**PARTICULATE BEHAVIOR IN A CONTROLLED-PROFILE PULVERIZED COAL-FIRED
REACTOR: A STUDY OF COUPLED TURBULENT PARTICLE DISPERSION AND
THERMAL RADIATION TRANSPORT**

Quarterly Technical Progress Report

For Period June 15, 1992 to September 14, 1992

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FORWARD

This report summarizes technical progress during the fourth quarter (June 15, 1992 to September 14, 1992) of a three-year study conducted for the Department of Energy (DOE) under contract number DE-FG22-91PC91308. The principal investigators for this work are Dr. Mardson Queiroz and Dr. Brent W. Webb; Dr. Clifford Smith is the technical representative for DOE.

TABLE OF CONTENTS

	PAGE
DISCLAIMER	I
FORWARD	II
ABSTRACT	IV
1. OBJECTIVES AND SCOPE	1
1.1 BACKGROUND	1
1.2 OBJECTIVES	1
1.3 TECHNICAL APPROACH	1
2. SUMMARY OF TECHNICAL PROGRESS	2
2.1 REACTOR REFURBISHMENT	2
2.2 TRANSMISSOMETER DEVELOPMENT	2
2.3 RADIATION AND PARTICLE DISPERSION MODELLING	3
3. REFERENCES	3
4. APPENDIX	4

ABSTRACT

During the fourth quarter progress has been made in the following areas: preparation for reactor refurbishment, instrumentation development, coal acquisition for experimental tests, and radiation and particle dispersion modelling. Refurbishment of the Controlled Profile Reactor was initiated this summer and is almost finished. Construction work for the local transmissometer probe is now completed. This laser-based instrument, combined with the data from the PCSV probe will enable estimate of the local concentration of particulates below $0.5\text{ }\mu\text{m}$ in size. Additionally, it will permit measurement of the temporal statistics of the local particulate number density.

1. OBJECTIVES AND SCOPE

1.1 BACKGROUND

Improved understanding of the fundamental processes involved in pulverized-coal combustion is needed to make the energy extraction more efficient and the combustion byproducts environmentally safe. While the characterization of the local particulate behavior (concentration, size, and velocity) is important to the understanding of virtually all processes in a pulverized coal-fired furnace, it influences in a more direct way the turbulent particle dispersion and thermal radiation heat transfer. Yet the local particulate dynamics have gone relatively unaddressed, primarily because of lack of adequate instrumentation to carry out such a study. With recent advances in optical techniques such an effort is now possible. This proposal seeks to characterize the local particulate concentration, velocity, and size distribution in a well-controlled, parametrically-varied laboratory-scale reactor using a new laser diagnostic technique. This newly-developed technique is the only one currently available for the investigation of aspherical particles. The particulate data will be collected simultaneously with local gas temperature and wall radiant heat flux distributions.

1.2 OBJECTIVES

This report describes recent progress in a fundamental, three-year investigation of the coupled problem of turbulent particle dispersion and thermal radiation transport. The project's objective is to make measurements of particle size, velocity, number density, temperature and wall radiant heat flux in a parametrically-controlled reactor presently existent at Brigham Young University (BYU). Although the study proposed here is primarily designed to provide experimental data not currently available for the evaluation of turbulent particle dispersion and radiation models, comparisons of analytical predictions and the experimental data obtained will be performed, using appropriate submodels integral to comprehensive pulverized-coal combustion codes existent at BYU.

1.3 TECHNICAL APPROACH

To accomplish the above objectives, the project is divided in the following tasks:

- Design and fabrication of a modified section for the BYU controlled-profile reactor, which will allow access of several probes to be used in the proposed study.
- Design and fabrication of a two-color pyrometer and cooled probe for local particulate temperature measurement.
- Characterization of the non-reacting turbulent flow field in the reactor using the PCSV-P probe, which will serve as an input during the turbulent particle dispersion submodel validation.
- Literature review dealing with particle dispersion and radiation transport in support of the model validation effort.

- Perform the parametrically-controlled measurements in the controlled-profile reactor.
- Experimental data analysis.
- A comprehensive comparison of experimental data and model predictions.
- Final report.

2. SUMMARY OF TECHNICAL PROGRESS

2.1 REACTOR REFURBISHMENT

During the fall of 1992 the controlled profile reactor (CPR) will undergo work to improve flame axisymmetry, coal feed rates, and reactor wall isothermality. New temperature data acquisition boards have been installed that allow sampling and multiplexing of 115 type K thermocouples which are potted at varying depths and positions on the reactor. Reactor wall temperatures, air flow rates, and coal feed rates will be acquired by a single Macintosh II computer running National Instruments' LabVIEW software package and utilizing 16-bit A/D boards for all signal sampling. Twin Acrison auger feeders, rotating 180° out of phase to minimize pulsing, deliver the pulverized coal, and dual load cells are multiply sampled and averaged every 40 seconds for feed rate calculations. Closed-loop control of coal feed rates and wall heater power will aid in maintaining uniform conditions over a given test period. Work is currently in progress to eliminate flame asymmetries thought to be caused by swirl generation at the reactor inlet. Testing will begin after initial runs are made to determine the factors necessary in maintaining stable test conditions.

2.2 TRANSMISSOMETER DEVELOPMENT

Figure 1 shows the design of a transmissometer probe to be used in combination with the Insittec Particle Concentration, Size, and Velocity (PCSV) instrument in resolving particle number densities below the 1 μm lower bound of the PCSV. The probe measures transmission along the beam path and uses a reference signal detector to minimize errors resulting from laser beam intensity drift. The double pass of the beam through the diagnostic volume increases the signal-to-noise ratio and allows the two temperature-sensitive detectors to be placed near each other to minimize temperature differences between them. Data acquisition is accomplished by simultaneous sample-and-hold of the two detector signals through a 12-bit National Instruments A/D board at a user-defined sampling frequency. The acquired transmission data will be used in Beer's Law and in combination with number density data gathered with the PCSV instrument to infer a sub-micron number density distribution. Emission and absorption properties of the measured particles for use in Beer's Law are derived using Mie particle light scattering theory.

Figure 1. Schematic of transmissometer probe.

2.3 RADIATION AND PARTICLE DISPERSION MODELLING

In the radiation modelling, a two-dimensional, axisymmetric discrete ordinates code for the solution of the Radiative Transfer Equation has been written, and predictions have been compared with published benchmarks. The comparisons reveal good agreement with previously reported predictions. Under separate funding, work has begun in the formulation of suitable particle and gas radiation properties for input to the code. A new spectral gas phase radiative property model is being developed that is suitable for use in complex geometries and multidimensional systems. The spectral gas model is being formulated so as to be compatible with continuum radiation properties of non-gray particulates and boundary conditions.

In particle dispersion modelling, the primary objective is to evaluate the performance of the turbulent particle dispersion sub-model incorporated in PCGC-2. The unique feature of this study is that the code predictions will be obtained for a swirling pulverized coal (particle laden) flame with the solution of the gas energy equation. Also this is the first attempt in which direct comparison of the particle dispersion statistics will be made with experimental data obtained with a recently developed laser-based diagnostic technique. The input data files required to simulate the CPR geometry on PCGC-2 have been constructed. The initial grid designed used had a total of 38 axial nodes with 4 of them inside the quarl region. The details of this grid are presented in Table 1. The results obtained with this grid showed erroneous flow field structure with flow along the reactor west wall. After a series of different runs it was found that the flow field predictions were sensitive to the grid arrangement inside and just outside the quarl region. A high density grid near the reactor quarl was required to resolve the flow structure in that region. The final 55x49 grid parameters which evolved after numerous trials are also presented in Table 1. This grid is believed to be the smallest grid which subjected to further refinement did not change the flow field structure. This grid had 20 grid points inside the quarl in contrast to only 4 in the initial grid design. Also the parameter EPSX, which is the ratio of cell sizes in axial direction, had to be decreased from the

initial value of 1.1 to 1.05 in order to have a finer grid just outside of the quarl region. The predictions were very sensitive to this parameter (EPSX) as it defined the difference between the last grid inside the quarl and the first one in the region outside the quarl.

Table 1. Grid parameters.

Parameter	Definition	Initial values	Final values
NJINS	Number of grid points in the radial direction in the secondary stream	7	9
EPSI	Ratio of cell increase in the radial direction	1.145	1.1
EPSD	Ratio of cell size decrease in radial direction	0.9	0.9
NIINQ	Number of axial grid points in the quarl region	4	20
EPSX	Ratio of cell sites in axial direction	1.10	1.05
NIWOQ	Number of grid points in the axial direction without quarl	34	35

4. REFERENCES

Bonin, M.P. (1992). "Optical Measurement of Particle Size, Velocity and Number Density in Pulverized Coal Flames," Ph.D. Dissertation, Mechanical Engineering Department, Brigham Young University.

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