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TEMPERATURE, VELOCITY AND SPECIES PROFILE MEASUREMENTS FOR REBURNING IN A PULVERIZED, ENTRAINED FLOW, COAL COMBUSTOR

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Executive Summary

Data for mean velocity and temperature have been obtained over a baseline matrix of operating conditions for pulverized coal without reburning. The data show the reactor to be symmetrical about the axial centerline. Effluent NO_x data have been seen to correlate with measured and modeled results of flow patterns within the reactor. At low swirl the fuel jet creates a downward flow at the centerline with some upward recirculation at the perimeter of the reactor near the walls. This recirculation pattern reverses as swirl is increased, changing the flame from a long toroidal shape to a flat annulus. The NO_x data show a local minimum at a swirl number of 1.0 which may be primarily the result of the direction and magnitude of the recirculation zone. Gas species and coal char burnout data have begun but have not yet been completed. Velocity data and modeling results have been used in the process of validating the comprehensive combustion code and in designing the reburning hardware. The details concerning storing and delivering the reburning fuel (natural gas) have been completed and the fabrication of the hardware is underway.

1. Introduction

A baseline map of species, temperature and velocity is almost completed for the reactor studying the baseline coal condition without reburning. The responsibilities for obtaining this data have been shared between the graduate students. Other responsibilities including reburning design and fabrication, LDA velocity measurements and comprehensive combustion modeling have been divided as outline in the last semi-anual report. Results from the baseline test data will be summarized followed by progress reports in each of the other areas. Most of the results are incomplete at this point and therefore conclusions from the data are tentative. The reburning apparatus should be completed in June. Baseline reactor studies should be completed in May and some reburning results are anticipated by the end of the summer.

2. Baseline Data

The majority of last year's efforts have been in obtaining a baseline map of temperature, velocity, and gas species data. This information is to be used in model comparison and refinement, reburning design, and for comparison to results with a reburning section added. The progress in these areas to date is summarized in Table 1 where and "X" denotes data which has been obtained.

TABLE 1. Summary of Reactor Data taken to date.

	Swirl = 0.	Swirl = .25	Swirl = 0.5	Swirl = 1.0	Swirl = 1.5
Temperature Symmetry	X	X	X	X	X
Temperature Profile	X	X			X
Mean Velocity	X	X	X	X	X
Turbulent Velocity					
Species Profile			X		
Effluent Species	X	X	X	X	X

Temperature measurements taken with a shielded suction pyrometer have given useful information about flame shape and penetration. Measurements from the same axial level but different sides of the reactor have shown flame symmetry at different swirl settings. Fig. 1 shows temperature profiles 0.5 m below the coal outlet demonstrating the symmetry obtained. The direction given on the figure refers to the direction of the window in each of the four quadrants of the reactor. In general, as swirl is increased, the temperature profile becomes more flat across radial profiles and cools slightly in the center. Axial temperature profiles show a decrease in temperature with axial distance, as expected. Temperature results have shown that an increase in swirl tends to push the flame out radially and up closer to the burner.

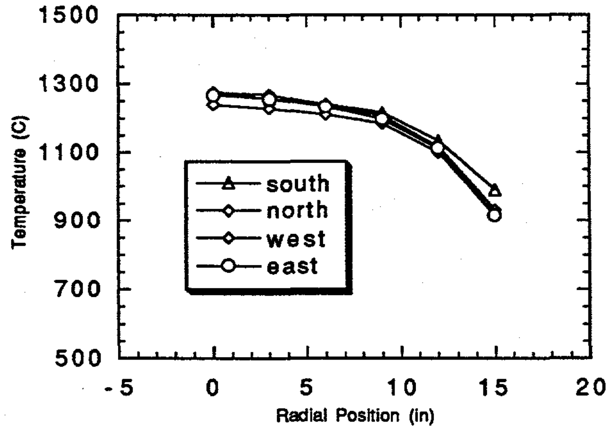


Figure 1. Temperature Results at 0 Swirl Number, 12 in below burner.

Mean velocity measurements have also been completed at several swirl settings. Figure 2 shows axial velocity measurements taken 2 cm below the quarl outlet and 0.26 meters below the primary cole feed inlet. The figure indicates a fairly symmetrical flame and shows a sharp decrease in axial velocity as swirl is increased. The reduced velocities in the middle region measured in the higher swirl cases may indicate the formation of a central recirculation zone. Turbulence velocity information made with LDA has not been gathered but the seeding apparatus and optical mounts have been designed and fabricated. Average and turbulent velocity information is expected to be useful in evaluation of flow field predictions which seriously affect other combustion parameters.

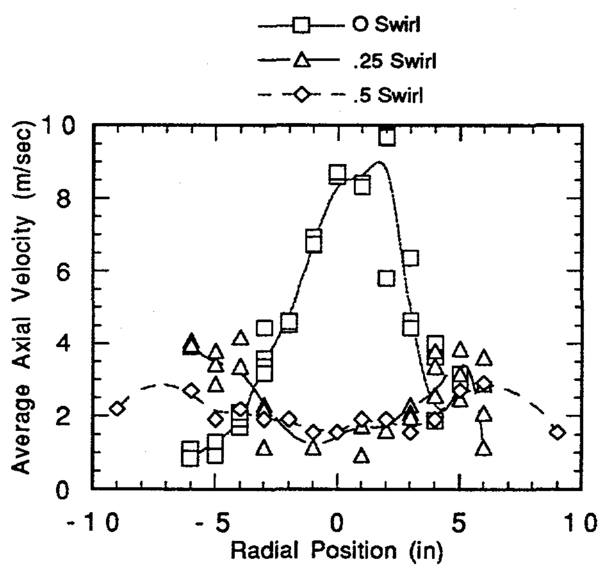


Figure 2. Average Axial Velocity 3 in from Burner.

Gas species profile information is still needed, but effluent species measurements have been made. Figure 4 shows NO_x measurements at several swirl settings. The figure shows that NO_x is maximum at low swirl numbers, then decreases, and begins to climb again as swirl is increased. It is thought that at low swirl numbers, the air and fuel are mixing enough for the formation of large amounts of fuel NO_x. Then as swirl increases, the air is pushed outward radially, which preserves a fuel rich region in the center and reduces the NO_x. This theory ot the flame shape is supported by the velocity measurements of Fig. 2. Finally, as swirl continues to increase, the more turbulent air stream begins to have a secondary mixing effect and NO_x increases. Species profile maps will help to bring further insight into this phenomenon.

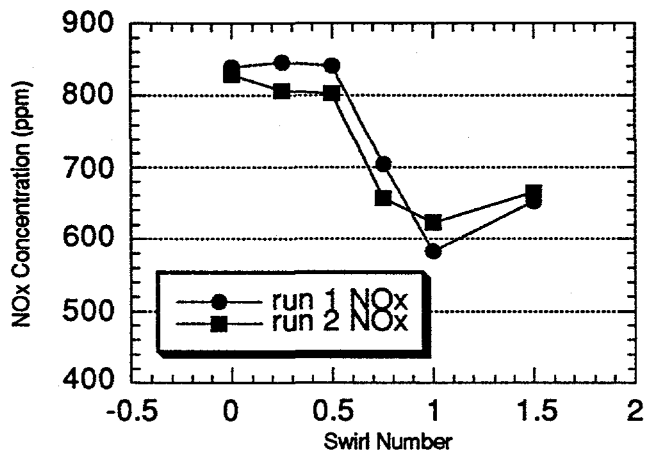


Fig. 4 Effluent NO_x Concentration as influenced by burner swirl number.

5. Model Predictions and Comparisons

The controlled profile reactor (CPR) has been modeled at 5 different conditions corresponding to incoming velocity profiles representative of 0, 0.25, 0.5, 1.0, and 1.5 swirl numbers. Two initial difficulties encountered in modeling of the CPR, defining good convergence criteria and grid independence, have been investigated and are being addressed.

Defining good convergence criteria for these cases was a crucial preliminary step. Reduction in the numerical residuals in and of itself was found to be insufficient to define convergence. Monitoring of key parameters (e.g. wall radiation terms, burnout, mass balance, energy balance) as a function of iteration now provides improved convergence criteria. Plots of these parameters as well as residual information are now monitored over the iteration history of each solution.

Matching the velocity data is the first step in getting a good model of the CPR. The completed solutions from PCGC-3 to date indicate that as the swirl number changes the flow field characteristics change quite dramatically, which can be seen by comparing the velocity vector plots of Fig 5. For both cases the flow is from left to right with the centerline being the bottom of the plots. Only the top half of the CPR is shown in both plots. The 0 swirl case is indicative of the low swirl cases (0 and 0.25). The flow comes down the center then recirculates up the outside wall, with the recirculation zone persisting to about the halfway point (axially) of the reactor. As the swirl increases to higher numbers

(0.5, 1.0, 1.5) the flow runs outward, down the outer region of the reactor then recirculates up the center line region. This behavior seen in the PCGC-3 solutions is consistent with the visual appearance of the flame in the CPR, which changes from a lengthened flame at low swirl to a flat flame at the top of the reactor as the swirl is increased. This marked change in the regions of high gradients presents difficulties in obtain good grid spacing for results for all cases.

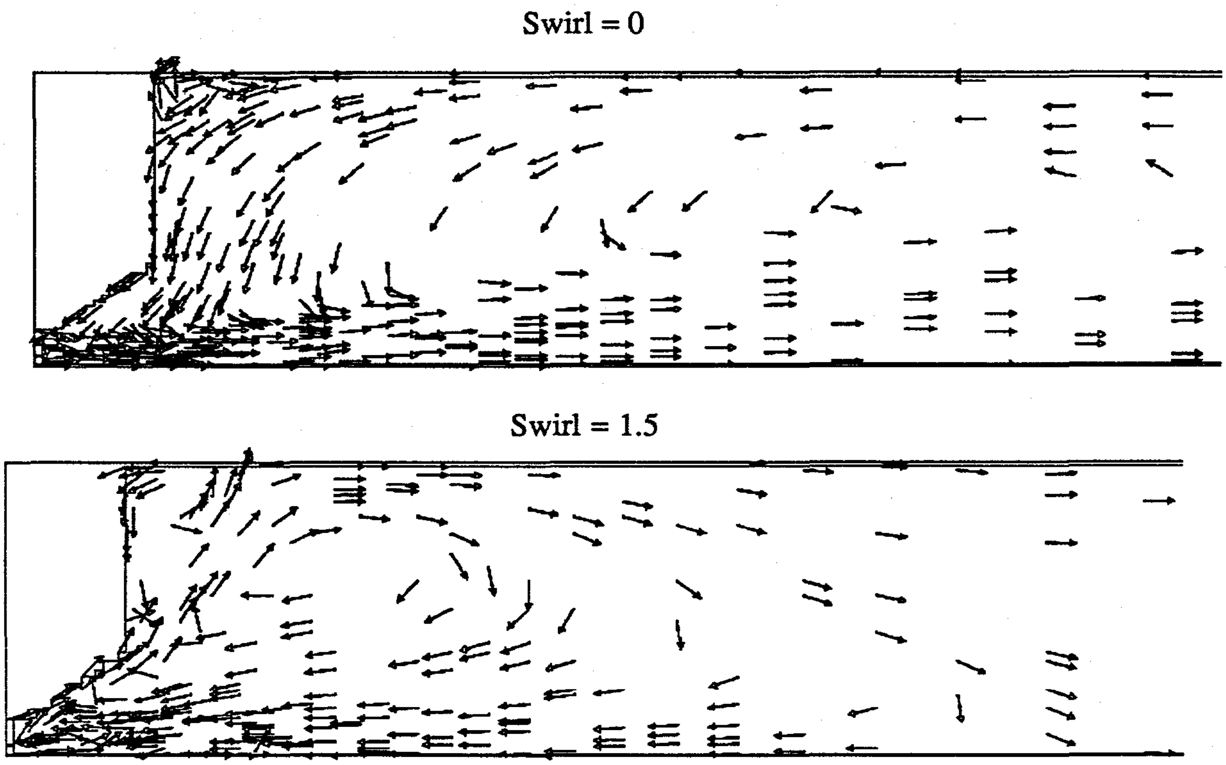


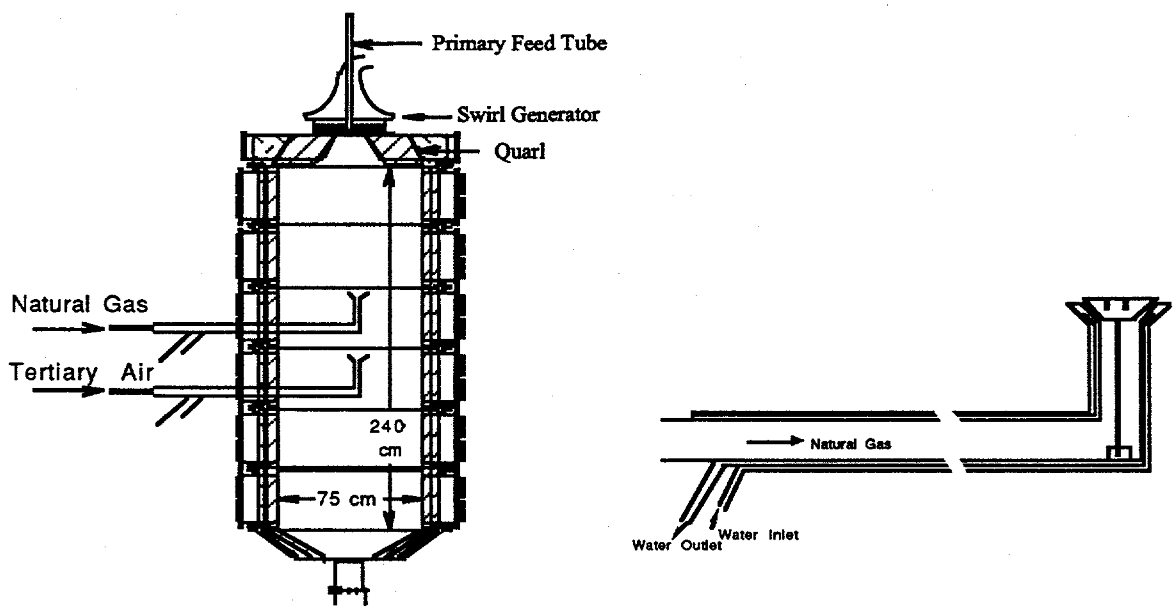
Fig. 5. Velocity vectors indicate a change in recirculation zones as swirl number increases.

3. Reburning Design and Fabrication

Reburning will be achieved by creating three distinctive zones inside the reactor. The main heat release zone will be operated fuel lean, 10% excesses air, where most fuel NO_x will be produced under oxidizing conditions. The secondary or reburning zone is where natural gas will be added to create fuel rich environment. Fuel radicals from the natural gas react with NO_x from the primary zone to form HCN, which under reducing conditions converts to elemental nitrogen. In the final stage, tertiary air will be added in the burnout zone downstream from the reburning zone to oxidize the remaining fuel radicals.

The key to demonstrating an effective reburning zone is thought to be the development of a fuel rich region through which the majority of combustion products containing NO_x must pass. Little published experimental work has been done on reactors of large diameter or large cross section. With this type of geometry, it is an important design issue to achieve a large enough fuel rich zone through which the bulk of the combustion gasses pass. The model predictions and measurements of gas velocity shown in Figs 2 and 5 have been used to develop an injector for the natural gas which can be adjusted to create an optimum reburning zone. In order to maintain symmetry and simplicity in modeling, it was decided that the reburning injector be located in the center or the reactor and that the spray pattern be symmetrical about the reactor centerline. Mass flow rates for the natural gas are fixed by the 10 - 20 % of the energy needed in the gas to create the reburning reduction. Inert gas or oxygen depleted combustion products were ruled out as a carrier to increase momentum because of complexity and expense. A numerical study done using FLUENT, a commercial three dimensional CFD code, was used to investigate the concentration of a gas injected into a turbulent nitrogen flow similar to that found at low swirl in the reactor. The results showed that a low velocity jet in counter flow to the reactor or a high velocity jet in cross flow produced similar shapes that appeared the most desirable for reburning.

The resulting design is to use a stainless steel water cooled tube to bring gas to an injector located on the axial centerline of the reactor. The nozzle will be of a pintle type design as shown in Fig. 6. The height of the pintle will allow an adjustment on the velocity changing the flow from an outwardly oriented flow with high velocity to a vertically upward flow of lower velocity. The location or distance down from the burner outlet and optimal opening of the pintle will be determined experimentally through effluent NO_x measurement where the location and shape of the injector spray is changed systematically. Natural gas will be supplied to the injector by high pressure tanks of about 2200 psi which will allow a variation in injected gas velocities. A compressor is available to compress the natural gas from the city line to pressurize the tanks. Fully loaded, the tanks will have the capacity for six to seven hours of continuos testing. Tertiary air will also be supplied from the compressor through a similar water cooled stainless steel probe. Both the probes will be Inserted through access ports from side of the reactor and will be movable in axial direction changing the location of the reburning and burnout zones.



(a) Reactor (b) Natural Gas Injector

Fig. 6 Schematic or the reburning injector location and injector design.