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PROJECT TITLE: Impact of Nonequilibrium Particle Temperature Considerations on Seeded Coal Combustion Plasma Properties

PRINCIPAL INVESTIGATOR: Dr. A.A. Oni
INSTITUTION: School of Engineering Morgan State University Baltimore, MD. 21239

CONTRACT SPECIALIST: Ms. Rhonda Dupree PETC; MS 921-165

TECHNICAL OFFICER: Dr. Harold Chambers PETC; MS 922-

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MASTER
THE RESEARCH TEAM:

1. Dr. Adeboyejo A. Oni, Principal Investigator
   Assistant Professor of Engineering and Applied Science
   Morgan State University, Baltimore, Maryland.

2. Mr. Feng Lin, Graduate Research Assistant
   Ph.D Student in Mechanical Engineering (Thermofluids)
   University of Maryland Baltimore County Campus
   Catonsville, Maryland.

3. Ms. Kimberly Myles, Undergraduate Research Assistant
   Senior Industrial Engineering student
   Morgan State University, Baltimore, Maryland.

4. Dr. Wolfgang Richter, Consultant on Gas-Particle Flows
   26251 Yolanda Street
   Laguna Hills, CA. 92656

5. Dr. Robin Kinosah, Consultant on Chemical Equilibrium Combustion
   Diversified Technologies Inc.
   551 Larimar Ave
   P.O. Box 5297
   Pittsburgh, PA. 15206

ABSTRACT

The main purpose of this research is to investigate the impact of nonequilibrium temperatures of the post-combustion entrained particles on the generator-bound combustion plasma properties and consequently on the overall performance of the MHD channels for both Linear and Disk configurations in the typical coal-fired MHD environment.

Aiming at this purpose, three major tasks should be completed within the 2-year period of grant. The first task is to establish a simulation model to present the steady state, non-equilibrium interactions between the post-combustion entrained particles and their carrier gases. The second task is to predict the overall performance of the MHD channels for both Linear and Disk configurations with the available fully-developed non-equilibrium simulation model. The third task is to evaluate the relative impact of gas-particle temperature difference on generator slag phenomena as well as MHD overall performance.

This past quarter, the linear MHD channel simulation model has been completely specified and partially modified to incorporate considerations for nonequilibrium particle
temperatures. Testing of the modified model with the initial values from the first submodel (Richter's combustion zone model) and evaluation of the non-equilibrium particle temperature effect on the overall MHD performance is currently ongoing.

INTRODUCTION:

By the end of June of this year, two major programs, MHD Linear and Disk Fortran programs which were originally run on the VAX machine, had been successfully converted to the MS-DOS environment on IBM PCs. The CEC code (Chemical Combustion Equilibrium) was also successfully installed on the school computer system to produce the state parameter values for the MHD channel without consideration for gas particle temperature differences. Both MHD Linear and Disk programs were verified with the aid of output data from the CEC code runs.

In order to incorporate temperature differences between particles and gases into the existing MHD simulation models, two submodels under the first task should be developed. The first submodel is a modified Richter's Combustion Zone model which has been successfully used to evaluate the nonequilibrium particle temperature effect on boiler furnace performance. The second submodel is a modification of the current Burns and Roe/SAIC linear channel and disk generator simulation models.

During the last three months, great effort was made on specifying and modifying the MHD linear channel program as well as establishing a fully-developed, steady state, nonequilibrium simulation model by the linkage of the two submodels as proposed.

QUARTER RESEARCH ACTIVITIES:

On the basis of previous work, four major accomplishments were achieved over the last two quarters.

1. All the equations, expressions and formulas used in the original MHD linear channel program were specified under the assumptions of one-dimensional, steady state, steady flow conditions. Since the original Fortran code has been used by a lot of people in different ways, some modifications together with mistakes might be introduced in various situations. Thus it becomes necessary to specify all the possible sources of those equations in the current code. Particularly, some discrepancies in some of the governing equations were picked out and corrected. Some empirical or semi-empirical formulas were replaced by more reasonable ones, as perceived from our extensive literature reviews.

In the original code, the particles and gases are assumed to be one continuum at the same temperature and same velocity. Thus, there had been no consideration for mass, momentum and heat transfer between particles and gases. These original-code equations, expressions and formulas describe the gaseous,
thermodynamic and electrical properties of the particle-laden plasma. Specific properties include velocity, temperature, pressure, Mach number, gas viscosity, gas Prandtl number, enthalpy, Hall parameter, Hall field, electrical conductivity, current density, electric power density (in the segmented Faraday type generator with high inlet temperature (2100 K-2600 K) and high velocity (Mach # = 0.9)).

The sources of these equations, expressions and formulas as well as their validation ranges were carefully determined through extensive literature studies (Appendix I).

2. A flow chart for the original linear channel code was developed by means of a flow-charting software. In the original Fortran code, a three-step Runge-Kutta method was used to calculate the plasma properties at the different cross-sections in the MHD channel with a total length of about 12 meters. The inlet parameter values of the channel were obtained by interpolating those properties at given temperature and pressure with subroutine Interpol and CEC output thermodynamic tables.

The flow chart (Appendix II) gives a clear outline or structure of both the main program and subroutines. With this flow chart, the large program was easy to analyze and modify.

3. Dr. Richter, one of the project consultants, is expected to provide a combustion performance table by the end of the fourth quarter. This table will provide combustor outlet values for gas temperature, particle temperature, particle sizes, particles densities, particle concentration, CO/CO₂ concentration, outlet pressure, particle molecular weight and particle constant pressure specific heat over the gas temperature range of 1000K-3000K, gas pressure range of 0.5-10atm, particle size range of 1um-100um, particle concentration range of 0.1-5% and CO/CO₂ concentration range of 100%/0-0/100%.

4. In order to obtain the second submodel, it is necessary to deal with particles and gases as separate phases in the MHD channel. The mass transfer, momentum transfer and heat transfer between the particulate phase and the gaseous phase were considered, although the interactions between particles were neglected due to the fact that the concentration of particles is usually within the mass ratio ranges of from 1% to 5%. Under the assumptions of one-dimensional, steady state and two-phase flow, three classifications of equations were written out for the nonequilibrium simulation model (Appendix III):

i) Governing equations for the gaseous phase: Gaseous combustion products such as CO, CO₂ or NOₓ are taken as one component, and only the mixture properties of the gaseous phase was considered here. The plasma properties are strongly dependent on the temperature of the gaseous phase
which are expected to be affected by the temperature of particles to some extent. The momentum and heat transfer between two phases are reflected in those modified equations.

ii) Governing equations for the particulate phase: There are mainly four different kinds of particles in the particulate phase: unburnt char, burnt char, ash and seed. These particles may be regarded as one component, described by similar characteristics of size, spherical shape, and temperature, with different types of particles displaying different physical properties. For example, the temperature of radiant chars is higher than that of the gaseous phase and thus the radiation effect becomes significant. The temperature of the added seed is usually lower than that of the carrier gases. Thus, radiation effects may be neglected, while contributions to the plasma electrical conductivities assumes major importance. The characteristics of these different types of particles are treated in present equations. The interactions between particles were neglected due to the small concentration of particles.

iii) Governing equations for the gas-particle continuum. In these equations, the total mass transfer, momentum transfer and heat transfer were considered in a selected control volume.

These equations will be introduced to the Burns and Roe/SAIC linear channel program, to obtain the second submodel which will then be used to evaluate the nonequilibrium particle temperature effect on the thermo-fluid dynamic and electrical properties of the plasma. Inlet plasma parameter values for the MHD channel will be obtained from the first submodel-modified Richter’s combustion zone model.

PREVIEW OF FIFTH QUARTER ACTIVITIES:

This quarter, we will attempt to do the following:

1. Run the modified linear channel code (the second sub-model) with input parameters as generated by the modified Richter code (the first sub-model). Output channel performance data will then be compared with previous predictions.

2. Begin the modification of the disk code. Next will be a similar development with the disk channel. Both modeling systems will be thoroughly tested for their robustness, i.e. their sensitivities to input parameter changes, and their conformance to experimental estimations, as discussed in the proposal for this study.