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October 1, 2010

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Subject: Microbeam Technologies Proposal entitled "Agglomeration and Ash Deposition Management in Fluidized Bed Combustion"

Dear Ms. Fine:

Enclosed please find an original and copies of the subject proposal. Microbeam Technologies Incorporated is pleased to submit this proposal to develop tools to improve the reliability of fluidized bed combustion systems firing North Dakota lignite. The project will provide develop a computer-based management tool to manage ash-related problems through a multi-client funded effort. The tool will include information on the potential for bed agglomeration and deposition on heat transfer surfaces as a function of bed materials, additives, fuels and fuel blends, and operating parameters. The project has co-funding as well as interest from the North Dakota Lignite industry. Also enclosed is the $100 application fee.

If you have any questions, please contact me by telephone at (701) 777-6530 or by e-mail at sbenson@microbeam.com.

Sincerely,

Steven A. Benson, Ph.D.
President

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AGGLOMERATION AND DEPOSITION MANAGEMENT IN FLUIDIZED BED COMBUSTION SYSTEMS

APPLICANT

Microbeam Technologies Incorporated

PRINCIPAL INVESTIGATOR

Margaret Laumb

DATE OF APPLICATION

October 1, 2010

AMOUNT OF REQUEST

$50,000

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ABSTRACT

Bed agglomeration and ash deposition in fluidized bed combustion systems are significant problems that impact plant efficiency, reliability, and maintenance. These ash-related problems depend on fuel composition, bed material type, additives, system design, and operating conditions. Microbeam Technologies Incorporated (MTI) proposes to incorporate our detailed understanding of bed agglomeration and ash deposition mechanisms into a computer-based tool that can be utilized by fluidized bed combustion systems operations personnel to manage ash-related problems through the selection and optimization of fuel, bed materials, additives, and operating conditions.

The computer-based management tool to manage ash-related problems will be developed through a multi-client and NDIC-funded effort. The tool will include information on the potential for bed agglomeration and deposition on heat transfer surfaces as a function of bed materials, additives, fuels and fuel blends, and operating parameters. Specifically, the tool will balance these variables to increase efficiency and reliability of the fluidized bed combustion systems. In addition, the cost of the specific fuel blends, bed materials and additives that provide optimum performance in a specific system will be available as well.

The effort will involve six tasks and is expected to take two years to complete. The total cost of the program is estimated to be $150,000 per year for two years, for a total of $300,000. The total amount requested from NDIC is $50,000. Individual industry sponsor cost-shares will be $50,000 for the two-year effort. At this time, Montana-Dakota Utilities (MDU) has committed $50,000 cost-sharing, and MTI is in discussions with Electric Power Research Institute (EPRI), Georgia Pacific Corporation, Cleco Corporation, and Jacksonville Electric Authority (JEA).

PROJECT SUMMARY

Bed agglomeration and ash deposition in fluidized bed combustion systems are significant problems that impact plant efficiency, reliability, and maintenance. These ash-related problems depend on fuel composition, bed material type, additives, system design, and operating conditions. Microbeam Technologies Incorporated (MTI) proposes to incorporate our detailed understanding of bed agglomeration and ash deposition mechanism into a computer-based tool that can be utilized by fluidized bed combustion systems operations personnel to manage ash-related problems through the selection and optimization of fuel, bed materials, additives, and operating conditions.

MTI proposes to develop a computer-based management tool to manage ash-related problems through a multi-client funded effort. The tool will include information on the potential for bed agglomeration and deposition on heat transfer surfaces as a function of bed materials, additives, fuels and fuel blends, and operating parameters. Specifically, the tool will balance these variables to increase efficiency and reliability of the fluidized bed combustion systems. In addition, the cost of the specific fuel blends, bed materials and additives that provide optimum performance in a specific system will be available as well. The effort will involve the following key tasks:

Task 1. Project Coordination and Training

Task 2. Database Development

Task 3. Case Studies

Task 4. Bench Scale Testing

Task 5. System Management Tool Development

Task 6. System Management Tool Validation

The total cost of the program is estimated to be $150,000 per year for two years, for a total of $300,000. The total amount requested from NDIC is $50,000. Individual client cost-shares will be $50,000 for the two-year effort.

PROJECT DESCRIPTION

Objectives

The goal of this program is to develop a computer-based management tool that can aid in minimizing ash-related problems (bed agglomeration and ash deposition) and increase efficiency and reliability of lignite coal-, biomass-, coal-, and petroleum coke-fired fluidized bed combustion systems. The tool will include the effects of fuel impurities, bed materials, additives, and operating conditions. In order to achieve the goal of the project, the following specific objectives must be met. The objectives include:

- Provide training workshops on ash behavior and management in fluidized bed combustion systems;
- Identify and perform case studies on selected plants;
- Integrate the components into a tool that can be used to predict performance; and
- Validate the ability of the integrated model to optimize boiler performance based on fuel composition, boiler operating conditions, bed material composition, and additives.

Methodology

Task 1. Project Coordination and Training

Project sponsor meetings will be conducted twice a year for the duration of the project (estimated two years). The meetings will be held in Grand Forks, North Dakota, in the spring and in the fall of each year. The meetings will provide the sponsors with the opportunity to review progress and provide direction for the program.

In conjunction with the project review meetings, training workshops will be held as needed. The workshops will provide the participant with information to increase understanding of the impacts of fuel properties and other system parameters on ash-related problems. This understanding will give the participants the ability to diagnose problems and use tools developed to manage bed agglomeration and deposition problems. The workshops will include the following topic areas:

- Fluidized bed combustion and the impacts of fuel impurities;
- Fuel composition – coal, waste coal, petroleum coke, biomass, biomass waste, refuse, tires;
- Bed material properties;
- Bed agglomeration processes;
- Wall deposition;
- Convective pass fouling;
- Managing ash-related issues through fuel blending, bed materials, additives; and
- Existing prediction and management tools.

The preparation of reports will also be a component of this task. Status reports will be provided to the NDIC and participating industry sponsors on a quarterly basis. Task reports will also be prepared upon completion of each task and provided to the NDIC and industry sponsors. In addition, a final report will be provided that will include all project results, interpretations, and conclusions.

Task 2. Database Development

MTI will use existing non-proprietary information on fuels, bed materials, additives, and system design and operating parameters, along with bed agglomeration and ash deposition data, to populate a database for fluidized bed combustion systems previously examined.

Database information will include:

a. Fuel composition including impurities;

b. Bonding materials for the formation of agglomerates as a function of fuel types, bed materials, and additives;
c. Bonding materials responsible for wall deposit formation;
d. Bonding material responsible for the formation of deposits in cyclones; and
e. Bonding materials responsible for the formation of convective pass deposits.

Mechanisms information will include:

a. Fuel impurity transformations to form vapors, liquids, and solids;
b. Bed material transformations, including decomposition, attrition, and reaction with fuel impurities;
c. Impurity and bed-derived material transport to furnace walls producing wall deposits;
d. Partitioning of ash constituents and bed material in cyclones and impaction devices; and
e. Transport and growth of deposits in convective pass.

Relationships to operating conditions will include:

a. Partitioning behavior of impurities during the combustion process;
b. Bed agglomeration bonding phases;
c. Wall deposition;
d. Partitioning in cyclone and impaction devices; and
e. Convective pass fouling.

Task 3. Case Studies

To increase the quantity of data and the overall quality of the database developed in Task 2, case studies will be performed on selected fluidized bed combustion systems. Case study sites will be selected to augment the existing database in order to fill information gaps. Project sponsor suggestions and opinions will also be taken into account for the selection of case study sites. A minimum of four case studies will be performed. The following are possible sites for case studies:

1. North Dakota lignite-fired fluid bed system;
2. Petroleum coke-fired CFB with limestone and sand bed material;
3. Petroleum coke and coal co–fired CFB with limestone bed material and kaolin additive ; and
4. Waste coal-fired CFB

Alternative case study sites include:

1. ND lignite and biomass co-fired system;
2. Petroleum coke- and biomass-fired systems ;
3. Petroleum coke and waste coal co-fired system; or
4. Sponsor suggestions.

These studies will be selected to provide sponsors with direct information on the impacts of specific fuel properties on system performance, ash behavior mechanisms, and suggested methods to manage ash behavior problems. Detailed analyses will be performed on fuels, bed materials, additives (if any), bed agglomerates, recycle streams, convective pass deposits, and fly ash. Analyses to be performed are listed and described on Page 9 of this proposal. The information from the analyses will be used to enhance the database used in the model predictions.

Task 4. Bench Scale Testing

Bench-scale testing will be conducted using MTI's bench-scale fluidized bed reactor (FBR) combustion test equipment shown in Figure 1. Selected fuels, bed materials, and additives will be tested for their ability to produce agglomerates in the small-scale FBR system.

This system has been used to screen bed materials and additives for their potential to reduce agglomeration.

The following properties will be identified:

- Bed particle fragmentation (friability);
- Bed particle reaction rates with sulfur species as a function of fuel impurity level;
- Transformations of fuel impurities;
- Bed material agglomeration; and
- Impacts of additives on agglomeration and deposition.

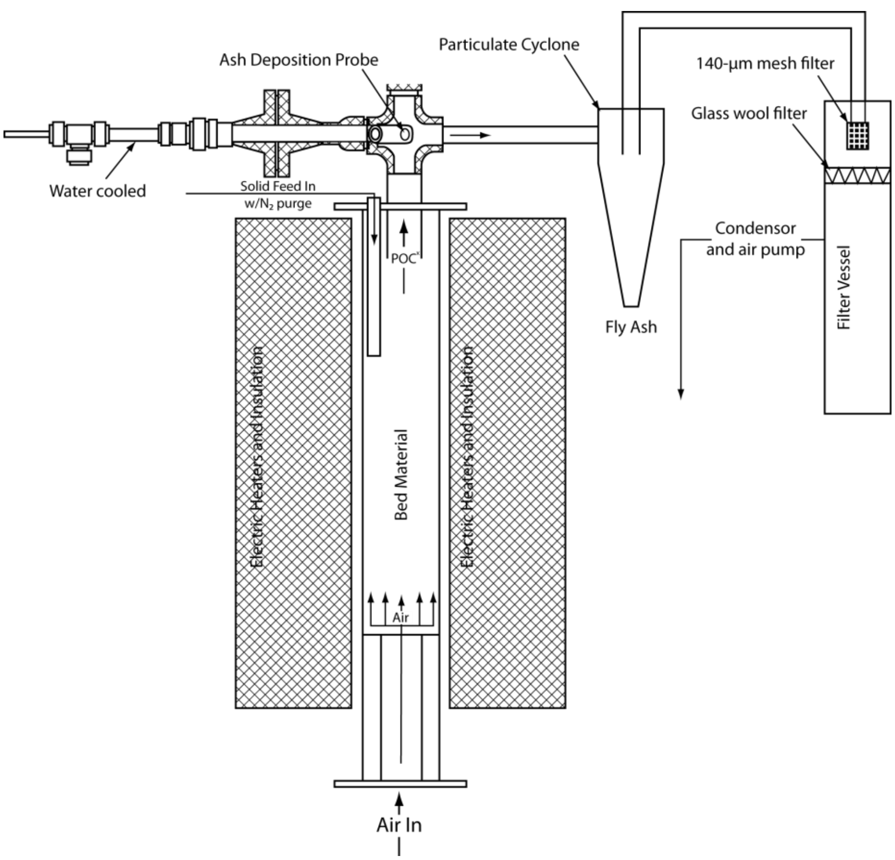

Figure 1. Small fluidized bed reactor at MTI.

Task 5. System Management Tool Development

The concept for the system management tool is shown in Figure 2. The tool will be incorporated into an Excel spreadsheet. Chemical and physical properties of fuels will be used as input into algorithms to predict the following processes:

- Transformations of fuel impurities to form inorganic vapors, liquids and solids as a function of combustion conditions.
- Transformations of bed particles, bed materials impurities, and additives to produce inorganic vapors, liquids, and solid as a function of combustion conditions.
- Transport, reaction, and sticking of bed components (vapors, liquids, and solids) to the surfaces of bed particles, resulting in coatings that lead to bed agglomeration.
- Agglomeration of bed particles as a function of particle coating, fluidization velocity, temperature, and oxygen level.
- Transport of bed components (vapors, liquids, and solids) to boiler walls, resulting in the formation of strong wall deposits through processes of sticking, growth, and strength development (sintering).
- Partitioning of ash, bed materials, and char in the cyclone or impaction system, resulting in the return of larger-sized materials to the combustor and the entrainment of finer materials and vapor phase components with the bulk gas flow to the convective pass. These processes will be estimated based on the properties of fuel, bed material, and additives.
- Transport of partitioned bed components (vapors, liquids and solids derived from fuel, bed, and additives) to the convective pass heat exchange system producing deposits through processes of sticking, growth, and strength.

The form of the prediction will be advanced indices for bed agglomeration, wall slagging, cyclone fouling, and convective pass fouling. Database information will be available on the properties of fuels, bed materials, and additives as input into the spreadsheet tool.

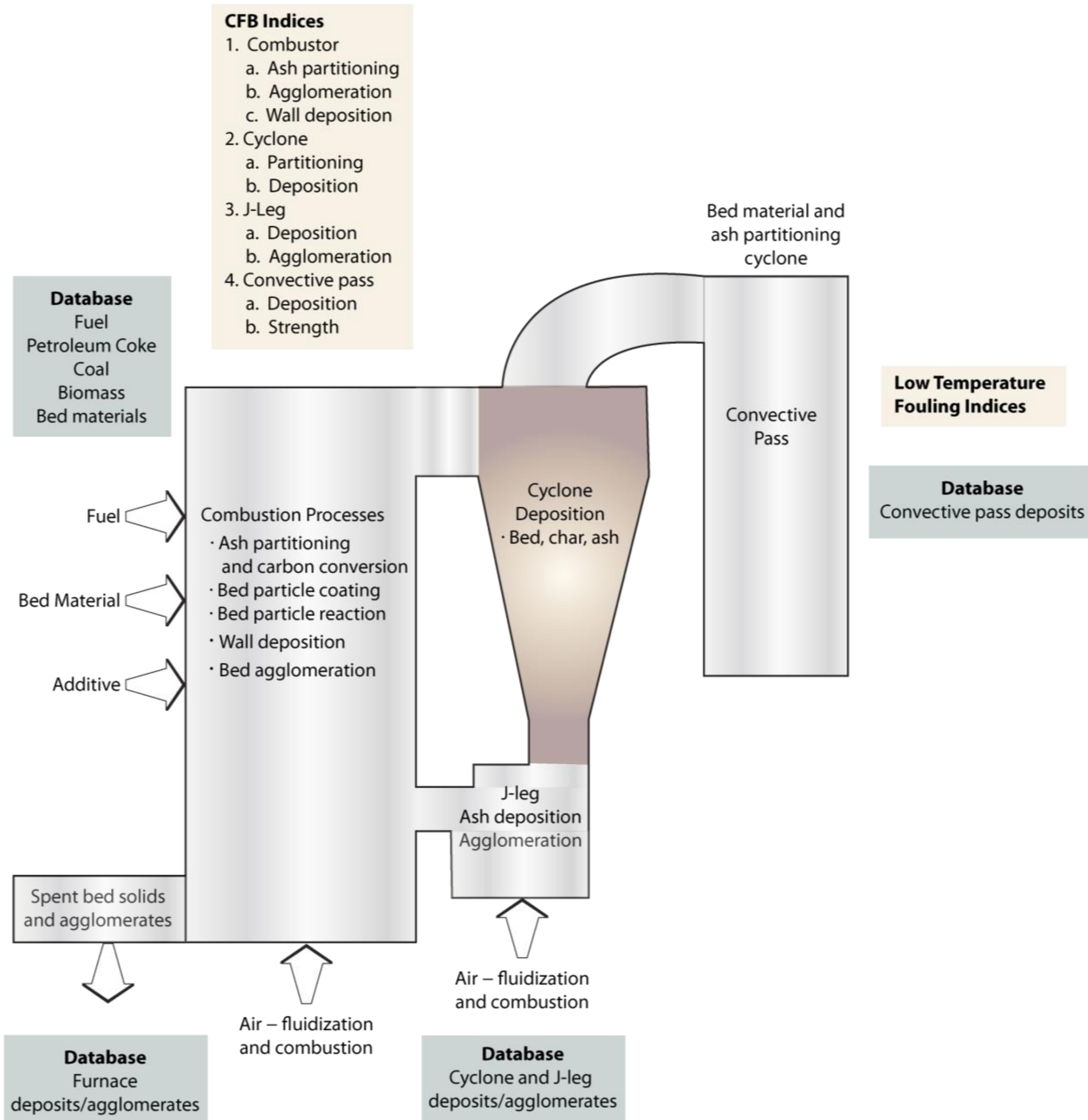

Figure 2. Overall concept for the ash agglomeration and deposition management system for a CFB system.

Task 6. System Management Tool Validation

Additional case studies will be performed on up to four selected systems for validation. The validation will include predicted performance of the CFB relative to agglomeration, wall deposition, cyclone fouling, and convective pass fouling based on the properties of the fuels and bed materials collected during the case study. The possible case studies include:

1. North Dakota lignite-fired fluid bed system;
2. Petroleum coke-fired CFB with limestone bed material and sand;
3. Petroleum coke- and coal-blend CFB with limestone bed material and kaolin; and
4. Waste coal-fired CFB.

Alternative case study sites include:

1. ND lignite and biomass co-fired system;
2. Petroleum coke- and biomass-fired systems;
3. Petroleum coke- and waste-fired system; or
4. Sponsor suggestions.

Anticipated Results

Deliverables resulting from the proposed work will include the following:

1. Training on ash behavior;
2. Database information on fuel, bed material, agglomerates, and deposits;
3. Ash management tools for bed-material selection, utilization, and management; and
4. Reports that include quarterly status reports, task reports and a final report.

Facilities, Resources and Techniques

MTI has laboratory and office space located in the Center for Innovation at the University of North Dakota. MTI's offices, at 780 sq. ft., are located at the Norm Skalicky Technology

Center, and laboratory space is located in the Ina Mae Rude Technology Incubator. These buildings are on the west end of the University of North Dakota campus. These buildings are connected; it is approximately 140 feet from MTI offices to the laboratory.

The 680-sq. ft. laboratory space contains MTI's bench-scale fluidized bed reactor system and bench-scale advanced heat exchange system. The laboratory is equipped with an automated scanning electron microscope equipped with x-ray microanalysis capabilities, sample preparation equipment, a small-scale fluidized bed combustor, small-scale gasifier simulator equipped with a syngas cooler, high-temperature 1700ºC refractory testing furnace, ash fusion furnace, chemical fractionation analysis equipment, and other laboratory equipment. The equipment is specifically designed and optimized to characterize coal and coal ash related materials.

In addition, MTI has developed numerous data analysis procedures designed to interpret the result of analysis of fuel and fuel ash related materials for clients worldwide. These techniques are used to assist combustion and gasification facilities improve reliability and decrease maintenance costs through fuel selection/blending and optimized operating condition. MTI has conducted over 1200 projects that involve the analysis of fuel, ash, slag, and metal materials.

Detailed analyses will be performed on fuels, bed materials, additives (if any), ash recycle streams, bed agglomerates, convective pass deposits, and fly ash from each case study. Analysis methods to be used will include standard ASTM analyses, advanced scanning electron microscopy analysis, and other types as needed.

<u>Fuels</u>

Fuels, including petroleum coke, coal, biomass, and other types will be analyzed using ASTM analyses proximate, ultimate, ash composition, and sulfur forms (ASTM D2492).

Petroleum coke samples will also be analyzed for chlorine and trace elements nickel, vanadium, and zinc. Biomass samples will be analyzed for chlorine. Tire-derived fuels will be analyzed for chlorine, bromine, and zinc. MTI will analyze all fuels using computer-controlled scanning electron microscopy (CCSEM) and morphological analysis.

Mineral size, chemical composition, and abundance by mineral type or phase will be determined using computer-controlled scanning electron microscopy (CCSEM). The CCSEM technique is fully automated, allowing up to 3,000 individual particles to be characterized in a single sample. Elemental compositions are used to categorize individual mineral particles by size and composition.

Morphological analysis consists of obtaining images and chemical compositions of features of interest within the sample. Images are typically taken using backscattered electron imaging, in which the brightness of the material is dependent upon its average atomic number. Higher atomic number materials, such as iron compounds, appear brighter than lower atomic number materials, such as silicates.

Bed materials and additives

All bed materials will be subjected to ash composition analysis (ASTM D3682) and sieve analysis. Bed materials will also be analyzed using scanning electron microscopy point count (SEMPC) analysis. SEMPC is used to determine the abundance of phases in ash or deposits. Up to 300 analysis points can be acquired in a pattern across the surface of a sample. Chemical composition of each point is matched to compositions of known phases, and the abundance of phases is then calculated.

Limestone samples will be tested for friability upon heating and fluidizing. Friability testing will be conducted using MTI's bench-scale Fluidized Bed Reactor (FBR).

Ash recycle streams and fly ash

Ash being recycled from the cyclone or separation device will be subjected to ash composition analyses (ASTM D3682), loss-on-ignition (ASTM D3174), scanning electron microscopy morphological analysis, and point count analysis (SEMPC).

Ash composition analysis, loss-on-ignition, and scanning electron microscopy morphological analysis will be performed on fly ash samples.

Bed agglomerates and convective pass deposits

Bed agglomerates and convective pass deposits will be analyzed using scanning electron microscopy morphological analysis and point count analysis (SEMPC).

Environmental and Economic Impacts

This project has the potential to economically improve the environmental performance of fluidized bed systems that fire lignite coals. Specific application of the results of this project will be cost-effective measures to utilize limestone bed materials with high-sodium lignite to control the emissions of sulfur oxides, while minimizing bed agglomeration and fouling of heat transfer surfaces. The current perspective on firing high sodium lignite in CFBs is that kaolin must be injected to manage bed agglomeration and ash deposition (Burns and McDonnell, 2010). The injection of kaolin drives up the variable cost significantly. Therefore, it is important that options be investigated to optimize bed composition to cost effectively minimize the impacts of sodium on CFB system performance, making CFB a more economic option for future power generation with lignite firing.

Ultimate Technological and Economic Impacts

Managing the effects of sodium in fluidized combustion systems is a key challenge to overcome to ensure the future use of lignite. Developing tools to enable CFB system developers and owners to operate the systems more efficiently will make CFB systems more competitive with pulverized coal-fired systems.

Why the Project is Needed

This project is needed in order to ensure there are viable, cost-effective options to fire lignite in systems other than pulverized coal-fired systems. The project offers potential for developing options and tools to enable the reliable use of lignite in fluidized bed combustion systems with lower maintenance costs.

STANDARDS OF SUCCESS

Four standards of success have been identified as listed below.

- A key component in the project is the training of operations personnel to develop an understanding of the effects of fuel quality and system operating parameters on agglomeration and ash deposition potential. Training operations staff to recognize problems is key to the implementation of measure and tools to predict impacts.
- The development of a complete database that includes information on fuel quality and system operating conditions will ensure the success of the project.
- Expanding the database to include the sponsor-specific systems and bench-scale testing results will ensure the mechanisms of agglomeration and deposition are consistent with the database information. The full database information will be used to develop algorithms for incorporation into the predictions tool.
- The algorithms will be tested with specific case studies to validate the tool. Adjustments will be made as needed.

BACKGROUND

Since 1992, MTI has conducted over 50 projects associated with agglomeration and ash deposition issues in fluidized bed combustion. These projects have provided MTI with a detailed understanding of the transformations of fuel impurities during combustion and gas cooling; bed particle coating and bonding processes; mechanisms of ash accumulation on boiler walls, cyclones, and convective surfaces; impact of bed material properties; and the impact of additives on agglomeration and deposition. Understanding and quantifying these processes are extremely important, since these processes contribute to the materials that produce the liquid or bonding phases that cause bed agglomeration and ash deposition in FBC systems. References related to the information presented in this section are provided on page 35. Key processes that influence the behavior of fuel impurities in fluidized bed combustion systems are illustrated in Figure 3.

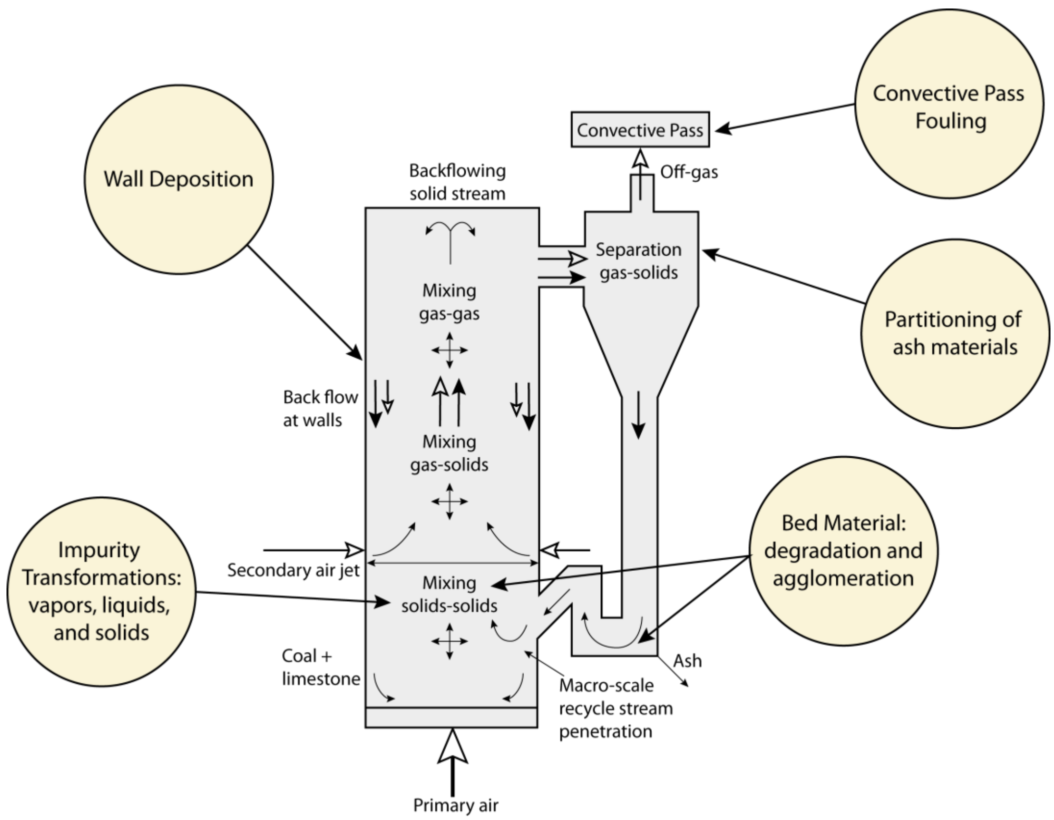

Figure 3. Overall mechanism of agglomeration and deposition in fluidized bed systems.

During the combustion of petroleum coke, biomass, coal, and waste materials in a fluidized bed system, impurities in the fuels are transformed into inorganic gases, liquids, and solids. The impurities present in the fuels vary significantly depending upon fuel type. A generalized diagram of the impurity transformation processes is shown in Figure 4.

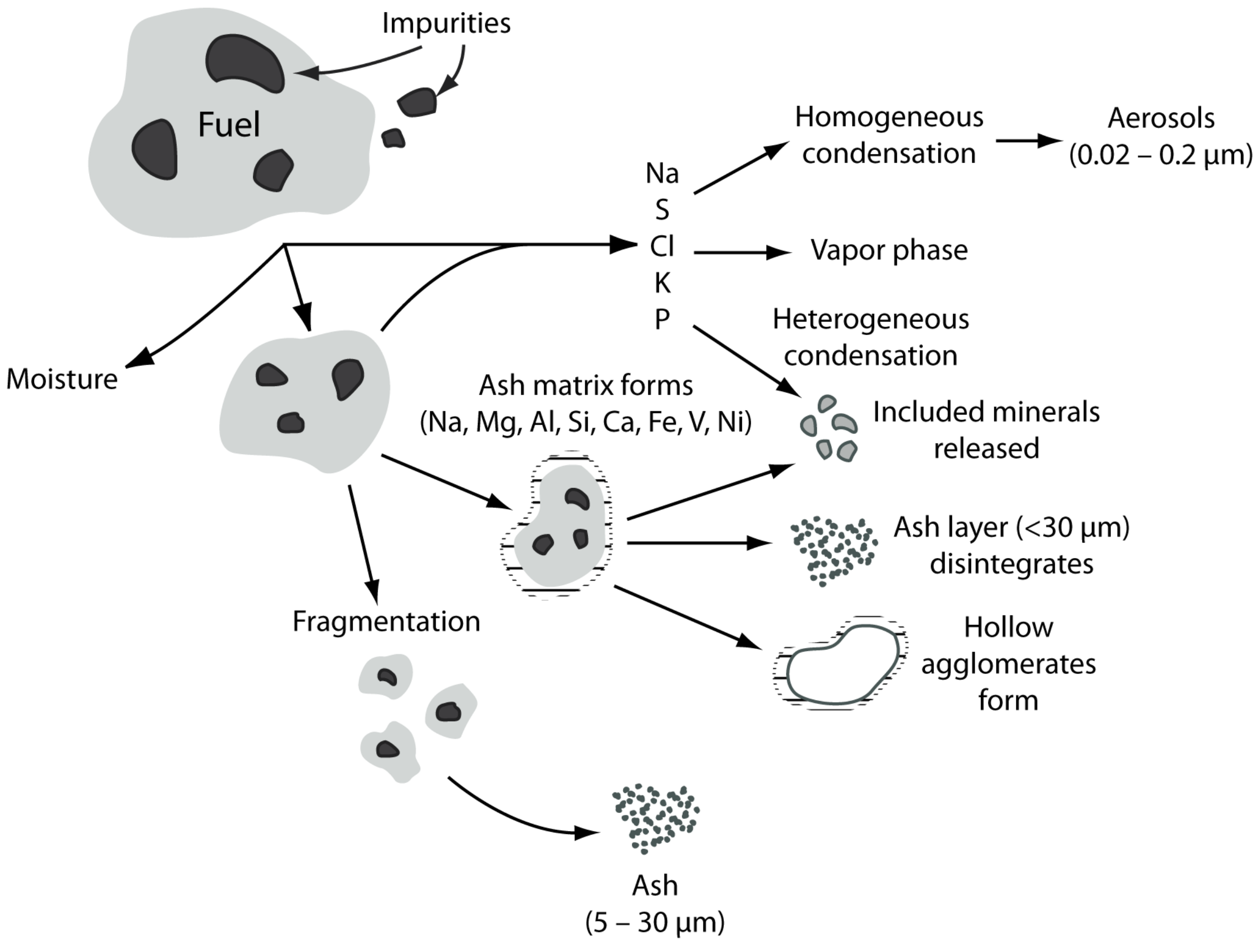

Figure 4. Ash formation mechanisms in fluidized bed combustion systems.

Some impurities or inorganic components associated with the fuel will vaporize during combustion, including sodium, potassium, sulfur, phosphorus, chlorine, and some minor and trace elements. Vapor-phase species will condense either heterogeneously on the surfaces of entrained ash particles or homogenously to form very small particles. Many of these condensed or reacted vapor-phase species produce bonding and liquid phases that are responsible for bed agglomeration and ash deposition.

Some impurities will melt during the combustion processes and form liquid phases. The ability of these fuel impurities to melt depends upon their chemical composition, association within the carbon matrix (included within carbon matrix, or separate from the carbon), temperature, and oxygen level (oxidizing or reducing environment). Some bonding phases form as a result of the reaction of a solid with a liquid phase during the combustion process, which produces the optimum chemistry for the formation of a low melting-point material.

There are several types of chemical phases that are important relative to formation of bed agglomerates and ash deposits. The type and abundance of these phases are dependent upon the composition and physical properties of the fuel, bed materials, and additives. The bonding phases produced during the fluidized bed combustion processes are listed in Table 1. These phases have a range of melting points and stabilities.

Table 1. Important phases in fluidized bed combustion systems.

Phase (major elements)	Associated elements
Aluminosilicates (Al, Si, O)	Ca, Na, Mg, Fe, K
Silicates (Si, O)	Ca, Na, Mg, Fe, K
Sulfides (S)	Fe, Ni, Zn
Sulfates (S, O)	Ca, Na, Mg, K, Ba, Sr
Phosphates (P, O)	Na, Mg, K, Ca
Pyrosulfates (S, O)	Fe, K, Na, Ca
Metals, metal oxides (O)	Fe, Ni, Zn
Vanadates (V, O)	Na, Ca, Mg, K
Chlorides (Cl)	Na, K, Ca

Ash species, consisting of inorganic gases, liquids, and solids, react with each other and with bed particles to produce liquid and bonding phases on the surfaces of the bed particles, resulting in the formation of bed agglomerates. Bed agglomerate formation is a complex process that depends upon bed particle composition and physical properties, fuel impurities, and system operating conditions.

Figure 5 illustrates the primary mechanisms of bed agglomeration in fluidized bed combustion. The process involves the formation of liquid or other bonding phases on the surfaces of the bed material. Many of these phases are sulfur-based. These sulfate-based materials form on the surfaces of limestone or dolomite bed materials. Optimizing in-bed sulfur capture while minimizing bed agglomeration can be attained by managing types of sulfate-based phases that form and reducing prolonged contact between bed particles.

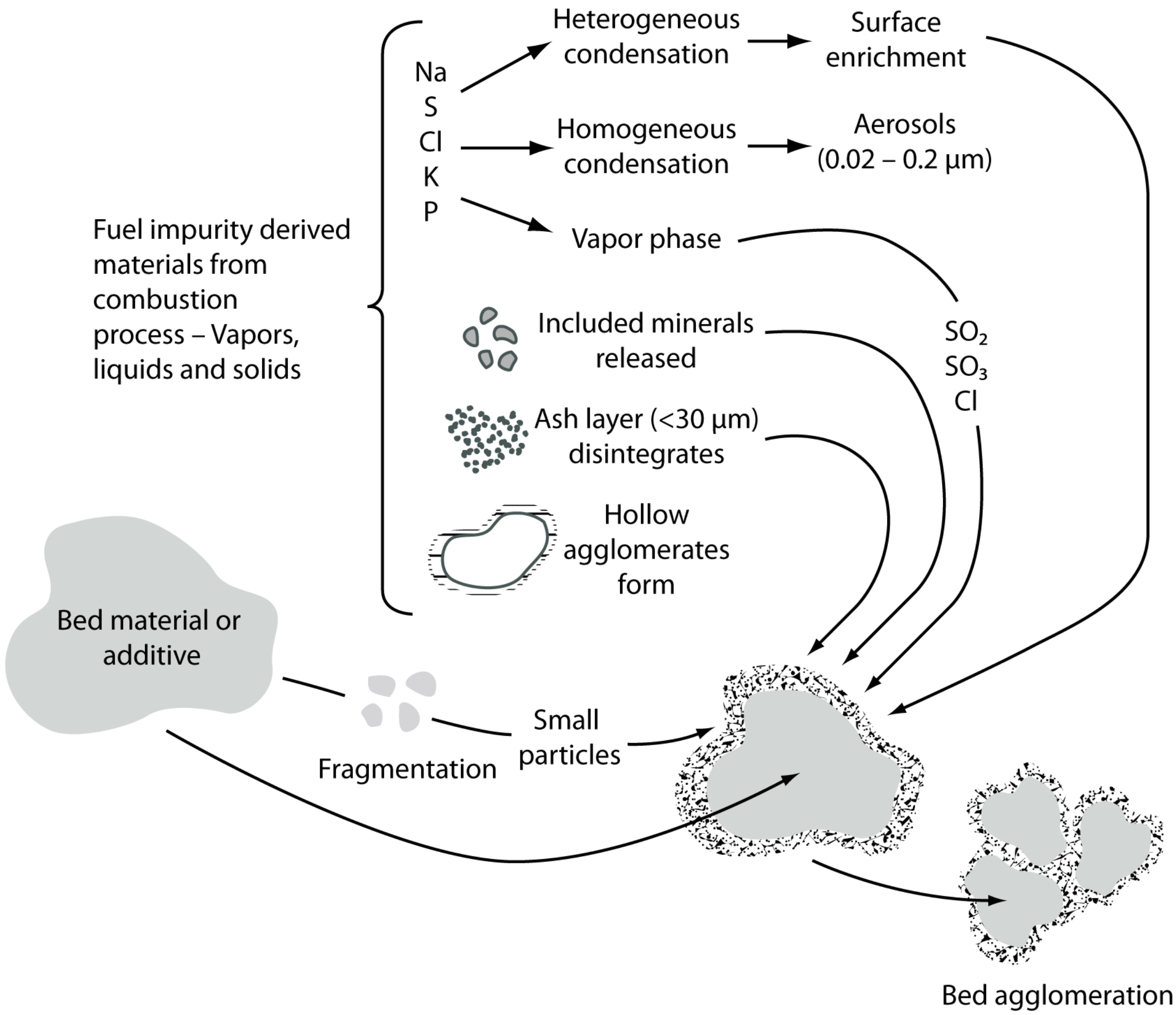

Figure 5. Ash agglomeration mechanisms in fluidized bed combustion systems.

In cases where sand is added to the bed to improve fluidization or as a diluent, surface layers rich in fuel impurity-derived materials and bed material fragments can contribute to bonding. The surface layers range from being silicate- to sulfate-based. In some cases, sand bed materials are rich in quartz grains. Quartz readily reacts with alkali elements sodium and potassium (Na and K) to form low melting-point, low-viscosity bonding phases. If alkali elements are present in the fuel, bed materials containing quartz must be avoided. Alkali elements are abundant in lignite and biomass fuels.

Accumulation of ash deposits on heat transfer and other boiler surfaces requires transport of the ash materials to the heat-transfer surface. Ash transport occurs by several mechanisms based on the state and physical characteristics of the inorganic species and the location in the fluidized bed combustion system. In the body of a circulating fluidized bed combustion system, the flow patterns of the gas and particulate phases are very important. The directions of the flows were shown in Figure 3.

The dense particulate phase consists of bed particles, combustion products, partially combusted fuel, and fuel impurities. In the core of the bed, particles flow in the upward direction with gas flow through the combustion system. At the walls of the combustor, an annular region exists, where the flow of gases and particulates is downward. A gas boundary layer exists near the walls of the boiler.

Behavior of particles and vapor-phase impurities in the annular region is very important. Through a variety of transport processes, the finer ash particles will be more concentrated in the annular region and will be transported to the wall surfaces by diffusion, thermophoresis, and electrophoresis processes. These fine particles are rich in bonding and liquid phases that will contribute to the formation of boiler wall deposits. The transport mechanisms are shown in Figure 6.

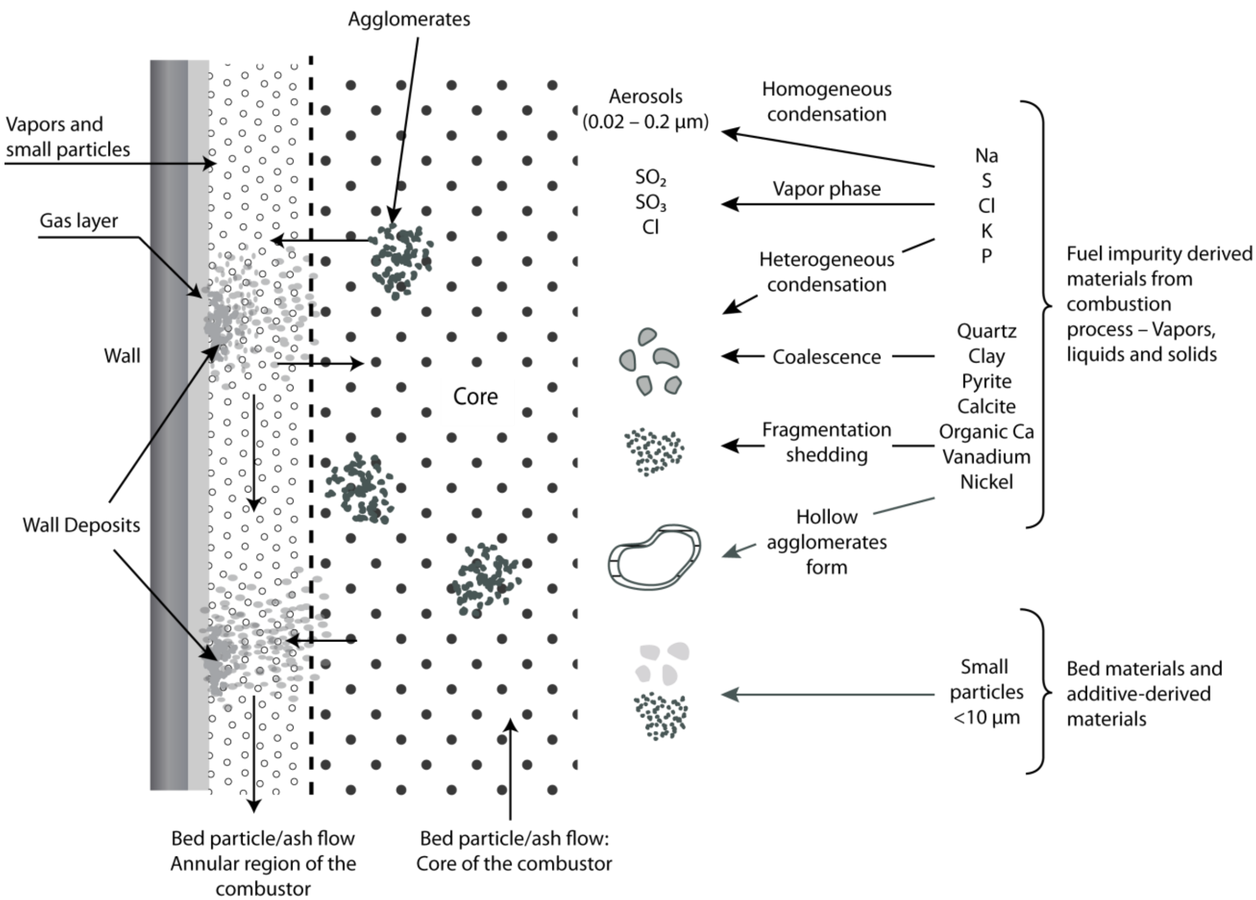

Figure 6. Particle transport near the wall in a fluidized bed combustion system.

In circulating fluidized bed systems, cyclones or impaction devices are utilized to maintain bed inventory, improve sorbent utilization, and enhance carbon conversion efficiency. These devices also partition the entrained ash materials by removing the large particles and recycling them to the bed. The finer particles, which are rich in condensed vapor phase species, remain entrained in the hot gas and pass through the cyclone into the convective pass. Partitioning mechanisms for separating large particles from the gas stream are illustrated in Figure 7. Dense, difficult-to-remove deposits can occur in the cyclone or separation device. The deposits form from the fine-sized particles. The fine-sized particles have high surface areas for reaction with gas-phase components and will have rapid sintering, which builds up high strength in the deposits.

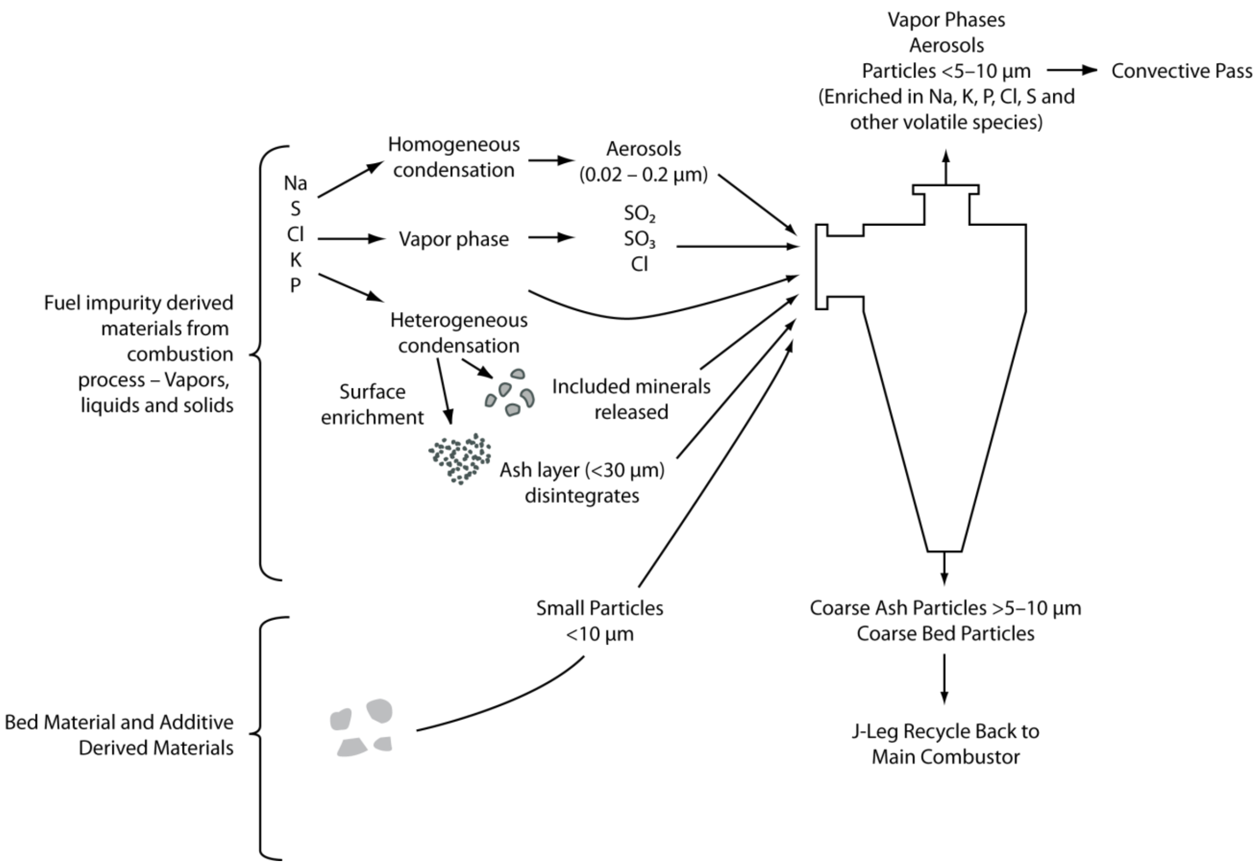

Figure 7. Ash partitioning in a cyclone in a fluidized bed combustion system.

The mechanisms of the formation of convective pass deposits are illustrated in Figures 8 and 9. Dominant transport mechanisms for fine particles and vapors include diffusion and thermophoresis. The larger particles are transported to the convective pass surfaces by impaction mechanisms. In systems equipped with particle separators, such as cyclones, the ash material entrained in the flue gas downstream of the cyclone is enriched in particles less than 10µm. These particles are enriched in alkali and alkaline earth elements. The alkali and alkaline earth elements will react with sulfur oxides components to produce sulfate-based bonding materials. The resulting deposits are typically very dense and extremely difficult to remove.

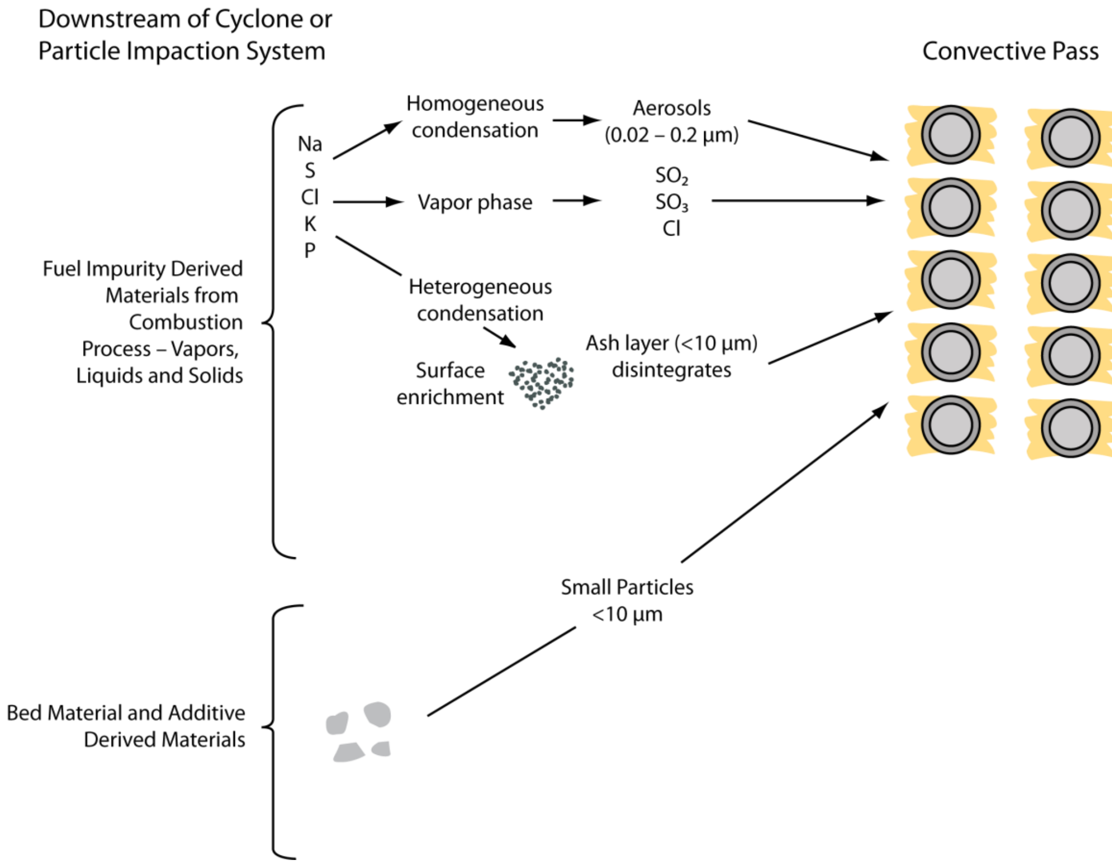

Figure 8. Ash fouling of convective pass surfaces downstream of cyclone or impaction particle separator.

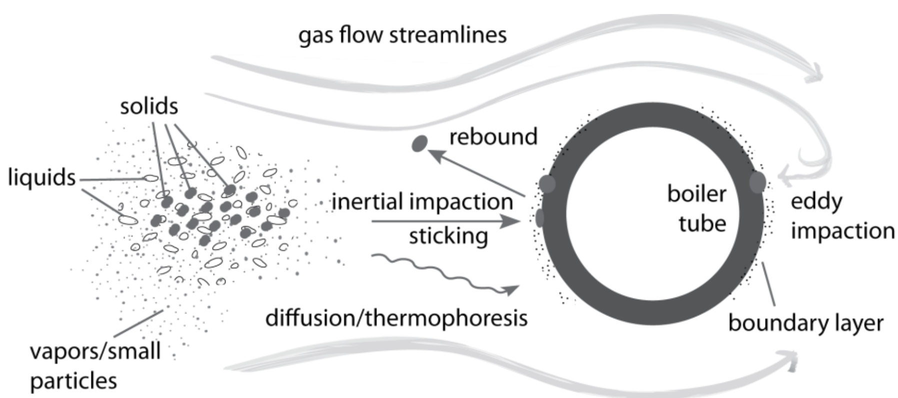

Figure 9. Ash particle transport mechanisms involved in the formation of convective pass fouling deposits.

Chemical and physical characteristics of materials responsible for the formation of the liquid-phase bonding components are dependent upon temperature and oxygen level. Higher-temperature liquid phases are silicate-based. The presence of sodium can reduce the melting point of these phases to as low as 1400°F (760°C). High silica- or quartz-containing bed materials combined with fuel-derived sodium or potassium can produce bonding phases that will contribute to ash deposition.

Iron-rich phases including silicates, sulfides, oxides, and metallic iron also contribute to the formation of agglomerates and ash deposits. Some FB and CFB systems have experienced significant agglomeration problems that were caused by the incomplete oxidation of iron sulfide and the formation of low melting-point and low-viscosity liquid phases.

At lower temperatures that are more typical of CFBC operation, sulfate-based bonding mechanisms dominate. This is the same mechanism that is necessary for SOx control using a limestone bed material. Sulfate-based bonding is a common problem when coals containing high levels of alkali (sodium and potassium) and alkaline-earth (magnesium and calcium) elements are fired. Sulfate-based bonding is a major challenge for high alkali containing fuels. The melting point of complex sulfates can be as low as 1200°F (650°C). In addition, sulfate-based bonding can be enhanced by the presence of vanadium derived from petroleum coke.

The formation and interaction of bonding phases responsible for the formation of agglomerates and ash deposits are shown in Figure 10. There are three general types of interactions that occur that contribute to the formation of agglomerates and deposits. These include: 1) gas-solid reactions; 2) reactive liquid-phase bonding; and 3) non-reactive liquid-phase bonding.

1. Gas-solid reactions: Bonding involves the reactions of gas-phase SO_2 and SO_3 with very fine CaO particles that are derived from the fuel or bed materials. This reaction leads to formation of sulfates. The reaction of CaO with sulfur oxides to form $CaSO_4$ results in an increase in the molar volume (molecule increases in size or swells), filling of pores, and bonding of fine particles producing a matrix of bonded sulfate materials. The reactions are catalyzed by the presence of vanadium oxides. This catalyzing mechanism is especially important for petroleum coke fired systems as it can increase the rate of sulfation.
2. Reactive liquid-phase bonding: This bonding comprises complete assimilation of the ash/bed material components into a melt phase. This is a high-temperature process, and the product is a complex silicate or aluminosilicate glass that can contain components such as Na, K, Mg, Ca, and Fe. Liquid phases are derived from the reactions of sand bed materials with the Na, K, Mg, Ca, and Fe derived from fuel impurities and bed materials. Crystallization of complex phases from the liquid phase typically occurs.
3. Non-reactive liquid-phase bonding: This type of bonding occurs on the surfaces of bed particles and ash particles that are silicate- or aluminosilicate-based. The phase coating the surface consists of Na, K, Ca, Fe, and/or Mg in the form of a sulfate, sulfide, phosphate, or halogen phase. These are lower–temperature, stable phases where limited reactions with the silicate or aluminosilicate phases occur.

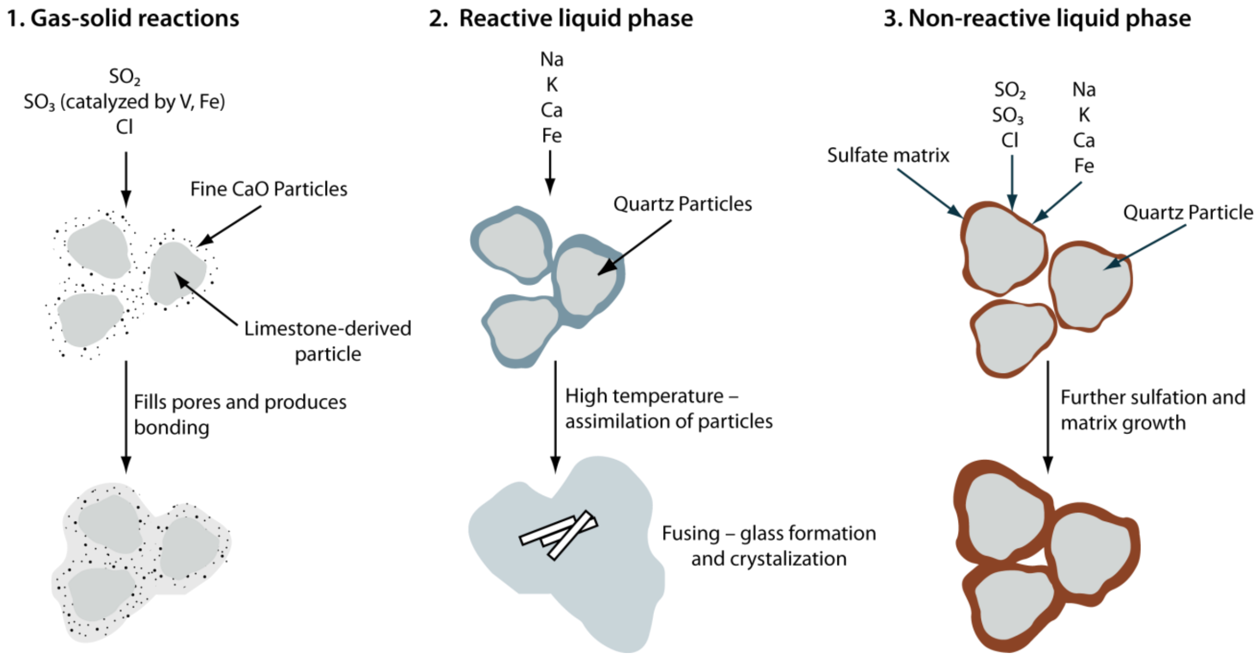

Figure 10. Examples of primary bonding mechanisms in fluidized bed combustion.

VALUE TO NORTH DAKOTA

A major challenge facing North Dakota lignite-fired fluidized bed combustion systems is bed agglomeration and ash deposition due to high levels of sodium and other alkali and alkaline earth elements present in lignite. These challenges decrease the efficiency and reliability of the fluid bed systems firing ND lignite. This project will develop data and a tool to identify cost effective measures to decrease the bed agglomeration and ash deposition potential as a function of system operation condition, bed materials, and ND lignite blends.

QUALIFICATIONS

Microbeam Technologies Inc. (MTI) corporate mission is to provide advanced analysis tools and technologies to minimize the impacts of inorganic components in solid fuels on power system performance. Since 1992, MTI has performed more than 1,200 commercial projects providing advanced analysis of coal, ash, ceramics, metals, and other materials, and consulting for researchers, power industry, boiler manufacturers, coal companies, and others. In 1999, MTI received a DOE Phase I SBIR on the abatement of corrosion and plugging of hot gas filters in gasification systems. In 2002, MTI was awarded a National Science Foundation (NSF) Phase I SBIR on the use of gasification systems to recover valuable elements from the gas stream. Based on the results of the Phase I SBIR work, Phase II was awarded in 2004. MTI has completed Phase II research and development and is working on commercializing the technology.

MTI's core competency lies in the understanding of the combustion and environmental control technologies for coal, biomass, petroleum coke, and waste fired systems. Efforts have been focused on behavior of fuel impurities in combustion and gasification systems as a function of fuel characteristics, system design, and operating conditions. The projects conducted on gasification and combustion systems have been aimed at matching fuel quality with plant design and developing methods to minimize impacts on system performance. MTI has a client base that includes customers from the United States, Canada, United Kingdom, Finland, Sweden, Hungary, Brazil, South Africa, India, South Korea, and Australia. Further information can be obtained from MTI's website at www.microbeam.com.

MANAGEMENT

Ms. Margaret Laumb will be the project manager and will be responsible for the coordination of efforts associated with testing and the development of the predictive methods. Ms. Laumb will work closely with the project sponsors to coordinate training and sponsors meeting, identify testing sites, and the development of the computer-based tool.

Ms. Laumb currently is Research Engineer at MTI. Ms. Laumb is responsible for the daily operations of MTI and for the coordination of projects involving the analysis of materials. Since joining MTI, Ms. Laumb has coordinated over 700 projects involving the behavior of major, minor, and trace elements in combustion and gasification systems. Ms. Laumb has experience in experimental design and various methods of analysis including: scanning electron microscopy, x-ray microanalysis, atomic absorption, mercury analysis methods, x-ray diffraction, and basic methods of coal analysis. Ms. Laumb also has background and experience in computer programming and development of software to predict the fate of inorganic components in combustion and gasification systems.

Mr. Arthur Ruud, Research Scientist at MTI, will be involved in the bench-scale testing and characterization of products. Mr. Ruud has a M.S. in Chemistry from the University of North Dakota, and nearly 30 years experience in the coal combustion and analytical chemistry fields. He has a strong background in experimental design and system design and construction. Mr. Ruud has extensive experience in the following analytical methods of analysis. He has extensive experience in the operation of the SCS. Mr. Ruud also has experience with standard ASTM methods for coal and fuel analyses, including all standard fuel analyses.

Dr. Steve Benson currently is President of MTI and Professor of Chemical Engineering at the University of North Dakota. Dr. Benson will serve as an technical advisor to the project. Dr.

Benson has over 25 years of professional experience in the behavior of the fate and behavior of fuel impurities in combustion and gasification system that includes the following areas: high temperature reaction mechanisms, coal ash slagging and fouling, inorganic constituents in coals, scanning electron microscopy analysis, and fundamentals of coal combustion. Dr. Benson has extensive experience in managing complex multidisciplinary projects for federal and state departments and agencies such as the U.S. Department of Energy and the Environmental Protection Agency. He has managed numerous projects for industry alone and for industry and government co-funded programs. Dr. Benson is a member of several professional organizations and has written or co-written over 210 publications.

TIMETABLE

The work is anticipated to take two years to complete. The overall project schedule is shown in Table 2.

Status reports containing details on activities and expenditures will be provided at the end of every quarter to the NDIC and participating industry sponsors. A total of seven quarterly status reports will be prepared. In addition, interim reports will be made at the end of each work task. The interim reports will include the data provided in the quarterly reports and will summarize the expenditures, activities and outcome of each task. Four interim reports will be made for Tasks 2, 3, 4 and 5. A final report comprising information from the interim reports and the outcome of Task 6 will be provided within three months' time of completing Task 6.

Table 2. Overall Project Schedule.

ID	*Task Name*	*Estimated starting date*	*Estimated completion date*	*2011*				*2012*			
				Q1	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*
1	Task 1. Project Coordination and Training	1/3/2011	12/31/2012								
2	Task 2. Database Development	10/1/2010	6/21/2011								
3	Task 3. Case Studies	12/16/2010	4/6/2012								
4	Task 4. Bench Scale Testing	3/17/2011	4/5/2012								
5	Task 5. System Management Tool Development	10/1/2010	6/28/2012								
6	Task 6. System Management Tool Validation	7/16/2012	11/29/2012								

BUDGET

The project budget is summarized in Table 3. The overall budget is approximately $300,000 for the two years. The project will be funded by five industry sponsors ($50,000 each) and the NDIC ($50,000). The NDIC grant money will support activities related to the use of North Dakota lignite. If less funding than anticipated is received from industry sponsors, the scope of work will be reduced to match the level of funding; however, the North Dakota lignite case study will not be removed from the work plan.

Table 3. Project budget by year and task.

NDIC Proposal

"Bed Agglomeration and Ash Deposition in Fluidized Bed Combustion"

					Year 1					Year 2	Total
Personnel Budget:											
	Hours	**Rate**	**Total**			**Hours**	**Rate**	**Total**			
S. Benson	100	$ 68.00	$ 6,800.00			100	$ 72.00	$ 7,200.00			$ 14,000.00
M. Laumb	800	$ 24.00	$ 19,200.00			1200	$ 26.00	$ 31,200.00			$ 50,400.00
A. Ruud	1000	$ 21.00	$ 21,000.00			850	$ 23.00	$ 19,550.00			$ 40,550.00
M. Mellmer	520	$ 19.00	$ 9,880.00			550	$ 20.00	$ 11,000.00			$ 20,880.00
Technicians	500	$ 14.00	$ 7,000.00			500	$ 15.00	$ 7,500.00			$ 14,500.00
Total Salaries				$ 63,880.00					$ 76,450.00		$ 140,330.00
Fringe Benefits:	23%	of Total Salaries		$ 14,692.40					$ 17,583.50		$ 32,275.90
Total Salaries & Fringe Benefits					$ 78,572.40					$ 94,033.50	$ 172,605.90
Analysis Budget:											
Fuels/Additives:	# of Samples	Rate	Total			# of Samples	Rate	Total			
Grinding/Prep	20	$ 75.00	$ 1,500.00			10	$ 75.00	$ 750.00			
Proximate	20	$ 90.00	$ 1,800.00			10	$ 90.00	$ 900.00			
Ultimate	20	$ 150.00	$ 3,000.00			10	$ 150.00	$ 1,500.00			
Ash Composition	20	$ 285.00	$ 5,700.00			10	$ 285.00	$ 2,850.00			
SEMPC	5	$ 600.00	$ 3,000.00			5	$ 600.00	$ 3,000.00			
CCSEM	5	$ 740.00	$ 3,700.00			3	$ 740.00	$ 2,220.00			
Total Fuels				$ 18,700.00					$ 11,220.00		
Bed agglomeration/ash deposition testin											
SEMPC	8	$ 600.00	$ 4,800.00			6	$ 600.00	$ 3,600.00			
Morphology	16	$ 400.00	$ 6,400.00			9	$ 400.00	$ 3,600.00			
Fusions	8	$ 126.00	$ 1,008.00			9	$ 115.00	$ 1,035.00			
Friability	8	$ 461.00	$ 3,688.00			9	$ 461.00	$ 4,149.00			
Sintering	8	$ 252.00	$ 2,016.00			9	$ 252.00	$ 2,268.00			
Fluid bed testing	8	$ 716.00	$ 5,728.00			9	$ 706.00	$ 6,354.00			
Total Bench				$ 23,640.00					$ 21,006.00		
Total Analysis					$ 42,340.00					$ 32,226.00	$ 74,566.00
Supplies					$ 9,700.00					$ 3,800.00	$ 13,500.00
Travel Budget (assuming 3 days, 2 nights/trip):											
	Cost/Trip	# of people	# of trips			Cost/Trip	# of people	# of trips			
Selectd sites											
Airfare	$ 510.00	2	2	$ 2,040.00		$ 500.00	1	4	$ 2,000.00		
Hotel	$ 150.00	2	2	$ 600.00		$ 150.00	1	4	$ 600.00		
Car rental	$ 280.00	1	2	$ 560.00		$ 275.00	1	4	$ 1,100.00		
Food (3 days)	$ 180.00	2	2	$ 720.00		$ 180.00	1	4	$ 720.00		
Total				$ 3,920.00					$ 4,420.00		
Travel Totals					$ 3,920.00					$ 4,420.00	$ 8,340.00
Total Direct Costs					$ 134,532.40					$ 134,479.50	$ 269,011.90
Indirect Costs (11.5% of D.C.)					$ 15,471.23					$ 15,465.14	$ 30,936.37
Total Project Expenses					$ 150,003.63					$ 149,944.64	$ 299,948.27

MATCHING FUNDS

The total project cost is $300,000, with the costs of the proposed project to be shared between NDIC for $50,000 and five industry sponsors for $50,000 each for a total of $250,000. Montana-Dakota Utilities (MDU) has committed $50,000 to the project. Great River Energy (GRE) has expressed interest in the project. MTI is currently in discussion with the Electric Power Research Institute (EPRI), Georgia Pacific Corporation, Cleco Corporation, and Jacksonville Electric Authority (JEA). MTI has initiated contact with Reliant Energy, Nova Scotia Power, and NewPage Corporation. Letters of interest and support for the project are attached on the following pages.

MONTANA-DAKOTA
UTILITIES CO.
A Division of MDU Resources Group, Inc.

Ms. Margaret L. Laumb
Research Engineer
Microbeam Technologies Inc.
4200 James Ray Drive, Ste 191
Grand Forks, ND 58203

October 1, 2010

Re: Support for project entitled "Agglomeration and Deposition Management in Fluidized Bed Combustion Systems"

Dear Ms. Laumb:

Montana Dakota Utilities (MDU) is pleased to support the Microbeam Technologies Inc (MTI) project on bed agglomeration and ash deposition in fluidized bed combustion systems. These are significant problems that impact plant efficiency, reliability, and maintenance. These ash-related problems depend on fuel composition, bed material type, additives, system design, and operating conditions. MTI proposes to incorporate their detailed understanding into a computer-based tool that can be utilized by fluidized bed combustion systems operations personnel to manage ash related problems through the selection and optimization of fuel, bed materials, additives, and operating conditions. This program will allow us to examine and optimize the use of limestone and other bed materials while firing North Dakota lignite.

Managing bed agglomeration and ash deposition in fluidized bed systems is key to efficient and reliable operation when firing ND lignite. MDU is pleased to provide $50,000 cost share for the two year project.

If you have questions and require additional information please contact Kris Hanson at MDU's RM Heskett Station, phone number 701-663-9576 Ext. 15.

Sincerely,

Kris Hanson

Kris Hanson
Sr. Results Engineer

cc: Tony Stroh, Montana-Dakota Utilities Co.

GREAT RIVER ENERGY®

Bismarck Office • 1611 East Century Avenue • Suite 200 • Bismarck, North Dakota 58503 • 701-250-2165 • Fax 701-255-5405

September 14, 2010

Ms. Carlene Fine
NDIC
State Capitol
Bismarck, ND 50504

Subject: Letter of Interest and Support for the Application of Agglomeration and Deposition in Fluidized Bed Systems Proposed by Microbeam Technologies Inc. Grand Forks, ND

Dear Ms. Fine:

Great River Energy is pleased to submit this letter of support and interest for Microbeam's project to study the agglomeration and deposition potential in fluidized beds. As you know, Great River Energy plans to run beneficiated lignite in combination with biomass at Spiritwood Station and is therefore very interested in the agglomeration potential with various fuel blends.

Great River Energy is the wholesale electric supplier for 28 member cooperatives in Minnesota and Wisconsin. Great River Energy is concerned about the environment and are aware of the greenhouse gas emissions raised by the scientific community. With approximately 50% of the electric generation coming from coal-fired power plants, GRE recognizes the need to develop and demonstrate deposition mitigation options for the fluidized bed coal fired power generation fleet. GRE endorses the subject proposed program as an important step to develop and demonstrate agglomeration & mitigation options. This program has the potential to help allow the continued use of coal fuel, our nation's largest domestic energy resource.

Great River Energy is pleased to offer support to the proposed program.

We look forward to NDIC's review of the proposal and partnering with NDIC on this interesting and needed project.

Sincerely,

Charles Bullinger, P.E.
Senior Principle Engineer
Great River Energy
cbullinger@GREnergy.com
(701)442-7001

TAX LIABILITY

AFFIDAVIT

STATE OF NORTH DAKOTA)
) SS.
COUNTY OF GRAND FORKS)

I, Steve Benson, being first duly sworn, state as follows:

That I am President of Microbeam Technologies, Inc. and make this affidavit of my own knowledge.

That as of the date hereof, Microbeam Technologies, Inc. has no outstanding federal or state tax liability.

Dated this 1 day of October, 2010.

Steve Benson

Subscribed and sworn to before me this 1st day of October, 2010, by Steve Benson, President of Microbeam Technologies, Inc.

Notary Public
State of North Dakota
My commission expires:

BRUCE GJOVIG
NOTARY PUBLIC
STATE OF NORTH DAKOTA
My Commission Expires: Feb. 15, 2014

CONFIDENTIAL INFORMATION

No confidential information is included in the proposal.

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