GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

USE INITIATION SHEET AS TERMINATION SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3822 **GTRI/~~GIT~~** **DATE** 4/26/84

Project Director: Tom McGowan **~~School~~/Lab** TAL

Sponsor: Cyprus Coal Co.; Elk River Resources; Peabody Development Co.,
Englewood, CO Knoxville, TN St. Louis, MO

Type Agreement: Letters dated 4/16/84

Award Period: From 4/23/84 To 10/22/84 (Performance) n/a (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$	$ 45,000
Funded:	$	$ 45,000

Cost Sharing Amount: $ ______ **Cost Sharing No:** ______

Title: Evaluation of State-of-the-Art Technologies in Industrial Coal Use and Pollution Control

ADMINISTRATIVE DATA

OCA Contact John W. Burdette x4820

1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:

Various Sponsors

Defense Priority Rating: ______ **Military Security Classification:** ______

(or) Company/Industrial Proprietary: ______

RESTRICTIONS

See Attached ------ Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with none proposed.

COMMENTS:

COPIES TO:

Sponsor I.D. #01.700.000.84N58

Project Director
Research Administrative Network
Research Property Management
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Procurement/EES Supply Services
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Research Communications (2)

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FORM OCA 4:383

EVALUATION OF STATE-OF-THE-ART TECHNOLOGIES IN INDUSTRIAL COAL USE AND POLLUTION CONTROL

FINAL REPORT
PROJECT A-3822

by

James L. Walsh, Jr.
Thomas F. McGowan
Michael L. Brown
Deborah R. Herman
Jeffrey R. Watson

Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

June 1985

Table of Contents

Overview

This report is a compilation of the data gathered, analyses conducted, and other research conducted during a one-year evaluation of state-of-the-art technologies in industrial coal use and pollution control. The overall objective of the evaluation was to identify future research required to eliminate impediments to the expanded use of coal in the Southeast and in particular in the State of Georgia.

In support of the overall objective, the initial task was to conduct a comprehensive literature review to establish the current state of research and identify the most promising avenues for future research. The details and major findings of this literature search are presented in Section I. Copies of the abstracts generated by the literature search are provided to each of the three sponsors under separate cover.

The literature search identified several very promising areas for future research. Two of these areas were considered to be of sufficient importance to develop concept papers for marketing to potential sponsors. These papers are entitled "Combustion Improvement Through Ultrasonically Enhanced Fuel Atomization" and "Gas Turbine Quiescent Bed Coal Combustor." Copies of these concept papers are included in Section II.

The concept of ultrasonically enhanced fuel atominzation was considered to have the greatest potential for future research sponsorship. It was decided to refine the initial concept paper and submit a proposal to the United States Department of Energy's Pittsburgh Energy Technology Center's program for "Support of Advanced Coal Research at U.S. Colleges and Universities." A copy of the proposal is included in Section III. At the time of publication of this report, the proposal is still under consideration by the Department of Energy.

Several other areas were considered promising for future research. Pollution control was one of these areas. However, time and resources did not permit in-depth analysis of these concepts.

Section I

Literature Search on Coal-Related Technology

The literature search is composed of two main parts, a current periodicals search and a computerized literature base search. The purpose of the literature search was to identify those areas where advancement would most quickly lead to increased coal usage. In particular, coal water slurries, desulfurization and pollution control, and fluidized bed combustion were the primary points of focus.

The current periodicals search was directed at identifying those articles written since January, 1984, addressing coal-related issues. This time period was chosen because most articles written before this time are adequately indexed in card catalogs and computerized literature bases. At the end of this section is the index compiled as a result of this search, grouped in alphabetical order according to the publication title and chronologically under each title.

Due in part to the literature search, and also because of previous work within the lab, the concept of applying quiescent bed combustion to coal was developed. This concept offers the advantage of extending the range of fuels acceptable for applications which require flow streams with extremely low levels of solids and impurities. With this in mind, the first concept paper presented in the next section addresses the application of a quiescent bed to a gas turbine system using coal as the fuel source. Although this paper addresses specifically the application to turbine systems, it would be a natural extension to consider such a system wherever low impurity contents are required, such as with chemical or textile plants.

As part of the literature search, a representative attended the Sixth International Symposium on Coal Slurry Combustion and Technology. Held June 25-27, 1984, by the United States Department of Energy (U.S. DOE) and the Pittsburgh Energy Technology Center (PETC), this symposium focused on current trends and developments in the coal slurry industry. Copies of the proceedings are available through PETC.

Based on review of these proceedings and discussion with several of the speakers, two major areas were identified as presenting the greatest barriers to widespread use of coal water slurries (CWS). One major problem is that of stabilizing the mixture, so that mixing within storage tanks becomes unnecssary and rheological properties remain fairly constant.

The second problem involves the atomization of the slurry just prior to combustion. Conventional atomizers, utilizing air or steam blast methods, produce droplets several times larger than desired. These large droplets cause incomplete combustion and high boiler tube erosion rates and limit the usability of CWS for systems needing flow streams with low particle loading, such as for turbines. Additional problems with current atomization systems include high erosion rates of nozzles and other atomization equipment and high power input required to pump the slurries at the high pressures needed in conventional atomizers. Because of these problems, the concept of applying acoustic atomization to CWS was developed. This is discussed in the concept paper presented in the next section and resulted in the proposal submitted to DOE, which follows the concept paper.

The results of the computerized literature search are a collection of abstracts in the supplemental volume, given to the funding parties of the project. Actually, several searches were performed, and they are separated from each other by the blue pages in the volume. Each search is of a particular data base, with the base searched given at the top of each page within a section. Before each section, on the first blue page, is listed a collection of key words used in the search. Below this list is given one or more groups of three numbers, preceded by the word "print." The first of these numbers refers to an item number in the list above. This item number specifies the particular word string submitted to the computer for searching. The second number specifies the type of response desired, whether it be simply title and source, an abstract, or the complete article. In all cases, a 5 was used to indicate that an abstract was desired. The third number refers to the number of article citations desired, starting with the most recent. For example, in the first search conducted, the first three-number string is 8/5/1-75. In this case, the first 75 articles will be abstracted which contain the following combination of words: coal and catalysts and (desulfurization or desulphurization or sulfur(W=with)removal or sulphur(W)removal). Note that the logical operators (and, or, and not) are used to specify the type of word combinations for which to search.

Coal Preparation--An International Journal

Combustion and Flame--The Journal of the Combustion Institute

Combustion Science and Technology

Energy

Energy Sources

Regulatory requirements are reviewed and suitable approaches to meet these requirements are suggested. Development of adequate data base for design and monitoring is discussed.

JAPCA--Journal of the Air Pollution Control Association

Mechanical Engineering

Modern Power Systems

Power

Page

January 1984

Calcium Chloride--A New Solution for Frozen Coal
David G. Boley — 67

February 1984

Smart Coal-Pile Management Can Cut Heating Value Losses
John Ripp — 53

This article reviews the benefits of inhibiting water percolation through a coal pile.

Fluidised Bed Retrofit a Practical Alternative to FGD
T. E. Stringfellow, F. S. Nolte and W. L. Sage — 78

May 1984

How Can We Protect Coal Bins from Rapping-Equipment Damage? — 148

Solutions presented by three readers.

September 1984

ESP Precharger Shows Promise in Solving Ash-Sensitivity Problems
Robert Schweiger — 115

January 1985

Alloy Liners Protect FGD Systems--and the Bottom Line
D. C. Agarwal — 35

External Combustor Gives More Life to Coal-Fired Gas Turbine
Jason Makansi — 63

This article examines performance of hot air cycle and examines areas of needed work.

February 1985

Fluidized-Bed Boilers Achieve Commercial Status Worldwide
Bob Schwieger — 17

Power Engineering

Page

January 1984

Slurry Valves for Power Plants
Richard G. Chapman — 26

February 1984

Combined Cycle Coal Gasification: Options for Power Plants
T. A. Vivenzio and J. V. Rossi — 57

May 1984

Nomogram Calculates Power Plant Coal Use
James McAlister — 39

Increasing Flue Gas Desulfurization System Reliability
L. N. Davidson, R. J. Mongillo, S. Ou and C. P. Weding — 50

June 1984

Coal Supplies, Acquisition and Transportation
R. C. Rittenhouse — 34

Minimizing Wastewater with Bottom Ash Recirculation Systems
Douglas M. Rode and Nancy C. Mohn — 50

August 1984

Study for Decommissioning Coal-Fired Power Plants
Roger D. Wilson — 38

Control of Solid Fuel Slagging
J. R. MacDonald — 48

Reviews problems with fireside slagging, corrosion caused by burning low-cost fuel, environmental restrictions and increasing the rating of existing units, and methods of control.

September 1984

Integrated Air Pollution Control for Coal-Fired Boilers
G. E. Baker, J. O. Milliken, et al. — 39

October 1984

Dry FGC System: Start-up, Performance and Acceptable Tests
Robert D. Emerson — 50

Progress in Energy and Combustion Science

Section II

Concept Papers

GAS TURBINE
QUIESCENT BED COAL COMBUSTOR

by

Technology Applications Laboratory

Engineering Experiment Station

Georgia Institute of Technology

Atlanta, Georgia 30332

September, 1984

QUIESCENT BED COAL COMBUSTOR

Introduction

The economic position of both industries and power utilities is being weakened by the escalating costs of conventional petroleum based fuels. The solution to this situation is the conversion to more abundant and economical fuels such as coal. However, conversion to coal is proceeding at a disappointing rate due to high capital costs, questionable environmental impacts, and the current depressed state of the economy.

One technique to encourage the widespread conversion to coal would be the development of a direct fired gas turbine system. Direct fired turbine applications of coal have been limited in the past due to the severe particulate erosion encountered and the high cost and poor reliability of particulate removal equipment. This paper presents an advanced combustion system concept that promises to overcome many of the barriers to direct coal utilization in gas turbines.

Concept

The objective of this research will be the development of a quiescent bed, lumped coal combustor which demonstrates decreased gas stream particulate entrainment levels and thus reduced blade erosion.

Earlier researchers have discovered that blade erosion is a function of many factors including particulate loading, particulate size distribution, blade material, aerodynamic design of the blades and gas stream velocity.(1) Australian work on an open cycle gas turbine fired with brown coal revealed that the critical particle diameter for erosion was 5 microns and that erosion increases with the cube of diameter above this point.(2) Therefore, the dust loading tolerable by a turbine is inversely related to particle size. For particle sizes on the order of 2 microns, 0. 03 grains/SCF is allowable, but if particle size increases to 20 microns the allowable particulate loading decreases to 0.002 grains/SCF.(3) A pulverized coal suspension burner which entrains all of the fuel ash will have a pre-cleaned ash loading of over 3 grains/SCF. To be acceptable for a turbine gas path, the loading would have to be decreased by a factor of 100 (assuming a minimum particle size of 2 microns). Atmospheric pressure quiescent bed combustors, on the other hand, have demonstrated particulate loadings as low as 0.06 grains/SCF at heat release rates of 500,000 Btu/hr ft^2.

The quiescent bed concept differs from previous combustor designs in that the fundamental combustion process is designed to produce hot gases without significant particle entrainment. Earlier methods, such as suspension burners, allowed significant entrainment during

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(1)Assess of Gas Turbine Erosion, Vol. 1, NYSERDA

(2)Aust. Coal Rese

(3)Assess of GT Erosion, Vol. 2.

combustion then attempted particulate removal subsequently. The quiescent bed combustor will consist of two coupled chambers (Figure 1). In the primary chamber where gas velocities will be low (on the order of 1 foot/second) to limit bed disruption and ash entrainment, lumped coal fuel will be introduced, and devolatilization and combustion of the fixed carbon will occur. Adequate volume above the primary chamber will be provided for particle disengagement. Above the disengagement area will be a transition zone where the hot pyrolysis gases will be accelerated before entering the secondary combustion chamber. In the secondary chamber, the low Btu pyrolysis gas will be mixed with additional combustion air and burned to completion. An underfeed stoker is employed for fuel induction to maintain quiescent conditions in the primary zone. Although the concept of two stage combustion has received limited application to coal, considerable effort has been devoted to wood firing.

The wood fueled quiescent bed systems have achieved some success although there have been few industrial installations. The operating units have demonstrated combustion efficiencies of 90%. Emission levels for the various designs vary from 0.03 grain/sdcf to 0.20 grains/sdcf.

Past Research

The concept of a quiescent bed coal combustor is the third step in the evolution of an acceptable coal-fired gas turbine. This concept combines the favorable aspects of earlier design efforts.

Past research has concentrated on two alternatives: direct combustion and gasification. Two methods of direct combustion have predominated: pulverized suspension burning and pressurized fluidized bed combustion. When pulverized coal is burned suspended in an air stream, almost all of the ash is entrained, requiring extensive gas clean-up to prevent erosion. Removal of a 80-90% of the entrained particulate has proven feasible, however, cleaning adequate to guarantee acceptable component life has not been obtained.[4]

Recent efforts to utilize coal directly as a gas turbine fuel have focused on applying pressurized fluidized bed technology. Fluidized bed combustion presents several advantages including efficient combustion, the prospect of significant sulfur clean-up, and tolerance of various sizes of fuel. Unlike the quiescent bed combustor, fluidized beds have extremely turbulent combustion zones which lead to significant levels of particulate entrainment. One

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(4) J. Smith, D. C. Strumbeck, N. H. Coates & J. P. McGee, "Bureau of Mins Progress in Developing Open and Closed Coal-Burning Gas Turbine Plants," ASME Paper No. 66-GT/CLC-7, March, 1966.

report noted that recent experience indicates it is doubtful that fluidized bed particulate concentration can be reduced at a reasonable cost for turbine inlet temperatures above 1,050°F.

Another combustion method that has received recent attention is conversion technology such as gasification. Gasifiers offer advantages because not all the ash is entrained due to the low superficial velocities and combustion of the low Btu gas product is relatively simple. Even though particulate is reduced over that encountered with suspension burning, gas clean-up is required. The clean-up equipment is expensive and thermal efficiency is decreased because the gases must be cooled before cleaning.

Quiescent bed combustion offers the prospect of directly using coal as a gas turbine fuel by overcoming disadvantages encountered with suspension burners, fluidized beds, and gasifiers. A quiescent bed combustor research program would be directed toward establishing their feasibility by optimized operating conditions. Research will address the tradeoffs between lower superficial velocity through the bed and reduced particulate entrainment versus increased velocity and reduced grate area. Heat release rates for underfed grate burning furnaces are in the 300,000 - 500,000 Btu/ft^2 range. At this level of output, a 10 MW (10,000 kW) gas turbine generator would require a combustor with a grate area of over 250 ft^2. This reflects data for atmospheric pressure operation. At higher pressures such as would be found in gas turbine combustors, the output per unit area will increase due to the increased oxygen concentration. The greater mass calculations of the minimum fluidization velocity of ash indicate that a superficial velocity of 0.02 ft/sec is the point of incipient fluidization for 10 micron particles. While this value is substantially below that expected in the quiescent bed, it cannot be assumed that entrainment of large ash particles will occur. The minimum fluidization velocity, corresponding to the point of incipient fluidization where the bed pressure drop equals the weight of the bed, is below the entrainment velocity. Another factor favoring the quiescent bed is that the ash particles themselves will be larger due to the lump nature of the fuel than ash from pulverizer coal burners. Table 1 shows the measured particle size distribution found in coal boilers and illustrates well the smaller particle sizes produced with suspension burning. Arrangements that minimize air flow at the point of ash removal will be stressed to help further restrict ash entrainment.

If this velocity proves unacceptable from an ash entrainment standpoint design, modifications that can serve to mitigate this situation can be addressed. Potential modifications include injection of secondary air in a swirling motion to act as a cyclone and force the ash to the combustor wall where it can drop out and experimentation with acoustical enhancement of combustion so that velocities in the primary zone may be reduced while adequate heat release rates can still be maintained.

flow of air through the gas turbine combustor would be achieved by an increase in air density and not velocity so particulate entrainment would still be low. While the quiescent bed combustor will without question be larger than previous solid fuel gas turbine combustors, the prospect that it may be able to operate without the degree of downstream clean-up devices required by the other systems will offset this disadvantage. Earlier Australian research on coal fired gas turbines recognized the advantage that could be gained by utilizing modern lump coal combustion methods which reduce the carryover of ash to the turbine and proposed this concept as an alternative to pulverized coal combustion.

Research Plan

Based on past experience, a conceptual quiescent bed coal combustor will be designed. The conceptual design will address chamber configuration, fuel and air feed rates, temperature and air distributions, and air velocities. Test will be made on a prototype unit to discover heat release rate, particulate loading, particle size distribution, grate temperature, and combustion and carbon burnout efficiency. This data will be evaluated to determine concept viabiity for turbine applications.

It is envisioned that an updraft combustor will be studied initially. Because particulate size must be below 10 microns to prevent significant erosion, velocities in the combustor vessel on the order of 0.5 to 1.0 ft/sec will be evaluated initially. Preliminary

TABLE 1

Typical Particle Size Distribution of Ash From Coal Combustion[5]

Particle Diameter (microns)	Percent by Weight of Particles in a given size range	
	Pulverized Coal	Lump Coal
0 - 10	25	-
10 - 20	24	-
20 - 30	16	11
30 - 40	14	-
40 - 75	13	12
75 - 150	6	30
over 150	2	47
	100	100

(5) P. Dimitry, et al, "Emission for Industrial Coal Fired Boilers," Combustion, January 1980, p. 20.

COMBUSTION IMPROVEMENT THROUGH ULTRASONICALLY ENHANCED FUEL ATOMIZATION

by

Technology Applications Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

September 4, 1984

COMBUSTION IMPROVEMENT THROUGH ULTRASONICALLY ENHANCED FUEL ATOMIZATION

Coal water mixtures (CWM) show great promise as a low-cost substitute for No. 6 fuel oil. However, laboratory-scale combustion tests have exposed a limitation of conventional atomization techniques. Recent evidence from several independent research programs indicate that, during the devolatilization stage that precedes combustion, individual coal particles within the CWM droplet aggregate to form particles that are approximately the same size as the original atomized droplet. For coals with a high swelling index, the aggregate particles may become even larger than the original slurry droplet. The resulting large particle size decreases combustion efficiency by limiting carbon burnout. Although carbon on the surface of the aggregate particle is easily combusted, oxygen cannot diffuse at an adequate rate through the surface to burn interior carbon. Large droplet size also ultimately produces large flyash particles. Generation of large ash particles causes erosion of boiler tubes and other surfaces within the combustor and may prohibit the application of CWM as a fuel in gas turbines.

The obvious solution to this dilemma is to reduce the size of the atomized fuel droplets. Droplet diameter is dependent on the method of atomization as well as physical properties such as viscosity and surface tension. Several airblast atomizers have been specifically designed for CWM, but each produces a relatively wide distribution of droplet sizes. Droplet sizes as large as 1,000 to 1,500 microns have been measured. Several researchers are undertaking work on secondary atomization techniques to enhance the results of conventional CWM atomizers. In contrast, we propose to investigate the use of ultrasonic vibration as the primary means of atomization for coal water mixtures and other slurries. Ultrasonic vibration has been used successfully in the atomization of various liquid fuels, and there is strong evidence to indicate that its use may be extended to inhomogeneous fuels such as coal water mixtures. If sufficiently small, uniformly sized droplets can be produced, high carbon burnout rates and improved combustion efficiency should result. Because flyash size and consequently erosion will be reduced, the ability to minimize slurry droplet size will also help to make CWM a viable fuel for gas turbines.

Ultrasonic atomization involves the production of small droplets by high frequency vibration of the liquid. Past research has revealed two basic classes of ultrasonic droplet formation: (1) formation of mists or fogs by focusing ultrasonic vibration at or near the surface of a liquid film and (2) formation of droplets by controlling the breakup of jets (See Figure 1). Both of these atomization mechanisms involves a different axis of applied vibration. In the first class, aerosols are formed from a liquid surface when capillary waves (surface waves) produced by vibration break off and are ejected into the combustion zone. In the second class, liquid jets are broken up into droplets in a controlled fashion by vibrating the injection nozzle. A comprehensive research program will need to examine both methods to determine the optimum technique for CWM atomization.

Both methods of ultrasonic atomization offer inherent benefits over existing techniques for the atomization of CWM. The advantages of capillary atomization include the elimination of the need for a high pressure fuel pump and reduction in fuel plugging problems because the feed passages are relatively large compared to pressure atomizing nozzles. Effective atomization is maintained at any feed rate up to the maximum. However, for this particular application, the most important advantage will be the capability to accurately control the droplet size of the mixture. A secondary advantage of larger fuel feed passages will be a significant reduction in injector erosion problems due to the abrasive nature of coal water mixtures.

Droplet formation through jet breakup induced by vibration is attractive because the equipment used for this purpose is relatively simple, and the method is applicable to liquids with widely varied properties. The primary advantage of this atomization method may be the production of droplets of uniform diameter. Initial examination of past experience has indicated that the mean diameter of droplets formed in this manner is determined primarily by the size of the orifice employed.

Most recent research, which has utilized oils, water, and similar liquids, has demonstrated excellent results for ultrasonic atomization. The smallest droplet sizes have been achieved using capillary waves, where water droplets as small as one micron have been reached. Jet vibration has not been shown to yield such small droplet sizes because droplet diameters smaller than the jet orifice are difficult to achieve. However, high flowrates may be easier to maintain with jet vibration. Common to all previous research is the use of liquids with relatively low viscosity, low surface tension, and fairly homogeneous composition.

The goal of the proposed research is to extend the method of ultrasonic atomization used for liquids to slurries such as coal-water or coal-oil mixtures. One major difference in such an extension is that these slurries are highly viscous, which may make capillary wave formation difficult. Furthermore, suspended particles in the mixture will tend to clog very small transport tubes. This will not be a problem with capillary wave atomization, but will limit the minimum droplet size which can be achieved in vibrating jet atomization.

In particular, two areas must be addressed to evaluate the effectiveness of ultrasonic atomization in improving coal liquid mixture combustion efficiency. The first issue, which is addressed by the questions below, concerns the goal of improving atomizer performance over conventional methods. The second issue concerns the effectiveness of improved atomization combustion efficiency. Phase I of the proposed research will be directed only toward the first issue.

These are the questions which are of primary importance in evaluating ultrasonic atomization:

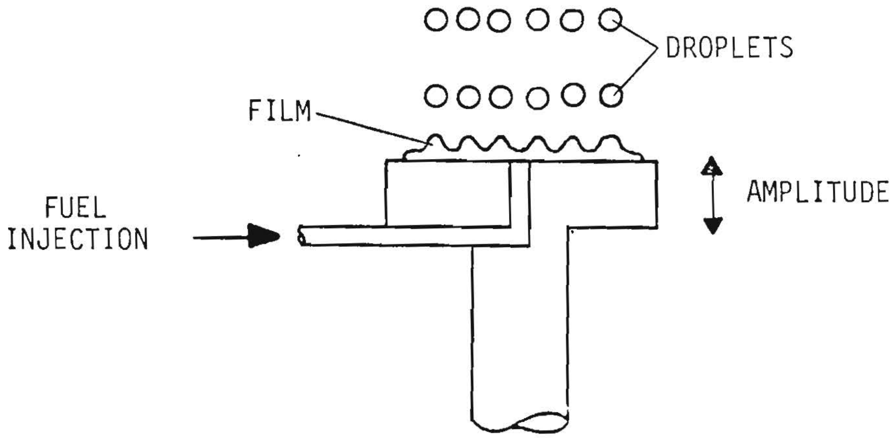
(1) What drop sizes can be achieved? It is anticipated that drops in the size range of 100 to 500 microns can be achieved. This would be a considerable improvement over the current atomization techniques.

(2) What power input is needed to produce suitably small drops? Preliminary estimates indicate that power inputs for ultrasonic atomization will be comparable to those used for conventional atomizers.

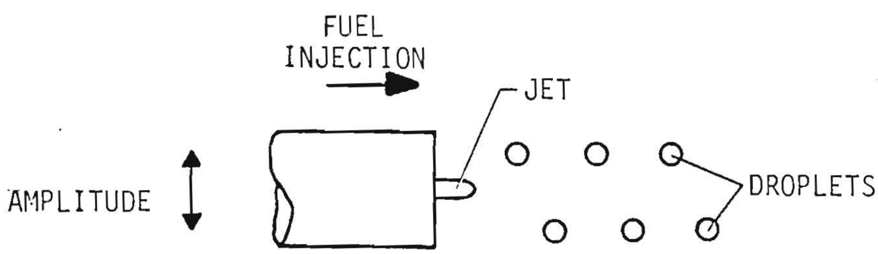
(3) How are the variables of flowrate, atomizer configuration, vibration frequency and amplitude related to droplet size? Past research, which developed expressions for droplet size as a function of liquid properties and vibration characteristics, would serve as a starting point for this work.

In order to investigate the viability of ultrasonic atomization of coal-water mixtures, and to answer the above questions, the following program of research is proposed. A bench scale atomization system will be constructed capable of producing vibrations in the transverse and longitudinal directions. Droplet formation will be recorded using high speed photographic techniques, as these have been shown to be the most reliable, accurate record of droplet size distribution in past research. To complete the construction of the test system, a flow loop with recirculating pumps and flow meters will be installed. Once these three major systems components are integrated, work can commence on actual atomization characterization. Tests at conditions of varying vibration amplitude, frequency, and fuel flow rate will be conducted to establish the operating conditions which yield the smallest droplet diameter with the minimal power inputs.

Following the successful completion of the atomization studies, Phase II of the proposed program will focus on the combustion of ultrasonically atomized slurry droplets. The atomizer designed in Phase I will be integrated with primary air flow into a slurry combustion chamber. Carbon burnout rates, combustion efficiency and ash particular size distribution will be primary measures of the effectiveness of ultrasonic atomization on improving combustion.



CAPILLARY WAVE ATOMIZATION



JET BREAK-UP ATOMIZATION

FIGURE 1

Classes of Droplet Formation by Applied External Vibration

Section III

Department of Energy Proposal

Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh, Pennsylvania 15236

MAR 4 1985

Dr. Michael L. Brown
Georgia Tech Research Institute
Technology Applications Laboratory
Centennial Building
Georgia Institute of Technology
Atlanta, GA 30332

Dear Dr. Brown:

This letter serves to acknowledge receipt of your proposal in response to Program Solicitation Number DE-PS22-85PC80501. The proposal title, and the DOE assignment number are indicated below.

Your proposal will receive a thorough evaluation and review, along with others received under the same solicitation. Grants to be awarded under this solicitation are planned for August. Provided your proposal meets the minimum initial acceptance criteria applied before the evaluation, communication from this office should not be expected until the awards are announced.

We appreciate your interest in the Fossil Energy Program and your response to this program solicitation. Please reference the DOE Proposal Number below if you have any inquiries regarding this proposal. Please address any questions on this matter to Mr. Keith R. Miles of this staff at (412) 675-5984.

Sincerely,

Louis J. Ruzzi
Manager
Acquisition and Assistance Division

Title: "Capillary-Wave Atomization of Coal Water Mixtures"

DOE Proposal Number: 80501-116

CAPILLARY-WAVE ATOMIZATION OF
COAL WATER MIXTURES

DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
PROPOSAL SUBMISSION

PROPOSAL SUBMITTED TO PROGRAM SOLICITATION, DE-PS22-85PC80501 (Fossil Energy Program) SUPPORT OF ADVANCED COAL RESEARCH AT U.S. COLLEGES AND UNIVERSITIES.

DOE Proposal No. *(For DOE Use Only)*	2. Date Received by DOE	Institution Proposal No.

bmitted by Principal Investigator(s) (PI)

3. Title	4. First Name, Initial(s)	5. Last Name	6. Telephone No. (Area-Number)
	Michael L.	Brown	(404) 894-3412
-PI Dr.	Peter H.	Rogers	(404) 894-3235
-PI			

. Department/Division
Georgia Tech Research Institute/ Technology Applications Laboratory

a. Institution/Organization
Georgia Tech Research Corporation

8b. Historically Black College or University
☐ Yes ☒ No

. Address
Centennial Bldg., Georgia Institute of Technology

Administrative Officer
Earnestine P. Smith

. City	11. State	12. Zip	Business Telephone, Area-Number
Atlanta	Georgia	30332	404/894-4817

. Proposal Title *(Limit to 60 Characters)*
Capillary-Wave Atomization of Coal Water Mixtures

. Program Category *(Check One for Review Purposes)*

- Coal Science
  - ☐ Structure
  - ☐ Characteristics
  - ☐ Analytical
  - ☐ Reaction Chemistry
- ☐ Surface Science
  - ☐ Coal Surface Science
  - ☐ Catalyst Surface Science
- ☐ Mechanisms & Kinetics
  - ☐ Conversion
  - ☐ Utilization
- ☐ Thermodynamics
  - ☐ Experimental Thermodynamics
  - ☐ Supercritical Phase Behavior
  - ☐ Thermodynamics of Solids
- ☒ Solids Transport
  - ☐ Bulk Properties
  - ☒ Multiphase Flow
- ☐ Environmental Science
  - ☐ Gaseous Pollutants
  - ☐ Liquid Pollutants

nding Requirements and Performance Period:

. DOE $	16. Institution $	17. Other $	18. Total $
132,682			132,682

. Source of Other Funds, If Any

. Performance Period (Limit to 60 Months) 24 Months

Desired Starting Date (9-15-85 or Later) 9-15-85

e, the following signatories, agree to external review of this proposal in confidence.
ignature (DOE Requires Signatures on Original Copy)*

. ______ Principal Investigator (PI)

22. ______ Department Head/Organization Head

______ incipal Investigator (Co-PI)

______ incipal Investigator (Co-PI)

23. ______ *Administrative Officer/Business Officer

2-27-85
Date Submitted

AIL TO: U.S. Department of Energy
Pittsburgh Energy Technology Center
Attn: FE Unsolicited
Proposal Operations: Code 2217
P.O. Box 10940, MS 900-L
Pittsburgh, PA 15236

OR

DELIVER TO: U.S. Department of Energy
Pittsburgh Energy Technology Center
Building 900-L, Wallace Road
South Park Township (Allegheny County), PA 15236
Attn: Proposal Operations (for code 2217)

PROPRIETARY INFORMATION DISCLOSURE

DE-PS22-85PC80501

---

heck either:

. (a) ____X____ **NO**. Proprietary information is **NOT** contained in this proposal submission.

(b) __________ **YES**. Proprietary information **IS** contained in this proposal submission; furthermore:

> "The data submitted on pages __________ of this application have been submitted in confidence and contain trade secrets and/or privileged or confidential commercial or financial information and such data shall be used or disclosed only for evaluation purposes, provided that if a contract is awarded to this applicant as a result of or in connection with the submission of this application, the Government shall have the right to use or disclose the data herein to the extent provided in the contract. This restriction does not limit the Government's right to use or disclose data obtained without restriction from any source, including the applicant."

In addition, each page of the application containing proprietary data which the applicant wishes to restrict must be marked with the following legend:

> "Use or disclosure of the application data on lines specifically identified by asterisk (*) are subject to the restriction of the cover page of this application."

Arbitrary and unwarranted use of this restiction is discouraged.

GEORGIA TECH RESEARCH CORPORATION

ADMINISTRATION BUILDING
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332-0420

Telex: 542507 GTRIOCAATL
Fax: (404) 894-3120

Phone: (404) 894-4817

Refer to: EPS/01.141.005.85.002

27 February 1985

PROPOSAL NO. TA-EC-1364
U.S. Department of Energy
Pittsburgh Energy Technology Center
Wallace Road, Building 900
FE Unsolicited Proposal Operation Code, 2217
Pittsburgh, PA 5236

Attention: Keith R. Miles

Subject: Research Proposal Entitled, "Capillary-Wave Atomization of Coal Water Mixtures"

Reference: Program Solicitation Number DE-PS22-85PC80501
Support of Advanced Coal Research at U.S. Colleges and Universities

Gentlemen:

The GEORGIA TECH RESEARCH CORPORATION desires to submit for your consideration the subject proposal prepared by Mr. Michael L. Brown, Georgia Tech Research Institute, Georgia Institute of Technology.

A description of the research program, the time required and estimated costs are included in the proposal. Should additional information be desired, please do not hesitate to contact Mr. Brown at 404/894-3412 regarding technical matters or the undersigned at 404/894-4817 for administrative concerns.

In the event of an award, we propose that the work be authorized by either a grant or a cost-reimbursement (no fee) type of contract drawn in the name of the GEORGIA TECH RESEARCH CORPORATION.

We appreciate the opportunity of submitting this proposal and look forward to the possibility of working with you on this project.

Sincerely,

Earnestine P. Smith
Contracting Officer

EPS/cfd

Addressee: Ten copies
Enclosure: Proposal - Ten (10) copies

TABLE OF CONTENTS

ABSTRACT

Coal water mixtures (CWM) show great promise as a low cost substitute for No. 6 fuel oil. The major problem limiting widespread application of this fuel is development of an atomization method capable of producing micron size droplets. The high viscosity and presence of relatively large solid particles in the slurry coupled with its extremely abrasive nature make conventional atomization techniques ineffective. Ultrasonic atomization by capillary wave action appears to offer a means to overcome the limitations faced by other methods. Capillary wave atomization has been successfully applied with liquid fuels, but this research would be the initial extension to slurries. A test program to examine ultrasonic transducer configurations, develop relations between droplet diameter, slurry properties and ultrasonic variables, and study the effect of ultrasonic atomization on solid-liquid separation is proposed. Completion of the outlined research will determine if ultrasonic techniques can be successfully applied to CWM.

CAPILLARY-WAVE ATOMIZATION OF COAL WATER MIXTURES

INTRODUCTION

Coal water mixtures (CWM) show great promise as a low-cost substitute for No. 6 fuel oil. Significant improvements have been made in the preparation, handling, and combustion characteristics of CWM in the past several years. However, laboratory-scale combustion tests conducted under several independent research programs have exposed a critical limitation in the combustion of atomized CWM droplets.[4,7,11] During the evaporation/devolatilization stage that precedes combustion, individual coal particles within the atomized CWM droplet fuse to form a single aggregate particle that is approximately the same size as the initial atomized droplet. For coals with a high swelling index, these aggregate particles may become even larger than the parent droplet. Addition of surfactants, widely used in the formulation of CWM to increase the wettability of coal particles, appears to exacerbate particle fusion.[3]

The resulting large coal particle size decreases combustion efficiency by limiting carbon burnout. Although carbon on the surface of the aggregate particle is easily combusted, oxygen cannot diffuse through the surface at an adequate rate to burn all interior carbon. Large particle size also produces large flyash particles which cause erosion and slagging of boiler tubes and other surfaces and may prohibit the use of CWM as a gas turbine fuel.

These findings indicate that CWM combustion efficiency and resulting ash particle size are most closely related not to individual coal particle size, but to the size of the atomized CWM droplet. A reduction in droplet diameter will, therefore, lead to an expected increase in combustion efficiency and a decrease in flyash particle size.

Preliminary research has identified a target maximum droplet diameter of 200 to 300 microns. Droplet diameter is dependent on the method of atomization as well as physical properties such as viscosity and surface tension. Conventional high-pressure atomizers have not been effective with CWM. Air- and steam-blast atomizers designed specifically for CWM produce significantly smaller average CWM droplet sizes that high-pressure atomizers but are not yet able to reliably meet this target diameter.[2,3]

An alternative technique is use of ultrasonic vibration as the primary means of atomization for CWM and other slurries. Ultrasonic vibration has been used successfully in the atomization of various liquid fuels and molten metals to produce very small, uniformly sized droplets.[5,8,10,12,13] There is strong evidence to indicate that its use may be extended to heterogeneous fuels such as CWM to produce droplets that fall within the prescribed maximum diameter.

SCIENTIFIC DISCUSSION

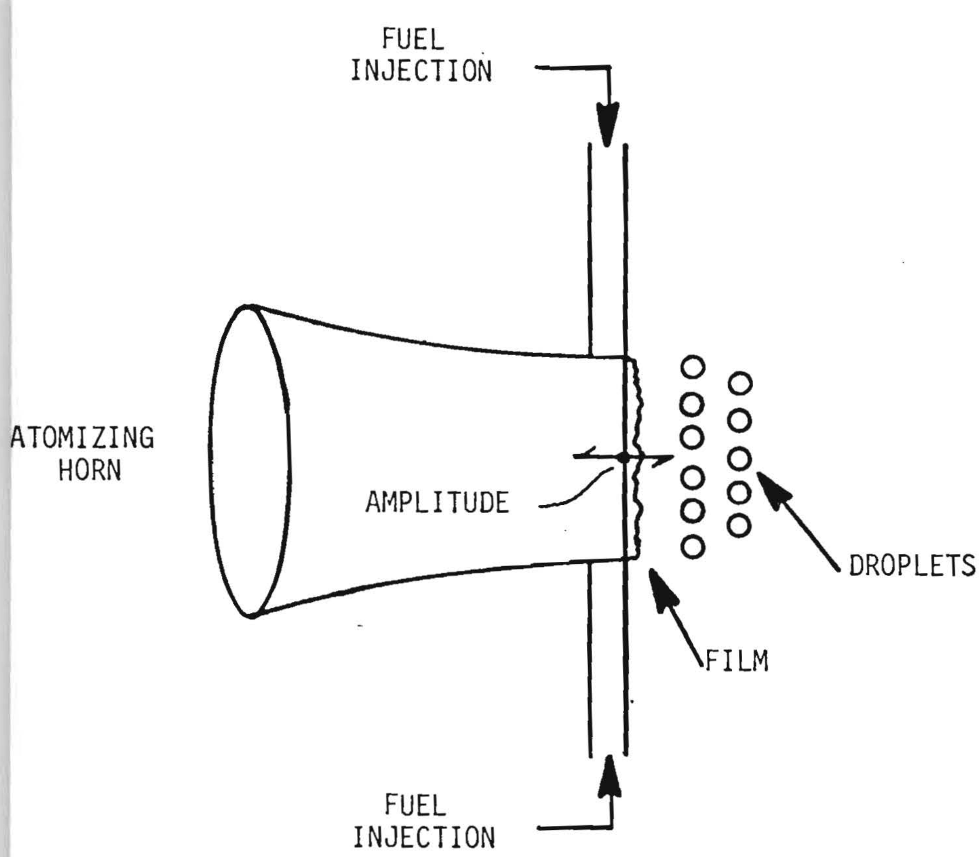
The purpose of any fuel atomization process is to produce a large number of small droplets, thereby increasing the surface area of the liquid to promote combustion of the fuel. Traditional methods of atomization rely on a high relative velocity between the liquid and the surrounding air to achieve droplet formation. In a high pressure atomizer, high relative velocity is attained by using pressure to accelerate the fuel into a slow moving surrounding gas. These atomizers have not been effective with CWM. The narrow feed passageways become plugged with coal particles, which have a maximum size of 300 microns in most current CWM formulations.[1] In addition, high pressure atomizers are incapable of handling highly viscous fuels. Attempts to modify these atomizers to handle CWM have resulted in slurry droplets of 1,000 to 2,000 microns.[3]

An alternate approach, referred to as air- or steam-blast atomization, utilizes a high velocity stream of air or steam to shear the slow-moving liquid. High gas velocity has been shown to effectively break up high viscosity liquids.[14] Although these CWM atomizers do not operate reliably within the 200 micron to 300 micron maximum, work is continuing to improve performance and decrease wear. Several researchers are currently undertaking work on secondary atomization techniques to augment the output of air-blast CWM atomizers.[2]

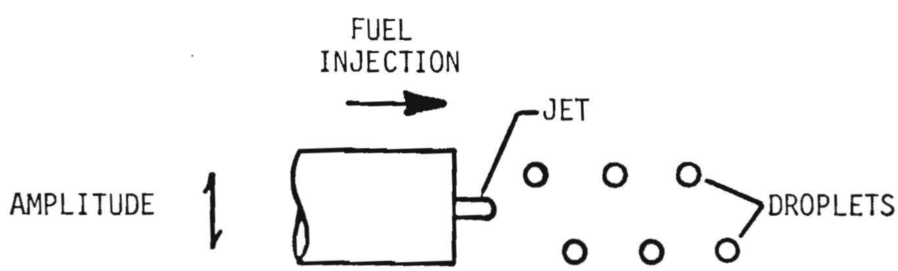
Ultrasonic vibration is proposed as a promising alternative technique for CWM atomization. Ultrasonic atomization produces small, relatively uniform size droplets by applying high frequency vibration to the liquid. Past research has revealed two basic classes of ultrasonic droplet formation: (1) formation of mists or fogs by focusing ultrasonic vibration at or near the surface of a liquid film and (2) formation of droplets by controlling the breakup of jets (see Figure 1). Each of these atomization mechanisms involves a different axis of applied vibration. In the first class, aerosols are formed from a liquid surface when capillary waves (surface waves) produced by vibration parallel to the axis of droplet propagation break off and are ejected. In the second class, liquid jets are broken up into droplets in a controlled fashion by vibrating the injection nozzle perpendicular to the axis of droplet formation.

Controlled ultrasonic vibration has been successfully used in the atomization of various liquids and slurries. Ultrasonic vibration of a liquid film to produce droplets by capillary wave action has been used to atomize fuel for combustion in a small, self-contained thermoelectric generator. The generator, developed for the U.S. Army, was successfully operated with gasoline, kerosene and No. 2 fuel oil, but no highly viscous fuels and slurries have been tested.[8] The second form of ultrasonic atomization, liquid jet breakup, has seen widest application in ink jet printers or similar devices where uniformity of droplets is a primary design criterion.[5]

Although droplet formation through vibration-induced jet breakup is applicable to liquids with widely varying properties, including



CAPILLARY-WAVE ATOMIZATION



JET BREAKUP ATOMIZATION

FIGURE 1

Classes of Droplet Formation by Applied External Vibration slurries such as ink, it does not appear to be an appropriate method for atomization of commercially-produced CWM. Mean diameter of droplets formed through jet breakup is determined by the size of the orifice employed.[13] In order to avoid plugging, an orifice diameter approximately two times the diameter of the largest solid particle in the slurry is required. To accommodate current CWM, an orifice diameter of 600 microns is required, resulting in droplets of the same average diameter. If new formulations of CWM, based on smaller maximum particle size, are developed, vibration-induced jet breakup may become a viable atomization method.

The proposed research will focus on capillary-wave atomization. This method offers several advantages over other atomization techniques. For CWM atomization, the primary advantage will be the capability to accurately control droplet size. A controlled spray of water droplets as small as 1 micron has been achieved with capillary atomization.[9] In addition, droplet size is not directly related to the diameter of feed orifices, so relatively large passages can be used. This will eliminate fuel plugging problems, lower the power input required to pump the slurry, and minimize injector erosion problems that arise due to the abrasive nature of CWM.

In a capillary atomizer, one central nozzle or multiple radial nozzles feed fluid onto a vibrating metal plate. The impressed vibration causes a standing wave to be set up in the film of fluid that forms on the plate. With vibration of sufficient amplitude and frequency, droplets of liquid will be ejected from the crests of the waves. The frequency and amplitude of the ultrasonic vibration are among the primary factors that determine the diameter of the ejected droplets.

Capillary-wave atomization has been successfully applied to water, water-methanol and water-glycerin solutions, and light hydrocarbon fuels, but no work has been done with highly viscous slurries such as CWM.[5,8,12] Droplet diameter achieved by capillary-wave atomization is dependent on many factors: frequency and amplitude of the ultrasonic vibration, liquid flowrate, atomizer geometry, and liquid properties such as surface tension, viscosity and density. Only limited correlations have been made between droplet size and liquid properties, and insufficient data exist to extrapolate the results to CWM atomization.

Several equations have been proposed to predict droplet diameter. For sonically-generated wavelengths, the capillary wavelength is related to the excitation frequency by the equation below.[5,9,12]

$$\lambda = \left(\frac{8\pi\sigma}{\rho f^2}\right)^{1/3} \qquad (1)$$

where λ = wavelength; σ = liquid surface tension; ρ = liquid density and f = excitation frequency. A portion of the wave peak will break off to form droplets. Therefore, the mean droplet diameter ($\overline{D}$) will be proportional to the capillary wavelength, or

$$\overline{D} = N \left(\frac{\sigma}{\rho f^2}\right)^{1/3} \qquad (2)$$

where N is an empirical function of vicosity, flowrate, amplitude, geometry, and other parameters.[11] The relationship between droplet diameter and surface tension, density and frequency has been verified for ultrasonic atomization of liquids, but no research has been done to determine if the relationship is affected by the presence of solid particles in slurries. In addition, little work has been done to develop an empirical expression for N for either liquids or slurries. The proposed research will focus on verifying the applicability of Equation 1 to CWM atomization, and establishing an empirical relationship between droplet diameter and CWM viscosity, flowrate and amplitude.

STATEMENT OF WORK

A two year research program is proposed to investigate the feasibility of capillary-wave atomization of CWM and to determine the relationship between atomized droplet diameter and both ultrasonic vibration charactertistics and CWM physical properties. A bench-scale atomization system designed with operating characteristics suitable to produce CWM droplets on the order of 100 to 300 microns will be developed. The proposed research program will consist of four related tasks: 1) Literature Search and Modeling; 2) Experimental Design and Construction; 3) Atomization Experiments; and 4) Data Analysis.

Task 1: Literature Search and Modeling

The initial task will consist of an extensive literature search. It will be performed to expand the existing data base and assure that state-of-the-art application techniques are utilized. Theoretical equations, as well as any applicable empirical relationships, will be used to model atomization by capillary wave action. Preliminary modeling will serve to predict the performance characteristics needed from the ultrasonic transducer. By defining an estimated range of required operating parameters, the test apparatus can be designed and transducers built.

Task 2: Experimental Design and Construction

Design and construction of the experimental apparatus is the second task of the research program. As shown in Figure 2, the atomization test rig will consist of three major components: 1) ultrasonic oscillator/atomizer, 2) CWM handling and delivery system, and 3) photographic recording system. Once modeling is complete, the required operating characteristics of the ultrasonic transducer, such as frequency, amplitude and power input will be estimated, allowing the complete atomizer to be designed and built. The Georgia Tech faculty has significant transducer design experience in the range from 10 kilohertz to 10 megahertz. This frequency range encompasses the expected operating region for capillary-wave atomization.

The equipment necessary to drive an ultrasonic capillary wave atomizer is shown in Figure 2. Input AC power drives an oscillator, also referred to as a wave form generator, whose purpose is to produce a high frequency AC signal. The high frequency signal from the oscillator must be fed into an amplifier since the oscillator output is at a low power level. The ultrasonic amplifier increases the signal power while maintaining constant frequency. In most cases, a matching transformer is necessary to step-up the amplifier voltage to a level compatible with the transducer. For most transducers, the voltage must be increased to approximately 500 V. The conditioned ultrasonic AC signal can then be fed into a transducer, probably of piezoelectric design, which converts it to a high frequency displacement. Two additional components illustrated in Figure 2, a

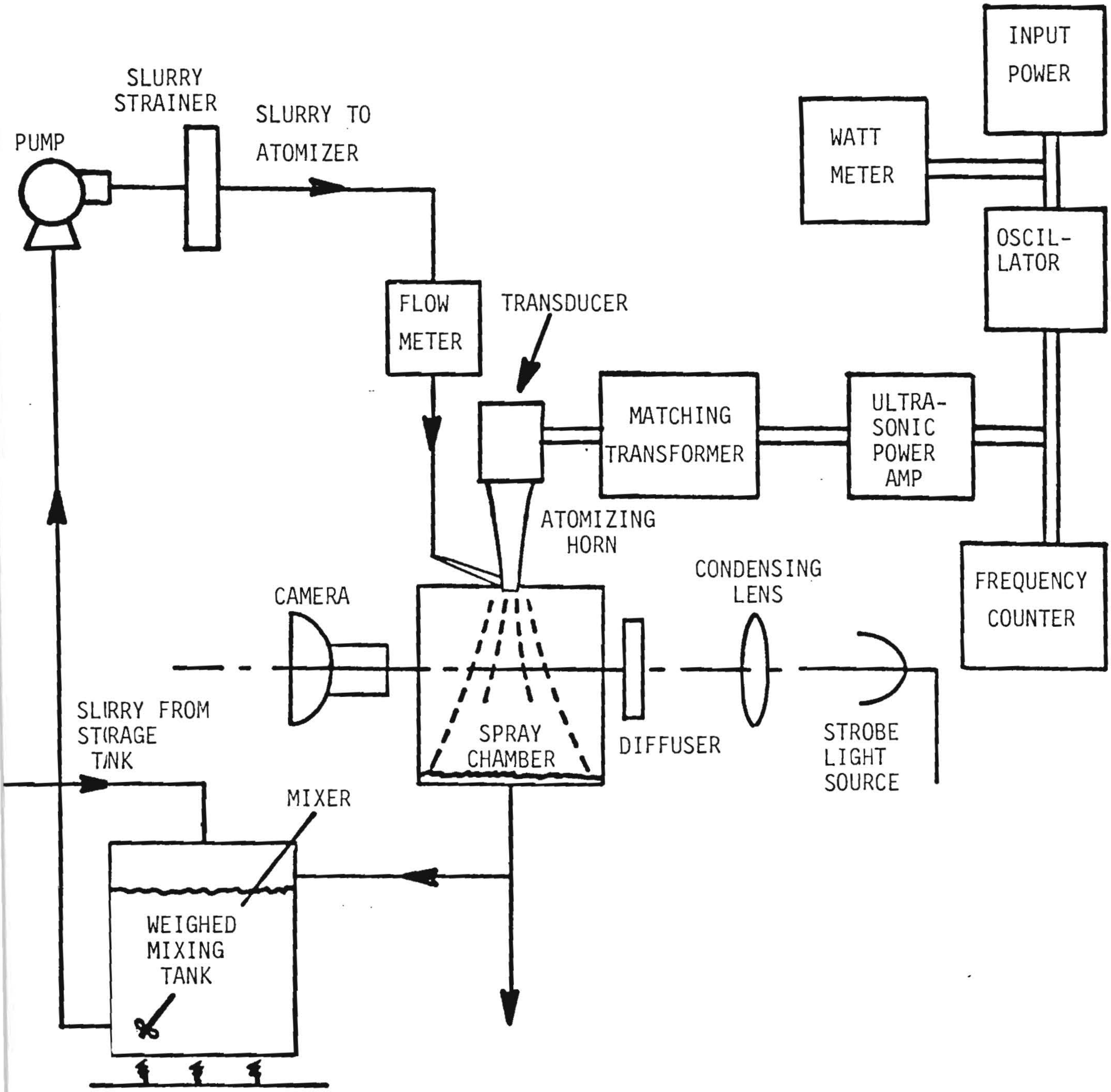


FIGURE 2: EXPERIMENTAL APPARATUS

frequency counter and a watt meter are provided to monitor the operating conditions.

With the exception of the transducer, all of the acoustic equipment shown in Figure 2 is available in the acoustics laboratory at Georgia Tech. Transducers with operating characteristics suitable for this specific application will have to be obtained once the project begins.

The other major component of the atomizer is a metallic horn. The acoustic horn is a necked-down cylinder 3/4 wavelength long. This length is selected because maximum velocity occurs at 1/2 wavelength intervals beginning at 1/4 wavelength. The necked-down geometry of the horn makes it an effective mechanical transformer, and, for a given power input, the displacement of a stepped cylinder is greater than an unstepped one. The horns will have to be machined specifically for the design operating characteristics. Since a range of frequencies will be tested, several atomizer horns of different lengths corresponding to the desired wavelengths will be required.

Task 3: Atomization Experiments

The third task of the program will be atomization experiments with commercial CWM. Initial tests will be run with special formulations of relatively low-viscosity CWM; subsequent tests will use CWM procured from several commercial suppliers. The experimental program will consist of a set of tests varying the following parameters within a specified range: excitation frequency, amplitude, CWM viscosity, surface tension and flowrate.

The effects of viscosity on atomized droplets will be of particular importance because CWM viscosity is highly variable. At ambient temperatures, viscosities between 500 and 2,000 centipoise have been measured. Depending on the CWM formulation, an increase in temperature can cause either significant increases or decreases in viscosity.[6] Therefore, CWM viscosities must be carefully measured at atomization conditions.

In addition to viscosity, measurements of CWM surface tension, density and particle size distribution will be made with equipment that is available in the Georgia Tech laboratories. Ultrasonic vibration frequency, amplitude and required power imput for atomization will be monitored by the frequency counter, accelerometer, and watt meter, respectively.

A photographic system capable of resolution below 100 microns will be used to observe both the atomized droplets and the capillary wave action at the vibrating plate. Photographic equipment capable of achieving this reduction is available at Georgia Tech. Photographic recording of the events will also allow inspection of the effects caused by the presence of solid particles. The results will be examined to determine if significant separation of solid and liquid occurs when CWM droplets are ejected from the atomizer film surface.

Task 4: Data Analysis

The final task will be data analysis and reduction. Much of this task will occur concurrently with Task 3. Results of ongoing data analysis will be used to plan subsequent test runs and to design additional acoustic horns. Statistical techniques will be used to develop a relationship between mean droplet diameter and both CWM physical properties and ultrasonic frequency and amplitude, as discussed in the preceding section. The data will be used to verify the theoretical relationship between capillary wavelength and frequency, surface tension and density and to derive an empirical relationship between CWM viscosity, flowrate and amplitude.

Project Reporting

Quarterly technical progress and financial reports will be issued detailing work activities and project expenditures. A final report summarizing the technical and scientific achievements of the project will be completed. The final report will also outline the potential for subsequent work in this area.

PROJECT BUDGET

A detailed budget for each year of the proposed two year research program is shown on the following pages. High-resolution photographic equipment and the acoustic instrumentation described under Task 2 will be provided by Georgia Tech.

BUDGET

FIRST YEAR COST ESTIMATE

Salaries		$29,036
Principal Research Engineer/Scientist 0.75 Person Months FY85 @ $5,741/mo.	$ 4,306	
Senior Research Engineer/Scientist 1.00 Person Months FY85 @ $4,704/mo.	4,704	
Research Engineer/Scientist II 2.00 Person Months FY85 @ $3,645/mo.	7,290	
Research Engineer/Scientist I 2.00 Person Months FY85 @ $2,944/mo.	5,888	
Secretary 0.50 Person Months FY85 @ $1,618/mo.	809	
Graduate Research Assistant 200 Person Hours FY85 @ $12.20/hr	2,440	
Student Assistant 200 Person Hours FY85 @ $7.24/yr	1,448	
Addition for 8% FY86 Salary Increase	2,151	
Fringe Benefits		
24.3% (Excluding Student Assistants		5,588
Travel		500
Materials and Supplies		5,250
Copying, printing and other Supplies	250	
Miscellaneous Equipment	5,000	
Equipment		$15,000
Total Direct		$55,374
Overhead		$22,327
55.3% of Modified Total Direct		
Total Project		$77,701

BUDGET

SECOND YEAR COST ESTIMATE

Salaries		$28,815
Principal Research Engineer/Scientist 0.75 Person Months FY85 @ $5,741/mo.	$4,306	
Senior Research Engineer/Scientist 1.00 Person Month FY85 @ $4,704/mo.	4,704	
Research Engineer/Scientist II 2.00 Person Months FY85 @ $3,645/mo.	7,290	
Research Engineer/Scientist I 2.00 Person Month FY85 @ $2,944/mo	5,888	
Secretary 0.50 Person Months FY85 @ $1,618/mo	809	
Graduate Research Assistant 200 Person Hours FY85 @ $12.20/hr.	2,440	
Student Assistant 150 Person Hours FY85 @ $7.24/hr	1,086	
Addition for 8% FY87 Salary Increase	2,292	
Fringe Benefits		
24.3% (Excluding Student Assistants)		5,588
Travel		500
Materials and Supplies		500
Copying, printing and other supplies		
Total Direct		$35,403
Overhead		$19,578
55.3% of Modified Total Direct		
Total Project		$54,981

FEDERAL ASSISTANCE BUDGET INFORMATION FORM

FORM EIA-459C
(10/80)

FORM APPROVED
OMB No. 1900-0127

1. Program/Project Identification No.

2. Program/Project Title: Support of Advanced Coal Research at U.S. Colleg[es] and Universities

3. Name and Address: Georgia Tech Research Corporation, Centennial Research Building, Georgia Institute of Technology, Atlanta, Georgia 30332

4. Program/Project Start Date: 9/15/85

5. Completion Date: 9-14-87

SECTION A - BUDGET SUMMARY

Grant Program, Function or Activity (a)	Federal Catalog No. (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1.		$	$	$132,682	$ -0-	$132,682
2.						
3.						
4						
5. TOTALS		$	$	$ 132,682	$ -0-	$ 132,682

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	Grant Program, Function or Activity (1)	(2)	(3)	(4)	Total (5)
a. Personnel	$ 29,036	$ 28,815	$	$	$ 57,851
b. Fringe Benefits	5,588	5,588			11,176
c. Travel	500	500			1,000
d. Equipment	15,000	- 0 -			15,000
e. Supplies	5,250	500			5,750
f. Contractual	- 0 -	- 0 -			- 0 -
g. Construction	- 0 -	- 0 -			- 0 -
h. Other	- 0 -	- 0 -			- 0 -
i. Total Direct Charges	55,374	35,403			90,777
j. Indirect Charges	22,327	19,578			41,905
k. TOTALS	$ 77,701	$ 54,981	$	$	$132,682
7. Program Income	$ - 0 -	$ - 0 -	$	$	$ - 0 -

[No]te: The fringe benefit and overhead rates used above were approved by the Office of Naval Research for the period 1 July 1984 - 30 June 1985 and are subject to change thereafter.

REFERENCES

[1]Alderman, John K., "Coal Water Mixtures for Industrial Applications," Wood and Coal for Industry's Energy Needs, Atlanta, GA, July, 1984.

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APPENDIX

PETER H. ROGERS
Professor
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

PERSONAL:

BIRTH - January 8, 1945 Married, 3 children

EDUCATION:

B.S. M.I.T., 1965 (Physics)
Ph.D. Brown University, 1970 (Physics)

EMPLOYMENT:

1. September 1983 to Present. Professor of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332.
2. September 1981 to August 1983. Underwater Acoustics Group Leader, Geophysical Sciences Division, Environmental Sciences Directorate, Office of Naval Research Arlington, VA 22217. Duties: Manage $2.5M 6.1 research program in underwater acoustics, serve as focal point within ONR for all 6.1 research in acoustics, serve as consultant in underwater acoustics to NAVELEX and ONT, carry individual research in nonlinear acoustics and bioacoustics.
3. October 1980 to August 1981. Head of Wave Effects Section, Physical Acoustics Branch, Acoustics Division, Naval Research Laboratory Washington, DC 20375. Duties: Lead a group of acoustical physicists conducting a broadbased research program in acoustics including nonlinear acoustics, fiber optic sensors, underwater anechoic materials and applied atmospheric acoustics. Also serve as consultnt in underwater acoustics to the NRL Acoustics Division and Naval Electronics Systems Command Code 612.
4. August 1975 to September 1980. Head of the Methods Section, Underwater Sound Reference Detachment, Naval Research Laboratory, Orlando, FL 32856.

Duties: Lead a team of acoustical physicists conducting basic and applied research in the theory and methodology of underwater acoustic and electroacoustic measurements, nonlinear acoustics and acoustic radiation and scattering.

5. October 1969 to August 1975. Research Physicist, Transducer Branch Acoustics Division, Naval Research Laboratory Washington, DC 20375. Duties: Research in electroacoustics, including mathematical modeling, energy conversion, radiation theory, and nonliner acoustics.

RECOGNITION:

1. NSF Trainee in Physics, Brown University
2. NRL Research Publication Award 1974, 1977, 1978
3. Member of ASA since 1970, elected Fellow 1976
4. Vice-President, FL Chapter, Acoustical Society of America 1978-1979, Pres-Elect 1979-1980.
5. Navy Superior Civilian Service Award 1979
6. A. B. Wood Award and Prize, Institute of Acoustics (U.K.) 1979
7. Acoustical Society of America, Biennial Award, April 1980
8. Navy Meritorious Civilian Service Award 1983

PUBLICATIONS, ORAL PAPERS, AND PATENTS:

Journal Articles: (Representative List)

1. P. H. Rogers, "Comments on 'Generation of Fractional Harmonics in a Resonant Ultrasonic Wave System'," JASA 52, 429-431 (1972) (L).
2. P. H. Rogers and A. O. Williams, Jr., "Acoustic Field of Circular Plane Piston in Limits of Short Wavelength or Large Radius," JASA 52, 865-870 (1972).

P. H. Rogers, "Comments on 'Scattering by Time Varying Obstacles'," Journal of Sound and Vibration 28, 764-766 (1973).

A. L. Van Buren and P. H. Rogers, "Diffraction Correction for a Circular Piston Source," Acustica 31, 45-47 (1974).

P. H. Rogers and A. L. Van Buren, "New Approach to a Constant Beamwidth Transducer," JASA 64, 38-43 (1978).

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D. H. Trivett and P. H. Rogers, "Scattering of a CW Plane-wave by a Pulse," JASA 71, 1114-1117 (1982).

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P. H. Rogers and A. L. Van Buren, "Mathematical Model for a Standing Wave Acoustic Parametric Source (SWAPS)," NRL Rpt No 7592 (1973).

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S. Hanish, B. J. King, R. V. Baier and P. H. Rogers, "Electroacoustic Modeling of Magnetostrictive Shells and Rings, Part 2: EIGSHIP Predicted Performance; Experimental Measurements and Computer Listing of EIGSHIP," NRL Rpt No 7964 (1976).

J. Gardner and P. H. Rogers, "Thermospheric Propagation of Sonic Booms from the Concorde SST," NRL Memo Rpt 3904 (1978).

r Publications Include:

P. H. Rogers, "Electroacoustics" in Encyclopedia of Physics, Van Nostrand Reinhard Co. Inc. N.Y. R. Besancon Ed. (to be published in 1984).

BIOGRAPHICAL SKETCH

, MICHAEL L.--Research Engineer II
Technology Applications Laboratory

tion

.S.M.E., Texas A&M University	1976
.M.E., Georgia Institute of Technology	1973

yment History

eorgia Institute of Technology, Research Engineer II	1979-Present
eneral Electric, Field Engineer	1977-1979
exas A&M University, Research Assistant	1975-1976
aterpillar Tractor Co., Research Engineer	1973-1975

ience Summary: Currently performing energy conservation work in the al industry area which includes food processing, apparel, printing, chemi- nd primary fabricated metal. Also involved with industrial workshop acti- s in the conservation area on subjects such as boiler efficiency vement and waste heat recovery. Worked in the Wood Energy Systems Branch ood fuel demonstration projects and feasibility studies. At General ric, worked in Installation and Service Engineering Division as borescope eer. Duties involved borescope inspections of steam and gas turbines, com- g reports on each inspection, and some development work on new inspection ment and procedures. As a graduate research assistant at the Gas Turbine of Texas A&M University, was involved in gas turbine fuel and combustion arch. Built two combustion test rigs at the Gas Turbine Lab for combustion fuel studies. At Caterpillar Tractor, entered training program which led to ssignment in the Gas Turbine Division as a research engineer. Projects uded thermal analysis of gas turbine blades and testing of ceramic turbine onents.

r Reports and Publications

THE INDUSTRIAL WOOD ENERGY HANDBOOK, Van Nostrand Reinhold Company Inc., 1984, coauthor

An Assessment of Increased Biomass Derived Energy Use in the Southeastern nited States," Final Report prepared for U.S. Dept. of Energy, Project E-AS09-81, February 1983, with B. William Riall and others

Alternate Fuel Gas Turbine Cycles," 17th Intersociety Energy Conversion ngineering Conference, 12 August 1982, Los Angeles, California, with T. F. lcGowan

'Energy Usage and Requirements in Mineral Processing," Energy Strategies for :he 80's Workshop, Georgia Mining Association, 11 February 1982, Macon, ;eorgia

'Case Study of a Commercial Small-Scale Wood-Fueled Steam Boiler for Textile ⁄lill Operations," Energy for Biomass and Wastes Symposium, January 1982, vith B. S. Dixit

'A Solid Fueled Gas Turbine Cogeneration System for the Mineral Processing Industries," Fourth World Energy Engineering Congress, October 1981, with J. :. Adams

"Feasibility Study of Waste Products Energy Conversion at Southwire Plant," Final Report, Project No. A-2705, January 1981, with P. H. Butler and others

"The Effect of Fuel Injection Angle and Pressure on Combustor Performance," M.S. Thesis, Mechanical Engineering Department, Texas A&M University, December 1976

"Liquid Fuels for Gas Turbines," First Venezuelan Symposium on Gas Turbines, April 1976, coauthor

"Rig Test of Silicon Nitride Nozzle Vanes," Gas Turbine Division Research Report, Caterpillar Tractor Co., August 1975

"Thermal Analysis of the 3500 HP Gas Turbine Nozzle and Shroud," Gas Turbine Division Research Report, Caterpillar Tractor Co., March 1975

BIOGRAPHICAL SKETCH

'AN, THOMAS F.--Senior Research Engineer
Technology Applications Laboratory

ıtion

I.Ch.E., Manhattan College, Bronx, New York	1974
;.Ch.E., Manhattan College, Bronx, New York	1972

ıyment History

;eorgia Institute of Technolgy, Senior Research Engineer, Assistant Division Chief, Wood Energy Systems Division	1978-Present
;unbelt Technology, Co-owner	1976-1977
'articulate Solid Research, Inc., Research Engineer	1971-1976

·ience Summary: Conducted numerous analyses of residential, industrial and ıced solar energy systems for heating, process energy, and synthetic fuel ıction. Also involved in numerous commercial and industrial wood combustion ›ms including the design and start-up of a one million BTU/hour wood ·ier. Other projects at Tech concern production of a manual and lecture ›s on building and marketing energy-efficient homes for builders and ·actors, and a study on reducing energy consumption and noise pollution in ite quarrying. Formed Sunbelt Technology, a consulting firm which spe- ized in energy and solar energy projects. Produced feasibility and design ies, and economic analysis, computer simulation heat transfer modeling on ve and passive solar designs. Worked in research and development of fluid- icle systems. Directed PSRI's pneumatic conveying program from its incep- , including design of test programs, data correlation, and research reports. in charge of design and installation of instrumentation and control systems gas and solids metering.

ent Fields of Interest

gy conservation and industrial alternate energy systems; passive solar gy applications; pneumatic conveying and fluidized bed operations; strial wood fuel processing systems; solid fuel fired boiler plants; design

:esting of wood gasifiers; solids handling.

;trations, Certifications, and Special Honors

;tered Professional Engineer, No. 12461, State of Georgia, 1980

'man, Georgia Solar Energy Association, Inc., (sub-chapter of International lar Energy Society), 1981, 1982

:ed Member of the Scientific Research Society of North America (Sigma Xi), 30

ıts

"Steam Injection System for Control of Wood Gasifier," Patent Pending No. 389468, filed 30 August 1982

"Air Cooled Grate and Ash Removal System for Wood Gasifier," Patent Pending No. 408,199, filed 16 August 1982

"Method of Disposal of Tar Effluent While Controlling the Operation of a Gasifier," Patent Pending No. 400658, Filed 22 July 1982

"Safety Alarm for Woodstove," Patent Pending No. 122474, Filed February 19, 1980

r Reports and Publications (Representative List)

"Economics of Solid Fuel Systems," presented at Wood and Coal for Industry's Energy Needs, July 25, 1984, Atlanta, Georgia

"Disposal of Effluents from Biomass Gasification Systems," presented at the American Chemical Society Annual Meeting, Philadelphia, Pennsylvania, August 29, 1984

"Wood Fired Boiler R&D Needs," Boiler Design Seminar, Canadian Energy Mines and Resources Department, Ottawa, Canada, April 24, 1984

"Experimental Wood Gasification for Textile Drying," 1983 Industrial Energy Conservation Technology Conference and Exhibition, 18-20 April 1983, ouston, Texas, coauthor

Utilization of Waste Streams in Biomass Gasifiers," Department of Energy hermo-Chemical Contractors Review, Atlanta, Georgia 16-17 March 1983, :oauthor

'Construction and Startup of a Wood Gasification Pilot Plant," Forest 'roducts Journal 32, No. 7, (July 1982) with A. D. Jape

'Alternate Fuel Gas Turbine Cycles," 17th Intersociety Energy Conversion :ngineering Conference, Los Angeles, California, 8-12 August 1982, with 1. L. Brown

'Wood Gasification Pilot Plant," Sixth International Industrial Wood Energy Forum, FPRS, Washington, D. C., 8-10 March 1982

"Potential Alternate Fuels and Combustion Systems," Energy Strategies for the 80's Workshop, Georgia Mining Association, Macon, Georgia, 11 February 1982

"Industrial Wood Energy Handbook," Volume III, Final Report, U.S. Department of Energy, Contract No. DE-FG05-79ET23076, December 1981, coauthor

"Production of Solid, Liquid, and Gas Fuels from Wood," ARC Wood Conference, Winston-Salem, N.C., 7-8 April 1981

"Granite Quarrying for the Monument Industry," prepared for National Science Foundation under Grant No. APR77-03288, September 1978, coauthor

"Pressure Drop in Cyclone Separators," Research Report 16, Particulate Solid Research, Inc., Bronx, New York, March 1976

"Pressure Loss in Dilute-Phase Pneumatic Transport of Ground Rutile Ore," Research Report 12, Particulate Solid Research, Inc., Bronx, New York, January 1975

ACILITIES

The project will be conducted jointly by the School of Mechanical ngineering at Georgia Tech and the Georgia Tech Research Institute. aculty members of the School of Mechanical Engineering have been ctive in transducer development in the 10 kilohertz - 10 megahertz ange. The acoustics lab has a wide variety of oscillators, mplifiers and signal generators that can be applied to this research. pecialty transducers used in the project will be procured as equired.

The Georgia Tech Research Institute has been active in solid uels applications and testing. The laboratory maintains a solid uels testing lab used to categorize fuels. Equipment to measure noisture content, proximate and ultimate analysis and heating value is available. GTRI has additional equipment that can be used to measure atomizer operating conditions. This includes two watt meters that will be used to measure atomizer power input, and accelerometers and a fast fourier transform (FFT) signal analyzer to measure nozzle displacement and frequency.

RELEVANT EXPERIENCE

Both the School of Mechanical Engineering and GTRI bring expertise important to the completion of this research. Faculty members of the School of Mechanical Engineering have wide experience in acoustics research and transducer development. Recent activities have included developing transducers for use in oil well logging and sonar applications. A 30,000 gallon acoustical tank for use in sound transmission studies is currently under construction. The tank will be equipped with dual computer controlled carriages for accurate X-Y-Z positioning and a 10 bit data acquisition system to digitize receiver signals. The Mechanical Engineering department is also currently conducting research in coal particle ignition, combustion and extinction phenomena.

The Georgia Tech Research Institute has been involved in research related to coal, biomass and solid waste fuels for many years. Recent activities include testing of process development units for both gasification and pyrolysis processes. A research-scale fuel gasification unit has been designed and operated at GTRI, and is currently being used in a research program to develop a process to destroy toxic gasifier effluents in a low cost, efficient manner. Other ongoing programs include an analysis of the application of state-of-the-art coal conversion/combustion technology and related environmental control systems to industrial-scale use. A solid fuels testing laboratory established within GTRI has supported the development of numerous ASTM test standards and provided fuel analyses for industrial sponsors.

ASSURANCE AND COMPLIANCE FORMS

U.S. Department of Energy

Assurance of Compliance

Nondiscrimination in Federally Assisted Programs

rgia Tech Rearch Corporation (Hereinafter called the "Applicant")

HEREBY AGREES to comply with Title VI of the Civil Rights Act of 1964 (Pub. L. 88-352), Section 16 of the Federal Energy Administration Act of 1974 (Pub. L. 93-275), Section 401 of the Energy Reorganization Act of 1974 (Pub. L. 93-438), Title IX of the Education Amendments of 1972, as amended, (Pub. L. 92-318, Pub. L. 93-568, and Pub. L. 94-482), Section 504 of the Rehabilitation Act of 1973 (Pub. L. 93-112), the Age Discrimination Act of 1975 (Pub. L. 94-135), Title VIII of the Civil Rights Act of 1968 (Pub. L. 90-284), the Department of Energy Organization Act of 1977 (Pub. L. 95-91), and the Energy Conservation and Production Act of 1976, as amended, (Pub. L. 94-385). In accordance with the above laws and regulations issued pursuant thereto, the Applicant agrees to assure that no person in the United States shall, on the ground of race, color, national origin, sex, age, or handicap, be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity in which the Applicant receives Federal assistance from the Department of Energy.

Applicability and Period of Obligation

In the case of any service, financial aid, covered employment, equipment, property, or structure provided, leased, or improved with Federal assistance extended to the Applicant by the Department of Energy, this assurance obligates the Applicant for the period during which Federal assistance is extended. In the case of any transfer of such service, financial aid, equipment, property, or structure, this assurance obligates the transferee for the period during which Federal assistance is extended. If any personal property is so provided, this assurance obligates the Applicant for the period during which it retains ownership or possession of the property. In all other cases, this assurance obligates the Applicant for the period during which the Federal assistance is extended to the Applicant by the Department of Energy.

Employment Practices

Where a primary objective of the Federal assistance is to provide employment or where the Applicant's employment practices affect the delivery of services in programs or activities resulting from Federal assistance extended by the Department, the Applicant agrees not to discriminate on the ground of race, color, national origin, sex, age, or handicap, in its employment practices. Such employment practices may include, but are not limited to, recruitment, recruitment advertising, hiring, layoff or termination, promotion, demotion, transfer, rates of pay, training and participation in upward mobility programs, or other forms of compensation and use of facilities.

iis assurance is given in consideration of and for the purpose of
)taining any and all Federal grants, loans, contracts (excluding pro-
irement contracts), property, discounts or other Federal assistance
<tended after the date hereto, to the Applicant by the Department of
iergy, including installment payments on account after such date of
)plication for Federal assistance which are approved before such date.
ie Applicant recognizes and agrees that such Federal assistance will be
<tended in reliance upon the representations and agreements made in
iis assurance and that the United States shall have the right to seek
udicial enforcement of this assurance. This assurance is binding on
he Applicant, its successors, transferees, and assignees, as well as
he person whose signature appears below and who is authorized to sign
his assurance on behalf of the Applicant.

February 27, 1985
(Date)

Georgia Tech Research Corporation
(Name of Applicant)

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