TECHNICAL PROGRESS REPORT NO.18

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

TO

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FEDERAL ENERGY TECHNOLOGY CENTER
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FOR

PROJECT NO.: DE-FG22-93MT93006--13

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APRIL 1998

ABSTRACT

This technical report summarizes the research conducted and progress achieved during the period from January 1, 1998 to March 31, 1998.

The systematic combustion tests were conducted to investigate the thermal performance and heat transfer effect of the exploratory hot model. The different ratios of the top to the bottom secondary air flow rate were chosen to study the effect of the secondary air flow rate. The test results indicated that the secondary air flow rate was a very sensitive factor to the combustion temperature profile. The heat transfer coefficients were changed along the combustor height.

Numerical simulation was continued to determine the pressure profiles and temperature profiles in the hot combustor model. The pressure change at the bottom is greater than that of the top region because of a large amount of primary air input. The higher pressure zone is formed where the secondary air flows into the center region of the combustor.

The high temperature zone of the bottom section is located at the fuel injector nozzle outlet. The lower temperature profiles were near the combustor wall because the cooling effect of the heat exchanger. The center temperature of the combustor at the upper secondary air nozzles is higher than that at the lower secondary air nozzles.

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SECTION 1

RESULTS AND DISCUSSIONS

TEST RESULTS OF THE EXPLORATORY HOT MODEL

Two different tests were analyzed to understand the thermal performance of the exploratory hot model [1].

1.1 Test Conditions

1.2

For the Test 1, fuel (natural gas) flow rate was 25 cubic feet per hour (cfh). The primary air flow rate was 2.9 cubic feet minute (cfm). The secondary air flow rates for the top and the bottom levels were both 1 cfm respectively. The cooling water flow rate was 0.5 gallon per minute (gpm). The detailed test conditions are shown in Table 1.1.

For the Test 2, the test conditions are same as Test 1 except the secondary air flow rates as shown in Table 1.2. The secondary air flow rates for the top and the bottom levels were 1.65 cfm and 1.1 cfm respectively.

1.2 Effect of the Secondary Air Flow Rate

For the Test 1, the ratio of the top to the bottom secondary air flow rate was chosen to be 1. The average combustion temperatures for the upper part, middle part, and bottom part were 1347.5 F, 1150 F, and 1419 F.

For the Test 2, the ratio of the top to the bottom secondary air flow rate was increased by 1 to 2. The average combustion temperatures for the upper part, middle part, and bottom part were 1414 F, 1347 F, 1372F. This results indicate that the average

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combustion temperature of Test 2 is higher than that of the Test 1. The secondary air flow rate may be very sensitive factor to the combustion temperature profile.

Once the secondary air flow rate is fixed to be 1 (Test 1), the swirling flame in the upper/middle part of the chamber were observed as same shaper. The flame at the bottom part of the combustor was smaller than of the upper or the middle part of the combustor.

When the secondary air flow rate was increased by 1 to 2 (Test 2), the swirling flame in the upper part was much stronger than that of the middle or the bottom part of the combustor. This flame was dominant in the combustor chamber which affected the combustion temperature profile. So, the large ratio of the secondary air flow rate causes the increase in the combustion temperatures.

1.3 Heat Transfer Coefficient

The heat transfer coefficients in the combustion chamber were computed by our developed C program. This computer program was based upon the energy/heat balance equations [2,3].

Figure 1.1 shows the heat transfer coefficient changes along the combustor height for Tests 1 and 2. For the fixed ratio of the secondary air flow rate (Test 1), the heat transfer coefficients at the top and bottom

parts of the combustor are $23.7 \text{ W/m}^2\text{C}$ and $21.3 \text{ W/m}^2\text{C}$ respectively. The swirling/vortex flame in the middle section of the combustion chamber was produced by the top/bottom secondly swirling flow. So, it causes the highest heat transfer coefficient in the

Table 1.1 Summary of Hot Model Test Result (1)

Primary Air Flow (CFM)	2.9		Room Temp. (F)		74
			Air Temp. (F)		74
			Fuel Temp. (F)		74
Fuel: Natural Gas Flow (CFH)	25		Primary (bottom)		16
Fuel Nozzle (Description)	5 holes nozzle 5" from chamber floor		Secondary (top)		9
Sec. Nozzle Yaw Angle	Top	30°	Middle in		
Sec. Nozzle Roll Angle	Top	30°	Bottom		
Secondary Air Flow (CFM)	Top	1	Bottom	1	
Total Air Flow (%)	Top (Sec.)	20.408	Bottom (Sec.)	Primary	
					59.184
Cooling Water Temp. (F)	Top in	68	Out	Cooling Water Flow Rate (GPM)	
	Middle in	68	Out	Cooling Water Flow Rate (GPM)	
	Bottom in	68	Out	Cooling Water Flow Rate (GPM)	

Length of Burn-in 30 min

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) Average	Temp (F) Surface	File Temp
K1	8"	1550	1400	1480	1320	1457.8	180	903
K2	12"	1570	1470	1310	1250	1409	182	940
K3	16"	1490	1250	1025	920	1171.25	174	950
K4	20"	1320	1200	1080	940	1135	215	890
K5	24"	1560	1490	1320	1200	1392.5	238	935
K6	28"	1410	1380	1250	1160	1302.5	300	904
Avg	Temp (F)	1483.2	1366.7	1244.2	1131.7	1206.5	214.5	906.3

Enatic 2600 Gas Analysis						
Position	Sit Temp (F)	Amb Temp (F)	Efficiency (%)	O ₂ (%)	CO (%)	CO (ppm)
Elia Gas Analysis	010	70	00.2	1.0	10.8	0

Table 1.2 Summary of Hot Model Test Result (2)

Length of Burn-in 30 min

Esterase 2000 Gas Analysis						
Position	Sk Temp (°F)	Amo Temp (°F)	Efficiency (%)	O ₂ (%)	CO ₂ (%)	SO (ppm)
Flue Gas Analysis	924	70	01.5	9.9	10.5	0

middle section of the combustion chamber as shown in Figure 1.1.

For the increased ratio of the secondary air flow rate (Test 2), the heat transfer coefficients at the top and bottoms are $25.7 \text{ W/m}^2\text{C}$ and $18.8 \text{ W/m}^2\text{C}$. The swirling/vortex flame in the top section was dominant in the combustion chamber. So, it affects higher heat transfer in top section of the combustion chamber.

Figure 1.1 Local Heat Transfer Coefficients for the Three Sections in the Combustion Chamber

SECTION 2

RESULTS AND DISCUSSIONS

NUMERICAL SIMULATION OF HOT COMBUSTOR MODEL

The numerical simulation was continued to determine the pressure profiles and temperature profiles in the hot combustor model. Test conditions and input boundary conditions were introduced in the previous report [4].

2.1 The Pressure Profiles

A side-view of static pressure profiles is shown in Figure 2.1. The ranges of pressure changes are 1.692 pascals to -3.525 pascals. Some top view of pressure profiles at eight different vertical levels; K=6, 10, 20, 30, 40, 50, 60, 70 are shown in Figure 2.2.

The pressure values in Figures are relative values based upon the reference point at the primary air inlet. The pressure change at the outer region of the wall is greater than that of the inner region of the axis. The pressure change at the bottom is greater than that of the top region because of a large amount of primary input as shown in Figure 2.1. The higher velocity was found at the center region. It is believed that the secondary air injection affected the pressure profile of the center region. The increasing velocity from the pressure potential energy is transferred into kinetic energy, which caused the higher velocity at the center region [5].

The higher pressure zone is formed where the secondary air flows into the center region of the combustion chamber as shown in Figure 2.2. A dead zone or a local swirling flow was formed at near the wall region as shown in Figure 2.1.

1.2 The Temperature Profiles

Figure 2.3 shows the side view of the temperature profiles in the vertical direction. Figure 2.4 shows the top view of temperature profiles at eight different vertical levels; $K=6, 10, 20, 30, 40, 50, 60, 70$.

The high temperature zone (1400 F) of the bottom section is located at the fuel injector nozzle outlet, which caused the ignition of the primary air and fuel mixing as shown in Figure 2.3. Figure 2.5 shows the temperature profiles of the top view at near the fuel injector nozzle outlet ($K=6$). The low temperature profiles were near the combustor wall because of the cooling effect of the heat exchanger as shown in Figure 2.5.

At the vertical level, $K=30$, the temperature was relatively high (1300) because of the secondary air input at the lower level nozzles as shown in Figure 2.4. Figure 2.6 shows more detailed temperature profiles of the top view at level, $K=30$. The temperature profiles are changed by the secondary air input as shown in Figure 2.6. Figure 2.7 shows the temperature profiles of the top view at the upper secondary air nozzles.

The center temperature of the combustor at the upper secondary air nozzles is higher than that at the lower secondary air nozzles as shown in Figures 2.6 and 2.7. The upper secondary air was used effectively to burn the rest of fuel in the combustor chamber. These results show the

relatively large temperature gradient along the combustion chamber height and the radial direction. The combustion temperature was affected by the cooling water of the heat exchanger.

Figure 2.1 Side View of Static Pressure Profiles

Figure 2.2 Top View of Pressure Profiles at Different Vertical Levels; K=6, 10, 30, 40, 50, 60, 70, 20

Figure 2.3 Side View of Temperature Profiles

Figure 2.4 Top View of Temperature Profiles at Different Vertical Levels; $K=6, 10, 20, 30, 40, 50, 60, 70$

Figure 2.5 Top View of Temperature Profiles at Level, K=6

Figure 2.6 Top View of Temperature Profiles at Level, K=30

Figure 2.7 Top View of Temperature Profiles at Level, K=50

SECTION 3

CONCLUSIONS

The systematic combustion tests were conducted to investigate thermal performance and heat transfer effect of the exploratory hot model. The different ratios of the top to the bottom secondary air flow rate were chosen to study the effect of the secondary air flow rate. The combustion temperatures were significantly affected by the different secondary air flow rates. The heat transfer coefficients were changed along the combustor height.

The numerical simulation was conducted to determine the pressure profiles and temperature profiles in the hot combustor model. The side view and top view of the pressure profiles were predicted at different vertical levels in the grid domain. The higher pressure zone is formed where the secondary air flows into the center region of the combustion chamber.

The temperature profiles of the vertical/horizontal directions were predicted by the numerical simulation work. The center temperature of the combustor at the upper secondary air nozzles is higher than that at the lower secondary nozzles. The numerical simulation will be continued to determine the concentration profiles of fuel species, the heat flux, and the heat transfer coefficients in the hot model.

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