LRC-II-11

Energy & Mineral Research Center

Fuels & Process Chemistry Research Institute
ND Mining & Mineral Resources Research Institute
Combustion & Environmental Systems Research Institute

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September 29, 1988

Mr. Tim Kingstad, Secretary
North Dakota Lignite Research Council
North Dakota State Land Department
Capitol Building
Bismarck, ND 58505

Dear Mr. Kingstad:

It is our pleasure to submit this proposal to the North Dakota Lignite Research Council for consideration in the second round of project selection. We look forward to the successful programs of the Council advancing and enhancing the many ways in which North Dakota lignite can serve the region's and nation's energy and materials needs, now and in the future.

This proposal requests funds as a part of a multiclient program entitled "Project Sodium." The objective of this program is a detailed understanding of the role of sodium in coal combustion processes. Through this understanding, methods will be developed to predict and mitigate the slagging and fouling problems experienced by utilities firing North Dakota lignites.

This request is for a total of $40,000 for the period November 1988 through February 1989. The total cost of the project is $240,000. Industrial commitments totalling $200,000 have been obtained at this time.

I look forward to the Council's positive endorsement of this proposal.

Sincerely,

Michael L. Jones
Director, Combustion & Environmental
Systems Research Institute

Alex Kotch
Alex Kotch, Director
Office of Research & Program Dev.

MLJ/clh

Enclosure

PROJECT SODIUM

Submitted by:

Michael L. Jones, Director
Combustion and Environmental Systems Research Institute
Energy and Mineral Research Center
University of North Dakota
Grand Forks, ND 58202

Submitted to:

North Dakota Lignite Research Council
North Dakota Land Department
State Capitol Building
Bismarck, ND 58505

Amount Requested: $40,000

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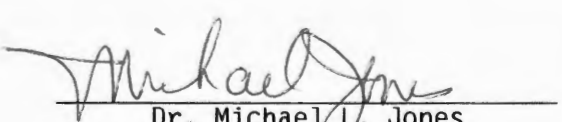

Dr. Michael L. Jones
Principal Investigator

Alex Kotch, Director
Office of Research and Program Development

SUMMARY

Project Sodium is a multiclient study which has been underway for over three years. The objective of Project Sodium is a detailed understanding of the role of sodium in coal combustion processes. The program is designed to follow the alkali from the coal through the combustion process. The specific goals of the current phase of project sodium are to ash modify ash behavior to affect the fouling and slagging properties of coal and to develop a model to predict the fate of sodium and other ash components in combustion systems.

Based on the results noted during the first three years of the project, the role of sodium in ash deposition appears to be the formation of low melting liquid phases. These liquid phases are the cause of the growth of strong deposits. This has led to the identification of three potential mechanisms of interaction leading to a beneficial modification of the ash behavior. These include the following: 1) retardation of the flame volatized elements (i.e. sodium), 2) crystallization of high melting point sodium-containing phases; 3) purely a physical interaction of the additive and deposited material. It is anticipated that the desired ash modification may come about by a combination of altered ash chemistry and process conditions. In addition, a modeling effort will be conducted to attempt to predict the behavior of ash components as a function of coal composition and combustion conditions.

The program has been under way for three years. This request is for the fourth year of the program running to February 1989. The anticipated total cost for this period is $240,000. The amount requested by this proposal is $25,000, plus a $15,000 initiation fee, for a total of $40,000. If successful

in the fourth year, the program will continue into year five and all sponsors will be asked to contribute an additional $25,000 for the fund year.

Current sponsors for the program include; Minnkota Power Cooperative, Knife River Mining Company, Montana-Dakota Utilities, Northern States Power Company, Otter Tail Power Company, Westmoreland Mining Company, ARCO Coal Company, Pacific Power Company, and NERCO Mining Company. Diamond Power Company participated in the first three years of the project, but declined participation in Year Four. Funding for the project through 1988 will total $975,000.

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OBJECTIVES

The principal operating problem in utilizing North Dakota lignite is ash deposition. Sodium in coal is the primary factor in coal linked to ash deposition in the convective pass of boilers fired on lignite and subbituminous coals. Therefore, the objective of Project Sodium is to understand the role of sodium in coal combustion processes. This understanding will provide insight into mechanisms to control and predict ash deposition. By developing a means to control and predict the ash deposition problems associated with North Dakota lignites, these coals will become a much more attractive energy resource.

The specific goals of Project Sodium in 1988 are ash modification to affect the fouling, and slagging properties of coal and to begin developing a model of ash behavior as a function of coal composition and combustion conditions.

BACKGROUND

Inorganic matter in coal continues to be the greatest single source of operational problems affecting coal combustion. For low-rank coals (i.e. lignite and subbituminous coal), the most common ash-related problems result from the formation of ash fouling deposits in a boiler's convective section. The sodium content of the ash has been identified as the principal cause of fouling. A 1981 study estimated that ash-related problems at a 500 MW power station burning a high-fouling Fort Union formation lignite would cost the host utility $8.4 million per year. The problem of high sodium content is especially noted in coals from North Dakota, but is also significant in many other coals from the U.S. and abroad.

Similar ash-related problems have also been identified as critical in several other low-rank coal utilization technologies. For example, the formation of low-melting sodium-containing phases during fluidized bed combustion of low-rank coals can cause extensive agglomeration of the bed material, forcing a shutdown of the combustor.

The University of North Dakota Energy and Mineral Research Center (EMRC) is one of the world's major coal research facilities. Since its founding in 1951, the Center has conducted research, testing, and evaluation of low-rank coals and associated technologies. The Center's transfer from the U.S. Department of Energy to the University of North Dakota in 1983 has made it possible for the Center's staff to work directly for industry to provide needed data and practical solutions for the specific problems they are encountering. Today, the Center is the leading organization in the U.S. doing contract research on characterization and utilization of low-rank coals. The

Center's state-of-the-art analytical equipment and pilot plant facilities provide a unique capability for these research programs.

Understanding the effects of ash and sodium on combustion systems and the mechanisms of ash deposit formation have long been key elements of the Center's activities. Until recently, this work was entirely government-funded and focused on determining of the fouling potential of coals combusted under carefully controlled conditions. With advances in analytical techniques and improvements in facilities, the Center is now studying slagging and fouling processes at a much more fundamental level, to understand more precisely both the nature of sodium in individual coals and the processes of ash formation and ash deposition in combustion systems.

It is unrealistic to believe any single technique will eliminate ash fouling. It is possible, however, to attempt to predict and to mitigate the ash deposition problem through detailed knowledge of the inorganic constituents in the coal being burned and the combustion system. Much of what has been done thus far in Project Sodium has been to detail the coal mineralogy and follow that material through the combustion system. This information has provided significant insight into the critical paths this mineral matter follows resulting in deposition. Since we know it is the type of ash which causes problems, it is expected that the proper change in ash at a critical point in the combustion system will lead to a significant decrease in the ash deposition problem. This approach is the challenge of the continued effort being proposed by the Energy and Mineral Research Center.

GOALS

The goals of the fourth year of Project Sodium can be divided into five major areas as defined below.

Literature Review

- o To perform a literature review to augment the information available from the first three years of the program. Focus of the review will be ash modification and modeling of ash behavior during combustion.

Laboratory Scale Studies

- o To conduct laboratory scale studies to cost effectively examine the behavior of ash and modified ash under combustion conditions. The thrust of this activity will be modification of ash behavior leading to decreased ash deposition.
  1. To characterize, in detail, deposits from full-scale boilers. This would involve the use of scanning electron microscopy and x-ray diffraction.
  2. To investigate the thermo-chemical properties of ashes. This will enhance the understanding of partitioning of ash between the vapor, liquid, and solid state during combustion.
  3. To determine the physical properties of ashes, including crystallization and sintering.

Drop Tube Furnace Studies

- o To study coal ash behavior using the drop tube furnace. The drop tube furnace is a small combuster designed to simulate the temperature history of a full-scale boiler. Combustion and ash deposit forming conditions can be closely controlled. The drop tube furnace will be used to test strategies for altering observed ash depositional behavior.

Pilot-Scale Combustion Studies

- To verify the results noted in the smaller drop tube furnace system, pilot-scale combustion tests will be performed. The tests are the precursor to the full-scale demonstration of results noted in the laboratory. The current plan calls for two pulverized coal tests on the pilot-scale to demonstrate improved ash depositional behavior. Additionally, if enought sponsors are obtained, a modification to existing equipment at the EMRC will be completed to allow for cyclone firing of a pilot-scale combustor.

Modeling as Ash Behavior

- To begin the development of a process model for ash deposition that can predict the fate of ash in combustors as a function of coal composition and combustion conditions. This process model will be used to predict the behavior of a given coal and to assist in choosing ash modification regimes for the coals under consideration.

METHODS

The work involved to obtain the goals of predicting modify ash behavior is pursued first at a laboratory scale, then transferred to the larger pilot-scale, and finally, if successful at both levels, will be taken to the full-scale for demonstration. The scope of work outlined here includes only the laboratory and pilot-scale. Support of a full-scale demonstration is beyond the scope of this activity, but will be pursued by the EMRC at the appropriate time.

The proposed work has been divided into five tasks to complete the activities that make up Year Four of Project Sodium. The logic diagram for the proposed work is shown in Figure 1. Note that the program is structured such that success must be achieved at each level prior to moving to larger scale experimentation.

Task One - Literature Review

Using all of the resources available through the library system at the University of North Dakota, a literature review will be completed. The focus of this review will be ash modification studies and modeling of ash behavior during combustion. This will extend the review completed during the first three years of the project.

Task Two - Laboratory Studies

Laboratory studies will be used to evaluate a large number of additive/coal ash combinations. The work involved in this effort will study the effects of materials on the formation of a sodium-containing liquid phase. The methods used will include sintering experiments; slag, viscosity and surface tension measurements; crystallization studies; and thermochemical modelling. This

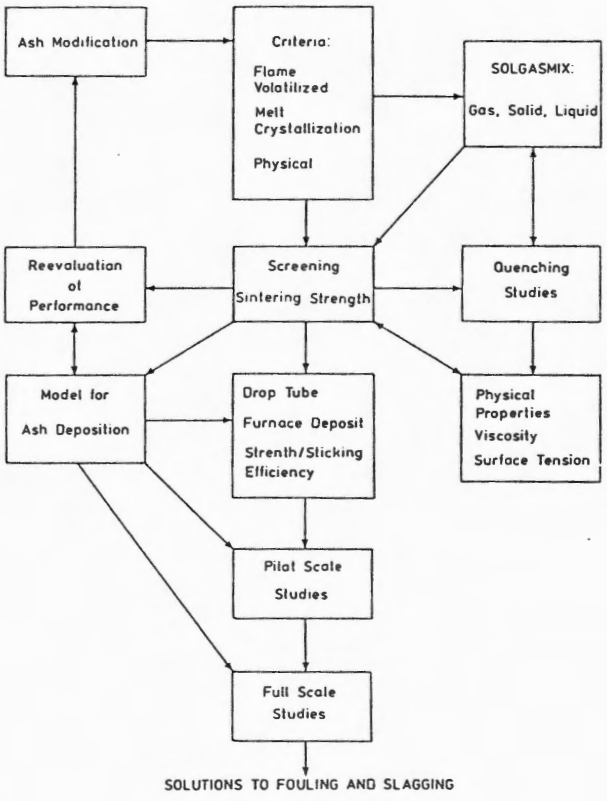

FIGURE 1 - LOGIC DIAGRAM FOR PROPOSED PROJECT SODIUM WORK

effort should minimize the expense by limiting the number of larger, more expensive pilot- of full-scale tests necessary.

Evaluation of Full-Scale Deposits

The objective of this work is to compare and contrast deposits formed in full-scale boilers with those formed in the ash fouling unit and drop tube furnace. A total of four deposits will be characterized. The techniques used to characterize the deposits will include scanning electron microscopy (SEM) and x-ray diffraction. The SEM will utilize a point counting routine developed under Project Sodium (Kalmanovitch, et al., 1987), that allows for a quantification of the amorphous phases present in the deposit. This technique together with x-ray diffraction allows for the quantification of both amorphous and crystalline phases in the deposit.

Prediction of Physical and Chemical Properties of Liquid Phase Material

SOLGASMIX is a computer code that uses thermodynamics to predict the phase assembleable that would exist for a given set of conditions under equilibrium. Thus, this tool can be used to predict the partitioning between vapor, liquid, and solid material for a given chemistry at a certain temperature. Even though the situation in a boiler is not at equilibrium, we feel this can be a helpful tool in describing mineral matter as it passes through the combustion system.

The chemistry common to low-rank coal ash is not well represented in the currently available data base. Additional experiments will be done to verify and extend the SOLGASMIX code to include the phases important in ash deposition.

Sintering Test

The sintering test will be used to screen additives. The sintering apparatus will be used to produce pellets of ash containing an additive at elevated temperatures and measure the mechanical strength. This test will be used on the selected coal fly ash produced in the drop tube furnace.

Physical Properties

Surface tension and slag viscosity tests will be conducted to determine the influence of the addition of additives. Surface tension and slag viscosity measurements will be performed on synthetic mixtures to simulate the liquid composition in some selected deposits. This information will be used to formulate and check equations used to calculate viscosity and surface tension of the liquid phases in deposits. This work will be used in the sintering model and will be closely coordinated with the SOLGASMIX work and sintering studies.

Task 3 - Drop Tube Furnace Studies

A drop tube furnace can be used to simulate the time and temperature history of a coal particle in a boiler. The system used at the EMRC is shown in Figure 2. This system allows rapid and inexpensive examination of numerous coals with altered ash chemistries. In addition, various combustion conditions can be simulated by altering gas composition, gas temperature, and residence time.

Production of Fly Ash

The drop tube furnace will be used to produce fly ash from the coals used in the ash modification studies. By using an extractive quenching probe, ash is removed that has been subjected to time temperature history and combustion conditions similar to a full-scale boiler.

Ash Deposition Studies

Ash deposits will be formed from the coals that have already been tested in the Ash Fouling Unit (AFU) using the ash deposition probe shown in Figure 3. The deposits will be compared to those formed in the ash fouling unit. In order to simulate the partitioning of inorganic species in a full-scale boiler, float-sink fractions of the coals will be tested in the furnace and

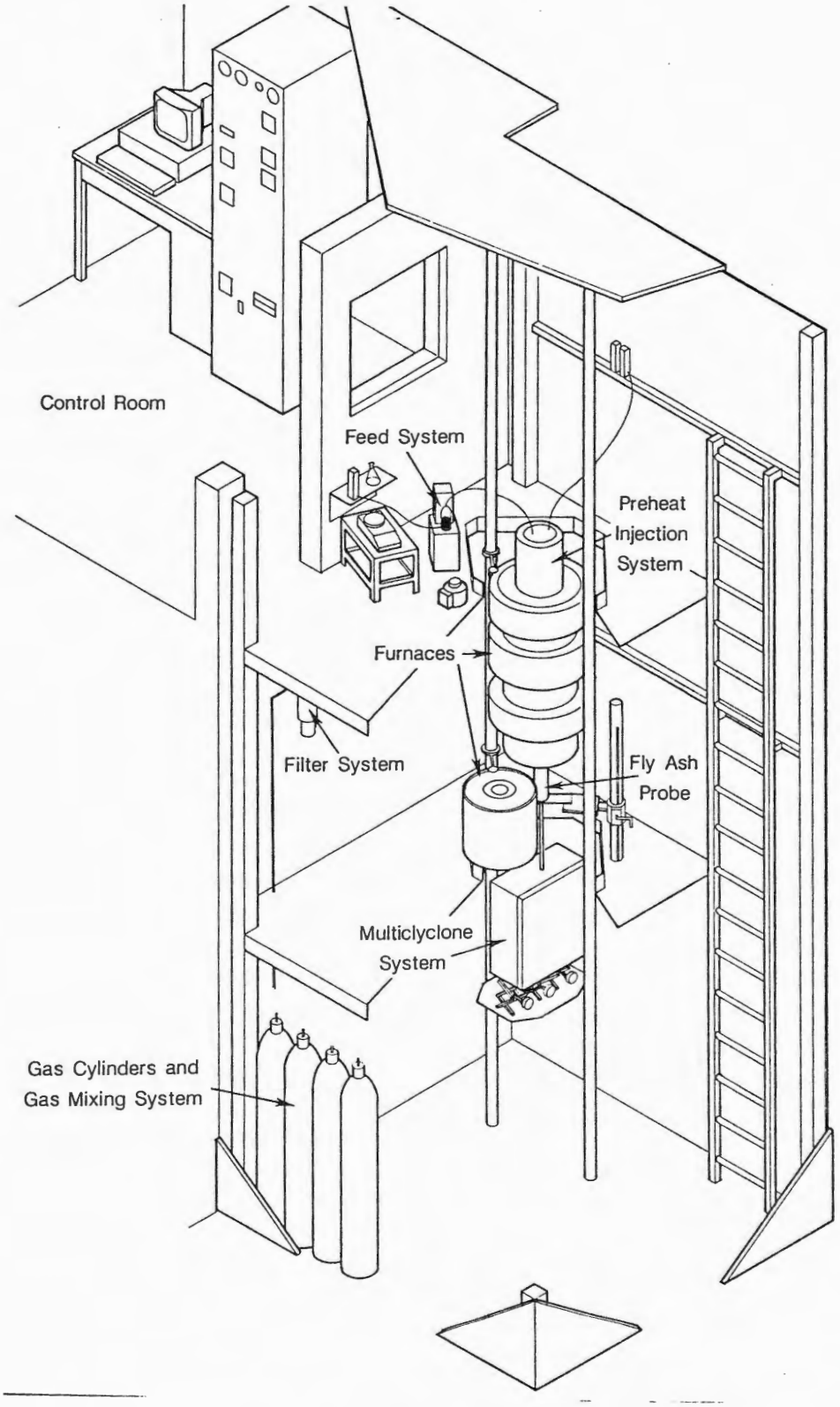

FIGURE 2 - SCHEMATIC OF EMRC DROP TUBE FURNACE

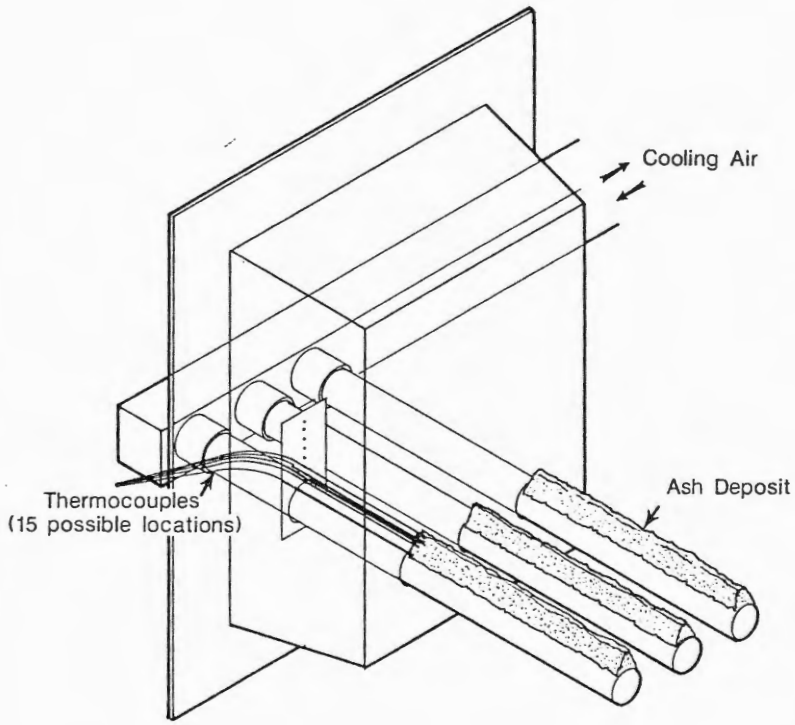

FIGURE 3 - SCHEMATIC OF ASH DEPOSITION PROBE FROM THE ASH FOULING UNIT

compared to the AFU. Both short (approximately one second long) and long (approximately three seconds) residence time tests will be conducted to simulate slagging and fouling conditions, respectively.

Ash formation studies will be conducted with coals having modified ash compositions. Deposit strength and sticking coefficients will be determined as a measure of the effectiveness of the additive. This task will be conducted during the first two years of the project.

Task 4 - Pilot-Scale Studies

Successful additive programs identified from laboratory experiments will be included in the pilot-scale test program. This program will be closely coordinated with the laboratory program. The ash fouling unit is shown in Figure 4. In addition, to more accurately mimic cyclone firing, a cyclone burner would be designed and added to an existing furnace at the EMRC.

Pilot-Scale Tests (P.C. Firing)

Four pilot-scale combustion tests will be performed with PC-fired configuration with ash modification. They will be conducted after preparatory bench- and lab-scale (drop-tube furnace) investigations. Pilot-scale combustion tests will evaluate the additives that have proven successful during smaller-scale tests. Deposits will be generated for comprehensive analysis.

Cyclone Burner (Design, Construction, and Firing)

Several sponsors operate cyclone-fired boilers. To properly evaluate the effect of ash modification on deposition, pilot-scale tests with a cyclone burner are necessary. A cyclone burner will be designed and constructed to operate on the existing combustion chamber of the ash fouling test combustor. This will allow generation of deposits under baseline combustor operating parameters (combustor exist temperature, gas velocities, residence times) similar to the PC tests. Shakedown testing of the system will be required,

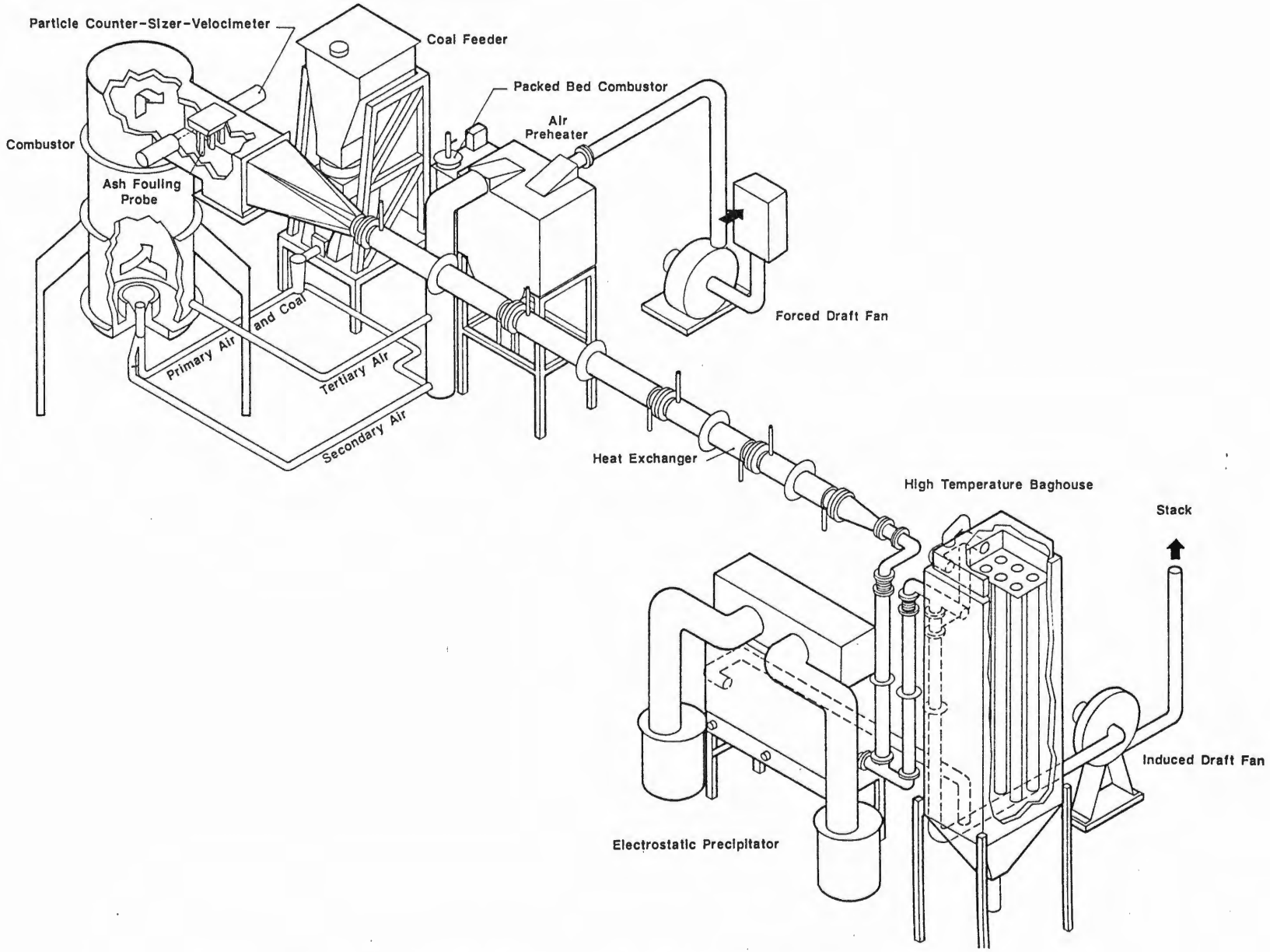

FIGURE 4 - SCHEMATIC OF EMRC 500,000 BTU/HR ASH FOULING UNIT

followed by two combustion tests generating baseline data. The deposits from the two baseline tests will be comprehensively analyzed and compared to deposits formed during PC testing of identical fuels. Two tests will then be conducted with ash modification and the deposits analyzed.

Efforts in this area will proceed if additional sponsors are found for the program. If funding of $300,000 is obtained this year, the design will be completed for the cyclone system.

Task 5 - Modeling of Ash Behavior During Combustion

The model of ash behavior during combustion will be developed to assist in decisions for ash modification. The varied coal characteristics and system characteristics necessitate a model to identify opportunities to modify the depositional behavior of the different coals. It is anticipated that the model will include the following criteria.

1. Abundance and mode of occurrence of inorganic constituents in coals.
2. Mechanism of fly ash formation.
3. Ash transport mechanisms.
4. Ash sticking coefficients.
5. Heat transfer and temperature profiles.
6. Formation of liquid and the development of deposit strength due to viscous flow sintering.

TIMETABLE

The program has been underway for three years. This request is for the fourth year of the program running from January to December, 1988. A detailed timetable for each task is provided in Table 1.

TABLE 1

TIMETABLE - PROJECT SODIUM YEAR FOUR

	Date
TASK 1 - LITERATURE REVIEW	
1. A short bibliography of important literature regarding modeling and ash modification	1/30/88
TASK 2 - LABORATORY SCALE STUDIES	
A. Characterization of Full-Scale Deposits	
A.2 Obtain deposits	1/30/88
A.3 Complete analysis (SEMPC, XRD, XRF)	2/28/88
A.4 Complete interim report. This report will focus on the directions of the laboratory program based on the pilot- and full-scale experience	3/30/88
B. Chemical Properties (Thermochemical)	
B.5 Evaluate thermochemical computational models and phase diagrams	2/28/88
B.6 Enhance existing thermodynamic data base for computational model	5/31/88
B.7 Complete testing of the model and compare to phase diagrams and laboratory results	8/30/88
B.8 Interim report on the application of thermochemical equilibrium computations to coal ash chemistry	11/31/88

TABLE 1 (Continued)

	Date
C. Physical Properties, Crystallization and Sintering	
C.9 Determine critical components to focus studies . . .	1/15/88
C.10 Complete sintering studies with ash produced in drop tube furnace	6/30/88
C.11 Complete studies of model mixtures	10/30/88
TASK 3 - DROP TUBE FURNACE STUDIES	
12. Produce Ash Deposits From the 12 Project Sodium Coals in the Drop Tube Furnace and Compare Results to the Ash Fouling Unit	3/31/88
13. Produce fly ash for sintering experiments	4/30/88
14. Complete ash deposition studies with modified ash compositions. Determine additional opportunities to interrupt the deposition of ash in boilers	9/30/88
TASK 4 - PILOT-SCALE COMBUSTION STUDIES	
15. Complete design of the cyclone burner for the ash fouling unit	11/15/88
TASK 5 - MODELING OF ASH BEHAVIOR	
A.16 Partitioning of ash constituents into vapors, liquids, and solids. A working thermochemical equilibrium code including the most up-to-date equilibrium data will be completed	4/30/88
B.17 The equations for the transport of ashes to deposit surfaces will be formulated	8/15/88
C.18 Sticking coefficients will be developed as a function of deposit temperature and quantity of liquid phase	8/15/88
D.19 The sintering model for the development of deposit strength as a function of the characteristics of the liquid phase	8/15/88
D.20 Combine the parts of the model	8/15/88
D.21 Identify additional regimes to modify ash depositional behavior	9/30/88

PROJECT SODIUM YEAR FOUR PROGRAM

J F M A M J J A S O N D

TASK 1 - Literature Review --1

TASK 2 - Lab Scale Studies

A. Characterize Full Scale Deposits ---2-3--4

B. Chemical Properties ------5--------6------7---8-------->

C. Physical Properties & Sintering ---9-------10----------11---------->

TASK 3 - Drop Tube Furnace Studies ------12------13----------14------>

TASK 4 - Pilot Scale Combustion Studies ----------15>

TASK 5 - Modeling of Ash Behavior

A. Partitioning ----------16

B. Transport ----------17

C. Sticking ----------18

D. Sintering ----------19

E. Combined Model ----20---21--->

PERSONNEL

Dr. Michael L. Jones

The Principal Investigator for the project will be Dr. Michael L. Jones. Dr. Jones (Ph.D. Physics) joined the Center in 1979 with a primary emphasis on the fate of inorganic materials during coal combustion. Currently Director of the Center's Combustion and Environmental Systems Research Institute, Dr. Jones' primary interests are in understanding the effects of mineral transformations on boiler fouling and in the combustion process itself.

Dr. Steven A. Benson

Dr. Steven A. Benson (Ph.D. Fuel Science, B.S. Chemistry) is Research Supervisor for the Combustion Studies group in the Combustion and Environmental Systems Research Institute. Dr. Benson has seven years of experience with analytical methods used to study inorganic materials related to coals including ash depositions and fly ashes. These analytical techniques include scanning electron microscopy, x-ray fluorescence, x-ray diffraction, Auger and ESCA. For the past three years, he has been involved in work on the behavior of ash constituents in combustion systems.

Mr. Bruce J. Zobeck

Mr. Bruce J. Zobeck (M.S. Chemical Engineering, B.S. Chemistry) has been directly involved in pilot-scale testing on the ash fouling unit for the past several years. As a project engineer, Mr. Zobeck has been involved in the development of detailed test plans, monitoring of the tests, and data reduction and reporting. Mr. Zobeck, as Manager of EMRC's Combustion Test Service, has been working with various utilities and coal companies assessing the impacts of coal quality on combustor performance.

Dr. David P. Kalmanovitch

Dr. David P. Kalmanovitch (Ph.D. Materials Science, D.I.C. Materials Science, B.S. Chemistry) has been involved in the use of advanced analytical techniques for the characterization of products of combustion. He has been directly associated with the fouling, slagging, and agglomeration work at EMRC since July, 1985. Prior to joining the EMRC, Dr. Kalmanovitch was involved in the study of boiler slagging and fouling, FBC agglomeration, and other coal ash related phenomena.

Technical personnel supporting the project would be drawn from the Center's existing research staff. This staff is highly trained and has had substantial experience with evaluation of sodium in coal and coal utilization systems. Ongoing research at the Center related to the inorganic properties of coal and coal combustion systems currently totals over $3.5 million annually.

Facilities at the Center for conducting the proposed work are among the best in the world and include several coal combustion pilot plants, field testing instruments, and laboratory analysis equipment. All facilities required for the proposed research are currently available. As such, 100 percent of toal funding for the project will be used for the actual research effort rather than for purchase of equipment and training of personnel.

BUDGET

The program has been under way for three years. This request is for the fourth year of the program running to February 1989. The anticipated total cost for this period is $240,000. The amount requested by this proposal is $25,000, plus a $15,000 initiation fee, for a total of $40,000. If successful in year four, the program will continue into year five and all sponsors will be asked to contribute an additional $25,000 for the fund year. A breakdown of budget items is provided in Table 2.

Current sponsors for the program include: Minnkota Power Cooperative, Knife River Mining Company, Montana-Dakota Utilities, Northern States Power Company, Otter Tail Power Company, Westmoreland Mining Company, ARCO Coal Company, Pacific Power Company, and NERCO Mining Company. Diamond Power Company participated in the first three years of the project, but declined participation in year four. Funding for the project through 1988 will total $975,000.

TABLE 2

ITEMIZED BREAKDOWN OF YEARLY COSTS

	Per Share[1]	Total[2]
Personnel	$10,850	$130,200
Operating Expense	8,377	100,524
Equipment	1,563	18,756
Indirect Cost	4,210	50,520
TOTAL COST	$25,000	$300,000

1 Non-members are assessed an additional $15,000 one-time initiation fee for the rights to proprietary data generated during the first three years.

2 Assumes twelve sponsors.

REFERENCES

Kalmanovitch, David P., SEM Point Count, 1987.