DOE/PC/91334--T25

DOE/PC/91334--T25

DE92 007867

TECHNICAL REPORT

September 1, 1991 through November 30, 1991

Project Title: Cooperative Research on the Combustion Characteristics of Cofired Desulfurized Illinois Coal and Char with Natural Gas

DE-FG22-91PC91334

Principal Investigator: Richard O. Buckius, UIUC

Other Investigators: Cheng-Kang Wu, Herman Krier, and James E. Peters, UIUC

Project Monitor: Dr. Kenneth K. Ho, CRSC

ABSTRACT

Previous studies at UIUC have shown that natural gas co-firing with coal has the effect of sulfur retention in the ash, and researchers have suggested that co-firing could reduce ash deposition problems. This project will study (1) the overall sulfur retention as a function of combustion conditions (temperature, coal type, residence time, etc.), (2) the effect of types of sulfur species and sulfur transformations (pyrite, organic, sulphates, etc.) on sulfur retention, and (3) the transformation of ash constituents important to fouling (iron, magnesium, potassium, etc.). The Drop Tube Furnace Facility (DTFF) is to be used for this study.

During this quarter, a complete review of literature related to the project was made, and detailed strategy outlined for carrying out the research. The range of parameters to be covered was considered. Preparatory work on apparatus modification to extend the operating range of the DTFF was begun. Diagnostic methods to be used in the study were surveyed, necessary preparations and arrangements, including cooperation with the Illinois State Geological Survey (ISGS), were made.

The initial emphasis of this project, is on the study of sulfur transformation in Illinois coal or treated Illinois coal under simulated boiler conditions with or without natural gas co-firing, the details of which have not been well studied before. Sampling at various residence times and analysis of the char and ash by various means will be the method of investigation. The gas temperature range will be extended to 2000 K by using a plasma torch preheater. This will better simulate flame temperatures in large boilers and advanced slagging cyclone combustors. A continuous coal feeder will provide larger quantities of char and ash for more accurate analysis. Residence times will be extended by the use of a larger inner ceramic tube.

During this first quarter, the plasma torch has been designed, constructed and set up, ready for testing. A SiC tube and heaters for high temperature operation of the DTFF have been ordered. The specific ash characterization experiments are reported in the first quarter TECHNICAL REPORT for the project entitled "Combustion of Illinois Coals and Chars with Natural Gas."

This project is funded by the U. S. Department of Energy (PETC) and by the Illinois Department of Energy and Natural Resources as part of their cost-shared program.

EXECUTIVE SUMMARY

The Clean Air Act Amendment of 1990 sets stringent and urgent requirements for the utility industry to meet the standards of environmental protection. To comply with the standards, many users are likely to switch to low sulfur coals. Illinois will be particularly affected because of the high sulfur content of Illinois coal, which at present constitute a large portion of the coal supplied to eastern American utilities. The solution of sulfur pollution problem in the combustion of Illinois coal is very important and urgent.

The DOE Clean Coal Technology Program aims to develop effective methods of clean utilization of coal through selection of government/industry supported demonstration projects. Illinois is actively involved in several of these projects, e.g., the advanced slagging combustor, natural gas reburning and limestone injection projects. A large mild gasification project is also under way. Research on the fundamental level can provide better understanding of the processes involved in the clean coal technologies, and offer basic data and new ideas with the purpose of improving the present technology or developing new technologies.

This project considers the effects of co-firing natural gas with Illinois high sulfur coals to determine sulfur retention potential as a function of sulfur content, types of sulfur and natural gas concentration. Previous experimental results from UIUC have shown that co-firing natural gas and coal has the potential for reducing sulfur emissions by increasing sulfur retention in the ash. Additionally, researchers have suggested that co-firing of natural gas and coal reduces ash deposition problems. Thus, important questions of significant impact to Illinois needs will be considered.

To study sulfur retention in ash and deposition problems, the mechanism and rate of sulfur and mineral transformation must be understood. A survey of literature shows that present works on sulfur transformation are mainly limited to pyrite, and the details of transformation in coal under boiler conditions have not been well studied. Ash formation and behavior under boiler conditions have just begun to be studied in a fundamental way, and the range in conditions and the degree of quantification are still quite limited. The effects of high temperature on ash behavior such as those encountered in large boilers (~2000 K) or slagging cyclone furnaces (~2000 K) have not been studied for lack of a suitable apparatus. Also, the effect of natural gas co-firing has not been well studied. Therefore, through the present project, we seek to obtain results contributing to the understanding of these subjects with the goal to find more effective ways to limit sulfur emission and to reduce boiler deposition.

The Drop Tube Furnace Facility provides an environment with a heating rate comparable to that in the boiler furnace (10^4~10^5 K/s) up to a temperature representative of boiler flame temperatures (1500~2000 K). Various residence times from tens of milliseconds up to seconds are possible. The samples are quenched and collected for observation and analysis. Both chemical analysis and scanning electron microscopy (SEM) have been and will be used. The high gas temperature will be obtained through using a plasma torch gas heater which will heat nitrogen to over 2000 K. Oxygen will be mixed in downstream to provide gas flow of the desired temperature and composition. A tungsten/rhenium thermocouple will be used to measure the high temperature in the inert gas. The coal is injected along the axis directly into the high temperature gas to achieve the high heating rate. A sampling probe positioned at various positions along the axis produces varying residence times. A LECO Sulfur Determinator loaned from another laboratory in the department can provide total sulfur values, and cooperative arrangement with the Illinois

State Geological Survey (ISGS) will provide chemical analysis and SEM-EDX (energy-dispersive-X-ray analysis) methods for the char and ash samples.

The work in the first quarter consisted of the literature survey, exploring and defining the relationship between requirements of Clean Coal Technology, especially those directly affecting the use of Illinois coal, and the works of the present project, and setting up of the strategy of the present project. With the desired range of parameters defined, modifications of the apparatus started in October and will be finished early next quarter.

A plasma torch operating on d.c. arc has been designed and built. The design is based on many years of experience in plasma torch development, and employs a unique cathode and anode arrangement which is known to give stable and durable operation. The power of the torch is 5-10 kW, and is supplied by a constant-current arc welder. The torch is currently being set up for testing. The gas temperature will be determined through a calibration using both thermocouples and a calorimeter. Also, a silicon carbide tube has been ordered and will be substituted for the alumina tube during the high temperature operation of the drop tube furnace facility.

Initial ash characterization experiments have been performed with the existing Drop Tube Furnace Facility. The specific ash characterization experiments are reported in the first quarter TECHNICAL REPORT for the project entitled "Combustion of Illinois Coals and Chars with Natural Gas."

The modification of the apparatus should be finished early next quarter, and the initial testing of the apparatus, the approach, and the analysis of the samples will be the goal of the next quarter.

OBJECTIVES

The overall objective of the project is to determine the effects of treatment processes and natural gas co-firing on the ash characteristics for Illinois coal, with a view towards finding better methods of reducing the sulfur emission and ash deposition problems. In order to achieve this objective, it is necessary to make detailed studies of sulfur and mineral transformation during combustion and behavior of ash under various conditions for parent and treated coals.

The specific objectives for the current year are to obtain sulfur and mineral transformation data under well controlled conditions in the Drop Tube Furnace Facility (DTFF) for two Illinois coals (high pyritic and high organic sulfur) and their treated products, with and without natural gas co-firing, thereby gaining an understanding of the mechanism and potential in reducing the sulfur emission and ash deposition problems. Each set of data will consist of a number of data points taken at various residence times under identical conditions of gas temperature, composition and flow velocity.

The tasks to be completed in order to meet the objectives for the current year are the following:

1. Formulation of the complete strategy, methodology and outline for this research combined with initial ash characterization experiments. (1st quarter)
2. Modification of the experimental apparatus and methods of analysis. (1st - 2nd quarter)
3. Refine the apparatus and perform further experiments. (2nd quarter)
4. Running of the experiments to obtain a series of reliable data. (2nd - 4th quarter)
5. Analysis of the data to arrive at an assessment of the effects of the various factors and an understanding of the processes involved. (4th quarter)
6. Project completion and recommendations for future work. (4th quarter)

INTRODUCTION AND BACKGROUND

There are many significant research issues impacting the use of our coal resources including the mechanism of pollutants emission and methods of pollution control, methods to achieve stable and efficient combustion, mineral matter transformation which mainly affects slagging and fouling in boilers, combustion modeling, database on fuels and combustion characteristics, diagnostic methods, etc. At present, the environmental requirements as exemplified by the Clean Air Act Amendment of 1990 is posing an important and urgent task to the coal producers and users, especially to the state of Illinois. Due to the high sulfur content of the Illinois coals, many users may switch to low-sulfur coals in order to comply with the standards. There will be significant losses of markets and jobs. Therefore it is of utmost importance and urgency to find better solutions to the sulfur pollution problems in the combustion of Illinois coal.

Illinois is actively involved in many of the clean coal research and demonstration projects. For instance, the Gas Reburning and Sorbent Injection project has started at Hennepin and Springfield. The Low NOX/SOX Burner for Utility Cyclone Boilers project is being carried out at Marion. The demonstration project of Mild Gasification of Illinois Coal has started at the Illinois Coal Development Park. Research on a fundamental level is also being supported. This fundamental research provides a better understanding to the processes involved in the clean coal technologies, offer basic data and new ideas to the pilot or industrial scale studies with the purpose of improving the present technology or developing new technologies.

UIUC has been doing basic research in coal combustion for many years. One of the most recent projects has been the study of combustion characteristics of desulfurized Illinois coal and char. An Entrained Dust Flow Facility (EDFF) and a Drop Tube Furnace Facility (DTFF) have been used to study the ignition, flame speed and emission characteristics of parent and treated Illinois coals. The DTFF provides the capability to study single particle combustion with simultaneous measurements of particle temperature, morphology and velocity of the coal. The effects of natural gas co-firing has been studied, and it was found that co-firing decreases ignition delay time for low volatile coals or chars. It was also found that addition of natural gas increased sulfur retention in the ash, so the reduction in sulfur emission could be more than the per cent substitution by natural gas.

The availability of the DTFF as a research tool for accurately controlling the environment of coal particle combustion and the possibility of increased sulfur retention in ash make further study into the details of sulfur transformation an important next step. Since ash deposition is a major problem with boiler operation, ash behavior under conditions simulating the actual boiler is also worth studying. Therefore it was decided to use the DTFF in a further study of sulfur and mineral transformation as affected by coal type, treatment methods and natural gas co-firing.

The results of this research project will provide a better understanding on how sulfur and minerals are transformed in combustion and how the coal type, treatment methods and natural gas co-firing affect these transformations. Thus better methods of reducing sulfur emission and ash deposition problems may be found.

EXPERIMENTAL PROCEDURES

The emphasis of this project is on the transformation of sulfur under conditions representing those in the actual furnace, ash formation and behavior at high temperature, and the effects of natural gas co-firing on these processes. To study sulfur retention in ash, the mechanism and rate of sulfur transformation must be better understood. The selected experimental technique is to heat the coal particles in a drop tube furnace at a heating rate comparable to that in boiler furnaces (10^4~10^5 K/s) up to a temperature representative of boiler flame temperatures (1250~2000 K) and keep them at various residence times from tens of milliseconds to the order of seconds. The samples are quenched and collected for observation and analysis.

Initial ash characterization experiments have been performed with the existing Drop Tube Furnace Facility. The specific ash characterization experiments are reported in the first quarter TECHNICAL REPORT for the project entitled "Combustion of Illinois Coals and Chars with Natural Gas." These experiments will continue along with facility modifications to obtain broader operating conditions as noted below.

The DTFF will be modified to provide the capability (with modifications currently under construction) of operating at gas temperatures up to 2000 K with continuous coal injection along the axis. Modifications are also being performed to produce larger quantities of char or ash samples in shorter periods. Coal particles will be injected directly into the high temperature gas to achieve high heating rates. A sampling probe will be moved along the axis of the tube to collect all the solid particles at various residence times. The gas will be preheated by an electric arc plasma torch. Power input will be about 5 kW, and N_2 and O_2 will be added downstream to give the required temperature and composition. A SiC tube will be used to withstand the high temperature. A tungsten-rhenium type thermocouple will be used to measure the high temperature in the inert gas. The determination of total sulfur content in the sample will be performed with a LECO Sulfur Determinator. Cooperative arrangements with Dr. R. Harvey of the Illinois State Geological Survey (ISGS) will facilitate analysis of coal, char and ash samples by both chemical and SEM-EDX methods. The Center for Electron Microscopy of UIUC has the necessary equipment for performing SEM studies of the char and ash.

The project includes the following major steps:

1. Preparation of the Apparatus

The high-temperature DTFF will be moved to the newly remodeled Mechanical Engineering Laboratory. The plasma torch has been designed and machined and currently is waiting to be tested and calibrated. The coal feed system will be assembled as the tube is being set up. The entire system should be calibrated and in operating condition by the end of of this calendar year.

2. Initial Testing of the Method of Studying Sulfur Transformation

For one sample, the high pyritic sulfur Illinois coal (IBC-102) with a tube and gas temperature of 1750 K and an oxygen concentration of 10%, samples will be quenched at residence times ranging from 10 ms to 1 s. After determining the extent of devolatization and burnout, mass balances and total sulfur determinations will be performed. Once consistent trends are obtained in these environments, a set of samples will be sent to ISGS for elemental and sulfur type analysis. This set of tests will not only make sure that the experimental method is reliable, but also provide data on sulfur transformation under one particular set of conditions.

3. Study of Effects of Certain Factors on Sulfur Transformation

With the method of study established, several parameters will be varied to investigate their effects. Important contributions are the extent of natural gas co-firing, amount and kind of sulfur in coal, gas temperature and residence time. From these investigations, it is hoped that some insight on how to better control SO_x emission may be obtained.

4. Study of Ash Formation and Behavior

With the use of optical microscope, scanning electron microscope (SEM), and SEM with energy-dispersed x-ray spectrum (EDX), the ash formation, melting, coalescence processes will be studied to better understand the effects of temperature, natural gas co-firing, and coal type on ash behavior. Additionally, the possibility of studying deposition tendencies in the drop tube furnace will be considered.

5. Study of Combustion Rates at High Temperatures

Burning rate data for various coals and chars will be obtained at gas temperatures up to 2000 K. Such high temperature data is needed for modelling of combustion in large boiler furnaces and cyclone slagging combustors but have not been obtained before due to apparatus constraints.

6. Study of Sorbent Addition to Coal

Sorbents can be injected along with sulfur species in the gas to study the governing mechanisms under known temperatures and gas compositions. These data can be used to understand the processes in sorbent injection.

The above steps may not be all completed within one year. According to the proposed project, work described in items 1 through 4 will be completed before August 31, 1992.

RESULTS AND DISCUSSION

Work Performed During the First Quarter

In the reporting period (Sept. 1 to Nov. 30, 1991), the following tasks have been performed:

1. A detailed literature survey on sulfur and mineral transformations and ash behavior, with emphasis on the most recent works and basic studies by other researchers, has been performed. It was concluded that there has been strong interest in this area (see Appendix). However, the efforts are just beginning, and many details under actual boiler conditions have yet to be studied. Present work on sulfur transformation is mainly limited to pyrite, and the details of transformation in coal under boiler conditions must be considered. For the ash studies, the range in

conditions and the degree of quantification are still quite limited. The effects of high temperature on combustion or ash behavior such as those encountered in large boilers (>2000 K) or slagging cyclone furnaces (~2000 K) have not been studied for lack of a suitable apparatus. The effects of natural gas co-firing have not been characterized.

2. Based on the special needs for Illinois coal and the overview of literature in the field, the approach detailed in the previous section has been formulated.

3. The DTFF is being modified to provide capability of gas temperatures up to 2000 K. A plasma torch, using d.c. arc with power of 5~10 kW has been built. The design is based on previous experience with a unique cathode and anode configuration, and should give stable operation and long life. Many previous applications of plasma heating have been handicapped by the torch not being very reliable. But our current design will be able to give trouble-free operation for extended periods. Each cathode tip only uses a tungsten rod of 2 mm (diameter) by 5 mm (length) and will operate for over 100 hours. The torch will provide a stream of N_2 or Ar gas over 5000 K, into which calculated amount of N_2 and O_2 will be added through a water-cooled mixing section to produce a stream of given temperature (≤2000 K) and composition (% O_2) at the entrance to the drop tube. The tube chosen is made of SiC, 35 mm i.d. and 1524 mm long. It is on order from the Carborundum Company and will be operational at 2000 K under an oxidizing atmosphere.

4. Small sample size is a difficulty with single particle experiments. Larger amounts of sample from the single particle combustion studies are possible from a continuous coal feeder based on a fluidized pulverized coal bed in a movable syringe system. This approach will be used in our future experiments. Our previous research indicates that a combination of chemical and SEM methods of analysis will be needed to determine the carbon, silicon, total sulfur, types of sulfur, and the other minerals. A LECO Sulfur Determinator has been obtained from another laboratory in the Department of Mechanical and Industrial Engineering which enables us to make direct determination of total sulfur. Cooperative arrangements have been made with ISGS to make the other analyses. The SEM at the Center for Electron Microscopy of UIUC is available for ash and char morphology studies (the operation procedure has been learned through attending a short course given by the Center).

Also, initial ash characterization experiments have been performed on the existing Drop Tube Furnace Facility. The specific ash characterization experiments are reported in the first quarter TECHNICAL REPORT for the project entitled "Combustion of Illinois Coals and Chars with Natural Gas."

<u>Work Scheduled for the Second Quarter</u>

The modification of the apparatus will continue into the second quarter. The plasma torch will be connected to the DTFF and the calibration of gas flow rate and temperature will be performed. The coal feeder will be assembled and tested. Test runs will be made with sample collection, mass balancing and total sulfur determination. If consistent, a complete set of analysis will be obtained. The goal at the end of the second quarter is to obtain a complete set of data showing sulfur transformation.

CONCLUSIONS AND RECOMMENDATIONS

This project addresses the effects of co-firing natural gas with Illinois high sulfur coals to determine sulfur retention potential as a function of sulfur content, types of sulfur and natural gas concentration. Previous experimental results from UIUC have shown that co-firing natural gas and coal has the potential for reducing sulfur emissions by increasing sulfur retention in the ash. Additionally, researchers have suggested that co-firing of natural gas and coal reduces ash deposition problems. Thus, important questions of significant impact to Illinois needs will be considered.

To study sulfur retention in ash and deposition problems, the mechanism and rate of sulfur and mineral transformation must be understood. Our literature survey shows that present works on sulfur transformation are mainly limited to pyrite, and the details of transformation in coal under boiler conditions have not been well studied. Ash formation studies under boiler conditions are also lacking. Therefore, we seek to obtain results contributing to the understanding of these subjects with the goal to find more effective ways to limit sulfur emission and to reduce boiler deposition.

The Drop Tube Furnace Facility provides an environment with a heating rate comparable to that in boiler furnaces up to a temperature representative of boiler flame temperatures. The high gas temperature will be obtained through using a plasma torch gas heater which will heat nitrogen to over 2000 K.

Preliminary ash characterization experiments at lower temperatures have been performed on the existing Drop Tube Furnace Facility during the first quarter (see the first quarter TECHNICAL REPORT for the project entitled "Combustion of Illinois Coals and Chars with Natural Gas"). Through examination of the relationship between requirements of Clean Coal Technology, especially those directly affecting the use of Illinois coal, and the work to be performed in the present project, a strategy for the present project has been defined. Preparatory work on apparatus modification to extend the operating range of the DTFF to meet this strategy has begun.

APPENDIX

FUNDAMENTAL STUDIES OF ASH FORMATION IN COAL COMBUSTION

In recent years, the problem of fireside deposition in boilers has attracted a great deal of attention among research groups. This is because slagging and fouling on the heat transfer surfaces and in flow passages in boilers are the major cause of unplanned shutdown and loss of plant availability. Large economic losses are involved in these problems. With coal switching and coal blending occurring more frequently in practice, the deposition behavior of ash becomes more unpredictable, as the simple concept of "ash fusion temperature" will not give reliable predictions. Therefore scientists are trying to study ash formation and behavior in a fundamental way and hope to arrive at reliable predictive methods for deposition problems in boilers with different coals. A logical approach to this problem is to first study the processes of mineral transformation under conditions representative of those in the actual boiler furnaces, then quantify the mechanisms and form physical models, and subsequently combine these models into one comprehensive model which can be used to predict ash deposition behavior. Some fundamental processes of ash formation have been studied through analytical methods and some preliminary submodels have been presented. First attempts at establishing a framework for a comprehensive models are just being initiated. Here a brief overview of recent research by several major groups in the U.S. will be given.

Research efforts headed by Drs. Beer and Sarofim have been engaged in the study of coal combustion for many years. They found that two kinds of ash particles formed, an above-micron size formed by residual ash in char burnout, and a submicron fume (~0.05 μm) formed by condensation of vaporized mineral components[1]. The evolution of fly ash during pulverized coal combustion, including the fragmentation and/or agglomeration of coal and ash particles were studied[2]. Recently, an attempt was made[3] to predict relative fouling tendencies of a coal and a coal blend, based on computer controlled scanning electron microscopy (CCSEM) of the coal minerals. Results were compared with those of experimental deposition studies obtained in the pilot scale Combustion Research Facility, and they are encouraging.

The modelling of mineral matter transformation in coal combustion has also received some attention[4]. Submodels are obtained from bench scale tests done in many laboratories, which include descriptions of 1) the coal minerals, 2) transformation of key mineral species, 3) particle transport and dispersion, 4) particle reaction and fragmentation, 5) deposition mechanisms, 6) particle sticking and 7) deposit characterization. The submodels are integrated into a comprehensive computer code for the simulation of mineral matter behavior during pulverized coal combustion. Results show promise. Close collaboration with industry is needed as developments proceed. Additional studies of the mechanisms of coal ash formation under closely controlled combustion conditions have been performed[5]. Minerals in the original coal and in char and ash particles obtained in a drop tube furnace were analyzed by advanced methods such as CCSEM and SEM microprobe methods. Transformations in early and late stages of combustion were described.

PSI Technology has been quite active in coal ash research in recent years. In the study of mineral transformation during pulverized coal combustion[6], they found that different coals showed different behavior in ash formation. In some coals, coalescence among illite, kaolinite and quartz minerals was dominant, while in others, pyrite fragmentation was observed. Transformation of pyrite and illite was studied separately[7].

Advanced analytical methods in the study of mineral transformation in coal combustion have been performed at the University of Kentucky. Their group pioneered CCSEM methods of coal mineral analysis[8], and used methods such as Mössbauer spectroscopy to supplement the analytical work.

Recently the Combustion Research Facility of Sandia National Laboratories engaged in the study of mineral matter transformation and char fragmentation[9, 10]. The long term goal is also the prediction of ash formation and deposition behavior of coals in combustion equipment.

Virtually all these fundamental studies of coal ash formation utilized some form of laminar flow reactor, most often a drop tube furnace. PSI Technology used a precombustor on top of the drop tube. References 9 and 10 employ an upward-flowing laminar-flow reactor with a flat flame for heating the gas and igniting the coal. Most facilities have gas temperatures lower than 1750 K because of the heating method and material limitations. The high temperature drop tube in references 1 through 3 used plasma heating with Argon gas up to 2500 K. Most facilities inject the coal on the centerline, but a few employed dispersed coal injection.

The problem of mineral transformation and ash formation and deposition is very complicated. The coal and its mineral composition, the method of firing, and the conditions of combustion all contribute to the ash behavior. A simple concept of "ash fusion temperature" cannot give reliable prediction on boiler deposition. A great deal of progress has been made in recent years to solve this problem through fundamental investigations, and important advances have been made. However, up to now, the studies have only begun to clear up some of the physical phenomena involved in mineral transformation and ash formation, and most understanding is generally qualitative. There are still many significant questions in all phases of the ash formation and deposition problem that must be answered. Quantitative results which can be used as database in comprehensive models for reliable prediction of boiler deposition problems are required.

Fundamental Studies of Ash and Mineral Transformation in Coal Combustion

Institution	Investigators	Subjects Studied	Diagnostic Tools	Reference
MIT	Sarofim, et al	Mineral vaporization, Ash formation mechanism, Fragmentation and Coalescence, Ash size distribution, Modeling of fouling tencencies.	CCSEM, Analysis, Cascade impactor	Env. Sci. Tech. 16, 776 (1982), R. J. Quann, et al. 22nd Symp. (Int'l) on Comb., 231, (1988), J. M. Beer 8th Pittsburgh Coal Conf., 3, (1991), E. L. Barta, et al. (Abstract)
PSI Andover, MA	Boni, Helble, Srinivasachar	Fragmentation, coalescence, Pyrite & Illite transformation, Impact deposition.	CCSEM, LT Ashing, Malvern sizing, Mössbauer spectr, Cascade impactor.	Prog. Ener. Comb. Sci., 16, 267, (1990) J. J. Helble, et al Ibid, 16, 231, S. Srinivasachar, et al. 8th Pittsburgh Coal Conf., 4, (1991), J. J. Helble, et al. (Abstract)
UND Grand Forks, ND	Benson, Zygarlicke, Steadman, Brekke	Particle size distribution, Ash composition, Char composition, Ash deposition.	CCSEM SEMPC XRD Analysis	6th Pittsburgh Coal Conf., 939, (1989), D. P. Kalmanovitch, S. A. Benson Prog. Ener. Comb. Sci., 16, 195, (1990), C. J. Zygarlicke, et al. 8th Pittsburgh Coal Conf., 12, (1991), D. W. Brekke, et al.
U. Kentucky Lexington, KY	Huffman, Huggins	Pyrite Transformation, Diagnostic methods.	CCSEM Mössbauer Spect.	Fuel, 68, 485, (1989), G.P. Huffman, et al. 8th Pittsburgh Coal Conf., 4, (1991), J. J. Helble, et al. (Abstract)
Sandia Livermore, CA	Hardesty, Mitchell, Baxter	Fe release, Fly ash formation, Mineral vaporization, Char fragmentation.	Analysis Particle size/vel. (will use) CCSEM	18th Symp. (Int'l) on Comb., 1239, (1981) D. R. Hardesty, et al. 8th Pittsburgh Coal Conf., 19, (1991), L. L. Baxter, Sandia Rep. SAND91-8233, L. L. Baxter, et al.
BYU	Harb, Richards	Modelling of ash deposition.		8th Pittsburgh Coal Conf., 33, (1991), J. N. Harb, G. H. Richards (Abstract)
UIUC		Illinois coal & desulfurized coal, Sulfur & mineral transformation, Effect of temp.-time-composition, High temp. (ash, slagging furnace), Effects of CH_4 co-firing.	Analysis, SEM, (CCSEM?)	

October 10, 1991 - C. K. Wu

Drop Tube Furnaces (Laminar Flow Reactors) for Coal Combustion Studies

Institution	Description	Used for	L (m)	D (mm)	Gas (Std l/min)	Coal (g/min)	Tg (K)	Tg, data (K)	Res. time (s)	Ref., Remarks:
U. North Dakota, EERC	2 Furnaces, Ash and Char produced	Ash studies, Mineral transformation	3 sections		Air 5.25 l/min	53-74 μm 0.32 g/min	#1 1588-1773 #2 1553	1680 1503	≤3.0 0.1-0.8	Prog. Ener. Comb. Sci. 16, 195, (1990); 6th Pittsburgh Coal Conf., 939, C. J. Zygarlicke, et al.
PSI (Andover, MA)	Resistance heated, CH_4-fired burner preheat gas	Ash studies Mineral transformation	1.3	Alumina tube	O_2 7% 21% in CH_4 comb. product	0.5-2.5 70% < 74 μm Mech. feed	1550	1500	3 s at 1500K	PECS 16, 267 (1990) J.J. Helbe, et al.
MIT	Graphite elements heated	Ash studies, Mineral matters	0.15 Hot Zone (0.30)	50 Alumina	$O_2$5-100% 6 l/min	0.03 g/min. H_2O cooled feeder on axis Total 1-5 g	1800	1750		PECS 16, 267, (1990), J. J. Helble, et al.; Envir. Sci. Tech 16, 776, (1982), R. J. Quann, et al.
U. of Newcastle Australia	Ceramic tube heated by cylindrical graphite element	Na-ash reaction during p.c. combustion	0.15 Uniform temp. zone	45	20% excess air		1273-1673 (10^4-10^5)(K/s)	1273-1673	~1s	23rd Symp. (Int'l.) on Comb. 1313, (1990) E. R. Linder & T. F. Wall
Combustion Engineering	Electrically heated preheater and test furnace	Pyrite transformation studies, etc.		50.8	95% N_2 5% O_2	38-74 μm Syringe pump	1311-1727	1311-1727	0.1-1.2	Fuel 68, 485 (1989) Huffman, et al.
B.Y.U.	Alumina tube in furnace	P.C. combustion, char reactivity	0.14	9	O_2/C ≥ 200	Positive displacement solid pump	≤1800	Part. T ≤2100		PECS 10, 4, 359 (1984) L. D. Smoot, et al.
BCURA (Brit. Coal Utiliz. Res. Assoc.)	R.F. plasma preheats gas, SiC tube, SiC heating elements	Char combustion rate studies	1.0 (test ≤ 0.15 m)	50	80 l/min N_2-25%, O_2-0, 5, 10%, Ar	28-105 μm 0.03 g/min 2mm Al_2O_3 Axis, vib. trough	1100-1800	1200-1720	27ms at 1620K (120mm)	Comb. Flame, 13, 237 (1969) M. A. Field
MIT	Arc heated Ar plasma into graphite tube, graphite heating elem.	Coal devolatization at high temp., Ash vaporization	0.01-0.22 (test length)	50.8	29-150 Ar	0.15 (1.2mm s.s. tube on axis) vibra. part. fluidiz.	1000-2100 (2500)	1000-2100 (10^4-2 x 10^5 K/s)	30ms-200ms	16th Symp. (Int'l) on Comb., 1265, (1976) H. Kobayashi, et al.; Comb. Sci. Tech. 16, 187, (1977), Sarofim, et al.
Stanford	Argon Arc-jet fired entrained-flow reactor	Coal fuel-nitrogen study, burning rates		117	Ar, O_2 20%	2 g/min, sprinkler head, dispersed	1150-2000 ($5x10^4$-2x 10^5 K/s)	1200-1750	80ms, up to 200ms	23rd Symp. (Int'l) on Comb., 1265, (1990). Huassmann & Kruger, 22nd Symp., 223
UIUC	Electrically heated, detailed diagnostics	Ignition, Combustion rate cofiring, Ash	~1.0 Alumina tube	8, 12.7	N_2, N_2+O_2, 0-4% CH_4	Pulsed (Fluidized 1mm tube)	1290-1700	1500 (10^4 K/s)	5ms to 2s	7th Pittsburgh Coal Conf. (1990), 483, A.R. Schroeder, et al.
UIUC (Under Construction)	Arc plasma heated, Alumina tube electrically heated	Ash studies, combustion, cofiring	~1.0	25.4-50.8	N_2 + O_2 ~10 l/min	~1g/min on axis	≤2000 oxidizing or inert		<1.0 ~	High Temp. Oxidizing. Long res. time

October 10, 1991 - C. K. Wu

REFERENCES

1. J. M. Beer, "Stationary Combustion: The Environmental Leitmotiv," 22nd Symposium (International) on Combustion, 1 (1988).

2. S. W. Kang, et al., "Agglomerate Formation During Coal Combustion: A Mechanistic Model," Comb. & Flame 86, 258 (1991).

3. E. L. Barta, et al., "The Relative Fouling Tendencies of Parent and Blended Coals: Modeling and Experiment," 8th Annual International Pittsburgh Coal Conference, Proceedings, 3 (1991).

4. J. Harb and G. H. Richards, "Simulation of Mineral Matter Behavior During Combustion," 8th Annual International Pittsburgh Coal Conference, Proceedings, 33 (1991).

5. C. J. Zygarlicke, et al., "Studies of Transformation of Inorganic Constituents in a Texas Lignite During Combustion," Prog. in Ener. & Comb. Sci., 16, 195 (1990).

6. J. J. Helble, et al., "Factors Influencing the Transformation of Minerals During Pulverized Coal Combustion," Prog. Ener. Comb. Sci., 16, 267 (1990).

7. S. Srinivasachar, et al., "Mineral Behavior During Coal Combustion 1. Pyrite Transformations 2. Illite Transformation," Prog. Ener. Comb. Sci., 16, 281 (1990).

8. F. E. Huggins, et al., "Scanning Electron Microscope-Based Automated Image Analysis (SEM-AIA) and Mössbauer Spectroscopy, Quantitative Characterization of Coal Minerals," Am. Chem. Soc. Symposium Series 205, Coal and Coal Products: Analytical Characterization Techniques, E.L.Fuller, Jr., Ed.,239 (1982).

9. L. L. Baxter, et al. "Coal Combustion Science," Sandia Report SAND91-8233, Quarterly Progress Report, D.R.Hardesty, ed. Sandia National Laboratories (1991).

10. L. L. Baxter, "Char Fragmentation and Fly Ash Formation During Coal Combustion," 8th Annual International Pittsburgh Coal Conference, Proceedings, 19 (1991).

END

DATE FILMED

4/01/92

I