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

TO

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ABSTRACT

This technical report summarizes the research conducted and progress achieved during the period from April 1, 1997 to June 30, 1997.

The exploratory hot model was modified to explore the operational limits, fuel flexibility, and the role of heat transfer in combustion control. Eight air injection nozzles were newly designed to set different angles. Three runs of independently controllable water-cooling tubes were arranged to study the local heat transfer characteristics along the flow direction of the combustor height. The fuel nozzle was carefully designed to improve the fuel atomization quality. The igniter system was designed to safe and dependable ignition.

According to the established safety and health guideline, the auxiliary subsystems are inspected carefully. All instruments are checked and calibrated for the system test.

The combustion test result was analyzed to understand thermal performance and heat transfer characteristics. The flame enthalpy decreased along the combustor height. The heat is removed by the cooling water at different zones during the combustion test. The axial variation of heat transfer coefficient was predicted. The heat transfer coefficient is generally lower in the top area than in the bottom of the combustor.

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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.

The exploratory hot model was modified to explore the operational limits, fuel flexibility, and the role of heat transfer in combustion control. Air injection nozzles were newly designed to set different angles. Three runs of independently controllable water-cooling tubes were arranged to study the local heat transfer

characteristics along the flow direction of the combustor height. Fuel nozzle and igniter system were developed to improve fuel atomization quality and safe ignition/startup. The auxiliary subsystems were inspected carefully by safety guideline.

The combustion test was analyzed to predict thermal performance and heat transfer characteristics. The computer program will be developed to analyze the combustion test results. Numerical simulation work will be continued to better understand thermal performance and heat transfer effect in the combustor.

SECTION 1

MODIFICATION OF THE EXPLORATORY HOT MODEL

Based upon the data and operating experience obtained from exploratory hot model tests, the exploratory combustor model [1] was modified to explore the operational limits, fuel flexibility, and the role of heat transfer in combustion control.

(1) Design of Air Injection Nozzles

Air injection nozzles was originally designed with a 90 degree input angle and yaw, which could be varied [4]. However, varying roll was difficult. one would have to place their arm inside the chamber and manipulate the roll by hand.

Eight air injection nozzles were incorporated into new design. Four nozzles were set at a 30 degree angle and the remaining four at a 60 degree angle. These nozzles can be rotated to 360 degree direction. The nozzle is approximately 111 in length with a tapered outlet with a 0.12511 diameter as shown in Figure 1. A round bar stock with a 0.12511 diameter and a measured length of 1/1611 was incorporated into the nozzle placement. These stocks were attached and held in place with a coins acting as a sliding lock. This coin was drilled and tapped into place as shown in Figure 2. In addition, an eccentric locking disc positioned the nozzles at the correct depth in the chamber wall. High temperature tubing attached the nozzles to the air supply.

(2) Design of Water Cooling Tube

Heat transfer surfaces, such as water jacket or water cool-

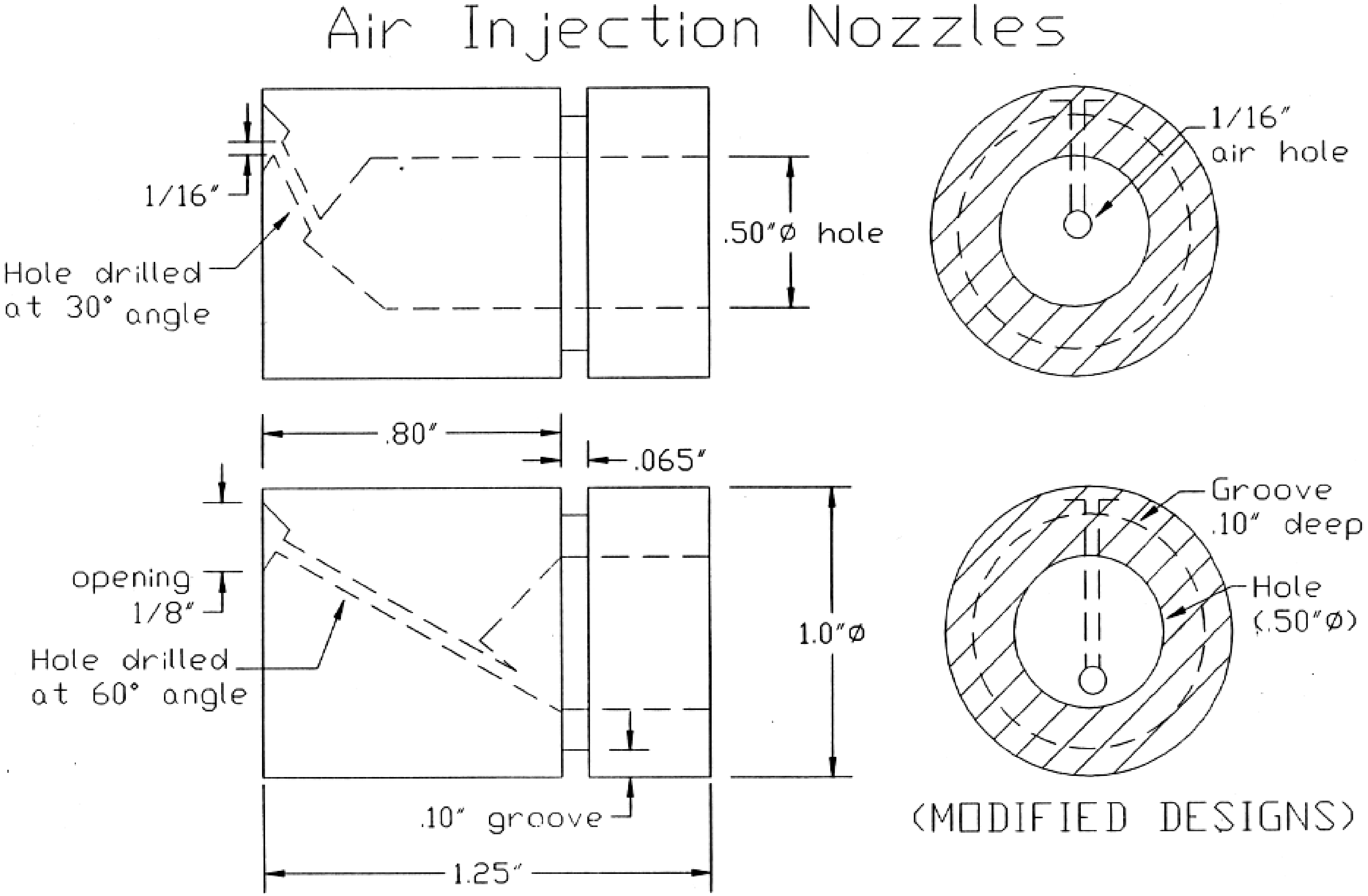

Figure 1 Schematic Diagram of Air Injection Nozzles (Type B)

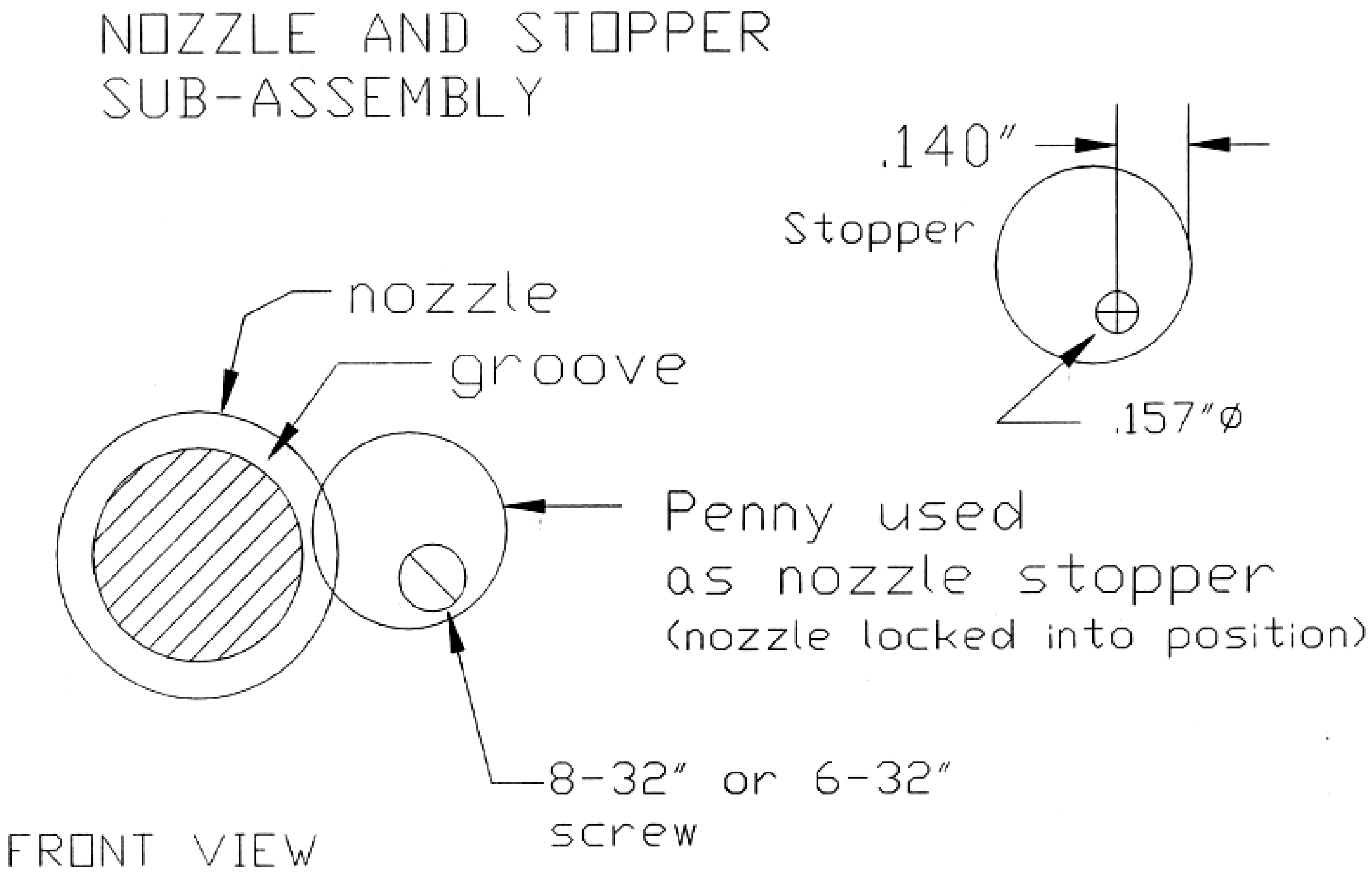

Figure 2 Schematic Diagram of Nozzle and Sub-Assembly System

ing tube, are provided to remove the excess heat and control for stable ignition and good burnout in the combustor.

For our hot model, three runs of independently controllable water-cooling tubes with 0.2511 diameter copper tube wound on the outer wall for studying the local heat transfer characteristics along the height of the combustor.

(3) Design of Fuel Injection Nozzle

The atomization quality and condition of a fuel nozzle significantly affect the ignitability, flame stability, and combustion efficiency of the fuel [5].

Type A nozzle [4] has been used for exploratory tests, which was designed with small cone to protect the flame. This nozzle could atomize the gas at 90 degree angle from vertical causing flame to hit chamber walls. However, the flame was not stable with secondary air injection.

Type B is carefully designed to atomize fuel effectively at 45 degree angle from the vertical direction as shown in Figure 3. Eight holes were drilled to keep stable flame.

(4) Design of Igniter System

The igniter system was designed to safe and dependable ignition of natural gas for combustion test. Electrodes were placed over fuel nozzle path. The igniter push button was attached to the ground screw as shown in Figure 4. Whenever the igniter button was pushed, the spark appeared in the collector box. This igniter system could ignite within 3 seconds.

(5) Design of Combustion Chamber

The combustion chamber is made from the carbon steel cylinder of 3011 height, 6.62511 outer diameter, and 611 inner diameter. This chamber was aligned with 0.511 a refractory coating of inside chamber. Eight holes of secondary air input are arranged with two different levels 1111 and 1911 respectively from the bottom of the

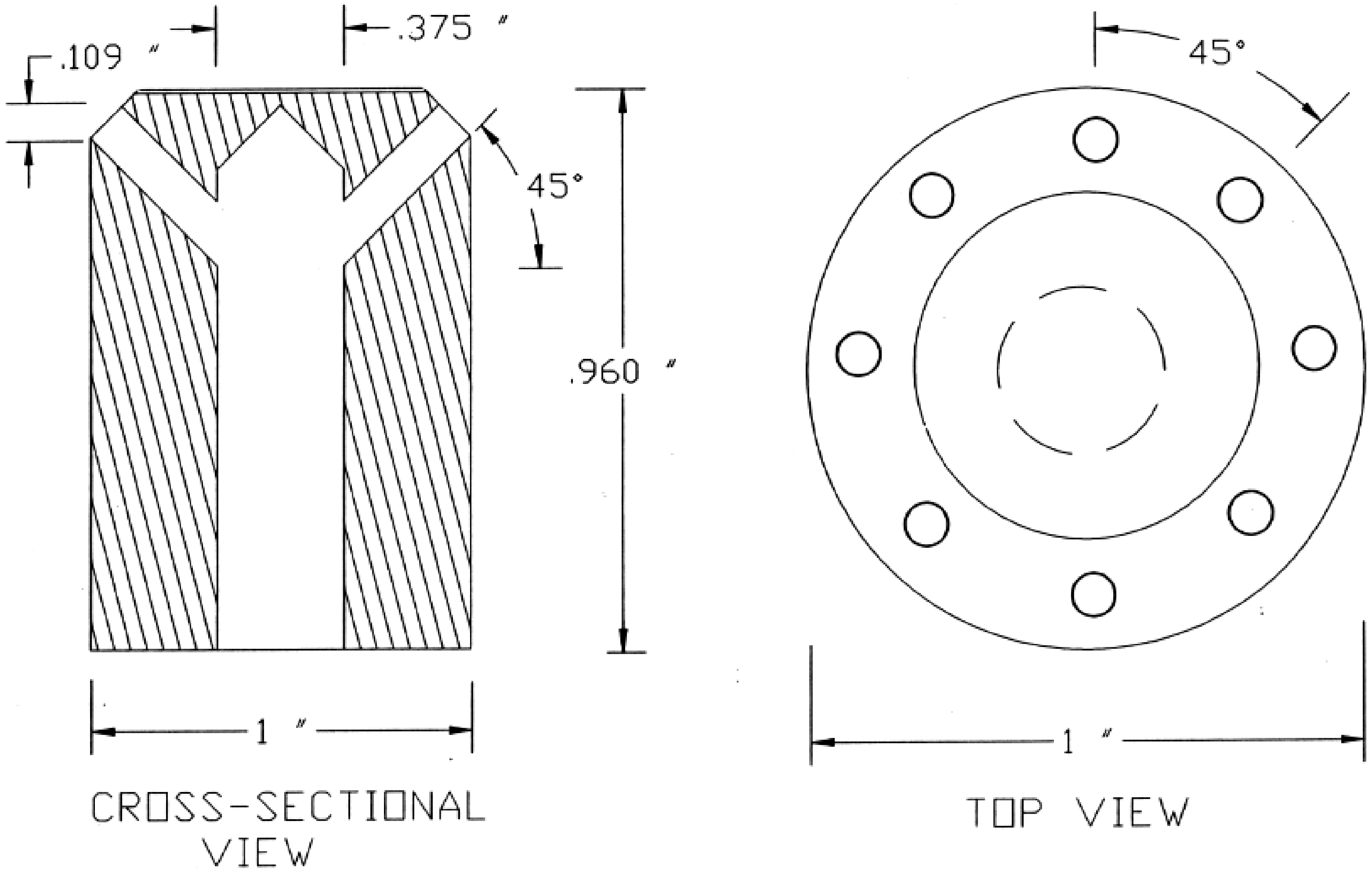

Figure 3 Schematic Diagram of Fuel Injection Nozzle

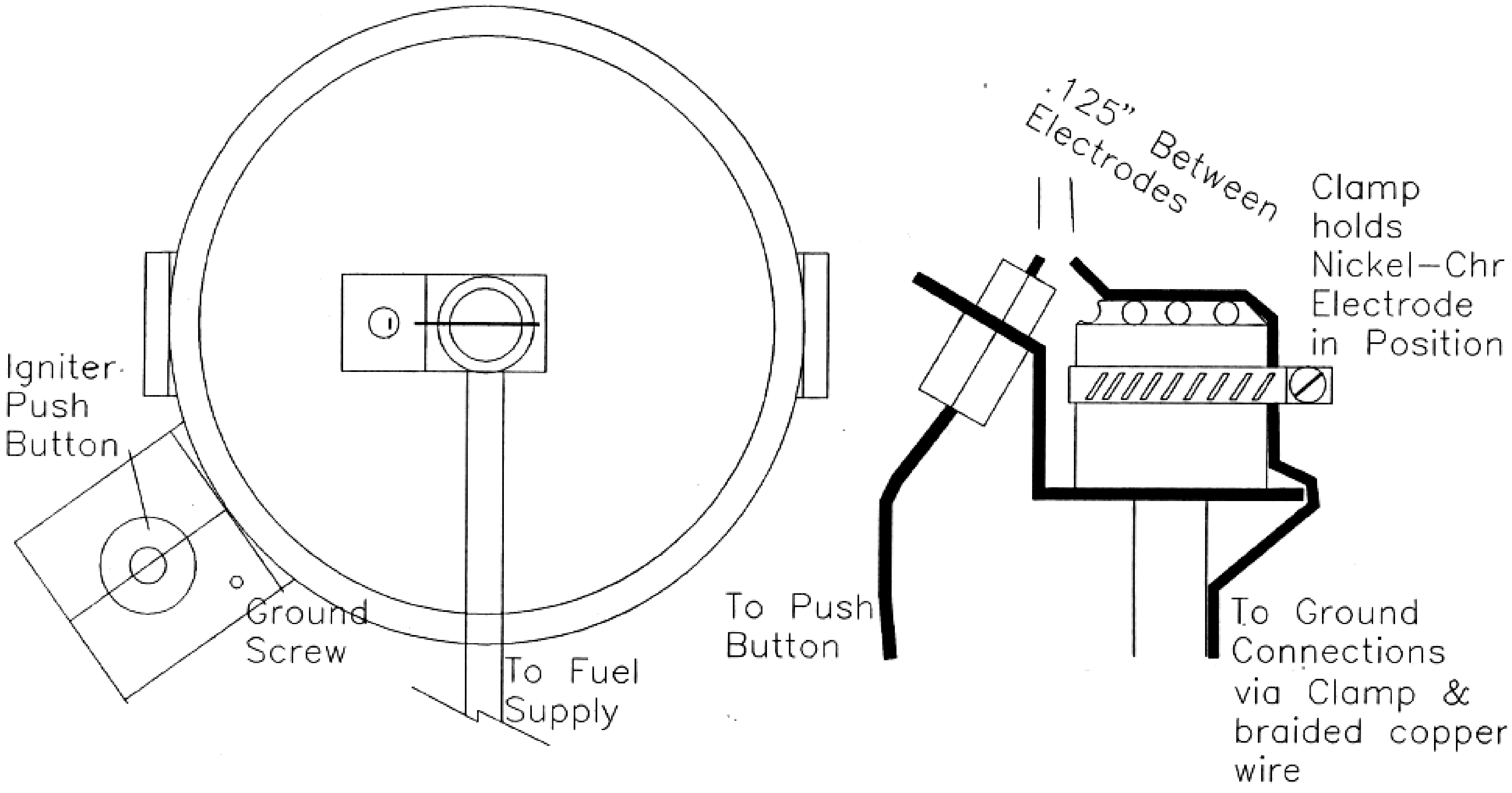

Figure 4 Schematic Diagram of Igniter System

combustion chamber. In addition, three holes were cut for the temperature measurements at different levels 1111, 1911, and 2711 respectively from the bottom of the combustion chamber.

SECTION 2

RESULTS AND DISCUSSIONS

2.1 Test Preparation and System Test

The experimental setup consists of the modified combustor, air supply system, fuel supply system, heat removal system, start-up system, and instrumentations for thermal performance analysis.

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

2.2 Thermal Analysis and Heat Transfer Effect

The combustion test result was analyzed to understand the thermal performance and heat transfer characteristics on the modified exploratory hot model. The fuel flow rate was 21 cubic per hour (cfh). The secondary air was provided evenly 2 cubic feet per minute (cfm) for upper and lower levels. The cooling water flow rates for the three different sections of the heat transfer surface were 0.81, 0.73, and 0.2 gallon per minute from the bottom to the top surface of the combustor chamber. The cooling water inlet temperature was 71 F. The average gas combustion gas temperature was 1209 F. The flue gas temperature was 843 F.

The related equations for thermal analysis, heat balance, and heat transfer coefficient calculation were described in the previous report (6]. The results of heat balance calculation are summarized as follows:

Based on 1 minute of time period. The fuel is natural gas (95% of CH4)

Fuel combustion heat, Qr:	**328.07**	**kJ**
Fuel input enthalpy, Hf:	**0.3828**	**kJ**
Air input enthalpy, @:	**3.573**	**kJ**
The input flow enthalpy,	**3.955**	**kJ**
Flu. gas enthalpy, H,,:	**76.17**	**KJ**
Heat loss from cooling water,	**Q,:**	
Bottom Section	**44.57**	***KJ***

Middle Section	70.61	KJ
Top Section	14.2	KJ

Heat loss from the reactor wall, QL, can be calculated using the equation (2)

QL = Q,-Q,,- (H--@') = 127.7 (KJ)

The local average heat transfer coefficient from hot gas to the cooling water, hg-,:

Bottom Section	10.15	W/@.OC
Middle Section	16.11	W/@.llc
Top Section	3.23	w/@ oc

The overall average heat transfer coefficient from hot gas to the enveronments, h.-L: 6.81 w/@.OC

The flame enthalpy and flame heat loss changing along the reactor height.

Distance from the bottom (inch)	Flame enthalpy (KJ)	Flame heat loss (KJ)
8	176.14	21.67
16	154.47	35.72
24	118.75	42.58

The dimensionless height based upon the combustor height, H are 0.28, 0.55, and 0.83. The flame heat loss increased along the combustor height. However, the flame enthalpy decreased as shown Figure 5. It is believed that the changes of heat loss/flame enthalpy depended on the combustion temperature and location.

The axial variation of heat transfer coefficient along the combustor chamber is shown in Figure 6. The heat is removed by the cooling water at different zones during the combustion test. The top portion of combustor absorbed least heat from hot combustion gases. The heat transfer coefficient is generally lower in the top area than in the bottom of the combustor as shown in Figure 6.

SECTION 3

CONCLUSIONS

The exploratory combustor model was modified to explore the operational limits, fuel flexibility, and the role of heat transfer in combustion control. Eight air injection nozzles were newly designed to set at different angles. Three runs of independently controllable water-cooling tubes were arranged to study the local heat transfer characteristics along the flow direction of the combustor height.

The auxiliary subsystems were inspected carefully by safety guideline. All instruments are checked and calibrated for the system test.

The combustion test was analyzed to predict thermal performance and heat transfer characteristics. The top portion of the combustor absorbed least heat from hot combustion gases. The heat transfer coefficient is generally lower in the top area than in the bottom of the combustor. The computer program will be developed to analyze the combustion test results.

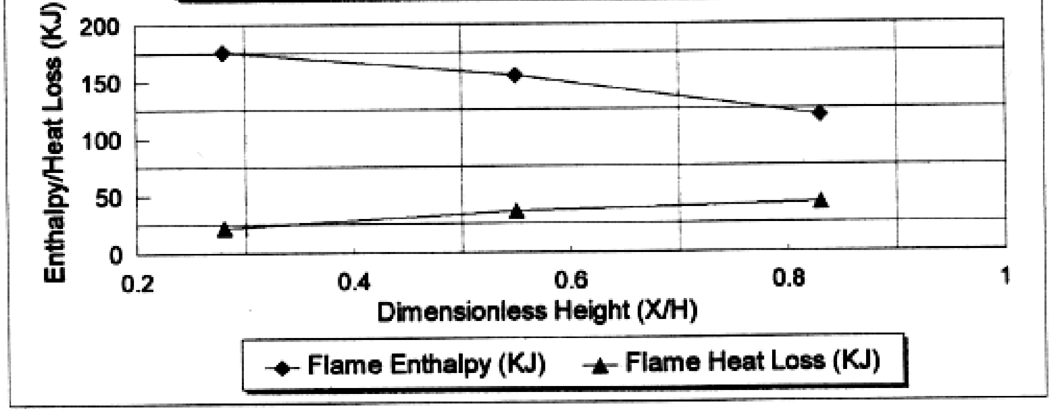

Figure 5 The Changes of the Flame Enthalpy/Heat Loss along the Combustor Height

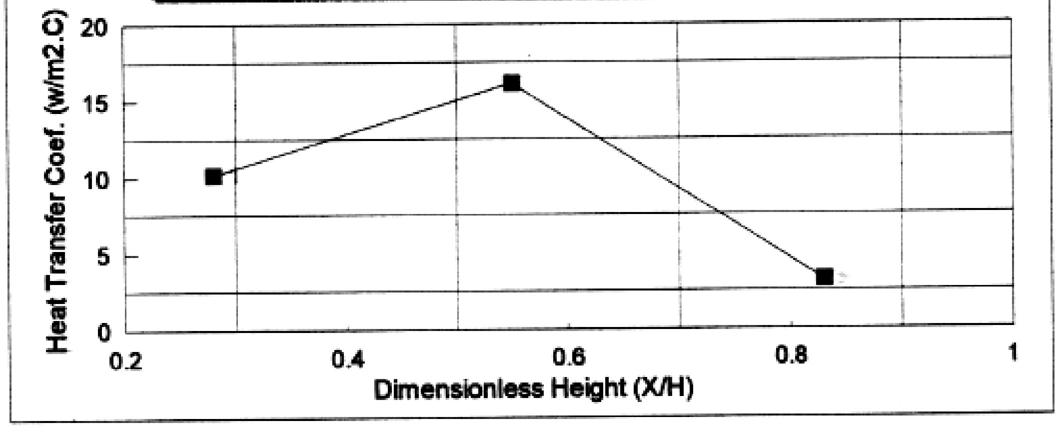

Figure 6 Local Heat Transfer Coefficients for the Three Sections in the Combustion Chamber

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