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TECHNICAL PROGRESS REPORT NO.13

INVESTIGATION OF HEAT TRANSFER AND COMBUSTION IN THE ADVANCED FLUIDIZED BED COMBUSTOR (FBC)

TO

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MASTER

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ABSTRACT

This technical report summarizes the research conducted and progress achieved during the period from October 1, 1996 to December 31, 1996.

Numerical simulation was acquired from the particle trajectories by means of the Reynolds Stress Model (REM) with general algebraic expressions. The typical particle trajectories for bunch particle injection were predicted by the top view, the side view, and the isolated 3-dimensional view. The simulation of particle trajectories showed top view, side view, and isolated 3-dimensional view.

Numerical simulation for the bunch particle injection will be continued to understand the particle characteristics in the combustion chamber.

The system test was conducted on the exploratory hot model. Thermal performance and combustion products of the test results were analyzed and predicted. The effect of cooling water on the combustion chamber was studied using the natural gas as a one of firing fuel. Without a providing of cooling water, overall combustion temperatures are increased.

A computer-assisted data acquisition system was employed to measure the flue gas compositions/stack temperature. The measurement of combustion products was conducted by the gas analyzer.

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EXECUTIVE SUMMARY

Fluidized bed combustion (FBC) has grown with the prospect that it can burn coal and low grade fuels in an environmentally acceptable manner. However, several undesirable features [1,2] were found to be inherent with a first generation FBC boiler system. The bubbling fluidized bed combustor and circulating FBC are known for high elutriation of unburned coal chars, in-bed and convective wall erosion [3], and a relatively low combustion intensity/calcium utilization. In order to improve these problems, the advanced swirling fluidized bed combustor (SFBC) was proposed. In this study, combustion air is tangentially injected into the annular chamber through the nozzles at various levels to form a strong swirling flow.

A series of experiment under different test conditions were conducted to explore the aerodynamic structure and the unique characteristics of the bench-scale advanced swirling fluidized bed (ASFB) system. Measurement and analysis of the gas/particle flow patterns were conducted to better understand the combustion processes and local heat transfer phenomena in the combustion chamber. Measurements showed the flow field in the ASFB to be characterized by a strong swirling flow in the tangential direction. Numerical simulation of the typical flow pattern of gas/particle flow in the ASFB freeboard was conducted using a computational fluid dynamics (CFD) code.

The exploratory hot model was designed and fabricated to understand the swirling-flow combustion process and heat transfer effect. The system test will be continued on the exploratory hot

SECTION 1

RESULTS AND DISCUSSION

Numerical Simulations ·for Particle Trajectories

1.1 Numerical Simulations for Bunch Particle Injection

An understanding of particle flow characteristics in the strongly swirling turbulent flow field is important to control the particulate emissions and fuel burnout in the swirling fluidized bed combustor.

The results of the single particle injection were discussed in the previous report [4]. The bunch particles injected into the combustor chamber were simulated by the CFD code, FLUENT. The test conditions for the bunch particle injections, in three cases, are summarized in Table 1.

Table 1 Test Conditions of Bunch Particle Injection for FLUENT Simulation

Particle Type		glass beads
Size	mm	0.04
Density	lb/ft^3	156.05
Particle injected at three locations and at the same initial velocity:		
Case 1 Injection Location		
I	degree	10
J	inch	1
K at the fluid bed surface	inch	3
Case 2 injection location		
I	degree	10
J	inch	2.5
K at the fluid bed surface	inch	3
case 3 injection location		
I	degree	10
J	inch	4
K at the fluid bed surface	inch	3
Particle injected velocity in K-direction	ft/s	25.5

Numerical simulation was pursued on the particle trajectories by means of the Reynolds Stress Model (RSM) with a general algebraic expression. The gas density was determined by the universal gas law which takes the gas density as a function of pressure and temperature. The bunch particle injection simulation was conducted in the whole reactor chamber in cylindrical coordinates [5].

The simulation results for the particle moving trajectories, in the combustion chamber, are shown in Figures 1, 2, and 3. Figure 1 shows the top view, Figure 2 shows the side view, and Figure 3 is the isolated 3-dimensional view.

The particle trajectories showed when the particle was injected from the surface of the fluidized bed; it was swirling up for case 1 and case 2, and swirling down for case 3. The swirling diameter is increased as it rises up (for case 1 and case 2) or falls down (for case 3).

For case 1, the particle moving up to the 8 inch level touched the wall, bounced against the wall several times, fell into the dense phase fluidized bed and finally escaped from the reaction region (see blue line in Figures 1 and 2).

For case 2, the particle moved up spirally, but stayed closer to the wall due to a stronger centrifugal interaction. After the particle bounced against the wall, then fell into the dense phase fluidized, which is similar to the case 1. (see green line in Figure 2).

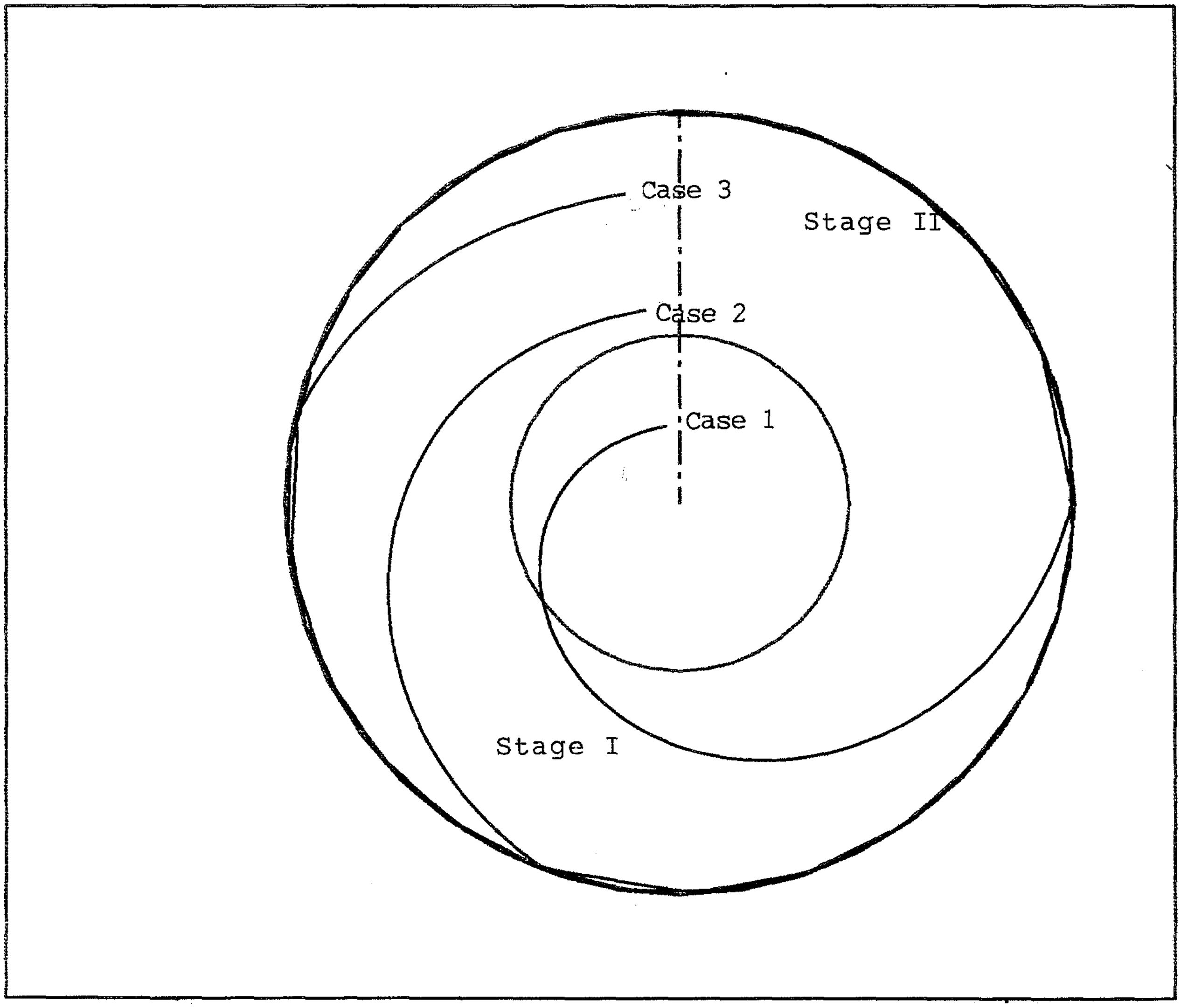


Fig. 1 Top View of Particle Trajectory in the Combustor

For case 3, the particle moved up to the 3.5 inch level and then started to fall down. At about the 2.5 inch level, the particle touched the wall and then bounced against the wall several times into the dense phase fluidized bed and finally escaped from the reaction region (see red line in Figures 1 & 2).

The particles moved in three stages: ascending stage (stage I), colliding/bouncing stage (stage II), and slipping stage (stage III). In stage I, the particle moved toward a summit (its highest point); in stage I, the particles touched the wall, bounced against the wall and slid along the wall smoothly. The ascending stage and bouncing stage for case 1 is longer than those for case 2 and case 3 (see Figure 1, the blue line indicates the case 1). In our test case, no sliding stage was found.

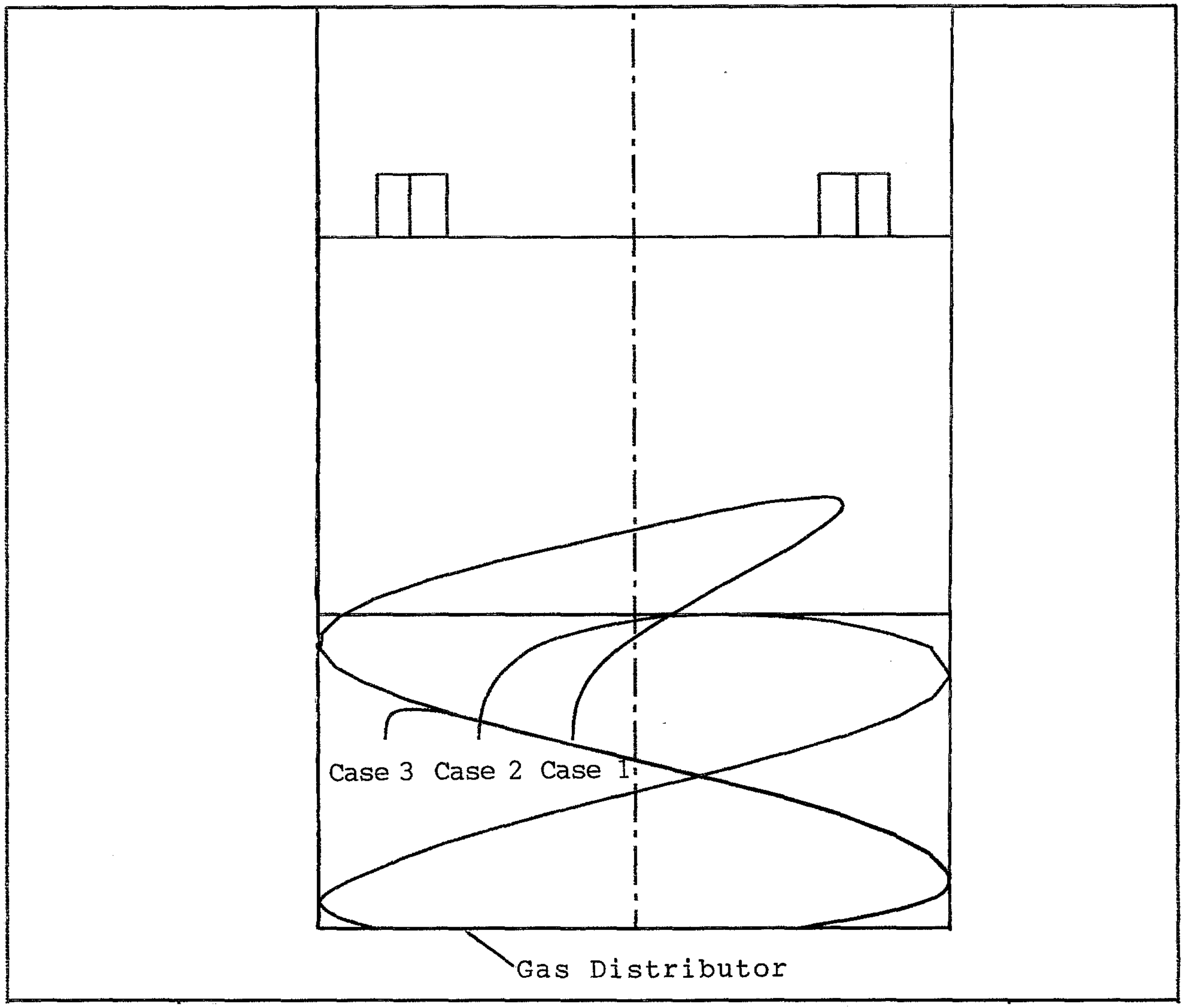


Fig. 2 Side View of Particle Trajectory in the Combustor

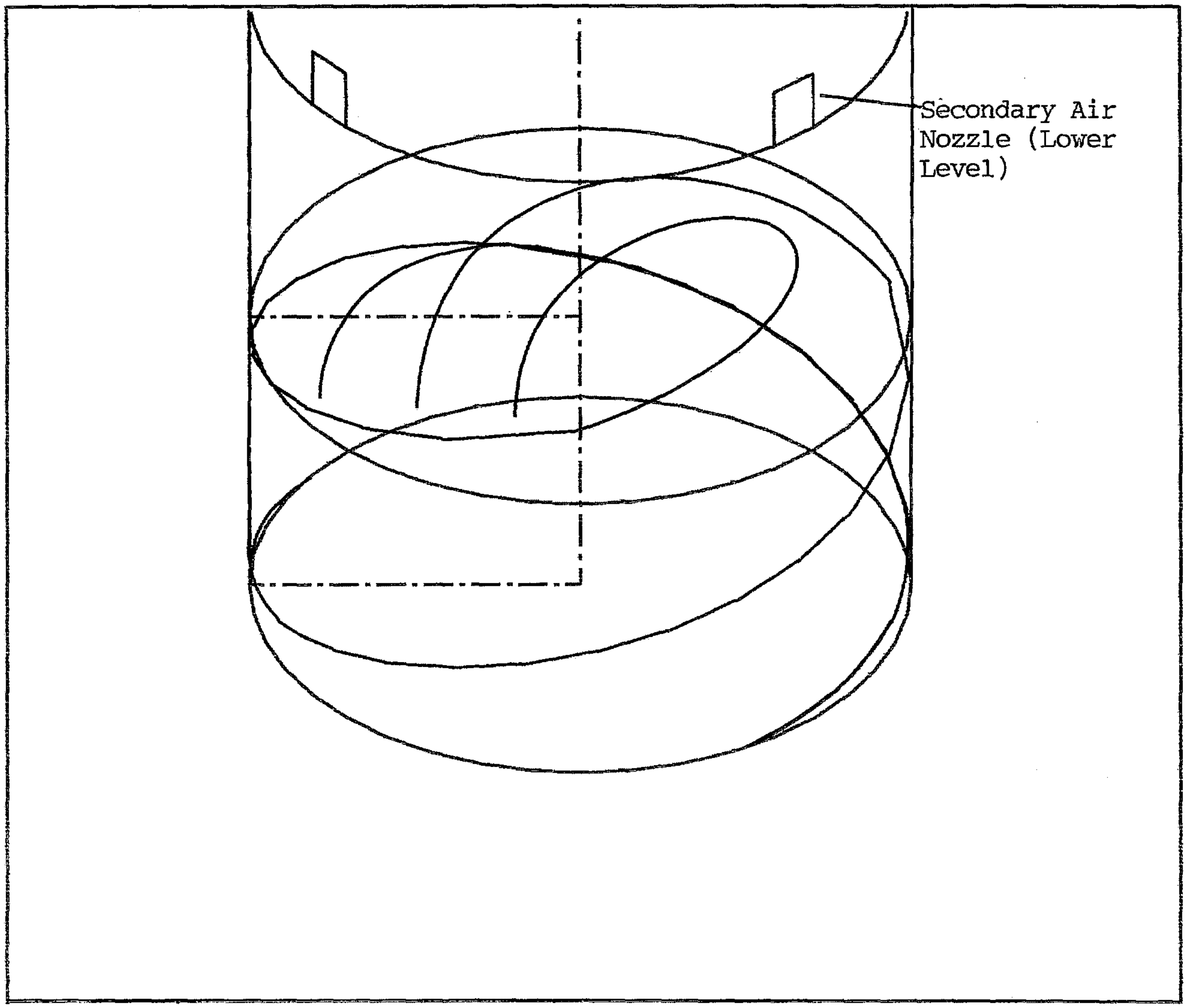


Fig. 3 Three-Dimensional Plot of Particle Trajectory in the Combustor

SECTION 2

RESULTS AND DISCUSSION

Test of Exploratory Hot Model

The system test was continued to analyze the thermal performance on the exploratory hot model.

2.1 Instrumentation for Flue Gas Composition Measurements

A computer-assisted data acquisition system for the flue gas compositions/stack temperature measurements was employed to accelerate the data taking process and to eliminate human errors.

The ENERAC 2000 gas analyzer was used to measure the composition of flue gases. This analyzer as designed to have an automatic self-calibrating system which can sample, condition, and measure oxides of nitrogen, carbon monoxide, sulfur dioxide, and oxygen on a continuous basis [6].

The ENERAC 2000 gas analyzer interfaced with an on-site personal computer with a software, ENERCOMP. This software includes a program that allows us to translate stored stack date into LOTUS program format for further manipulation. To take the average values, set the Log-In period of ENERCOMP program to the shorter average period.

2.2 Procedures of Flue Gas Composition Measurements

Measurements of combustion products by the gas analyzer start at the sampling probe which is inserted into the outlet of exhaust tube of the exploratory hot model. The sampled flue gases are transported to the monitor console of the gas analyzer.

2.3 Effect of Cooling Water

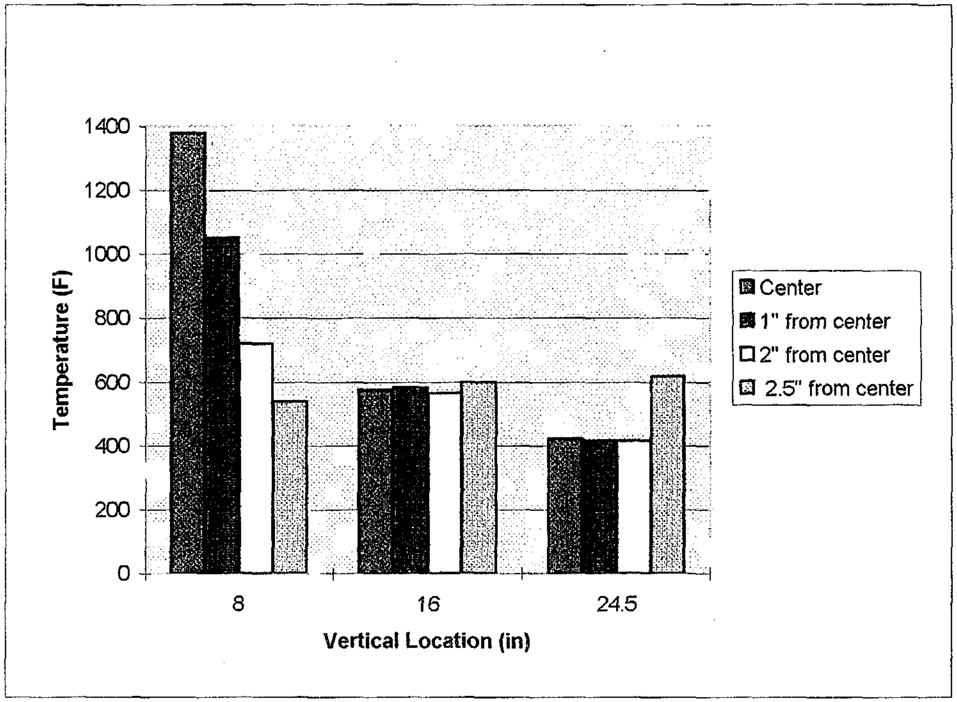
Figure 4 shows one of the system test results to analyze the thermal performance on the exploratory hot model. This test was conducted with the top combustor plate sealed with a 1/4" thickness of the steel plate. The exhaust system was located 180 from the thermocouples 5.5" from the bottom with a 5/8" diameter opening.

The data shows an average temperature of 657 F and a close to homogeneous heat distribution. This average temperature is higher than that of the test at the lowest combined primary and secondary air flow [4]. This result indicated that the exhaust location influenced the mixing of the chamber gas and heat similarly. The vertical location of the exhaust was very close to the fuel nozzle, which also affected the increasing of the combustion temperature.

Two tests were conducted to examine the effect of cooing water using the natural gas. The gas analyzer, ENERAC 2000 was used to measure the composition of flue gases. Test A was run on the exploratory hot model with the cooling water. The cooling water flow rate was 1.5 gallon/min. for three levels of cooling water tube. These cooling tubes are consisted of three runs of independently controlled water cooling tubes. The secondary air flow rates for the upper and lower nozzles are 3 cfm and 3.5 cfm respectively. The average combustion temperature was 326.8 F. The detailed test conditions and results were shown in Table 2.

Table 3 summarized the test results without the cooling

Fig. 4 Test Conditions and Temperature Profile in Combustion Chamber



Hot Model Preliminary Test Data

With Primary Air (in of H2O)	0.05 (20 cfm)	
Straight 5 hole Fuel Nozzle at 5"		
FUEL: Natural Gas	Fully open	
Water flow rate	1.5 GPM	All coils @ 100%
secondary nozzle angle	90	
Horizontal angle	45	
Secondary air top (CFM)	0	
Secondary air top (CFM)	5	
Cooling Water in	70.8	
Cooling Water out	75.7	
Cooling water flow (GPM)	1.5	
Flue Temp	900?	

Dist.(in) from Bottom	Center	1" from cei	2" from center	2.5" from cent	Surface	Avg temp		
8	1380 (F)	1051	720	539	186	922.5		
16	574	583	564	599	185	580		
24.5	420.9	415	416	617	184	467.23		
avg 3 therm.cpls	791.633	683.000	566.667	585.000			656.575	Total Average

Sealed combustor top	
Exhaust size	5/8 "
Exhaust Location	5.5" from bottom

Table 2 Summary of Test Conditions (with Cooling Water)(Test A)

Hot Model Preliminary Test Data

With Primary Air	0.40 in (55 cfm)				
Straight 5 hole Fuel Nozzle at 5"					
FUEL: Natural Gas	Fully open				
Water flow rate	1.5 gpm All coils @ 100%				
secondary nozzle angle	90				
Horizontal angle	45				
Secondary air top	3 cfm				
Secondary air bottom	3.5 cfm				
Cooling Water in	46.5				
Cooling Water out	47.7				
Cooling water flow	1.5 GPM				
Flue Temp	235.7	238.1	233.4	233.6	235.2 AVG

Thermocouple No.	Distance (in) From Bottom	Temp (F) Center	Temp (F) 1" from center	Temp (F) 2" from center	Temp (F) 2.5" from center	Temp (F) Surface	Avg temp
K1	8	255.1	250.2	228.9	209.8	98.9	236.0
K2	16	297.8	278.5	230.2	196.2	104.1	250.7
K3	24.5	721	601.8	196	151.6	117.8	417.6
	avg 3 therm.cpls	424.63	376.83	218.37	185.87	106.93	**301.4**

Test performed with dome on top & fixed analyzer position

Table 3 Summary of Test Conditions (without Cooling Water) (Test B)

Hot Model Preliminary Test Data

With Primary Air		0.40 in (55 cfm)				
Straight 5 hole Fuel Nozzle at 5"						
FUEL: Natural Gas	Fully open					
Water flow rate		none All coils @ 0%				
secondary nozzle angle		90				
Horizontal angle		45				
Secondary air top		3 cfm				
Secondary air bottom		3.5 cfm				
Cooling Water in		n/a				
Cooling Water out		n/a				
Cooling water flow		0				
Flue Temp		235.4	234.6	233.6	233.9	234.375 AVG

Thermocouple No.	Distance (in) From Bottom	Temp (F) Center	Temp (F) 1" from center	Temp (F) 2" from center	Temp (F) 2.5" from center	Temp (F) Surface	Avg temp
K1	8	255.8	244.4	234	205.4	103	234.9
K2	16	301	279.8	219.7	191.3	107.3	248.0
K3	24.5	1065	587	171.6	166.7	117	497.6
	avg 3 therm.cpls	540.60	370.40	208.43	187.80	109.10	**326.8**

Test performed with dome on top & fixed analyzer position water. The secondary air flow rates were same as the test with the cooling water. The average combustion temperature was 301.4 F. The detailed test conditions and results were shown in Table 3. Without a providing of cooling water, overall combustion temperatures are increased. Especially, the average temperature at the center of the combustor was increased by the range of 27%. When the cooling water provided, the combustion temperatures decreased. In addition, the top portion of the combustor absorbed the least amount of heat from the hot combustion gases.

It is believed that the heat removal rate by water at each section of heat transfer surface affects the local heat transfer rate in the combustion chamber [7]. This local heat transfer effect in the combustion chamber will be further investigated and analyzed in the future.

2.4 Combustion Products and Pollution Performance

Figures 5 and 6 show the concentration of oxygen, carbon dioxide, carbon monoxide, oxides of nitrogen, and sulfur dioxide. The sampling was collected from the exhaust at the top portion of the combustor. The carbon monoxide was found to be about 14% to 20%. As expected, the existing CO and NOx levels were very low (0 ppm-0.3 ppm) because the fuel tested was gas as a clean fuel. Natural gas is practically free from noncombustible gas or solid residue.

Methane (CH4) and ethane (C2H6) are the principal combustible components of the natural gas. The existing SOx level was found to be relatively low (13 ppm to 16 ppm). It may be considered that the sampling gas included some saturated moisture. Usually, natural gas which is delivered from a pipeline has often been "rehydrated," that is saturated with water vapor by means of steam jet [2]. It is believed that with a better-arranged and careful instrumentation, the accurate flue gas analysis could be obtained.

Fig.5 Stack Temperatures vs Combustion Gas Analyzer

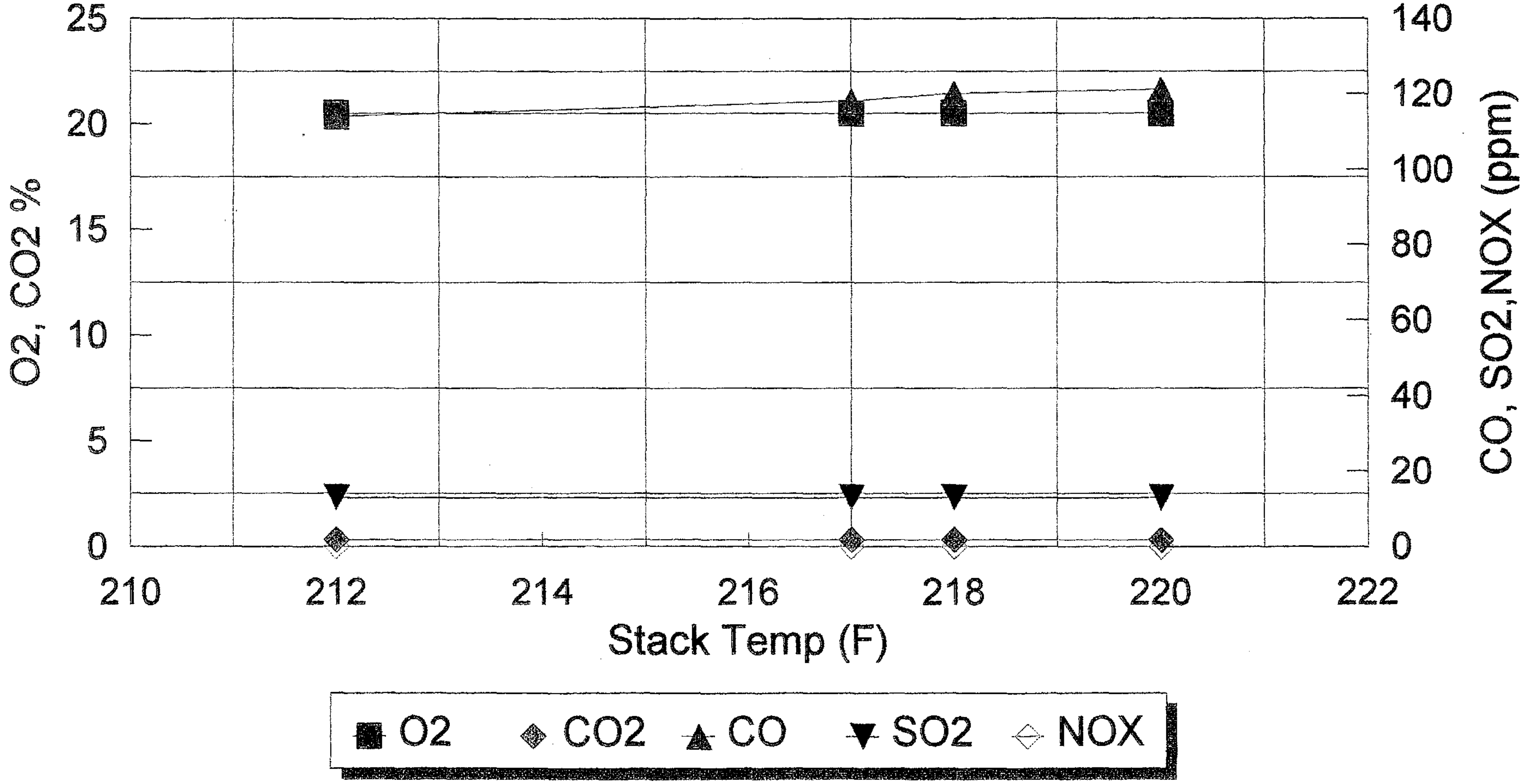
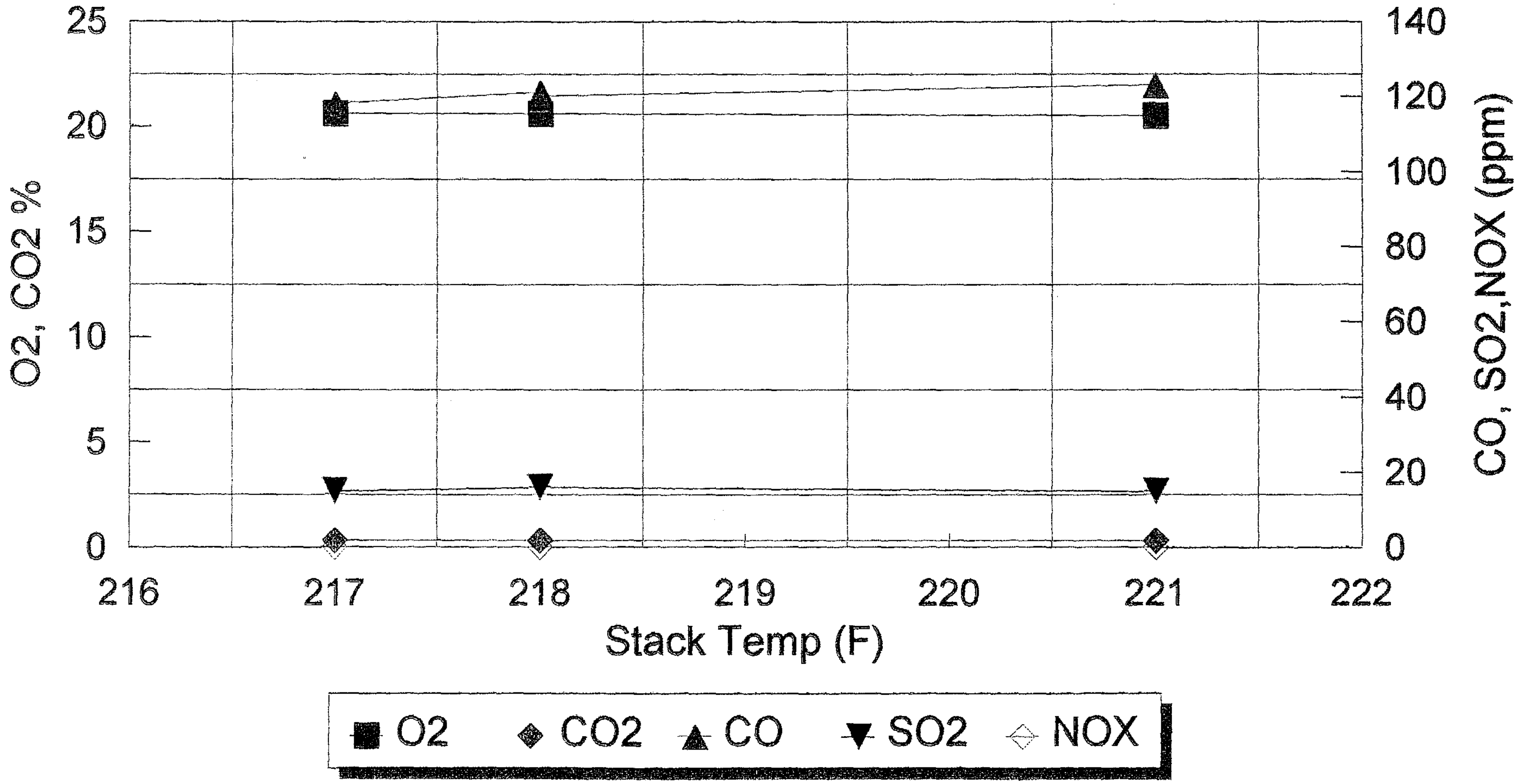


Fig.6 Stack Temperatures vs Combustion Gas Analyzer



SECTION 3

CONCLUSIONS

Measurement and analysis of the gas and particle flow patterns were very useful to better understand the combustion processes and local heat transfer phenomena in the combustion chamber of the advanced swirling fluidized bed combustor.

Numerical simulation of the typical flow pattern of gas particle flow in the freeboard of the bench-scale advanced swirling fluidized bed was conducted using a conducted using a computational fluid dynamics code, Fluent, which is loaded onto Supercomputer Cray J916. The results showed the non-isotropic structure with vigorous fluctuation in axial and radial directions.

The system test was conducted on the exploratory hot model to analyze the thermal performance and flue gas compositions. A computer-assisted data acquisition system was employed to measure the flue gas compositions and stack temperatures. Test on the exploratory hot model will be continued to analyze the local heat transfer rate, thermal performance, and combustion products.

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