TITLE: **DEVELOPMENT OF A NOVEL RADIATIVELY /CONDUCTIVELY STABILIZED BURNER FOR SIGNIFICANT REDUCTION OF NO_X EMISSIONS AND FOR ADVANCING THE MODELING AND UNDERSTANDING OF PULVERIZED COAL COMBUSTION AND EMISSIONS**

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ABSTRACT

OBJECTIVE

The primary objective of the proposed study is the rigorous modeling, analysis, experimental exploration, and validation, and design recommendations for a novel radiatively-conductively stabilized combustion (RCSC) process for pulverized coal, which, based on our prior studies with both fluid fuels and pulverized coal, holds a high promise to reduce NO_x production significantly. The unique suitability of this type of burner for the experimental study of coal particle combustion in general would also be exploited for additional fundamental studies of the highly promising combustor.

ACCOMPLISHMENTS TO DATE

We have primarily engaged in continuing our process modeling and analysis, and making preparations for the experimental work. The accomplishments highlights are:

- The older 3-layer simplistic turbulent flow model was replaced by an advanced k-ε model.
- The kinetic description of the major reactions was improved and their role was better clarified. The improvement includes a better computational method for this very stiff differential equation system.
- Using the numerical model, the effects of changing the combustor wall conductivity, thickness and emittance, the flame location, the fuel-air ratio, and the extent of fuel-air mixture preheating, on NO_x emissions, was studied. A major conclusion was that the ability of the RCSC to produce thin flames has a stronger effect on reducing NOx emissions than some lower temperature combustion alternatives, such as the reduction of flame temperature by decreasing the fuel-air ratio. Preheating was found to reduce NO_x emissions by about 14%.
- The previous uniform particle distribution model was replaced by the Probabilistic Formation method to estimate the particle distribution in RCSC tube. It makes use of a probability density function (PDF) to characterize the distribution of particles in the continuous phase. Rather than the continuous distribution of the Eulerian approach, or the collection of discrete trajectories in the Lagrangian approach, in the probabilistic approach the particle transport is characterized as a cloud with particle properties distributed through the cloud on the basis of PDF. Adaptation of the approach to a gas flow-field simulation based on the k-e

turbulence model, called the stochastic transport of particles (STP) model, developed by Baxter and Smith (Energy & Fuel 1993, 7, p852-859) was further adapted to the RCSC combustor The STP model with a single point source was expanded for use in our research by assuming that the entire flow of particles is composed of a large number of uniformly distributed point sources at the RCSC inlet, also assuming that there is no interaction among these point sources since the gas-solid flow is sparse. The particle concentrations from each point source are computed and then these concentrations are combined to get the total particle concentration distribution. At the combustor wall we assume that the particles that the model predicts would exist beyond the wall will be "absorbed" by the wall and flow along it in the axial direction. This permits the calculation of the particle concentration near the wall.

- Some interesting conclusions from this model are (1) that direction of the coal particles towards the wall improves the heat transfer by convection between the wall and flow, and the particles would this be preheated and ignited in a shorter time and travel distance, thus also helping stabilize the flame, especially during ignition, (2) in particular, we found that control of upstream heat transfer and particle concentration may be better for flame stabilization than manipulation of the flame position, as we have done so far, and (3) an explanation of the experimentally observed slagging near the combustor exit: based on our computations, the downstream wall temperature can reach the hemispherical and fluid temperature of ash. The ash particles there will therefore deform and melt, and, as observed, stick to the wall. Because of high particle concentration near the wall, slagging develops quickly. This has also allowed a proposal for a modified configuration of the RCSC that would reduce slagging.
- An exergy analysis capability was added to our model. It allows the computation of the total exergy as well as the exergy components distributions in the RCSC. This information is very important for fundamental understanding of the process with aim to minimize exergy destruction and ultimately increase the power production effectiveness of combustors. One of the results obtained is that 70% of the original coal exergy emerges with the hot gas, with 30% lost due to the combustion process. This loss is somewhat lower than that experienced in conventional boilers, where about 40% of the exergy is lost in the combustion furnace.
- Preparation of the experimental facility continued, including the design and incorporation of a computer-aided data acquisition system.
- Initial estimates have been made of the configuration needed for a commercial/industrial RCSC.

Encouraged by the FETC project monitor, Dr. Philip Goldberg, we have made contacts with the two other groups engaged in DOE funded research on reducing NO_x emissions in coal combustion (Prof. Wendt, U. of Arizona with Prof. Sinclair, Purdue U., and Profs. Pershing, Lighty and Sarofim, U. of Utah) to explore ways of cooperation in this work. We have agreed among us on several specific cooperative efforts, as well as on continued communications for extending this cooperation as the projects develop.

SIGNIFICANCE TO FOSSIL ENERGY PROGRAMS

The national goal expressed by the USDOE is to reduce NO_x and SO_x emissions in coal plants by at least an order of magnitude by the year 2030, and at least by four-fold by 2005. The NOx emissions, currently at several hundred ppm, should be reduced to single-digit levels. Using fluid fuels, the RCSC has been proven in the laboratory to indeed produce NO_x at levels below 10 ppm Using coal, our analysis and experiments conducted so far indicate that this novel approach to combustion is highly likely to reduce NO_x levels significantly.

PLANS FOR THE COMING YEAR

- To complete the modifications and improvements of the RCSC model so that it represents particle motions and the reaction kinetics better
- To conduct validation experiments
- To assess several promising further improvements in the RCSC, including staged combustion, enhanced upstream heat transfer for better preheat and flame stabilization, and NH_3 injection.
- To produce the design and optimized configuration of a commercial/industrial version of this RCSC combustor.

ARTICLES, PRESENTATIONS, AND STUDENT SUPPORT

Publications

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Presentations

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N. Lior, "Radiatively-conductively stabilized combustion for reducing NOx emissions", Luleå University of Technology, Sweden, 1998

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N. Lior, "Some advances in energy conversion to power", University of Lund, Sweden, 1998

N. Lior, "Radiatively-conductively stabilized combustion and its effects on reducing NOx emissions", Chalmers University of Technology, Sweden, 1998

S. W. Churchill, "Some projections on energy technology" RAN Conference on Energy and Environment for the 21st Century", Nagoya University, , Nagoya, Japan, 2000

S.W. Churchill, "Thermally stabilized combustion - flow, heat transfer, and chemical kinetics in the fast lane" Academy of Chemical Engineers Lectureship, U. Missouri, Rolla, 2000.

Students, **Supported under This Grant**

Fanfan Xiong, graduate (Ph.D.) student at the University of Pennsylvania
Mary Connaghan undergraduate student at the University of Pennsylvania (work-study student)
Joe Corcoran, undergraduate student at the University of Pennsylvania (graduated)