraction point would provide significant economic and environmental benefits.

The removal of pure rock using a relatively high-density separation of around 2.0 is referred to as "deshaling". Wet-based technologies are the most commonly employed cleaning units for removing rock from coal; however, these processes are generally massive and immobile, while also requiring water addition and a slurry treatment system. This study focused on evaluating a novel dry separation technology, the FGX Separator, at several coal mining operations throughout the U.S. The FGX Separator applies table concentration principles using air as the medium.

Parametric evaluations were conducted at nearly all tests sites using a 3-level experimental design in an effort to realize optimum performances. Regardless of coal type, table frequency and longitudinal slope were found to be the most critical factors in controlling product ash content over a range of energy recovery values. Additionally, the amount of fluidization of air applied through the deck was critical for ensuring optimum energy recovery.

29-4

Improving the Efficiency of Lignite Drying

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The feasibility of using mechanical vapor recompression (MVR) to increase the efficiency of drying North Dakota lignite coal has been examined. MVR is used to recover the latent heat of vaporization by compressing the moisture-laden process streams from the drying process. The work conducted includes: 1) compiling and analyzing lignite coal data from lignite-fired power plants; 2) identifying achievable drying goals for the plant, and 3) performing computer simulations to determine potential efficiency gains through the use of MVR. Scenarios examined included drying the lignite from an initial moisture content of 38% to less than 10% using direct MVR, indirect MVR, and combined indirect and direct MVR. In addition, options for utilization of waste heat in the system were examined.

29-5

Effect of Particle Size, Shape and Density on the Performance of the Air Fluidized Bed in Dry Coal Beneficiation

Pheneas Chikerema, Michael Moys, University of the Witwatersrand, SOUTH AFRICA

Most of the remaining coalfields in South Africa are found in arid areas where process water is scarce and given the need to fully exploit all the coal reserves in the country, this presents a great challenge to the coal processing industry. Hence, the need to consider the implementation of dry coal beneficiation methods as the industry cannot continue relying on the conventional wet processing methods such as heavy medium separation. Dry coal beneficiation with an air dense-medium fluidized bed is one of the dry coal processing methods that have proved to be an efficient separation method with separation efficiencies comparable those of the wet heavy medium separation process. Although the applications of the fluidized bed dry coal separator have been done successfully on an industrial scale, the process has been characterized by relatively poor (Ecart Moyen), Ep values owing to complex hydrodynamics of these systems. Hence, the main objectives of this study is to develop a sound understanding of the key process parameters which govern the kinetics of coal and shale separation in an air fluidized bed focusing on the effect of the particle size, shape and density on the performance of the fluidized separator as well as developing a simple rise/settling velocity empirical model which can be used to predict the quality of separation.

As part of this study, a (40 x 40x 60) cm air fluidized bed was designed and constructed for the laboratory tests. A relatively uniform and stable average bed density of 1.64 with STDEV < 0.01 was achieved using a compound mixture of silica and magnetite as the fluidizing media. Different particle size ranges which varied from (+9.5 -16mm), (+16 -22mm), (+22 -31.5mm) and (+37 -53mm) were used for the detailed separation tests. In order to investigate the effect of the particle shape, only three different (+16 -22mm) particle shapes were used namely blockish (+16 -22mm Blk), flat (+16 -22mm FB) and sharp pointed prism particles (+16 - 22mm SR). Different techniques were developed for measuring the rise and settling velocities of the particles in the bed.

The Klima and Luckie partition model (1989) was used to analyze the partition data for the different particles and high R² values ranging from (0.9210 - 0.9992) were recorded. Average Ep values as low as 0.05 were recorded for the separation of (+37 - 53mm) and (+22 -31.5mm) particles under steady state conditions with minimum fluctuation of the cut density. On the other hand, the separation of the (+16 -22mm) and (+9.5 - 16mm) particles was characterized by relatively high average Ep values of 0.07 and 0.11 respectively. However the continuous fluctuation or shift of the cut density for the (+9.5 -16mm) particles made it difficult to efficiently separate the particles. Although, particle shape is a difficult parameter to control, the different separation trends that were observed for the (+16 -22mm) particles of different shapes indicate that particle shape has got a significant effect on the separation performance of the particles in the air fluidized bed.

A simple empirical model which can be used to predict the rise/settling velocities or respective positions of the different particles in the air fluidized bed was developed based on the Stokes' law. The proposed empirical model fitted the rise/settling data for the different particle size ranges very well with R² values varying from 0.8672 to 0.9935. Validation of the empirical model indicate that the model can be used to accurately predict the rise/settling velocities or respective positions for all the other particles sizes ranges except for the (+9.5 - 16mm) particles where a relatively high average percentage error of (21.37%) was recorded.

The (+37 -53mm) and (+22 -31.5mm) particles separated faster and more efficiently than the (+16 -22mm) and (+9.5 -16mm) particles. However, the separation efficiency of the particles can be further improved by using deeper beds (bed height > 40cm) with relatively uniform and stable bed densities. Prescreening of the coal particles into

relatively narrow ranges is important in the optimization of dry coal beneficiation using an air fluidized bed since different optimum operating conditions are required for the efficient separation of the different particle size ranges and shapes. The accuracy and the practical applicability of the proposed empirical model can be further improved by carrying out some detailed rise/settling tests using more accurate and precise equipment such as the gamma camera to track the motion of the particles in the fluidized bed as well measuring the actual bed viscosity and incorporate it in the model.

SESSION 30

Coal-Derived Products: Coal-to-Liquids/Fischer-Tropsch - 1

30-1

Deactivation of Iron Based Fischer-Tropsch Catalyst: A Critical Problem

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Fischer-Tropsch synthesis (FTS) catalytically converts syngas, a mixture of CO and H₂ to hydrocarbons through a surface polymerization reaction. Iron-based FTS catalyst precursors consist of Fe₂O₃ nanocrystals. Promoters are often added to these nanocrystals in order to improve catalyst performance. However, the exact structural composition of the active sites and the deactivation mechanism of this catalyst are still not clearly understood. Iron based Fischer-Tropsch catalysts undergo two types of deactivation during use. One is due to the physical degradation of the catalyst because it destroys the integrity of the catalyst. This is considered as a serious problem because it forms fine particles that cannot be easily separated from the heavy wax products. It also increases the viscosity of the slurry which may cause extreme pressure drops. The other deactivation pathway can be classified as being due to chemical or phase change. Moreover, carbon deposition, pore blocking, sintering and deposition of other chemicals such as sulfur on the catalyst are also considered as the possible reasons of Fe based Fischer-Tropsch catalyst deactivation.

30-2

The Effects of La and K on Nano – Sized Iron Catalyst for Fischer – Tropsch Synthesis

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Fischer – Tropsch synthesis (FTS) is an important route for production of liquid hydrocarbons from coal-derived syngas and natural gas. Iron catalyst has low cost and excellent water gas shift reaction activity. Iron catalysts contain small amounts of promoters to improve their activity and selectivity[1-5]. In this paper, nano-sized iron catalyst concluding nano-sized iron, copper and lanthanum oxides or potassium oxides separately were prepared then mixed. The catalyst characterized by AAS, XRD, TEM, SEM and BET. 1.3 g catalyst was loaded in a fixed-bed stainless steel reactor then activated by %10H₂/N₂ gas mixture with GHSV=12 nl.h⁻¹.g.Fe⁻¹ at atmospheric pressure with increasing temperature from ambient to 380 °C at 2 °C /min which is maintained for two hour and then reduced to 270 °C. Activation is followed by the synthesis gas stream with H₂/CO=1 and GHSV= 2 nl.h⁻¹.g.Fe⁻¹ for 24 h in atmospheric pressure and 270 °C. After activation, the catalyst activity tests were performed at 285 °C, 18 atm reaction pressure, H₂/CO= 1 and GHSV=1-4 nl.h⁻¹.g.Fe⁻¹. We investigated effect of K and La promoters on catalyst activity and products selectivity.

Type of Catalyst	CH ₄	C ₂ -C ₄	C ₅ -C ₁₁	C ₁₁ ⁺	CO Conversion to CO ₂ (%mol)	CO Conversion (%)
Fe/Cu/La	4.3	10.2	68.1	19.4	49.5	86.9
Fe/Cu/K	5.1	6.4	27.2	67.5	46.3	80.1

Addition of K promoter improves adsorption of CO and suppresses H₂ adsorption. As results showed that K promotes chain growth and retards hydrogenation reaction. Addition of La facilitate dissociation of C-O bond and increases hydrogenation reaction. Nano-sized iron catalyst consist of La produces lower hydrocarbons than other promoter.

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30-3

Fe-Co/TiO₂-Catalysts for the Fischer-Tropsch Synthesis: Role of Fe

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The influence of the addition of Fe to supported Co has been investigated for FT Synthesis. Co/TiO₂ and Fe/TiO₂ catalysts containing 10 wt% of Co and Fe were prepared by a single step incipient impregnation of Co(NO₃)₂.6H₂O or Fe(NO₃)₃.9H₂O respectively on TiO₂ support. Fe:Co/TiO₂ bimetallic catalysts containing 10 wt% of Co and different amount Fe were prepared by co-impregnation of Co(NO₃)₂.6H₂O and Fe(NO₃)₃.9H₂O on TiO₂ support. They were reduced in situ for 24 hours at 350°C under atmospheric pressure using pure H₂ and tested separately in a fixed bed reactor at 230°C and 20 bar. Other runs were performed on the physical mixtures of the two catalysts using different Co/TiO₂: Fe/TiO₂ ratios.

The physical mixtures of Fe/TiO₂ and Co/TiO₂ in the same catalytic bed display high conversion and chain growth probability and less olefin to paraffin ratio than the Fe: Co/TiO₂ systems. However, CH₄ selectivity is significantly high when mixing physically Fe/TiO₂ and Co/TiO₂ in the same catalytic bed. CO conversion, CH₄ selectivity and the chain growth probability increase with the addition of Fe content for the physical mixture while they decrease in the Fe:Co/TiO₂ bimetallic catalysts.

30-4

Product Distribution and Reaction Pathways during Fischer-Tropsch Synthesis on an Iron Catalyst

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A precipitated iron Fischer-Tropsch (F-T) catalyst was tested in a stirred tank slurry reactor under different process conditions. The extent of water-gas-shift (WGS) reaction increased with increase in conversion of the limiting reactant, indicating that the WGS is a consecutive reaction with respect to water formed in the F-T synthesis reaction. The experimental results indicate that 1-olefins participate in secondary reactions (e.g. 1-olefin hydrogenation, isomerization and readsorption). Secondary hydrogenation and isomerization of 1-olefins increased with increase in partial pressure of hydrogen. Gas residence time had significant effect on selectivity of ethylene and other gaseous 1-olefins. Chain growth probability factor increased with increase in molecular weight.

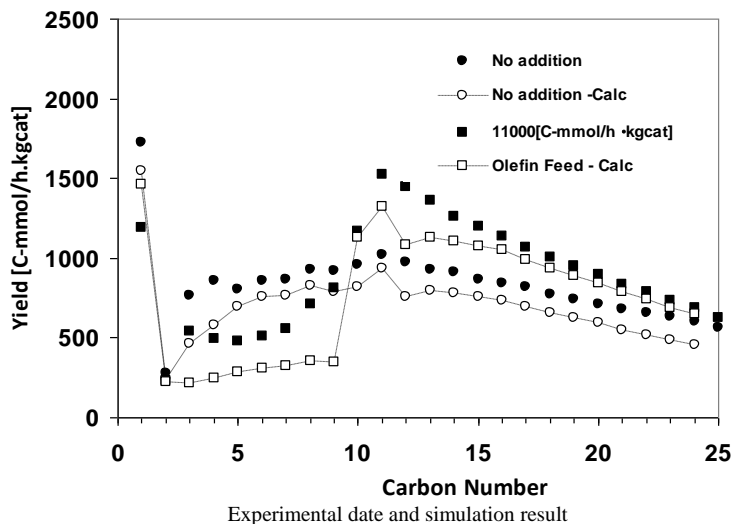
30-5

Simulation of Rate and Product in the Fischer-Tropsch Synthesis

Yoshifumi Suehiro, Japan Oil, Gas and Metals National Corp.; Masato Murayama, Kaoru Fujimoto, The University of Kitakyushu, JAPAN

For a long period of time the carbon-number distribution of the Fischer-Tropsch Synthesis (FTS) product has been simulated by Anderson-Schulz-Flory (ASF) distribution which is based on the concepts that (1) the chain growth probability is independent on the carbon number (c-number) of the fractions, and (2) products are never subjected to the secondary reactions which change the c-number. For this ideal ASF the product distribution is characterized by a single parameter, α. This type of ideal distribution only can be obtained if the kinetic environment is identical and constant at each catalytic site of synthesis. It is widely considered that the occurrence of the deviation of the real data from the ideal data can be attributed to the secondary reactions (reinsertion into the chain growth process, hydrogenolysis and isomerization). It gives the most reasonable explanation for these deviations.

In our previous study, effective control of carbon number distribution in FTS was demonstrated with co-fed 1-olefins in a trickle bed reactor. In the presence of suitable n-paraffin solvent, 1-olefin selectivity was as high as 40 mol%, irrespective of c-number. In this study, we show a reaction model analyzed it by a simulation method to elucidate the rate parameters which control the c-number distributions, and also effect of added olefins using parameters. And we also report the result of effect of co-fed 1-olefin in the slurry system.



SESSION 31

Combustion: Fluidized-Bed Combustion and Co-Firing – 1

31-1

Smartsheet Tool Applied to Boiler Performance Analysis and Economic Optimization of a Circulating Fluidized Bed Boiler

Abhinaya Joshi, Xinsheng Lou, Carl Neuschaefer, Paul Panos, Alstom Power Inc.; Weikko Wirta, AES Thames, USA

In the current deregulated competitive electricity market and with tighter environmental regulations, it is an important goal that power plant boilers are operated and controlled in the most efficient, economic and cleanest manner while fulfilling the grid load demand requirements. This paper presents the development and testing results of a boiler performance analysis and optimization tool referred to as "Smartsheet", capable of assisting plant owners and operators in meeting the stated optimization goals. The Excel based tool includes a neural network process model, economic relationships, an optimization solver and a number of user functions and interface for use in the analysis and the operational optimization of a circulating fluidized bed (CFB) boiler. In view of the fact that a CFB boiler process is nonlinear with strong interactions among process variables, an artificial neural network (ANN) based model was developed to capture the nonlinear relationships between the variables representing operating conditions and the variables that relate to operating costs. The tool has been tested at the AES Thames, station in Uncasville Connecticut. The validation testing involved developing two orthogonal test matrices based on Design of Experiments (DoE) methods that were then used to carry out two independent tests in the Alstom supplied CFB boiler (100MW). The test data collected from the first set of tests was used to train the ANN model and the data from a second set of tests was used for the model validation. The model was combined with the other software developed functions into a tool to support power plant engineers and operators in boiler and total plant performance analysis. The tool is specifically designed to assist in generating economically optimal operating plant settings based on a utility's specified current cost and emission credit factors. The optimization results to date show that the optimized operating settings can save, on average, more than 2% of operating costs over the current operating conditions, which have been fine tuned by almost 20 years of operating experience. Additional validation tests of the optimal operating conditions suggested by the optimization tool have been planned with the customer to further validate the tool.

31-2

A Model of Primary Fragmentation of Coal Particles in Fluidized-Bed Combustion

Adam Luckos, Sasol Technology R&D, SOUTH AFRICA; Monika Kosowska-Golachowska, Czestochowa University of Technology, POLAND

Fragmentation of coal particles plays a significant role in fluidized-bed boilers because it accelerates devolatilization and influences the size distribution of char particles in the bed. A model is proposed to describe heating, devolatilization and fragmentation processes for large coal particles burnt in a fluidized-bed combustor. Results of tests carried out in a bench-scale bubbling-bed unit at conditions similar to those prevailing in fluidized-bed boilers are compared with predictions of the model.

31-3

Main Problems Concerning Co-Firing Biomass Mixture with Hard Coal in Pulverized-Fuel Boilers

Krzysztof Jesionek, Henryk Karcz, Marcin Kantorek, Wrocław University of Technology, POLAND

The methods of burning used in Poland are limited mainly to stocker-fired and fluidic fuel boilers application as well as to co-burning coal powder mixtures in pulverized fuel boilers. The co-burning of timber with coal results however in lowering thermal efficiency of steam producing installation or impairs its operational reliability i.e. increases its running costs and lowers its safety or service. Generally speaking it results from the difference in kinetic characteristics at timber and coal. Into consideration were taken typical pulverized fuel boilers working according to the method established for Polish power engineering for feeding with hard coal. Operating indexes of boilers were analyzed (fired with mixture of biomass and hard coal) bound with combustible portion ratio in slag and volatile ash. The analysis was made for the boilers OP-1050, OP-210, OP-230, OP-430, OP-650, applying the normal combustion chambers. Results obtained concern the maximum boiler heat-load and maximum number of working mills defined as optimum quantity for a given type of boiler. The unburned part in slag and volatile ash has been marked as that ment for a standard boiler fuel and for various mixtures of biomass and hard coal.

31-4

Technical and Economic Evaluation of the Desulphurization Processes at Power Stations Using Lignite

Hasancan Okutan, Bülent D. Çift, İstanbul Technical University, TURKEY

Due to industrial development and population growth Türkiye's energy demand is increasing every year. Although renewable energy sources are becoming widespread these sources are not sufficient enough to meet all of the energy demand of Turkey in the near future. Therefore fossil fuels are going to be used for a long time for domestic heating and electricity production. The disadvantage of using fossil fuels is sulfur dioxide (SO₂) emissions during the combustion according to the sulfur content of the fuel. Turkey's energy consumption depends heavily on fossil fuels. Therefore SO₂ emission level is going to be higher than the legal limits according to Industrial Based air Pollution Control Regulation since our lignite has a low calorific heating value and high sulfur content which are 1807 kcal/kg and 1.85 % respectively. Although there are disadvantages of using lignite for electricity production it's our native energy source and by applying appropriate desulphurization methods it is possible to reduce emission of SO₂ to lower levels. Removal of SO₂ is not only legal obligation but also an act for protection of the public health and environment. Because an important effect of SO₂ is it's contribution to acid rain. Acid aerosols cause chlorosis, the loss of chlorophyll and plasmolysis, tissue collapse of leaf cells in plants. In this study, most prevalent way to prevent SO₂ emission, desulphurization flue gas after combustion of fossil fuel especially lignite, is elaborated wet scrubbing, spray dry and dry sorbent injection methods are investigated. A computer program is written to determine the lowest capital investment among those three methods of desulphurization is found as dry sorbent injection capital investment cost model for certain methods are developed as a function of plant capacity and sulfur content for trona sorbent.

31-5

Desulfurization Characteristics of Powdered Hydrated Lime for Flue Gas Sorbent Injection Process

Hyok Bo Kwon, Kyungnam University; Sang Whan Park, KIST; Hyung Taek Kim, Ajou University, KOREA

In this study, the effect of property change of hydrated lime by methanol treatment and adsorption temperature change on desulfurization efficiency in flue gas sorbent injection process was determined. Desulfurization efficiency of methanol treated hydrated lime increased and it was affected by BET surface area change. In addition, reaction temperature did not affect desulfurization efficiency at normal operating temperature range of 70-150 °C. Desulfurization efficiency increased significantly when water was added to sorbent. Desulfurization efficiency increased as moisture content of untreated sorbent increased; however, it decreased as moisture content of methanol treated sorbent increased. In conclusion, desulfurization efficiency increases by adding water and moisture content should be modulated by sorbent property for optimal desulfurization efficiency.

31-6

Status of Large Circulating Fluidized Bed Boiler Operation in China

Jie Yu, Beijing Research Institute of Coal Chemistry, China Coal Research Institute, CHINA

Circulating fluidized bed (CFB) boiler technology has been rapidly developed in China due to its fuel flexibility including low rank coal and low cost emission control. In the past twenty years, the CFB technology was developed by the local institute and companies. In the same time, it was also introduced from foreign famous companies. Now, China has the largest installed number and capacity of CFB boiler in the world. The total number of CFB boilers in China is over 3000, of which capacity ranges from

6MWe to 330 MWe. The fuel in the CFB boilers includes anthracite, lean coal, bituminous, lignite, gangue, petroleum coke, biomass, municipal solid waste, and many kinds of industrial waste. The total installed capacity of CFB boiler in China is 66GWe, sharing about 15% of the total thermal power generation, among which, the number of 135MWe CFB boilers is over 200, while that of running 300MWe CFB boilers is 26, and there are other more than 60 units of 300MWe CFB ordered. Now, the 600MWe supercritical CFB boiler demonstration is being constructed. The operational performance of large CFB boilers including 135MWe and 300MWe was investigated in the present paper. And the reliability, economy, emission are also discussed as well as the problems in these units.

SESSION 32
Gasification: Fundamentals - 3

32-1

An Updating of Coal Gasification Experimental Tests in a Pilot CO₂-Free Coal-to-Hydrogen Plant

Alberto Pettinau, Caterina Frau, Francesca Ferrara, Sotacarbo S.p.A., ITALY

Large-scale hydrogen production through near zero emissions coal gasification plants represents a reliable technology characterized by a very low environmental impact and it is being more and more interesting for its potential implications from the economic point of view. However, the application of these technologies is currently subject to high capital and operative costs. This need a great scientific and technical effort in order to optimize the processes and the equipments, thus reducing the hydrogen production cost.

In this context, a flexible and fully equipped pilot platform has been built up in the Sotacarbo Research Centre in Carbonia (South-West Sardinia, Italy), in order to study several integrated gasification and syngas treatment process configurations for a CO₂-free combined production of hydrogen and electrical energy, to be used in medium and small-scale commercial plants.

The platform includes a demonstrative and a pilot fixed-bed coal gasifiers, both based on an up-draft and airblown gasification reactor; in particular, the pilot unit is equipped with a flexible and complete syngas treatment process for the development and optimization of hydrogen and electrical energy production technologies.

This paper reports an updating about the main gasification results obtained in the pilot plant during an experimental campaign which is currently under development in order to define the optimal operating conditions of the plant. In particular, after a significant improvement in the plant configuration, a series of experimental tests has been carried out between December 2009 and July 2010 in order to optimize the gasification process in different operating conditions. Moreover, a mention of the global plant performance (based on the experimental results obtained in each plant section, processed through a simulation model for the evaluation of the material balances) has been presented, with particular reference to hydrogen, carbon and pollutant emissions.

32-2

Performance of a 500 KWTH Pressurized Entrained-Flow Coal Gasifier

Kevin J. Whitty, Randy Pummill, David R. Wagner, Travis Waind, David A. Wagner, The University of Utah, USA

In order to acquire industrially-representative data on performance of coal gasification systems, the University of Utah has commissioned a small pilot-scale, pressurized, oxygen-blown entrained flow coal gasifier. This system has a maximum throughput of approximately 1.5 tons coal/day (approx. 500 kWth) at the maximum design pressure of 31 bar. Operationally, the system performs well, achieving good conversion and producing hydrogen- and carbon monoxide-rich syngas. Operation at very low pressures (< 5 bar) is challenging, primarily because the system was designed for operation at 10-30 bar. Initial results from experimental campaigns suggest that a residence time on the order of 5-6 seconds is necessary to achieve good conversion.

32-3

Characterization of a Small Scale Slurry-Fed, Oxygen-Blown Entrained Flow Gasifier: How Injector Geometry Affects Flame Stability and Performance

Travis Waind, Kevin Whitty, University of Utah, USA

The University of Utah operates a 1 ton/day pressurized, slurry-fed, oxygen-blown entrained-flow coal gasifier. To determine the ideal design settings for the coal slurry injector in this system, a number of factors were evaluated. The injector is a twin-fluid design with coal slurry flowing through the central channel and oxygen entering at high velocity through a concentric, angled annulus around the slurry, providing atomization. The injector is positioned in a water-cooled sleeve to keep the injector cool.

The tip of the injector can be removed from the injector and replaced. The angle that the oxygen tube is tapered can be adjusted to change the pattern of the injector discharge. The tip of the injector can also be adjusted so that the oxygen flow path is

small or large, which affects the pressure drop across the nozzle. A balance needs to be stricken between the pressure drop across the nozzle (atomizing velocity) and the angle of the injector discharge. The geometries of the injector design should be optimized to provide a thorough devolatilization of the coal-water slurry.

Through cold-flow testing, a higher pressure drop was shown to provide better atomization. By increasing the impingement angle, the water droplets in the plume appeared to be smaller than those of a smaller impingement angle. The smaller impingement angle provided the smallest water spray angle, giving it a larger velocity component in the downward direction. Changing the gas and liquid flow rates for a given impingement angle and pressure drop did not appear to affect atomization. During tests on the entrained flow gasifier, a higher impingement angle caused a slight increase in gasification products. Also, higher pressure drops led to an increase in gasification products as well as a slight increase in temperature.

32-4

Analysis of Fines Produced from Non-Slagging Coal Gasifier and Evaluation of Economic Usage

Yongseung Yun, Seok Woo Chung, Na Rang Kim, Institute for Advanced Engineering, KOREA

Most coal gasifiers apply the slagging method for coal ash under high temperature, which gives an advantage on ash disposal with smaller volume and non-leaching of heavy metal components. Slagging was related to many operational problems that had been occurred in pilot and demonstration-scale coal gasifiers. Slagging causes distinctive problems in gasifier operation such as slag-tap plugging and the accumulation of a sticky fly-slag on the radiant cooler and in syngas passage. If the fly-ash from the gasifier can be used as an economically viable material such as cement filler or construction raw material, the coal gasification on non-slagging mode might be an attractive option which replaces coal slag to fly-ash as a final product. In particular, coals that contain ash components exhibiting a high melting temperature such as many Australian coals can be utilized more widely in gasification. Coals of high ash melting temperature should add a certain fluxing agent to reduce the ash flowing temperature. If the fly ash from the non-slagging gasification can be used as a useful material as much as slag, development of a versatile gasifier that can be applicable to wide range of coals would be possible.

For usage of fly-ash for other applications, it should meet a certain criteria. Typically, the combustion fly-ash should contain less than 5 wt% remaining carbon to be useful as cement filler, etc. However, fines from the one-stage entrained-bed coal gasifier of pilot-scale 1 ton/day contain 20-70% remaining carbon. In this case, final fines might be applicable for another low-grade fuel if combustibility and other criteria are satisfactory, or a specialty fuel that does not contain volatiles with high surface area. The pilot-scale coal gasifier which was designed to complete the conversion in one pass through the gasifier normally produced 1-5 wt% of feed coal powder as entrained fines. In terms of carbon conversion, typically more than 97% has reached. Although the internal recycle amount of reacted fines to the gasifier can reach more than 50% in two-stage gasifiers, actual amount of fines and slag remains at the ash amount in feed coal plus a small portion of un-reacted carbon which is below than 1-3 wt% of total carbon.

In the study, remaining carbon in fines and their physical characteristics were evaluated for the samples obtained from a non-slagging gasifier with slags from the same coal. In short, in order to compare and verify the applicability of fines from the non-slagging gasifier as a useful by-product, an Indonesian subbituminous coal was gasified in the 1 ton/day scale non-slagging gasifier. Samples of entrained fines from the gasifier were analyzed by SEM, EDX, ICP-OES, particle size analyzer, and TGA. Leaching result of heavy metals on the entrained fines was compared with that from gasification slag on the same coal. And a preliminary evaluation on the possible usage of entrained fines as a useful material is discussed.

32-5

Development of Gas, Power and Tar Co-Generation System with Circulating Fluidized Bed Technology

Qinhui Wang, Mengxiang Fang, Zhongyang Luo, Mingjiang Ni, Kefa Cen, Zhejiang University, CHINA

A gas, power and tar cogeneration technology, which combines a circulating fluidized bed (CFB) boiler and a fluidized bed gasifier to realize gas, power and tar cogeneration in one system, has been developed. A 12 MWe gas, power and tar cogeneration demonstration plant fired Huainan bituminous coal has been operated successfully and the demonstration operation results showed that the constructed cogeneration system may be operated continuously under the design requirements. A series of test operation results showed that the operation temperature in the gasifier has great influence on the pyrolysis gas composition and tar yield. The tar yield reaches a maximum value at a temperature range from 550 to 600°, and hydrogen content in the produced gas increases with increasing the operation temperature in the gasifier.

32-6

Thermal Chemical Process Study on Chemical Reaction Network of Jet-Fluidized Bed Gasifier Reaction System

Jie Feng, Xuecheng Hou, Wenying Li, Xiao-Hui Chen, Taiyuan University of Technology, CHINA

To study and optimize gasification characteristics of jetting fluidized bed coal gasifier, we studied the influence law of two gasification parameters, oxygen feed rate into center nozzle and coal feed rate, on gasifier gasification process and gas composition variations using established reactor network model, and analyzed the calculation results. Results show that the gasifier temperature distribution is one of the most critical factors affecting gas compositions for jetting bed coal gasifier, and oxygen feed rate into center nozzle and coal feed rate result in obvious changes of gasifier temperature distribution. Within the calculation range, with the increase of oxygen feed rate into center nozzle, jet region increased nearly twice, temperature increased by 306 K and high-temperature region moved up, carbon conversion efficiency rose from 68% to 97% (jet region temperature had exceeded the ash melting temperature), and in generated gas, CO and H₂ content changed obviously. With the increase of coal processing capacity, jet region temperature decreased by 252 K, the gasifier overall temperature decreased, and carbon conversion efficiency reduced from 98% to 74%. Dilute phase region has a great effect on effective gas composition in final products, especially H₂ content.

SESSION 33

Carbon Management: Post-Combustion CO₂ Capture - 2

33-1

An Efficient Membrane Process to Capture Carbon Dioxide From Power Plant Flue Gas

Bilgen Firat Sercinoglu, Tim Merkel, Xiaotong Wei, Haiqing Lin, Jenny He, Richard Baker, Karl Amo, Hans Wijmans, Membrane Technology and Research, Inc., USA

To mitigate the harmful effects of global climate change, CO₂ in power plant flue gas must be captured and sequestered. Current absorption technologies proposed to capture CO₂ from flue gas are costly and energy intensive. Membrane technology is an attractive CO₂ capture option because of advantages such as energy-efficient passive operation, no use of hazardous chemicals, tolerance to acid gases and oxygen, a small footprint, no additional use of water, and no steam use requiring modifications to the existing boiler and steam turbine.

Working with DOE, MTR has developed new membranes and process designs to recover CO₂ from power plant flue gas. MTR Polaris membranes have CO₂ permeances ten times higher than standard commercial membranes, which greatly reduces the cost of a membrane capture system. These membranes are combined with a novel process design that uses incoming combustion air as a countercurrent sweep to maximize membrane module performance and recycle CO₂ to the boiler. Design calculations estimate that this membrane process can capture 90% of the CO₂ in flue gas as a supercritical fluid using <20% of the plant power, at a cost of \$20-\$30/ton of CO₂ captured. This translates to an increase in the levelized cost of electricity (LCOE) of about 40%.

Currently, MTR is testing this membrane CO₂ capture process with Arizona Public Service (APS) at natural gas and coal-fired power plants. The test at APS' Cholla power plant uses commercial-scale membrane modules and captures about 1 ton CO₂/day. Technical results from the field tests and future plans will be discussed in this presentation.

33-2

CO₂ Capture by Condensed Rotational Separation

R.J. van Benthum, H.P. van Kemenade, J.J.H. Brouwers, M. Golombok, Eindhoven University of Technology, THE NETHERLANDS

Condensed rotational separation is a technique in which flue gas is cleaned by condensation of the CO₂ and mechanical centrifugal separation. It requires a purification of CO₂ in the flue gas, prior to separation. This purification can be realized with existing techniques like oxygen enriched coal combustion or CO₂ separating membranes. Combined with an enrichment technique, condensed rotational separation provides an answer that can compete with promising conventional techniques for CO₂ capture, like oxy-fuel combustion or amine absorption. These conventional techniques produce a waste stream with a high CO₂ purity that can be compressed to supercritical pressure for transport and storage. It is shown that energy consumption of CRS is only slightly more than gas compression of a sequestration stream resulting from conventional separation techniques.

33-3

Influence of Pressure on Dry Reforming of Methane over Carbonaceous Catalyst

Bingmo Zhang, Yongfa Zhang, Guojie Zhang, Fengbo Guo, Taiyuan University of Technology, CHINA

Reforming of methane by CO₂ to syngas has been studied on carbonaceous catalysts on high pressure. The catalysts have been characterised by BET and FITR techniques. The catalytic activity and stability of catalysts are closely related to the pressure. It has been observed that the catalytic activity, CH₄ and CO₂ conversion decrease with the pressure increased. Some process methods, such as increasing the reaction temperature, prolonging reaction residence time and increasing CO₂ and CH₄ molar ratio, can improve catalysts stability. Moreover, the positive effect of carbonaceous catalysts oxygen-containing groups(C-O) on catalysts activity has been evidenced. The basic function of the carbonaceous materials surface area also seemed to increase H-abstraction of methane and CO₂ adsorption.

SESSION 34

Coal Science: Coal Chemistry - 3

34-1

Predetermination of the Fault Crossing the Underground Coal Mine Galleries by Seismic Reflection Method: An Application at a Longwall Coal Mine in Turkey

G.G.U. Aldas, B. Kaypak, B. Ecevitoglu, Ankara University; A. Can, General Directorate of Mineral Research and Exploration, TURKEY

In longwall mining operations, to provide continuous coal production, it is crucial to know the locations, types, dips, strikes and throw of the faults, before the operations. The aim of this study was to determine the existent faults and their important features in the longwall coal mining region, before starting the exploitation. Multi channel seismic reflection method, which is the most widely used and powerful geophysical method to view the tectonic structures, was used in the study. The method provides good results in determining the existent faults and their structures in the region.

34-2

Alberta's 2 Trillion Tonnes of 'Unrecognized' Coal

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Historically and currently Canada is considered by the international energy industry to have minor coal reserves relative to those of the traditionally accepted major coal nations. Recent estimates by the World Energy Council (WEC) for proved recoverable reserves (that is, the tonnage of coal that has been proved by drilling etc. and is economically and technically extractable) has the United States at 238,308 Gt (gigatonnes or billion tonnes), Russian Federation at 157,010 Gt, China at 114,500 Gt, Australia at 76,200 Gt, India at 58,600 Gt while Canada is listed as having only 6,578 Gt; less than a 1% share of the world coal reserves and a little less than nations such as Poland (7,502 Gt), Brazil (7,059 Gt) and Columbia (6,814Gt).

In Alberta (the Canadian Province having the largest coal resources) the Alberta Energy Resources Conservation Board (ERCB) estimates the remaining established reserves (similar to WEC's proved recoverable reserves category) of all types of coal in Alberta at December 31, 2008, to be 33.4 Gt. Of this amount, 22.7 Gt (or about 68 per cent) is considered recoverable by underground mining methods, and 10.8 Gt is recoverable by surface mining methods. In addition the ERCB recognize an ultimate potential of 620 Gt and ultimate in place coal resource of 2000 Gt (the Alberta Geological Survey using different methods put the estimate at a minimum of 2500 Gt). Alberta's coal resources are vast and at 2000 Gt it is similar in scale to that of total coal resources of the United States.

Coal data varies in quantity and quality from nation to nation and part of the definition of reserves involves economics and again changes markedly from place to place and from time to time. In addition there is geological complexity to consider in estimating reserves. Resource estimates can be even more wide ranging.

Alberta does have a substantial amount of publically available geological data that can be used to establish coal resources. In addition to tens of thousands of shallow coal exploration holes and more than 17 thousand recent Coal Bed Methane (CBM) wells there are data from over 350 thousand oil and gas boreholes drilled in Alberta. The database grows by 15-20 thousand boreholes a year.

Many of these oil and gas boreholes intercept deep coals and the coals that are readily identified on geophysical logs. Industry geologists often use hundreds to thousands of these oil and gas boreholes to outline CBM plays. Almost all of the deeper coals are not extractable (economic) through traditional mining at present.

However traditional coal mining is no longer the only option for coal. Thinking about coal has changed in recent years with new and improved technology for in-situ gasification paired with Carbon Capture and Storage (CCS) and with the current concerns of world depletion of oil and climate change. The recent international interest in in-situ gasification, surface gasification and associated energy technologies such as

CTL, GTL, hydrogen and fuel cells has surfaced in a number of jurisdictions including Alberta. Now with coal being in-situ mined up to 1400m depth in an Alberta coal gasification pilot project; Alberta's huge coal endowment needs to be recognized.

34-3

Temperature as a Factor Affecting Adsorption Behavior of Coal to Lead (II) Ions

Boleslav Taraba, Petra Vesela, Roman Marsalek, Zuzana Navratilova,
Ostrava University, CZECH REPUBLIC

Adsorption behavior of lead (II) ions on bituminous and subbituminous coals was investigated at temperatures 30, 60 and 80°C. Adsorption isotherms as well as adsorption kinetics were studied using batch adsorption experiments. In addition, flow calorimetric measurements were applied to direct determination of adsorption enthalpy.

The shape of the adsorption isotherms indicated that the adsorption data could be tightly fitted by the Langmuir adsorption model. For both coal types, practically no change in adsorption capacity of the coals to Pb(II) ions was ascertained with increasing temperature. On the other hand, practically doublefold increase in the values of adsorption rate constant k was found when temperature rises from 30 to 60°C. The interaction of lead (II) ions with coal was then confirmed to be slightly exothermic process giving „net“ adsorption heat = 1 J/g for both coal samples.

34-4

Bioflotation of Coal

Peter Fecko, Tana Kantorkova, Radomir Michniak, Lukas Koval, Alena Kasparkova, VSB - Technical University of Ostrava, CZECH REPUBLIC

This work deals with application of bioflotation on samples of brown and black coal. The bacteria *Acidithiobacillus ferrooxidans* were used for the purposes and the effect of bacterial action (0-24 hours) on the results of flotation was observed. The acquired results imply that bacterial action manifested itself in a negative way on the black coal samples (drawn in the localities of Marcel mine and Zygłowice), in principle, there was a Loir concentrate yield and the ash and sulphur contents were higher. On the other hand, the results of bioflotation using brown coal samples drawn CSA Mine in Most brought positive results and it is apparent that even short-term action of the bacteria, i.e. 30 minutes, is able to increase the concentrate yield and improve the concentrate quality, which means that both contents of ash and sulphur were lower.

SESSION 35 Coal Science: Beneficiation – 2

35-1

Suitability of the Sulcis Coal for CWS Preparation

Raimondo Ciccu, Giovanni Mei, Caterina Tilocca, University of Cagliari;
Paolo Deiana, Sezione Impianti e Processi ENEA - Agenzia Nazionale per le Nuove Tecnologie, ITALY

A *Coal Water Slurry* (CWS) containing about 65-70% solids by weight can be defined as a stable combustible mixture having a high heat power, in spite of the presence of water. A suitable particle size distribution accompanied by a small quantity of additives contribute to the obtainment of such properties enabling handling, transportation, storage and combustion as a heavy fuel oil. The utilization of CWS offers a number of economic and environmental advantages concerning either the transport and storage operations (better management of coal stockpiles, lower intensity of traffic ...) and the final combustion (CWS can be the starting phase for the application of a number of clean coal technologies including gasification and hydrogen production)

Aim of the research work dealt with in the paper is the study of the influence on suspension stability and rheologic characteristics (viscosity, thixotropy) of various parameters such as:

- Particle size distribution
- Type and dosage of a fluidising additive
- Type and dosage of a stabilising agent
- Proportion of coal in the mixture.

Optimum CWS should be characterised by a high heat value, good stability and a viscosity low enough for pipeline delivery.

Results obtained through a systematic experimental programme, while confirming a better aptness of high-rank coals, have shown that also the sub-bituminous coal mined in the Sulcis coalfield is amenable to the preparation of CWS to be burned in the nearby power stations.

35-2

Comparative Study of Oil Agglomeration and Flotation of Low Grade Coals

Feridun Boylu, Fırat Karakas, Istanbul Technical University, TURKEY

In this study, the collector, also called as the bridging oil, used in both oil agglomeration and flotation is introduced to test in the form of emulsion. Kerosene, Fuel oil and Diesel oil were used for both flotation and oil agglomeration as bridging oil or collector. In flotation experiments, MIBC, DTAB and n-Decanol were also used as frother, and emulsifiers respectively.

In agglomeration tests, it was found that diesel oil was superior to kerosene and fuel oil according to the combustible recoveries and ash contents of the agglomerates. The emulsification of the bridging oils resulted in enhancement on combustible recoveries from 40 % to 75 % and the reduction on the ash contents of original coal samples from 35 % to 19 %. In flotation tests with emulsified diesel oils of 8000 g/t based on the coal weight, the clean coal products with approximately 15 % ash contents and 60-70 % combustible recoveries were obtained.

Finally the oil agglomeration and the flotation of low grade coal were compared and it was found that the oil agglomeration methods should be announced as superior method to flotation for providing higher combustible recoveries and lower ash contents.

35-3

Briquetting Studies of Canakkale-Can Coals

Oguz Altun, Akan Gulmez, Ayşe Erdem, Zafer Gencer, Mineral Research and Exploration Directorate in Turkey; Zeki Olgun, Turkish Coal Enterprises, TURKEY

Canakkale-Can coals, after being washed within 1.4 g/cm³ density, were studied and air channeled briquettes were prepared to be used for domestic consumption, in this study.

Due to high sulfur content, Canakkale-Can coals cause to emit large amount of sulfur oxide gasses and resultantly, environmental pollutions. This property of the coals makes the usage of the coals hard as domestic fuels or conventional power plants' fuels.

It is obvious that, due to high moisture, volatile matter, ash and sulfur contents, direct usage of Canakkale-Can coals will cause environmental pollutions. Utilizing the coals domestically may only be possible with decreasing ash values and increasing calorific values with beneficiation processes, and also with some additions of lime. Moreover, making air channeled briquettes out of them, will make it possible to decrease their sulfur and smoke emissions to tolerable limits.

In this study, chemical analysis and stove thermal efficiency test results of the briquettes, made of Canakkale-Can coals were presented.

35-4

Drying Kinetics of Çanakkale – Çan Lignite

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In this research, the drying kinetics of Çanakkale - Çan lignite was investigated. Experiments were carried out in Denver IR 35 M model moisture analyzer. Drying experiments were performed at temperatures of 80, 100, 120, 140 and 160 °C. Five different particle sizes (1.5, 2.6, 5.6, 10 and 30 mm) were studied. The critical moisture of lignite and kinetic parameters of the drying process (k_0 , Arrhenius equation pre-exponential factor and E_a , activation energy) were determined from the weight loss data as a function of drying time. The average value of critical moisture was found to be 0.23 kg water/kg dry lignite from experiments performed at different drying temperatures and with different particle sizes. Pre-exponential factor of the Arrhenius equation and activation energy were calculated as 0.517 s⁻¹ and 25,381 kJ/kmol, respectively. It was observed that a 4 minute drying process was enough to decrease the moisture content below 20 % in the range of particle sizes of 1.5 – 10 mm.

35-5

Beneficiation of Lignites by Heat Treatment

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The proven Turkish coal reserves, particularly of lignites, amount to 10 billion tons. The majority of these lignites are characterized by their high ash (14% to 42%), moisture (15% to 55%) and volatile matter (16% to 38%) contents. In addition, the lignites contain sulfur levels ranging from 1% to 5%. As most of these coals are consumed without any upgrading processes; high moistures, low calorific values and high sulfur contents become the main causes of coal based air pollution. However, the advanced coal cleaning technologies can achieve substantial reductions in coal-based emissions.

In this paper, low carbonization tests were carried out on lignite samples from Istanbul-Yeniköy region. The results indicate that these low-rank coals can be upgraded to the desired quality both in terms of heating value as 6246 kcal/kg, total sulfur content is 1.45% calorific value and sulfur content.

Simple economical outcomes were conducted for the semi-coke and briquetting techniques. An investment was found \$80 million, for a 1000 tons/day plant. The net benefit/investment ratio is found to be around 80%. Tar, liquid and gas substances, acquired as the by-products of the coking process, were also included into this economic evaluation.

35-6

Innovative High Energy Efficiency Brown Coal Drying based on Self-Heat Recuperation Technology

Muhammad Aziz, Chihiro Fushimi, Yasuki Kansha, Kazuhiro Mochidzuki, Shozo Kaneko, Atsushi Tsutsumi, The University of Tokyo, JAPAN

Brown coal drying based on Self-Heat Recuperation (SHR) technology which recovers effectively both latent and sensible heat is introduced to improve the drying energy efficiency. SHR based fluidized bed drier (SHR-FBD) with heat exchanger immersed inside the bed is adopted as the evaporator. To evaluate the drying efficiency of the proposed SHR-FBD system, a comparison to the available Mechanical Vapor Recompression (MVR) based FBD (MVR-FBD) system in relation to the fluidization velocity and bed aspect ratio in respect of the required energy input was conducted.

From the results, the proposed SHR-FBD system was found to be able to drastically reduce the drying energy consumption in all evaluated fluidization velocities and bed aspect ratios. Furthermore, the proposed system can decrease the energy consumption to about 15% and 75% of that required in hot air and MVR drying systems.

SESSION 36

Coal-Derived Products: Coal-to-Liquids/Fischer-Tropsch - 2

36-1

Using Pyrolysis Tar to Meet Fuel Specifications in Coal-to-Liquids Plants

Jaco Schieke, Foster Wheeler, UNITED KINGDOM

Indirect Coal-to-Liquids (CTL) facilities (i.e. liquids production via gasification and Fischer-Tropsch synthesis) are often sited adjacent to the coal mine feeding the facility, but these coal deposits are often found in remote locations; far from coastal refinery hubs where synergies with conventional refining operations can be exploited. The ability to produce a final saleable product as opposed to a blendstock is therefore an important consideration when designing a CTL facility. This opens up marketing opportunities in the immediate area of the facility and reduces the logistical cost of shipping the CTL product to a blending facility.

There are several challenges to meeting final product specifications from a low temperature Fischer-Tropsch-based CTL facility. Hydrocracked Fischer-Tropsch diesel, although attractive from a cetane and sulphur perspective, has a lower density than conventional diesel. Fischer-Tropsch naphtha on the other hand is a very good chemicals feedstock, but typically has a lower octane than required.

Foster Wheeler recently performed a number of feasibility studies on projects where there was a requirement to produce saleable product from the CTL facility. This article describes some of the key challenges and potential solutions to meeting this constraint. Through the integration of the refining needs with the coal and gasification technology selection, these challenges were addressed. By selecting the right combination of gasifier and coal, combined with the recovery of tar and oil by-products from the gasification process, the blendstock requirement to meet product specifications was substantially reduced.

36-2

Overview of the Rentech Process

Belma Demirel, Harold Wright, Rentech, Inc., USA

Rentech's mission is to develop and commercialize technologies that transform underutilized energy resources into valuable "green" fuels and power. Rentech has developed and is commercializing its patented and proprietary technology that converts synthesis gas produced from biomass into clean-burning liquid hydrocarbon and "green" electricity. For nearly 30-years, Rentech and our licensees have successfully applied the Rentech Process in facilities ranging in size from pilot scale to approximately 250 barrels per day of synthetic fuels and chemicals production.

Rentech completed construction of the product demonstration plant (PDU) located in Commerce City, CO in June 2009. Six weeks after the mechanical completion, Rentech made the first fuel from their integrated operation on August 9, 2008. Catalyst productivity, production rate, fuel yields and performance of all technology elements meet expectations. The PDU is currently only operating synthetic fuels facility in the United States with capability of making multiple fuels and chemicals. Rentech's ultra-clean diesel fuel and jet fuel meet ASTM standards ASTM D7566/D1655 and ASTM D975, respectively. Rentech holds the first ASTM certification for domestic use of alternative fuels for aircraft operations and diesel engines. Rentech fuels are fully compatible with transportation infrastructure and aircraft system, and require no blending limits. Both fuels were extensively tested by US government, universities and

private organizations in wide range of equipment and under severe operating conditions.

Rentech made a 25% strategic investment in ClearFuels technologies, Inc. ClearFuels owns a proprietary flexible biomass gasification technology platform that converts multiple rural cellulosic biomass feedstocks such as sugarcane bagasse and virgin wood waste into clean syngas suitable for integration with synthesis gas-to-liquids technologies. Rentech and ClearFuels. To facilitate the development process, ClearFuels will build a 20 ton-per-day biomass gasifier designed to produce syngas from bagasse, virgin wood waste and other cellulosic feedstocks at Rentech's PDU in Colorado. The gasifier will be integrated with Rentech's Fischer-Tropsch Process and UOP's upgrading technology to produce renewable drop-in synthetic jet and diesel fuel at demonstration scale. Rentech and ClearFuels have been selected to receive up to \$23 million grant from the U.S. Department of Energy (DOE) to construct the biomass gasifier at the PDU site.

Rentech will build a plant at the capacity of approximately 640 barrels per day of renewable synthetic fuels using Rentech-SilvaGas biomass gasification technology in Rialto, CA. In addition, the plant will be exporting approximately 35 MW of renewable power.

36-3

Graphical Methods for the Representation of the Fischer-Tropsch Reaction Systems: Method and Water Gas Shift Reaction

Thierry Musanda, Diane Hildebrandt, David Glasser, University of the Witwatersrand, SOUTH AFRICA

The successful FT reaction is very largely dependent on catalysts, reactor and operating conditions such as temperature, pressure, space velocity and conversion. It is also important to understand how the catalyst and the operating conditions interact. In this paper we develop a simple graphical technique to represent the mass balance and thermodynamic constraints that affect both the catalyst and the reactor.

This graphic model is shown to be capable of opening up insights into reactor operations and indicating preferred operational regions. The diagrams make it possible to visualize operations and understand the interactions between the catalysts and the reactor. The mass balance also provide information about the best possible region in which the FT reactor system can be designed and operated.

36-4

Comparative Evaluation of Different Coal to Liquid Process Conditions via Fischer-Tropsch Synthesis

Serhat Gul, Atilla Ersoz, Murat Baranak, Omer Faruk Gul, Fehmi Akgun, TUBİTAK Marmara Research Centre, Energy Institute, TURKEY

The aim of this study is to investigate the optimum design of process configuration and operation parameters for coal to liquid (CTL) fuel production process by using an engineering simulation software tool Aspen HYSYS. The CTL process has several sub systems such as gasification, gas cleaning, gas conditioning and FT units. For gasification process of selected coal (Soma-Turkish lignite), Gibbs reaction model has been used obtaining thermodynamic equilibrium conditions. The set parameters considered in the simulations are the fuel feeding capacity, gasifier temperature and H₂O/CO ratio of syngas. At the gas cleaning stage, there are 5 different gas cleaning units which are the removal of H₂S unit, cracking/reforming unit for tar and methane, HCl removal unit, particulate removal and finally H₂S guard unit. Gas conditioning section consists of water gas shift reactor in order to adjust the H₂/CO ratio of syngas for obtaining the stoichiometric ratio for FT process by using equilibrium reactor, and CO₂ removal unit where approximately 90% of the CO₂ content of the gas is removed. At the end of gas conditioning section, syngas has to be compressed to the level of FT reactor requirements which is minimum 20 bara. FT process consists of reactor itself, off gas condenser unit and off gas turbine for electricity generation. Conversion reactor model is used for FT reactions with 20 bara operation pressure and 260°C operation temperature. The Anderson-Schulz-Florry (ASF) approach is used for determining the product distribution of the liquid fuel. The liquid product compose of C_nH_{2n+2} molecules, where n is in the range of C1 to C30.

36-5

Technoeconomic and Environmental Life Cycle Analysis of Coal and Coal/Biomass to Liquids Facilities

Anastasia M Gandrik, Idaho National Laboratory; Vivek P. Utgikar, University of Idaho, USA

A technical and economic evaluation as well as a life cycle emissions analysis of a synthetic fuels plant utilizing coal or a coal/biomass feedstock is presented in the following paper. The feedstock is first converted into synthesis gas (syngas) in a dry-fed, entrained flow gasification process. Syngas, comprised mainly of H₂ and CO, is converted into higher hydrocarbons (diesel, naphtha, and liquefied petroleum gas) via the Fischer-Tropsch reaction in a slurry bubble column reactor. A detailed chemical process model was developed using Aspen Plus® process simulation software for the production of approximately 50,000 barrels per day of liquid products. Optimal design requirements and operating conditions were determined to maximize heat integration between different areas of the plant and the benefits of blending biomass with coal to

reduce greenhouse gas emissions were studied through the simulation of the process. The Aspen model results were input into the economic model to determine the economic viability of the synthetic fuel facilities using standard evaluation methods. The life cycle emissions analysis presents the well-to-wheel greenhouse gas emissions for the coal and coal/biomass configurations. A comparison of the emissions of the synthetic diesel with conventional petroleum derived diesel is also presented. The following conclusions can be drawn from the technical, economic, and life cycle assessments performed:

1. Coal and coal/biomass based synthetic fuel production are technically feasible processes. However, incorporation of biomass co-feed causes the size of the facility to increase due to its lower heat content and higher moisture content. In addition, the amount of power available for export from the plant decreases with incorporation of biomass.

2. Both processes are economically feasible given today's market conditions. However, incorporation of CO₂ sequestration and biomass cause the rate of return to decrease slightly from coal based production. Overall, coal and coal/biomass based synthetic fuels will provide a highly desirable rate of return for major investors if fuel prices remain above \$2.00/gallon (wholesale).

3. Integration of biomass co-feed and CO₂ sequestration are both necessary to reduce life cycle, well-to-wheel, greenhouse gas emissions for a coal to synthetic fuels facility to levels below those for imported and/or baseline petroleum diesel.

36-6

Conversion of Waste Biomass to Transportation Fuels: Energy for the Future

S.K.Srivastava, S.R.K.Rao, Amlendu Sinha, Central Institute of Mining and Fuel Research, INDIA

The growing availability of economically competitive bio-based alternatives to petroleum can be attributed mainly to advances in the production and use of transportation fuels. The rising exhaust gas emission standards and the increasing demand for cleaner and cheap energy sources prompt oil companies to develop technologies such as the Gas to Liquid (GTL) technology which showed great potential. Parallel to the GTL Technology, strong research and development activities have started on the Biomass to Liquid (BTL) production process. This process is envisioned to be more carbon dioxide neutral than using fossil fuels because the primary energy source is renewable plant matter. In India, wild variety of Babool wood is available in huge quantity, which is practically a waste biomass, not being used for any other purpose. First time in India, a 50 liter/day capacity pilot plant has been built up wherein firstly dried Babool wood is gasified in a 2100 Kg/hour feed gasifier, giving rise to real gases containing mainly Hydrogen 19.1%, Carbon Monoxide 17.2%, Nitrogen 50.4% along with other gases viz. methane, carbon dioxide and oxygen. From the gaseous mixture thus produced, moisture and oxygen have been removed. Additional hydrogen has been added to the product gas to make the carbon monoxide to hydrogen ratio of 1:2. This synthetic gas was then converted into transportation fuels in Fisher-Tropsch Synthesis process using catalyst in a fixed bed reactor at the desired temperature. Typical products obtained are: straight run gasoline 48-50%, Jet Fuel 21-25%, Diesel Fuel 22-25% and soft (Pharmaceutical Grade) Wax 1-10%.

SESSION 37

Combustion: Oxy-Coal Development – 3

37-1

The Effect of Coal Composition on Ignition and Flame Stability in Co-Axial Oxy-Fuel Turbulent Diffusion Flames

Dadmehr M. Rezaei, Eric G. Eddings, Kerry E. Kelly, Jingwei Zhang, Jost O.L. Wendt, University Of Utah, USA; Yuegui Zhou, Shanghai Jiao Tong University, CHINA

Past research on flame stability and stand-off distance under oxy-coal combustion conditions has used a 100 kW pulverized coal test rig with a co-axial turbulent diffusion burner, and has been described at previous Pittsburgh Coal Conferences. These studies were for one specific coal, namely a Utah Bituminous Coal. The purpose of the research described in this paper is to extend the previous work and to explore how coal composition changes affect the following dependencies that control flame stand-off distance and flame ignition, namely:

- 1) the effect of partial pressure of oxygen (P_{O₂}) in the primary stream with differing preheat temperatures in the secondary stream; and
- 2) the effect of P_{O₂} in the secondary stream with zero O₂ in the primary stream.

The results of this new study were designed to extend previously obtained knowledge on effects of secondary preheat temperature, turbulent mixing, P_{O₂} in various streams, from one single coal to other coals of differing compositions.

This paper, therefore, explores the effects of coal composition on ignition in oxy-coal, coaxial, turbulent diffusion flames. In this research, the stability and stand-off distance of the flame were studied for the following three types of coal: Utah Skyline Bituminous, Illinois #6 Bituminous, and a Powder River Basin (Black Thunder) coal.

To this end we investigated: 1) the effect of P_{O₂} in the primary stream, 2) the effect of P_{O₂} in the secondary stream, and 3) the effect of preheat temperature in the secondary stream, on flame stand-off distance, using the same photo-imaging methodology described elsewhere. The results of the ignition and flame stability analysis for these three coals under oxy-firing conditions are compared, and the effects of coal composition are elucidated.

37-2

Study on the In-Furnace Desulfurization in Oxy-Fuel Combustion using Drop Tube Furnace with Limestone

Hyung-Keun Lee, Wook Choi, Hang-Dae Jo, Won-Kil Choi, Korea Institute of Energy Research; Sang-In Keel, Korea Institute of Machinery & Materials, KOREA

Oxy-fuel combustion uses high-purity oxygen as combustion oxidant instead of air used in conventional air combustion to produce pure CO₂ stream as combustion products for easy separation and storage of CO₂. Oxy-fuel combustion with many advantages like high combustion efficiency, low flue gas flow rate and low NO_x emission has emerged as a promising CCS technology for coal combustion facilities.

In this study, the effects of limestone types and characteristics, reaction temperature, Ca/S molar ratio, the concentrations of CO₂, O₂, SO₂ on SO₂ removal efficiency and decomposition of CaSO₄ were investigated in a drop tube furnace under typical oxy-fuel combustion conditions represented by high concentrations of CO₂ and SO₂ formed by gas recirculation to control furnace combustion temperature. SO₂ removal efficiency increased with reaction temperature, but over around 1250 °C decreased with reaction temperature due to promoted decomposition of CaSO₄ formed by sulfation reaction. And SO₂ removal efficiency increased with SO₂ concentrations, because the increased SO₂ concentrations suppressed the decomposition of CaSO₄. The increased SO₂ removal efficiency by increased CO₂ and O₂ concentrations showed that SO₂ removal by limestone is mainly done by the direct sulfation reaction under oxy-fuel combustion conditions. Also, it was proved experimentally that the increased concentrations of CO₂ and O₂ have inhibited the decomposition of CaSO₄.

37-3

Ignition Loss and Ultrafine Particle and Soot Emissions From Air and Oxy-Coal Flames

William J. Morris, Dunxi Yu, Jost O. L. Wendt, University of Utah, USA

A 100kW maximum design down-fired laboratory combustor was used to determine effects of switching from air to oxy firing on soot, unburned carbon and ultrafine particle emissions from practical pulverized coal flames. Of interest here were potential practical effects of substitution of the N₂ in air by CO₂ in practical pulverized coal flames. Therefore, the focus is on effects of using once-through CO₂, simulating cleaned flue gas recycle with all contaminants removed. Three coals, a western bituminous, PRB sub bituminous, and a high sulfur eastern bituminous, were fired at 36.6kW in a) air, b) 27% O₂/ 73%CO₂, c) 32% O₂/68%CO₂, respectively. Tests were conducted at (nominally) 3%, 2%, 1% and 0% O₂ in the exhaust. For each condition, particulate samples were iso-kinetically withdrawn far from the radiant zone, and analyzed using a scanning mobility particle sizer (SMPS) for ultra-fine particles, a photo-acoustic analyzer (PA) for "black carbon", and a total sample loss on ignition (LOI) method for unburned carbon in ash. Data suggest that at low stoichiometric ratios ultra-fine particles consist primarily of black carbon, which is produced in lesser amounts under oxy-fired conditions than under air-fired, even when adiabatic flame temperatures are matched. For the three coals, significant differences in the ultrafine particle distributions were noted indicating that particles formed in this region are affected by coal rank, moisture content, and sulfur content. However, significant changes in mineral matter vaporization were not observed unless the flames were hotter. These and other results are interpreted in the light of available mechanisms.

37-4

High Speed Video Analysis of Oxycoal Combustion in 40kw Coaxial Turbulent Diffusion Flames

Terry A. Ring, Jingwei Zhang, Husam el Gendy, Jost O.L. Wendt, Kerry Kelly, Eric G. Eddings, University of Utah, USA

A 61 cm diameter, down-flow, axial-flame combustion system utilizing various ratios of oxygen to CO₂ for combustion of various types of coal has been studied. In companion work flame stability and the standoff distance between the burner and the point of flame ignition has been determined using low-speed video analysis of the flame. A large number of images were analyzed and probability density functions (PDFs) for flame detachment has been determined. In addition, high speed video analysis of the flame has also been performed.

These images, performed at 3,000 f/s and with a shutter speed of 1/500,000 s, show hot coal particles less than 100 microns in diameter and flamelets of hot soot generated by eddies of volatiles reacting with oxygen that range in size from several hundred microns in size to centimeters in size and have temperatures that range from 1600 K to 2300 K. The size and shape of the flamelets are analyzed giving fractal shapes for the larger structures. Finally, frequency analysis of the video images were performed giving a Fourier transform power spectra with resonance characteristics associated

with the frequency at which coal particles and flamelets pass by, and power spectrum decay that is characteristic of isotropic turbulence.

37-5

Comparison of the Mathematical Model of Pulverized Coal Burnout with Results Gained from Experimental Tests on Drop Tube

Radim Paluska, Marian Bojko, VSB – Technical University of Ostrava, CZECH REPUBLIC

In connection with construction of new supercritical power plants which burn pulverized lignite coal it was started the research of kinetic parameters of coal reserves in Czech Republic. Experimental facility and methodology of pulverized coal thermokinetic properties determination with use of mathematical modelling is described in the paper. Thermokinetic properties as a mean for better understanding the nature of combustion process can be determined by experiment using the Drop Tube Test Facility (DTTF) described further in the text. DTTF provides conditions occurring in pulverized coal fired boiler by emulated oxygen concentration, temperature and velocity of reaction gas. The DTTF presented in the paper was built recently at the Energy Research Center. Experimental data acquired from DTTF are planned to be used in mathematical modelling using the code Fluent. The paper describes in detail main differences between used Fluent models of particles combustible fraction and reaction rate. Program Fluent can define different mathematical models of volatile evolution (devolatilization model) and char combustion (surface combustion model) to simulate coal combustion. The single kinetic rate devolatilization model assumes that the rate of devolatilization is first-order and the kinetic diffusion-limited rate model assumes that the surface reaction rate is determined either by kinetics or by a diffusion rate. Temperature field and distribution of species mass fraction is evaluated for comparing with experimental tests. Results from adjusted mathematical model should provide closer information about combustion process in real operation.

SESSION 38 Gasification: Fundamentals – 4

38-1

Optimization of Canadian Petroleum Coke, Coal and Fluxing Agent Blends via Slag Viscosity Measurements and Models

Marc A. Duchesne, Arturo Macchi, University of Ottawa; Ben Anthony, CanmetENERGY, CANADA; Alexander Y. Ilyushechkin, CSIRO Energy Technology, AUSTRALIA

The slagging behavior of petroleum coke must be known to determine suitable feedstock blends for entrained-flow slagging gasification. To increase the amount of slag formed and maintain a low viscosity, petroleum coke may be blended with coal and/or a fluxing agent such as limestone or dolomite. Viscosity measurements were performed for various blends of artificial Genesee coal ash, Suncor petroleum coke ash, limestone and dolomite in a neutral gas atmosphere. Adding petcoke to the coal provided a moderate reduction in viscosity, while limestone and dolomite additions were very effective for viscosity reduction. FactSage phase equilibrium predictions and quenched sample analysis via SEM and EPMA were used to link solids formation to changes in the viscosity-temperature relation. Slag blends without limestone or dolomite showed glassy-type behaviour, while those with limestone or dolomite showed crystalline-type behaviour. Predictions from several slag viscosity models were compared to measured values. The viscosity model which provided the most accurate predictions was utilized for optimization of fluxing agent addition to various petcoke and coal blends.

38-2

Effect of Dense Medium Separation of a South African Coal Source on Slag-Liquid Formation: An Experimental and Factsage Approach

JC van Dyk, SASOL Technology; FB Waanders, North West-University, SOUTH AFRICA

The AFT of coals and coal blends is one of the parameters currently widely used in coal marketing and utilization to assess coal quality, ash fusibility and melting characteristics, as well as to predict the melting behaviour of the coal ash in coal conversion processes. The AFT of a coal source gives an indication of the extent to which ash agglomeration and ash clinkering are likely to occur within the gasifier. It has been demonstrated that ash flow temperature can be correlated with FACT equilibrium calculations.

The principle aim of this investigation is to quantify the effect of dense medium separation (DMS) and the change in mineral composition on slag-liquid formation during fixed bed gasification, by using amongst others, experimental results derived from AFT analyses and FACT equilibrium calculations.

The results indicated that dense medium separation of coal has a significant effect on slag-liquid formation and the associated mineral matter transformations during gasification. Results indicated that the amount of anorthite increased with decreasing

relative density and that the amount of slag-liquid present at 1250°C during gasification decreased with decreasing relative density. The higher concentration of CaO seems to result in a higher amount of anorthite formation at specific operating temperatures.

38-3

Compositional Variations in Pilot Gasifier and Laboratory-Produced Slags and their Impacts on Slag Viscosity and Coal Assessment

Alexander Ilyushechkin, D. Roberts, D. Harris, CSIRO, Energy Technology, AUSTRALIA

The flow behaviour of coal mineral matter at high temperatures is an important parameter for coal use in entrained-flow gasification technologies. Recently, gasification performance data was obtained from a series of pilot-scale gasification tests on a suite of well-characterised Australian black coals. Evaluation of the results of the pilot tests and the detailed laboratory investigations provided the opportunity for evaluation of the practical applicability of different laboratory and modelling techniques for coal assessment in terms of mineral matter behaviour in entrained flow gasification.

A series of viscosity measurements of gasifier-produced and laboratory-produced slags was performed over the temperature range 1200–1600°C. These data were compared with viscosity predictions based on an empirical model developed from an extensive database of slag viscosity measurements. Major differences between predicted and measured viscosities were investigated and, where appropriate, related to slag composition and microstructure.

There were some significant differences (in some cases up to 100% of the viscosity values) in the viscosity behaviour of laboratory-prepared slags and those produced during the pilot-scale gasification test runs. These differences were attributable to differences between the composition of the laboratory-produced slags and those tapped from the pilot scale gasifier.

The major source of these compositional variations appears to be a result of partitioning of mineral matter components into fly ash and slag in the gasifier, and the possible subsequent interaction of this slag with slag already present on the wall of the gasifier.

These observations have implications for the manner in which coal mineral matter is assessed for its likely behaviour, and ultimate suitability for use, in entrained flow gasification systems. In order to improve the reliability of coal slag assessment procedures, test procedures should include preliminary modelling based on expected coal ash and slag compositions, viscosity measurements of laboratory-produced slags, and analyses of ash and slag compositions where possible to ascertain the degree of compositional partitioning and its impact on slag behaviour.

Ongoing work is required to better understand the nature of mineral matter transformations under gasification conditions and the impact of this on coal and gasifier performance.

38-4

Shaping Slag Flow in an Entrained Flow Gasifier: Numerical Simulation and Physical Experiments

Randy Pummill, Gabriel Hansen, Kevin Whitty, University of Utah, USA

The aggressive environment inside a high temperature slagging gasification reactor can make getting reliable data from the reactor difficult. Any probes used to obtain data are subject to the extreme temperatures and reducing environment of the reactor and will have a very short lifetime. One way to overcome this limitation is to use a non-invasive measuring device such as a tunable diode laser. By firing a tunable laser through the reactor, data such as temperature and major species concentrations can be obtained [1]. In order to function properly, the laser would need a clear line of sight across the reactor.

As coal is converted, much of the mineral matter present in the coal remains as ash. In a gasification environment, the high temperatures cause the ash to become molten slag. The slag accumulates on the walls of the reactor and runs downward. This slag flow would interfere with the line of sight necessary for the laser measurements.

It is the goal of this paper to demonstrate a possible solution that would divert the slag flow around sight ports in the reactor so that a clear line of sight is maintained during operation of the gasifier. Using a physical diverter attached to the refractory above the sight port would be inefficient, as the aggressive environment would destroy any such device in short time and the device would need to be replaced frequently. Instead, it is thought that by employing a focused stream of purge gas the slag can be diverted around the sight port. Experiments simulating flow of high viscosity fluid around sample ports and a numerical model were developed in order to simulate and model the slag flow inside the reactor. The results of these experiments are presented here.

Influence of Gasification Conditions on the Properties of Fly Ash in a Bench-Scale Opposed Multi-Burner Gasifier

Qinghua Guo, Guangsuo Yu, Fuchen Wang, Zhenghua Dai, East China University of Science and Technology, CHINA

Entrained-flow coal gasification offers a high efficiency and low pollutant emission way in coal's utilization. Opposed Multi-Burner (OMB) entrained-flow coal gasification technology is now widely used. During the coal gasification process, fly ash and slag are the main solid by-products. In this study, experimental work has been carried out to characterize the fly ash particles which were generated in the bench-scale OMB gasifier. The composition of fly ash was determined by SEM and EDS. The particles size distribution was measured by Malvern particle size analyzer. The influencing factors of the fly ash particles properties with coal water slurry gasification, such as gasifier operation temperature and O/C ratio, were considered during the gasification experiments. The results show that the shape of the ash particles has irregular shape, and C in the fly ash is the major content element. O/C ratio and operation temperature affect the shape of particles and the particle size distribution significantly. At a fixed operation condition, the concentration of unburned carbon decreases along the gasifier. At various O/C ratios, fly ash particle size distribution had a bimodal distribution. The investigation on the characteristics of fly ash will be beneficial to the operation and optimization of the OMB entrained-flow gasifier.

SESSION 39

Gasification: General Session - 2

39-1

GTI's Sampling and Analysis Systems for Gas Streams of Gasification and Downstream Processes

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Since early 2004, GTI has been operating its state-of-the-art pilot-scale gasification facility, the Henry R. Linden Flex Fuel Testing Facility (FFTF), to investigate the renewed interest in various gasification technologies. The use of FFTF in the recent years has been a key point in GTI's focus on the development and commercialization of various programs ranging from research in evaluation of selected coal and biomass feedstock gasification characteristics, to programs where performance evaluation of downstream syngas processing units take the front stage.

Syngas analysis of different constituents is important at different process locations. During these research programs, GTI has developed and implemented innovative analytical approaches to meet the challenging task of characterizing the composition of process streams. In addition to measuring major gas species, techniques are applied to analyze select contaminant species both upstream of cleaning, at higher concentrations and downstream of cleaning at trace levels.

These systems ensure precise and accurate data that provide for the performance evaluation of the complete process. With every completed project on the FFTF, GTI has optimized these systems further and continues to develop flexible, scalable and reproducible analytical solutions for sampling and analysis for gas streams of gasification and downstream processes.

In this paper, these systems are described to illustrate the effectiveness of these innovative systems. The main objective of the discussion is to illustrate the various unique analysis equipment capability of GTI. During the development process many analysis instruments, such as gas chromatographs (GC), mass spectrometers (MS and GC/MS), Fourier transform infrared spectrometers (FTIR) and multiple wet chemistry methods, that are commonly found in much less challenging laboratory environments were adapted to be used in a pilot plant environment.

Multiple disciplines of chemistry, chemical engineering and mechanical engineering were merged together to interface with some of the most challenging sampling locations to condition and then deliver representative samples to delicate analysis equipment that were expected to operate almost autonomously. This paper shows how GTI has developed its analytical solutions capability and how such innovative systems can add significant value to any research that is on the pilot scale where gas composition analysis is critical.

39-2

Design of Comminution Unit for the Gasification Pilot Plant

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The comminution unit for the gasification pilot plant to be constructed for Turkish Coal Enterprises has been designed at the Department of Minerals Processing of Istanbul Technical University.

It has been designed that the comminution unit will be fed with coal below 100 mm and grind it under 100 μm whose moisture content should be 1% maximum prior to be

fed to the gasification unit. The capacity has been chosen to be 1800 kg/h. The run of mine coal should have 18% moisture, 25% ash and 38% volatile matter at maximum.

The primary crushing in the unit will be accomplished using a hammer crusher below - 20 mm. Followed by crushing the moisture of the product will be decreased less than 10% from about 18% of initial value. The crushed and partially dried product will be stored in a silo before feeding to a vertical mill. Coal will be ground below 100 μm in the vertical mill while dropping the moisture content under 1%.

The project for a comminution process has been designed according to the information given above.

39-3

Preparation of Coal Water Mixture with High Concentration from Low Rank Coals and Lignite by Dry Fine Coal with Optimum Particle Distribution

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A new technology for preparation of coal water slurry (CWS) with high concentration from low rank coals and lignite by dry fine coal with optimum particle distribution was developed. According to coal characteristics the micronized coal was achieved by pre-drying and dry grinding of coal using several modified mills to obtain various fineness coals. CWS powder, which can prepare high concentration CWS, was produced by mixing different ratio of various fineness coals in optimum condition.

CWS with concentration of up to 68% of eligible slurry using low rank coals has been produced by this technology in the industrial CWS powder plant with capacity of 750,000 t/a. 63% CWS using lignite as raw material has also been produced. Compared with conventional wet process for CWS preparation, the new technology provides less power consumption of about 5 kWh/t CWS and a half amount of additives. The reduction of the relative cost is about 8 CHYuan/t CWS with obvious economic and social benefits. This new technology will greatly promote the clean conversion and utilization of low rank coals and lignite.

39-4

Fluidised Bed Co-Gasification of Coal and Biomass Under Oxy-Fuel Conditions

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Fluidised bed gasifiers are the preferred option to utilise low value coal, biomass and waste. However, fluidised bed gasifiers are traditionally air rather than oxygen-blown to avoid high temperatures in the gasifier leading to ash melting and loss of fluidisation. Therefore the flue gas of a possible FB-IGCC plant would be diluted by nitrogen, making expensive N_2 - CO_2 separation technology necessary for subsequent capture and storage of the CO_2 (CCS). To overcome this disadvantage, an oxy-fuel process is proposed, where the bed is fluidised with recycled flue gas (mainly CO_2) and oxygen.

A laboratory scale fluidised bed gasifier capable to operate up to 1000°C and 20 bar was set up to study the implications of oxy-fuel firing on flue gas composition and overall operability of the gasifier.

Replacing N_2 with CO_2 in an air-blown gasifier, produced a marked increase in carbon conversion and fuel gas heating value. The addition of steam enabled the gasifier to operate at lower temperatures and to gasify higher ranked coals with lower char reactivity. The trends in carbon conversion, fuel gas composition and heating value for different feedstocks as a function of operating conditions such as temperature, pressure and inlet gas composition will be presented.

These results show that oxy-fuel firing of a fluidised bed gasifier could be a promising route to avoid N_2 dilution of the fuel gas and enable integration of fluidised bed gasification with CCS technology.

39-5

Co-Gasification of Footwear Leather Waste and High Ash Coal: A Thermodynamic Analysis

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The leather and shoe industry is one of the sectors generates more wastes at same time that has a high polluting potential. In Brazil, the majority of these wastes are disposed of in landfills and less than 5% are recycled. It corresponds to 62.5% of about 190,000 tons per year of hazardous wastes have been generated there. Since 1997 the Laboratory of Residues Processing (LPR) at the UFRGS has been developing practical projects on thermal treatment of leather wastes (biomass) based on the combined gasification-combustion technology for cogeneration.

This work evaluates the co-gasification of leather wastes together a fraction of local coal over the fuel gas (syngas). The coal is subbituminous and high ash content (nearly 50%). A thermodynamic equilibrium model is applied for analysis of the co-gasification process. A sensitivity analysis of biomass cogasification related to usual operational parameters (air, steam and blending ratios) is done. That allows to identify

efficiencies of ~64% for middle air demands (~60% of stoichiometric demand) at any leather-coal blending. Whereas an efficiency of ~75% should be reached with steam-to-carbon ratios higher than 1.5. From future studies the model can be used to evaluate the formation of N and S compounds in the flue gas.

SESSION 40
Coal Science: Coal Chemistry – 4

40-1

Mineralogical, Petrographic and Geochemical Features of the Achlada and Mavropigi Lignite Deposits, NW Macedonia, Greece

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The Achlada and Mavropigi lignite deposits in northern Greece provide the main coal source for the next generation of Greek power plants. A comparative characterization of these two lignite deposits is presented, covering the coal rank and the features of the maceral components, based on detailed coal petrography, and the mineralogical and geochemical features of the coals and their ashes, based on XRF and XRD analysis. The data are used to interpret the palaeoenvironments of the lignite beds, and identify factors that may affect their combustion behavior.

The Achlada lignite, with ash yields >30 wt % (db), contains a higher proportion of inorganic material than the Mavropigi deposit (ash values <30 wt %, db). Petrographic data indicate significant fragmentation of the organic matter in the Achlada lignite, attributed to accumulation mostly of soft herbaceous tissues combined with mechanical destruction of the tissues during transportation.

Deposition took place in a fluvial environment, mainly in a reed-marsh setting but with minor peat accumulation under forest swamp conditions. The associated mineral matter is dominated by illite, smectite and I/S with lesser proportions of kaolinite and quartz. The calcium sulphate mineral bassanite, derived from interaction of organically-associated Ca and S during oxidation of the maceral components, is also found in the low-temperature ash (LTA) of the Achlada materials.

The Mavropigi lignite was developed in a lacustrine environment, in which peat-forming periods alternated with deposition of shell-rich calcareous sediment during widespread flooding events. The nature of the organic matter suggests formation in a reed-marsh environment, interrupted by short dry periods and the formation of inertinite macerals. Greater proportions of calcium sulphates are developed in the LTA than from the Achlada lignite, consistent with a lower proportion of detrital input to the paleomire and a greater overall proportion of organically-associated Ca. Kaolinite, thought to be mainly authigenic, is also more abundant, consistent with a lower rate of detrital input in the less-contaminated lacustrine setting.

The different nature of the inorganic matter in the two deposits needs to be taken into account in optimizing their utilization for power production. A preliminary assessment indicates that the Achlada lignite may have more favorable slagging and fouling properties than the Mavropigi lignite, although experimental studies are required for more definitive conclusions to be reached.

40-2

X-Ray Computer Tomography on Coal Particles

Patrick J. Masset, Freiberg University of Mining and Technology, GERMANY; Heikki Suhonen, European Synchrotron Radiation Facility, FRANCE

Computer tomography was used to investigate the local microstructure of coal particles. For German lignite grade coal four different areas have been observed. The shape, size and distribution of pores and minerals have been evidenced and it provides quantitative data for further modelling of coal gasification of single particle. In addition, 3D-representation of particles was achieved using the images of the single slices recorded along the tomographic axis.

40-3

Mineralogy, Geochemistry, and Petrography of Upper Permian Bituminous and Carboniferous Anthracite Coals from Xuanwei County, Eastern Yunnan Province, China

Harvey E. Belkin, U.S. Geological Survey; James C. Hower, Jordan W. Drew, University of Kentucky, CAER, USA; Linwei Tian, Chinese University of Hong Kong, CHINA

Certain townships in Xuanwei County, eastern Yunnan Province, have some of the highest lung cancer mortality in China. Early workers attributed the high incidence of lung cancer to domestic combustion of locally mined coal in houses with unvented stoves. The townships using smoky coal (bituminous) accounted for more than 90% of the lung cancer cases for both men and women whereas those townships using smokeless coal (anthracite) had a lower incidence of lung cancer. The relationship of

polycyclic aromatic hydrocarbon (PAH) generation with combustion and lung cancer was first thought to be the disease etiology, but more recent work suggests that the presence of nano-size quartz particles may be a major factor.

Examination of twelve bituminous coals of the Upper Permian Xuanwei Formation (correlative with the Longtan Formation) that represent smoky coal is the main focus of our study, but also we have examined three Carboniferous anthracite (smokeless) coals of the Weining Formation. Major-, minor- and trace-element chemistry, proximate and ultimate analysis, organic petrography, and vitrinite reflectance have been used to characterize these coals. Scanning electron microscopy and electron microprobe wave-length dispersive spectroscopy have been used to define the mineral chemistry and mode of occurrence of trace elements.

The coals have ranks ranging from high volatile A bituminous (Hongchong) to semi-anthracite (Reshui, Luoshui, and Xize). Vitrinite reflectance (R_{max}) ranges from 0.93 to 1.74% in the bituminous coals and from 2.26 to 2.77% in the anthracite coals. Maceral analysis shows that the bituminous coals are predominantly collotelinite, fusinite, semifusinite, and suberinite with lesser amounts of telinite, vitrodetrinite, micrinite, macrinite and others. 'Barkinite' as defined in the Chinese coal literature, but counted as suberinite in this study, is common in the bituminous coals. Anthracite coals are mainly collotelinite, semifusinite, fusinite and vitrodetrinite. The bituminous coals on an as-received basis are lower sulfur (0.1 to 0.4 wt.%) and have ash yields of 13 to 32 wt.%; anthracite coals have higher sulfur (3 to 5 wt.%) and somewhat higher ash yields of 30 to 38 wt.%. Mineral matter in the bituminous coals, especially as authigenic cell-fillings, show a wide variety of mineral species and textures. Common cell-fillings are chlorite, kaolinite, quartz, and calcite and less commonly TiO_2 , chalcocopyrite ($CuFeS_2$), and clausthalite ($PbSe$); pyrite is uncommon. The chlorite is chamosite with $Mg/(Mg+Fe)$ that ranges from 0.08 to 0.32 and MnO less than 0.2 wt.%. Calcite is low MgO (< 1 wt%) and has total MnO and FeO contents < 6 wt.%. Kaolinite and various sulfides are stoichiometric. Anthracite mineral matter consists mainly of clay and sulfides.

Mineral-growth textures in the authigenic cell-fillings of the bituminous coals define the passage of fluids of variable composition that were mostly silica and carbonate saturated, but also, in part, Fe-rich. Both the Fe-rich siliceous fluids and the organic coal constituents were low sulfur and did not form abundant iron sulfides. Deformation and cross-cutting textures suggests that the introduction of cell-filling fluids was accompanied by moderate compression of some parts of the coal.

40-4

Improvement, Afforestation Methods of the Residual Materials of Ağaçlı (İstanbul) Open Coal Companies, and Consequences of 22 Years

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Ağaçlı is located in the waterside land lying through the Black Sea coasts, North of Çatalca Peninsula (North of İstanbul). In Miocene, plants growing in the lakes and swamps of the area were covered with clay and sand afterwards and became carbonized in lenses. Thus, in the waterside land lying between Yeniköy-Ağaçlı-Kumköy, lignite coals, white sands and china clay beds appeared. Coal beds were opened by digging up to a depth of 80-120 m. Excavation materials were filled to the valleys and former open mine pits. Sandy materials available for soil and afforestation were placed to the bottom and sulphurous (some of them salty) clay materials which are top materials of coal were placed on the top. Heavy showers in the area caused coves and gaps in these bare materials. Severe storms of Black Sea carried the thin (dust and clay) part of the materials and therefore started the period of a dune. It has been necessary that the said residual materials should be afforested, water and erosion should be stopped, raw materials should be soiled and put into production. Since the land was previously a forest owned by the government, afforesting it with fast developing tree types did not cause an intellectual problem.

At first, a material movement plan was prepared (1988) and materials which are available for afforestation were spread on the top (1989). The land was leveled and processed up to the depth of 80 cm with crawler (1989). The surface was processed with disc harrow and large lumps were crumbled, thus the surface became available for planting (1989). Slopes were terraced (1989). Lakes of different sizes were established in the coves (1989). Small fishes were thrown to the deep lakes (1990). In forestation, generally maritime pine (*Pinus maritima* = *P. pinaster*) (1-0 soiled) and locust tree (*Robinia pseudoacacia*) (2-0 bare rooted) were used. In steep sloping land, Stone pine (*Pinus pinea*) (2-0 or 3-0 soiled) saplings were planted with 3x3 m distance. In the roadsides, 3-5 lines branchy Mediterranean Cypress (*Cupressus sempervirens* var. *horizontalis*) (2-0 soiled) were planted (1989-1990). Maintenance hoeing of the saplings (gathering grasses and earthing up) continued for 3 years. Afforested area was closed 50% in the third year, and 80% in the 5th year, dead cover composed of deciduous needles covered the surface and earth transport was stopped.

In the 12th year of the afforestation (2002) length of the maritime pines; reached 9.0-9.5 m length and 16-18 cm barked diameter in sandy loam material, 8.0-8.5 m length and 16-18 cm barked diameter in sandy loam/heavy loam bedded materials. A line of the afforestation was cut, and the distance between the trees became 3x6 m. Gained wood material (stem and thick branches) was sold to fiber and chipping industry.

Animals and birds living in the undestroyed natural oak forests came to the water in the lakes, and they left the seeds they ate to the afforestation area through defecation. By germination of these seeds, afforested area gradually started to become a forest ecosystem.

SESSION 41
Coal Science: Beneficiation - 3

41-1

Pyrolysis Residue from Waste Materials in Black Coal Flotation

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The paper deals with verification of floatability of classical collector Montanol 551 and pyrolysis oils, which were obtained through pyrolysis of waste, namely mixed plastics, tyres and waste rubber in combination with black coal from Lazy Mine, in black coal flotation. Black coal from ČSA OKD, a.s. coal preparation plant was used for flotation tests. The results imply that it is possible to produce collectors from waste materials which may be applied in the flotation of black coal.

41-2

Studies of a Multi Gravity Separator (MGS) to Produce Clean Coal from Turkish Lignite and Hard Coal Fine Tailings

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TURKEY

The multi-gravity separator (MGS) is a novel piece of equipment for the separation of fine and ultra-fine minerals. This study was conducted to evaluate the effects of different process variables on the performance of the Multi Gravity Separator (MGS) for beneficiation of Turkish lignite and hard coal fine tailings to recover ultra-fine coal. The main minerals of Tunçbilek lignite tailings are kaolinite, illite and mica. The dominant minerals of Zonguldak hard coal tailings are chlorite, quartz, mica, calcite, pyrite, and amorphous materials. Various operating and design conditions of MGS such as drum speed, tilt angle, shaking amplitude, wash water rate, feed rate and pulp solid ratio were investigated. A hydrocyclone was used for pre-enrichment with the MGS. Operation parameters of the hydrocyclone, namely feed solids, inlet pressure, vortex finder and apex diameters were investigated. The results showed that clean coal was obtainable with 22.83% ash, 5.696 kCal/kg calorific value and recovery of 49.32% from lignite has 66.21% ash and 1.835 kCal/kg calorific value, with 6.98% ash, 7.214 kCal/kg calorific value and recovery of 85.61% from a hard coal has 28.41% ash and 5863 kCal/kg calorific value by this two-stage concentration process.

41-3

Petrographic Characterisation of Beneficiated Material of Tailings from Soma Isıklar Dereköy Coal Washing Plant (TURKEY), by Multi Gravity Separator (MGS)

Selami Toprak, Ayşe Erdem, Akan Gulmez, Oguz Altun, Mineral Research
and Exploration Directorate in Turkey; Sarper Alyildiz, Turkish Coal
Enterprises, TURKEY

In this study, coal tailing samples taken from Soma Isıklar Washing Plant belonging to Aegean Lignite Enterprise of Turkish Lignite Authority were analyzed petrographically and the results were used in the ore beneficiation studies. Representative sample was taken from determined tailing pond and with aid of a mechanical mixer working by electricity; a homogeneous mixture of the material was obtained and reduced to a working amount in a laboratory. Samples were obtained for analysis (mineralogic-petrographic, chemical and sieve analysis) and wet screening. The tailing is composed of coal and associating gangue minerals. In order to determine the types, percentages and liberation degree and their average sizes, mineralogic and petrographic analyses were conducted to the samples. It was determined that the tailing is composed of 55% of mineral matter which contains of clay, calcite and pyrite minerals. And the coal part seems to contain about 45% of the material and is composed mostly of Huminite macerals.

According to evaluation of the mineralogic and petrographic, chemical and sieve analyses, the samples with $-0.5+0.3$ mm and $-0.3+0.02$ mm sizes were determined as suitable for beneficiation studies by MGS and -0.02 mm size were determined as to be worked by flotation methods. The sizes of different pyrites were determined and their sizes seemed to be too tiny for beneficiation. MGS was used to upgrade and increase the calorific values of the coal wastes. After the cleaning process, the ash content of the concentrate lowered up to 16.45%, total sulfur to 1.26% and calorific value to 5335 kcal/kg.

41-4

Soma Region's Coals Washing at Dereköy Washery with Working 800 TPH and it's Washing Performance Evaluation

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Coal is one of the major energy sources in most nations like Türkiye. The washing of coal is an important industry in Turkish coal mining. For this reason, run of mine

(R.O.M.) coal must be washing. The TKI (Directorate of the Turkish Coal Enterprises) administration came to the decision to set up a coal washing plant to produce high quality coal according to the demands of the industry and the thermal power plant. In 2006 a coal washing plant was set up by a private company (Çiftay Şti.) by means of build-operate model for washing 20 Million tonnes R.O.M. coal. This plant consists of heavy medium drum, heavy medium cyclone and spiral concentrators with a washing capacity of 4 million tonnes. With two parallel circuits each working with 400 tph capacity, 800 tonnes of raw coal can be washed. 17.6 million tonnes of run of mine coal have been washed by this company until August 2010 in Soma Region. The product and calorific values of tailings are given. Minimal coal losses to reject were achieved.

SESSION 42

Coal-Derived Products: H₂ Production/SNG

42-1

Development of Hydrogen Transport Membranes for Separating Hydrogen from Coal Gasification Stream

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Hydrogen, the fuel of choice for both electric power and transportation sectors, can be produced from fossil and renewable resources by various technologies. Because it is produced in gas streams with numerous components, purification is a critical step in its production. Argonne National Laboratory is developing dense cermet (i.e., ceramic-metal composite) hydrogen transport membranes (HTMs) for separating hydrogen from coal gasification streams. Hydrogen separation with Argonne's HTMs yields high purity hydrogen, thereby eliminating the need for post-separation purification steps. HTMs were prepared by standard ceramic fabrication techniques, and their hydrogen permeation rate, or flux, was measured in the range of 400-900°C. A cermet membrane (thickness ≈ 18 μ m) on a porous support structure gave a maximum hydrogen flux of ≈ 52 cm³ (STP)/min-cm² at 900°C in tests using 100% H₂ at ambient pressure as the feed gas. We also measured the hydrogen flux through a thicker membrane (≈ 150 μ m) at 400°C using H₂, CO, CO₂, H₂O, and He as feed gas at ≈ 200 psig. Because good chemical stability is critical for HTMs, due to the corrosive nature of product streams from coal gasification, we evaluated the effect of various contaminants on the chemical stability of cermet membranes. Hydrogen sulfide (H₂S), a particularly corrosive contaminant, impedes hydrogen permeation through cermet membranes by reacting with them to form palladium sulfide (Pd₄S). To evaluate the chemical stability of membranes, the Pd/Pd₄S phase boundary was determined in the temperature range ≈ 400 -700°C in tests using various feed gases that contained 10-73% H₂ and ≈ 8 -400 ppm H₂S. The Pd-containing cermets are stable between about 430°C and 680°C in gas stream containing 73% H₂ with between about 60 and 400 ppm H₂S. When the gas contains only 10% H₂, the membrane is stable for H₂S concentrations between about 8 and 50 ppm. We assessed the effect of syngas components on the Pd/Pd₄S phase boundary by locating the phase boundary in feed gas that contained CH₄, CO₂, and CO in addition to 400 ppm H₂S. The present status of membrane development at Argonne and the challenges involved in bringing this technology to fruition will be presented in this talk.

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42-2

HTGR-Integrated Coal to Liquids Production Analysis

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As part of the Department of Energy's (DOE) Idaho National Laboratory (INL) nuclear energy development mission, the INL is leading a program to develop and design a high temperature gas-cooled reactor (HTGR), which has been selected as the base design for the Next Generation Nuclear Plant (NGNP). Because an HTGR operates at a higher temperature, it can provide higher temperature process heat, more closely matched to chemical process temperatures, than a conventional light water reactor. Integrating HTGRs into conventional industrial processes would increase U.S. energy security and potentially reduce greenhouse gas emissions (GHG), particularly CO₂. This paper focuses on the integration of HTGRs into a coal to liquids (CTL) process, for the production of synthetic diesel fuel, naphtha, and liquefied petroleum gas (LPG). The plant models for the CTL processes were developed using Aspen Plus. The models were constructed with plant production capacity set at 50,000 barrels per day of liquid products. Analysis of the conventional CTL case indicated a potential need for hydrogen supplementation from high temperature steam electrolysis (HTSE), with heat and power supplied by the HTGR. By supplementing the process with an external hydrogen source, the need to "shift" the syngas using conventional water-gas shift reactors was eliminated. HTGR electrical power generation efficiency was set at 40%, a reactor size of 600 MWth was specified, and it was assumed that heat in the form of hot helium could be delivered at a maximum temperature of 700°C to the

processes. Results from the Aspen Plus model were used to perform a preliminary economic analysis and a life cycle emissions assessment. The following conclusions were drawn when evaluating the HTGR-integrated CTL process against the conventional process:

When compared to conventional CTL production, HTGR integration decreases coal consumption by 65% using electrolysis and nuclear power as the hydrogen source. In addition, HTGR integration decreases CO₂ emissions by up to 95% when compared to conventional CTL.

In order to support a 50,000 barrel per day CTL facility, 11 HTGRs (600 MWth each) are required.

The preliminary economic assessment indicates that the incorporation of HTGRs and the associated HTSEs impacts the expected return on investment, when compared to conventional CTL with or without sequestration. However, in a carbon constrained scenario, where CO₂ emissions are taxed and sequestration is not an option, a reasonable CO₂ tax would equate the economics of the HTGR-integrated CTL case with the conventional CTL case. The economic results are preliminary, as they do not include economies of scale for multiple HTGRs and are based on an uncertain reactor cost estimate. Refinement of the HTGR cost estimate is currently underway.

To reduce well to wheel (WTW) GHG emissions below baseline (U.S. crude mix) or imported crude derived diesel, integration of an HTGR is necessary. WTW GHG emissions decrease 8% below baseline crude with HTGR-integrated CTL. Even with CO₂ sequestration, conventional CTL WTW GHG emissions are 24% higher than baseline crude emissions.

Current efforts are underway to investigate the incorporation of nuclear integrated steam methane reforming for the production of hydrogen, in place of HTSE. This could potentially reduce the number of HTGRs required for the process.

42-3

Methane Production from Coal, Coal-Biomass Mixtures

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Viresco Energy has developed an innovative conversion technology that can produce methane (Synthetic Natural Gas) from carbonaceous feedstocks such as coal, biomass, municipal and green waste and biosolids. This technology uses the Steam Hydrogasification Reaction (SHR) based gasification process invented at the College of Engineering – Center for Environmental Research & Technology (CE-CERT) at the University of California Riverside (UCR). SHR gasification uses steam and hydrogen to convert feedstocks into high energy content product gases under relatively modest temperatures and pressures. This gasification process has several advantages over conventional partial oxidation or air blown gasifiers. The process configuration for methane production involves the utilization of the innovative SHR gasifier with a shift reactor. The slurry made of the carbonaceous feed and water, along with the recycled hydrogen is fed to the SHR gasifier. The SHR generates a high methane content product gas that is subjected to warm gas cleanup in order to remove contaminants such as sulfur. The clean product gas is then fed into a water gas shift reactor. In the shift reactor, the CO present in the clean product gas reacts with the steam to produce H₂. Methane This product gas is then cooled down and H₂ is separated for recycle to the SHR as feed. The recycle hydrogen stream eliminates the hydrogen supply problem. The final product gas contains high quantity of methane.

Gasification experiments have been conducted using lignite coal and lignite-biomass mixtures. The experimental work was conducted in a pressurized kiln type continuous flow steam hydrogasifier. The product gas was passed through a Non-Dispersive Infrared Sensor (NDIR) and a Gas Chromatograph (GC). After each test, the unreacted char and ash were collected and weighed. The experiments were conducted over a temperature range of 650 to 850 C. All the experiments were conducted at 150 psi operating pressure and at a 2:1 ratio of H₂O to feed mass ratio. The experimental data including the carbon conversion and the gas composition information will be presented. Aspen Plus based simulations have been performed in order to evaluate the impact of parameters on the process efficiency. The simulation results will also be presented.

42-4

Methanation of Syngas over Coral Reef-Ni/Alumina Catalysts

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Coral reef-Ni/alumina catalysts prepared by coprecipitation method was used for methanation of syngas. The Ni/Al₂O₃ catalysts were tested in a continuous flow type fixed-bed reactor. The experimental results show that the Ni/Al₂O₃ catalyst calcined at 673 K exhibited better activity than those calcined at 573 K and 773 K. Under the reaction conditions of H₂/CO(molar ratio)=3:1, 593 K, atmospheric pressure and 2500 h⁻¹, CO conversion and CH₄ selectivity reached to 98.8% and 86.9%, respectively. The structure and properties of fresh and used catalysts were analyzed by SEM, XRD and H₂-TPR and BET techniques.

SESSION 43

Combustion: Fluidized-Bed Combustion and Co-Firing - 2

43-1

Sulphur Capture Under Fluidised Bed Combustion Conditions Using Coal Ashes as Sorbents

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An investigation to determine whether coal ash can be used for reduction of sulphur emission from coal combustion was carried out. The experimental work involved the determination of sulphur retention and capturing capacities of three ashes derived from typical South African low grade coals. The coals under investigation had ash content which varied between 37 and 46 wt %, reactive calcium oxide between 1.48 and 4.13 wt % and total sulphur (organic and inorganic) within the range 0.70 to 1.90 wt. %. The sulphur capture experiments were carried out under isothermal (750°C and 900°C) and atmospheric pressure conditions. The simulation to assess the desulphurization potential of the ashes was carried out with a typical flue gas mixture composed of 3000 ppm SO₂, 8% CO₂, 8% O₂ concentration and balance N₂. Reactivity measurements were carried out with a Thermogravimetric analyser.

A detailed examination of phase transformation of the calcium containing minerals during combustion and desulphurization was executed in order to identify and quantify reactive phases for the evaluation of sulphur retention and desulphurization properties of the coal ashes. Mineral analyses of coal and ash samples were done by QEMSCAN. The transformation of a large fraction of the calcium bearing minerals to sulphates is evident with total sulphur retention of between 55.3% and 66.9 % of the total sulphur present in the parent coal. The transformation of all the other minerals is also evident with the formation of calcium containing non-crystalline phases with no sulphur capturing properties.

The results showed that approximately 40% of the reactive calcium was converted within the first 90 minutes of reaction at 900 C. The shrinking core model with diffusion through the product layer as the controlling mechanism was found to describe the reaction.

43-2

CO₂ Reduction Potential and Co-Combustion Possibilities of the FBC-Boilers on the Czech Conditions

Dagmar Juchelkova, Helena Raclavska, Jiri Bilik, Pavlina Pustějovská, VSB-Technical University of Ostrava, CZECH REPUBLIC

At present the task of minimizing carbon dioxide emissions in relation to its influence on environment belongs to the priorities of EU research activities. For achieving the best possible results it is necessary to focus attention on information concerning input materials character study of production as well as manufacturing processes and subsequent returning the products back to environment (anthroposphere). The problem is very extensive and covers many fields. Problem of CO₂ reduction is one from the EU priority in longtime context (2010 and further).

The aim of research in our University is large scale experiments in the fluidized-bed boilers. The experiments are carried out for Czech brown coal, wood, sewage sludge and wastes including analyses and recommendations for optimal thermal utilization and minimizing CO₂ and harmful emissions. The next step is thermal analyses of coal, alternative fuel- wood pellets and sewage sludge from treatment plant. From the results of experiments it is clear that alternative fuels can be used in the large fluidized-bed boilers in the Czech Republic.

43-3

Co-Combustion of Various Biowastes with a High-Sulfur Turkish Lignite in a Circulating Fluidized Bed Combustor

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In this study, combustion and co-combustion of two biomasses and a Turkish lignite coal was carried out in a circulating fluidized bed combustor. A lignite coal which has high sulfur content and two biomasses were used in the experiments. The biomasses were hazelnut shells and woodchips. The combustion system consists of a circulating fluidized bed combustor column, a fuel feeding system, electrical heaters, and two cyclones. Its thermal capacity is 30 kW. The combustor column has an inside diameter of 108 mm and a height of 6 m. The temperatures along the column are observed with thermocouples located at specific heights. The temperature of the column is kept at about 850 °C during the combustion experiments. The pressure drops along the combustor column, cyclone, downcomer, and loopseal are continuously measured and observed in order to determine the solid mass flux within the combustor. A series of combustion tests for each fuel and mixture was performed in order to investigate the effect of excess air ratio on the flue gas emissions. During the combustion

experiments, CO₂, CO, O₂, NO, and SO₂, emissions in the flue gas was continuously measured by ABB-AO2000 Advanced Optima continuous gas analyzer and recorded. The results of the experiments showed that as the biomass ratio in the fuel mixture increases for co-combustion, the combustion takes place more in the freeboard of the main column. Therefore, the maximum temperatures are seen in the freeboard rather than in the bed. Also the CO emissions increase as the biomass percentage increases in the fuel. Biomass fuels have high CO emission which indicates that a secondary air addition is required for the system. Secondary air injection into the freeboard may be a good solution to decrease the CO and also hydrocarbon emissions and to increase the combustion efficiency.

43-4

Co-Combustion Performance of Oil Shale and Biomass Fuels

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In this study, the thermal analysis of co-combustion of biomass fuels and oil shale were investigated. The objective was to assess the effect of the biomass on combustion performance when blended with oil shale. Thermogravimetric analysis and differential scanning calorimetry were used to analyze the samples. The biomass samples studied were hazelnut shell, wheat bran, poplar, and miscanthus. Co-combustion of blends were performed at different biomass proportions (10, 20, 50 % by wt.).

43-5

Study on NO_x Reduction and its Heterogeneous Mechanism during Biomass Reburning

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Effects of biomass types (such as rice straw, wheat straw, cotton stalk, rice husk and wheat straw char), reburning fuel fraction (R_{ff}); reaction temperature in the reburning zone (T_2); stoichiometric ratio in the reburning zone (SR2) and particle sizes of reburning fuel (d_p) on NO reduction efficiency during biomass reburning were investigated in an entrained flow reactor. The contribution of NO heterogeneous reduction by wheat straw char to the total NO reduction was analyzed. Results indicate that cotton stalk behaves the best performance of NO reduction for tested four kinds of biomass; followed by wheat straw; and rice husk and rice straw are less effective. NO reduction efficiency increases with increasing of reaction temperature in the reburning zone at the same SR2 and in the range of $T_2 = 900 \sim 1100^\circ\text{C}$ NO reduction efficiency increase insignificantly with decreasing of biomass particle sizes while $d_p < 425 \mu\text{m}$. NO reduction efficiency of biomass reburning behaves a trend of first increase and then decrease with decreasing of SR2 or increasing of R_{ff} . The higher NO reduction efficiency (more than 50%) can be achieved at the range of SR2=0.7~0.8 or $R_{ff} = 20\% \sim 25\%$ during reburning by four kinds of biomass. The contribution of heterogeneous reduction by wheat straw char to the total NO reduction is in the higher range of 59%~68% while R_{ff} is in the range of 10%~26%.

SESSION 44 Gasification: Fundamentals – 5

44-1

Influence of Steam on the Release of Alkali Metal, Chlorine, and Sulphur Species During High Temperature Gasification of Lignite

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Coal will remain one of the top energy resources for the foreseeable future due to its low cost, its diversity location, the low mining and transportation costs, and of course the widespread of the amount of existing power generating systems. However, the use of coal has been connected to several problems regarding both the environment and the plant systems. New, cleaner and more efficient coal utilisation technologies are required to meet the environmental needs and to satisfy the steadily rising demand in electric power production as well. Higher efficiency can be reached by higher turbine inlet temperatures. To prevent the turbines from several problems which occur at the desired temperatures (e.g. hot corrosion) hot gas cleanup systems have to be developed. Over years, progress in coal science has been made partly by pragmatic stepwise improvements in engineering practice, but in more recent years by an enhanced scientific understanding of the underlying reactions and the relation of the reactions to the process conditions. Basic investigations on the release of alkali metal, chlorine, and sulphur species form a crucial element in designing control measures and to develop hot gas cleaning strategies for coal gasification systems. Together with other experimental approaches a large body of useful data has already been delivered in this area, but the underlying reaction mechanisms are not yet sufficiently understood. Therefore, release experiments have been done in lab-scale with six hard coals and four lignite at 1400°C, 1 atm and a gas stream of He/7.5%O₂ and

He/7.5%O₂/additional steam, respectively. The Molecular-Beam-Mass-Spectrometry-technique (MBMS) used for hot gas analysis is well established and is able to detect and differentiate key chemical species released during the different phases of gasification. The release of inorganic species occurred for the most part during pyrolysis phase. Main species detected by the MBMS were 34H₂S⁺, 36HCl⁺, 39K⁺/39NaO⁺, 56KOH⁺, 58NaCl⁺, 60COS⁺, 64SO₂⁺, and 74KCl⁺. The release behaviour is primary related to the coal composition and secondary to the content of steam. Especially, the amounts of 39K⁺/39NaO⁺ and 56KOH⁺ have been strongly influenced by the presence of steam.

44-2

Kinetics of Char and Catalyzed Char Gasification under High H₂ and Steam Partial Pressure

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JAPAN

Effects of high H₂ and H₂O (steam) partial pressure (H₂ up to 1.2 MPa, H₂O up to 2 MPa) on coal char and Ca loaded coal char gasification rate were investigated by using thermogravimetric apparatus with low temperature range (923 K to 1123 K). It is found that gasification rate was quickly decrease with PH₂/PH₂O increase, but gasification rate of Ca loaded coal char was much higher than that of coal char gasification, and the reduction of gasification rate by the increase of H₂ partial pressure for Ca loaded coal char gasification was smaller than that for char gasification. Effect of H₂O and H₂ partial pressure on char and Ca loaded coal char gasification rate were analyzed by applying L-H mechanism.

Temperature effects on gasification rate under high H₂ and H₂O pressure shown much difference for char and Ca loaded char. Gasification rate of Ca loaded coal char was about 4 times higher than that of char gasification rate at 1123 K, but it was 26 times higher at comparatively low temperature 923 K. The activation energy for char gasification, E was 234 [kJ/mol], and for Ca loaded coal char, E was smaller as 138 [kJ/mol].

44-3

Modeling of Steam Gasifier in Dual Fluidized Bed Gasification

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Corporation, JAPAN

Dual Fluidized Bed Gasification (DFBG) is one of the promising technology to produce high calorific and hydrogen rich syngas without using pure oxygen. It is a combination of steam blown gasifier and air blown combustor, and several configuration of dual fluidized bed (selection of bubbling fluidized bed or high speed riser) has been proposed in the world. Up to know, this technology has been used in gasification of biomass or waste to use syngas as a fuel of power generation or feed stock of synthetic fuel.

Although it is preferable to apply this technology to low rank coal gasification, designing of the gasifier is one of the difficult issue because of the difference of gasification behavior between biomass and coal.

Basically, coal has less volatile and more char than biomass, which means that larger residence time in the gasifier is necessary to achieve enough carbon conversion. Therefore, the modeling of fluidized bed steam gasifier is performed to predict the performance of the gasifier for low rank coal. The model is made by the combination of residence time distribution (RTD) of coal in bubbling fluidized bed with the fundamental rate equation of steam gasification. RTD of coal is calculated from the empirical model of particle movement in the fluidized bed including mixing and segregation effect. Rate equation of steam gasification is derived from the experiment using small scale fluidized bed steam gasifier. The gasification experiment using pilot scale DFBG is also performed, and the result of carbon conversion is compared with the prediction by the modeling work. From the result, although there is a certain difference between the experimental and predicted value, both value showed the same tendency for the effect of temperature, steam flow rate, size of the gasifier, which shows that the model basically can be used to predict the performance of the steam gasifier in DFBG for low rank coal.

45-4

Steam Gasification of Low Rank Coals with Ion-Exchanged Sodium Catalysts Prepared Using Natural Soda Ash

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Ion exchange reactions of brown and sub-bituminous coals with natural soda ash, which is composed of > 99 % Na₂CO₃, have been studied at 20 – 40 °C without any pH-adjusting reagents, and the pyrolysis and subsequent steam gasification of the resulting Na-exchanged coals has been carried out with a fixed bed quartz reactor mainly at 700 °C.

When the Na⁺ concentration and pH of an aqueous mixture of each coal and the soda ash are monitored in the ion exchange process, these factors decrease both at a larger rate with the brown coal that contains a higher content of COOH groups, showing that the ion exchange of Na⁺ with the H⁺ of the COOH takes place predominantly. About

65 % of the COOH can be exchanged with Na⁺ ions under the optimized conditions, irrespective of the coal type.

The reactivity of these raw coals in steam at 700 °C is almost the same to be low, and char conversions are less than 20 mass % even after 2 h reaction. The exchanged Na promotes remarkably the gasification of both coals at this temperature, but the rate profile is different:

The conversion for the brown coal increases linearly with increasing time and reaches almost 100 % at 1 h, whereas it needs approximately 2 h for the sub-bituminous coal to be gasified completely. The temperature dependency of the conversion with this coal reveals that the use of the Na catalyst can lower reaction temperature by about 120 °C, and the Arrhenius plots of the initial specific rate show that apparent activation energies are estimated to be 190 and 120 kJ/mol without and with the catalyst, respectively.

The SEM-EPMA and XRD measurements of Na-bearing chars recovered after the pyrolysis and gasification suggest that the Na catalysts are finely dispersed at the initial stage of the reaction but that they may be deactivated by the formation of sodium silicates at high char conversions of more than 90 % even at a low temperature of 700 °C.

45-5

Separation of Pyrolysis from Fluidized Bed Steam Gasification: Its Conception and Application

Masahiro Narukawa, Makoto Takafuji, Toshiyuki Suda, IHI Corporation, JAPAN

The pyrolysis separation dual fluidized bed gasification (P-DFBG) place a bubbling fluidized bed pyrolyzer above a bubbling fluidized bed gasifier involved in the normal dual fluidized bed gasification (N-DFBG) systems. The heat carrier particles circulated from the char combustor enter first the pyrolyzer to facilitate the pyrolysis reactions of fuel occurring therein, and the particles are in turn forwarded into the gasifier to provide endothermic heat for the steam gasification reactions of chars. By feeding fuels into the upper pyrolyzer, the pyrolyzer can separate pyrolysis gases from fuel chars so that the lower gasifier gasifies the resultant chars produced in the pyrolyzer. Therefore, the steam gasification reactions in the gasifier proceed without pyrolysis gases, which inhibit the steam gasification reactions of chars. Consequently, by using P-DFBG it is hopeful to increase gasification efficiency. This anticipation was verified through gasifying subbituminous coal in two 2.0 kg/h experimental setups configured according to the principles of P-DFBG and N-DFBG, respectively. Increases in carbon conversion and cold gas efficiency of P-DFBG compared with N-DFBG were about 3%, respectively.

SESSION 45 Gasification: Modeling – 1

45-1

Process Simulation - The Way from Pilot Plant to a Training-Centre for a 500 MW Gasifier System

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The plant automation together with the design of the emergency shutdown system is one of the most important topics in the project execution of gasification plants. The Siemens Fuel Gasification Technology (SFGT) 500MW class gasifier is an improved design based on about 20 years operation experience with a 200MW gasification plant and the 5MW pilot plant at SFGT headquarter in Freiberg, Germany.

The automation of the first SFGT 500MW gasification plant was developed with the Siemens Power Plant Automation System (SPPA) T3000 together with a dynamic simulation of the gasification island in “Dymola” and “SIMIT”.

The knowledge and experiences from the pilot plant could be used perfectly as basis for the processes simulation and later on for the validation of simulation results. These validated simulation results have enabled SFGT to predict the behavior of the large scale gasification system properly and with only few uncertainties.

The paper presents two different concepts of process simulation its goals and application. It shows how simulation can support the engineering and design as well as the automation of customer projects e.g. our 500MW gasification plant in the PR China. Dynamic testing of the control and emergency shutdown logics saves time and cost during plant commissioning. Customer training with a validated dynamic simulation and the same automation system used in real plants guarantee the best learning conditions.

In the Research & Development program of SFGT dynamic process simulation helps very efficiently to make judgments on advanced design philosophies or cost saving measures. A real time data transfer from site to SFGT headquarter will support commissioning and operation as well as the validation of the dynamic model with a commercial size gasification plant. All this ideas were driven by the aim of cost reduction and an improved operation philosophy together with the highest demands of plant safety.

45-2

A Dynamic Simulator of a Commercial-Scale IGCC Plant

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In this study, the simulator for a commercial-scale plant of IGCC (Integrated Gasification Combined Cycle) is developed for dynamic tests and an education of plant operation. The simulator consists of a dynamic process model and a HMI (Human-Machine Interface). The dynamic process model of plant includes ASU, Gasifier, Gas treatment units, Combined Cycle using dynamic process simulation tool. Specially, a model of gasifier is analyzed in detail, flow which has gasification reaction in the gasifier is divided by 6 zones, and heat transfer and mass balance of each zone are calculated. The dynamic process model acts as a field and DCS (Distributed Control System) of plant. DCS in the simulator has master-control of plant like turbine lead mode, gasifier lead mode, coordination mode. The master-control means a plant selects to follow and control output of gas turbine or gasifier first as changing total power command and a plant will be operated under three kinds of master-control as following plant condition. The HMI of simulator works connection between controller of the dynamic model and operator, operator can control a whole plant. Operator can do start-up and shut-down of plant easily using HMI. In addition, Operator can monitor conditions of plant through graphs of real-time based data and history data of important process variables in the HMI. Developed simulator is possible to perform engineering studies of IGCC plant like dynamic test for process variables and changing feed stock and analysis for control logic and so on.

45-3

Accelerating Clean and Efficient Coal Gasifier Designs with High Performance Computing

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Coal-based power plants are made up of complex devices for handling and processing coal, such as feed systems, gasifiers and combustors of various designs, gas cleanup systems, heat exchangers, etc. These devices are extremely difficult to probe experimentally and are difficult to design using standard engineering tools used for more traditional process industries. In the last two decades, computational modeling and simulation has evolved to become the third pillar of science under the discipline of computational sciences in addition to theory and experimentation. Computational science tools, such as computational fluid dynamics (CFD) models, are being routinely used to tackle challenging problems, such as, coal combustion and offer a viable alternative to experimentation.

Green Energy initiatives such as Clean Coal Initiative have aggressive targets to pave the way to environmental sustainability due to the dire need of secure, affordable and clean energy by the major consumers of the world's energy resources today. For example, one of the targets for coal gasification in the near future is capturing 90% of the carbon with less than a 10% increase in cost of electricity.

These aggressive goals can be only achieved with innovative designs that reach the market place quickly with a shorter design cycle, minimal risk for the investor and in an economically viable way. The role of computational modeling tools in achieving these goals heavily depends on the use of high performance computing (HPC) effectively to aid the design of complex innovative industrial scale gasifiers with a short time-to-solution.

There are number of factors that make simulating commercial scale gasifiers challenging. The computational algorithm involves iterative solution of more than twenty non-linearly coupled conservation equations at each time step in three dimensions, which makes multiphase simulations extremely CPU intensive. The transient nature of gas-solid flows and the small time-steps required to resolve the physics, which is bounded by time-scales like particle relaxation time and collision time, are two reasons necessitating long computation times. Another contributing factor is the non-linearity of the problem, which requires several non-linear iterations per time step. The non-linearity stems from complex constitutive closures for solids-phase stresses as well as interactions between the gas and solids phases, the chemical species reactions, and the heat transfer. Another important aspect that makes the problem computationally intensive is the numerical grid resolution requirement. Numerical predictions cannot mirror the physical model unless grid independence studies are conducted and grid-converged solutions are obtained.

Researchers at the National Energy Technology Laboratory (NETL) are collaborating with industry, academia, and other national labs on multiphase computational models like the legacy code MFIX (Multiphase Flow with Interphase eXchange) which can help design, operate, and scale-up clean coal gasifiers to meet the new challenges of a carbon sensitive world. MFIX is an open source code with over two decades of development towards state-of-the-art models for simulating coal gasification (i.e., detailed Carbonaceous Chemistry for Continuum Modeling (C3M) capability), which was recognized for its uniqueness with several awards including a 2008 Federal Laboratory Consortium (FLC) award for C3M and 2007 R&D 100 award for MFIX.

MFIX is based on a continuum multiphase flow model that considers gas and solids to form interpenetrating continua. MFIX has been validated with the experimental data from a smaller scale prototype reactor. Validated CFD models play crucial role in

scalability studies for commercial size reactors due to the limited availability of experimental data at that scale. Recently the U.S. Department of Energy granted a multiyear Innovative and Novel Computational Impact on Theory and Experiment (INCITE) award to NETL researchers to perform high-fidelity simulations of a transport gasifier for a commercial scale plant design with MFIX on the leadership class supercomputers such as Cray XT5 at National Center for Computational Sciences (NCCS). This award has enabled researchers to perform perhaps first-of-its-kind simulations of gas-solids reacting flows with a grid resolution in the order of ten million cells, providing detailed information about the gas-solids flow structure and the pressure, temperature and species distribution in the gasifier. Preliminary results of the high-resolution simulations have prompted the study presented in this paper. To better understand the effect of coal jets in the gasifier a separate set of reduced configuration simulations focusing on the coal jet region were performed by imposing flow conditions from the full-scale gasifier. Several grid resolutions (0.3M, 0.7M and 2.4M cells) and numerical discretization schemes were employed. In spite of the additional transient details captured with the high resolution and high order numerical scheme, the computational cost was reported to be nearly tripled when compared to a lower fidelity simulation, which brings up an important consideration, i.e., the trade-off between fidelity and cost.

Prior work on the detailed numerical analysis of the reduced configuration simulations of coal jets had focused on the flow hydrodynamics primarily. In order to better understand the influence of simulation fidelity on the prediction of gasifier reactions, a standalone study was conducted to investigate the effect of grid resolution and numerical discretization scheme on the computed chemical reaction rates. The instantaneous and time averaged reaction rates based on the C3M model is compared for different grid resolutions and numerical schemes is presented in this paper. The objective is to develop effective simulation strategies to solve industrial scale gasifier problems by employing techniques such as hybrid strategy that uses both low and high fidelity simulations to strike a balance between accuracy and the cost of time-to-solution.

45-4

Entrained Flow Slagging Slurry Gasification and the Development of Computational Fluid Dynamics Models at CanmetENERGY

Robin Hughes, Dennis Lu, Adrian Majeski, Ben Anthony, CanmetENERGY;
Andrew Corber, National Research Council, CANADA

The development of computational fluid dynamics (CFD) models representing entrained flow slagging slurry gasification has proven difficult due to limited information being available in the open literature regarding gasifier geometry, burner spray characterization, and local gas and char conditions. This paper describes efforts made by Canadian national laboratories CanmetENERGY and the National Research Council, to provide the data required for developing and validating gasification CFD models.

The CanmetENERGY two tonne per day (slurry feed rate) pilot-scale gasifier has been modified to allow local gas and char conditions to be sampled from within the gasifier and from the syngas exiting the quench vessel during gasifier operation. A series of Canadian and U.S. solid feedstocks have been gasified and a subset of the results of these gasification tests is presented here.

The National Research Council's Institute for Aerospace Research spray characterization laboratory is determining droplet size and velocity characteristics for the CanmetENERGY slurry gasifier burner spray at elevated pressure and temperature. Gasifier geometry, burner spray characterization, local gas and char conditions, fuel characteristics, and slag viscosity measurements have been used in the development of CanmetENERGY CFD models representing the system. The data is being forwarded to our industrial, academic, and government research partners in Canada and the U.S.

45-5

Numerical Simulation Analyses of an Entrained-Bed Gasification Reactor

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A three-dimensional numerical simulation model for the coal combustion and gasification of an entrained-bed gasification reactor has been developed by employing the computational-fluid-dynamic software FLUENT. The numerical simulation model is able to predict the flow and reaction characteristics of a gasification reactor fed by dry pulverized coal, wet pulverized coal, and/or biomass. It adopts several physical models, including the coal gasification model, the turbulence flow model, the turbulence reaction model, and the thermal radiation model, and can be applied to analyzing a gasification reactor with a multi-feeding fuel-injection system at varying operation conditions. The results obtained from the present study show that the generated syngas is primarily composed of carbon monoxide and hydrogen, and the predicted outlet gas composition is in good agreement with the experimental result. For coal gasification, a lower oxygen/carbon ratio is found to produce more carbon monoxide and hydrogen, and the outlet temperature is relatively lower. The produced carbon monoxide decreases with an increasing water/coal ratio.

However, there exists an optimal water/coal ratio for the maximum hydrogen production. The generated syngas by using a general low-carbon high-oxygen biomass as the stock is predicted to have a composition much lower in carbon monoxide and higher in carbon dioxide than that by using the coal.

SESSION 46 Coal Science: Coal Chemistry - 5

46-1

An Understanding of the Porosity of Residual Coal/Char/Ash Samples Dissected from a Pilot Scale Packed Bed Reactor Operating on Inertinite-Rich Lump Coal

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The thermal treatment of coal causes a development of internal porosity of the resultant char due to the changes in the coal char pores such as the opening of previously closed pores, the formation of new pores and an increase in pore size of existing and newly formed pores. Furthermore, the porosity formed during pyrolysis causes changes in pore structural elements such as: density, pore size distribution, total open pore volume, porosities and average pore diameter. Much research has been conducted in this area, but was mainly focused on fine particle sizes (<1mm) and vitrinite-rich coals, particularly from the Northern hemisphere. The objective of this study was to obtain an understanding of both the macro and micro-porosity development within the pyrolysis zone of a packed bed consisting of lump inertinite-rich coal (75mm x 6mm) from the Highveld coalfield in South Africa. This was achieved by generating samples in a pilot-scale packed bed reactor and conducting proximate, CO₂ reactivity, mercury intrusion porosimetry, and BET CO₂ surface area analyses on the dissected coal / char / ash samples.

From mercury-intrusion porosimetry results obtained for the pyrolysis reaction zone of the reactor, it was found that although the percentage macro-porosity and average pore diameter increased by 11% and 77% respectively (which confirms pore development), that these developments do not enlarge the surface area, and thus has no significant contribution on the reactivity of the coal/char. On the other hand, the micro-pore surface area, pore volume and pore diameter were all found to increase during pyrolysis, resulting in an increase in the coal char reactivity. The micro-porosity is thus generally responsible for the largest internal surface area during pyrolysis, which enables increased reactivity. The CO₂ reactivity (at 1000 °C) increased from 3.8 to 4.5 hr⁻¹ during fast pyrolysis, and then decreased to 3.8 hr⁻¹ in a slow pyrolysis regime. This is due to the maximum pore expansion and volatile matter evolution reached at 4.5 hr⁻¹, before coalescence and pore shrinkage occur with a further increase in temperature within the slow pyrolysis region of the reactor. During pyrolysis there is thus both an increase and decrease in reactivity which might suggest two distinct intermediate zones within the pyrolysis zone.

46-2

Comparison of Measured and Calculated Viscosities of German Lignite Based Slags

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The viscosity of German lignite based slags was investigated at temperatures up to 1700 °C with a Couette type viscometer under reducing conditions to simulate gasification conditions. The experimental values are compared with available models of the literature. For iron, sulphur and sodium rich slag and for silica poor slag some discrepancies have been observed. For the other investigated compositions a pretty good agreement was observed between experimental and calculated values.

46-3

Drying Mechanism of Low Rank Coal with Different Reacting Conditions: Fixed Bed vs. Fluidized Bed

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Low rank coal (lignite) can be successfully utilized in the thermal power plant through the pretreatment of coal with efficient way. The price of low rank coal is equivalent to one third of steaming coal. However, it is difficult to be utilized in thermal power plant mainly for two reasons: high moisture, and instability. In the present investigation, experiments are progressed with low rank coal to reducing moisture content. The experimental parameters of this study are drying temperature and time duration as well as particle size as divided three sections of 0.3~1mm, 1~1.18mm and 1.18~2.8mm. Temperature variation on the drying results that moisture content is not much changed below 80°C and drying is saturated above 150°C. With different particle size investigated in this study, drying behavior is not much different with particle size. Furthermore, it also indicated that pore structure changed after dewatering which can be discerned the SEM microscopy such that Lignite progressively transforms pore structure of mesopore into micropore when it is dried. Consequently, it can be found

that a total dimension of pore is reduced through the dewatering lignite. Investigation will be progressed with different reaction condition, especially in fluidized-bed. The resulting data will be used in designing the fluidized bed drying demonstration plant.

46-4

The Natural Technology for Pretreatment and Utilization of the Energetic Fly Ash

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The progressive usage of primary raw materials force on to the higher wastes utilizations and processing in the case of the useful components containing. By the development of new technologies of this wastes processing can be imitate the processes that are running in the nature by the geo-sphere formation. Provided research confirmed that the fly ash can be used as the substituent for volcanic ashes by the synthetic zeolites and mullite-corundum materials preparation, using the principles of natural genesis of raw materials.

46-5

Physical Structure and Chemical Properties of Organic Matter of Brown Coals from Different Fields in Relation to the Composition of Mineral Components

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The cation-exchange forms of a considerable portion of metals that occur in brown coals from various deposits were identified. Based on swelling data, the interaction of the organic matter of coals with solvents was studied depending on the concentrations of mineral components. It was found that natural brown coals exhibit a densely crosslinked supramolecular structure with the predominance of molecular-size pores. In the course of decationization, the organic matter underwent partial depolymerization; the rate of diffusion and the accessibility of fragments to solvents with relatively bulky molecules dramatically increased.

SESSION 47 Coal Science: Beneficiation – 4

47-1

A Study to Recover Coal from Turkish Lignite Fine Coal Tailings: Comparison of Falcon Concentrator and Multi Gravity Separator (MGS)

Eyüp Sabah, M. Fatih Can, Selçuk Özgen, Afyon Kocatepe University, TURKEY

Lignite coal is the primary domestic source of energy in Turkey, for this reason effective exploitation of the reserves of Turkey is very crucial. In Turkey the fine tailings of lignite coal processing plants are sent in most cases to the tailing ponds without any treatment. However, recovery of fine coals from coal preparation tailings and recycle of processing water are of both economic and environmental incentives, not only preserving natural resources but also reducing environmental consequences of discharging large volume of tailings. Recent developments in the use of various gravity equipments in fine-coal beneficiation have been discussed and their relative merits have been compared. In this study, the possibility of beneficiation of lignite tailings included quartz, kaolinite, siderite, mica/illite, dolomite, feldspar compounds in the Tunçbilek/Kütahya region was investigated by Multi Gravity Separator (MGS) and Falcon Concentrator and these two methods compared. The entire exercise revealed that the MGS could produce a clean coal with an ash content of 22.83%, 5696 kCal/kg calorific value and a recovery of 49.32% and that the Falcon could produce a clean coal with an ash content of 40.26%, 4224 kCal/kg calorific value and a recovery of 64.53% from a feed coal having an ash content of 66.21% and 1835 kCal/kg calorific value.

47-2

Evaluation of Dense Medium Separation Performance of İmbat Coal Preparation Plant

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The aim of this study is determination of the washability characteristics of İmbat coal preparation plant feed and evaluation of performance of operating coal preparation plant for two different capacities. This plant was established to clean the r.o.m. coal with 2200 k.cal/kg average calorific value and 40-45 % ash content.

The washability characteristics of plant feed were determined for the size fractions of + 50mm, -50 +18 mm and -18 mm fractions separately. A sink and float tests were carried out with representative test samples of each size fractions with the specific gravities of 1.30, 1.40,1.50, 1.60, 1.70ş 180 and 1.90. Cumulative float ash curve,

cumulative sink ash curve, Elementary ash curve, specific gravity curve and specific gravity distribution curve were drawn. It was possible to decrease ash content of coal down to 4.61%, 3.1% and 5.1% for the sizes of +50mm, -50 +18 mm and -18 mm fractions respectively at the lowest separation density of 1.30 g/cm³ with very low yield.

The operating coal preparation plant have a Drew boy and dense medium cyclones for cleaning of coarse and fine coals respectively. The first separation in the Drew boy is carried out at high density. The float fraction of first Drew boy is send to the second drew boy which is operating with low separation density. Here the float product for thermal power station is ptduced. The fine fraction of plant feed is cleaned in single stage operation of dense medium cyclones.

A detailed in-plant operation of the dense medium separation employed in İmbat coal preparation plant was also conducted to determine the relationship between the plant capacity and the plant performance. The separation performances achieved by the Drew boy and dense medium cyclone circuit under two different capacity conditions indicated that the increase in the capacity from 500 t/hour to 600 t/hour resulted a slight decrease in the performances of both equipments.

47-3

Aggloflotation of Coal

İhsan Toroglu, Dilek Cuhadaroglu, Serdar Yılmaz, Zonguldak Karaelmas University, TURKEY

Agglomeration is an industrial process traditionally used to separate or recover fine solids dispersed in a liquid suspension through the addition of a second immiscible liquid (binder) which presents an affinity for the solids and is capable of forming small liquid bridges that hold the particles together. Under appropriate physico-chemical conditions, the desired particles can be selectivity agglomerated and removed from the sullury (Rosetti, Simons, 2003, Petela, at al., 1995, Cebeci, 2003, Subero Courouyer at al., 2006).

Aggloflotation being a combination of agglomeration and flotation, this technology was developed for removal of pyrite and other mineral components from bituminous coal, for recovery and beneficiation of fine coal from of fine coal streams in coal preparation plants and for recovery and cleanup of fine coal recovered from tailings ponds and coal dumps (Szymocha, 2003).

The study targeted to reduce the ash content of fine coal by producing a low ash coal for metallurgical use and supplying the rest to the power plant without any further cleaning by using agfloat. Oil type and quantity, agitation speed and time during the/prior to the agglomeration, solid content are the important factors affecting the agglomeration process (Sahinoglu, 2008). The effect of these parameters on the ash content and combustible yield were investigated in the agglomeration studies and were obtained optimum conditions from agglomeration experiments.

Aggloflotation process was carried out with the agglomerate obtained from the optimum conditions of agglomeration. The effects of oil amount, solid content, pH, flotation time, Na₂SiO₃ amount on the ash content and combustible recovery were investigated. Oil amount used in aggloflotation is smaller than that used for agglomeration. Although reduced oil amount caused loosely bound agglomerates, this had no effect on the ash and recovery since agglomerates were recovered by flotation.

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47-4

Effect of Shape Factor on Coal Flotation

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In this study, the flotation behavior of hard coal products having different particle shapes produced by different grinding conditions was investigated with and without reagents. As a reagent kerosene + isooctanol mixture was used in coal flotation. The flotation kinetics of coal particles with different shape was studied as a function of time. Shape characteristics of the particles were investigated by Leica Qwin program. The results showed that particles presenting lower fullness ratio and roundness properties were recovered better during flotation of the coal mineral studied. As a

result, the shape of the particles produced by the ball mill changed upon to their roundness, their floatability was increased.

47-5

Experiment and Research on Deep Cleaning by Selective Oil Agglomeration

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Aimed at solving the series of problems about coal flotation, for example, the particle size is increasingly smaller, the concentrate ash is hard to reduce and the cost of the flotation is high, the paper studied on the deep cleaning of the anthracite from Jincheng in Shanxi province by selective oil agglomeration. In this study, the effects of some parameters that influence the effectiveness of selective oil agglomeration, such as collector dosage and frother dosage, on the recovery and the ash content of the clean coal were investigated. It was found that the ash content of the coal significantly decreased from 14.45% to 1.71% by selective oil agglomeration.

SESSION 48

Coal-Derived Products: General Session – 1

48-1

Reforming of Low Rank Coal by Solvent Treatment at Around 350 °C

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Recently, we proposed degradative solvent extraction at around 350 °C as an efficient upgrading method of low rank coals. In this study, eight low rank coals including lignites and sub-bituminous coals were thermally treated and fractionated by using 1-methylnaphthalene as solvent at 350°C. The coals were partly decomposed and were separated into three fractions having different molecular weights. The yields of the three fractions respectively ranged from 17wt% to 27wt% (soluble), 4 wt% to 17 wt% (deposit), and 47 wt% to 64 wt% (residue; upgraded coal) on d.a.f. coal basis. The total higher heating value (HHV) of the fractions (sum of HHV of soluble, deposit and residue on raw coal basis) was not lost. The carbon contents of the three fractions were much larger than those of their parent coals, suggesting that significant amount of oxygen was effectively removed from the coals during the treatment. The interesting findings were that the solubles and deposits obtained from the eight coals were respectively very close to each other in elemental composition, chemical structure, molecular weight distribution, pyrolysis behavior, and thermal plastic behavior. Thus, the proposed degradative solvent extraction method was found to be effective in converting low rank coals into upgraded coal and compounds having very similar chemical and physical properties.

48-2

An Experimental Investigation of Factors Related to Coke Strength Degradation in Coke Milli-Structure

Tetsuya Kanai, Yoshiaki Yamazaki, Kenichi Hiraki, Xiaoqing Zhang,
Masakazu Shoji, Hideyuki Aoki, Takatoshi Miura, TOHOKU University,
JAPAN

In order to clarify the factors related to coke strength degradation, relationship between coke strength and pore structure is quantitatively investigated. The tensile strength of coke is measured by diametral-compression test and analyzed by Weibull plot. Pore structure is analyzed with wide range(10 mm×10 mm) and high resolution(2.43 μm/pixel) photographs which are acquired by combining approximately 20 photographs. Absolute maximum pore length, pore area ratio and pore roundness are measured by image analysis of the photographs. By comparison of strength and absolute maximum pore length in coke, strength is degraded with an increase in area ratio of pores over 1000 μm in absolute maximum length. From image analysis, it is found that the pore roundness decreases with an increase in absolute maximum length. The length of 1000 μm corresponds with the critical crack length calculated by Griffith equation in scale.

48-3

An Experimental Study on the Effect of Metallic Iron Particles on Strength Factors of Coke after CO₂ Gasification Reaction

Yoshiaki Yamazaki, Kenichi Hiraki, Tetsuya Kanai, Xiaoqing Zhang,
Masakazu Shoji, Hideyuki Aoki, Takatoshi Miura, Tohoku University,
JAPAN

In order to prevent the pulverization and the fracture of coke lump in blast furnace, control of degradation part (reaction mechanism) in coke lump and that of the embrittlement behavior are significant. Addition of catalyst particle is an effective and a simple method for advancement of the CO₂ gasification reactivity and control method for reaction mechanism. In this study, the effect of iron particles on coke-

matrix state after gasification reaction is investigated experimentally. Coke-matrix vanishing is evaluated by spatial distribution of lump porosity and microscopic observation.

Elastic modulus of coke-matrix is evaluated by nano-indentation method. Coke lumps with and without iron-particles (ferrous coke and formed coke, respectively) were used. These coke lumps were gasified by CO₂-containing gas.

Reaction temperature was set at 1173 K. Reaction gas compositions were set at 100/0 and 50/50 in ratio of CO₂/CO. In each reaction gas composition, in ferrous coke, a decrease in the elastic modulus of coke-matrix with progress of gasification is smaller than that in formed coke and coke-matrix vanishing occurred. It is suggested that the iron particle promotes gasification reaction of coke-matrix selectively around itself (and coke-matrix in that part is rapidly vanished).

It is also suggested that this reaction mechanism maintains elastic modulus of coke-matrix because of the local rapid gasification reaction around the iron particle.

SESSION 49

Combustion: Ash Deposition and Heat Transfer

49-1

Spectral Emissivities of Ni and Fe based Boiler Tube Materials with Varying Chromium Content at High Temperature Atmospheres

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To evaluate radiative heat transfer characteristics of boiler tube materials, spectral emissivities of 6 types of Fe-based and Ni-based alloys with varying chromium contents of 2, 9, 18, 23 and 25% have been investigated under high temperature oxidizing conditions. Metal samples were heated in an electric furnace and spectral emissivities were determined by using a monochromator system at wavelengths from 1 to 178nm in the temperature range from 773 to 1073K. After the measurements, the sample surfaces were analyzed by means of SEM (scanning electron microscope). The experimental values of the spectral and total emissivities were discussed in relationship to chromium content in metals. The obtained results are as follows: (1) Spectral emissivities of metals containing more than 9% of chromium have the typical wavelength and temperature dependencies of metal emissivities; they decrease with increasing wavelength and increase with increasing temperature. In contrast, spectral emissivities of the metal containing 2% of chromium have weak dependencies both on wavelength and temperature; they were high under most measurement conditions and changed periodically with the wavelength, (2) Spectral emissivity levels tend to decrease with increasing chromium content in metals. The SEM analysis showed that the thickness of the oxidation layer formed on the sample surface was small for the sample containing higher amounts of chromium, and (3) Total emissivity also tends to decrease with increasing chromium content in metals. SEM observation indicates that the growth of the oxidation layer increases metal emissivity. Based on SEM and emissivity measurement results, it appears that the difference in spectral emissivities among metals with varying chromium content is due to the thickness of the oxidation layer.

49-2

Effect of MgO Additive on the Reduction of Ash Deposition of Upgraded Brown Coal

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Ash with low melting temperatures causes slagging and fouling problems in pulverized coal combustion boilers. Ash deposition on the heat exchange tubes affects the decrease in the overall heat transfer coefficient due to the low thermal conductivity of the ash as well as several other operation problems. Therefore, the operational conditions of the boilers directly relate to the ash deposition behavior. The objectives of this study are to evaluate the effect of MgO addition with the coal on the reduction of ash deposition during upgraded brown coal (UBC) combustion and to understand the reduction mechanisms of ash deposition. The melting temperature of the UBC ash is 1494 K, which is relatively lower than that of bituminous coal ash. Before the actual ash deposition experiments, the molten slag fraction in the UBC ash was estimated by means of chemical equilibrium calculations while varying the mixing mass ratio of MgO to coal ash. The results of a simulation indicate that the MgO addition played a role in decreasing in molten slag fraction. It was confirmed that Mg formed solid composites with Si, Fe, Al, Ca, and Mn and played a role in decreasing the molten slag fraction in ash on the tube. As a next step, ash deposition tests were conducted using a pilotscale pulverized coal combustion furnace equipped with a refractory wall. The thermal load in the furnace was fixed at 149 kW, and the maximum gas temperature exceeded 1750 K. A water-cooled stainless-steel tube was inserted at 1573 K in the furnace to measure the quantity of the ash deposits. As a result, the MgO addition contributed to the decreasing rate of ash deposition even for the UBC. These

calculations and experimental results suggested that the MgO addition contributed to the reducing UBC ash deposition on the tube.

49-3

Modeling and Optimization of NO_x Emission and Pulverized Coal Flame in Utility Scale Furnaces

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The emission of NO_x is of great concern to designers and operators of most industrial furnaces and boilers. The pulverized coal flame in utility scale boilers is also of great importance, affecting the levels and distribution of temperature and heat flux. Numerical studies of combustion and heat transfer processes in energy conversion systems can describe how the fuel chemical energy is converted into thermal energy with high efficiency and acceptable emission. Although there is much technology now available to compute complex flows in energy systems, development of submodels describing individual processes, as well as comprehensive CFD codes are increasing worldwide. A comprehensive 3D differential mathematical model and software were previously developed in-house and validated against experimental data. A practical motivation was to solve operation problems in tangentially-fired furnaces of the power plant Kostolac-B 350 MWe boiler units. The software is aimed for prediction of processes and operation situations in utility boiler pulverized coal-fired furnaces and it is adapted to be used by engineering staff dealing with the process analysis in boiler units. Characteristics of the model are Eulerian-Lagrangian approach to multiphase flow, k-ε turbulence model, particles-to-turbulence interactions modeled by PSI Cell method, diffusion model of particle dispersion, six-flux method for radiation modeling, heterogeneous reactions in kinetic-diffusion regime on the basis of experimentally obtained case-study coal kinetic parameters, within a "shrinking core" concept and with respect to the model of char oxidation, as well as homogeneous reactions controlled by chemical kinetics or turbulent mixing. In addition, submodel describing formation and destruction of thermal and fuel NO_x has been developed and validated against available data obtained by monitoring of NO_x emission from boiler units. The main motivation for this study was to achieve optimal position of flame with acceptable levels of NO_x emission. The flame position depends on many influencing parameters. Selected predictions of pulverized coal flame geometry and position are given in the case-study furnace under different operating conditions, like fuel and air distribution. Even when both the fuel nitrogen content and the combustion temperature are not very high, the emission of NO_x may still surpass environmental limits if the combustion process is not managed correctly. It is therefore essential to understand the NO_x formation process so that the NO_x emission can be controlled. Although post-combustion clean-up is viable, modifying combustion process often controls NO_x most economically. In air staging method, e.g., the portion of combustion air is introduced downstream, through special, over-fire-air ports. In this work, the numerical study has been performed to achieve both NO_x emission reduction and favorable position of flame in the case-study furnace, by investigating the impact of pulverized coal distribution over the burner tiers, without need for construction changes. The contributions of fuel and thermal NO_x are reported as well. The results of the model can help in increasing combustion efficiency, lowering emission of pollution, fuel savings and corresponding economy and environmental benefits during the facility exploitation.

49-4

Observation of Heat Release Region as Functions of Coal Properties in Turbulent Jet Pulverized Coal Flames

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One issue of interest is to develop diagnostic methods for the monitoring and control of the pulverized coal flames in power plants. The purpose of this study is to establish visualization and diagnostic methods in the pulverized coal combustion fields. An advanced instrumentation and research methodology was employed to observe the structure of pulverized coal flame in a laboratory scale burner. The effects of pulverized coal properties, volatile matter, particle size and moisture content, on the heat release region in turbulent jet pulverized coal flames were investigated experimentally. To understand the accuracy of line of sight measurement in the two-dimensional (2-D) visualization, point measurements of chemiluminescence intensity by Cassegrain optics were also conducted. The heat release region for the structure of pulverized coal flame was observed through visualization by CH⁺ chemiluminescence image with an intensified high-speed camera, and by CH⁺ chemiluminescence intensity for local point measurements. The streamwise length of the heat release region based on 2-D visualizations was about 11.4% longer than that of point measurements and increased proportionally to the volatile matter content. The temperature rise for 35–45 μm coal particles was faster than that for 75–90 μm particles, which resulted in a shift of reaction region toward upstream direction. The coal moisture content less than 15%, however, had little effect on the structure of the pulverized coal flame. The obtained results give us useful information for evaluating practical pulverized coal flames.

49-5

Mathematical Model of the Low-Temperature Oxidation of Coal in Coal Stockpiles and Dumps

Marian Bojko, Milada Kozubkova, VŠB-Technical University; Zdeněk Michalec, Institute of Geonics AS CR, v. v. i., CZECH REPUBLIC

Article defines mathematical model of the low-temperature oxidation of bituminous coal. The mathematical model defines single phase mathematical model with porous zone as coal where consumption of oxygen, production of smoke exhaust and heat are solved as source terms in transport equations. The rate constant defines by Arrhenius expression. Parameters of Arrhenius equation (activation energy and pre-exponential factor) are determined from experimental measurement. For numerical calculation method of finite volume (software ANSYS FLUENT 12) was used.

SESSION 50 Gasification: Gas Cleanup

50-1

Slipstream Tests of Palladium Sorbents for High Temperature Capture of Mercury, Arsenic and Selenium from Fuel Gas

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In gasification for power generation, the removal of mercury and other trace elements such as arsenic, selenium and phosphorus by sorbents at elevated temperatures preserves the high thermal efficiency of the integrated gasification combined cycle system. Most commercial sorbents display poor capacity for elemental mercury at elevated temperatures.

Palladium is an attractive sorbent candidate for the removal of mercury and the trace elements from fuel gases at elevated temperatures. The National Carbon Capture Center at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama, is a large-scale flexible test facility established to develop and demonstrate a wide range of advanced power generation technologies that are critical to developing highly efficient power plants that capture carbon dioxide. The palladium-based sorbents have been tested for extended periods of time in slipstreams of fuel gas at the NCCC. These results will be described, and possible future testing will be discussed.

50-2

Mercury Measurement and Removal from an Entrained Flow Slagging Coal Gasifier

Dennis Lu, Robin Hughes, Ben Anthony, CanmetENERGY/Natural Resources Canada; Karl Abraham, Environment Canada, CANADA

In typical synthesis gas (syngas) from entrained flow slagging coal gasification thermodynamic calculations predict that only the elemental form of mercury (Hg⁰) is stable rather than the bivalent oxidized form (Hg⁺⁺), such as is present in HgCl₂. Therefore, Hg⁰ is expected to be dominant in such a reducing environment. However, the chemical and physical processes governing the interactions of mercury forms with syngas components are poorly understood, particularly the results of heterogeneous reactions involved in gasification syngas are lacking. Data on Hg emissions from gasification systems have not been sufficiently reliable and the mass balance closures have high associated error ranges because of problems with sampling and analysis, which make understanding mercury characteristics under gasification conditions difficult.

This paper presents studies on mercury measurement specifically applicable to an entrained flow slagging gasifier at the CanmetENERGY 0.6MW pilot scale gasification plant. Mercury speciation has been successfully measured directly from a high-P and high-T gasifier vessel and as well quenched downstream syngas containing nitrous and sulfurous species. A bench-scale fixed-bed system was also used to investigate the Hg removal performance of sorbents, including commercial activated carbon, sulphur- and alkali-doped activated carbons, limestone and dolomite. The fixed bed was operated above the dew point temperature of the synthesis gas for the activated carbon sorbents, and for CaO-based sorbents at a higher temperature in the range of 500–700°C, which has been chosen to match the operating conditions of the CaO-sorbent looping process for CO₂ capture.

50-3

Performance Improvement of a Desulfurization Sorbent for Warm Synthesis Gas Cleanup

Jeom-In Baek, Jungho Ryu, Tae Hyoung Eom, Joong Beom Lee, Yong-Ho Wi, Chong Kul Ryu, Korea Electric Power Research Institute, KOREA

KEPCO Research Institute has improved the performance of a solid regenerable desulfurization sorbent prepared by spray-drying method. Here, we present a newly

developed desulfurization sorbents which showed improved physical properties and reactivity compared to our previous desulfurization sorbents. The attrition resistance of the new desulfurization sorbents was much higher than the previously developed sorbents. Other physical properties such as average particle size, tap density, and shape were suitable for the fluidized-bed applications. Sulfur sorption capacity of the new sorbent, which was measured by thermogravimetric analyzer using a simulated synthesis gas containing 1% H₂S, was around 10 wt% at the reaction temperatures of 500 and 650 °C for absorption and regeneration, respectively. In the future works, an in-depth sorbent analysis and reactivity test according to the reaction temperature change will be carried out to improve the performance of the spray-dried desulfurization sorbent and a fluidized-bed desulfurization process.

50-4

Study on Sulfidation Performance of Zn-Mn Based Sorbent from Different Precursors

Liping Chang, Yingli Wang, Ying Zhang, Weiren Bao, Kechang Xie, Taiyuan University of Technology, CHINA

A series of Zn-Mn mixed-oxide sorbents with high surface area were prepared by impregnation method. The granular activated γ -Al₂O₃ with 162m²/g specific surface area was selected as support and Zn(NO₃)₂·6H₂O and Mn(NO₃)₂ or Zn(C₂H₃O₂)₂·2H₂O and Mn(C₂H₃O₂)₂·4H₂O were used as precursors of active components Zn and Mn oxides. Sorbents were dried at 90-100 °C and calcined at 400-500°C for 3 hours. The sulfidation performances of Zn-Mn based sorbents with different precursors were studied in this paper. The desulfurization activities of sorbents were evaluated in a lab-scale fixed bed with quartz tube (20mm i.d., 23mm o.d.) placed in an electric furnace equipped with PID controller, under the condition of 400 °C sulfidation temperature, 2000h⁻¹ space velocity and gases of 55% H₂, 35%CO, 500ppm H₂S and N₂ balance. The properties of different sorbents were characterized by X-ray diffraction (XRD) and Brunauer-Emmett-Teller (BET) analyzer. Results of XRD showed that ZnO, ZnAl₂O₄ and MnAl₂O₄ can be observed in fresh sorbents, indicating the interaction between zinc and manganese oxides with support. BET surface area and pore volume of fresh sorbent is higher and the sorption of H₂S on sorbent caused the loss of surface area, which should be attributed to the conversion of mixed oxides to manganese and zinc sulfides. The sulfidation activity of sorbents increases with their surface areas and pore volume increased. Sorbent ZAMAA made from Zn(C₂H₃O₂)₂·2H₂O and Mn(C₂H₃O₂)₂·4H₂O precursors has higher H₂S removal efficiency than that from Zn(NO₃)₂·6H₂O and Mn(NO₃)₂. The decomposition characteristics and reduction properties of different sorbents were also studied by means of TG-DTA technique in the gases of O₂/N₂ (1/4) or H₂/N₂ (1/1). TG-DTA investigations confirmed that the reduction temperature of ZAMAA sorbent is lower, and this property is favored to sulfidation reaction.

SESSION 51 Gasification: Modeling - 2

51-1

Investigation of Coal Gasification Process under Various Operating Conditions Inside a Two-Stage Entrained Flow Gasifier

Ting Wang, Armin Silaen, University of New Orleans, USA

Numerical simulations of coal gasification process inside a generic 2-stage entrained-flow gasifier are carried out using the commercial CFD solver ANSYS/FLUENT. The 3-D Navier-Stokes equations and eight species transport equations are solved with three heterogeneous global reactions, three homogeneous reactions, and one thermal cracking equation of volatiles. The Chemical Percolation Devolatilization (CPD) model is used for the devolatilization process. Finite rates are used for the heterogeneous solid-to-gas reactions. Both finite rate and eddy-breakup combustion models are calculated for each homogeneous gas-to-gas reaction, and the smaller of the two rates is used. The water-shift reaction rate is adjusted to match available syngas composition from existing operational data. Study is conducted to investigate the effects of different operation parameters on gasification process including coal mixture (dry vs. slurry), oxidant (oxygen-blown vs. air-blown), and different coal distribution between two stages. In the two-stage coal-slurry feed operation, the dominant reactions are intense char combustion ($C + \frac{1}{2} O_2 \rightarrow CO$ and $CO + \frac{1}{2} O_2 \rightarrow CO_2$) in the first stage and gasification reactions (mainly char-CO₂ gasification, $C + \frac{1}{2} CO_2 \rightarrow CO$) in the second stage. Char gasification is enhanced in the second stage with the injection of the remaining coal. The higher gas temperature in the first stage for the dry-fed case (3200 K compared to 2400 K for slurry-fed) means that the refractory walls in the first stage will experience higher thermal loading than that in the coal slurry operation. One-stage operation yields higher H₂, CO and CH₄ combined than if two-stage operation is used, but with a lower syngas heating value. High heating value (HHV) of syngas for the one-stage operation is 7.68 MJ/kg, compared to 8.24 MJ/kg for two-stage operation with 72%-25% fuel distribution and 9.03 MJ/kg for two-stage operation with 50%-50% fuel distribution. Carbon conversion efficiency of the air-blown case is 77.3%, which is much lower than that of the oxygen-blown case

(99.4%). The syngas heating value for the air-blown case is 4.40 MJ/kg, which is almost half of the heating value of the oxygen-blown case (8.24 MJ/kg).

51-2

Start-Up Behavior of a Fixed Bed Gasifier: One Dimensional Modeling

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This work copes with the development of a mathematical model for the investigation of the transient behavior of a countercurrent fixed bed gasifier. The phenomenological model is based on heat and mass continuity equations. Heterogeneous is somehow considered by the insertion of two separated heat balances, one for the gas and one for the solid phase.

All the main phenomena involved in the gasification process are inserted: drying, pyrolysis, gasification and combustion reactions of the solid phase and homogeneous gas phase reactions including secondary pyrolysis reactions. The system is described with a pseudo homogeneous approach. Moisture loss calculation is carried out by the introduction of a first order kinetic on the moisture content of the bed; a competitive reaction model is used for primary pyrolysis; heterogeneousness of the system is considered for gas phase reactions by the introduction of a shrinking core reaction model where the external diffusion and the kinetic resistance are considered. The solid phase is constituted by four pseudo components: coal, ash, char and moisture. The ash behavior is described by the introduction of a shell progressive model with variable particle diameter. Gas species considered by the model are: CO, CO₂, H₂, H₂O, CH₄ and tar.

Input for the model are flowrates, temperature and composition profiles at the initial state for both: the gas and the solid phase.

The model was used to study the start up of an air blown atmospheric gasifier in the case of a Pittsburg n°8 coal seam feedstock. The initial conditions chosen for the dynamic simulation are in accordance with the start up procedure of an existing gasification pilot plant.

Output for the model are the variation with time of temperature, composition and spatial velocity profiles of the system. In particular the dynamics is analyzed with reference to the bed behaviour in a long time investigation. Scarce information about this topic was before present in the literature. The influence of steam injection also revealed the presence of multiple steady states for this system.

51-3

Entrained Flow Coal Gasification: Modeling, Simulation & Experimental Uncertainty Quantification for a Laboratory Reactor

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Modeling and simulation on petascale computing platforms offers unprecedented opportunities to explore new transformative technology options in entrained-flow coal gasification. However, before these advanced simulation tools can be used with confidence, formal validation and uncertainty quantification is required. In this paper we explore the uncertainty in predictions from large eddy simulations (LES) of the Brigham Young University (BYU) pilot-scale entrained flow reactor1. The specific focus of this paper is to produce predictive capability for gasification with quantified uncertainty bounds through a formal validation and uncertainty quantification (V/UQ) analysis. We have employed the Data Collaboration methods of Michael Frenklach and coworkers at the University of California-Berkeley in our V/UQ analysis. Data Collaboration requires consistency between simulation results and experimental data. Having developed the ARCHES code, that combines LES with the Direct Quadrature Method of Moments (DQMOM) for the gasification simulation, we now perform V/UQ employing the BYU experimental data. The simulation produces temporally and spatially resolved data of the reacting, multiphase flow field, including the moment description and evolution of the full particle number density function. Specifically, we have studied three key particle behaviors; particle size segregation (Stokes number effects), particle clustering, and particle pyrolysis. We perform the V/UQ analysis with the spatially resolved compositional data measured in the BYU gasifier. In this study we have extracted experimental error for each of the measurements taken. Used prior ARCHES validation information to produce prior uncertainty bounds on the most sensitive simulation parameters. We have included uncertainties in numerical parameters, models, and scenario parameters. The resulting V/UQ analysis produced posterior uncertainty bounds on both the quantities of interest and the uncertain parameter space studied.

51-4

Numerical Simulation of the Hydrodynamics of a Fluidized Bed Combined with an Entrained Bed Gasifier

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The ash agglomerating fluidized bed (AFB) coal gasification process, developed by the Institute of Coal Chemistry, Chinese Academy of Sciences, has the advantages of moderate operation temperature, lower oxygen consumption, lower operation cost, higher coal adaptability, and especially the fitness to coals of high ash content and high ash fusion temperature. The commercial pressured AFB gasifier (300t/d, 0.6MPa) have

been put into operation for the ammonia and methanol synthesis. However, the carbon conversion (~90%) still has the potential to be highly improved by increasing the gasification efficiency of fly ash with high carbon content and low reactivity. Therefore, a new concept for coal gasification was evolved for coal gasification, combining the fluidized bed gasifier and the entrained flow gasifier into one unit. The combined gasifier can gasify feedstock with higher reactivity in the fluidized bed and further gasify fly ash with lower reactivity in the entrained flow bed at higher temperature (~1200°C). The preliminary experiments have been carried out to confirm its feasibility. The present work aims to establish a rational mathematic model to simulate the fluidization dynamics to assist with the design, operation and scale-up of the gasifier. The CFD model is established base on the results from the simulation on the entrained flow bed and the fluidized bed. The advanced hybrid grid technology was used to build the numerical mesh. A series of simulation works were carried out using the CFD model established for the pilot scale coal gasifier. The gas-solid flow field, particle distribution, the mutual influence of the gas and particle flow between the entrained flow bed and the fluidized bed were discussed in detailed.

51-5

Numerical Simulation of the Gasification Process inside a Cross-Type Two-Stage Gasifier

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Numerical simulation of oxygen-blown coal gasification process inside a cross-type two-stage (E-Gas like) gasifier is studied with the commercial CFD solver ANSYS FLUENT. The purpose of this study is to use CFD simulation to improve understanding of the gasification processes in the E-Gas like gasifier. In this paper, chemical reaction time is assumed to be faster than the time scale of the turbulence eddies. All the species are assumed to mix in the intermolecular level. The 3-D Navier-Stokes equations and species transport equations are solved with eddy-breakup reaction model (instantaneous gasification). The simulation follows one of the cases documented in the report published by NETL at 2000. The influences of coal slurry concentration and O₂/coal ratio on gasification process are investigated in this paper. Under the condition of feeding carbon being nearly completely converted, low slurry concentration is preferred over high concentration if more H₂ is wanted with lower syngas temperature, while higher slurry concentration is more preferable for producing more CO with higher syngas temperature. The case of higher O₂/Coal ratio results in more combustion and leads to lower syngas heating value and higher temperature. Meanwhile, lower O₂/Coal ratio involves more gasification reactions and results in higher CO concentration and lower temperature. In summary, the trends of simulated results of coal combustion and gasification processes in the cross-type two-stage gasifier are reasonable.

**SESSION 52
Coal Science: Coal Chemistry - 6**

52-1

Uranium and Some Other Trace Metal Element Concentration of Some Turkish Coal Ashes

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This study focuses on uranium and some other trace element concentrations and distributions of some coal occurrences that had been formed in Trachea and Anatolia, Turkey. Coal occurrences are in different age and rank. Most of them are young and their ranks are low. Ashes of coal samples have been picked up from different parts of Turkey and were analyzed and evaluated in terms of uranium and some trace element contents.

Chemical investigations were performed on the coal ashes via fluorometric method for analyzing uranium concentration, some trace and major element concentrations were analyzed by AAS (Atomic Absorption Spectrometry) and FP (Flame Photometry) methods. The analyses results show that the uranium content in coal ashes change between 0 – 178 ppm, while the average of Turkish coals is 10 – 33 ppm. Ni, Co, Cu, Zn, Pb, Ag, Fe, Ca, Na and K concentrations were also detected. The mentioned trace element concentrations are over the world averages in most of coal ash samples. Uranium was enriched in the western Anatolia, especially in Mugla – Yatagan, Aydin – Soke, Kutahya – Gediz and Acemkiri coal fields. Also, an asphaltite sample from Sirkak includes noticeable amount of uranium concentration. Uranium accumulation of the coal samples probably depended on surrounding units as the source rocks.

52-2

Transformations of Karaman -Ermenek Lignites of Turkey under Accelerated Electrons Impact

Islam Mustafayev, Fethullah Chichek, Azerbaijan National Academy of Sciences, AZERBAIJAN; Guven Onal, Istanbul Technical University, TURKEY

The regularities of transformation of lignites from Karaman-Ermenek deposits of Turkey under accelerated electron impact were studied. The absorbed dose in lignites changed within the limits of 1170-3120 kGy. As basic indexes of process rate of gas formation, decreasing of initial mass of lignite, the contents of sulfur in the solid have been defined. The gaseous products H₂, CO and CH₄ were identified. The specific features of radiation-chemical decomposition of organic mass of lignite under accelerated electrons impact are discussed.

52-3

Co-Pyrolysis of Malaysian Bituminous Coal and Industrial Solid Waste (Tyre Waste and Wood Waste) Blends via Thermogravimetric Analysis (TGA)

Sharmeela Matali, Norazah Abd Rahman, Siti Shawalliah Idris, Azil Bahari Alias, Universiti Teknologi MARA, MALAYSIA

Investigations on co-pyrolysis between Malaysian bituminous coal, wood waste (WW), tyre waste(TW) and their blends were carried out by thermogravimetric analysis (TGA). Experiments were performed under inert N₂ atmosphere at various heating rate of 10, 20, 40 and 60°C/min with temperature heating range from 25°C to 900°C. By observing the derivative thermogravimetric (DTG) profiles of individual raw samples, thermal degradation event of coal occur at higher temperatures (in between 350°C to 850°C) in comparison to the wastes due to the lower content of volatile matter. Thermal degradation of wood waste occur at temperature interval of 215°C to 550°C while tyre waste degrades twice at temperature intervals of 220°C to 460°C and 640°C to 760°C. Pyrolysis of coal/WW and coal/TW blends generates bimodal thermogravimetric curves where the lower temperature mode corresponds to the release of cellulosic and polymeric matters in the wastes and higher temperature mode corresponds to coal pyrolysis. The absence of interactions between coal and the wastes indicates no synergistic effect during pyrolysis. However, an increase of coal reactivity is observed with increasing coal blend ratio. The results, thus far, show that coal/WW ratio blend of 70:30 and coal/TW ratio blend of 60:40 have the lowest activation energy (E_a) values of 231.5 kJ/mol and 202.6 kJ/mol respectively. Effect of heating rate, effect of blending on char yield and activation energy during pyrolysis will also be reported.

52-4

Desulfurization and Kinetics of Removal of Sulfur from High Sulfur Coal under Hydrogen Atmosphere

Guojie Zhang, Yongfa Zhang, Fengbo Guo, Bingmo Zhang, Taiyuan University of Technology, CHINA

The reaction between hydrogen and sulfur in high sulfur coal at high temperature was studied in this paper. Crashed and sieved high sulfur coal sample (with particle size of 0.6mm) was placed in batches in 23 mm I-D differential reactor. The release of hydrogen sulfide at run temperature and under different hydroatmospheres was followed by a hydrogen sulfide detector.

The desulfurization yield was obtained from elemental analysis of residual char. The hydrogen can greatly promote the effect of desulfurization and more than 65% sulfur in the coal can be removed.

The releasing curves of H₂S in hydropyrolysis process obviously showed two peaks. The desulfurization process in hydropyrolysis of high sulfur coal can be regarded as in two stages according to the evolution profiles of H₂S. The first peak at 250~450 °C was from the desulfurization of aliphatic sulfide and the second peak at 450~650 °C could be from both the sulfur in pyrite and aromatic thiophenic structure. Results show that the desulfurization of high sulfur coal could be described much better with the grain reaction model than with the random pore model. The random pore model is only adapted to the initial stage of sulfur removal from high sulfur coal under hydrogen atmosphere while the grain reaction model is adequate the whole stage.

**SESSION 53
Coal Science: Beneficiation – 5**

53-1

Preparation of Alternative Fuel from Compost and Coal Slurries

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New strategies in municipal solid waste (MSW) management, i.e., a separate collection of the organic fraction (EU Directive 1999/31/EC, EU Directive 2008/98/EC) and a

reduction of the biodegradable MSW fraction allocated in landfills (EU Directive 2003/33/EC), have favored the development of composting as a useful biotechnology in transforming organic wastes into suitable agricultural products. In order to meet the requirements of the Directive in the Czech Republic in by the year 2013 it will be allowed only 697 tons for deposition on landfills and it will be necessary to find other utilization for 2477 tons of waste. The produced compost which does not meet the requirements for quality (concentrations of trace metals, C/N ratio and content of PHs) can be utilized for energy generation. It is supported by Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

One of the most important steps in the production of pellets is an increase of pellet density and at the same time preservation of their sufficient mechanical durability and low consumption of energy. The aim of this paper is to describe the preparation of suitable fuel mixture which has required mechanical properties using waste products.

53-2

Investigation of Effect of Reagents on the Coal Recovery from Coal Washing Plant Tailings by Flotation

Okтай Bayat, Huseyin Vapur, Cukurova University; Metin Ucurum, Nigde University, TURKEY

In this study, effects of collector and frother types on the coal recovery from Tunçbilek Ömerler coal washing plant tailings by froth flotation were investigated applying statistical analysis. For this purpose, collectors used on the flotation experiments (keresene, diesel oil and commercial fatty acids as ionic collectors) were compared by ANOVA, and frothers (pine oil and MIBC) were compared by t-analysis. As a result of statistical analysis, it was found that there was not a significant difference among collector types, but there was a significant difference among frothers types. Despite their lower flotation yield and higher consumptions, ionic collectors can be used successfully in coal flotation where cleaner concentrates are required from high ash coal fines. The results showed that the decrease of 53.44% in the ash content of the coal has been obtained in the flotation experiments whereas, the combustible recovery was 87.61% using commercial fatty acids as ionic collectors.

53-3

Coal Flotation Tests: Effect of Operatinal Errors

Sait Kizgut, Dilek Cuhadaroglu, Ihsan Toroglu, Zonguldak Karaelmas University, TURKEY

As in pilot scale and plant scale studies operational parameters are also important working at laboratory scale. Operator faults resulting from stripping deep froth, leaving froth at the edges of cell, froth collapse due to low stripping speed are common in the practice. Size distribution and size limits, reagent amounts are also important parameters affecting the effectivity of the process.

To determine flotability of coals prior to plant application and to verify operational data various techniques have been used. Release and tree test methods have found wide applications. This study is aimed to compare various laboratory scale flotation test techniques for coal flotation. Tree, release, and timed-release test techniques were carried out on flotation size coal sample. Coal sample as taken slurry screened at 0.5 mm. Size distribution and ash content of size groups were determined prior to flotation tests. A Humboldt Wedag Flotation Machine with a 3-liters cell was used. Air was provided by the suction of impeller. Two impeller speed was used; at lower speed conditioning was carried out than, impeller speed was increased and air valve was turned on. This procedure was used in all tests. To determine the effectivity of the test technique, here ash, yield and combustible recovery, three methods were conducted by two operators at two different reagent dosages. Tree and timed-release tests, with many repeated flotation stages, have been found more practical to reduce operational errors.

53-4

Column Flotation of Fine and Coarse Coal using a Novel Approach

B.K. Parekh, D.P. Patil, University of Kentucky CAER; Edgar B. Klunder, NETL, USA

Froth flotation, applied to the separation of solid particulates, has been practiced commercially for a long time in the coal and mineral industries. The potential benefits of establishing a deep froth, especially in column flotation have been shown by a number of researchers, and that includes demonstrating that the froth phase is much more efficient at mineral upgrading than is the pulp phase. This approach could be useful in where the particles have difficulty in reporting from pulp phase to froth phase. Hence, it is expected that introduction of particles into the froth phase will significantly improve the grade and recovery of particles. In this paper, a novel way of operating a flotation column was implemented, and the results were compared to those when operating the same column in the conventional fashion. Tests were conducted with both fine and coarse coals. Feeding into the froth zone enhances bubble-particle contact as observed by a higher product yield of 79.4% compared to a conventional column flotation yield of 73.4%, both at about 9% product ash. It was also observed that the novel froth feed improved the recovery of coarse (+ 1 mm) coal particles from 0.9 weight percent to 2.2 weight percent compared to the conventional way of feeding

slurry to pulp. Similarly, recovery of 1x0.6 mm particles improved from 4.6 weight percent to 8.3 weight percent at the same ash level. Positive results were also obtained by external reflux of a portion of the concentrate back into the top of the column. The potential to simultaneously achieve improvement in both recovery and grade can be explained by application of conventional mass transfer concepts, analogous to developments in two-phase foam fractionation.

53-5

Study of the Lignite Qualitative Parameters Modification, During its Storage

Sanda Krausz, Nicolae Cristea, University of Petrosani; Ion Bacalu, Mihail Dafinoiu, Daniel Burlan, National Society of Lignite, Oltenia, ROMANIA

The research goes out upon the quest of establishing the qualitative parameters variation based on the lignite storage conditions, from different open pits of the biggest coal basin from Romania.

We start from the premise that the physical-chemical processes which inevitably occur during the lignite storage have negative effects on their quality. The lignite oxidation can cause the calorific power decrease, the burning capacity diminution and the modification of the lignite grains proprieties. Experimental approach was carried out in two stages: in the laboratory and on field. The lignite qualitative parameters modification depending on storage duration and coal moisture was studied and the implications of the storage duration are discussed.

The effect of the climatic factors on the deposited lignite quality has also been analyzed: the temperature, the air moisture, the atmospheric pressure, the wind action.

SESSION 54

Coal-Derived Products: General Session – 2

54-1

Investigating the Yield and Distribution of Products Obtained from the Co-Pyrolysis of Biomass and Coal

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The co-utilization of alternative feedstock such as agricultural residues in industrial coal gasification is attracting increasing interest worldwide because of its potential to improve the environmental performance of coal based systems, while diversifying supply options for feedstock. Pyrolysis is an important first step in gasification and is more susceptible to the change in the fuel that will arise from co-feeding biomass. In order to obtain information about the pyrolysis of coal-biomass blends, experiments were conducted in a pressurized fixed-bed pyrolyser operating at 26 bars, 600°C, and average heating rate of 10°C/min using coal-biomass blends of 95:5(wt%) and 50:50(wt%). The effect of adding sugarcane bagasse and corncobs to coal on the distribution of pyrolysis products were evaluated and discussed with attention focused on tar and gas production. It was observed that adding 5% bagasse and corn cobs to the coal feed increased pyrolysis gas yields by 68% and 50% respectively. Blending corn cobs with coal increased the overall production of pyrolysis condensates as well as the production of the tarry phase of the condensates. Adding sugarcane bagasse and coal also increased total condensates production but reduced the tarry fraction to lower values than would be otherwise obtained from 100 % coal pyrolysis. Total hydrocarbon content was increased when both type of biomass were added and the production of oxygenates like phenols, ketones and acids were favoured at the expense of polycyclic aromatic hydrocarbons which was dominant in tars from 100% coal. No significant synergistic effects were detected between the components of any of coal-biomass blends.

54-2

Natural-Gas-Level Emissions when Burning Naphtha (without Water Injection) in a Commercial Gas Turbine using the LPP Technology, Creating a “Clean Power” Alternative for an Integrated Gasification Combined Cycle (IGCC) Polygen Plant

Leo D. Eskin, LPP Combustion, LLC., USA

Emissions test results from operation of a commercial dry, low-emissions Capstone gas turbine demonstrate the commercial feasibility of using the Lean, Premixed Prevaporized (LPP) Technology to burn a range of light liquid fuels in a power generation gas turbine, without water injection, while simultaneously achieving ultra-low, natural-gas-level emissions for NO_x, CO and particulates. The presented test results have significant implications for future Integrated Gasification Combined Cycle (IGCC) plants.

The Integrated Gasification Combined Cycle technology, as currently defined, couples a complex coal gasification process plant with a custom, coal syngas-fired, combustion turbine combined cycle power plant. The IGCC process is a two-stage combustion design with gas cleanup between the stages. The first stage employs a gasifier where partial oxidation of the coal occurs. The second stage utilizes the gas turbine

combustor to complete the combustion with the gas turbine/combined cycle (GT/CC) technology. Due to the impracticality of storing significant quantities of the coal syngas, it is necessary to ensure that the combustion turbine remains operational whenever the gasification plant is running. The shutdown of the combustion turbine requires immediate shutdown of the gasification plant. In addition, it is difficult to operate the gasification plant at part load; hence it is preferable to run the combustion turbine in a base load configuration. These are significant operating limitations.

The current test results demonstrate the commercial viability of combining the gas-to-liquid technology (GTL), e.g. Fischer-Tropsch synthesis or similar, and the Lean Premixed Prevaporized combustion technology to create a much more robust power generation system. The GTL process is a method whereby coal syngas is transformed into one or more forms of liquid fuel. These coal liquids can include diesel fuel, kerosene and naphtha (among others). The conversion of coal syngas to liquids is a well-known process and has been utilized for many years. The LPP process transforms a wide variety of liquid fuels into a synthetic natural gas (or LPP gas) which the current results clearly show can be burned in conventional natural gas dry low emissions combustion hardware, precluding the use of water or steam to achieve low criteria pollutant (NO_x , CO and PM) emissions levels, and hence the penalties discussed above are avoided.

By combining the LPP combustion technology with the GTL process, IGCC operation is made much more flexible, dependable, and the overall economics is improved. Three alternative IGCC design scenarios are presented which would allow the IGCC plant to use a standard, natural gas fired combustion turbine together with an LPP skid to provide increased operating flexibility for the plant and to reduce the plant capital equipment cost.

Emissions and performance test results for the Capstone gas turbine are presented for both naphtha and bioethanol as a liquid fuel source for the LPP skid. The tests were conducted at the LPP Combustion facility located in Columbia, MD (just north of Washington, DC) and the generated power was sold to Baltimore Gas and Electric as part of a net metering agreement. Future gas turbine testing is planned using additional liquid fuels such as diesel and biodiesel.

54-3

Laminar Flame Speed Study of Syngas Mixtures (H_2 -CO) with Straight and Nozzle Burners

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Laminar flame speeds of undiluted syngas (H_2/CO) mixtures have been studied at atmospheric conditions using chemiluminescence and schlieren techniques for straight cylindrical and nozzle burner apparatus. A wide range of mixture composition, from pure H_2 to 1/99 % H_2/CO , has been investigated for lean premixed syngas flames. To achieve a better flame stabilization and reduce flame flashback propensity, two nozzle burners of different sizes have been designed and fabricated and were further used to compare the flame cone angle and the total surface area of the flame techniques. Results are compared to predictions using recent H_2/CO mechanisms developed for syngas combustion.

54-4

Structural Changes in Bituminous Coal Fly Ash Due to Treatments with Aqueous Solutions

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Coal fly ash is produced in Israel via the combustion of class F bituminous coals. The bulk of coal fly ashes produced in Israel stems from South African and Colombian coals and therefore these ashes were the subject of the present study. It has been shown that during treatment of the flyash with aqueous solutions appreciable Structural Changes in the Matrix do occur. The flyash can be used as a scrubber and fixation reagent for acidic wastes. Recently it was reported that the scrubbing product can serve as a partial substitute to sand and cement in concrete. The bricks have proved to be strong enough according to the concrete standards.

In order to have a better understanding of the fixation mechanism we have decided to treat the flyashes with water or acidic solution (0.1M HCl) thus changing the surface of the flyash particles. Surface analysis of the treated and untreated fly ashes have demonstrated that the treated flyashes have changed appreciably its' interactions with transition metal ions. Three possible modes of interactions were observed: cation exchange, chemical bonding and electrostatic adsorption of very fine precipitate at the flyash surface.

54-5

Influence Factors on Density and Specific Surface Area (Blaine Value) of Fly Ash from Pulverized Coal Combustion

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In the Japanese electric power industry, it is desirable to reduce the cost of the treatment and expand the range of use of fly ash, such as in concrete admixtures. Therefore, it is necessary to form high-quality fly ash. To obtain high-quality fly ash, it is important to clarify the factors affecting its properties. In this study, the factors affecting the density and specific surface area (Blaine value) of coal fly ash were investigated on the basis of experimental results obtained using our combustion test facility and the ash data from the boiler of an actual electric power plant. The density was affected by the ash particle size, the true density of the component materials and aluminum content which is closely related to the fusibility. The specific surface area was affected by the particle size distribution and particle shape. The shape was affected not only by the ash particle size but also by the unburned carbon concentration, the ash fusibility and the ash content in the coal. It was also found that the specific surface area of the ash generated from our combustion test facility is higher than that of ash from actual boiler for ash with the same particle size. This result indicates that the shape of particles is affected by their heating and formation histories in the boiler. On the basis of the above findings, correlation equations were obtained for the density and Blaine value.

POSTER SESSION 1 COMBUSTION

P1-1

Alternative Sorbents for Desulphurization of Flue Gases

Pavel Kolat, Vaclav Roubicek, Zbyszek Szeliga, Bohumir Cech, VŠB-Technical University Ostrava, CZECH REPUBLIC

Natural limestone, as the conventional sorbent, is used for desulphurisation of waste gases for combustion of fossil fuels. There are two ways, simplified, to minimize the consumption of limestone as natural primary source in desulphurization technology of flu gases. One is increasing of the efficiency of the process, second is replace the limestone with alternative sorbents.

Alternative sorbents, in the research, are defined by authors as the waste substances, by-products from from sugar industry product (saturation sludge) and paper industry production (caustic sludge), and they represented, under the present conditions of knowledge, the alternative of the so far most frequently used sorbents – natural limestone. The general motivation for selection of these substances was the fact that those substances are waste materials from the processes described below.

The article is focused on desulphurization tests with alternative sorbents in the real combustion units.

After general research into chemical and physical properties of investigated waste substances suitable for dry additive method of desulphurization in fluidized layer and their study, the authors found out the already mentioned set of substances. These substances are appropriate for the desulphurization process not only from the viewpoint of the above-mentioned properties, but also because of their availability. Their availability may be one of criteria for their real implementation in heavy duty facilities.

Prior to application of alternative sorbents in the process of dry additive method of desulphurization in real equipment, there was necessary to test the behavior of sorbents in laboratory conditions.

The research of behaviour of alternative sorbents in laboratory conditions in dry additive method of desulphurization prepared the base for performance of tests on real equipment. Results from tests may be evaluated as very good with the prerequisite for utilization, testing of investigated substances in real combustion units.

On the basis of carried out laboratory and pilot tests one may expect good results from those real units (equipment with greater output), some of these experiments have been already performed.

It may be stated that results of the given sorbents on the given equipment are in mutual accord.

Primarily by comparison of results from the unit CFBC and unit FBC $P_{\text{im}}=100\text{kW}_t$, as a pilot tests units, it may be concluded that the tests on the model CFBC were carried out correctly and the designed unit is very satisfactory. Some aspects of application of ultra-fine sorbents will be further investigated on this unit.

The process of stay of ultra-fine particles of alternative sorbents in fluidized layer of model CFBC was recorded as one of phenomena of behaviour of investigated substances for the period exceeding the period calculated on models. Further, the hypothesis was defined and partially examined, which explains this phenomenon.

Authors in this article attempted to describe the research of alternative sorbents that have a chance to replace the primarily natural raw material, limestone. It should be emphasized that waste substances were identified and investigated as alternative

sorbents. This article describes individual steps of research, primarily laboratory tests on the real unit.

It was carried test with the saturation sludge in unit with circulating fluidized layer with rated output of $P_{jm}=120$ MWt, with the saturation sludge as the substitute for natural limestone the results of laboratory tested were confirmed.

The desulphurization test was also carried out with the saturation sludge in the powder boiler with granular furnace $P_{jm}=72$ MWt, the results appear already as good.

The conclusions from these tests confirm a very good sorption capability on substances identified by authors as alternative sorbents in the process of dry additive method of desulphurization of the given technologies.

The following quantities were measured and observed during the test

Data of operating measuring instruments

Measurement of basis gaseous components of emissions CO, NO_x, SO₂ and relating O₂

The samples of ashes, flue ashes and fuel were taken for other analyses

The following criteria were chosen for test evaluation:

- The course of concentration of SO₂, as the means for evaluation of the particular course of dry additive method
- Behavior of fluidized layer, the general parameters were monitored using the own monitoring unit with regard to the use of saturation sludge
- Evaluation of effect of the use of saturation sludge as the substitute sorbents on residues after combustion

P1-2

Operation of Large Fluidized Bed Boilers and Methods of Diagnostics

Pavel Kolat, Zdenek Kadlec, Bohumir Čech, VŠB-Technical University Ostrava, CZECH REPUBLIC

The article gives a summary of the measurement units that are used for diagnostic measurements in fluidized bed boilers. During the verification process, the Technical University of Ostrava designed and tested various types of probes for temperature and velocity measurements, and for sampling both flue gases and solid particles. Since 1995, 29 large fluidized bed boilers of different designs and power outputs have been into operation in the Czech Republic. All boilers have been constructed based on foreign experience, technical documentation, licensing and engineering. Every large power project is always preceded by trial measurements and measurements on smaller pilot, trial or if need be model equipment. Due to the great difference in scale, some unexpected measuring equipment behavior or problems must be taken into consideration.

This article reviews the development of verification methods and presents some equipment for the determination of all important and interesting measuring data. The conclusions might be useful to energy companies and operators that want to verify operation data of fluidized bed boilers, flue gases and air channels.

Apart from basic measurements there are a number of other similar measurements of specific equipment parts that might be initiated because:

- the manufacturer is interested in using the experience to improve or design new units,
- the operator is interested in both eliminating problems and improving the economics of the operation process.
Diagnostic measurements at a particular unit basically cover:
- the measurement of fluidized bed temperatures, furnace temperatures, flue gases temperatures at ancillary heating surfaces up to the boiler,
- the measurement of flue gas velocity in the furnace chamber and exits of cyclones, in cyclones, at the cyclone exit to second pass as well as in the area of additional boiler surfaces,
- sampling of flue gas in the combustion chamber, heat and mass transfer,
- sampling of characteristic solid ash particles including isokinetic sampling to determine solid particle concentrations.

The results give more detailed information about the behavior of the fluidized layer in various fluidized bed boilers.

P1-3

Additive Desulphurization by Sodium Bicarbonate in Pulverized-Fuel Furnaces

Pavel Kolat, Zdenek Kadlec, Pilar Lukas, VŠB-Technical University Ostrava, CZECH REPUBLIC

The main objective of research is to assess the effectivity of reduction of sulphur oxides content in combustion products below the 200 mg/m_N³ emission limit by dosing sodium bicarbonate NaHCO₃ into the flue ways before the electrostatic fly-ash separator, i.e. employing the dry additive method of reducing the content of sulphur oxides in combustion products. The first experimental desulphurization in the Czech Republic, employing the sodium bicarbonate additive method, was performed with the use of a 220t/h boiler. The article is divided into several, closely related chapters quoting all indispensable information.

The article as mentioned above, is divided into several thematically related chapters. The initial chapter deals with the current energy demanding ness in the Czech

Republic, European Union and in other parts of the world. It further quotes the legislative issues concerning sources of SO₂ emissions and their limits, in accordance with the Act 146/2007Coll., as the main goal is elimination of sulphur oxides in combustion products. In order to provide a full view, this chapter quotes a range of data concerning annual SO₂ emission values of some major sources in the Czech Republic. The objective of the theoretical part is to bring out information concerning energy budgets, legislative issues, yearly values, and substantial SO₂ emission sources in the Czech Republic.

The following chapter brings a detailed description of the theoretical part concerning reduction of sulphur oxides, including both primary and secondary measures. The second chapter, dealing with an in-depth view of the problems related to elimination of sulphur oxides, further offers overall information on lime and coal management of ČEZ, a.s., representing the company which covers a major part of electric energy consumption in the Czech Republic.

The above mentioned chapters introduce the theoretical part. However, the main objective of the research is carrying out of an experimental desulphurization test the purpose of which is to find out and explore the possibilities of reducing the levels of sulphur oxides below the emission limit of 200 mg/m_N³ by way of a dry method using a different additive than CaCO₃. During the experiment, a sodium bicarbonate NaHCO₃ based preparation was used. This preparation was first ground to a required fraction and fed consequently into the flue ways before the electrostatic fly-ash separator.

The whole experiment is supported by gaseous emission measurements located before the point where the NaHCO₃ based preparation is fed to the flue ways, as well as subsequent measuring of SO₂ gaseous emissions behind the electrostatic fly-ash separator. The results are further supported by chemical analyses of fly-ash samples from individual sections of the separator.

P1-4

Ionic Liquids with Amine Functional Group: A Shortcut to Improve the Performance of Ionic Liquids for CO₂ Scrubbing

Jelliarko Palgunadi, Jin Kyu Im, Antonius Indarto, Hoon Sik Kim, Minserk Cheong, Kyung Hee University, KOREA

One of the global environmental problems of today is the increase of the greenhouse gases concentrations in the atmosphere. This problem partly corresponds to the increase of carbon dioxide (CO₂) emission from the burning of fossil fuels for power generations. To response this challenge, carbon capture and storage (CCS) using liquid scrubber receives great attentions because there is potential for retrofit to existing power plants without changing the existing process. Within this framework, ionic liquids (ILs) have been proposed as alternative media for scrubbing CO₂ from post-combustion emission where SO_x, NO_x, and tiny particulates are also inevitably co-produced. Due to the ionic nature of these low-melting point salts, the problem associated with the solvent lost during cyclic absorption-desorption processes might be minimized. Experimental results from our group combined with numerous published data demonstrated that the CO₂ solubility in many conventional ILs at the pressure close to atmosphere is very low. Thus, these conventional ILs are not feasible compared to the molecular amine-based scrubbers, i.e. monoethanol amine (MEA) for capturing CO₂ contained in a post-combustion stream. Regular solution theory and quantum chemical calculations demonstrate that the CO₂ solubility in common ILs is merely controlled by weakly physical interactions (i.e. van der Waals interactions). To improve the performance of ILs, various task-specific ILs dissolved in a simple room temperature IL or in a non-volatile organic solvent were evaluated for CO₂ capture at low pressures. Cost-effective ILs containing an amine moiety were prepared by quaternization of commercially available diamines. Similar CO₂ loading capacity as found in a molecular amine system was observed likely through the formation of a carbamate salt-like structure. The CO₂ solubility measurements, the computational calculations of the CO₂-IL complexes, and some factors associated with the optimum absorption conditions are discussed.

P1-5

Absorption of Sulfur Dioxide in Task Specific Ionic Liquids Containing SO₂-Philic Groups on the Cation

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Fossil fuel burning power plant is one of major producers of sulfur dioxide emissions worldwide. To mitigate the emissions of SO₂, scrubbing process employing liquid absorbents is considered as an alternative method in addition to the flue gas desulfurization (FGD). Room temperature ionic liquids (RTILs) have been demonstrated to absorb SO₂ effectively. Tunable physicochemical properties derived from the combinations of tailored ionic components and non-volatility of RTILs resulted from the coulombic force stabilization are the key features making these materials more attractive than volatile organics for SO₂ capture. Some literatures suggest that the formation of specific interactions such as Lewis acid-base interactions control the SO₂ solubility. Thus, the presence of SO₂-philic groups on the molecular structure of RTILs is required to achieve high SO₂ solubility. In our group, imidazolium-based cations containing various pendant groups with capabilities to form specific yet reversible interactions with SO₂ combined with [RSO₃]⁻ as the anion were

synthesized. The solubility measurements for SO₂ are presented and the effects of the cation structure on the absorption-desorption processes are discussed.

P1-6
Reaction Characteristics of New Oxygen Carriers for Chemical Looping Combustion

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In this paper, natural gas combustion characteristics of new oxygen carrier particles were investigated in a batch type fluidized bed reactor (0.052 m ID, 0.7 m high). Three particles, OCN703-1100, OCN705-1100, and OCN708-1300 were used as oxygen carriers. Natural gas and air were used as reactants for reduction and oxidation, respectively. To check feasibility of good performance, inherent CO₂ separation, and low-NO_x emissions, CH₄, CO, CO₂, O₂, H₂, NO concentrations were measured by on-line gas analyzer. Moreover, the regeneration ability of the oxygen carrier particles was investigated by successive reduction-oxidation cyclic tests up to the 10th cycle. All three oxygen carrier particles showed high gas conversion, high CO₂ selectivity, and low CO concentration during reduction and very low NO emission during oxidation. Moreover, all three particles showed good regeneration ability during successive reduction-oxidation cyclic tests up to the 10th cycle. These results indicate that inherent CO₂ separation, NO_x-free combustion, and long-term operation without reactivity decay of oxygen carrier particles are possible in the natural gas fueled chemical-looping combustion system. However, OCN708-1300 represented temperature and pressure fluctuations during reduction and slightly decay of oxidation reactivity with the number of cycles increased.

P1-7
Combustion Reactivity of Char Derived from Solvent Extracted Coal

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This study produced char from ash-free coals and investigated its reactivity with air. Ash-free coal was manufactured by using the solvent extraction technique. Three different ranks of coal were used as samples: Australian lignite coal, Indonesian subbituminous coal, and American bituminous coal. 1-MN and NMP were used as solvents for extraction. The FT-IR analysis showed that the 3490 cm⁻¹ absorption band, which usually appears in high high-rank coal, appeared in the 1-MN-extracted coal regardless of the rank of the original coal. Furthermore, the 1011–1095 cm⁻¹ band of the extracted coal decreased greatly due to the reduction of ash. The FT-IR data of the residual coal samples was not much different from that of the original coal. The 1-MN-extracted coals showed the same burning profile regardless of the rank of the original coal, and had a higher range of burning temperatures than the bituminous coal. On the other hand, the 1-MN-extracted coal had the same burning speed as that of the original coal. The NMP-extracted coals all showed lower burning temperatures than the original coal, whereas the residual coals showed a similar range of burning temperature to that of the original coal.

P1-8
Flue Gas Desulphurization and Denitration by Activated Char Obtained from Anthracite

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In order to clarify the mechanism of desulphurization and denitration from flue gas using activated char obtained from anthracite, the orthogonal design method was introduced in the experiment, the connections between the desulphurization and denitration effect, and influencing factors: space velocity, react temperature, the concentration of NO and SO₂ were studied. Besides, the structure and elements of activated char were characterized by SEM and XPS respectively in this paper. The experimental results show that the competed adsorption on activated char contained NH₃ existed between SO₂ and NO, and SO₂ took priority of NO on activated char; NO was removed by selective catalytic reduction with NH₃, and SO₂ was removed by direct catalytic and producing ammonium sulphate on activated char, simultaneously, chelate nitrate came into being. The optimum condition was found out, that is space velocity, react temperature, the concentration of NO and SO₂ were 4500h⁻¹, 130 °C, 1500ppm and 1000ppm respectively, at which the SO₂ adsorption capacity and the removal capacity of NO were 152.82 mg/g and 57.88mg/g respectively. The reaction temperature was the key factor to decide desulphurization and denitration ability on activated char.

P1-9
Forced Flame Response Measurement in a Gas Turbine Combustor with High Hydrogen Fuel

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The forced response of swirl-stabilized lean-premixed turbulent flames to acoustic oscillations in a hydrogen enriched laboratory-scale gas turbine combustor was experimentally investigated. Nonlinear flame transfer function measurements were taken to investigate the flame's heat release response to upstream acoustic perturbations. This analysis shows that the dynamics of natural gas-air premixed flames are characterized by several regimes: the linear, transition, and first and second nonlinear regimes, depending upon steady-state flame geometry, modulation frequency, and amplitude of excitation. The present results show that the flame geometry changes from a dihedral V flame to an enveloped M flame with an increase in hydrogen mole fraction, and the changes in steady-state flame structures have a significant impact on the flame's response to acoustic modulations. The present results suggest that the M flame, unlike the V flame, has the unique dynamic characteristic of acting as a damper of flow perturbations. The response of the M flame remains in the linear regime, irrespective of the shedding of a vortex-ring structure, because the interaction between the large-scale structure and the flame is not strongly coupled.

P1-10
Development of Commercial CFBC Boiler for Refuse Derived Fuel

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A 6 MW_{th} pilot scale Circulating Fluidized Bed Combustion (CFBC) Boiler is designed and constructed to perform a feasibility of alternative fuel combustion. The capacity of the boiler is equivalent to 1MWe power generation boiler and it produces 8tons of steam per hour. The maximum qualities of the steam are 38ata 723K. This boiler burns 1000 kg of refuse derived fuel (RDF). Two kinds of refuse derived fuel fabricated by under the regulation of Department of Environment were tested in this pilot plant. One is plastics oriented and the other is from municipal waste. The combustion and the emission characteristics were monitored. The results were compared with those of bench scale or commercial scale data of refuse derived fuel (RDF) or coal combustion. The major combustion zone of RDF combustion was confined to the fuel feeding area and it was narrower than that of coal due to high volatile content of RDF. The emission of SO₂ and NO_x was much lower than that of coal but the emission of HCl was much higher than the Korean regulation of 20ppm at 12% O₂. An external device for HCl control was adopted for the operation. The emission of HCl was less than 10ppm at the stack after the control.

The heat transfer coefficients of evaporator, super-heater, economizer and air heater were analyzed. Most of the numbers showed that the heat transfer coefficient was similar to that of coal boiler. But evaporator showed less value than that of coal boiler. The phenomenon is considered to be related to the narrower combustion zone of the RDF combustion.

The corrosion characteristics of heat transfer tube were not identified due to relatively short operation hours. But the analysis of boiler deposits and ash showed high amount of iron oxide and chloride contents. The chlorine was highly concentrated in deposits and ash. The test of the toxic characteristics of ash by leaching was also performed and it showed the fly ash is relatively inert and could be safely disposed.

The combustion and hydrodynamic data obtained from the operation and construction of this pilot plant were applied to the design of a 10MWe CFBC co-generation boiler for RDF in Korea. The capacity of the boiler is 56MW_{th} output and 10MWe. The steam qualities of the boiler are 47ata and 728K. This boiler is designed to consume 10tons of RDF made of municipal waste per hour.

P1-11
Simplified Quantification of Tetrafluoroborate Ion in Flue Gas Desulfurization Effluent for Management of Fluorine Emission

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Boron compounds in industrial wastewaters mainly exist as boric acid and tetrafluoroborate ion (BF₄⁻). BF₄⁻ contributes to the emission regulations of both boron and fluorine. In coal-fired power plants, BF₄⁻ is formed in a flue gas desulfurization (FGD) unit, depending on the type of FGD and coal. BF₄⁻ is quite stable and slow to decompose, which may lead to increased values of especially fluorine in discharged effluents. Thus, in some plants, a dedicated treatment to decompose BF₄⁻ is employed to manage BF₄⁻ emission. The conventional measurements of BF₄⁻, *i.e.*, spectrophotometry and ion chromatography requires a tedious pretreatment or a stationary equipment and are difficult to carry out onsite. The onsite measurement of BF₄⁻ is helpful for the efficient treatment of BF₄⁻, which may lead to a reduced amount of sludge. We propose a simple and rapid analytical determination method of BF₄⁻ for properly managing the BF₄⁻ emission in FGD effluents. We build up a compact flow measurement system using BF₄⁻ ionselective

electrode (ISE) mounted in a flow cell. By measuring samples in a flow mode, the stability and reproducibility of measurements is largely improved compared to the conventional static batch measurement. The system can measure BF_4^- in the range of 1-100 mg/L and the measurement completes in less than 10 min. The proposed method is an easier and more rapid determination compared with the conventional analytical methods. The application of the system to the FGD effluents is discussed.

P1-12

Enhancing Thermal Efficiencies in Steam Power Plants by Utilizing the “W2” Prime Mover as Auxiliary Equipment

Jerry F. Willis, Admiral Air, Inc., USA

Coal fired power plants are the primary source of electrical power today. There are huge reserves of relatively inexpensive coal resources around the world. The coal fired electrical plant is here to stay.

The thermal efficiency of the typical coal fired electric plant is understood to be approximately 35%. This thermal efficiency leaves a lot of room for improvement. Thermal efficiency today is improved by incorporating new boiler and steam turbine technology that produces only minor improvements in thermal efficiency.

Increasing thermal efficiencies in power plants will reduce emissions, create potential for carbon credits, and extend coal reserves well into the future. This paper describes a method to substantially improve the thermal efficiencies in existing power plants by adding the new “W2” Prime Mover as auxiliary equipment to steam turbines.

P1-13

Comparing Efficiencies of the Steam Turbine Versus the “W2” Prime Mover

Jerry F. Willis, Admiral Air, Inc., USA

Coal fired power plants operate today using equipment which was designed during an era when fossil fuels were plentiful and relatively inexpensive. Greenhouse gas emissions and thermal efficiencies were of little concern when steam turbines were first developed.

This paper compares the system characteristics of a typical coal fired power plant utilizing a steam turbine versus the new concept “W2” Prime Mover. The “W2” Prime Mover will be shown to increase the thermal efficiency of coal fired electric power plants from approximately 35% to values approaching 60%. This efficiency is achieved by utilizing static steam pressure to drive the “W2” Prime Mover whereas steam flow characteristics drive the steam turbine.

P1-14

Optimization of Fuel Properties with Utilization of Biodegradable Municipal Wastes for Combustion Units

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The Landfill Directive 1999/31/EC obliges Member States to reduce the amount of biodegradable municipal waste (BMW) that they landfill. The decreasing amount of landfilled BMW is not comply in Czech Republic. The waste production of BMW in Czech Republic is 494 Mt (400 kg per year and inhabitant). Only 25 % of biodegradable waste in municipal waste is in area with central heating or gasification. Czech Republic utilized for energetic purposes only 10 % of municipal wastes.

Limited utilization of separated BMW from municipal wastes is connected with lower gross calorific value, which is influenced by presence of anorganic matter (soils, construction rubbish). Separated biodegradable wastes (without paper) contained from spring to autumn 22 – 49 wt % combustible matter, 10 – 25 wt % organic carbon and gross calorific value between 2700 – 7950 kJ/kg. The composition of biodegradable wastes is different in winter (grass and leaves are missing), the contamination with soil particles is restricted. The gross calorific value is higher – 13533 kJ/kg.

The paper is devoted to the preparation of fuels with utilization of biodegradable municipal wastes, black coal and additives for improving of mechanical and combustion properties with pelleting. The requirement of gross calorific value for middle energetic sources (> 10 000 kJ/kg) can be complied for fuel with maximal content 50 wt % of biodegradable wastes. The main advantages of BMW for energetic utilization are very low content of alkalis (maximal is 2.5 % - bound in silicates) and CaO addition for sanitation of biodegradable wastes.

P1-15

Sulfur Retention in the Ash During Combustion of Tuncbilek Briquettes

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In this study, it was aimed to briquette the mixture of Tuncbilek lignite in the size range of 0.5-10 mm and Tuncbilek Coal Washing Plant's slurry waste involving 0.1-0.5 mm particles with molasses and dolomite bindings and to achieve retention of sulfur in the ash during combustion. In this way coal fines with high sulfur content was converted by briquetting into a strong and uniform fuel giving rise to low sulfur emission upon combustion. In addition, Coal Washing Plant's slurry waste which is

currently not being utilized has been converted into a usable form in industry by the addition to coal fines.

Different amounts of dolomite and waste were used in briquetting and their effects on the efficiency of retention of sulfur in the ash were examined. A pilot equipment with 100 kg capacity was used for briquetting. Briquettes were burned in a TGA analyzer and in a commercial stove, and sulfur analyses were made in the ash. A mixture of 67% lignite, 20% slurry waste, 7% molasses and 6% dolomite gave the best result. Sulfur retention in the ash was found as 74.6% and 60.2% by TGA and stove tests, respectively.

Types of sulfur in the original Tuncbilek lignite were also determined experimentally. Since original sulfate in the coal is not affected in combustion, the retention efficiency of sulfur in the ash was also evaluated on the basis of combustible sulfur and was found to be 90.8 % and 73.2 % by TGA and stove tests, respectively. Thus, briquetting provided a decrease in sulfur dioxide emission not less than 70%. Proximate analyses and heating values of the briquettes were also made and the results indicated that the briquettes obtained were marketable.

P1-16

Experimental Study on Performance that Carbon Dioxide Inhibits Coal Oxidation and Spontaneous Combustion

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Coal resource is greatly abundant in China, the coal production and consumption of China is in the leading positions of the world, it accounts for about 85% of total production and consumption of domestic primary energy. Coal spontaneous combustion is becoming a critical factor that obstructs production safety and efficiency of coal mines in China. In many existing kinds of coal fire prevention and extinguishment measures, CO_2 is one of the widely used and most effective methods in coal fire prevention and controlling. Based on analysis to current mechanism of coal spontaneous combustion and fire prevention and extinguishment techniques, adopting oil-bath temperature programming experiment and gas chromatography, CO_2 's inhibitory performance to spontaneous combustion of coal sample of Tingnan coal mine is analyzed in paper.

Oil-bath temperature programming experiment system is improved, the accuracy, stability and reliability of the improved system proved superior to traditional temperature programming experiment system through temperature rise rate test experiment. Spontaneous combustion characters parameters test of coal sample in pure air is carried out by using this experiment system in order to offer comparison standard for further research. Furthermore, temperature programming to coal sample is conducted in oil-bath in different concentration of CO_2 . Testing results are compared with the concentration of CO , O_2 , temperature, CO generation rate and O_2 consumption rate tested and calculated in previous experiment in pure air. Proportion between concentration of CO and O_2 , CO concentration and temperature, CO generation rate and O_2 consumption rate are carried out to eliminate obstructions from certain external factors, such as inlet of CO_2 , the influences of CO_2 of different concentrations to coal oxidation and spontaneous combustion are investigated. Results indicate that: above 100°C, CO_2 whose concentration is over 30% can obviously inhibit coal oxidation and CO generation under the experimental conditions. Finally, CO_2 is used in spontaneous combustion prevention in workplace No.106 of Tingnan coal mine, the data of CO and O_2 indicates that CO_2 performs well in inhibiting coal oxidation and spontaneous combustion.

P1-17

Development of an Analytical Solution for Jet Diffusion Flame Equations

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Exact solutions of nonlinear equations help us to understand the mechanism of nonlinear effects. Any exact solution for flame propagation must make use of basic equations of fluid dynamics modified to account for the liberation and conduction of heat and for charges of chemical species within the reaction zone. The present work develops an analytical solution for a jet diffusion flame. The model is based on the solution of the mixture fraction for turbulent fluid flow with no constant eddy viscosity and the results are found to compare favorably with data in the literature.

P2-1

Suitability of a South-African High Ash Content and High Ash Flow Temperature Coal Source for Entrained Flow Gasification

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In slagging gasifiers the ash flows down the gasifier walls and drains from the gasifier as molten slag. Coals selected for slagging gasifiers should thus have an ash flow temperature (AFT) below the operating temperature of the gasifier, and in practice can be lowered by the addition of a flux, such as limestone. As the mineral matter start to melt and become a liquid (between the softening temperature and the flow temperature of the mineral matter in coal), it will have a specific composition and a related viscosity (ease of flow). During entrained flow gasification the viscosity has to be low enough for the slag to flow and drain from the gasifier. As a consequence, the viscosity of the slag, which depends on the slag composition, is one of the most critical factors in the operation of slagging gasifiers.

The pilot gasifier at Corus in The Netherlands, as used to produce reduction gas for the steel industry, was used for the test. The objective of the experiment was to investigate the gasifiability of high ash coal in an oxygen blown, atmospheric pressure entrained flow pilot gasifier, and to quantify / qualify where possible and within the known limits of such a pilot test unit, the slag, fly-ash, water and gas characteristics.

The coal was fed pneumatically with N₂ at ±50kg/hr through the oxygen coal burner. The outlet velocity of the burner was set at 110m.s⁻¹ (oxygen flow rate of 20Nm³hr⁻¹). The header temperature was controlled at maximum 1600°C, resulting in a temperature at the bottom part of the gasifier between 1200 and 1300°C. Due to this rapid heat loss over the gasifier length, the coal was over-fluxed in order to maintain a running slag and avoid blockages at the bottom temperature of 1200°C, which is almost 150°C lower than normal slagging operating conditions. The refractory hot face showed limited wear or penetration of minerals into the refractory. The slag viscosity was thus fluxed adequately for the specific setup to flow gently over the refractory and protecting the SiC. The measured and equilibrium simulated carbon balances corresponded well and could be closed with a high degree of accuracy. During stable and high load periods, the CO content varied between 50 and 60 vol%, H₂ between 10 and 20 vol% and CO₂ <10%. Carbon conversion varied between 79% and 96%. The calculated residence times were 1.9 to 2.2 seconds.

The testing facility at Corus Ijmuiden was able to maintain conditions for high-ash coal gasification at relatively long periods of stable operation and high production rates. High coal conversions were achieved and high ash flow temperature coal, blended with limestone as fluxing agent, can be regarded as successful within the limits of the test unit.

P2-2

Continuous Experiments of Hot Gas Desulfurization Process Using Zn-Based Solid Sorbents in a Pressurized Condition

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The high temperature desulfurization technique is one of the elemental technologies of syngas purification having both higher thermal efficiency and lower emissions compared with conventional wet cleanup processes. The high temperature desulfurization is a novel method to remove H₂S and COS efficiently in the syngas with regenerable solid sorbents at high temperature and high pressure condition which are preferable to gasification condition. In this study, we developed 5 Nm³/h of hot gas desulfurization process composed of a riser type desulfurizer, a fluidized-bed type regenerator, and a loopseal. We reported several hydrodynamics testing results of the proposed process in the previous Pittsburgh Coal Conference. In order to investigate the desulfurization performance, we used Zn-based solid sorbents which were provided by Korea Electric Power Research Institute (KEPRI). The solid sorbents was manufactured by a spray-drying method, so the shape of the sorbents is spherical, which is adequate for the fluidization. We performed high-temperature and high-pressure tests to check feasibility of stable operation with solid circulation and to investigate the desulfurization performance using simulated syngas with 2,000 ppm of H₂S inlet concentration. We are now developing a bench-scale hot gas desulfurization system which handles 100 Nm³/h of syngas treatment at 20 bar of operating pressure and this system will be integrated with a coal gasifier which was installed in the Institute for Advanced Engineering (IAE).

P2-3

Biomass Gasification in Dual Fluidized Reactors: Process Modeling Approach

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A process model including chemical reactions and mass/heat balances is investigated for biomass steam gasification in a dual fluidized bed (DFB) system. Gasification in the DFB gasifier is calculated using a two-stage thermodynamic equilibrium model in which the carbon conversion of biomass is predicted using solid-gas reactions, while the composition of syngas is calculated in gas-phase reactions. The drying and devolatilization of biomass are considered to be completed within the gasifier. Complete combustion of unconverted char and additional fuel is assumed in the combustion chamber (riser). Heat required for the endothermic gasification reactions is provided by the circulating bed material (silica sand).

The model proposed in this paper is first validated using experimental data taken from published works. Then, the effects of gasification temperature and steam to fuel ratio on the carbon conversion of biomass, the composition of product gas and the circulation rate of bed material are examined.

P2-4

The Role of O₂/COG Ratio on Non-Catalytic Partial Oxidation Process of Coke Oven Gas

Haizhu Cheng, Sufang Song, Yongfa Zhang, Taiyuan University of Technology, CHINA

Coke oven gas (COG) was the main high-quality hydrocarbon resource, and its major component were H₂ 57~60%, CH₄ 25~28% and CO ~ 6% by volume. It was an important way for the coke oven gas to convert into synthetic gas, and then for the production of methanol and other chemical products. In this study the influence of O₂/COG ratio on the content of synthesis gas was researched based on the small-scale single-hole nozzle experiment. The main equipments are single-hole nozzle and quartz tube reactor of which the size was 700 × 70mm. The contents of O₂, N₂, CH₄, CO, CO₂, C₂H₄ and C₂H₆ in the synthesis gas were determined by chromatography GC-950 and the content of H₂ by chromatography GC9890A. The experimental precision was determined by Content Subtraction of H₂. The experimental data was analyzed based on Excel. The reaction process and the temperature distribution in the reactor were researched and the results showed that: methane conversion increased with the increasing O₂/COG ratio. CH₄ conversion rate reached 95%~97% when the O₂/COG ratio increased from 0.22 to 0.26, and the content of CH₄ in the synthesis gas was ≤ 1%. When the O₂/COG ratio varied from 0.18 to 0.40, the H₂/CO ratio changed from 2.0 to 2.8, H₂ 65% to 58%, CO 24% to 28%, CO₂ 5% to 7.5%. O₂ fluctuated in 0.15%~1.0%, N₂ fluctuated in 2.5% ~7%, C₂H₄ ≤1.7% and C₂H₆ not detected. The temperature at the bottom of the reactor increased with increasing O₂/COG ratio from 750~850°C to 950~1050 °C, the central temperature slightly higher from 600~680 °C to 650~750 °C, the temperature at the top dropped from 450~ 550 °C to 420~ 500 °C.

P2-5

Effect of Alkaline Oxide on the Coal Ash Fusion Temperature

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Coal ash fusion temperature is an important process index during gasification operation. In order to meet process demand and make use of more different coals in gasification some fluxing agents should be blend in coal to reduce ash fusion temperature. The relationship between ash fusion temperature and chemical composition of ash is very complicated. Ash fusion temperature of coal depends largely on the quaternary mixture system of SiO₂-Al₂O₃-Fe₂O₃-CaO in ash, meanwhile, some lower content components, such as Na₂O, in coal ash also play a certain role in ash fusion temperature. In general, it will have higher fusion temperature if SiO₂ and/or Al₂O₃ contents are higher in ash. According to above opinion, this paper focus on Fe₂O₃, CaO and Na₂O as ash-fluxing agents to find efficiency way for reducing coal ash fusion temperature, which is too high to match gasification operation index.

The melting temperature of ash under oxidizing conditions was measured in this work by using SJHR-3 Smart Ash Fusion Analyzer, according to GB/T219-1996 (China standard) test procedures. Testing temperature ranges of this instrument from room temperature to 1500°C. Simulation coal ash samples with high ash melting temperature consist of SiO₂ and Al₂O₃ in different ratio. Experiment results indicated that ash fusion temperature can be reduced evidently by adding any fluxing agent Na₂O, CaO and Fe₂O₃, respectively, and degree of fluxing is Na₂O > CaO > Fe₂O₃. Different ratio of CaO and Fe₂O₃ mixture as composite fluxing agent can also reduce fusion temperature. And it was noticed some synergy effects had taken place during this process. The results showed that mixture ratio of CaO and Fe₂O₃ as complex fluxing agent has an optimum value in reducing fusion temperature. These experiment results were used in three kinds of high ash fusion temperature coals (A, B and C). When single and composite ash-fluxing agent was added respectively in coal, according to different ration, the consistent results had been gained in reducing ash fusing temperatures from coal samples and simulation ashes.

Numerical Simulation of Carbon Catalytic Reforming Reactor

Haizhu Cheng, Yongfa Zhang, Sufang Song, Taiyuan University of Technology, CHINA

Coke oven gas (COG) was the main high-quality hydrocarbon resource, and its major component were H_2 57~60%, CH_4 25~28% and $CO \sim 6\%$ by volume. It was an important way for the coke oven gas to converse into synthetic gas, and then for the production of methanol and other chemical products. Based on the experiment of a small-scale single-hole nozzle reactor, coke oven gas carbon catalytic reforming reactor have been designed. CH_4 and CO_2 reforming catalyst is traditionally a precious metal catalyst. Because of carbon deposition the catalyst was easily inactivation. The prior study showed that carbon is a catalyst in CH_4 and CO_2 reforming. Therefore, for using carbon catalyst to prevent effectively carbon deposition in the test reactor, it has provided the experimental foundation for the continuous industrial production. In this paper the Computational Fluid Dynamics (CFD) software was used to simulate reactor for the analysis of temperature distribution, flow field, and synthesis gas composition. Simulation results show that the reforming reactor demonstrated good flow field and temperature distribution. The H_2/CO ratio was about 1.8-2.8 in the synthesis gas, which is the raw material for methanol synthesis.

P2-7

A Study on the Temperature Profile and Heat Transfer Coefficients in Underground Coal Gasification Cavities

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Underground Coal Gasification (UCG) is the potential in-situ method of converting un-mined coal into combustible syngas which can be served as a fuel for power generation, industrial heating or as chemical feedstock. UCG process provides a source of clean energy with minimal greenhouse gas emissions, when it is compared with the conventional coal mining and gasification. As gasification proceeds underground cavity is formed as the coal burns, and its shape and size changes with time as the coal is consumed. The shape and rate of growth of this cavity will strongly depend on the temperature profile inside the cavity. As underground coal gasification cavities are of irregular three-dimensional shapes, computational fluid dynamics studies (CFD) are essential in order to understand the temperature distribution inside the UCG cavities. A complete knowledge of the transport phenomena inside the UCG cavity is important for both cavity growth modeling and process modeling as it determines the quality and rate of production of the product gas. In the present study, CFD simulations are performed to study the convective heat transfer characteristics of UCG cavities at specified boundary conditions. By changing the feed flow rate, surface heat transfer coefficients are obtained over a wide range of Reynolds number for four different cavity sizes. The methodology of determining heat transfer coefficient through FLUENT is validated by performing simulations for a circular pipe over a wide range of Reynolds number. The predicted heat transfer coefficients are consistent with the correlations.

P2-8

Some Results of UCG Ex-Situ Trials from HBP Company Point of View

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The Hornonitrianske bane Prievidza, a.s., Company (www.hbp.sk) as a private company which core business is deep coal mining and mining powered supports production has an interest on underground coal gasification at coal deposits in Slovak Republic for a certain time period.

In 2007 year the company started a national grant research project in cooperation with the Technical University in Kosice aimed towards gaining knowledge on underground coal gasification especially for conditions of the Slovak Coal Deposits.

The presentation briefly describes Coal Deposits in Slovakia as well as chosen quality parameters of coal seams. It evaluates in more details coal properties from the Novaky and the Handlova Coal Deposits and also the deposits conditions in which the company has mining licenses. Ex-situ research results are evaluated from possible practical usage point of view mainly in electro energy and heat energy sectors, because there is a power plant close to the deposits and the company. In a context of used research methods basically "UCG via Channels" and by means of "Fissured Coal Seam" it analyzes practical questions of future application of vertical boreholes or directed ones respectively of course in connection with mining and geological conditions of the coal deposits.

The paper also describes Company's plans with the underground coal gasification in future times.

P3-1

The Coagulation in Electric Field of the Argillaceous Suspensions from the Wastewater Resulted in Coal Processing

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The water resulted from mining industry and coal processing is characterized by a high concentration in argillaceous colloidal suspensions, which do not precipitate free not even in weeks.

Waste water from U.P. Coroesti washing technological process has a lot of argillaceous colloidal substances and is recalcitrant in cleaning.

Because the dispersion grade is high, these particles have a large specific surface, this explaining the high value of surface energy and their high capacity for absorption the ions from water. Because they will have the same electrical sign they will also have a high gravitational stability. So the flocculation process is a complex one, by electrical, chemical and mechanical nature where the cations tied by anionic group of flocculants challenge the inversion of the solid particles charged and in this way they lose the water layer adherent at their surface.

The most efficient process is electrical discharge of the particles.

Some research show that between electrodes happen similar phenomena to those from water electrolyze, liberating H^+ ions, which are absorbed at the hydrated part of the micelle, changing its sign, or liberating Al^{3+} ions from consumables electrodes, who in their way to cathode, meeting some minerals particles negatively charged, they partially neutralize this particles and provoke their coagulation by decreasing the electro kinetic Zeta potential (Z_p).

The galvanic chemical process for cleaning permits to reach the necessary cleaning level, based on the utilization of galvanic elements formed by electrodes pairs, placed in the solution that must be cleaned, by applying a current from an exterior source, without using chemical coagulants reactive.

The purpose of this study is to replace Zetag reactive – with coagulation role, used in present time at Coroesti processing plant, with electro coagulation in continuous electric field with consumable anode.

P3-2

Experimental Research on the CO Impact on the Explosion Characteristics of CH_4

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The gases explosion in coal mine is multi-component flammable gases explosion mostly caused by methane (CH_4). The flammable gases are mainly CO , C_2H_6 , C_3H_8 , C_2H_4 , H_2 and so on besides CH_4 in coal mine. All of them have a great risk of explosion. The existence of these flammable gases will influence the explosion characteristics of CH_4 to some degree. Because there are many different kinds of flammable gases, and the compositions and contents of the flammable gases changes dynamically according to different time and places, it is very difficult to provide exactly the same experimental conditions as the environment in a coal mine. For this reason, flammable gas CO has been selected to be researched in the laboratory on the impact of its presence on the explosion characteristics of CH_4 . The experimental results show that the adding of CO could lower the explosion limits of CH_4 and increase the intensity of the explosion of CH_4 , so that reinforce the risk of the explosion. The research results provide reference for the further research on the multi-component flammable gas explosion in coal mine.

P3-3

Thar Coal Mining Challenges

Farid A. Malik, EMR-Consult, PAKISTAN

Despite tremendous potential the mining sector remains seriously deficient in the country. From Coal to Chromite the mining, beneficiation and refining practices are either outdated or non-existent. In the seventies Resource Development Corporation (RDC) was created for the development of the Mineral sector. Saindak Copper and Gold Mine Development was the first major project of RDC.

Lack of field experience and mismanagement not only consumed RDC, it also resulted in the lease out of the Saindak Metals Ltd (SML) to Chinese contractors (Metallurgical Construction Company). Despite huge investment (Rs.14.5 billion) an opportunity was missed to nurture local mine development process capability.

Chromite mineral has been mined in Hindubagh District of Baluchistan since decades but exported without subsequent processing or value addition. In case of Thar Coal Field the Asian Development Bank (ADB) in their experts review report has declared 80% mining challenge and only 20% thereafter. Unfortunately this single world's largest coal deposit has remained un-tapped due to lack of mining focus. Like most mineral deposits, Thar poses its unique mining and hydrology challenges that can be overcome by modern mining techniques, technologies and know how.

In this paper the best mining practices will be discussed for the development of Thar Coal Field on sound commercial basis. A development pit will be developed to mine coal for subsequent processing and evaluation and also to establish the optimum mining techniques.

With a deposit like Thar the energy future of Pakistan is bright. As food and fuel are gaining importance globally, country has a potential to emerge as an important player. It is time to put our house in order.

P3-4

Submerged Sequencing-Batch Membrane Bioreactor to Treat the Coke Wastewater

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The coke wastewater contains toxic substances and higher ammonium nitrogen, it is difficult for biological treatment. Removal of COD and $\text{NH}_4^+\text{-N}$ from the coke-plant wastewater in a laboratory scale by the Submerged Sequencing-Batch Membrane Bioreactor (SSBMB) was investigated in this article. The reactor was fed with coke wastewater in descending dilution multiples until finally original coke wastewater was supplied. Results showed in the "anoxic-aerobic" process, most of the organic compounds were removed in the aerobic stage, the COD removal efficiency of the two stages were 24% and 65% respectively; in the "anoxic-aerobic-anoxic" process, the removal efficiency of organic compound in the former anoxic stage was increased to 32%. Removal mechanisms indicated that there existed the membrane filtration and biological degradation occurred simultaneously on the membrane surface, but the former was the dominant.

POSTER SESSION 4 CARBON MANAGEMENT

P4-1

Options of CO₂ Capture in Oxyfuel Coal Combustion Technologies

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A review of the projects that are developing the oxyfuel coal combustion technology around the world has been undertaken based on their available progress. The evaluation carried out is focused on different projects, such as small and large pilot scale as demonstration projects. All these studies and projects undertaken and in process show that fundamental understanding of the principles and basis of oxyfuel combustion with flue gas recirculation have been well established during the past 20 years of R&D activities, but there are still some gaps in knowledge that are trying to be solved. The last objective of all of these projects is to demonstrate the oxyfuel technology in a commercial scale, taking into account another competitive alternatives, such the post-combustion for retrofitting existing power plants or the IGCC option. The conclusion of this study is that the oxyfuel combustion technology is suitable for retrofitting pf boilers and achieves clean coal combustion, lowering NO_x , increasing SO_2 removal, possibly lower mercury emissions and obtaining a CO_2 concentration for sequestration.

P4-2

Installation and Operation of 0.5 MW-Scale Dry Sorbent CO₂ Capture Pilot Plant Integrated with Real Coal-Fired Power Plant

Chang-Keun Yi, Sung-Ho Jo, Young Cheol Park, Korea Institute of Energy Research; Chong Kul Ryu, Korea Electric Power Research Institute, KOREA

Korea Institute of Energy Research (KIER) and Korea Electric Power Research Institute (KEPRI) have developed the dry sorbent carbon dioxide (CO_2) capture system since 2002. The principle of this technology is the reversible reaction between potassium carbonate, CO_2 and water vapor to form potassium bicarbonate in a thermal-swing process. Based on this reaction, we developed a bench scale unit (BSU) which treated 100 Nm^3/h of flue gas in late 2006. The BSU consisted of a transport fluidized-bed carbonator, cyclones, a loop-seal, and a bubbling fluidized-bed regenerator. We have tested the BSU facility using a slip stream of the real flue gas from 2MW coal-fired circulating fluidized bed combustor located in KIER in order to check the performance of CO_2 removal, the stability of operation and the possibility of deactivation of dry sorbent by contaminants such as SO_x and NO_x in the real flue gas. The results showed that more than 80% of CO_2 removal had been maintained for more than 50 hour continuous operation. Those results indicated that the CO_2 capture system using developed solid sorbents, which was supplied by KEPRI, could be applied to the real coal-fired power plant regardless of the presence of several contaminants. We have finished the detail design of pilot plant based on the long-term operation and the several tests. The pilot plant consists of a transport type carbonator and a bubbling type regenerator, which configuration is the same as the BSU facility. The pilot plant has been constructed at Hadong coal-fired power plant in Korea Southern Power Company. It can treat 2,000 Nm^3/h of flue gas (0.5 MW scale). The construction has

been done in late 2009 and the operation has been performed in 2010. The utilities such as cooling water for maintaining the carbonator temperature and steam for the regeneration energy have been supplied by the power company. It is expected that we can analyze the exact energy consumption of the dry sorbent CO_2 capture system after the operation of the pilot plant. We plan to start the next scale-up in late 2011 up to 10 MW-scale which will be reflected in the operation results of a pilot scale unit.

P4-3

Reaction Characteristics of Water Gas Shift Catalysts for SEWGS Process in a Bubbling Fluidized Bed

Seung-Yong Lee, Ho-Jung Ryu, Dowon Shun, Dal-Hee Bae, Korea Institute of Energy Research, KOREA

As a next generation hydrogen production technology from syngas with in-situ CO_2 capture, SEWGS (Sorption Enhanced Water Gas Shift) process has been developing. In this paper, the best operating conditions of three WGS catalysts for SEWGS process have been investigated in a bubbling fluidized bed reactor. The commercial low temperature WGS catalyst (MDC-7) produced by Süd-chemie and new WGS catalysts (PC and RSM) produced by KEPRI (Korea Electric Power Research Institute) by means of spray-drying method were used. MDC-7 catalyst has pellet shape and we crushed the pellet to 106~212 μm . However, PC and RSM catalysts have spherical shape and the same particle size range was prepared. The RSM catalyst was reformed using fine powder of MDC-7 catalyst. Reaction temperature, steam/ CO ratio, and gas velocity were considered as experimental variables. Moreover, long-term operation results of WGS catalysts were compared as well. The best operating temperature and steam/ CO ratio showed different results depend on the WGS catalysts. For MDC-7 catalyst, high CO conversion up to 99.4% was observed in the range of 220~240°C at 4.0 of steam/ CO ratio. For RSM catalyst, 95% of CO conversion observed more than 250°C at 4.0 of steam/ CO ratio. However, for PC catalyst, 90% of CO conversion achieved even at higher temperature (>350°C) at the same steam/ CO ratio. The effect of steam/ CO ratio on CO conversion showed different results for three WGS catalysts. For MDC-7 and RSM catalysts, CO conversion increased slightly as the steam/ CO ratio increased up to 2.0, and maintained. However, CO conversion of PC catalyst increased continuously as the steam/ CO ratio increased up to 5.0. The reactivity of MDC-7 catalyst was maintained more than 8 hours but that of PC catalyst decreased as the reaction time increased. As a conclusion, MDC-7 and RSM catalysts showed better reactivity and PC catalyst should be improved its reactivity. However, MDC-7 catalyst generated much fines during operation, and therefore, attrition resistance should be improved.

P4-4

Carbon Dioxide Capture of Flue Gases from Coal-Fired Power Plant Using Enzymes Originated Marine Life

Sihyun Lee, Soonkwan Jeong, Kyungsoo Lim, Jeonghwan Lim, Mari Vinoba, Korea Institute of Energy Research (KIER); Daehoon Kim, Korea University, KOREA

The focus of this study is the separation and storage of green house gas, CO_2 , and the use of enzymes from marine life in development of technology to provide novel method for CO_2 capture. Carbonic anhydrase has recently been used as a biocatalyst to accelerate an aqueous processing route to carbonate formation. In this study, we compared soluble proteins of HDS (Hemocytin from Diseased Shell) and EPF (Extrapallial Fluid) extracted from *Crassostrea gigas* with HCA (Human Carbonic Anhydrase) and BCA (Bovine Carbonic Anhydrase) on their ability to promote CO_2 hydration and the production of calcium precipitates. HCA, BCA, HDS, and EPF have shown promising results for use as promoter to accelerate CO_2 hydration and increase the rate of precipitation of carbonate mineral with Ca^{2+} ions. The ideal temperature and pH of operation was found to be 40 °C and 6~7, respectively. Lineweaver-Burk relationship was employed to estimate Michaelis-Menten kinetic parameters for the enzymes. BCA showed the fastest rate constant and followed HCA, HDS and EPF. In previous efforts to use CO_2 mineralization as a method for CO_2 sequestration the slow rate of hydration of CO_2 to carbonic acid has been limiting factor of CO_2 mineralization. In the presence of enzymes, rate determining step is eliminated, and therefore the overall reaction rate is enhanced dramatically. Precipitated CaCO_3 was all calcite and the particles size was below 100nm. These nano-particles could be use in other industrial processes such as paper, ink, or building materials. Therefore it can be reduced the operating cost of CO_2 capture, which increase feasibility to install CO_2 capture process in coal-fired power plant. This result suggests that enzymes mentioned above may be involved not only in CO_2 hydration but also in CO_2 mineralization.

P4-5

Preparation and Characteristics of Formed Active Carbons for Natural Gas Storage

Grzegorz Łabojko, Aleksander Sobolewski, Institute for Chemical Processing of Coal; Leszek Czepirski, AGH – University of Science and Technology, POLAND

Natural gas as an automotive fuel presents various advantages versus petrol and gasoline including reduced vehicle emissions, lower maintenance and savings in fuel

costs. Main problem in using natural gas as fuel for vehicles is low volumetric energy density of methane at room temperature. Compressed Natural Gas (CNG) is a solution used worldwide (more than 4 millions vehicles), but heavy and expensive cylinders have to be used for its storage at pressures about 200 bar. Adsorbed Natural Gas (ANG) can overcome issues with heavy storage systems by lowering operating pressure down to 35-40 bar. Key to the success of adsorptive storage is the choice of suitable adsorbent and operating conditions. Porous carbonaceous materials are well known as one of the best adsorbents for gases.

Preparation procedure of carbonaceous adsorbents for natural gas storage is described. Based on physicochemical parameters Polish hard coal type 34.1 from KWK Marcel was selected as precursor material for adsorbents for gas storage. Four grindings were performed on selected coal and particle size distribution was determined. Fullers distribution was calculated as providing best packing of precursor material. Comparison between optimal and obtained distributions allowed to select the best way of grinding coal providing best packing of precursor material. Thermo prepared coal tar and phenol-formaldehyde resol type resin were selected as binders, thermoreological study of binders and coal-binder mixtures were performed. Granules and pastilles from coal-binders mixtures were prepared and pyrolysed. Influence of binder amount in mixtures on mechanical resistance of granules were studied. Influence of steam activation time of granules on sorption parameters (Iodine number) of obtained active carbon monoliths was studied. High pressure adsorption of methane and low pressure adsorption of nitrogen was performed on selected samples of obtained active carbon monoliths.

P4-6

The Kinetics of the CO₂ Reforming of CH₄ over Carbonaceous Catalyst

Fengbo Guo, Yongfa Zhang, Guojie Zhang, Bingmo Zhang, Taiyuan University of Technology, CHINA

The CO₂ reforming of CH₄ on carbonaceous catalyst was performed in a Plug Flow Reactor (PFR) at temperatures range from 1223 K to 1323 K, the ratio of CH₄/CO₂=1 and residence time 3~30s under normal pressure. The outlet gas was analyzed by Gas Chromatogram (GC-960TCD and GC-950TCD), the carbonaceous catalyst was analyzed with element analyzer and specific surface area analyzer. The experimental results show that the conversion of CH₄ and CO₂ increases with the increase of the reaction temperature and residence time. The reaction temperature remains the chief influential factors on the conversion of CH₄ and CO₂. Under the conditions of the temperature of 1323 K and residence time over 20s, the conversion of CH₄ and CO₂ can be expected over 90%. In addition, the conversion of CO₂ was significantly higher than the conversion of CH₄, which indicate that the gasification reaction of the carbonaceous catalyst and carbon dioxide was occurred during the reforming process.

A mechanism of the CO₂ reforming of CH₄ on carbonaceous catalyst has been proposed based on the experimental results. Based on the mechanism, a kinetic model was developed. The kinetics of the CO₂ reforming of CH₄ on carbonaceous catalyst was described in a rate law, the experimental data was analysed in non-linear regression. The apparent activation energy E_a and the pre-exponential factor A were solved. The rate constant was as follows:

$$k = 1765 \exp\left(-\frac{109.9 \pm 10.1 \text{ kJ}}{RT}\right)$$

A comparison is made between calculation data and experimental data of the CH₄ conversion, which illustrates the rationality of the kinetic model.

P4-7

A Study on the Absorption Characteristics of CO₂ with a Vortex Tube Type Absorber

Keun-Hee Han, Woo-Jung Ryu, Jong-Ho Park, Won-Kil Choi, Jong-Sub Lee, Byoung-Moo Min, Korea Institute of Energy Research, KOREA

In this study, the CO₂ removal characteristics of the vortex tube type absorption apparatus were investigated to enhance the compactness of CO₂ absorption process and to reduce the amount of absorbing solution for the process. The vortex tube with the diameter of 12 mm and the length of 200 mm was introduced in the experimental apparatus to treat 20 Nm³/hr of CO₂ containing flue gas. The flue gases for the experiments containing 11-15 vol% of CO₂ were supplied from the coal-firing CFBC power plant with 12 ton/hr of steam producing capacity.

EDA and DETA based on MEA were used as the absorbing solution. The absorption experiments were executed under the various conditions like the absorbing solution concentrations in the 30 wt%, the flow rate of CO₂ containing flue gases in the range of 6 to 12 m³/hr and the flow rate of absorbing solution in the 0.18m³/hr and the range of operation pressure in the 1.4 to 5.5 kgf/cm². As a results, the CO₂ removal efficiency increases with the operation pressure but decreases with the flow rate of flue gas. However, the development of an additional process to improve the efficiency of CO₂ absorption is required.

P4-8

Pd-Free Composite Membrane for Pre-Combustion Capture

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Pre-combustion CO₂ capture technology is recently focused on one of reduction methods of carbon dioxide from power generation system in view of environmental (carbon management) and sustainable (Hydrogen economy) point. Separation of hydrogen from water-gas shift reactors through dense hydrogen transport membranes, while retaining CO₂ produces essentially pure hydrogen in the permeate and CO₂ at high pressure and high concentration in retentate, which is ideal for efficient sequestration of CO₂. Moreover, the combination of a hydrogen selective membrane with a water-gas shift catalyst in a single reactor would allow a high degree of CO conversion, despite a low equilibrium constant at high temperature, due to the continuous depletion of H₂. This equilibrium shift can provide more hydrogen productivity, higher concentration of CO₂ and lower impurity such as CO. Nowadays, many researches have been studied on various membranes for low cost separation of hydrogen. Pd and Pd alloy membranes have been studied for separating hydrogen from pre-combustion capture process but there is limitation for large scale application without reduction of Pd layer and improvement of membrane stability, due to the price and embrittlement of noble metal. Recently, Pd-free membranes using V, Ta, and Nb which has higher permeability have been researched to improve its high cost and low stability.

In this work, metal alloy and composite membranes have been developed to separate hydrogen from mixed model gases, particularly product streams generated during coal gasification and/or water gas shift reaction. The powder mixture for fabricating the cermet membranes was prepared by mechanically mixing 60 vol.% vanadium with Y₂O₃-stabilized ZrO₂ (YSZ). The powder mixture was pressed into disks, which were then sintered in vacuum at 1600 °C for 2 h. As-sintered membrane was dense and mounted to a stainless steel ring with brazing filler. Hydrogen fluxes of V/YSZ membrane have been measured in the range of 200~350 °C with 100% H₂. The crack was formed in the both sides of membrane at 350 °C and pressure of 0.5 bar. During permeation experiment, vanadium of V/YSZ membrane reacted with hydrogen to form V₂H which was the origin of crack formation. To improve the membrane stability, we prepared metal alloy membranes with vanadium. Hydrogen fluxes of metal alloy membranes have been measured in the range of 350~500 °C with 100% H₂ and the mixture gas of H₂ and He (or CO₂). In addition, the stability of membrane was investigated according to operating temperature and hydrogen partial pressure.

P4-9

Composite Ceramic Membrane for Oxygen Separation

Jung Hoon Park, Soo Hwan Son, Korea Institute of Energy Research; Jong Pyo Kim, Chungnam National University, KOREA

Oxygen and nitrogen are used in many industrial processes. Pure oxygen is used in the production of metals and in the integrated gasification combined cycle (IGCC) for partial oxidation. Recently, oxy-fuel combustion CO₂ capture process as one of carbon capture technologies has been developed and this process also needs large scale oxygen separation unit. It has been predicted that the total market would grow significantly if pure oxygen could be produced at lower cost. The technology used for commercial separation of oxygen varies according to the scale and requirements for oxygen purity. For example, the cryogenic distillation method that was started in 1902 is used for large-scale production of pure oxygen, and the simultaneous production of nitrogen, argon and helium. However, high investment costs and energy consumption make it difficult to integrate this process with other power generation. Over the last decade, membrane technology for gas separation has developed rapidly. The interest in dense ceramic membranes for the transport of oxygen has grown considerably. As a result, the knowledge of the intrinsic properties of the membrane materials is now overwhelming, and new reports are being published frequently. The use of a dense mixed-conducting, perovskite-type ceramic membrane is a new technology for the production of pure oxygen. An obvious advantage of perovskite membranes is their 100% selectivity for the permeation of oxygen. However, ceramic membrane process has some drawbacks; the crack formation of membrane under high pressure and temperature condition, low stability of perovskite structure under ambient air, the difficulty of heat exchange integration with flue gas.

In this work, the effect of carbon dioxide in ambient air was studied using the composite membrane with La_{0.6}Sr_{0.4}Ti_{0.3}Fe_{0.7}O_{3-δ} (coating layer, denoted as LSTF-6437) and Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-δ} (bulk permeation body, denoted as BSCF-5582). BSCF-5582 and LSTF-6437 powder have been synthesized using polymerized complex method. BSCF-5582 powders were compressed into disks of 20 mm in diameter and 1.0 ~ 2.0 mm of thickness in a stainless steel mold under a hydraulic load by unilateral press. The green disk sintered at 1353 K for 5 hr. The sintered disk was polished to smooth the surface and to control the thickness of disk with 600 grit SiC. The surface of membrane was modified by coating of LSTF-6437 slurry. The optimum coating condition was evaluated according to coating time, rate and number. The coating membrane was sintered again to obtain composite dense membrane. The phase of the powder and the disk before and after sintering was characterized with an X-ray diffraction. Prior to oxygen permeation test, the cell part is purged with He gas to remove the air in permeation cell tube and to confirm sealing of the assembly for 20 hr.

The leakage through membrane during oxygen permeation test was also measured for all runs at each temperature and the oxygen permeation fluxes were corrected on the basis of the measured leakage. Permeation study was performed in the temperature range of 750–950 °C and pressure of 1–3 atm with synthetic air (21 vol.% O₂+79 vol.% N₂) and ambient air model gases (CO₂ 300–700 ppm). Oxygen permeation flux was increased as temperature increased irrespective of membrane coating. In the case of LSTF coating membrane, it reached 1.9 ml/cm²·min at 950 °C exposed to flowing air (Ph =0.21 atm, feed side of membrane) and helium (Pl =10⁻⁵ atm, permeated side of membrane). The oxygen permeation of BSCF-5582 membrane in the condition of air and CO₂ (300–700 ppm) in feed stream decreased more than 43% in comparison with air feed stream while that of LSTF coating membrane maintained almost same flux irrespective of CO₂ concentration.

P4-10

A Conceptual Process for Selective Capture of CO₂ from Fuel Gas Streams

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Recent publications demonstrated that human emissions of greenhouse gases (GHG) are very likely warming our planet and therefore actions to mitigate such emissions are needed. Carbon dioxide (CO₂) is the main GHG produced by the combustion of fossil fuels in power and energy production facilities. It is anticipated that until 2030, fossil fuels will be the dominant source of energy, and that's why it is becoming crucial to develop technologies that reduce CO₂ emissions [1,2]. CO₂ can be potentially captured and then sequestered from fuel or flue gas streams using solid-based or solvent-based processes. The solvent-based processes include (1) chemical solvents; (2) physical solvents; and (3) mixed chemical/physical solvents.

The focus of this study is on physical solvents for CO₂ capture from fuel gas streams. Ionic liquids are our physical solvent of choice because they have: (1) low vapor pressure to prevent solvent loss; (2) high selectivity for CO₂ when compared with those of CH₄, H₂ and CO in the fuel gas stream; (3) low viscosity at the system temperature to minimize solvent pumping cost; (4) thermal and chemical stability to prevent degradation; (5) environmentally benign effects, and (6) non-corrosive behavior.

After obtaining the solubility and mass transfer parameters for the selected ionic liquid TEGO IL K5 experimentally, the data were used to simulate a large scale process, a so call "conceptual" process. This task was completed using an ASPEN simulator. First using an absorber (model as a packed bed) followed by a few regeneration units, in which pressure swing or temperature swing are used to regenerate the ionic liquid solvent. The simulation of the absorption process will help assess the performance of the TEGO IL K5 as a physical solvent for CO₂ capture.

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POSTER SESSION 5 COAL-DERIVED PRODUCTS

P5-1

Reactions of Coal Structures with Polymers Leading to Hydrogen Production

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Thermal reactions of polystyrene, acrylonitrile-butadiene-styrene and styrene-butadiene rubber with chosen coal fraction were investigated from point of view of hydrogen production. As method a two-stage copyrolysis of coal/polymer mixtures was selected. Experiments were carried out on pyrolysis laboratory unit with a vertical quartz reactor (the first stage) and a horizontal cracking oven (the second stage). Thus, coal/polymer mixtures contained 30 wt.% of polymer were heated and products further cracked. From the results, the process conditions leading to maximum hydrogen production were defined and the yields of products determined. If the mixtures with 30 wt.% of polymers are considered, the heating rate of 5 K/min and final temperature of 900°C at vertical reactor and 1200°C at horizontal cracking oven are sufficient for

achievement of a hydrogen-rich gas with 77–79 vol.% H₂. On the basis of solid-state NMR, FTIR and GC analyses of coal fraction and cokes, obtained tar, and obtained gas, respectively, reactions of coal structures with polymers leading to hydrogen production were described and, using the results of isoconversional analysis, discussed.

P5-2

Catalytic Performance in Fixed-Bed and Bubbling Fluidized-Bed Reactor during Fischer-Tropsch Synthesis on the Iron-Based Catalysts

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Fischer-Tropsch synthesis (FTS) for olefin production from syngas was investigated on the four different iron-based catalysts in a fixed-bed and a bubbling fluidized-bed reactor. The catalysts were prepared by wet-impregnation using Al₂O₃, SiO₂ and iron ore (FeO_x) with active components of Fe, K and (or) Cu, and K/FeCuAlO_x catalyst was prepared by co-precipitation method. The impregnated K/FeO_x catalyst is found to be one of the promising catalysts to be applied in bubbling fluidized-bed reactor for high temperature FTS reaction due to its high resistance to catalyst attrition with high catalytic performance.

P5-3

Operation of Slurry Reactor for Fischer-Tropsch Synthesis

Ho-Tae Lee, Jung-Il Yang, Jung Hoon Yang, Dong-Hyun Chun, Hak-Joo Kim, Heon Jung, Korea Institute of Energy Research, KOREA

A slurry bubble column reactor with a capacity of 0.03 bbl/day, was designed and operated for Fischer-Tropsch reaction. Active Fe based catalysts were prepared and tested at 2.5 MPa and H₂/CO=1. The average CO conversion higher than 80% was observed. The effects of the reaction temperature and the superficial velocity of synthesis gas on the conversion, the product selectivity and the oil productivity were investigated. The liquid oil productivities increased with the increasing superficial velocity and the increasing temperature.

P5-4

Process Simulation of Steam Hydrogasification to Produce F-T Products and Electricity

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A new process for the co-production of synthetic fuels and electricity based on steam hydrogasification is being developed at the College of Engineering – Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside. One of the key benefits of this new process is the enhanced conversion of carbonaceous material to synthesis gas compared to other thermochemical processes. Another benefit is that it does not require the use of oxygen from a cryogenic air separation unit or ASU, thus reducing capital costs. One current coal-based application being considered for this technology (called the CE-CERT process) is to co-produce Fischer Tropsch products and electricity. The results of a process simulation model of an integrated conceptual design of a 4000 TPD Sub-Bituminous coal conversion to Fischer-Tropsch liquids and electricity is presented in this paper. A circulating fluidized bed with a regenerator setup for providing the heat to the Steam Hydrogasification Reactor (SHR) is modeled. The process simulation model involves the major steps of: 1) simulation of the steam hydrogasification reactor using gasification units based on built-in Aspen reactor blocks with the determination of the equilibrium composition of the gaseous components in the reactor by means of Gibbs free energy minimization; 2) empirical simulation of a warm gas cleanup system; 3) a steam methane reforming process simulated by using a built-in REQUIL equilibrium block; 4) empirical simulation of a hydrogen separation process for syngas ratio adjustment and excess hydrogen recycle to the steam hydrogasifier; and 5) a Fischer-Tropsch diesel synthesis by means of an empirical expression. The regenerator is essentially a combustor where residue char is burnt in the presence of air to heat circulating sand. The hot sand flows back into the SHR to provide the process heat for the main reactor. The material and energy balance of the whole process was developed using Aspen Plus. The overall process performance and the optimum F-T liquids/electricity output from the 4000 TPD coal plant is determined. The optimum process thermal efficiency is 50.25% with 37.1% of coal carbon in F-T liquids.

P5-5

Further development of the PSRK Model for the Prediction of the Vapor-Liquid-Equilibria of Direct Coal Liquefaction System at High Temperatures and High Pressures

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Since Huron and Vidal (1979) developed the basic idea of so called G^E mixing rules, similar models have been proposed by different authors. The aim of all recent developments of G^E mixing rules is to combine the successful G^E models or group contribution methods with equations of state to enable the description of Vapor-liquid equilibria at high temperatures and pressures including supercritical compounds.

The system involved in direct coal liquefaction was a three-phase state of solid, liquid, and gas phases at high temperatures and high pressures. One of the challenges in the analysis of the Coal liquefaction process was due to the fact that the contents of both hydrogen and methane are very high and both of them were in the supercritical state. Besides, when small, spherical hydrogen and methane molecules were mixed with liquefaction oil, the huge difference between their molecule weights causes extreme asymmetry of the system, bring about the difficulty in analysis and modeling of the liquefaction process.

To Predict the vapor-liquid equilibria of direct coal liquefaction system at high temperatures and high pressures, a group contribution equation of state called PSRK was proposed, wherein the group contribution equation of state PSRK(predictive Soave-Redlich-Kwong) as suggested by Holderbaum and Gmehling (1991) combines the mod UNIFAC model (Hansen et al.1991) with the SRK equation of state. In this work, the range of applicability of the PSRK method was extended by the introduction of additional gases and the determination of missing interaction parameters between the following gases: CH₄, CO₂, CO, H₂S, H₂, H₂O and the original UNIFAC structural groups.

A computational method to solve the flash model for coal liquefaction system at high temperatures and high pressures has been developed. The numerical code has two-cycle iteration, including the inner cycle of β iteration and the outer cycle of K iteration, and the results of fast convergence can be achieved. Generally, after about 5 times of iteration (outer cycle), the program can reach the convergence precision. Based on the model of PSRK, the composition of 24 components of the gas-liquid phase and the gas-liquid equilibrium constant has been calculated. Calculated results were consistent with the literature results and the vapor-liquid equilibria for the coal liquefaction reactor were calculated. The comparison of the results showed that the capability of the PSRK model to describe and predict the vapor-liquid equilibria of coal liquefaction systems at high temperatures, high pressures, strong asymmetry and strong polar.

P5-6

Arsenic and Mercury Removal by Using Iron Humate Prepared from Turkish Coal Based Humic Acid

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Humic acid produced by TKI (Turkish Coal Enterprises) was used in the production of iron humate. Different iron sources (iron (II) sulfate, iron (III) sulfate and iron (III) chloride) were used in the ion exchange reactions. Iron (II) sulfate (FeSO₄) was found to be most suitable iron source in terms of iron content and adsorption capacity for As, Pb, Ni and Cd. The Fourier transform infrared (FTIR) spectroscopy, thermal gravimetric analyzer (TGA) and scanning electron microscopy (SEM) were used to characterize the humic acid and iron humate samples. The efficiency of iron humate as adsorbent has been studied as a function of amount, contact time and initial arsenic (As) and mercury (Hg) concentration by a series of batch experiments. The adsorption capacity of iron humate for As and Hg was above 90 % and higher than that of humic acid. It was concluded that iron humate can be used as an effective sorbent for the removal of As and Hg. Its application on the sorption of cadmium (Cd), cobalt (Co) and nickel (Ni) was not successful.

P5-7

Heavy Metal Adsorption of Turkish Coal Based Humic Acid/Epoxy Composites

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The objective of this study was to investigate the adsorption capability of Humic acid/epoxy based composites. Humic acid produced by TKI (Turkish Coal Enterprises) was used as a co-curing agent for epoxy resin system based on Bisphenol F. The stoichiometrical amount of humic acid as co-curing agent, Diethylene triamine (DETA) as curing agent and Bisphenol F based epoxy resin were mixed. The homogenous mixtures were cured at 190 °C into the preheated molds. The curing agent/humic acid compositions were optimized to investigate the effect of humic acid concentration to removal of As, Pb, Ni and Cd. The Fourier Transform Infrared (FTIR) Spectroscopy, Thermal Gravimetric Analyzer (TGA), Differential Scanning Calorimeter (DSC) and Scanning Electron Microscopy (SEM) were used to characterize the humic acid/epoxy based composite samples.

P5-8

Effect of Interface Modifier on Mechanical Properties of Lignite-SPI Composites

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Using soy protein isolate (SPI), lignite (LC) as raw materials, glycidyl methacrylate (GMA) as the interface modifiers, glycerol (Gly) as plasticizers, LC-SPI composites were prepared by compression molding. The effects of LC content, GMA content and

modification methods on mechanical properties of LC-SPI composites were investigated by the analysis of bending property, impact property, tensile property and XPS. The results showed that, Gly and GMA content were the most factors to significantly affect tensile properties of compression-molded SPI-LC-Gly-GMA sheets over the range of molding temperature and pressure conditions. A small amount of interfacial modifier could effectively strengthen and toughen LC-SPI composites. When using GMA as interfacial modifier, its epoxy group reacted with COOH and Ar-OH in coal or COOH, OH and NH₂ in SPI, then grafted on to LC or SPI.

P5-9

Numerical Simulation of Syngas Production by Partial Oxidation of Coke Oven Gas under Non-Premixed Condition

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China is the largest coke producer in the world. The yield of coke oven gas (COG), a byproduct of the coking process, reached 1190 billion Nm³ per year in 2007. COG is a good feedstock for many chemical processes e.g. FT synthesis, methanol synthesis and ammonia synthesis, instead of only as a heating fuel. The main component of COG is hydrogen (~56-60 vol. %) but there are also other compounds such as methane (~25-30 vol. %), carbon monoxide, carbon dioxide, and nitrogen. There are several methods to convert the methane into hydrogen in order to fully make use of the COG resources to the larger extent. The non-catalytic partial oxidation of COG with oxygen is one of important routes for COG comprehensive utilization.

In the present work non-premixed combustion of coke oven gas under low oxygen condition was investigated through computational fluid dynamic (CFD) simulation coupled with radiation heat transfer. The mathematical model was formulated to describe the fluid flow, heat transfer, mass transfer, and gas phase chemical reactions. The obtained model was numerical solved with finite volume method using commercial software FLUENTTM.

Temperature profile and product distribution in the reactor were obtained from simulation. Calculated temperature profile indicates that oxygen react strongly with coke oven gas in region near the oxygen nozzle and the temperature in this region increase sharply. Significant influence of reactor wall temperature on product distribution could be found in simulation results. Higher selectivity of syngas could be archived at higher reactor wall temperature, while conversion rate of methane in coke oven gas was suppressed simultaneously. Reactor wall temperature should be treated as a key parameter and optimized well in this process. The simulation results are helpful the development and design of the COG non-catalytic partial oxidation reactor and process.

P5-10

Coal Supply Agreements and Competition

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Coal is used for many different purposes. It is primarily used as a solid fuel to produce electricity and heat. It can also be converted into liquid fuels such as gasoline or diesel. It can be used to produce synthetic natural gas, synthesis gas and hydrogen through gasification. Coal supply agreement is critical for the usage of coal for different purposes.

Under a coal supply agreement, the supplier agrees to sell coals to a purchaser at pre-determined prices with minimum/maximum annual quantities. Duration, quality of coal, quantities, delivery, risk and ownership, price determination, termination and force majeure clauses are important clauses of a coal supply agreement. In drafting coal supply agreements antitrust laws should be reviewed. This paper aims to analyze how a coal supply agreement may violate competition.

P5-11

Chemicals from Turkish Lignites

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In this paper experimental and calculated gasification results of Turkish lignites shall be discussed. Material and energy balance for production of synthetic natural gas (SNG) and ammonia from various type of lignites shall be explained with the gasifier selection criteria.

P5-12

Methane Cracking over De-ashed Coal Chars and the Effect of the De-ashing Conditions

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Methane cracking over different de-ashed coal chars derived from the same parent coal (Xiao-long-tan lignite) was studied using a fixed-bed reactor operating at atmospheric pressure and 1123 K. The first set of samples of Xiao-long-tan lignite chars were

prepared by heating the coal 1173 K in nitrogen for 30 minutes and then washing the resulting char with 5 N HCl (char 1), 5 N HCl and 29 N HF (char 2), respectively. The second set of samples of Xiao-long-tan lignite chars were prepared by washing the coal with 5 N HCl, 5 N HCl and 29 N HF, respectively and then pyrolyzing the de-ashed coal samples in nitrogen, also at 1173 K for 30 min (char 3 and char 4). Comparing to blank experiments using quartz particles, the chars were shown to have a significant catalytic effect on methane cracking. Hydrogen was the primary gas-phase product of methane cracking. Different chars also showed different catalytic activities in methane cracking. Chars 1 and 2 were shown to have higher catalytic activities than chars 3 and 4. These observations were also confirmed by additional experiments using a temperature-programmed desorption coupled with mass spectroscopy (TPD-MS), using methane, instead of nitrogen. Chars 1 and 2 were found to be more porous than chars 3 and 4, which is speculated as the major cause of the difference in their catalytic effect in methane cracking.

P5-13

CeO₂-K₂O Promoted Co-Mo Sulfur-Tolerant Shift Catalyst for the Shift Reaction of CO in Coke Oven Gas

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To avoid energy and H₂ consumption in the process of CH₄-CO₂ reforming (CH₄ in coke oven gas and CO₂ in gasification gas), a method was proposed, which through CO shift reaction makes CO in coke oven gas converted and simplifies the separation of CH₄ and H₂. In this work, CeO₂-K₂O promoted Co-Mo sulfur-tolerant shift catalyst for the shift reaction of CO in coke oven gas is investigated. The results indicate Ce and K have a synergy effect on promoting the catalytic activity, and the Co-Mo-Ce-K/γ-Al₂O₃ catalyst with 3.0 wt-% CeO₂ and 6.0 wt-% K₂O exhibits the highest activity. Moreover, CeO₂ contained Co-Mo catalysts have higher catalytic activity with low steam/COG ratio, demonstrating that introduced CeO₂ increases the water adsorbability of catalyst.

P5-14

Effects of Preparation Conditions on Ru/Al₂O₃ Catalyst for Coal-Based Syngas Methanation Reaction

Liping Wang, Yongfa Zhang, Yaling Sun, Xianglan Li, Taiyuan University of Technology, CHINA

Effects of preparation conditions on Ru/Al₂O₃ catalyst for coal-based syngas methanation reaction have been studied. The catalysts have been characterized by XRD technique. Using of ultrasound impregnation method can significantly decrease impregnated time and improve catalytic activity of the catalyst. The catalyst prioritizing preparation conditions are: Ru loading of about 2%, calcination temperature of 500 °C, and H₂ reduction temperature of 400 °C. Under the optimum catalysts conditions, the conversion of CO and the CH₄ selectivity reach 97.18% and 83.29%, respectively. Besides, the catalyst washed with deionized water and diluted ammonia can remove chlorine ions and increase catalytic activity.

P5-15

The Production of Organic Fertilizers from Göynük, Iğın and Elbistan Lignites with H₂SO₄ Oxidation

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Various organic fertilizer production processes related with alkali and oxidation of coals, with HNO₃ has been developed. In spite of this, these products are controversial for agriculture due to their high pH content of alkali oxidation products, high temperature and pressure comprising control difficulties. It is known that production with HNO₃ is difficult and has not found any application in time. Except pH, due to similar reasons and chemical structures of the produced products are not clearly known, therefore, nitro humates have not found any application areas.

In this study, partial molecular disintegration of high humus, with H₂SO₄ oxidation, comprising of Iğın, Göynük and Elbistan lignite were studied, the neutralization reaction was carried out with ammonia by increasing acid ratios and a new type of organic fertilizer production with a total chemical work base and a new molecular structure was produced.

While the used material was chosen randomly from the material's beds and Iğın contains of 42.02%, Göynük of 33.19 % and Elbistan of 53.00 % humic compounds. The samples cleaned with "acid leaching" in case of metal pollution and stoichiometric amounts of H₂SO₄, H₃PO₄ and Mardin phosphate were added through these compounds to substantiate of required amount for theoretical N-P₂O₅-K₂O. Moreover, rested oxidized coal was neutralized with liquid ammonia and KOH. As a final product, fertilizer was produced in theoretical form of (8-6-1) + S.

Humic acid ratio in produced fertilizers varied between 33.43% and 37.40 %; nitrogen amount, between 7.35 % and 8.46; P₂O₅ amount, between 5.84 % and 6.46 %; K₂O ratio, between 0.96 % and 1.12 %. Organic material changes between 70.92 % and 74.58 %. This is a cheap fertilizer which may be evaluated in the framework of the National Organic Fertilizer Regulation.

Cheap raw material resource is a type of fertilizer which fixation of direct industrial chemicals' usage and "industrial humification", being used as an alternative of long time taking natural humidification as well as theoretical N, P₂O₅, K₂O like macro and micro nutrition elements, can be adjusted as desired ratios.

P5-16

Modeling, Scaleup and Optimization of Slurry Bubble Column Reactors for Fischer-Tropsch Synthesis

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The Fischer-Tropsch (F-T) synthesis appears to be a promising technology to help reduce the dependence of our society on oil and diversify our energy sources towards more environmentally friendly and sustainable forms of energy. Transforming Natural Gas, Coal or Biomass into clean liquid fuels is one of the many attracting aspects of the F-T process. However the scaleup of new F-T reactors such as Slurry Bubble Column Reactors (SBCRs) remains a difficult task due to their complex hydrodynamics and flow patterns.

New correlations for the estimation of the hydrodynamic and mass transfer parameters were developed and along available reaction kinetics and heat transfer characteristics, were used in a comprehensive computer model in order to predict the effects of reactor geometry and operating conditions, such as reactor diameter, length, superficial gas and slurry velocities, temperature, pressure, syngas composition and catalyst loading on the performance of SBCRs operating under FTS conditions.

P5-17

Biogasification of Soma Lignite (A Preliminary Study)

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In this project, the bacterial gasification on the coal samples which were evacuated from Soma basin in Turkey and gas adsorption mechanism of these samples were analyzed. It is known that coal can be solubilized chemically (alkaline solutions) and biologically by using wood-rotting fungi species. Chemical solubilization of coal samples was investigated. For this purpose, coal samples were solubilized in the different Lewis base solutions. For biogasification process, solubilization at moderate pH (9 ≥ pH ≥ 5) level is an important factor for the conserve bioactivity of the microorganisms. We found that carbonate and oxalate systems can be solubilized coal at moderate pH and also these Lewis bases was used in biogasification process to solubilized coal samples and increase gasification efficiency. To understand gas adsorption on the coal surface, high pressure gas adsorption experiments were conducted.

POSTER SESSION 6 COAL SCIENCE

P6-1

Modeling of Coal Drying in a Pneumatic Dryer

Sihyun Lee, Sangdo Kim, Kyoungsoo Lim, Soonkwan Jeong, Youngjoon Rhim, Korea Institute of Energy Research (KIER), KOREA

Operation of the pneumatic conveying system for drying coal was influenced by many parameters, in particular, gas velocity, gas temperature, coal residence time, and coal particle size. In this study, the pneumatic conveying drying system was simulated for drying wet coal. Numerical studies were conducted to examine the effect of these parameters on drying coal. As the gas temperature, the drying rate of wet coal was increased. In addition, coal drying increased with an increase of coal residence time.

Particle size is one of the most important parameter on moisture removal efficiency of the pneumatic conveying dryer. The moisture removal increased in short drying time with a decrease in particle size due to the large surface area.

P6-2

Characterization of Chars Made of Solvent Extracted Coals

Sihyun Lee, Jiho Yoo, Hokyung Choi, Sangdo Kim, Jeongwhan Lim, Thirupathi Raja, Korea Institute of Energy Research (KIER); Wantaek Jo, Yonsei University, KOREA

Of contaminants contained in coal, ash was blamed for the serious issues in the power sector; a decrease in the power efficiency and discharge of fly ash into the air. Thermal extraction of coals with solvents has produced ash-free coals successfully, potentially solving the ash problem and bringing new applications such as direct coal feeding into gas turbine. Whereas the properties of the ash-free coals are well known, chars made of the extracted coals have not yet been characterized. In this study, the organic portion of a sub-bituminous coal (Roto south) was extracted at 370 °C using 1-methyl-naphthalene solvent. The extract/residue coal as well as its parent coal were pyrolyzed at 300 – 900 °C. The carbonized products were then characterized. Proximate and ultimate analysis were performed to study the compositional change. The difference in

chemical structure was investigated using a solid-state ^{13}C -NMR. Calorific value was also determined. The discussion focused on how the physical/chemical properties of the chars varied depending on the kind of the coals and the temperature pyrolyzed.

P6-3

Upgrading of Low Rank Coal by Hybrid Flash Dryer

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Deposit of low rank coal (LRC) represents nearly half of the estimated coal resources in the world. But, these cannot be economically utilized due to the characteristics of high moisture contents (30% or more), low heating value (5,000kcal/kg or less) and spontaneous combustion ability during transportation and storage. To avoid such problems, development of upgrading technology of low rank coal is needed. In this study, hybrid flash dryer system for upgrading coal was tested in the laboratory scale of 5kg/hr apparatus.

In a flash dryer, a feed material is rapidly dried by direct contact with hot air while being transported by the air stream. Coal samples obtained from Mongolian coal (lignite) that has moisture contents of 29.74%, volatile matter contents of 27.83%, ash contents of 10.51% and heating value of 4,270kcal/kg (as received basis). Drying air is heated with a burner and inlet velocity of hot gas is in the range of 10-20m/sec, inlet air temperature ranges of 300-600°C, particle size of raw coal is in the range of 0.1-2mm. Moisture content of raw coal was rapidly decreased to lower than 7% with increasing the inlet air temperature and the heating value was increased to more than 5,550kcal/kg. Also, the moisture contents decreased with decreasing gas inlet velocities.

P6-4

Drying Kinetics of Low Rank Coal in Multi-Chamber Fluidized Bed

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When low rank coals such as subbituminous coals and lignites are combusted with high moisture content, they cause higher flue gas flow rate resulting in lower plant efficiency. A better understanding of the drying process would improve the development of the use of these low-grade coals, and they could be economically treated for further processing such as combustion, gasification and liquefaction after appropriate drying processes. Among various drying technologies, fluidized bed drying has the advantages of temperature control due to uniformity of bed temperature and high drying rate. When hot air is passed upward through a perforated distributor, the coals in the dryer are suspended and the bed has many properties similar to a fluid. It offers a way of drying coal in more economical and environmentally acceptable means. Drying can be done in any state of fluidization, however the optimum condition is highly related to drying gas temperature and gas velocity.

The objective of this research work is to develop bench-scale (1ton/day) multi-chamber continuous fluidized bed coal dryer to overcome the disadvantages of low rank coal with high moisture such as low calorific values, costly transportation, high emissions of pollutants, and operation problem. The effects of gas temperature, gas velocity and coal feed rate on drying rate were studied to obtain information relating to optimum operating conditions. Coal characterizations (proximate analysis, ultimate analysis, Thermogravimetric Analysis (TGA), BET, Higher Heating Value (HHV), Lower Heating Value (LHV)) were performed to identify the effect on the change of moisture content. This investigation aims to study the drying process under moderated heating conditions.

The coal drying experiments were performed in a 100 mm width, 500 mm length, 1700 mm high fluidized bed dryer consisting of preheater, plenums, bubbling bed, and cyclone. The particles size of crushed coals was minus 3 mm. The gas temperatures and velocities were varied up to 150 °C and 0.9 m/s, respectively. As a result of the experiments it was concluded that the thermal fluidized bed process could be successfully applied to reducing moisture in low-rank coal. Results also indicate that about 80 of total moisture could be reduced, including some of the inherent moisture, yielding high heating value product. The drying rate of coal in a fluidized bed was increased by increasing the temperature and velocity of the drying gas and by decreasing the coal feed rate. However gas temperature had limitations causing from the spontaneous combustion and gas velocity had to be decided considering energy efficiency. Those parameters will be used for the design of pilot scale (10 tons/day) fluidized bed dryer.

P6-5

The Influence of the Temperature on Adsorption of SDS on Coals

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The influence of temperature on adsorption behavior of anionic surfactant – sodium dodecyl sulfate (SDS) has been studied. Batch mode was used for adsorption of SDS on three different types of coal, namely oxidative altered coal (BO), subbituminous coal (SB) and bituminous coal (BC). The adsorption from aqueous solutions was carried out at temperatures 25, 40, 60 and 80 °C. Linear as well as nonlinear regression

analyses of experimental data confirmed that adsorption process can be described using Langmuir adsorption theory of monolayer coverage.

Thus, equilibrium constant of adsorption was possible to calculate from Langmuir binding constant **b**. Further, from the dependence of **b** constant on temperature, thermodynamic parameters as enthalpy ΔH_{ads} , entropy ΔS_{ads} and Gibbs energy ΔG_{ads} were evaluated. Calculated thermodynamic parameters indicate that the adsorption of SDS on the coals is exothermic ($\Delta H_{ads} < 0$) and spontaneous ($\Delta G_{ads} < 0$) process. The adsorption capacity of SDS on coal was found to increase with rise in temperature for all studied samples, the highest adsorption capacity being observed for bituminous coal. Also, tight relationship between adsorption capacity and critical micelle concentration (CMC) of SDS has been found. In addition, from zeta potential measurements, correspondence between adsorbed amount of SDS on coal surface and zeta potential value arose.

P6-6

Assessment of Elemental Sulphur in Bidesulphurized Coals

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Recently clean coal use became foreground of coal technology. Desulphurization strategies take considerable part of this trend. A requirement of any research in this field is to acquire an accurate method for determining the forms of sulphur. It is important to evaluate the effect of the treatment on the properly selected coals for sulphur specific desulphurization processes. There are direct standard analytical procedures for sulphur forms determination, i.e. total sulphur (St), pyritic sulphur (Sp) and sulphatic (Ss). The indirect way for organic sulphur assessment (So) by subtracting the sum of Sp and Ss from the St, can create an overestimation of So content in Sel presence.

Two Bulgarian high sulphur containing coal samples, sub-bituminous (Pirin) and lignite (Maritza East), and one Turkish lignite (Cayirhan-Beyazari) are used in the experiments. Prior biotreatments the samples are demineralized and depyritized. The white rot fungi "*Phanerochaeta Chrysosporium*" – ME446 and the thermophilic and acidophilic archae "*Sulfolobus Solfataricus*" – ATCC 35091 are the microorganisms applied in the bidesulphurization processes.

A procedure for elemental sulfur determination is developed in order to specify the changes in the organic and elemental sulfur as a result of the studied coals biotreatments. Its application gives us ground to achieve better sulphur balance. The results of experiments demonstrated that more suitable solvent for the extraction of Sel in the studied coals is chloroform instead of described in the literature c-He. The highest content of elemental sulphur is registered in the preliminary demineralized and depyritized coals. It can be related to their chemical alteration. As a result of the implemented biotreatments the amount of the elemental sulphur is reduced by 55%. It is found that extracted Sel in the samples varied in the range of 0.7% - 4.6% of total sulphur and from 0.8-5.1% of organic sulphur.

P6-7

Study of Bidesulphurized High Sulphur Coals from Bulgaria

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Bidesulphurization is one of the perspective methods for production of friendly fuels.

The aim of the present study is to determinate the changes in two Bulgarian coal samples, their soluble products and residues after treatment with bacteria.

Low rank high sulphur Maritza East lignites and Bobov Dol subbituminous coal, are of important energy significance for Bulgaria. The treatment by bacteria *Pseudomonas putida* B2 attained 44% total desulphurization for lignites while the biotreatment by *Acidithiobacillus ferrooxidans* F3 of the subbituminous coal achieved 14% desulphurization. The bitumen (chloroform soluble portion) and fractions with different polarity of neutral oils of initial and biotreated coals are under study. Some increase in oxygen containing homologues of polar diterpenoids, i.e. phenols, ketones, quinone and ketophenol derivatives, an indication for oxidative process, is confirmed by GC/MS for subbituminous coal treated by *Acidithiobacillus ferrooxidans* F3. During the same treatment two new formed oxygen containing compounds, ~25% from total amounts of polar diterpenoids are found. Concerning polar diterpenoids of treated by *Pseudomonas putida* B2 lignites their relative contents are comparable with initial lignites.

Temperature programmed reduction coupled "on-line" with mass spectrometry (AP-TPR/MS) and its "off-line" TD-GC/MS mode to determine the sulphur changes in solid residues after bitumen extraction are applied. TD-GC/MS profiles are quantitatively interpreted by spiking with deuterated sulphur compounds as inner standards.

It is concluded that *Acidithiobacillus ferrooxidans* F3 bacteria generally decrease pyritic sulphur and slightly oxidize coal organic matter, probably due to microbial metabolites secreted into media. *Pseudomonas putida* B2 bacteria influence lignite

organic matter but pyritic sulphur is also affected probably by metabolites' formation in the experimental conditions.

P6-8

Samples in the World Coal Quality Inventory - A USGS Compilation on Global Coal

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The main objective of the World Coal Quality Inventory (WOCQI) was to collect and analyze a set of samples of mined coal from around the world during a set time period, from about 1995 through 2006. Generally, international collaborators were provided sample collecting guidelines and forwarded their samples to the U.S. Geological Survey (USGS). Samples were subsequently analyzed for major-, minor-, and trace-elements at the USGS Inorganic Geochemistry Laboratory located in Denver, CO and for proximate and ultimate analyses at a commercial laboratory located in PA using ASTM methods (2007). The resultant dataset, in EXCEL 2003 format, includes nearly 1,600 individual samples from 56 countries and is not subject to the inter-laboratory variability present in many coal chemistry compilations.

About 70 percent of the WOCQI samples have data from the commercial laboratory, which are presented on an as-received basis.

Values for nearly 50 elements from the USGS laboratory were calculated to a consistent dry, whole-coal basis in the dataset. The WOCQI data should be used with care, given two caveats: 1) sampling on a one-time basis is incapable of showing temporal or spatial heterogeneity of a coal deposit and 2) a review of quality assurance in the USGS laboratory in 2008 discovered that standardization (normalization) was beyond accepted limits of 10 percent. Re-analysis of some WOCQI samples by the USGS Laboratory has shown that the original results are generally valid; although they may be plus or minus 30 percent from values obtained more recently under more rigorous quality control procedures (Energy Geochemistry Lab, 2010).

Additional coal sample data were added to a second EXCEL file from USGS international studies conducted prior to WOCQI. These are split into two time periods: before 1990 and after 1990. The sample locations for all three datasets are plotted on a map (Figure 1) that depicts surficial coal-bearing areas of the western hemisphere (North and South America) and of Africa, compiled in Geographic Information System (GIS) format by the USGS in 2008.

P6-9

Research on One Kind of High Volatile Matter 1/3 Coking Coal Used into Blending-Coking

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One kind of 1/3 coking coal from Shan-dong Province in China, has low metamorphism, high volatile matter, and the caking index (G value) is 70~75, and the coke misconstrue has lots of isotropic structure, so the coal show gas coal properties. This paper presents when the high volatile matter 1/3 coking coal and gas coal is used into blending-coking, the effects on blending coal property and coke structure was researched. The results indicate if the blending ratio of this kind of 1/3 coking coal was equality or less than gas coal, the coke quality was high, but if the blending ratio of this kind of 1/3 coking coal was equality to normal 1/3 coking coal, the coke quality will be deteriorated.

P6-10

The Research on Meager Lean Coal Coking Compatibility with Different Coking Coal

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The meager lean coal, after fine crushing, coked compatibility with gas-fat coal, fat coal, 1/3 coke coal and coking coal by weight ratio of 1:1. The results showed, to ensure quality of coke, if the mixture ratio of meager lean coal was improved, the blending coal must have amount of fat coal and gas-fat coal and moderate to restrict the amount of coking coal and 1/3 coking coal; In the coking process, the expansion and mobility of 1/3 coking coal is far less than the gas-fat coal and fat coal, so when it coked with the meager lean coal, the result was different from the conventional coking mechanism.

P6-11

Microwave-Assisted Extraction of Shenfu Coal by Fractional Method

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According to fractional extraction principle, acetic acid, tetrahydrofuran and ethylene diamine were used to fractional extraction of Shenfu coal. The acetic acid, tetrahydrofuran, ethylene diamine-extractable fractions and the residue were analyzed by GC/MS and Solid-State ¹³C NMR, from which abundant structural information of

the coal was obtained, such as f_a^a , f_a^c , f_a^l , f_a^H , etc., respectively. Distributing

rules of organic chemical compounds were achieved to provide basis for reasonable utilization of Shenfu coal.

P6-12

Use of Flicker Noise Spectroscopy for Analyzing the Morphological Characteristics of Coals

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The genetic classification subdivides coal vitrinites into genetic types according to the conditions of their genesis. They differ in the degree of decomposition of lignin-cellulose tissues. Obviously, these differences largely determine a number of important characteristics of coals, such as fragility, granulometric composition, and gas permeability. However, the use of the genetic classification for estimating the properties of coals was limited until recent time because there were no quantitative estimates reflecting the morphological characteristics of vitrinites with different genotypes.

Flicker noise spectroscopy (FNS) was used to quantitatively estimate the morphological parameters of coals. Thin sections of coals were used for parametrization. The analysis was performed in transmitted polarized light. More than 150 coal samples from different deposits were studied.

The use of FNS for parametrization of coal images yielded quantitative parameters adequately describing the morphological characteristics of the organic matter of different coal genotypes. The main morphological parameters are σ , which is the measure of changes in the contrast (arb. un.) calculated as the standard deviation of the contrast from its mean level, and $S01$, which is the index of sharpness of changes in the contrast (arb. un.) serving as a measure of spike irregularities.

Linear relationships were found between the obtained FNS parameters and coal microfragility. The statistical parameters of the particle size distribution after grinding were demonstrated to be closely related to the FNS parameters of coals.

P6-13

The Property and Utilization Trend of Low-Rank Bitumites in West China

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More and more low-rank bitumites in West China will be developed and utilized. This type of coal is used for combustion, gasification, hydro-liquefaction, and carbonization. The coal has more semi-inertinites, and is shown as moderate gray under microscope; hence the coal has the nature of moderate liquefaction and gasification. This paper proposed a way to deeply study on the properties of chemical reaction and process of the semi-inertinites.

P6-14

Model Structure of High Sulphur N.E. Region Indian Coals

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As per Model structure of coal proposed by Shri B. K. Mazumdar, number 9 and 10 positions are available in phenanthrene unit, which is the mother nucleus of coal (lignite to semi anthracite). In this model structure, one unit of coal is linked with other unit by certain linkages such as ether and methylene groups. Oxygen in coal has been distributed in the form of different functional groups such as -OH, -COOH, >C=O and ether. The functional groups -OH and -COOH are available at the site of phenanthrene nucleus either at 9 position or at any other place. Position 10 is available for linkage with other unit of coal. >C=O group is present in a cyclic ring. Assuming this model structure of coal to be correct, oxidation of such a coal should lead to carboxylic acid formation up to a maximum extent of 5-6% because oxidation of methyl group and carbonyl group are expected to yield of -COOH groups. The actual experimental results obtained on oxidation of the same coal by 3N dilute nitric acid yielded 18% of -COOH groups. Hence this model cannot explain this experimental fact. If one assumes that besides these two positions, oxidation occurs at several other sites also then more solubility of coal in alkali / organic solvents on oxidation is expected to occur but this would lead to the formation of low molecular weight products on oxidation, which is not actually obtained. Hence a modification is needed in this coal structure so that the new model structure of coal can explain these experimental results also. Thus a modified model structure of coal has been proposed. Mr. Mazumdar has not spelt out anything about model structure of high sulphur coals of North Eastern Region. With the help of the data generated by Dr. Srivastava's group on disposition pattern of sulphur in NE region coal structure, a model structure of high sulphur NE coal has been proposed.

P6-15**Research on Infra-Red Spectrum of Microcosmic Characteristics of Coal Oxidation at Low Temperature**

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Coal spontaneous combustion is severe in China, according to statistics, there are 51.3% state-owned key coal mines have possibility of spontaneous combustion, and more than 90% coal fire were caused by spontaneous combustion. Not only coal spontaneous combustion pollutes environment and wastes resource, but also it seriously threatens the coal mine production safety and obstructs the sustainable development of coal industry. Coal spontaneous combustion is a complex physic and chemical change procedure, the macro characters reflected in the course of it embody the micro changes of oxidation of coal molecule structure at low temperature. Therefore, it entails mastering relation between macro phenomenon of coal spontaneous combustion and micro character changes of coal oxidation at low temperature, which is practical for deeper research on coal spontaneous combustion mechanism and making effective coal fire prevention and controlling measures. According to sample gathering code, fresh coals of different ranks from 4 typical coal areas of China are collected as experiment samples, including Chaijiagou coal mine and Dongshan coal mine, etc. FTIR characters of original and oxidized coal samples at different temperatures are compared and analyzed, micro structure changes of coal at low temperature oxidation is studied, oxidation ways of active groups of coal molecules are discussed, the laws that active groups in coal molecules change along with the temperature are analyzed. Experimental research results indicate that many categories of different amount of active groups exist in all coals of diverse ranks, different kinds of active groups have different activation energies, even the same type of active group has dissimilar oxidation activities in different types of coal, because of the influence of the inductive effects and conjugated effects of main structure of coal molecule, accordingly, the degrees of difficulty of oxidation are distinct. Comparing the spontaneous combustion characters of coal samples, the relation between the active groups of coal and its self-ignition propensity is discussed. Research shows that the amount of certain kinds of active group in coal can be used to judge the coal self-ignition propensity. The result of research further revealed mechanism of coal spontaneous combustion, and it has theoretical significance to research on coal molecule structure based quantified coal self-ignition propensity evaluating methods.

P6-16**Research on the Deep Cleaning of Anthracite by Selective Oil Agglomeration**

Binbin Zhao, Qiaowen Yang, Linlin Liu, Jian Chang, Huanling He, China University of Mining and Technology, CHINA

Aimed at solving the series of problems about coal flotation, for example, the particle size is increasingly smaller, the concentrate ash is hard to reduce and the cost of the flotation is high, the paper studied on the deep cleaning of the anthracite from Jincheng in Shanxi province by selective oil agglomeration. In this study, the effects of some parameters that influence the effectiveness of selective oil agglomeration, such as collector dosage and frother dosage, on the recovery and the ash content of the clean coal were investigated. It was found that the ash content of the coal significantly decreased from 14.45% to 1.71% by selective oil agglomeration.

P6-17**Influence of the Surface Treatment with O₃ and NH₃ on the Physical and Chemical Characteristics of Dried Low Rank Coal**

Gi Bo Han, Yongseung Yun, Changsik Choi, Institute of Advanced Engineering, KOREA

In this study, the dried coal with the surface treatment was characterized to investigate the effect of the surface treatment on the chemical and physical properties of dried coal. The surface treatment was conducted by the dry method with 5 vol% NH₃ at 200 °C and 15 g/m³ O₃ at room temperature. As compared with the fresh dried coal, it was found that the dried coal obtained after the surface treatment was changed in aspect of chemical and physical properties such as the increase in the content of carbon, hydrogen and fixed carbon. From the change of the chemical and physical properties, the various effects were obtained as follows: 1) Removal of oxygen-contained functional group, 2) Elevation of calorific value, 3) Inhibition of spontaneous ignition potential, 4) Suppression of H₂O adsorption of dried coal.

P6-18**Buried Cultural Assets and Archaeogeophysical Studies at TKI's Coal Fields**

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Cultural assets, buried due to the natural events such as earthquakes, landslides are also observed in open pit mines operated by Turkish Coal Enterprises (TKI). Archeological excavations in Muğla (Yatağan-Eskihisar, Tınaz, Bağyaka, Milas-Belentepe Hüsamlar), Kütahya (Seyitömer), Bursa (Orhaneli) and Bolu (Göynük) open pit mines are being excavated by the logistic support of Turkish Coal Enterprises and the

collaboration of Universities and the Ministry of Culture and Tourism. By this way the cultural wealth of Turkey is exposed and the underlying coal is gained by the Turkish economy. Geophysical studies (resistivity-ground penetrating radar), which provide excavations at the exact positions and the direct reach to the ancient sites, have been continuously used since 1996 in Eskihisar (where ancient findings are frequently found), 2006 in Belentepe and Hüsamlar and 2007 in Seyitömer open pit mine.

P6-19**Energy, Natural Gas, Türkiye & Ankara**

İbrahim Halil Kirsan, Başkent Doğalgaz Dağıtım A.Ş., TURKEY

Natural gas; environment friendly, economic, comfortable, safe as long as it is used properly, clean, harmless to nature, is an "environmentalist" energy source. Is a combustible gas formed in the lower layers of the earth and primarily consisting of methane and ethan hydrocarbons. Has been formed by decaying organic substances millions of years ago. It is a primary energy source ie: it can be used immediately after drilling out. Being lighter than air it can readily effuse into the atmosphere.

Natural gas; when burned does not produce environmentally harmful wastes such as sulphur dioxide and carbon particles. Natural gas; is a serious insurance to nature, environment hence the future of mankind. As a fossil energy source similar to petrol, however does not leave behind ash or slag when burnt and has no need for storage during use.

Total natural gas reserves of the world is 178,7 trillion cubic meters and 3 Trillion cubic meters natural gas is consumed annually throughout the world. May be all natural gas reserves will last 50 or 60 years.

Our country in 2006, 19.6 billion cubic meters of natural gas consumed imported from Russia. This corresponds to 63% of total consumption. The amount of LNG imported from Nigeria and Algeria, 5.3 billion cubic meters.

Our total reserves our calculated to be less than our annual consumption amount.

Türkiye relies on foreign countries for the supply of natural gas. Majority from Russia and Iran (through pipes), remainder from Algeria and Nigeria (as LNG).

Başkentgaz is the second largest company with 2 billion cubic meters consumption per year and oldest distribution company in Türkiye.

P6-20**An Alternative Application to the Centrifugal Dryer at a Coal Preparation Plant**

Ahmet Gitmez, Mustafa Yılmaz, Western Lignite Establishment (GLI), TURKEY

In this study, compared with centrifugal dryer and dewatering screens substitution instead of centrifugal dryer used for drying of the fine clean coal product at the Omerler Coal Preparation Plant. This comparison was made to both rates of humidity of the product initial and investment and management costs.

In the Omerler Coal Preparation Plant, fine clean coal washing at primary heavy medium cyclone and then dewatering. Fine clean coal had been feeding a centrifugal dryer after classification. The centrifugal conical sieve required change once a month and mechanical malfunction had increased, so it was thought that a different solution.

The centrifugal dryer instead mounted two units dewatering screens manufactured by Omerler Coal Preparation Plant's repair and maintenance team. The average moisture content in the range 18,5-19,5% at fine clean coal were obtained using centrifugal dryers. After the use dewatering screen, moisture content in the range 16,5-18% at fine clean coal were obtained.

Initial investment cost of centrifugal dryer was \$100,000. Initial investment cost of founded two units dewatering screen instead of centrifugal dryers was \$50,000. These dewatering screens were mounted with machinery spare parts of Omerler Coal Preparation Plant.

The annual operating cost of the centrifugal dryer has been \$75,000. But the annual operating cost of two units dewatering screens have been \$20,000. At the same time these dewatering screens was in operation a major contribution for dewatering process of fine clean coal.

P6-21**The Evaluation of the Contributions to the Productivity of the Process Changes at Tuncbilek Coal Preparation Plant**

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The most important business mission in coal washing plants, just as in all mineral processing plants, is to implement the processes and working methods in order to get access to extract the saleable products in targeted and desired quality which is theoretically possible. Coal is a non-recyclable energy source as all other underground sources. Therefore, the coal should be made best of it to ensure maximum benefit since it is produces in very difficult conditions. The process changes for the acquisition of products for all of the additional revenue derived from the run-of-mine coal are identified in this study.

At Tuncbilek Coal Preparation Plant under the direction of Western Lignite Establishment of (TKI) Turkish Coal Enterprise, the implementation regarding process changes and engineering application is discussed and an evaluation is made on the

increase of production and productivity and decrease in operating costs and increase in profitability. In this assessment, the decreases in operating costs as well as increase in profitability are achieved as a result four years of implementation with respect to productivity. The approximate total income increase was annual \$15,600,000, through process changes and engineering applications.

P6-22

The Dump Truck Requirement Planning Studies of Turkish Coal Corporation

Mustafa Ziyapak, Turkish Coal Corporation, TURKEY

Operation field of Turkish Coal Corporation (TKİ) is lignite production, most of which is achieved from open pits. The Corporation is realized important portion of overburden removal and coal production activities carried out at open pits by means of its own facilities (personnel and equipment). For overburden removal workings carried out at TKİ's open pits, generally electrical excavator – dump truck combinations have been applied. Economical life of electrical excavators, whose operation costs are low, has been going on. In addition, these excavators have idle capacities due to dump truck inefficiency. On the contrary, economical life of The Corporation's dump trucks is expired to a great extent owing to high working hours and obsolete technology. Because of this, by scraping most of existing dump trucks of Turkish Coal Corporation, instead new dump truck investment is inevitable.

In this study, by taking capacities and loading heights of existing excavators as a base, classes of trucks to be purchased have been determined; by considering estimated overburden removal to be performed by TKİ facilities, total capacity of excavators which is working at TKİ site, annual capacity of dump trucks whose economical life is not completed, annual capacity of dragline excavators that are working at TKİ sites, number of dump trucks to be invested have been calculated. Furthermore, comparison of operating costs of advanced technology dump trucks (electrical) with old technology mechanical trucks have been made; calculation of pay back period of trucks to be replaced has been made.

P6-23

Estimation of the Risk-Adjusted Discount Rate for Hard Coal Projects Depending on Geological Factors at Various Stages of Exploration

Piotr Saluga, Eugeniusz J. Sobczyk, POLAND

A level of geological factors affects the risk of coal projects. The most important risk factor for a typical Polish hard coal project at each stage of exploration is the estimating error of coal quality parameters. The paper distinguishes four important factors influencing future feasibility of the project, i.e. seam thickness, calorific value, ash and sulphur content. Above mentioned factors were estimated from the data obtained in consecutive stages of exploration. The estimation accuracy was assessed with the help of ordinary kriging in particular blocks of six coal seams of the Upper-Silesian Coal Basin and two coal seams of the Lublin Coal Basin. The estimation errors were used to determine the risk-adjusted discount rate (RADR) at various stages of exploration. Surprisingly, among the parameters analyzed the least significant for the project's feasibility is the coal seam thickness and, as a result, coal reserves that are the essential determinants of the project life.

P6-24

Investigation of Radioactive Contents Soma Coals

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Coal, world's the most abundant, the most accessible and the most versatile source of fossil energy was brought to the forefront of the global energy scene by the industrial revolution of the 18th century. Like any fossil fuel, coal is associated with naturally occurring radioactive materials. This is due to their U, Th, and K contents. This certainly has radiological implications not only for the miners but also for the populace in the immediate environment of the mines and the users. In this study, the radioactive elements in Manisa-Soma coals and their ashes were carried out. In the experimental section, the coal and thermal power plant ashes which were taken from Manisa – Soma were used. Sieve, moisture, ash, calorific value, volatile amount, total carbon, total sulphur, major element and radioactive element analysis of the samples were carried out. The float and sink analysis and flotation tests of the samples which were taken from Manisa-Soma were carried out. Thus, radioactive elements changes and moving mechanisms were investigated with coal preparation and burning methods. Furthermore, the pre-investigation of the assessment of the thermal power plant ashes was carried out with the experiments on the ash samples which were taken from Soma thermal power plant.

P6-25

Effect of Triboelectrostatic Separation on Coal Desulfurization and Deashing

Byoung-Gon Kim, Ho-Seok Jeon, Sang-Ho Back, Chong-Lyuck Park, Korea Institute of Geoscience and Mineral Resources (KIGAM), KOREA

Coal deposit among the fossil fuels is very plentiful in natural resources and has high economical efficiency but its application techniques are very inconvenient. Coal is not

an expensive mineral compare with other natural energy resources, therefore a various researches for economical coal pre-preparation technique have been developed. Triboelectrostatic separation cost less in operation process than the others separation methods for coal purification. A principle of this separation process is use a difference of work function when mixed particles crush a surface of the other material, at this time, surface of particles is charged by positive and negative. A coal particle that have a small work function is moved to the negative electric rode because the particle is positively charged by loss of an electron, and an ash particle that has a big work function is moved to the positive rode because the particle is negatively charged by getting an electron when charged particles pass through electronic magnetic field by high current.

In this study, we made a bench-scale's triboseparation equipment using electrostatic technology, and got an optimum condition of various factors for increasing recovery rate and purification in separation. Also, we used a copper that has middle work function between coal and ash by pipe's quality.

An optimum condition in coal separation by this process is particle size of 20mesh, flow rate of air is 3kg/cm², electric voltage of 30kV and using a coated screen rode by film, also rejection rate of ash and sulfur content is very different in each samples. Therefore we got a clean coal that recovery rate is 68.10%, rejection rate of ash and sulfur content is 31.23% and 28.33%.

P6-26

Remove of Ash and Sulfur Minerals from Coal by Triboelectrostatic Separation

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Electrostatic separation technique has received much attention in recent years as a method of removing pyrite sulfur and ash-forming minerals from coal. Recent efforts to use electrostatic methods for the cleaning of coal have focused on the use of triboelectric charging of the coal particles followed by separation of the dry charged material in a static high voltage field. These studies have demonstrated that it is feasible to use the triboelectric charging to achieve high separation efficiency, but the application of this technique at a commercial scale has yet to be demonstrated. In triboelectrostatic separation, the coal is entrained in a stream of nitrogen carrier gas and then collides with the surface of the charger under turbulent conditions. The coal and mineral matter acquire opposite charges (coal +, mineral -) and can be separated by a strong electric field according to polarity.

In this study, triboelectrostatic separation process has been proven in bench-scale tests to be capable of better than 50% removal of pyritic sulfur and greater than 60% reduction of ash for coal from China.

P6-27

Recovery of Valuable Metallic and Non-Metallic Minerals from Coal Mine Wastes

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Disposal methods of coal mine wastes were mainly suggested a landfill and a revegetation in Korea. Tailings and mine wastes generated from coal mines (mainly anthracite in Korea) contain at least a little iron sulfide. These wastes, like abandoned metal mines, are often conspicuous because of iron oxide staining and the acidity of the water that drains them. Hazards to adjacent areas are also associated with subsidence problems due to the abandoned space, and debris from mining and milling operations that do not involve sulfide minerals. In this investigation, reprocessing tests were carried out on various types of coal mine wastes in order to recover valuable metallic and non-metallic resources and to minimize long-term environmental damages. Reprocessing tests were carried out by employing various separation techniques such as gravity and magnetic separation, classification, etc. Tailings from coal preparation plants were crushed, pulverized and screened to obtain below 1.0 mm size fraction which was evaluated to utilize as ceramic materials. Especially, silica minerals were recovered from the coal mine wastes by applying the selective crushing and grinding, and screening methods, processes were also developed to recover valuable metals and non-metallic resources, which will be used for aggregates, ceramic materials, foundry sands, and other construction applications. The processes we developed should meet the major conditions such as process with large scale treatment, easy operation and low maintenance cost, no secondary pollution. As a result of this study, fundamental information is now available for future pilot and commercial scale testing of the proposed processes, and will contribute to the utilization of coal mine wastes and the improvement of the environment in old mine regions.

P6-28

Manufacture of Fired Clay Brick from Coal-Preparation Refuse and its Characteristics

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Large amount of coal-preparation refuse (CPR) has been discharged from coal mines all over the world. This disposal of CPR is somewhat toxic to living organism since

though CPR contains small amounts of heavy metals, sulfur, and organic materials, they contaminate the surface and ground water through the leachate generated at the dump-sites. Therefore, it is important to find a possibility for effective utilizing CPR generated from coal mines in terms of environmental and economic points of view. CPR generated from anthracite contains the $\text{SiO}_2/\text{Al}_2\text{O}_3$ weight ratio of 2.0-4.0, which is nearly similar to that contained in fired clay bricks. In this study, a manufacture of fired clay bricks using CPR and its characteristics were investigated. The results indicated that firing shrinkage ratio and compressive strength decrease with increasing the addition amount of CPR, while water absorption ratio is almost constant under the entire addition amount ranges of that. It was also found that the properties of plasticity, firing shrinkage, water adsorption, and compressive strength of bricks manufactured using CPR satisfied them of the 1st grade clay bricks of Korea Standard L (ceramics) 4201. Therefore, it is expected that the use of CPR as a raw material to make fired clay bricks can save energy and decrease pollution.