DEVELOPMENT OF METHODS TO PREDICT AGGLOMERATION AND DEPOSITION IN FBCS

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The Industrial Commission
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Submitted by:

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ABSTRACT

If a new minemouth power plant is to be built in North Dakota in the next decade, fluidized-bed combustion will be one of the leading candidates for the installation. It has been demonstrated that the thermal and environmental performance of North Dakota lignite is very good, however, the alkali in the ash can cause deposition and agglomeration problems in fluidized-bed combustion (FBC) systems. Most boiler vendors recognize the problems associated with alkali in FBCs and will not provide guarantees on their units if high-alkali fuels are used.

Recognizing these problems, the Energy and Environmental Research Center (EERC) is proposing a three-year intensive effort investigating agglomeration and deposition in FBC systems. The objectives of the program are to develop ways to predict the agglomeration and deposition problem, with the end result being methods of mitigating the problem. A predictive model will be developed in the first year of the program, with the balance of the program focusing on mitigating measures.

A three-year program is proposed at a total project cost of $1,200,000. Committed sponsors of the program include Ahlstrom Pyropower, Inc., Riley Stoker Corporation, the Electric Power Research Institute, and the U.S. Department of Energy. Northern States Power Company (NSP) is also expected to join the program. This request is for $200,000, which, with a contribution from NSP, will make the program fully sponsored. The cost-benefit ratio of this program will be enormous if the results from this program help site a new FBC facility in the state.

DEVELOPMENT OF METHODS TO PREDICT AGGLOMERATION AND DEPOSITION IN FBCS

1.0 PROJECT SUMMARY

Agglomeration and deposition in fluidized-bed combustors (FBCs) have been noted by users of several different FBC designs firing a number of different fuels. These ash-related phenomena have been shown to cause a loss in steam temperature; operating difficulties; and, in some cases, unplanned shutdowns. To predict and, ultimately, mitigate ash-related problems, information must be gathered on the abundance and association of ash-forming constituents in the fuel and on the ash transformations that occur under the typical operating conditions of the fluid bed. Responding to these needs, the Energy and Environmental Research Center (EERC) is proposing to determine the factors that influence ash partitioning, agglomerate formation, ash deposition on heat-transfer tubes and refractory, and deposit strength development. The ultimate goal is to develop a method to aid in the prediction of ash behavior prior to firing the fuel in an actual system and to provide methods to reduce or mitigate agglomeration and deposition associated with problem fuels.

This project is critical for the promotion of North Dakota lignite as a fuel for fluidized-bed combustion. Most of the major boiler vendors have an upper limit of alkali content in the fuel where they will no longer present guarantees for their units. This limit varies, depending upon other properties of the fuel. Most North Dakota lignites have alkali contents that exceed this "safe" range of operation. Special design features can be used to increase the safe range of operation. An example is the use of high bed makeup as is being done at the MDU Heskett Station. Although this option has been successful for the MDU bubbling bed, fewer options are available for circulating fluid bed combustors. Therefore, if any new combustion systems are built in North Dakota using fluid bed technology, the problems associated with agglomeration and deposition due to alkali must be resolved.

This prospectus details a proposed three-year program to determine the behavior of inorganic compounds from various fuels in fluidized-bed combustion environments using advanced methods of analysis coupled with laboratory experiments. Using this knowledge base, a predictive technique will be developed to determine the propensity of a fuel to agglomerate or form deposits under FBC conditions and to determine potential methods for reducing or mitigating the problem. The proposed objectives are as follows:

- To determine the mechanisms of inorganic transformation that lead to inorganic partitioning, ash deposition, and bed material agglomeration.
- To determine the factors that influence the sintering behavior and strength development of agglomerates and deposits under FBC conditions.
- To develop a means of predicting the behavior of inorganic components as a function of fuel composition and bed material selection.
- To develop methods that can be used to reduce or mitigate ash-related problems associated with particular fuels.

The program is structured to provide significant deliverables on a yearly basis. During the first year, detailed analysis of samples from full-scale plants will be performed, with the information generated incorporated into EERC's current data base to develop a preliminary empirical predictive model. During the second and third years of the program, full-scale data will be supplemented with bench-scale and fundamental testing to develop a better understanding of the mechanisms of agglomeration and deposition formation. Practical engineering solutions to mitigate ash-related phenomena with problem fuels will be suggested. The advances made in the predictive techniques and suggested mitigating measures will be reported at the end of each year. It is hoped that this will allow the sponsoring agencies to utilize the information generated from this program in a timely fashion.

2.0 PROJECT DESCRIPTION

To meet the objectives of the program, efforts will focus on 1) detailed characterization of the fuels; 2) carefully controlled laboratory-/bench-scale experiments to produce agglomerates, entrained ashes, and deposits; 3) experiments designed to determine physical properties of agglomerates and deposits; and 4) detailed characterization of materials collected from full-scale FBCs. This approach requires the development of advanced methods of analyses to include the further development of the automated scanning electron microscope/microprobe techniques to characterize fuels, chars, entrained ashes, agglomerates, and deposits. These techniques provide the information needed to elucidate mechanisms of inorganic transformations that form intermediate ash, agglomerates, and deposits. Carefully controlled experimentation on the bench scale that simulates the conditions in larger-scale systems must be performed to determine the behavior of fuel as a function of coal composition and FBC conditions. Subscale testing offers an opportunity to perform tests under very controlled conditions and greatly reduced costs, compared to larger systems. The subscale system may also provide a method of predicting the tendency for a fuel to form agglomerates or deposits. Physical properties, such as surface tension, viscosity, and strength of agglomerates and deposits, will be determined. Specific attention will focus on the development of agglomerate and deposit strength as a result of sintering processes and on the wetting ability of ash on bed material, heat-exchange surfaces, and other related materials. These efforts will be accomplished through the following six tasks:

Task 1. Development of Analytical Techniques

Task 2. Analyses of Material from Full-Scale FBCs

Task 3. Bench-Scale Reactor Development and Testing

Task 4. Fundamental Chemistry

Task 5. Development and Verification of Predictive Techniques and Mitigating Measures

Task 6. Final Report

The overall goal of this program is 1) to develop an understanding/mechanism of the formation of agglomeration and deposits during fluidized-bed combustion, 2) to develop a method to predict the tendency of a fuel to form agglomerates and deposits during fluidized-bed combustion, and 3) to suggest methods to mitigate agglomeration and deposition with problem fuels.

Task 1. Development of Analytical Techniques

Problems such as bed agglomeration and ash deposition are closely tied to the abundance and association of the inorganic components in the fuel and the system conditions. Current conventional analytical methods for solid fuels and ash materials do not provide adequate detail regarding their complex chemical and mineralogical properties. Advanced analytical techniques are currently being used by the EERC to determine the association and forms of inorganic components in solid fuels (1,2) and fuel ash-derived materials (3,4). In addition, other laboratory-scale techniques are routinely used to determine viscosity, surface tension, sintering behavior, and deposit strength development (5,6). Utilization of these advanced analytical techniques, coupled with closely controlled bench-scale combustion experiments, can potentially provide significant advances in understanding the behavior of inorganic components during FBC that will ultimately lead to better methods to predict and mitigate ash-related problems.

To achieve this goal, additional development work on the scanning electron microscopy (SEM) will be required to ensure that good quantitative analysis can be performed for all of the fuels. This will include the quantitative determination of carbon and oxygen. The scanning electron microscopy point count (SEMPC) and the computer controlled scanning electron microscopy (CCSEM) techniques will be combined with automated digital image analysis. Digital image analysis transfers the information contained on images into a computer. Once digitized in such a manner, images can be stored, retrieved, and manipulated as any other computerized information. The applications for these digitized images are limited only by mathematics and the imagination of the user.

The techniques that will be developed will provide data on the following: 1) quantitative determination of the mineral phases and sizes in noncoal-based fuels; 2) determination of the degree and composition of neck growth and thickness and composition of coatings in agglomerates; and 3) quantitative determination of the size and quantity of $CaCO_3$, CaO, and $CaSO_4$ in fly ash.

Task 2. Analyses of Material from Full-Scale FBCs

A comprehensive, detailed characterization of all of the inorganic materials from full-scale FBC systems experiencing agglomeration and deposition problems is needed in order to understand the nature of the ash transformations taking place. This characterization effort will not only provide insight into the processes taking place in the full-scale systems, but it will also provide for a continuum of data from the full-scale to the bench-scale system. The bridging of this gap is a critical step in the efficient use of the bench-scale experiments. By having data from all scales, we can ensure the validity and relevance of the bench-scale tests to be performed. The data from the larger-scale systems will be a guide to the ability of the bench-scale system to accurately mimic the processes and inorganic transformations taking place in the utility boiler systems.

A key part of this task will be obtaining samples from operating units experiencing some sort of particle growth, agglomeration, or deposition. Each sponsor will be asked to contribute samples from units that are experiencing problems. The EERC will also make requests for samples from other organizations that are experiencing ash-related problems. The budget for this task includes analysis on samples from ten different units. Samples to be analyzed include the fuel, agglomerates, spent bed material, fly ash, and any deposits from heat exchange or refractory surfaces. This information will 1) identify the coating and bonding material causing the agglomeration, 2) allow a detailed analysis of the coal causing the agglomeration, and 3) indicate which mineral species are contributing to strength development. SEMPC and CCSEM will be combined with advanced image analysis techniques in order to provide the data needed. The types of analyses to be used on each sample are listed below:

Fuel	Ultimate, proximate, CCSEM, chemical fractionation, XRF
Ash	CCSEM, SEMPC, XRF, XRD
Agglomerates	SEMPC, CCSEM, SEM image analysis, XRD, XRF
Deposits	SEMPC, CCSEM, SEM image analysis, XRD, XRF
Bed material and sorbents	SEMPC, XRD, XRF

The results from this characterization effort will be used to develop a Phase I model for predicting agglomeration and deposition. This empirical model will be refined and improved based on results from the bench-scale testing proposed in Task 3.

Task 3. Bench-Scale Reactor Development and Testing

With enough experience and a large enough data base, the propensity of a fuel, sorbent, bed material combination to form agglomerates or deposits based solely on advanced chemical analyses may be predicted. To build such a data base using full- and/or pilot-scale testing would be prohibitively expensive. However, if a bench-scale reactor can be designed to simulate the chemistry that occurs in the fluid bed, extensive testing can be performed at a reasonable cost. The overall objective of this task is to simulate the process of bed agglomeration and deposition and to correlate chemical analyses with run operating variables to effectively anticipate the occurrence of agglomeration. In addition, this reactor may be useful for studying techniques to control bed agglomeration, including selection of bed material and particle size, average bed temperature, and the use of bed additives.

A small bench-scale reactor will be designed and constructed. A reactor with a 3-in ID and 5 ft high is envisioned, with a bed height ranging from 6 to 18 inches. A preliminary design is proposed and is shown schematically in Figure 1. This design is fashioned after the EERC 2-in ID bubbling fluid-bed reactor, the EERC drop-tube furnaces, and test rigs used by other researchers. Some of the salient features that will be designed into the bench-scale reactor are presented below:

- Gas stream that simulates FBC atmosphere: CO_2, O_2, CO, and SO_2.
- Use of inert bed or sorbent bed under fluidized conditions.
- Burning fuel, not just using spent ash from another combustion or ashing procedure.
- Ability to operate under oxidizing or reducing conditions.
- Ash and bed material sampling as a function of time.
- Conical bottom for circulation patterns similar to CFBC, replaceable with cylindrical bottom to represent bubbling bed mode.
- Outlet gas stream sampling for normal combustion gases. Using existing gas analyzer panels, the EERC can sample for O_2, CO, CO_2, SO_2, NO_x, and N_2O.
- Ability to look at alkali getters in the bed and, possibly, after the bed.
- Probes to look at deposits in the freeboard.
- Continuous operation for at least 120 hours.
- Ability to sample alkali in the gas stream from the top of the combustor to quantify amount in particulate, aerosol, and gas, or total alkali. At the present time, the EERC does not have an alkali monitor and cannot speciate the forms of alkali leaving the combustor.
- The ability to operate under pressure may be added, based on the needs of the program sponsors.

The general mode of operation is envisioned as starting up with an inert bed, preheating to 1000°F using a combination of reactor heaters and air preheaters, starting fuel feed at a preset rate of 100 to 500 g/hr (to be

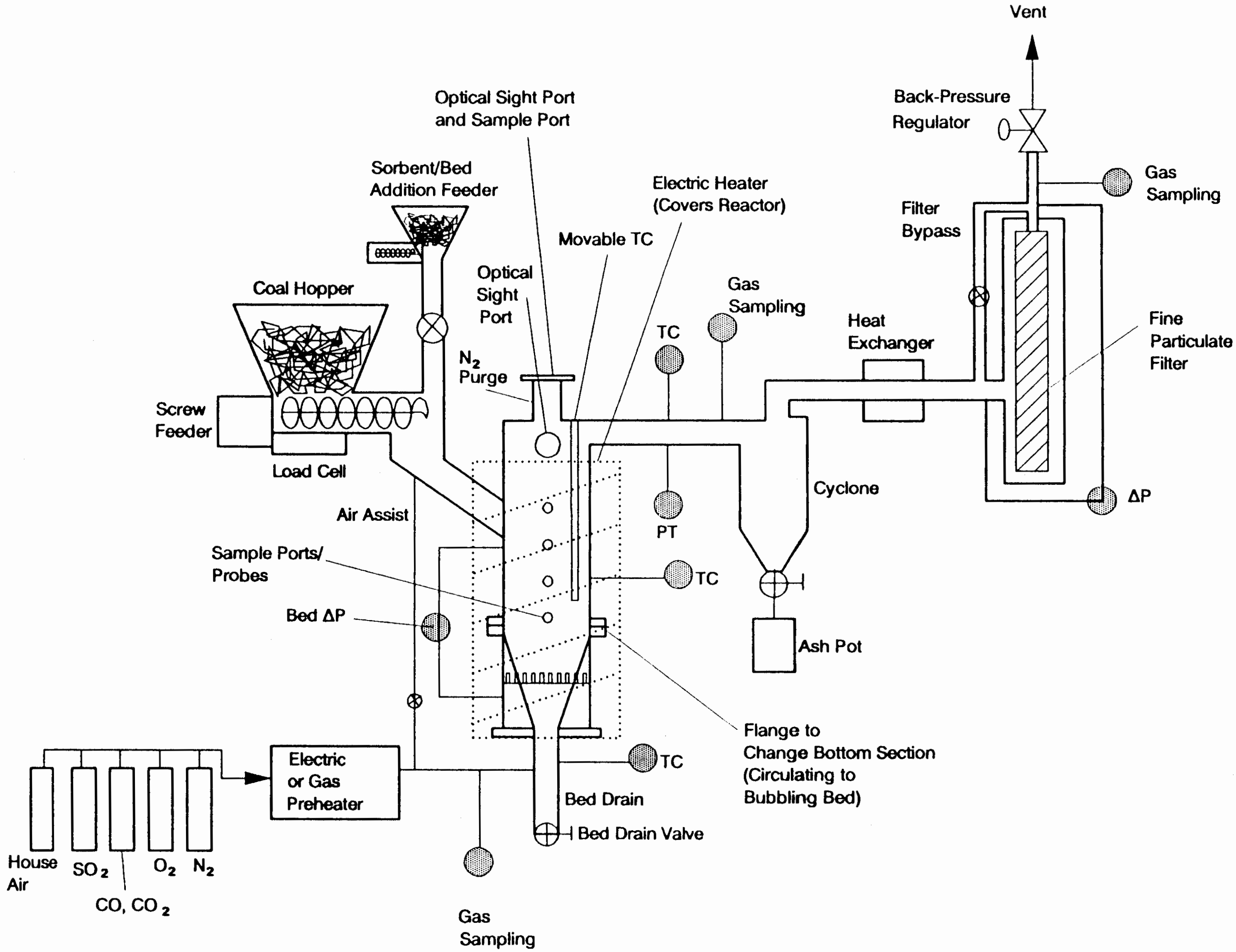

Figure 1. Preliminary design of bench-scale reactor for agglomeration and deposition testing.

determined during final design and shakedown), setting velocity at the desired rate, setting gas mixture (CO, CO_2, O_2, SO_2, etc.), and bringing temperature up to set rate by the burning of a selected fuel and use of reactor heaters. Sorbent, getters, bed material, or other additives as called for in the test plan will be added during each test. Bed samples will be withdrawn during the run to monitor the buildup of ash coatings or formation of agglomerates. At completion of the test, the bed will be drained, and samples of the fuel, bed material, agglomerates, deposits, and ash will be taken for detailed analyses.

A test matrix will be established to investigate the effect of the following variables on bed agglomeration and deposition:

- Fuel type and mineral properties of the fuel
- Bed material and sorbent type
- SO_2 level in the flue gas
- Gaseous environment (oxidizing vs. reducing)
- Temperature

The primary objective of this study is to develop a technique to predict the propensity for a given fuel/sorbent/bed material combination to form agglomerates and/or deposits during fluidized-bed combustion. Therefore, fuel type and mineral properties will be the primary test variables. Fuels will be selected by the EERC with input from the program sponsors.

After each test, the fuel, agglomerates or ash coatings, spent bed material, fly ash, and deposits from simulated heat-transfer surfaces and/or combustor walls will be analyzed. The advanced analytical techniques that will be used to characterize the deposits from full-scale units (Task 2) will be used on each of these samples. In addition, the techniques that will be developed during Task 1 should provide much insight into the agglomeration phenomena. The data generated during this task will be used in Task 5 to develop the predictive technique. This device will also be used as a preliminary screening device for any mitigating measures developed during the program.

Task 4. Fundamental Chemistry

In general, the inorganic components are associated in the fuel as minerals or organic complexes (salts of carboxylic acid groups or organic coordination complexes). The minerals associated in solid fuels vary widely in size, composition, and association of the mineral grains with other mineral grains and fuel particles. These associations directly influence the chemical and physical transformations that occur during the combustion process. Depending upon the type of combustion system, the inorganic components are initially partitioned into intermediate species in the form of inorganic gases, liquids, and solids. The state of these species at any given stage or position in the combustor directly influences their behavior at that stage. The transformations and partitioning of the inorganic species directly influence the corrosion and erosion of materials, as well as growth rate, quantity, and type of ash agglomeration and deposition on heat-transfer surfaces.

Work will focus specifically on the processes taking place which form inorganic vapors, liquids, and solids and the partitioning of inorganic components in various sections of the combustor. In addition, the interaction of these components upon gas cooling, deposition, and sintering will be examined in full-, pilot-, and bench-scale systems. Specifically, the reactions of alkali and alkaline earths, silicates, aluminosilicates, and sulfur-containing systems will be examined in detail.

In order to understand, and ultimately control, the fundamental chemical mechanisms taking place in FBC, this project will utilize three methods: 1) use advanced fuel, ash, and deposit characterization techniques in order to quantify the effects and mechanisms of inorganic transformations that lead to inorganic partitioning, ash deposition, and agglomerate formation under FBC conditions;

2) use materials and mechanistic data produced in this project in order to use existing thermochemical models to predict potentially troublesome fuels and operating conditions; and 3) perform a series of experiments using modified fuels or fuel additives to isolate the specific phenomenon responsible for the formation of problem-causing phases and to develop mitigating methods.

Task 5. Development and Verification of Predictive Techniques and Mitigating Measures

An attempt will be made to isolate common factors in agglomerate and deposit formation and to describe the agglomerates and deposits according to standard procedures (SEMPC, image analyses, x-ray fluorescence, sintering, and other spectrochemical and microscopic methods). Also, the thermodynamic constraints of agglomerate formation will be studied to provide a theoretical understanding of fuel ash and bed material interactions.

The objective of this program is to develop a technique so that the agglomeration and deposition tendency of a given fuel and sorbent/bed material combination can be predicted a priori to actually burning the fuel in a pilot- or full-scale unit. The predictive technique may ultimately consist of some combination of three components: 1) detailed analyses of the fuel, sorbent, and bed material; 2) bench-scale testing; and/or 3) the use of thermochemical models. During Task 5, data collected during the first four tasks will be correlated and the best set of predictive criteria developed. To help verify these techniques, a set of fuels with which a sponsor(s) has previous experience will be obtained by the EERC. Without prior knowledge of the agglomerating or depositional tendencies of these fuels, the EERC will predict their performance based on the criteria developed in this program. The predictive techniques will be refined, depending on how well the actual performance of these fuels matches the EERC predictions.

A preliminary predictive technique will be developed by the end of the first year based on results from the sampling from the full-scale units. This first-generation model will be empirical in nature, based on correlation of the analysis of materials from the full-scale plants coupled with experience from previous pilot-scale testing at the EERC. The predictive technique will be refined in each of the subsequent two years, as additional information becomes available from the bench-scale and fundamental testing.

Upon final verification of the predictive techniques, detailed procedures of the techniques used will be written and provided to each of the sponsoring agencies. This will allow the sponsors to use these techniques at their facilities. This capability will also be retained by the EERC, so sponsors will be able to make arrangements to have their fuel tested at the EERC.

Task 6. Final Report

During the course of the program, short, bimonthly status reports will be issued. At the conclusion of each of the first two years, an annual report will detail the activities for that year. A comprehensive final report will be issued upon completion of the first five tasks.

The final report will describe the various types of agglomeration and deposition studied, the mineralogy of the parent fuels, the bed material characteristics, the combustors used, and the operating conditions during the period of formation. The purpose of this report will be to inform sponsoring agencies about agglomeration and deposition of ash from a wide variety of fuels and bed material and to instruct on the abatement of these ash-related problems. Information gathered during this program will provide insights for those marketing and using FBC as an energy option and also those selling fuel or sorbent materials. Agglomeration and deposition will affect the economic, engineering, and environmental aspects of a project; therefore, matching a fuel with a particular bed material will be important.

Since a major portion of this effort is focused on developing an understanding of the mechanism of agglomerate and deposit formation, a special section of the report will detail their chemical and physical nature. The reactions and mechanisms that lead to agglomeration and deposition will also be discussed. Details of how this fundamental data were used to develop the predictive technique will be presented, along with details on the actual predictive technique(s). Finally, any potential methods of reducing or mitigating the agglomerating and deposition tendencies that were identified during the study will be presented.

3.0 STANDARDS OF SUCCESS

Deliverables of the program are listed in Section 8.0. Success of the program is partially measured by the timely completion of each phase of the project. The ultimate measure of the success of this program is the verification of the techniques developed during the program. One of the final tasks of the program is to take a set of fuels with which a sponsor(s) has previous experience and predict its performance based on the criteria developed during this program. Any mitigating measures developed during the program would be likewise demonstrated.

4.0 BACKGROUND

Although fluidized-bed combustors typically operate at relatively low temperatures, evidence from pilot, industrial, and utility boilers indicates that certain ash components have the potential to cause ash-related problems. These problems can manifest themselves as agglomeration and sintering of bed material, or as deposition on the heat-exchange tube surfaces and refractory walls. A variety of different fuels have been reported to cause agglomeration and/or deposition problems.

A good example of these problems is noted at the MDU Heskett Station. Even operating at a low-bed temperature while turning the bed over frequently with makeup with fresh sand, deposition on in-bed tubes, wing walls, and convective pass tubes continue to be a problem. Unscheduled shutdowns due to bed agglomeration have also occurred. Another example of ash-related problems associated with North Dakota lignites occurred during the testing done at the EERC as a part of the Lignite Research Council-funded project entitled Project CFB. Although no catastrophic problems were noted using this low-sodium coal, some small agglomerates did form during the test, deposits formed on the convective pass fouling probes, and some pluggage in the downcommer and loop seal occurred. A higher sodium level in the coal probably would have caused premature shut down of the CFBC for these one-week duration tests.

Bed material agglomeration is the process which causes relatively small bed particles to stick together, forming larger masses of material. Ash from the fuel reacting with bed material forms the substance which acts as the "glue" in agglomeration. These ash-related interactions occur under normal FBC-operating conditions and include the formation of low melting eutectics between sodium-, potassium-, calcium-, and sulfur-rich components and possibly some solid-solid reactions. Agglomeration can also occur as a result of localized hot spots of bed material, where temperatures in the FBC system can exceed the typical 1700°F limit. Temperatures capable of melting various ash species can be attained even during relatively stable operation of the FBC.

A very fine-grained ash matrix deposited on in-bed and convective surfaces has been noted in both pilot facilities and utility-scale systems (7). This deposition is related to the fuel ash chemistry and has been observed in stations operating with a bed temperature as low as 1450°F, despite the high erosive forces of bed material in a fluid bed. The mechanism of adherence and growth appears to be via a molten sulfate matrix, due to the fluxing action of the sodium. The sulfate matrix sinters over time to form a strongly bonded deposit. These deposits have been found in both bubbling and circulating units operating at atmospheric and pressurized conditions.

These phenomena are related to certain properties of the fuel and mineral matter. The presence of alkaline or alkaline earth elements that can be liberated during combustion enhances agglomeration and deposition. Other elements can play a role in this process. Organically bound elements are typically liberated during combustion and have been shown to be the major precursors to agglomeration. In addition, competing reactions with other mineral components in the fuel can reduce the alkali availability. The fate of these potential deposit- and agglomerate-forming minerals will ultimately influence the extent of deposition and agglomeration. Therefore, it is important to understand the nature of the mineral matter in the original fuel so that improvements can be made in the prediction of FBC performance.

In general, the inorganic components that ultimately make up the ash are associated in the fuel as minerals or organic complexes (salts of carboxylic acid groups or organic coordination complexes). The transformations of inorganic components during combustion consist of a complex series of chemical and physical processes. These transformations are dependent upon the physical and chemical properties of the fuel and combustion conditions. The behavior of the inorganic components largely depends upon the initial partitioning of ash components. This partitioning influences the distribution of the ash species in agglomerates, entrained ash, and deposits. Partitioning can be responsible for concentrating low melting species in the entrained ash and on the surfaces of ash particles and bed material and sorbents. These low melting point phases aid in deposit initiation, growth, and sintering. The low melting point species also contribute to ash agglomeration.

Currently, ash-related problems cannot be accurately predicted by examination of the raw fuel because the partitioning phenomena change the distribution of the inorganic components in the ash. Therefore, the characterization and modeling of partitioning phenomena are critical to the development of methods to predict ash behavior. These associations directly influence the chemical and physical transformations that occur during the combustion process. Depending upon the combustion temperature, the inorganic components are initially partitioned into intermediate species in the form of inorganic gases, liquids, and solids. The state of these species at any given stage or position in the FBC directly influences their behavior at that stage. The transformations and partitioning of the inorganic species directly influence bed agglomeration and corrosion and erosion of materials, as well as growth rate, quantity, and type of ash deposition on heat-transfer and refractory surfaces. Utilization of advanced analytical techniques, coupled with laboratory methods, can potentially provide significant advances in understanding the behavior of inorganic components during fluidized-bed combustion that will ultimately lead to better methods to predict and mitigate ash-related problems.

5.0 QUALIFICATIONS

The University of North Dakota Energy and Environmental Research Center is one of the world's major coal research facilities. Since its founding in 1951, the EERC has conducted research, testing, and evaluation of coals and associated combustion and gasification technologies. Fluidized-bed combustion research was initiated in 1975. As a part of the EERC FBC program, agglomeration, deposition, corrosion, and erosion in FBC systems have been investigated. A listing of publications generated as part of this DOE-funded research is presented in Appendix A. The Center's transfer from the U.S. Department of Energy to the University of North Dakota in 1983 made it possible for the Center's staff to work directly for industry to provide the needed data and practical solutions required for the specific problems and challenges encountered. The EERC possesses state-of-the-art analytical equipment and extensive laboratory- and pilot-scale facilities, providing unique capabilities for research programs.

Extensive research on the transformations of inorganic and mineral components in fuel has been conducted at the EERC. Research has been performed to develop methods to determine the association, size, and composition of ash-forming constituents in coal. Techniques are now available to determine the distribution of phases in fly ashes, deposits, agglomerates, and slags. Fundamental studies of the transformation of inorganic components to form intermediate ash components in the form of vapors, liquids, and solids have been performed using a laboratory-scale drop-tube furnace combined with advanced analytical techniques. Recently, the EERC has developed the ability to perform laboratory-scale studies under pressure. These techniques have been used to study fly ashes generated from coal, wood, peat, and petroleum coke.

6.0 VALUE TO NORTH DAKOTA

Sponsorship of the proposed research will be open to private companies and organizations. Each sponsoring company or organization will become a member of the project's Advisory Committee and will have one vote. An Advisory Committee Chairman will be elected from among the members at the first meeting of the Committee. The Advisory Committee will review project plans, budgets, and policies. Specific benefits of participating in the program will include:

- Rapid access to state-of-the-art research on the effects and possible control of ash-related problems in FBC systems, specifically agglomeration and deposition.
- Cost-effective research at a fraction of the cost available to a single company.
- Ability to rapidly effect transfer of information and data through consultation with EERC staff and sponsor personnel.

- Interaction with other sponsors and with personnel interested in agglomeration and deposition problems.
- Access to predictive techniques for agglomeration and deposition in FBC systems.

Each sponsor shall have a nonexclusive, perpetual, royalty-free, worldwide license to practice any invention, discovery, or improvement (whether patentable or not) conceived or made by the EERC as a result of this program. The EERC assumes no liability for warranting the validity of any patent issued or for prosecuting patent restrictions on third parties.

Specific to North Dakota, the most important benefit of this project is to expand the range of coals, in terms of alkali content in the ash, that boiler vendors will be willing to guarantee. This will greatly enhance the chances of a new minemouth fluid bed combustion system being constructed in North Dakota. It is important to note that Northern States Power is considering expansion, with a CFBC reference plant already planned. North Dakota is one of several potential locations for this plant, and the state needs to be in a position to ensure alkali-related problems will not force NSP to choose another site.

7.0 MANAGEMENT

Project Manager--Mr. Michael D. Mann

Mr. Mann (M.S. Chemical Engineering, B.S. Mathematics and Chemistry), Research Supervisor for the Combustion Systems Group, has more than 11 years of research experience. Mr. Mann's primary responsibilities at the EERC are in management of projects related to combustion research with emphasis on fluidized-bed combustion and fuels performance in pulverized coal-fired systems. Recent projects include management of a DOE-funded project on corrosion, erosion, and deposition during AFBC; management of a multiclient-funded project to design, build, and operate a pilot-scale CFBC; characterization of coals in an AFBC as part of conceptual design studies for vendor consulting companies and an international agency; and observation and evaluation of AFBC testing by a boiler vendor for a utility company. Mr. Mann will be responsible for the overall technical management of the program, including monitoring project schedules and budgets. Mr. Mann will also be responsible for integrating full-scale experience with fundamental and bench-scale data.

Co-Project Manager--Dr. Steven A. Benson

Dr. Benson (B.S Chemistry and Ph.D. Fuel Science) joined the Center in 1977 and is involved in research related to coal combustion and gasification, mineral matter transformations, coal ash fouling and slagging, and advanced methods of analytical analysis. He is currently the supervisor of the Combustion Studies Group in the Combustion and Environmental Systems Research Institute and has been actively involved in coal-related combustion and gasification studies using laboratory- and pilot-scale equipment, along with analytical methods of coal and ash characterization most of his career. Dr. Benson will be responsible for the technical management of the fundamental chemistry and detailed analytical characterization.

Institute Director--Dr. Michael L. Jones

Dr. Jones (Ph.D., M.S., B.S. Physics), Institute Director for the Combustion and Environmental Systems Research Institute, has been involved in coal combustion research for more than 12 years and has significant experience in analyzing the fate of mineral matter during combustion. As institute director, Dr. Jones is responsible for internal oversight and coordination of the project with other work at the EERC.

Principal Investigator--Mr. Edward N. Steadman

Mr. Steadman (M.S. Geology, B.S. Geology) has seven years of experience in characterizing coal and coal mineralogy using analytical techniques such as quantitative mineralogy using computer-controlled scanning electron microscopy/microprobe analysis, x-ray diffraction, and optical methods. Mr.

Steadman will be responsible for integrating the analytical results, fundamental chemistry, and bench-scale results into predictive models and mitigating measures.

8.0 PROJECT SCHEDULE AND DELIVERABLES

Project Schedule and Milestones

No.	Task Description	Schedule by Project Years 1	2	3
1	Development of Analytical Techniques	a b c		
2	Analyses of Material from Full-Scale FBCs	a	b	c
3	Bench-Scale Reactor Development and Testing	a	b c	d e
4	Fundamental Chemistry	a	b	c
5	Development and Verification of Predictive Techniques and Mitigating Methods	a	bc	de
6	Final Report	a	b	c
	Planning and Review Meetings	# #	#	#

The descriptions of milestones/deliverables are summarized below:

YEAR 1

Task 1. Development of Analytical Techniques
- a. Extension of SEM analytical techniques to identify minerals in noncoal fuels
- b. Method for determining extent and composition of neck growth
- c. Determination of size and quantity of $CaCO_3$, CaO, and $CaSO_4$ in fly ash and spent bed material

Task 2. Analyses of Material from Full-Scale FBCs
- a. Detailed analysis of materials from full-scale FBC systems

Task 3. Bench-Scale Reactor Development and Testing
- a. Design and begin construction

Task 4. Fundamental Chemistry
- a. Evaluation of ash partitioning in FBC systems

Task 5. Development and Verification of Predictive Techniques and Mitigating Measures
- a. Empirical predictive model based on full-scale analysis

Task 6. Final Report
a. First-year report

YEAR 2

Task 1. Development of Analytical Techniques
No work this year

Task 2. Analyses of Material from Full-Scale FBCs
a. Analysis of selected samples to fill data gaps

Task 3. Bench-Scale Reactor Development and Testing
b. Construct and shake down reactor
c. Initiate matrix investigating the effect of fuel and operating parameters on agglomeration and deposition

Task 4. Fundamental Chemistry
b. Fuel modification and combustion additives tests

Task 5. Development and Verification of Predictive Techniques and Mitigating Measures
b. Refine predictive techniques
c. Suggest potential mitigating techniques

Task 6. Reporting
b. Second-year report

YEAR 3

Task 1. Development of Analytical Techniques
No work this year

Task 2. Analyses of Material from Full-Scale FBCs
c. Analysis of selected samples to fill data gaps

Task 3. Bench-Scale Reactor Development and Testing
d. Complete matrix investigating the effect of fuel and operating parameters on agglomeration and deposition
e. Develop bench-scale method of predicting propensity for agglomeration and deposition

Task 4. Fundamental Chemistry
c. Modifications of models for prediction of coal behavior

Task 5. Development and Verification of Predictive Techniques and Mitigating Measures
d. Verify and refine predictive techniques
e. Recommend mitigating techniques

Task 6. Reporting
c. Final report

The target date for initiation of the program is May 1, 1992. Bimonthly letter reports will provide updates on the overall project status. Project review meetings will be held twice each year of the program. The draft final report will be submitted to the project sponsors for review one month prior to the final review meeting. The reviewed and edited task reports will be major inputs into the final report.

9.0 BUDGET AND FUNDING

The total cost of the program is $1,200,000, or $400,000 per year. Table 1 presents an itemized breakdown of the program costs, and a detailed cost breakdown is attached. This program has been approved for cofunding through the U.S. Department of Energy Jointly Sponsored Research Program. Riley Stoker Corporation, Ahlstrom Pyropower Inc., and the Electric Power Research Institute have already committed to funding levels of $33,333/yr. Northern States Power Company is expected to make a similar commitment. This request is for $66,667/yr for three years for a total program cost of $200,000. This represents 16.7% of the total program cost.

TABLE 1

Itemized Breakdown of Project Costs

	This Request	Total
Personnel	$68,000	$420,000
Operating Expenses	$11,000	$66,000
Analytical Support	$53,000	$276,000
Equipment	$0	$90,000
Indirect Cost	$68,000	$348,000
Total Cost	$200,000	$1,200,000

10.0 REFERENCES

1. Jones, M.L.; Kalmanovitch, D.P.; Steadman, E.N.; Benson, S.A. "Application of SEM Techniques to the Characterization of Coal and Coal Ash Products," Advances in Coal Spectroscopy, 1990, in press.

2. Steadman, E.N.; Zygarlicke, C.J.; Benson, S.A.; Jones, M.L. "A Microanalytical Approach to the Characterization of Coal, Ash, and Deposits," Seminar on Fireside Fouling Problems; Brigham Young University, Provo, UT, April 1990.

3. Kalmanovitch, D.P.; Montgomery, G.G.; Steadman, E.N. ASME Paper Number 87-JPGC-FACT-4, 1987.

4. Steadman, E.N.; Zygarlicke, C.J.; Benson, S.A.; Jones, M.L. "A Microanalytical Approach to the Characterization of Coal, Ash, and Deposits," ASME Seminar on Fireside Fouling Problems; Brigham Young University, Provo, UT, April 1990.

5. Zygarlicke, C.J.; Steadman, E.N.; Benson, S.A. "Studies of the Transformations of Inorganic Constituents in a Texas Lignite during Combustion," Progress in Energy and Combustion Science 1990, 16, 195-204.

6. Benson, S.A.; Zygarlicke, C.J.; Toman, D.L.; Jones, M.L. "Inorganic Transformations and Ash Deposition during Pulverized Coal Combustion of Two Western U.S. Coals," Seminar on Fireside Fouling Problems; Brigham Young University, Provo, UT, April 1990.

7. Mann, M.D.; Galbreath, K.C.; Kalmanovitch, D.P. "The Role of Ash Chemistry and Operating Parameters on Ash Agglomeration and Deposition in FBC Systems," Engineering Foundation Conference on Inorganic Transformations and Ash Deposition During Combustion, Palm Coast, FL, March 1991.