DOE/MT/93006--T6

Technical Progress Report No.11

Investigation of Heat Transfer and Combustion in the Advanced Fluidized Bed Combustor (FBC)

to

U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940, MS 921-118
Pittsburgh, PA 15236-0940

for

Project No: DE-FG22-93MT93006

by

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July 1996

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SUMMARY

This technical report summarizes the research performed and progress achieved during the period of April 1, 1996 to June 30, 1996.

Measurements of particle flow field were conducted to better understand particle behavior and combustion performance in the advanced fluidized bed combustor under swirling flow condition. The modified dual static pressure probe (MDSPP) along with a data acquisition system was employed to measure particle velocity in the test chamber. Three test cases, with different probe locations, have been conducted on 6" ID cold flow model. The statistical particle velocities were predicted for three test cases.

Design and fabrication of the exploratory hot model were continued with an arrangement of the auxiliary subsystems including air supply subsystem, water supply subsystem, and ignition subsystem. According to the established safety and health guideline, the auxiliary subsystems were inspected carefully. All instruments are checked and calibrated for the preliminary system test. The preliminary system test was conducted on hot model. Thermal performance of the preliminary test results was analyzed and predicted.

Based upon the preliminary test results, the auxiliary subsystems will be modified and improved for the systematic test. Flue gas exhaust subsystem will designed and installed for the controlling particulate emissions. A computer-assisted data acquisition system will be developed to accelerate the data taking process and to eliminate human errors.

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Section 1

Measurements of Particle Flow Field

In the advanced fluidized combustor under swirling flow condition, the combustion of coal-based fuel particles takes place in a highly swirling, developing, turbulent flow, whose gas flow has been studied in the previous reports [1]. In order to better understand and control particle behavior, and further improve the combustion performance, it is necessary to investigate the particle dynamic characteristics in the combustor chamber.

1.1 Probe Development and Working Principle

The probe used for the particle velocity measurement is a modified dual static pressure probe (MDSPP), which was designed and fabricated by Advanced Energy Systems/Industrial Technologies Laboratory of Morgan State University. The MDSPP included four copper tubes with 0.19" of diameter and 30" of length as shown in Figure 1.1. This probe measures two differential pressures $\Delta P1$ and $\Delta P2$, at the same time. The distance between the pair of tubes for P1 and P2 is 1/2 inches; the distance between the centers of the pair of tubes for P1 and P2 is 2 inches. The signals by differential pressure were transmitted and measured by two differential pressure transducers, Validyne P30D1N120S4 (pressure range; 0.08 psi) and P30D1N122S4(pressure range; 0.2 psi). These pressure transducers produce an analog voltage output with a range of ± 5 volts. The voltage signal is converted to a digital signal through the analog-to-digital (A/D) board

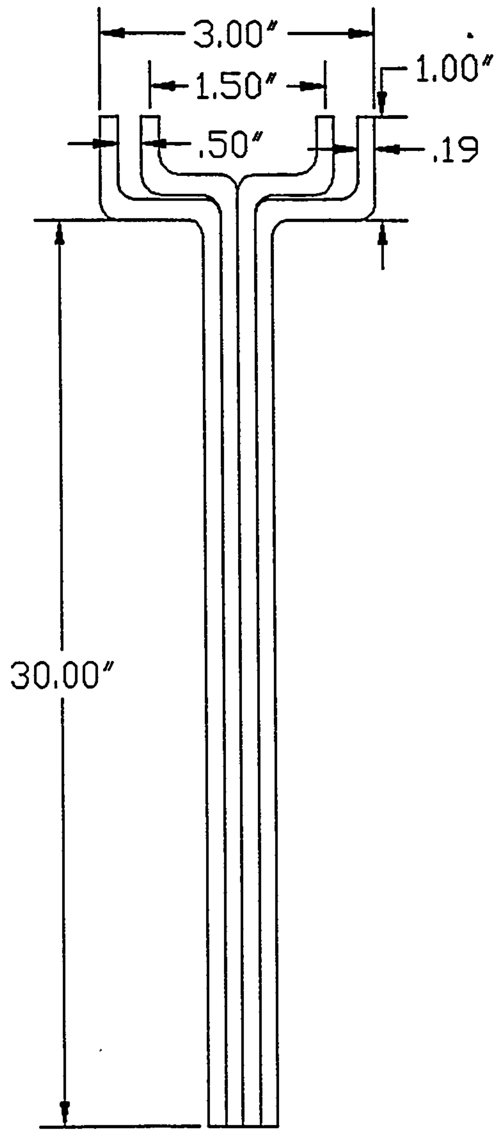


Figure 1.1 Schematic Diagram of Modified Dual Static Pressure Probe

and recorded in a computer file. Then the signals are analyzed by the cross-correlation function which is a program 'xcorr' in MATLAB language. The cross-correlation function [2] is used to find time delay (or shift time) between the delta P signals. The shift time can be considered as the time for particles moving from the sensor point of ΔP1 to the sensor point of ΔP2. The particle velocity can be calculated by the distance between the two ΔP and the signal shift time, tsf. If we assume that the first signal delta P is Rx(t) at time t, and the secondary signal delta P is Ry(t + tsf), the results can presented as follows [3],

$$R_{xy}=\frac{1}{t_1}\int_0^{t_1}R_x(t)\,R_y(t+t_{sf})\,dt$$

The time-tag, tsf, is such that the maximum value of the cross-correlation function is an indication of the dominant peak in the plot. The particle moving velocity can be calculated by using the following function:

$$V_p=\frac{L}{t_{sf}}$$

1.2 Experimental Setup and Instrumentation

Based on signal transport technology [4], an experimental method was developed to measure the particle tangential velocity in the 6" ID cold flow model. The MDSPP probe is inserted into the chamber at 1.5" from the gas distribution plate and set at three radial location at 1", 2", and 2.25" from the axis line of the combustion chamber. The particles used in this test are tubular macaroni with a average size of 5 mm, and particle density of about 1.8 g/cc without holes and 0.9 g/cc with the inside hole. The particles terminal velocity is 12.21 m/s, and the minimum fluidization velocity is 1.15 m/s. In the test about 300g of the particles are put in the chamber. The primary air flow rate into the wind box is 0.0343 m^3/s. The primary air pressure is about 1 psi. The total secondary air flow rate into the chamber is 0.0239 m^3/s, and the secondary air pressure is close to the atmospheric pressure. The primary superficial velocity in the bottom of the test chamber is 1.88 m/s, and the velocity at the secondary air nozzle outlet is 5.24 m/s. Under these test conditions, a good solid tangential movement was observed. Then particle tangential velocities at the three locations (Z=1.5", R=1", 2", and 2.25", Z and R are vertical distance from the distributor plate and radial distance form the test chamber respectively) were measured by the MDSPP probe.

1.3 Test Results and Discussions

Three test cases, with different probe locations, have been conducted on 6" ID cold flow model.

For the first test case, the probe was set at a location of Z=1.5" and R=1". Figure 1.2 shows the pressure fluctuation signal from channel #0 along with 0.08 psi pressure transducer, the average pressure drop is about 19.5 mmH_2O with a average pressure fluctuation of 3 mmH_2O. Figure 1.3 shows the pressure fluctuation signal from channel #1 along with 0.2 psi pressure transducer. The average pressure drop is about 1 mmH_2O with an

Figure 1.2 Background Signal from Channel #0 (0.08 psi)

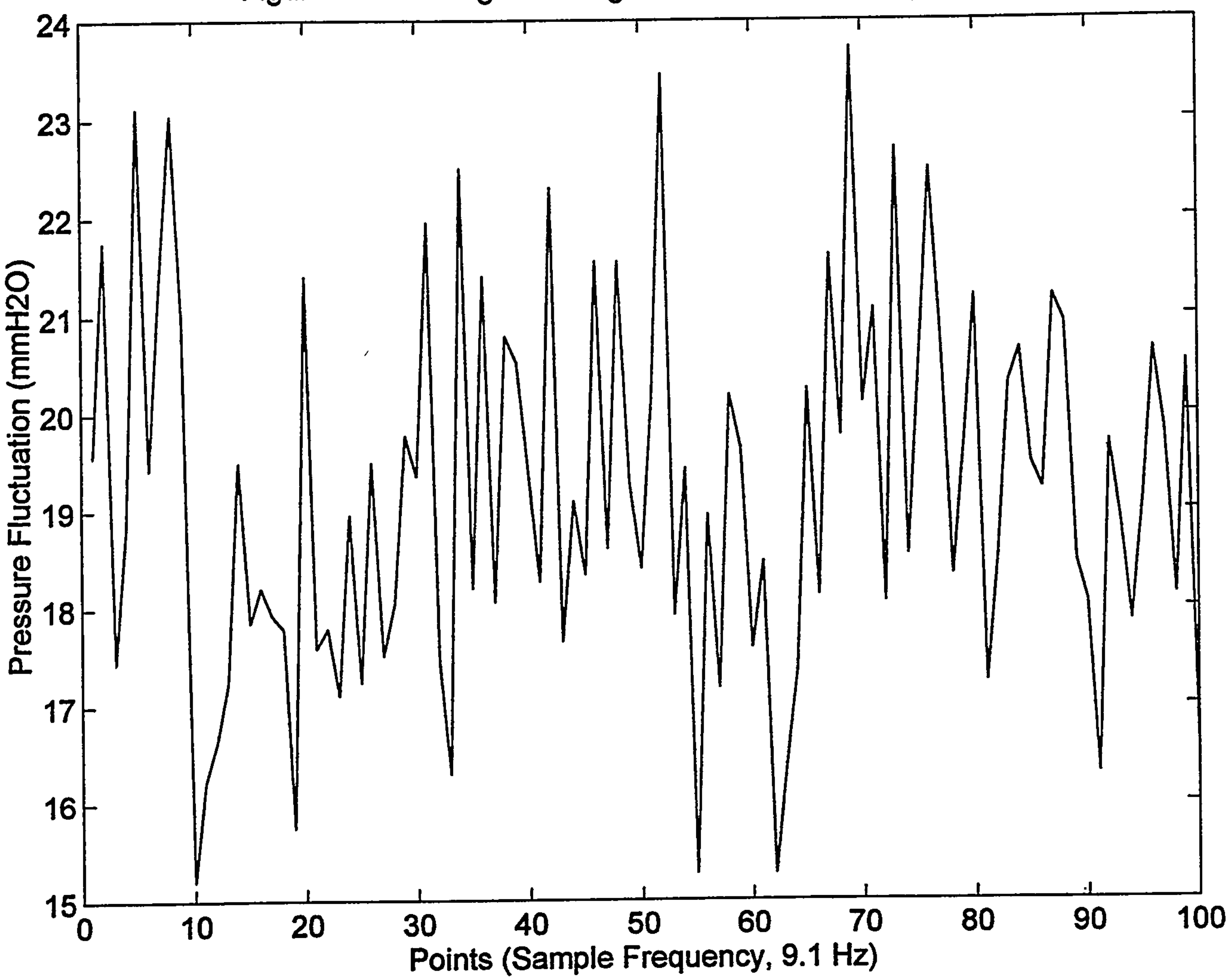
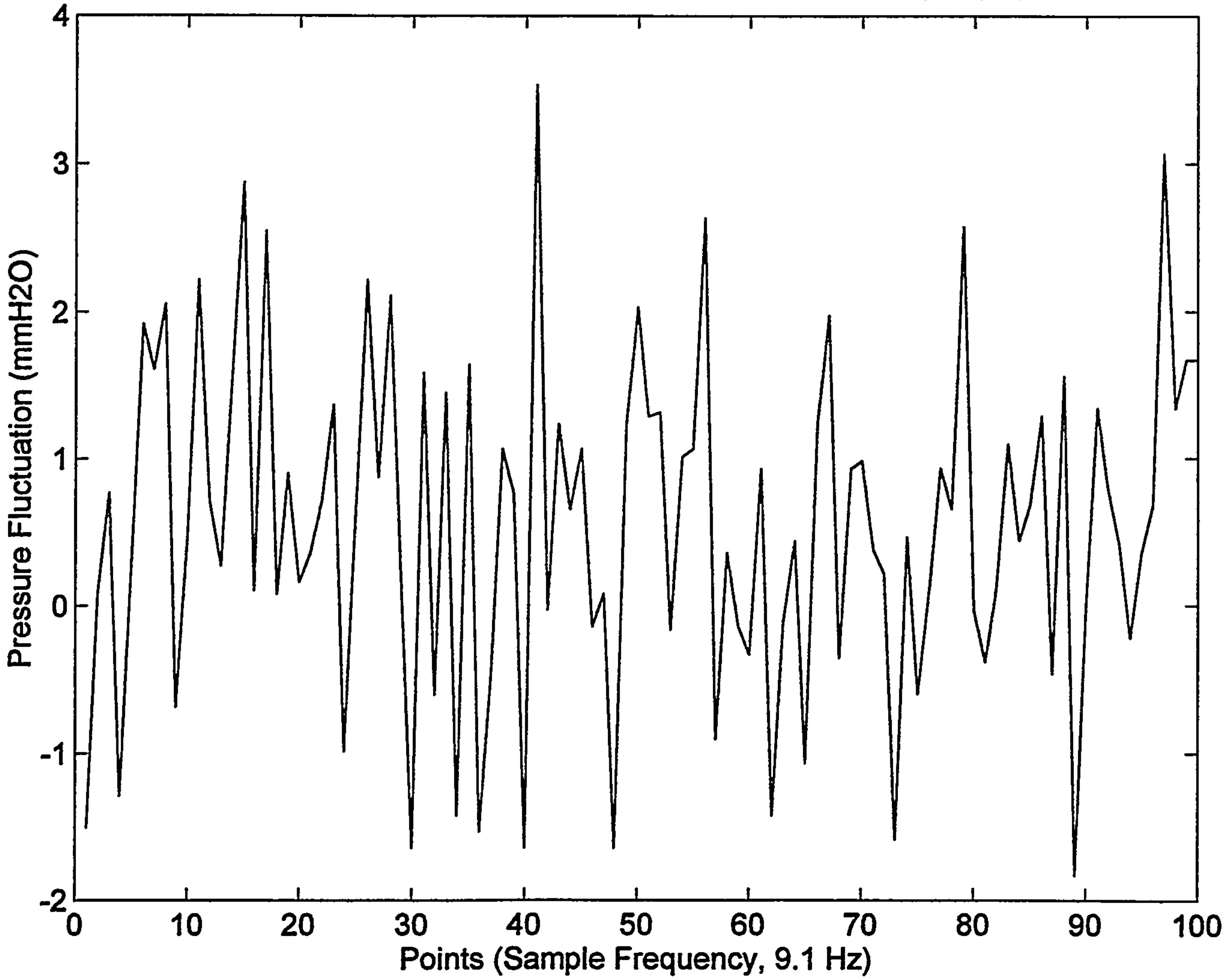


Figure 1.3 Background Signal from Channel #1 (0.2 psi)



average pressure fluctuation of 1 mmH_2O. By comparing Figure 1.2 and Figure 1.3 two figures have similar regions which indicate the same particle cloud. This particle cloud passed the two delta P sensor points with a shift time. The shift time of 0.33 second was determined by cross-correlation function and shown in Figure 1.4. The statistical velocity of particle or particle cloud is 15.3 cm/s.

For the second test case, the probe was set at the location of Z=1.5" and R=2". Figure 1.5 shows the pressure fluctuations signal from channel #0 along with 0.08 psi pressure transducer. The average pressure drop is about 17 mmH_2O with a average pressure fluctuation of 3 mmH_2O. Figure 1.6 shows the pressure fluctuation signal from channel #1 along with 0.2 psi pressure transducer. The average pressure drop is about -1 mmH_2O with a average pressure fluctuation of 0.5 mmH_2O. By comparing two Figures 1.5 and 1.6, they have similar regions. The shift time of 0.77 second was determined and shown in Figure 1.7. The statistical velocity of particle or particle clouds is 6.5 cm/s.

For the third test case, the probe was set at a location of Z=1.5" and R=2.25". Figure 1.8 shows the pressure fluctuation signal from channel #0 along with 0.08 psi pressure transducer. The average pressure drop is about 3 mmH_2O with a average pressure fluctuation of 1 mmH_2O. Figure 1.9 shows the pressure fluctuation signal from channel #1 along with 0.2 psi pressure transducer. The average pressure drop is 4 mmH_2O with a average pressure fluctuation of 2 mmH_2O. The shift time of 0.33 second is determined and shown in Figure 1.10.

The statistical velocity of particle or particle cloud is 15.3 cm/s. The case 3 and case 1 indicate that the moving velocity of particle at near the wall region is faster than that at near the axis (or inner region). It is believed that the gas velocity near the wall region is faster than that the center region.

Figure 1.4 Signal Shift Time in 6" unit

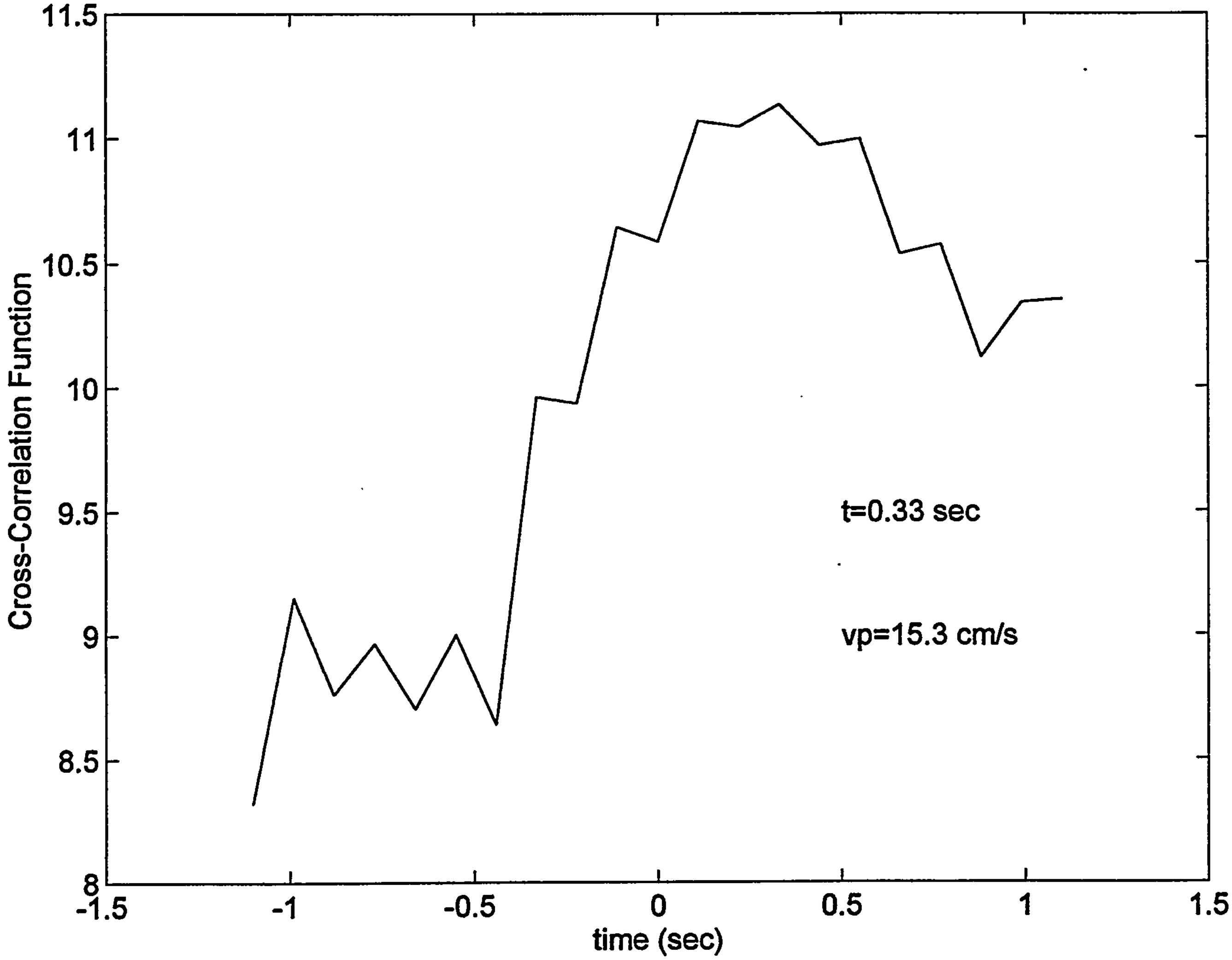


Figure 1.5 Background Signal from Channel #0 (0.08 psi)

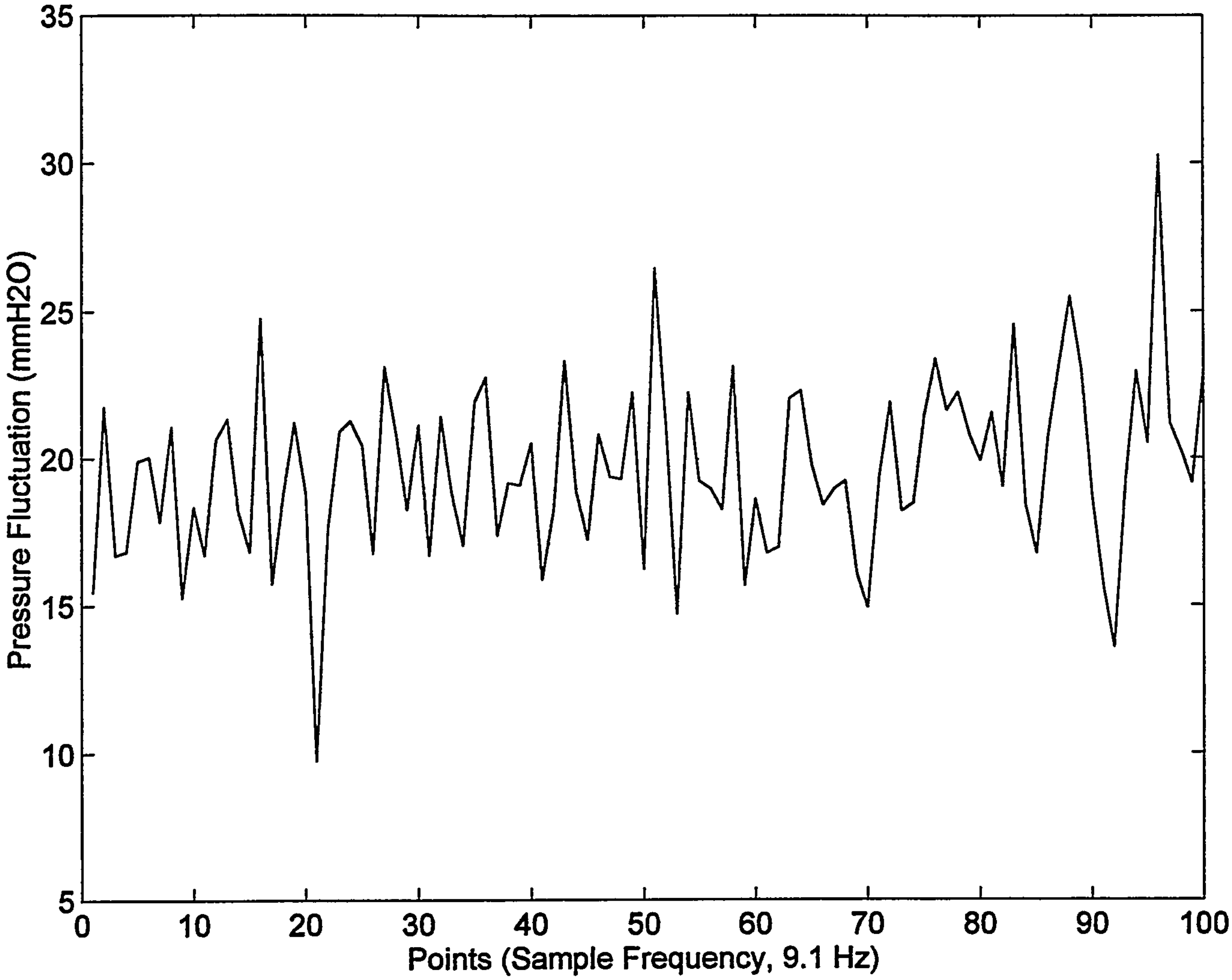


Figure 1.6 Background Signal from Channel #1 (0.2 psi)

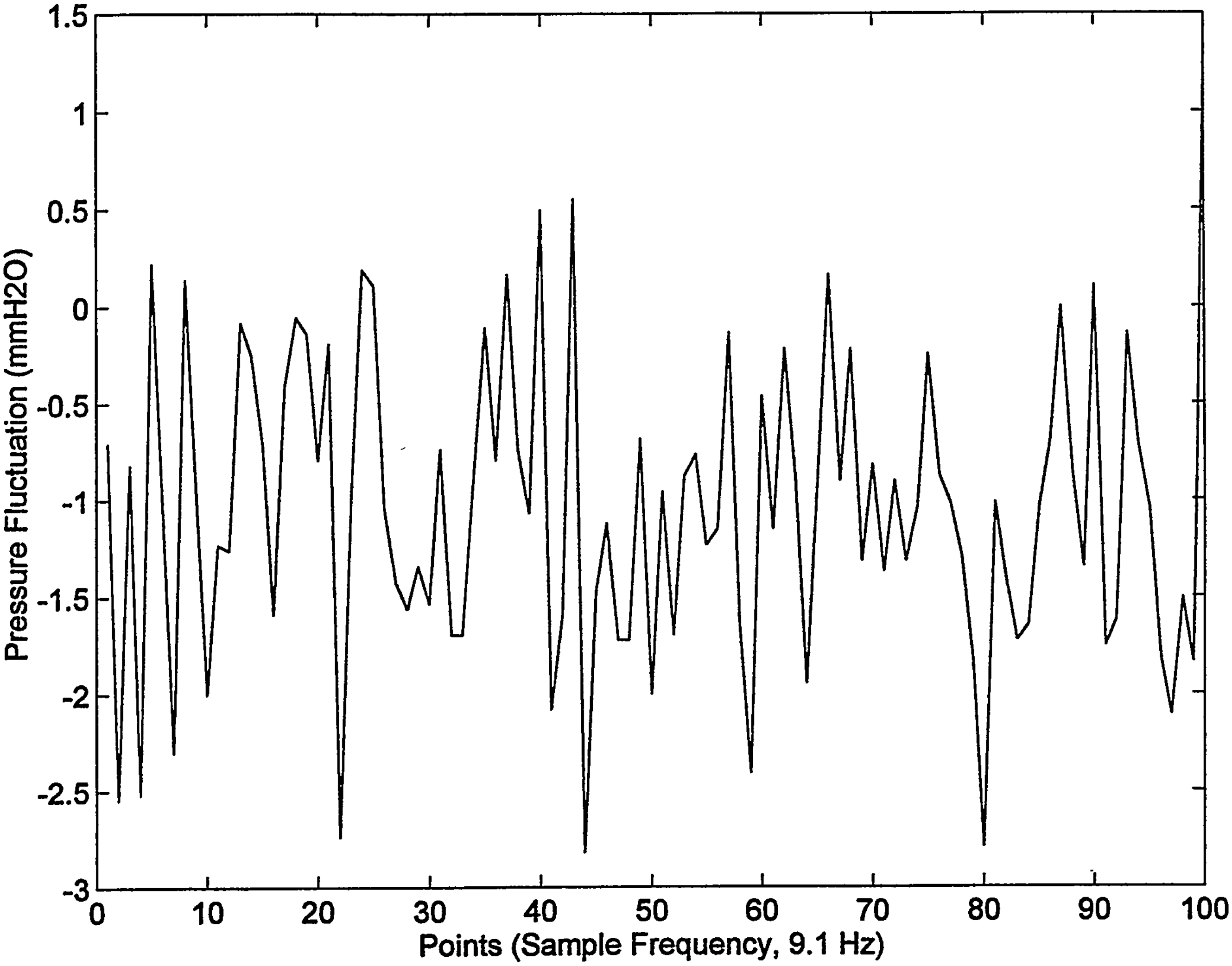
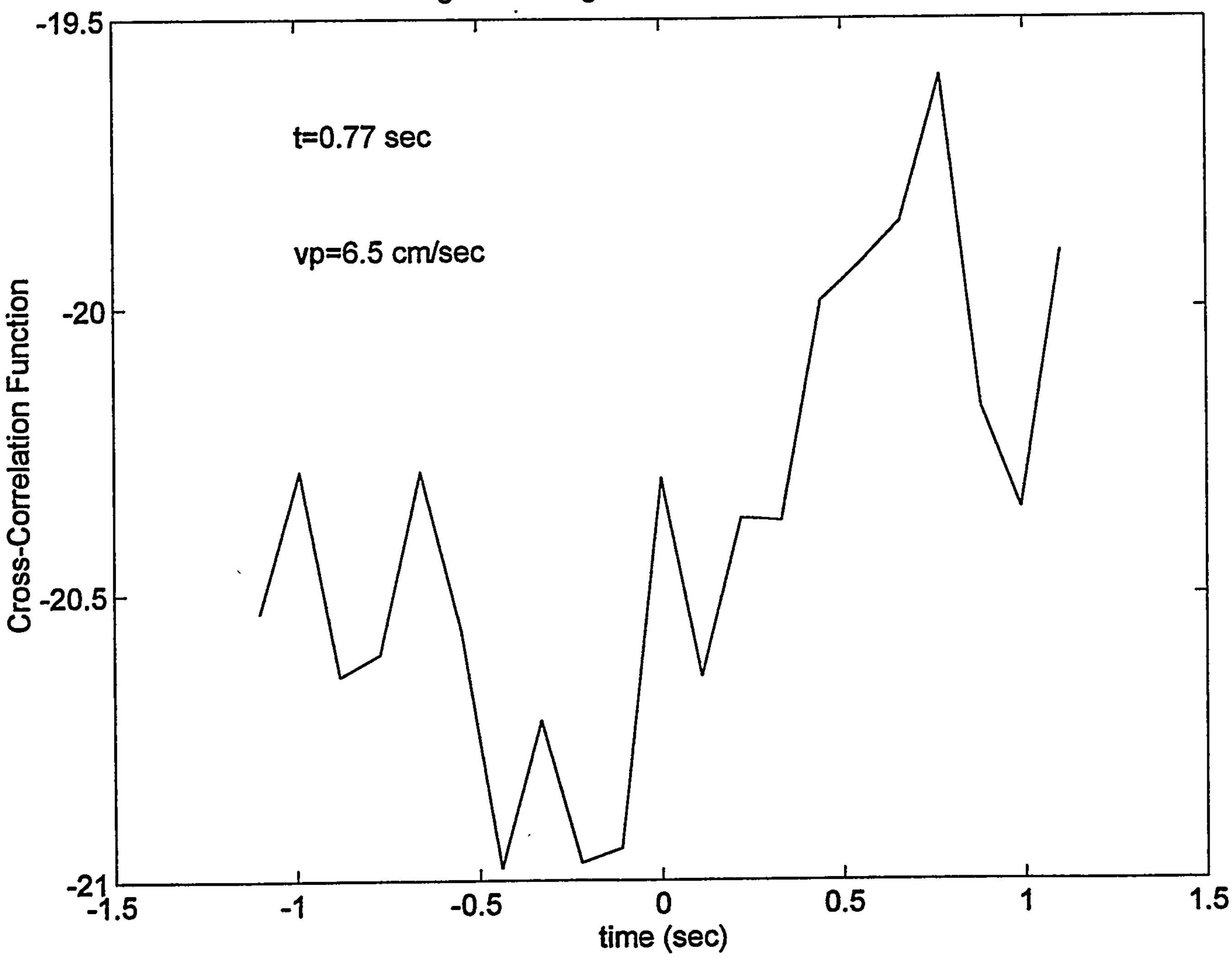


Figure 1.7 Signal Shift Time in 6" unit



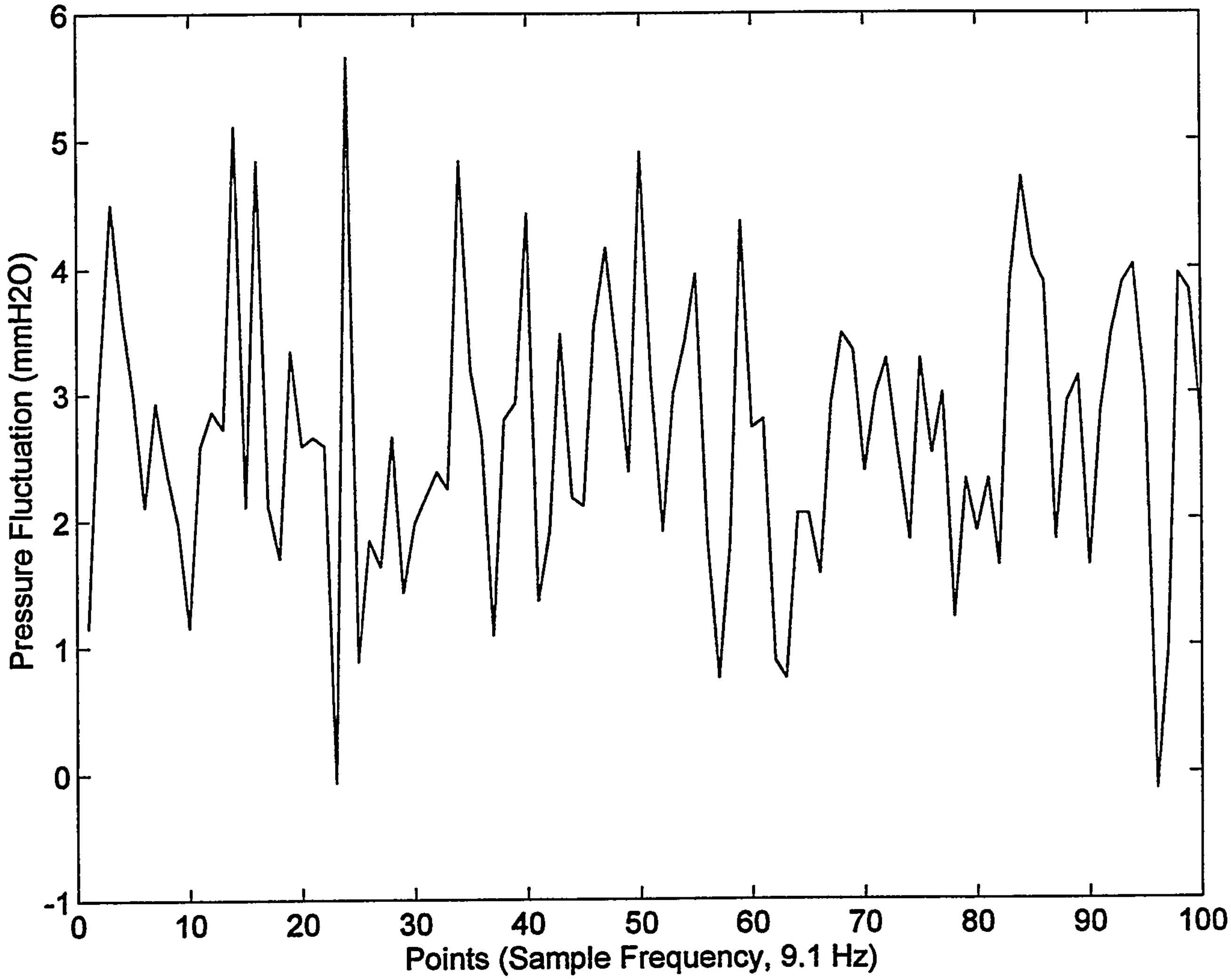


Figure 1.8 Background Signal from Channel #0 (0.08 psi)

Figure 1.9 Background Signal from Channel #1 (0.2 psi)

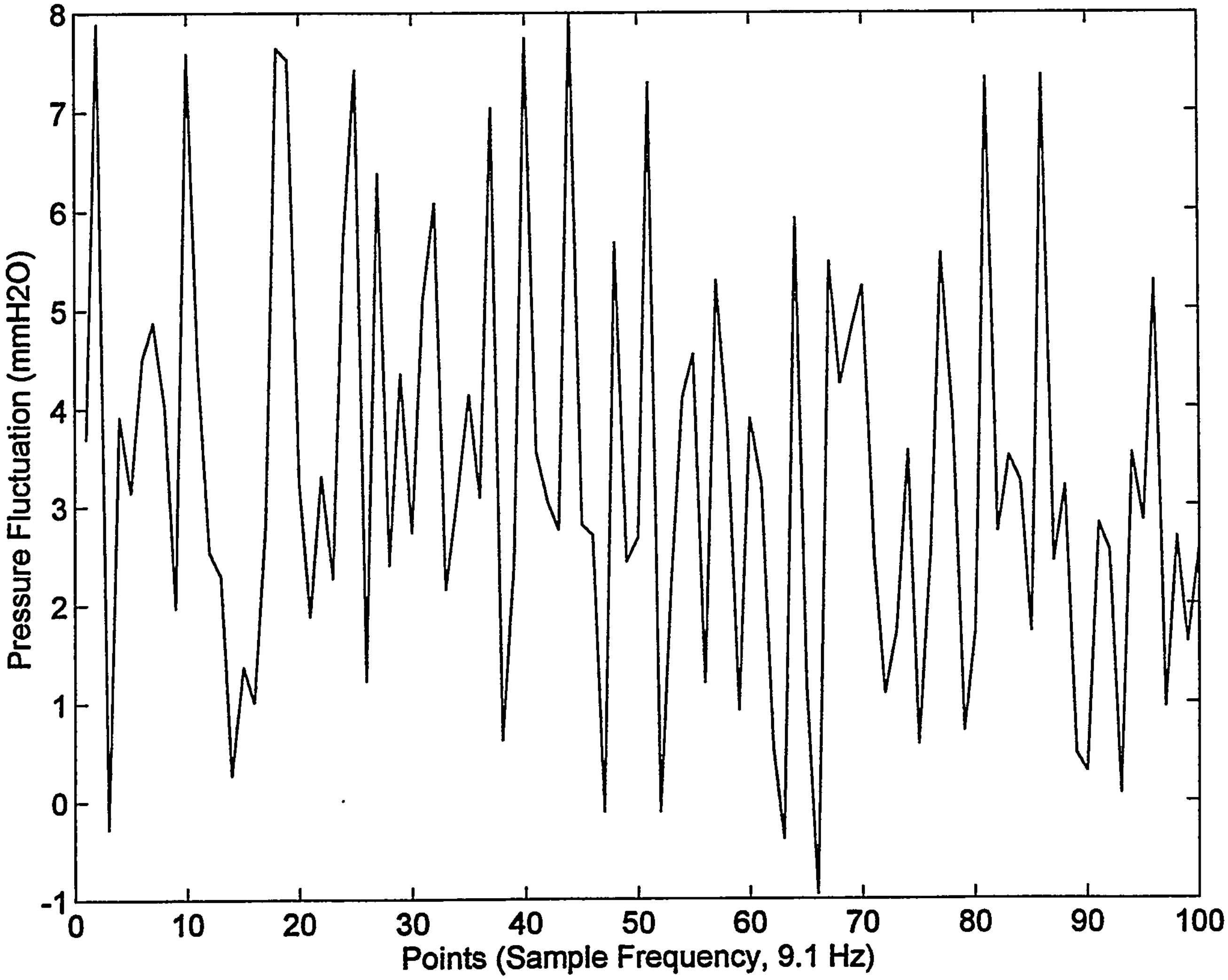
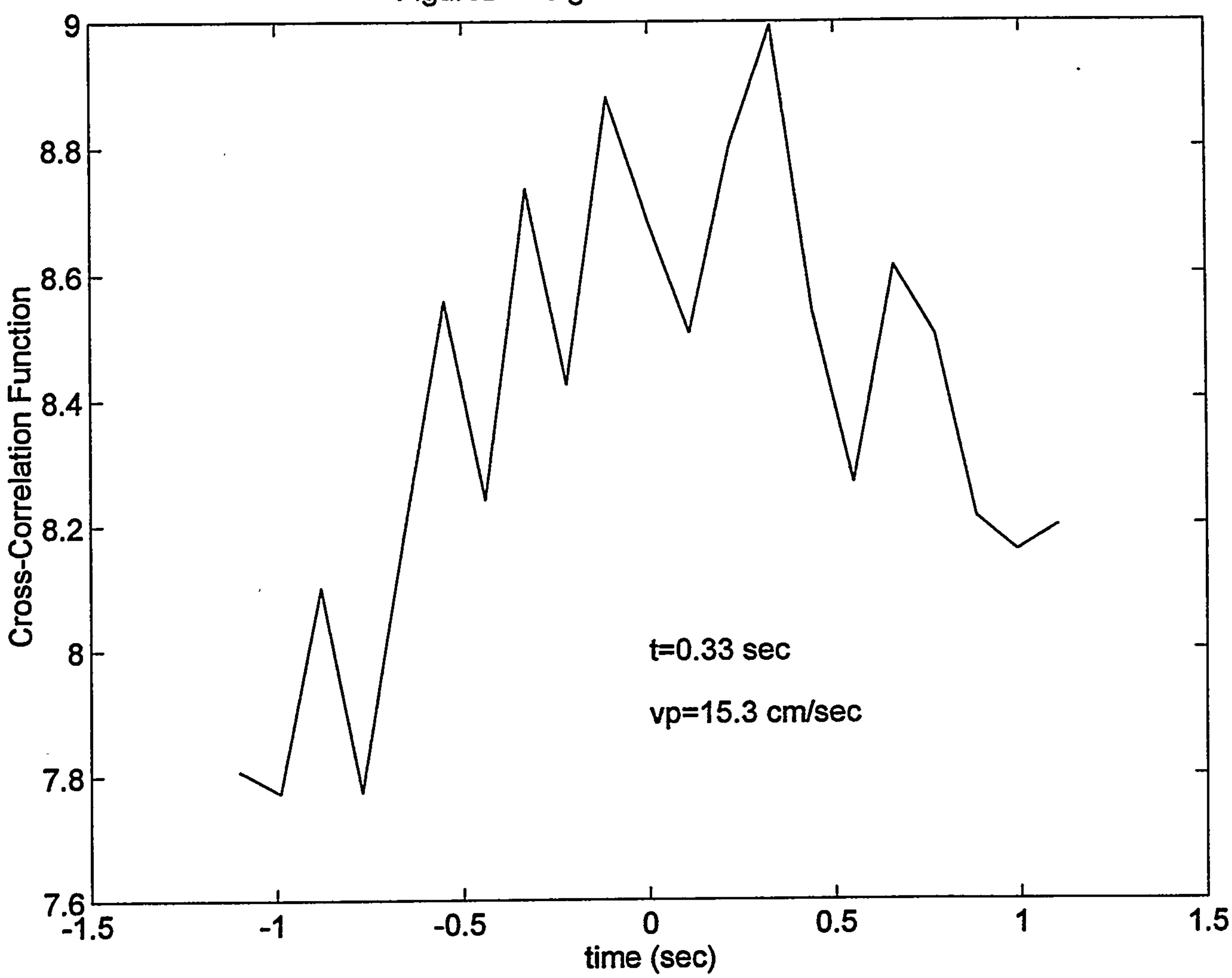


Figure1.10Signal Shift Time in 6" unit



SECTION 2

Auxiliary Subsystems of the Exploratory Hot Model

Design and fabrication of the exploratory hot model [5] were continued with an arrangement of the auxiliary subsystems.

2.1 Air Supply Subsystem

The primary air for this hot model was supplied by air blower. The blower's output is varied by changing the input voltage via a variable AC transformer. The primary air supply enters at the bottom of the combustion chamber through a wind box. The wind box is a small chamber with a perforated plate. Its purpose is to diffuse the air supply across the entire bottom of the combustion chamber.

The secondary air supply consists of two sets of four nozzles. The nozzles are entering the combustion chamber at 90 degrees. Each nozzle has a 45 degree angle cut on it. The air is supplied via the building at a pressure of 90 psi. Control valves can vary the air output. Two flow meters monitor the air flow in each of the two sets of nozzles.

2.2 Water Supply Subsystem

The water circulation subsystem for removing excess heat from combustion consists of a series of three different copper coils, water connecting pipe line, control valve, and flow meter. Each of three coils has its own control valve. These coils wrap around the outside of the chamber and provide surface cooling. The waste water is deposited into a drain. A main control valve varies the water input, while each coil's valve controls the coil flow. A flow meter monitors the total water flow.

2.3 Ignition Subsystem

Natural gas was used as the preliminary testing fuel. The ignition subsystem consists of regulators, flow meter, propane burner, fuel nozzle, and connecting tubing. The natural gas is supplied via the building at a pressure of 90 psi.

The fuel nozzle was specially designed with varying configurations, i.e. one hole, four holes to supply/burn the natural gas effectively in the chamber. A cone was added to the top of fuel nozzle which can protect the flame. The cone is constructed of a steel alloy approximately .015 " thick and has a top diameter of 1.5" and a height of 1.5" as shown in Figure 2.1. It is attached to the fuel supply tubing with a small hose clamp.

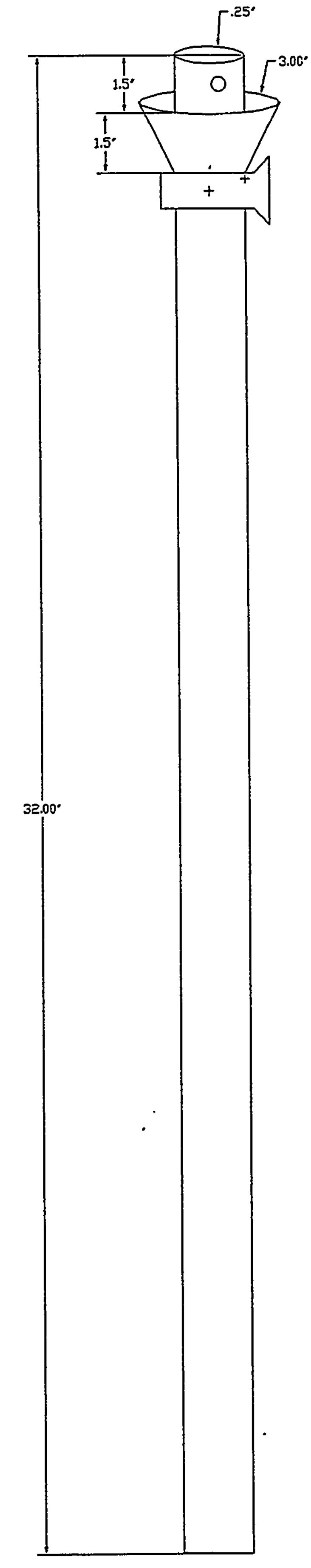


Figure 2.1 Schematic Diagram of Fuel Nozzle with a Cone

SECTION 3

Preliminary Test Results and Discussions

3.1 Test Preparation and Operating Procedures

According to the established safety and health guideline, the auxiliary subsystems were inspected carefully. All instruments are checked and calibrated for the preliminary test of exploratory hot model.

o Verify that all main control valves are closed. The water, secondary air, and gas valves are closed. Start the blower to supply primary air of the desired amount and mix with fuel (natural gas).

o Lighted propane torch through a hole in the combustion chamber. Observe the flame in angled mirror. Adjust control valves to the desired settings while constantly observing the combustor flame.

o According to the test plan, adjust the test parameters, such as primary/secondary air flow rate, and total excess air to the desired values.

o Allow the system to stabilize for a minimum of 10 minutes prior to recording any temperatures.

o After moving any thermocouple probe to measure temperature, let the temperature stabilize for a minimum of 5 minutes before recording data.

3.2 Thermal Performance of the Preliminary Test Results

Temperature is measured via K-type thermocouples connected to a rotary switch and displayed on a digital display. Thermocouples are located in holes in the chamber at distances of 8", 16", and 24.5 " from the bottom of the combustor. The thermocouples' positions will be varied radially within the chamber. Their radial positions will be the center, 1" from the center, 2" from the center, and 2.5" from the center. Thermocouples are also located at the top of the chamber to measure flue gas temperature.

Figure 3.1 shows a typical distribution of combustion temperatures at the different location of the combustor. The fuel nozzle is located at 8" from the bottom of chamber. Secondary flow rates for top and bottom regions are 4 CFM and 8.5 CFM respectively. Table 3.1 shows detailed test conditions for this test. The averaged vertical temperature gradient along the longitudinal axis of the combustion chamber decreased.

Figures 3.2 and 3.3 show test results with the primary air on and secondary air nozzles at 90 degrees. Tables 3.2 and 3.3 show detailed test condition for each test. Results showed as before that the highest temperatures were obtained in the radial center of the chamber and at 8" vertical location. Having the primary air at 100% and approximately 55% respectively lowered the radial center temperature by approximately 900 F. This could be a result of too high primary air velocity with fully opened exit of the combustor.

TABLE 3.1 **Test Conditions**

Hot Model Preliminary Test Data Conducted 6/14/96
Straight 4 hole Fuel Nozzle height at 8" from bottom
NO Primary air flow
FUEL: Natural Gas
Water flow rate 1.5GPM / all valves open

Secondary air top	4 cfm
Secondary air top	8.5 cfm
Cooling Water in	70.9 F
Cooling Water out	70.5 F

Thermocouple No.	Distance (in) From Bottom	Temp (F) Center	Temp (F) 1" from center	Temp (F) 2" from center	Temp (F) 3.5" from center	Temp (F) Surface	Avg temp
K1	8	630	1131	1144	444	360	837.25
K2	16	464	606	583	281	254	483.5
K3	24.5	523	530	500	195.8	205	437.2
	avg 3 therm.cpls	539.00	755.67	742.33	306.93		**585.98**

FIGURE 3.1

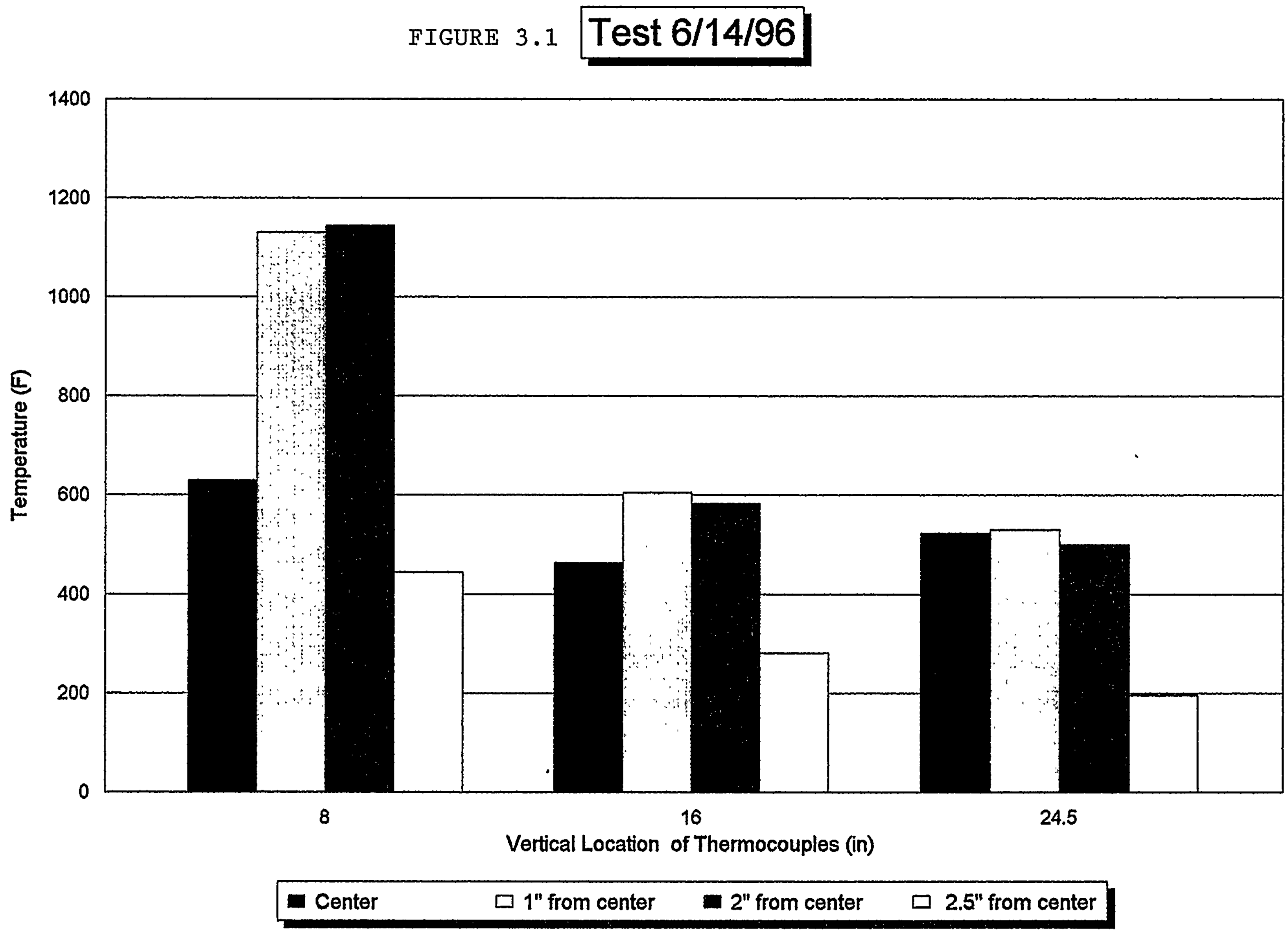
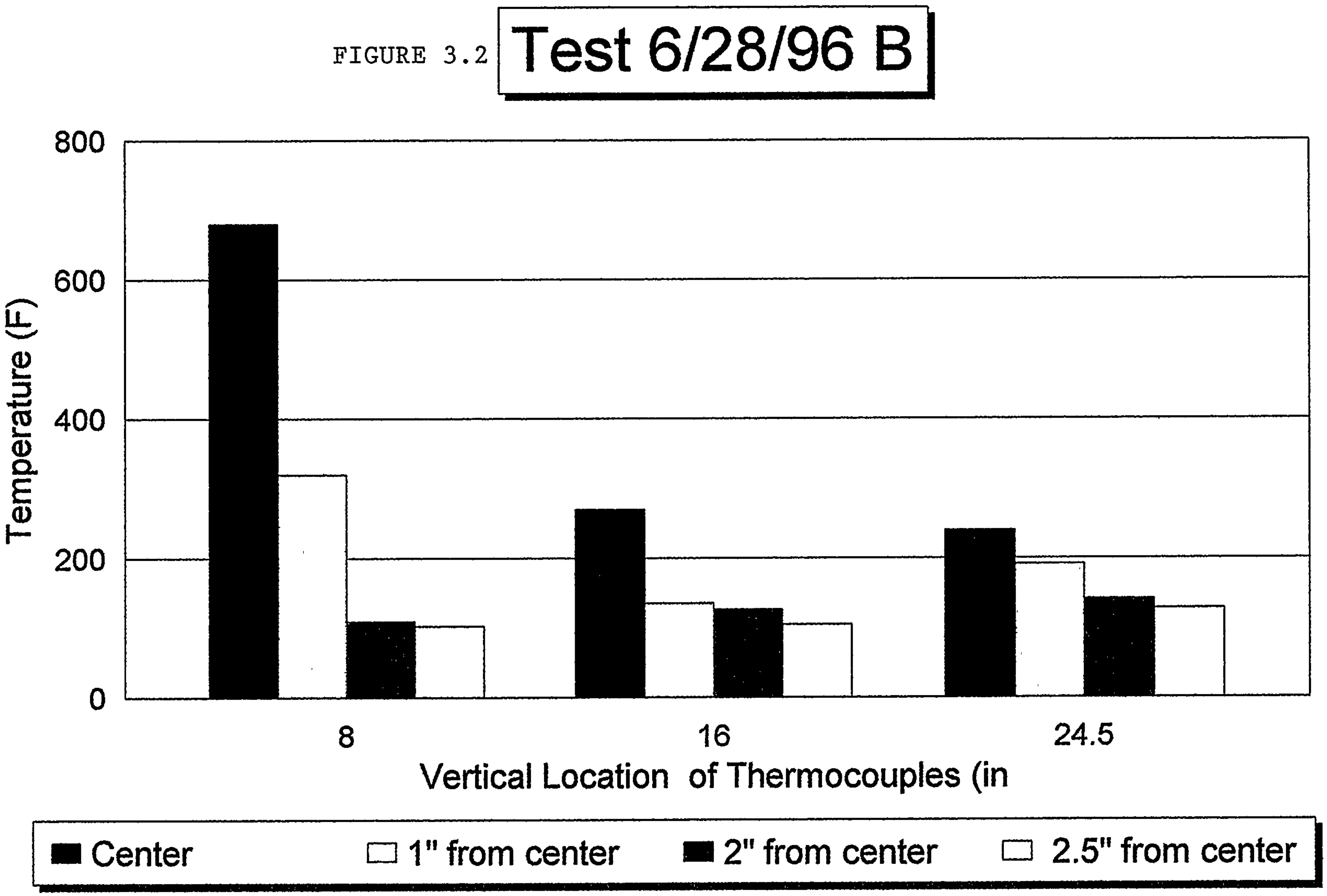

Test 6/14/96
Temperature (F)
1400
1200
1000
800
600
400
200
0
8
16
24.5
Vertical Location of Thermocouples (in)
Center
1" from center
2" from center
2.5" from center

TABLE 3.2 **Test Conditions**

Hot Model Preliminary Test Data	Conducted 6/28/96 B	
With Primary Air	1.7 in H_2O	
Straight 5 hole Fuel Nozzle at 5"		
FUEL: Natural Gas	Fully open	
Water flow rate		All coils @ 100%
secondary nozzle an(	90	
Secondary air top	11 cfm	
Secondary air top	11 cfm	
Cooling Water in	71.2	
Cooling Water out	71.2	
Cooling water flow	1.5 gpm	
Flue Temp	216	

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	680	320	109	102	87.5	302.75
K2	16	270	135	126	105	87.5	159
K3	24.5	240	191	141	127.7	110	174.925
	avg 3 therm.cpls	396.67	215.33	125.33	111.57		212.23

FIGURE 3.2



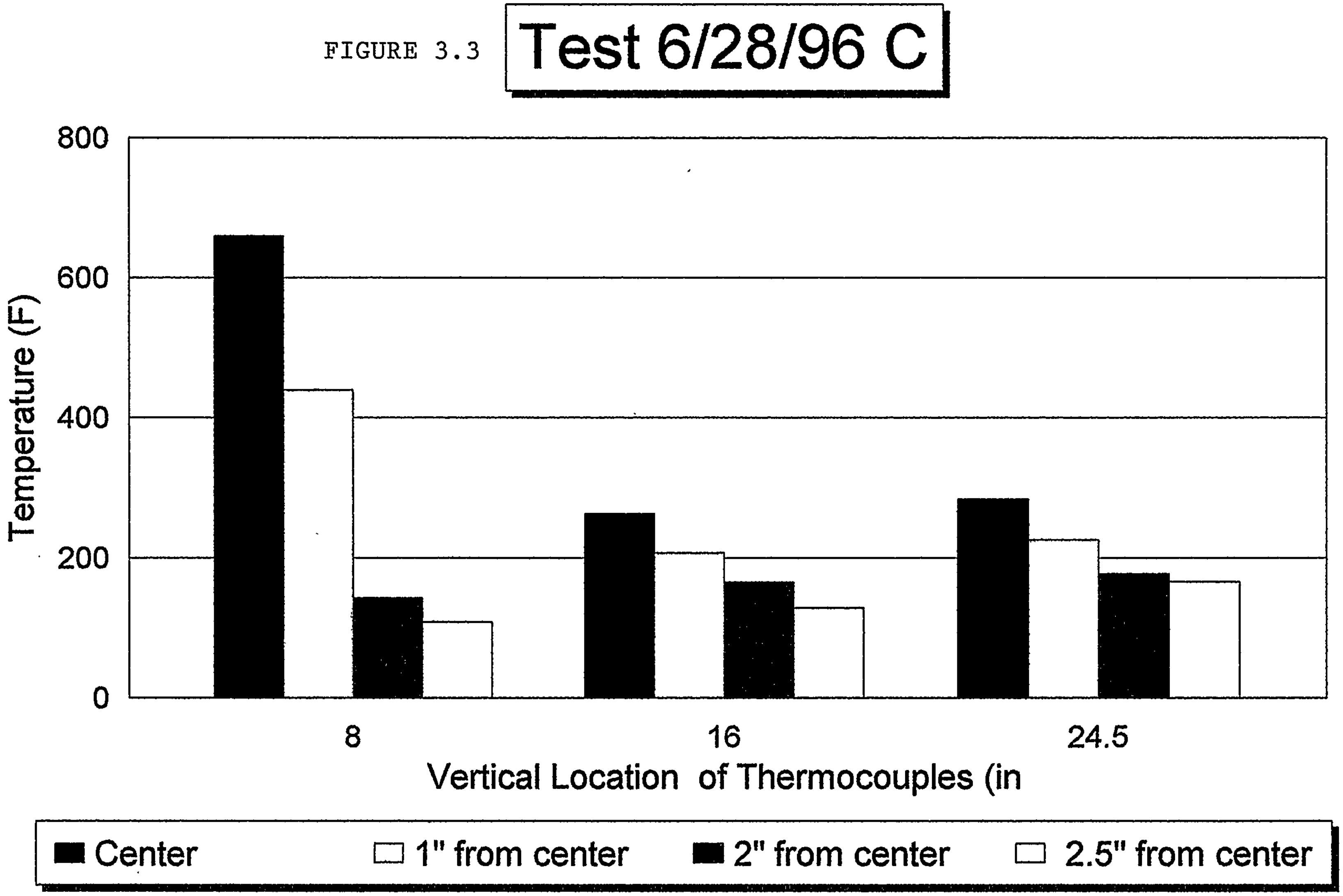
Test 6/28/96 B
800
600
400
200
0
Temperature (F)
8
16
24.5
Vertical Location of Thermocouples (in
Center
1" from center
2" from center
2.5" from center

TABLE 3.3 **Test Conditions**

Hot Model Preliminary Test Data	Conducted 6/28/96 C	
With Primary Air	.68 to .85 in H_2O	
Straight 5 hole Fuel Nozzle at 5"		
FUEL: Natural Gas	Fully open	
Water flow rate	1.5 gpm	All coils @ 100%
secondary nozzle an(	90	
Secondary air top	11 cfm	
Secondary air top	11 cfm	
Cooling Water in	71.2	
Cooling Water out	71.2	
Cooling water flow	1.5 gpm	
Flue Temp	216	

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	660	440	143	108.5	89.6	337.875
K2	16	263	207	165.1	129	92.6	191.025
K3	24.5	284	226.3	176.9	166	112.6	213.3
	avg 3 therm.cpls	402.33	291.10	161.67	134.50		**247.40**

FIGURE 3.3



Test 6/28/96 C
800
600
400
200
0
Temperature (F)
8
16
24.5
Vertical Location of Thermocouples (in
Center
1" from center
2" from center
2.5" from center

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