FE-2489-40
Dist. Category UC-90

DEVELOPMENT OF COMBUSTION DATA TO UTILIZE LOW-Btu GASES AS INDUSTRIAL PROCESS FUELS

MASTER

Project 61004 Special Report No. 6

HIGH-EXCESS-AIR BURNER

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Date Published — March 1979

Prepared for the
UNITED STATES DEPARTMENT OF ENERGY

Under Contract No. EX-76-C-01-2489

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ABSTRACT

Data were collected to evaluate the performance of a high-excess-air type burner when retrofit with low-Btu gases. The burner, a North American Model 4422-7 XSA, was fired on the IGT pilot-scale test furnace with a load simulating a section or zone of a refractory kiln. The low-Btu gases simulated for these combustion trials were Koppers-Totzek oxygen (KTO), Wellman-Galusha air (WGA), and Winkler air (WA) fuel gases.

KTO exhibited no flame stability problems at a 3 million Btu/hr firing rate with excess air levels from 10% to 77% - the maximum air flow our blower could attain. KTO did not require a burner pilot for stability. WGA fired at 3 million Btu/hr was stable with a pilot flame at excess air levels from 10% to the blower maximum, which was 65% excess air for WGA. With no pilot flame, WGA blew off in all cases. With the pilot, WA, at 3 million Btu/hr, did not have a stable flame, even with only 10% excess air; however, at 2.5 million Btu/hr WA had a stable flame at excess air levels from 10% to the maximum, 97%, with the pilot on. Blowoff occurred when the pilot was extinguished.

KTO, with 50% excess air, gave a higher thermal efficiency and peak flame temperature than natural gas with the same excess air level. WGA fired at 10% excess air performed as well as the natural gas with 50% excess air in terms of thermal efficiency and exceeded natural gas in radiant flux. WGA however, had a flame length about 3 times that of natural gas. WA at 2.5 million Btu/hr, 10% excess air had the same thermal efficiency (25%) as natural gas exhibited at 3.0 million Btu/hr with 50% excess air, but had lower gas temperatures and radiant flux.

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OBJECTIVE

The use of low-Btu gases is a promising way for industry to meet its need for an environmentally acceptable fuel to supplement or replace natural gas and oil. Information is needed, however, to determine the extent of the problems of utilizing these fuels on existing equipment. This program is designed to develop the combustion data necessary to evaluate the feasibility of converting existing process heating equipment to the use of low-Btu gases.

Eight types of industrial burners are being tested during the program using three different low-Btu gases. The performance of each burner with these gases will be compared to its performance with natural gas in terms of flame stability and shape, furnace efficiency, heat absorption profile, noise level, temperature profiles, radiant heat flux, post-flame emissivity, and flow direction.

INTRODUCTION

The relative availability of coal makes it desirable to utilize coal as an energy source for more industrial processes. However, for technical or environmental reasons, many processes are not able to directly fire coal. The conversion of coal to a low-sulfur, ashless, low-Btu gas for use in boilers and industrial heating processes could solve the environmental and energy supply problems. Of particular concern, however, are the potential furnace operating problems or losses in production when a facility originally designed to use natural gas is retrofit to use low-Btu gas. This program was developed to gather the combustion data necessary to evaluate the feasibility of converting existing process heating equipment to use low-Btu gases.

Combustion data will be gathered for eight types of industrial burners with three low-Btu gases in order to evaluate the magnitude of the retrofit problem. The three fuel gases are Koppers-Totzek oxygen, Wellman-Galusha air, and Winkler air. The eight types of burners are forward flow, kiln, nozzle mix, high forward momentum, flat flame, high excess air, premix tunnel, and boiler burner. The firing level and load configuration on the IGT pilot-scale furnace will be adjusted to simulate a furnace on which each burner is typically found. The following data will then be collected:

- Rate of gas and air flow into the burner
- Combustion air preheat temperature
- Velocity of fuel and air at burner outlet
- Flue-gas temperature
- Volume of flue gases
- Flue-gas species concentrations
- Heat absorption profile
- Resonance noise level
- Flame length measurements and photographic documentation of the flame
- Flame-width measurements
- Furnace efficiency
- Radiant heat flux from the flame

- Radiant heat flux across the furnace
- Post flame emissivity
- Average flame temperature at six axial and ten radial positions along the furnace center line
- Flow direction profile.

This report presents the results of combustion trials using a North American Model 4422-7 XSA burner, which is representative of the high-excess-air burner type. The burner size and firing rate were chosen to simulate the firing density (Btu/CF-hr) in a section or zone of a refractory kiln.

While firing natural gas at 3 million Btu/hr with 50% excess air, the load was adjusted to extract 25% of the heat input. Data were collected for natural gas firing and then for each of the three low-Btu gases. The following sections describe the furnace facility, test equipment, experimental procedures, and results.

FACILITIES

Description of Furnace Test Facility

The experimental work is being carried out in the pilot-scale furnace, shown in Figure 1. It is 14 feet long and has a cross-sectional area of 21.3 square feet. The facility can be used for firing burners rated up to 6 million Btu/hr. Combustion air temperatures up to 1000°F can be generated with a separately fired air preheater.

The furnace is also equipped with 58 water cooling tubes, each of which can be independently inserted through the roof, along the sidewalls. Varying the number of tubes, their location, and the depth of insertion allows control over the magnitude and character of the load that can be placed on the furnace. The amount of heat absorbed by each tube can be determined by measuring the water flow through each tube and the temperature difference between the inlet and outlet. The water temperature measurements are made with a Vertronix digital thermometer. The stated accuracy is 0.25°F. These measurements were checked with a mercury-in-glass thermometer, accurate to 0.1°F, and were found to agree within 0.2°F. A temperature difference of 25° to 60°F was maintained between the water inlet and outlet. This helped minimize the effect of temperature measurement error on the heat balance. The water flow rate from each tube was determined by measuring the time to fill a bucket of known capacity. The time was measured using a quartz digital stopwatch.

In addition to the combustion air preheater, a separately fired fuel preheater is available that can heat 12,000 SCF/hr of low-Btu gas to any desired temperature up to 800°F. Temperatures up to 1200°F are attainable with lower flow rates.

The overall system, shown in Figure 2, has the flexibility to independently vary —

- Fuel firing rate
- Air input
- Furnace load
- Air preheat temperature
- Fuel preheat temperature.

There are 33 panels or "sampling doors", shown in Figure 1, along one sidewall that allow insertion of probes at any axial position from the burner wall to the rear wall.

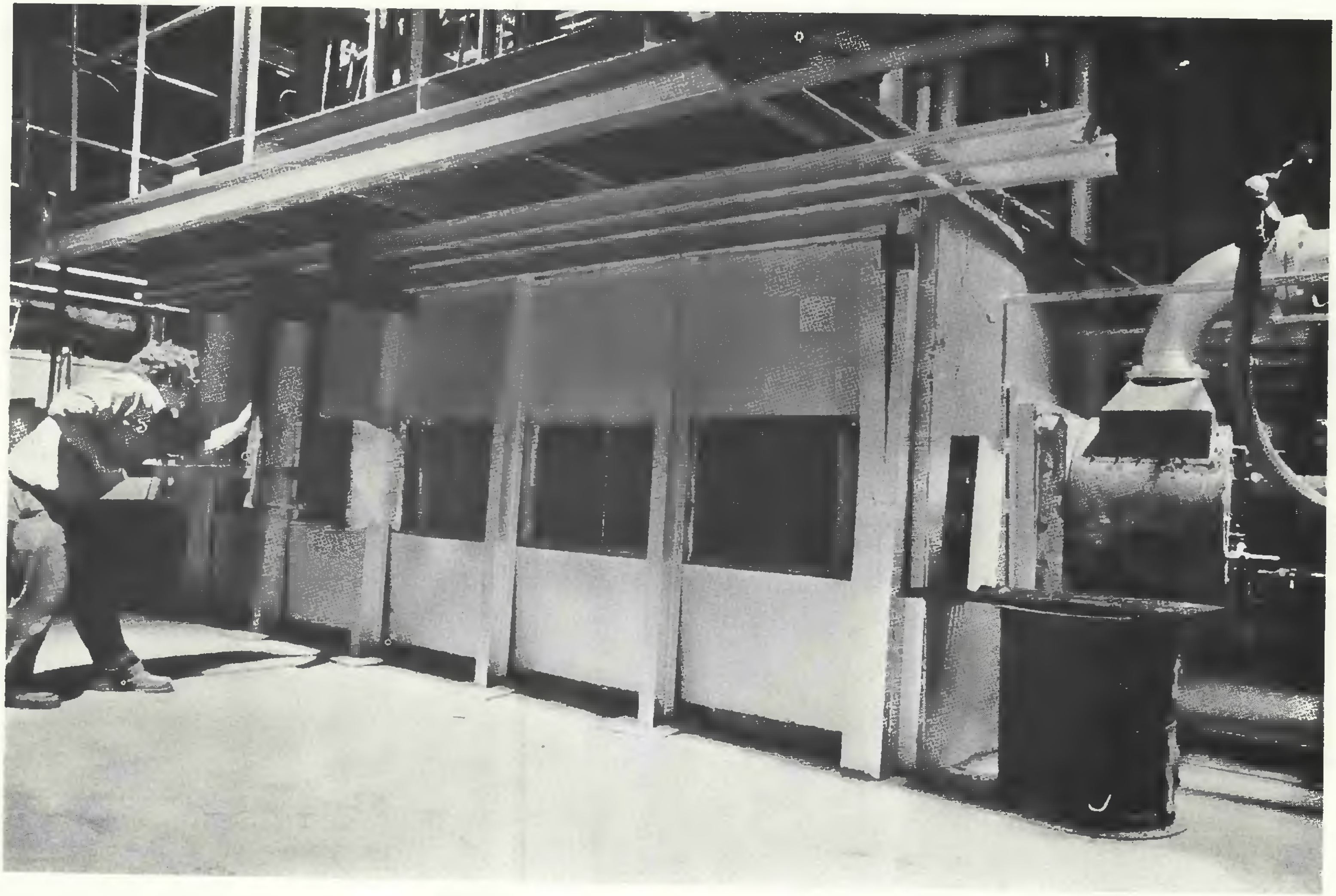


Figure 1. PILOT-SCALE TEST FURNACE P78103213

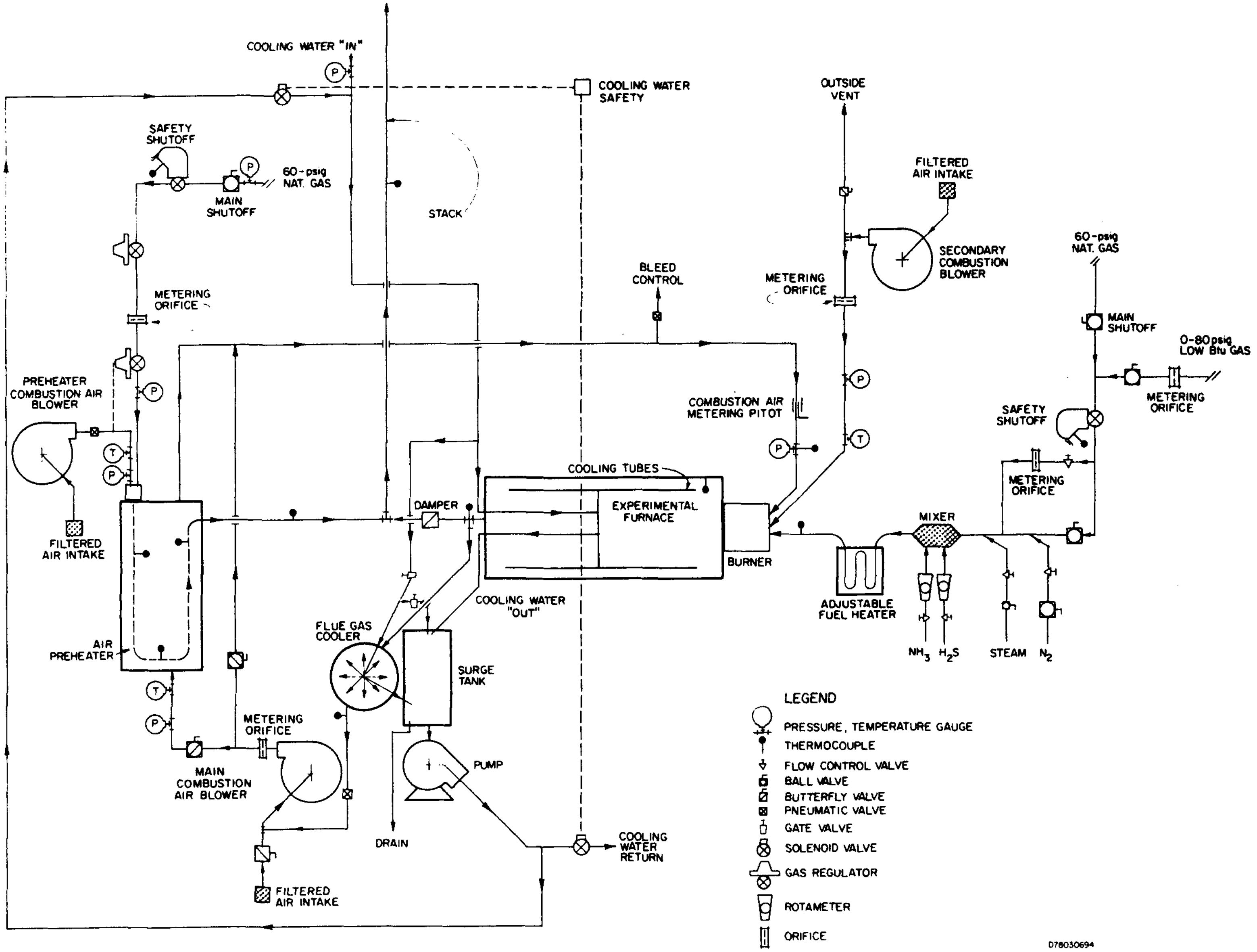


Figure 2. OVERALL FURNACE SYSTEM

Description of the Low-Btu Gas Generating System

The low- and medium-Btu gases are generated using a special gas generating and fuel preparation facility. The critical items are the special gas generators or reformers that can produce varying ratios of hydrogen and carbon monoxide. Natural gas, carbon dioxide, and steam are passed through reaction retorts contained in a vertical cylindrical furnace. The catalyst-filled retorts are heated by the furnace and the input gases undergo endothermic chemical reactions at a temperature of 2100°F. The gases are then quenched and compressed (maximum 80 psig). Facilities are available to remove excess carbon dioxide, if necessary. After compression, the product gas is blended with nitrogen, methane, carbon dioxide, and/or steam, as required, to obtain the specified composition of the fuel gas to be tested.

Up to 5.75 million Btu/hr of simulated low- or medium-Btu fuel gas can be generated. This corresponds to 50,000 SCF/hr of 115 Btu/CF low-Btu gas. Table 1 gives the composition of the Koppers-Totzek oxygen (KTO), Wellman-Galusha air (WGA), And Winkler air (WA) fuel gases, which were chosen to be simulated as test gases for the program.

Table 1. FUEL COMPOSITION FOR LOW-Btu GASES TESTED

Fuel	CO	H_2	CO_2	CH_4	N_2	H_2O	Heating Value, Btu/SCF	Adiabatic Flame Temp,* °F	Specific Gravity
Koppers-Totzek Oxygen (50% Excess Air)	53.0	34.3	9.3	0.5	1.0	1.9	287	3056	0.68
Wellman-Galusha Air (10% Excess Air)	26.0	14.3	7.4	2.6	46.9	1.9	160	2990	0.83
Winkler Air (10% Excess Air)	21.1	13.0	6.9	0.6	56.5	1.9	116	2700	0.85

* The adiabatic flame temperature for natural gas with 50% excess air is 2730°F.

Description of Instrumentation

A major task of this program is to measure temperature profiles, thermal radiation from the flame, flow direction profiles, and flue-gas composition. Modified designs of the International Flame Research Foundation were used to construct probes that enabled this type of data collection.

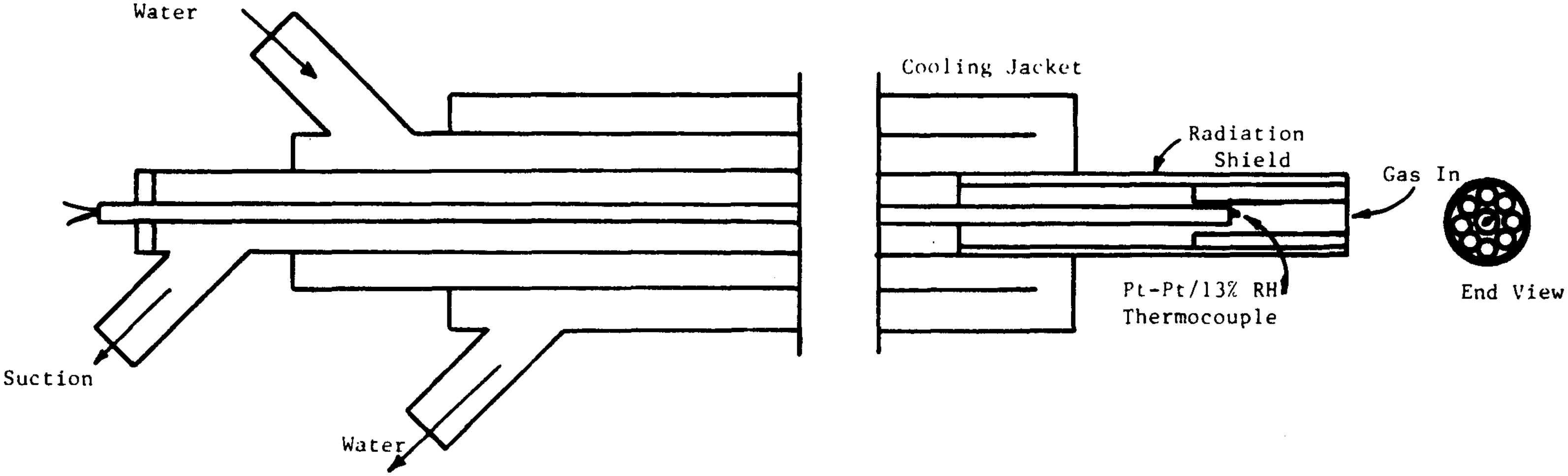
Temperature data were collected using a suction pyrometer; the design is illustrated in Figure 3. A Pt/Pt-13% Rh thermocouple was used. The efficiency of the pyrometer was monitored and was better than 95% with a 15-second response time.

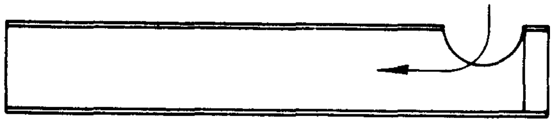
The flow direction was measured using a water-cooled Hubbard probe, with the upstream and downstream pressure taps connected to a Datametrics Barocel transducer and Datametrics CGS electric manometer.

Figure 4 shows the assembly drawing of the gas-sampling probe used in the flame and the flue. To minimize NO_2 losses, the probe is water-cooled stainless steel joined to a Teflon sample line. At the end of the probe is a section of teflon tube heated to 190°F, followed by a Millipore filter and a Permapure gas dryer. This dryer reduces the dew point to less than 32°F. In the dryer, water in the sample gas diffuses through a thin membrane into a stream of dry nitrogen. Tests have shown that only water is lost from the sample stream.

The analytic instrumentation equipment consists of the following items:

- Beckman 742 Polarographic Oxygen (O_2)
- Beckman Paramagnetic Oxygen (O_2)
- Beckman NDIR Methane (CH_4)
- Beckman NDIR Carbon Monoxide (CO)
- Beckman NDIR Carbon Dioxide (CO_2)
- Varian 1200 Flame Ionization Chromatograph (Total HC and C_2 to C_9)
- Beckman NDIR Nitric Oxide (NO)
- Beckman UV-Nitrogen Dioxide (NO_2)
- Thermo Electron Pulsed Fluorescent Sulfur Dioxide (SO_2)
- Hewlett-Packard Thermoconductivity Chromatograph, Hydrogen (H_2), Nitrogen (N_2), Argon (Ar), CO, CO_2, C_1 to C_5, Oxygen (O_2)
- Beckman Chemiluminescent $NO\text{-}NO_x$
- Data Integration System.





Alternate Probe Tip

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Figure 3. ASSEMBLY DRAWING OF THE SUCTION PYROMETER

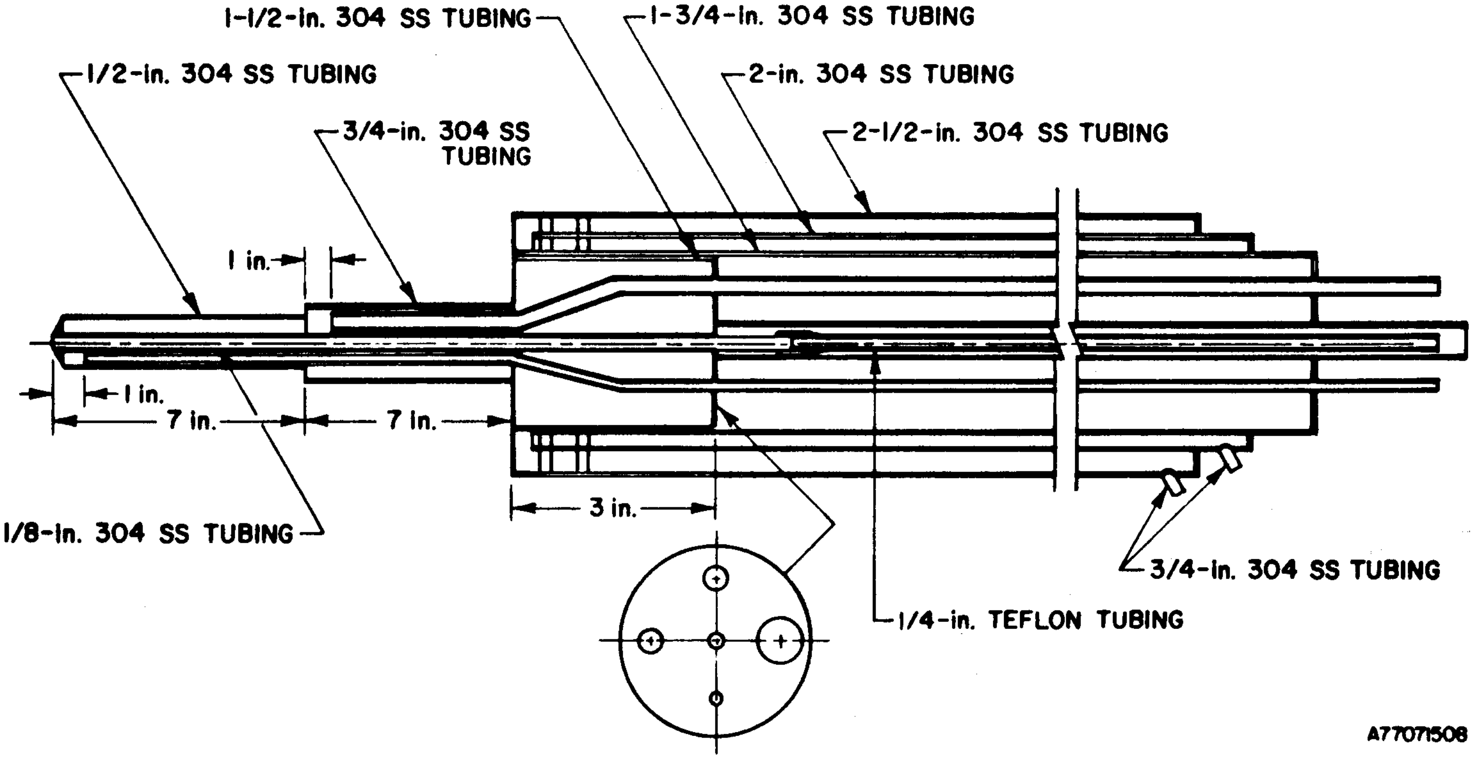

Figure 4. ASSEMBLY DRAWING OF GAS SAMPLING PROBE

To evaluate radiation intensity, which is needed for determination of radiant flux and flame emissivity, a PR 200 Pyroelectric radiometer, manufactured by Molectron Corp. in Sunnyvale, California, was used. This radiometer uses a permanently poled lithium tantalate detector that is capable of resolving radiant power in the nanowatt range while maintaining a continuous spectral response from the vacuum UV to 500 µm. A built-in optical calibration system, in the form of a highly stable LED (light-emitting diode) that is calibrated against an NBS traceable standard of total irradiance, permits a direct correlation of experimental data from different trials.

BURNER TESTS

A North American Model 4422-7 XSA burner was chosen to represent the high-excess-air type burners. Photographs of this burner are shown in Figure 5 and a schematic drawing is shown in Figure 6. These burners are used on heat-treat furnaces, nonferrous melting furnaces, kilns, ovens, air heaters, dryers and chemical process equipment. High-excess-air burners have been very popular because the flame temperature and other characteristics can be varied by adjusting the air flow to the burner, which is specially designed to produce stable, reliable operation over a wide range of operating conditions. By adjusting the amount of excess air, the flame temperature can be adjusted. Thus, with high excess air, a relatively low-temperature flame with a large volume of combustion products can be obtained — e.g., to initially dry and heat a load of "green" refractories. With less excess air, the flame temperature can be increased to "fire" the refractories to the high temperatures required for proper curing.

We chose to simulate a section or zone of a refractory kiln with our pilot-scale test furnace. We employed a fuel input rate of 3 million Btu/hr and a 50% excess air level. The air was at ambient temperature. The load was adjusted to extract 25% of the natural gas heat input, with the tubes equally spaced along one wall, as shown in Figure 7.

Natural Gas Base-Line Tests

After adjusting the cooling load, base-line data were collected for natural gas. Table 2 lists the furnace and burner operating conditions for the base-line trials and the subsequent low-Btu fuel gas tests. Figure 7, showing the cooling tube locations, also shows the size and shape of the natural gas flame. The flame envelope depicted is the region within which 99% of the fuel is consumed. This is determined by making time-averaged gas species concentration scans across the furnace at selected axial positions along the flame. Analysis of the carbon monoxide and oxygen concentration measurements determines the location of the region within which 99% of the fuel is consumed.

Figure 8 shows the temperature profiles measured with a suction pyrometer on a horizontal plane through the flame axis. There is a high-temperature zone corresponding to the flame shown in Figure 7; however, most of the furnace gas temperatures ranged between 1050° and 1200°C. The peak temperature measured was 1658°C (3016°F) at 15 cm from the burner exit.

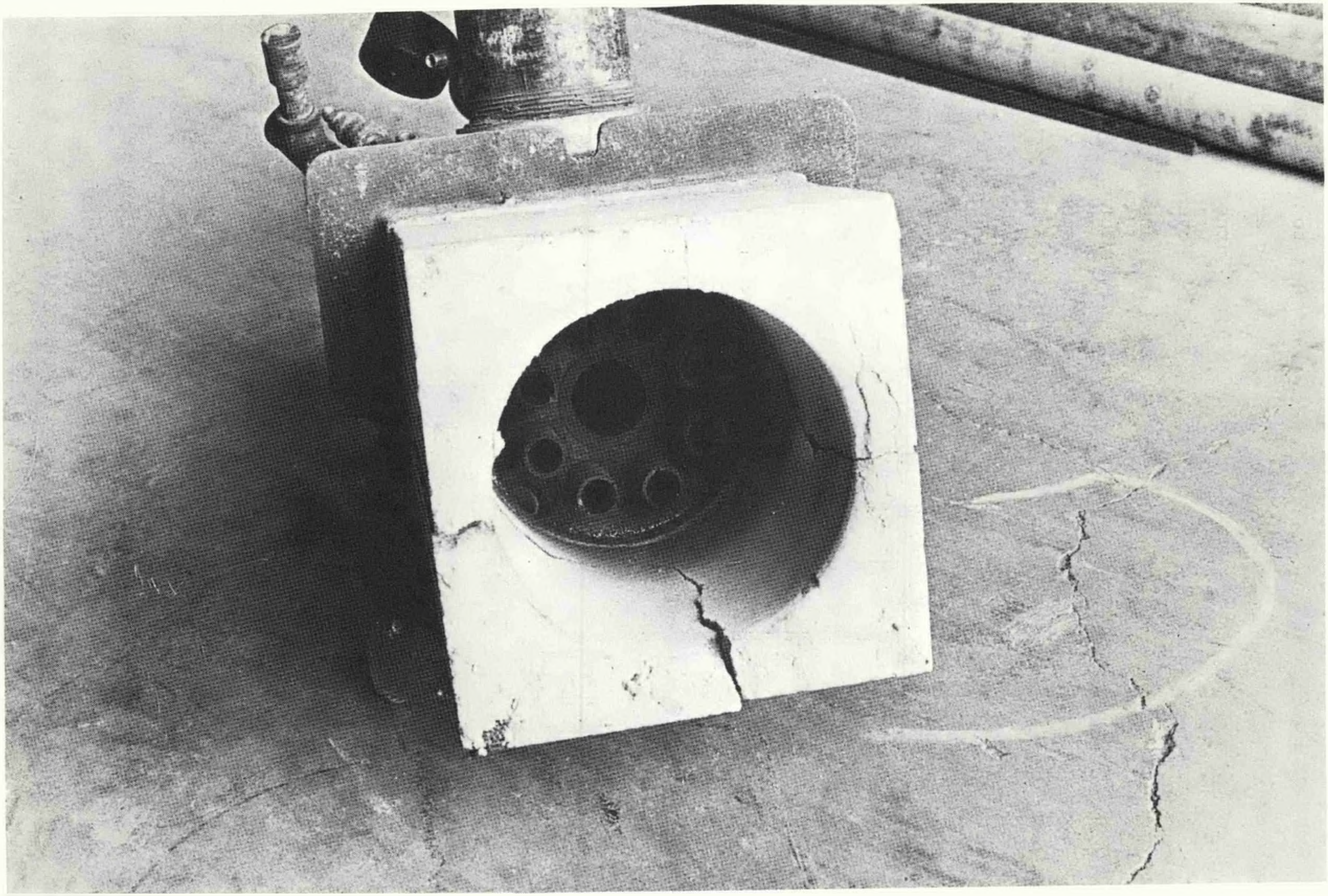

Figure 5. PHOTOGRAPH OF HIGH-EXCESS AIR BURNER

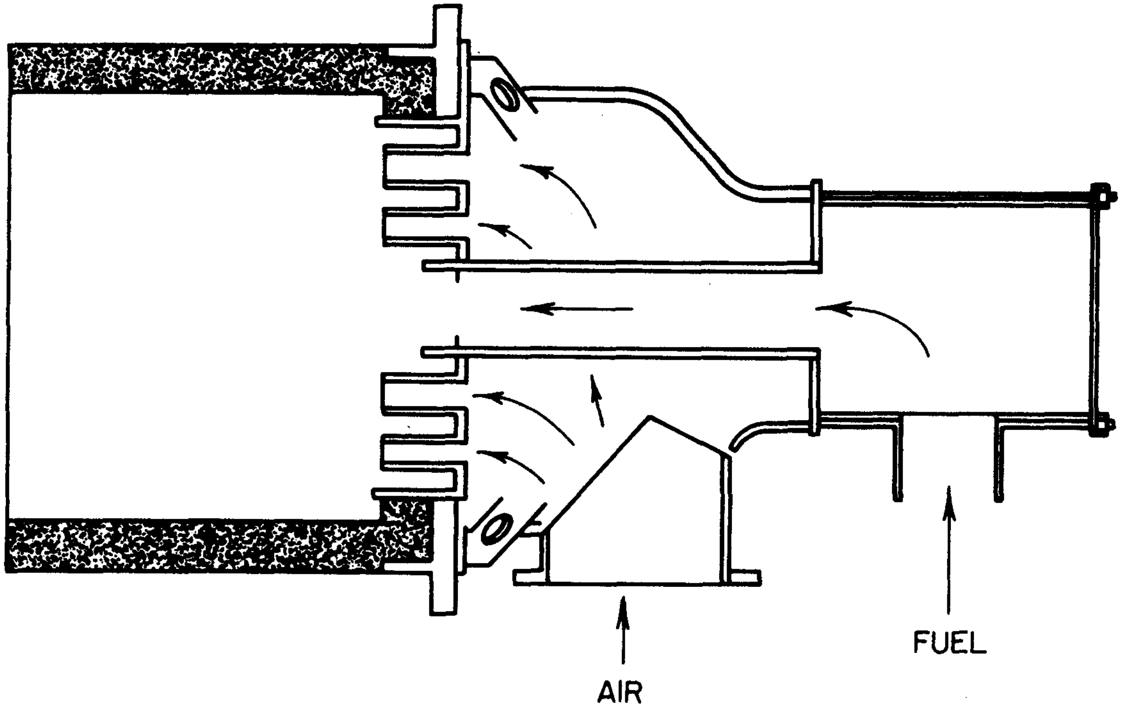

Figure 6. SCHEMATIC CROSS-SECTIONAL DRAWING OF NORTH AMERICAN HIGH-EXCESS-AIR BURNER

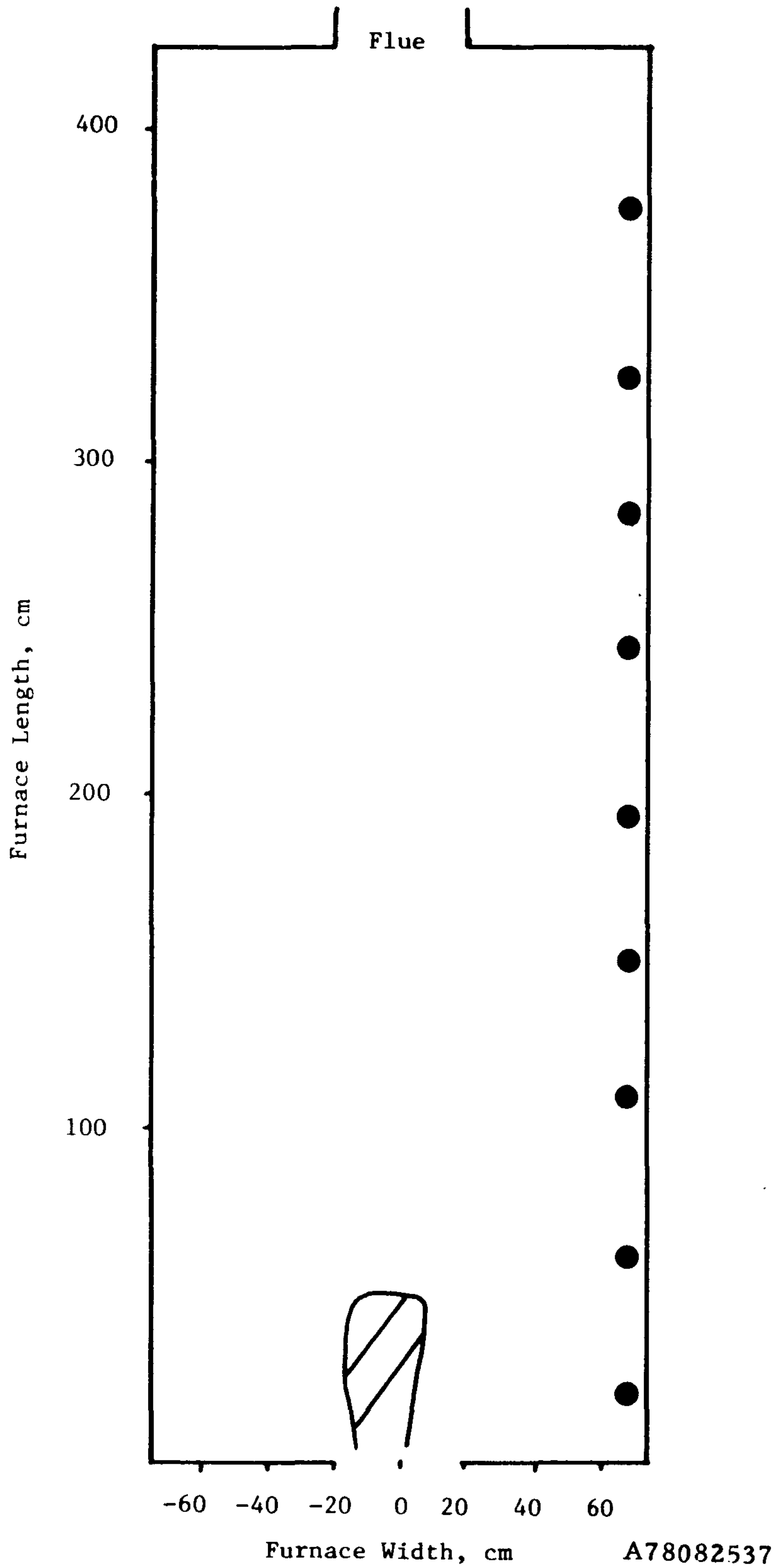

Figure 7. FLAME SHAPE FOR NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

Table 2. FURNACE AND BURNER OPERATING CONDITIONS FOR HIGH-EXCESS-AIR BURNER

Fuel Type	Fuel Flow SCF/hr**	Fuel Pressure at Burner, psig	Air Flow SCF/hr	Air Pressure at Burner, oz/sq. in	% Excess Air	Fuel Velocity ft/s	Air Velocity ft/s	Flue Gas Temperature °F	Volume Flow Flue Gas, SCF/hr	Flame Length, cm	Thermal Efficiency, %†	Post Flame Emissivity	Flue-Gas Analysis				
													NO_x ppm	CO ppm	CO_2 -%, Dry Basis	O_2 -%, Dry Basis	N_2 -%, Dry Basis
Natural Gas	2 900	1	41,800	31	50	42	403	2082	44,700	55	25	0.21	40	25	7.5	7.5	85
Koppers-Totzek Oxygen	10,600	2	34,200	24	50	155	330	2213	40,100	74	27	0.20	42	15	16.3	6.6	75
Wellman-Galusha Air	19,100	5	25,700	13.5	10	278	248	2225	40,900	160	25	0.20	20	10	18.9	1.3	80
Winkler Air*	21,500	6	21,100	8	10	313	204	1898	39,000	141	25	0.22	12	22	17.7	1.0	81

*Maximum stable fuel enthalpy input rate of 2.5 million Btu/hr.

**Fuel flow rate adjusted to give desired enthalpy input ± 0.05 million Btu/hr.
(Fuel heating value can vary from nominal value due to slight variations in actual fuel composition).

†Thermal efficiency defined as the load divided by the product of the fuel volume flow rate times heating value.

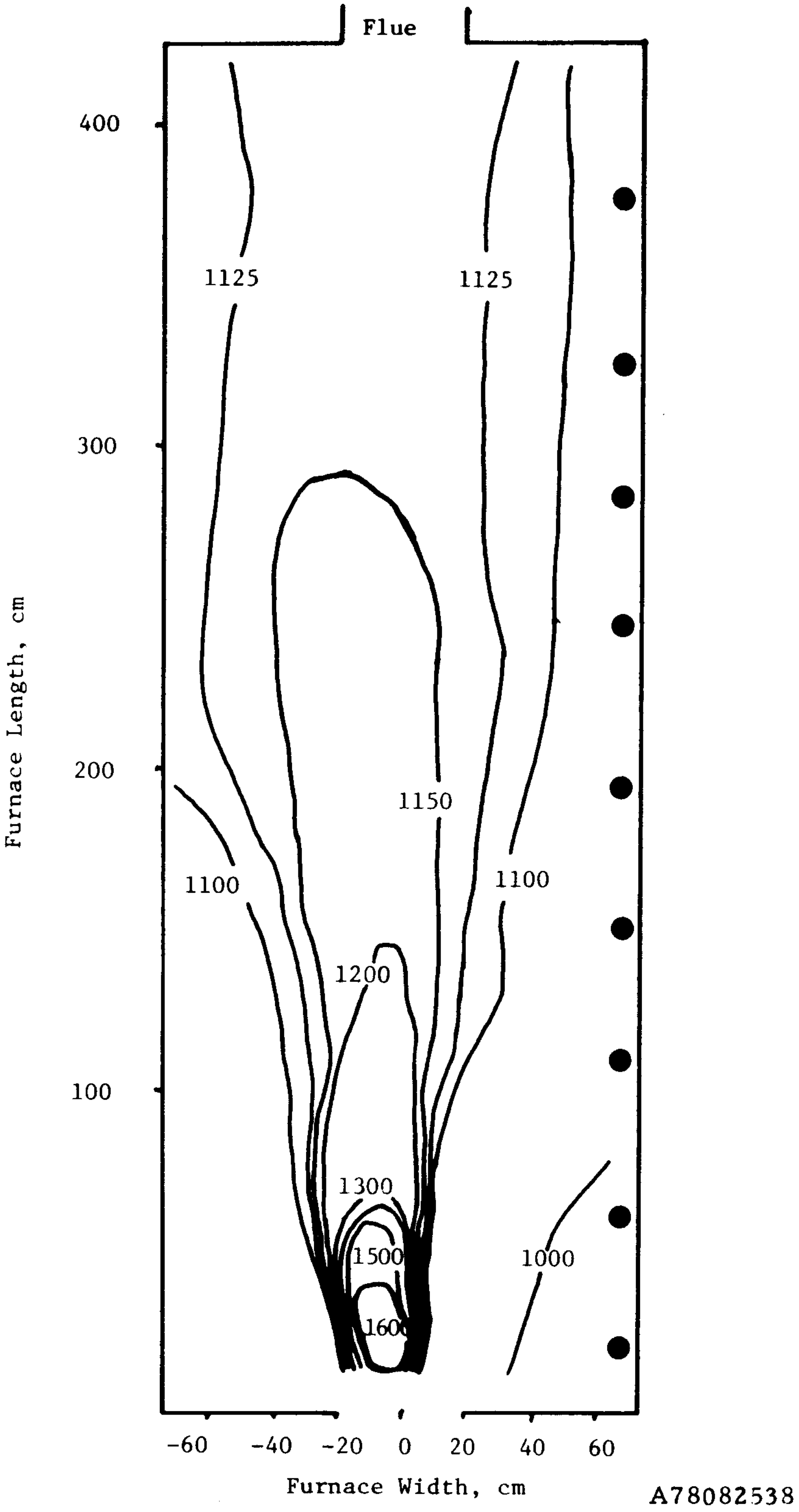

Figure 8. TEMPERATURE PROFILES (°C) FOR NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

Figure 9 shows the flow direction profile for this burner. The open circles in this figure show the locations where the flow changed its direction from forward to reverse. This profile is typical of an enclosed jet and nearly identical profiles were found for all of the flames.

Noise-level measurements were made adjacent to the furnace and burner. During the natural gas tests the background noise level was 92 db at the burner and 89 db alongside the furnace because of the combustion air fan. The noise level at the burner increased to 94 db when the burner was fired. Alongside the furnace the noise level increased to 94 db with the furnace closed and to 96 db with one of the sampling doors removed.

Figure 10 shows the heat-absorption profile measured for the natural gas flame. This will be used for comparison with the heat absorption profiles measured with the substitute fuels. Radiant heat flux measurements taken for the natural gas flame will be presented with the low-Btu fuel gas data. The post-flame emissivity measured for the natural gas base-line case was 0.21. This is nearer to the 0.22 value calculated by the method proposed by Leckner[2] than the 0.19 value calculated by the Hottel and Sarofim[1] method.

Low-Btu Gas Tests

Flame Stability Tests

After conducting the base-line tests, flame stability tests were performed for the low-Btu fuel gases. KTO exhibited no stability problems at a 3 million Btu/hr firing rate at excess air levels of 10%, 30%, and 77%, with and without a burner pilot. WGA fired at 3 million Btu/hr was stable at excess air levels of 10%, 30%, and 65% as long as the pilot remained lit; with no pilot flame, WGA blew off in all cases. Even with the pilot, WA blew off at 3 million Btu/hr at all excess air levels used; however, at 2.5 million Btu/hr WA had stable flames at excess air levels of 10%, 42%, and 97% with the pilot on; blowoff occurred when the pilot was extinguished.

Koppers-Totzek Oxygen Fuel Gas Tests

After the flame stability trials, Koppers-Totzek oxygen fuel gas was fired on the burner at 3 million Btu/hr and the furnace was allowed to heat up and attain thermal stability. Data were then collected similar to data obtained during the natural gas base-line trial. Table 2 compares some of the KTO data with the natural gas data. The KTO fuel volume flow rate is considerably greater than

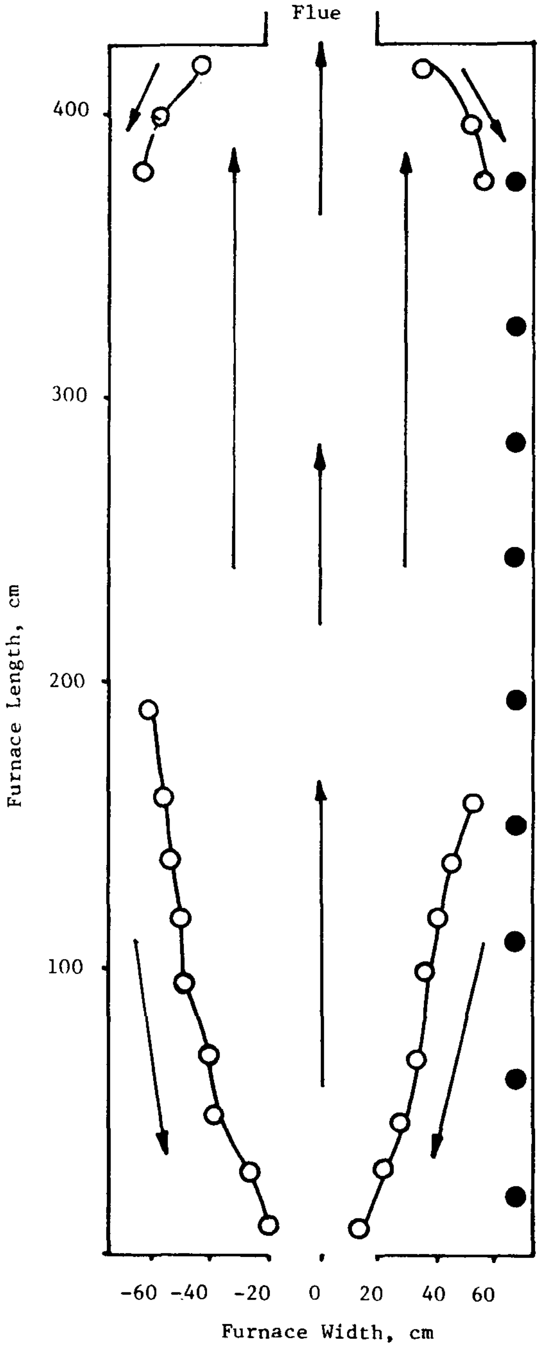

Figure 9. FLOW DIRECTION PROFILES FOR NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

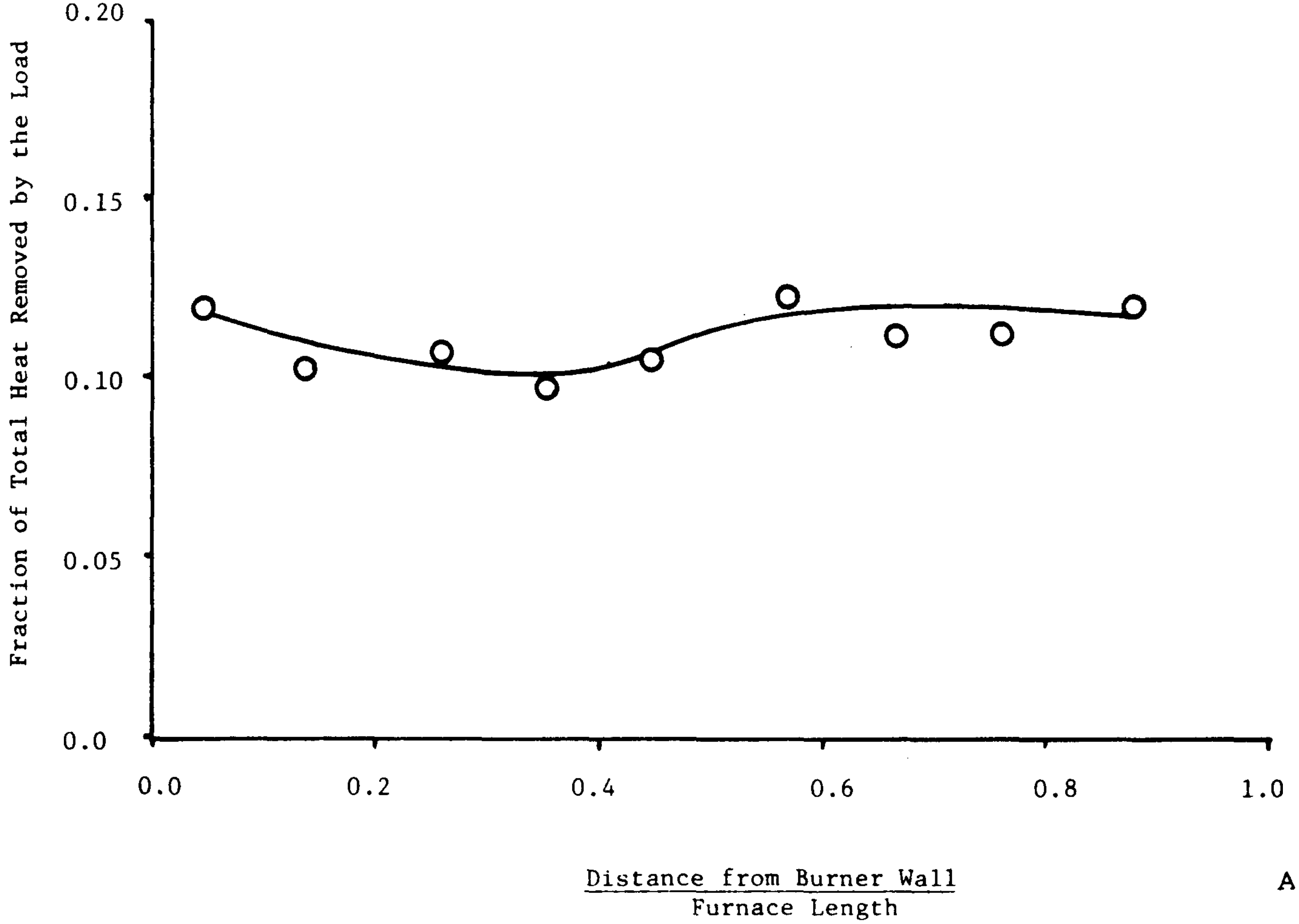

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Figure 10. HEAT-ABSORPTION PROFILE FOR NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

the natural gas flow rate because of the lower heating value per SCF for KTO. This is also reflected in the fuel velocity at the burner outlet. The flame length for KTO, 74 cm, is longer than that measured for natural gas, 55 cm. The KTO flame shape is shown in Figure 11.

The thermal efficiency measured for KTO was 27%, somewhat higher than the adjusted value (25%) for natural gas during the base-line tests. The oxides of nitrogen levels for KTO and natural gas are comparable while carbon monoxide (CO) levels are lower for KTO.

The heat-absorption profile for KTO is compared with the profile for natural gas in Figure 12. The two profiles are very similar. This is because the flames for these two fuels are small relative to the overall furnace dimensions. Thus the flame shapes, although different for the two fuels, are sufficiently similar relative to the furnace dimensions to produce similar heat-transfer patterns.

Figure 13 shows the radiant emittance from the flame and combustion products for the low-Btu gases and natural gas. This measurement was made by placing a water-cooled target on one side of the furnace and a narrow angle radiometer on the other side. Comparing the radiant emittance measurements for KTO and natural gas, it is not surprising that the thermal efficiency of KTO is higher because its radiation levels generally exceed those of natural gas.

Figure 14 shows the radiant emmittance from the flame alone. The natural gas and KTO flames were so short that data could only be obtained at a few points. The KTO flame radiation was the same as that of natural gas.

Figure 15 shows the temperature profiles measured for KTO. The profiles for KTO are similar to those measured for natural gas; however, the peak temperature found for KTO fuel gas was 1740°C (3164°F) at 36 cm. This is considerably higher than the 1658°C (3016°F) measured for natural gas.

The post-flame emissivity was measured by the Schmidt method and has been described in a previous report.[3] The emissivity measured for KTO fuel gas is about that which would be calculated by the methods proposed by Hottel and Sarofim[1] (0.20) or Leckner[2] (0.22).

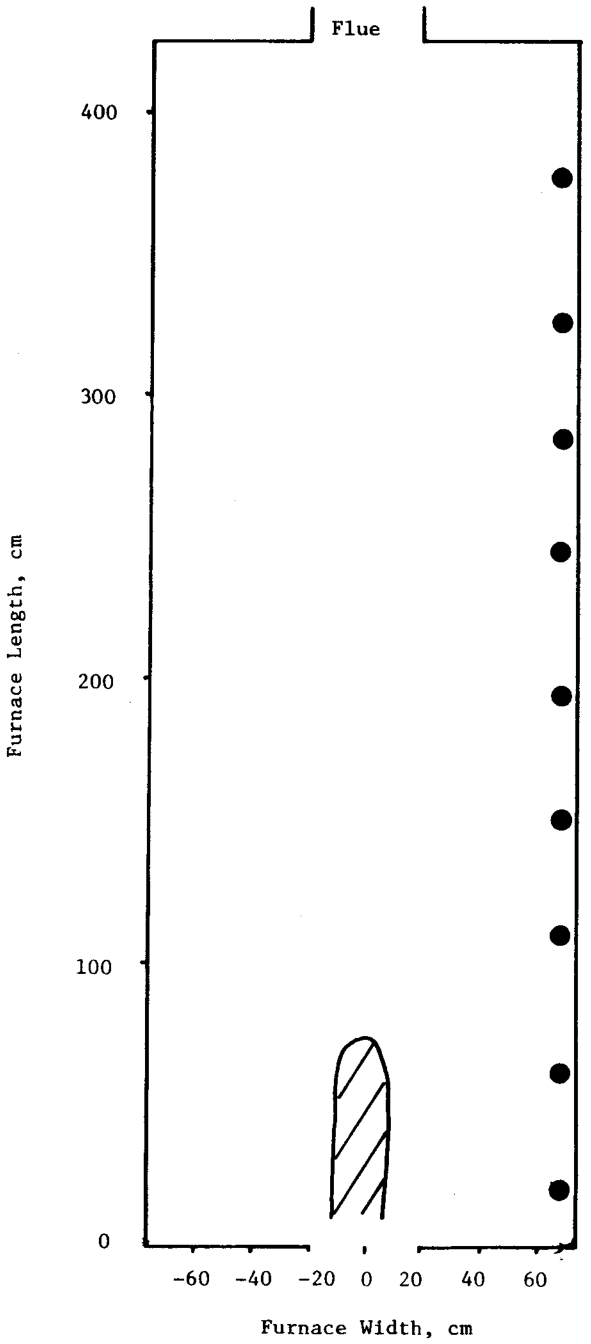

Figure 11. FLAME SHAPE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE HIGH-EXCESS-AIR BURNER

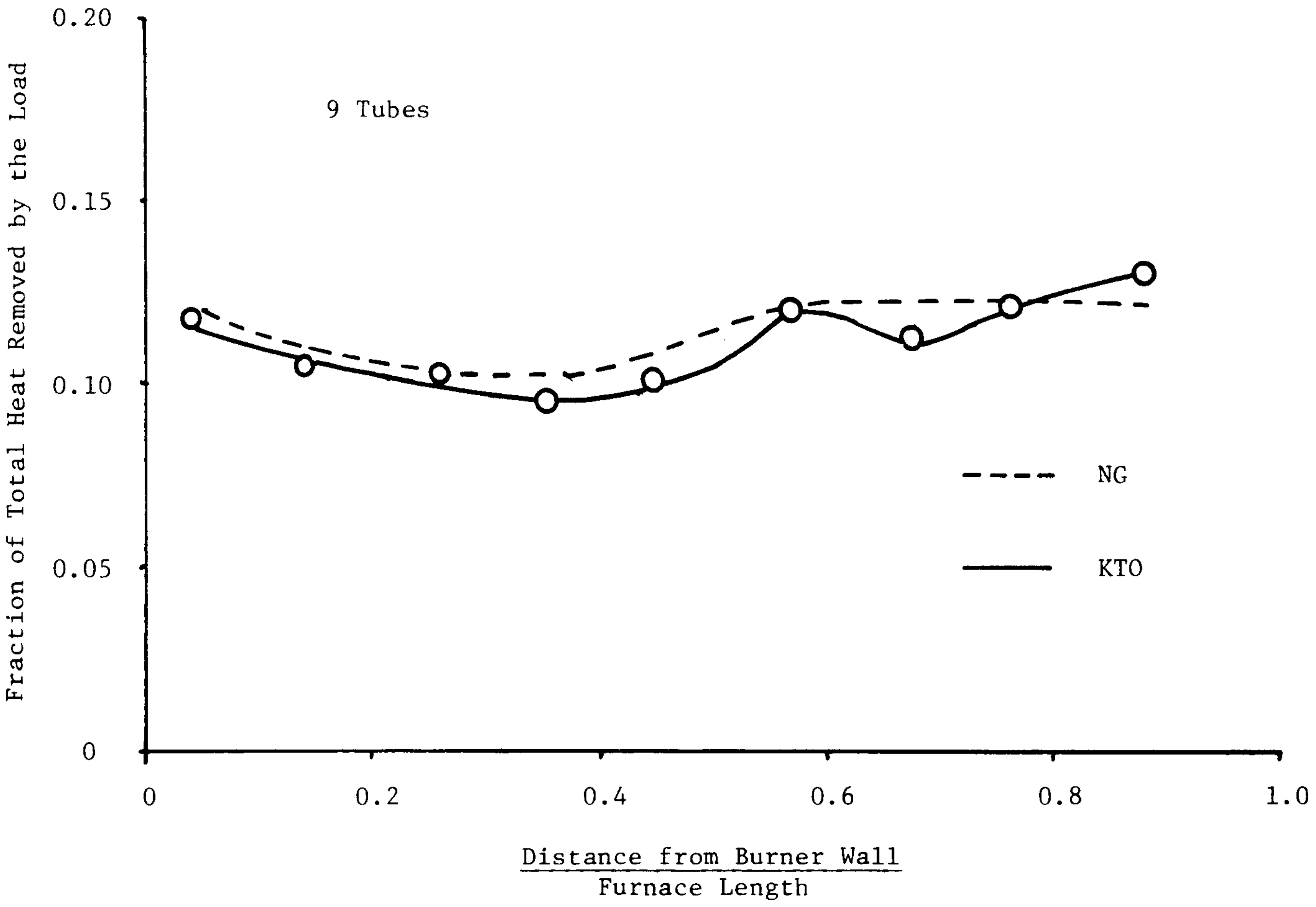

Figure 12. HEAT-ABSORPTION PROFILE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS COMPARED WITH NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

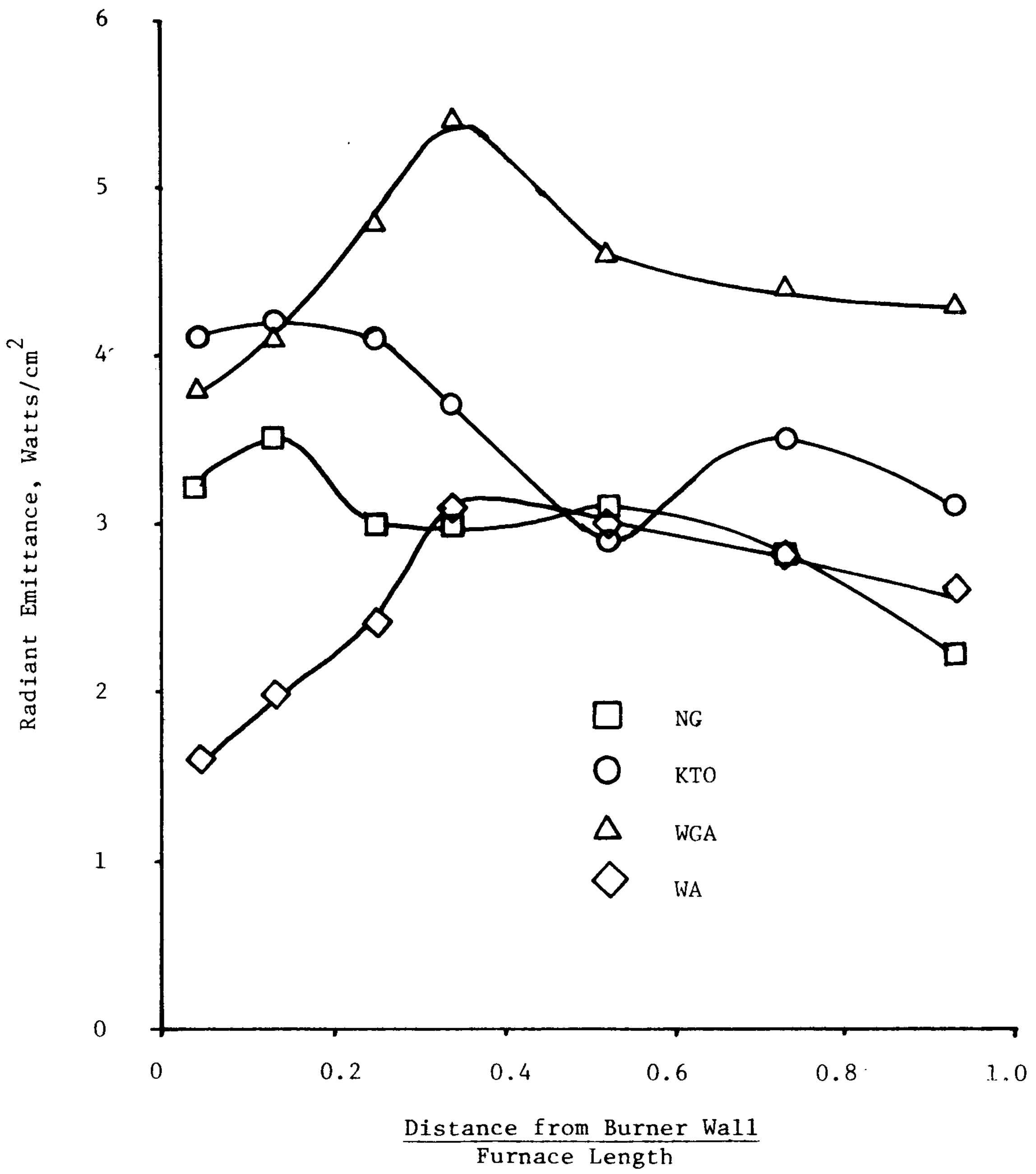

Figure 13. RADIANT EMITTANCE FROM FLAME PLUS COMBUSTION PRODUCTS FOR THE HIGH-EXCESS-AIR BURNER

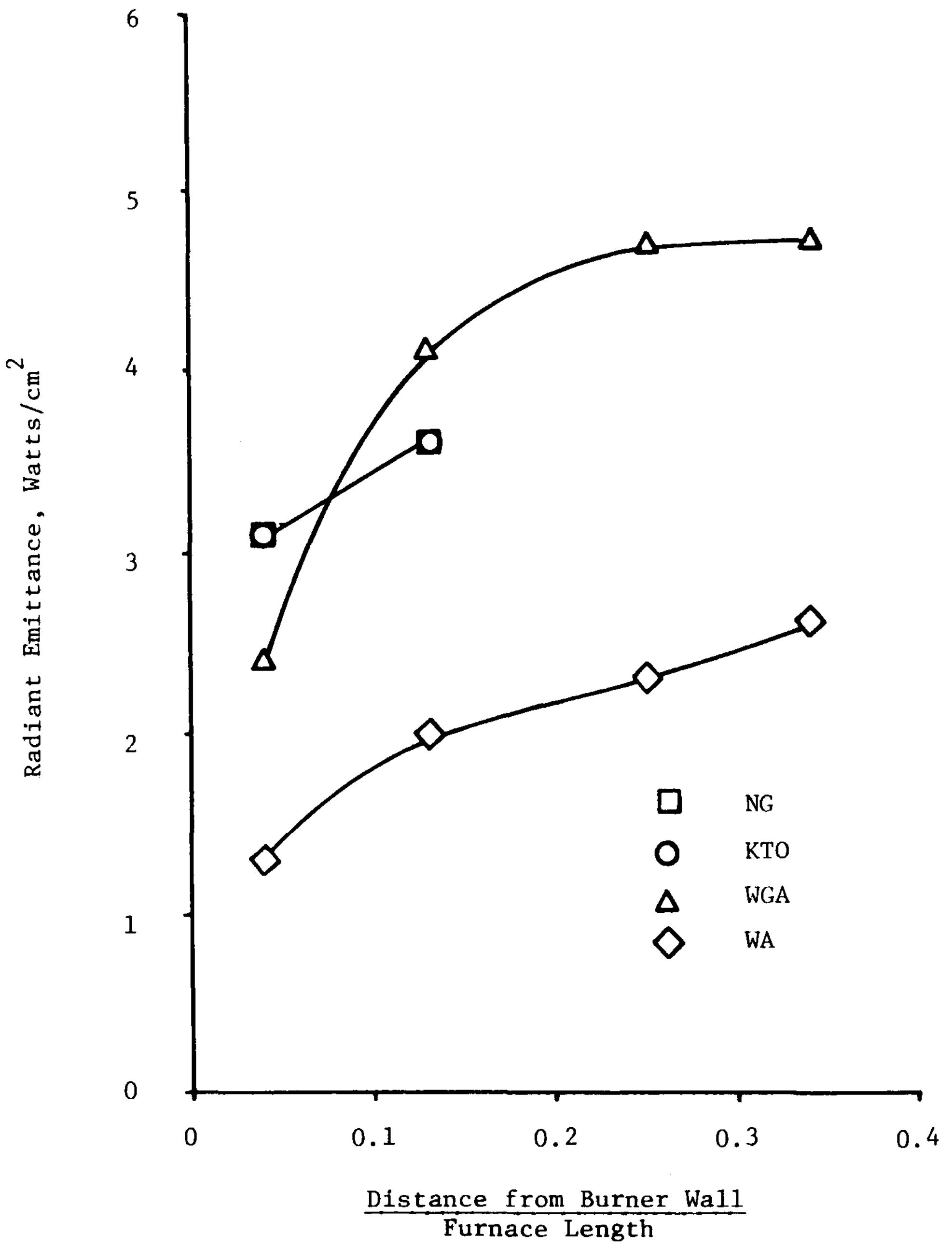

Figure 14. RADIANT EMITTANCE FROM THE FLAME ALONE FOR THE HIGH-EXCESS-AIR BURNER

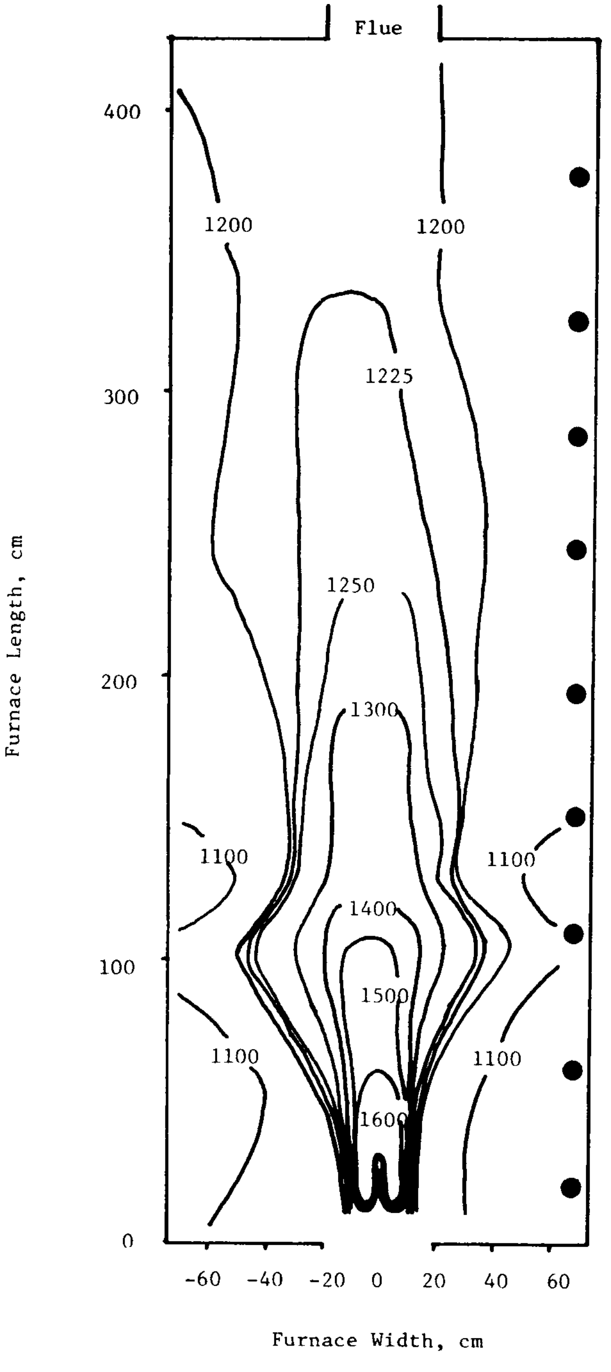

Figure 15. TEMPERATURE PROFILES (°C) FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE HIGH-EXCESS-AIR BURNER

Sound level measurements were made for the KTO fuel gas. The background noise level was 96 db at the burner and 89 db at the side of the burner because of the combustion air fan. There was no increase at the burner, a 10 db increase at the side of the furnace with the furnace closed, and an 11 db increase at the side with a sampling door removed during firing.

As stated earlier, the flow direction profiles were nearly identical for all the fuels tested.

Koppers-Totzek Oxygen Fuel Gas Retrofit Conclusions

For Koppers-Totzek oxygen fuel gas the flame temperatures, thermal efficiency, and heat-absorption profile all indicate that this fuel will retrofit well on this type of burner. Although the flame length is increased compared with natural gas, this did not seriously affect the heat-transfer pattern to the load.

These results show that some low-Btu gases, such as KTO fuel gas, can be expected to perform as well or better than natural gas on high-excess-air type burners.

Wellman-Galusha Air Fuel Gas Tests

The results of the WGA fuel gas combustion tests are also included in Table 2. The fuel input rate was 3 million Btu/hr. Because WGA has a low heating value per cubic foot, the fuel velocity at the burner is high, resulting in some flame stability problems. WGA flames are much cooler than either natural gas or KTO flames at the same excess air level. Because heat-transfer rates to a load mainly depend on flame temperatures, it was decided to fire WGA at an excess-air level significantly below the 50% used for natural gas (and KTO) to attempt to match the natural gas thermal efficiency of 25%. When the excess air level for WGA was set at 10%, this efficiency was obtained. At 10% excess air the WGA flame length was 160 cm.

The flame shape is shown in Figure 16. Figure 17 shows the flame temperature for WGA. The peak temperature occurred at 126 cm from the burner wall and was 1366°C (2491°F). This is considerably lower than the temperatures found for natural gas and KTO and is reflected in the lower NO_x levels for WGA.

The heat-absorption profile for WGA is compared with the natural gas profile in Figure 18. The profiles show no great dissimilarities.

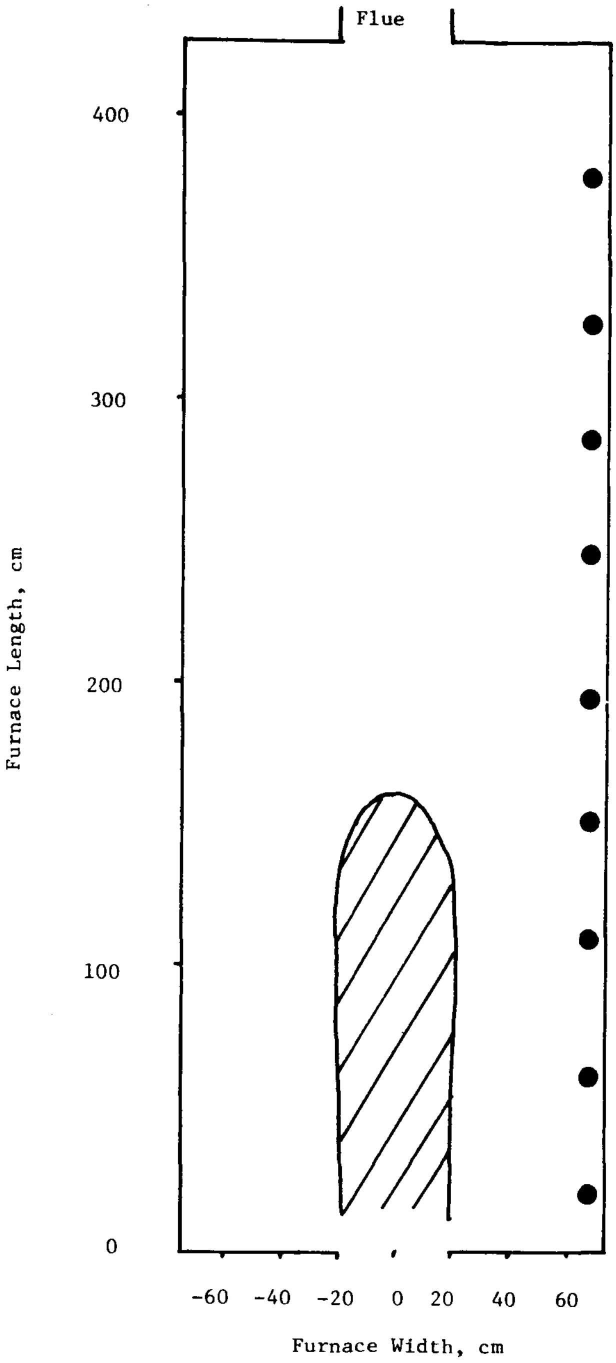

Figure 16. FLAME SHAPE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE HIGH-EXCESS-AIR BURNER

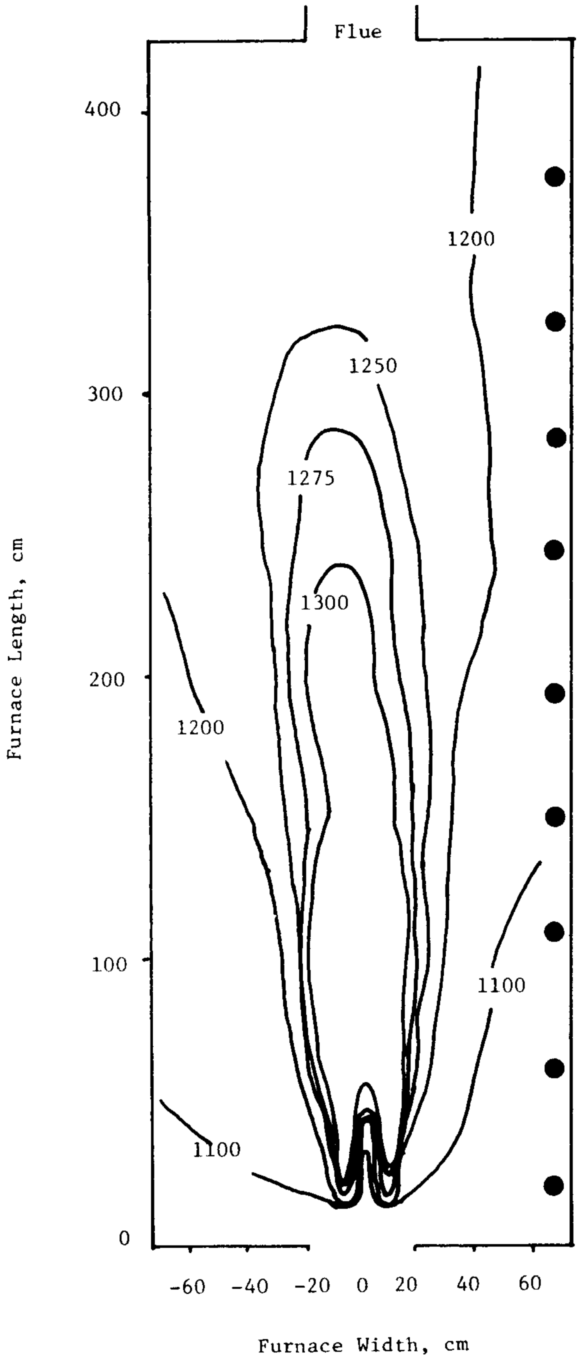

Figure 17. TEMPERATURE PROFILES (°C) FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE HIGH-EXCESS-AIR BURNER

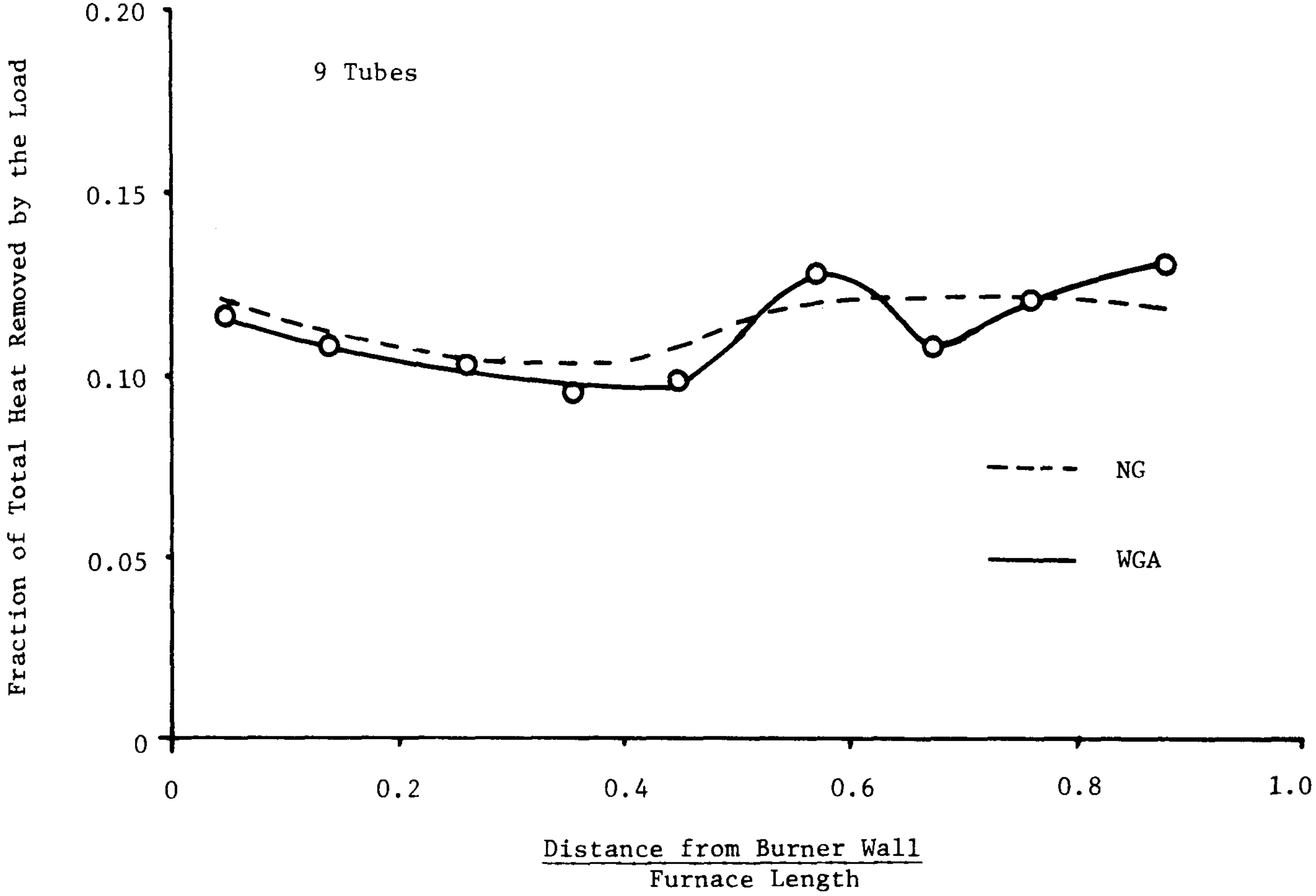

Figure 18. HEAT-ABSORPTION PROFILE FOR WELLMAN-GALUSHA AIR FUEL GAS COMPARED WITH NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

Comparing the thermal radiation measurements in Figures 13 and 14, we see that the radiation levels for WGA are higher than those for natural gas or KTO. The post-flame emissivity was measured as 0.21. The Hottel and Sarofim[1] calculation gave a value of 0.20, while the Lecker[2] calculation gave 0.22.

During the WGA sound level measurements, the background noise level at the burner was 96 db because of the combustion air fan. The noise level went to 98 db when the burner was fired. Along the side of the furnace, the background noise level was 89 db. The level increased 8 db with the furnace closed and 9 db with one sample door removed during firing.

The flow direction profile in the furnace was the same as shown in Figure 9 for natural gas.

Wellman-Galusha Air Fuel Gas Retrofit Conclusions

Wellman-Galusha air fuel gas fired with a stable flame at firing rates up to 3 million Btu/hr and at excess air levels up to 65% as long as the pilot remained lit. Firing WGA at an excess air level below that used with natural gas can yield a thermal efficiency, heat-transfer curve, flame temperatures, and thermal radiation levels comparable to or greater than those for natural gas at the higher excess air level. The flame length obtained for WGA (10% excess air) is roughly 3 times longer than that for natural gas (50% excess air) and may be of consequence in some applications.

Winkler Air Fuel Gas Tests

For 2.5 million Btu/hr with 10% excess air, Winkler air fuel gas transferred 25% of this heat input to the load. Figure 19 shows the temperature profile obtained for WA. The peak temperature was 1201°C (2193°F) at 56 cm from the burner wall. This yielded the lowest NO_x values measured. The flame shape is shown in Figure 20. The flame length was 141 cm.

The radiant flux measurements, Figures 13 and 14, show that WA generally had the lowest radiation. This is consistent with the temperature data.

The heat-absorption profile, seen in Figure 21, is essentially equivalent to that for natural gas.

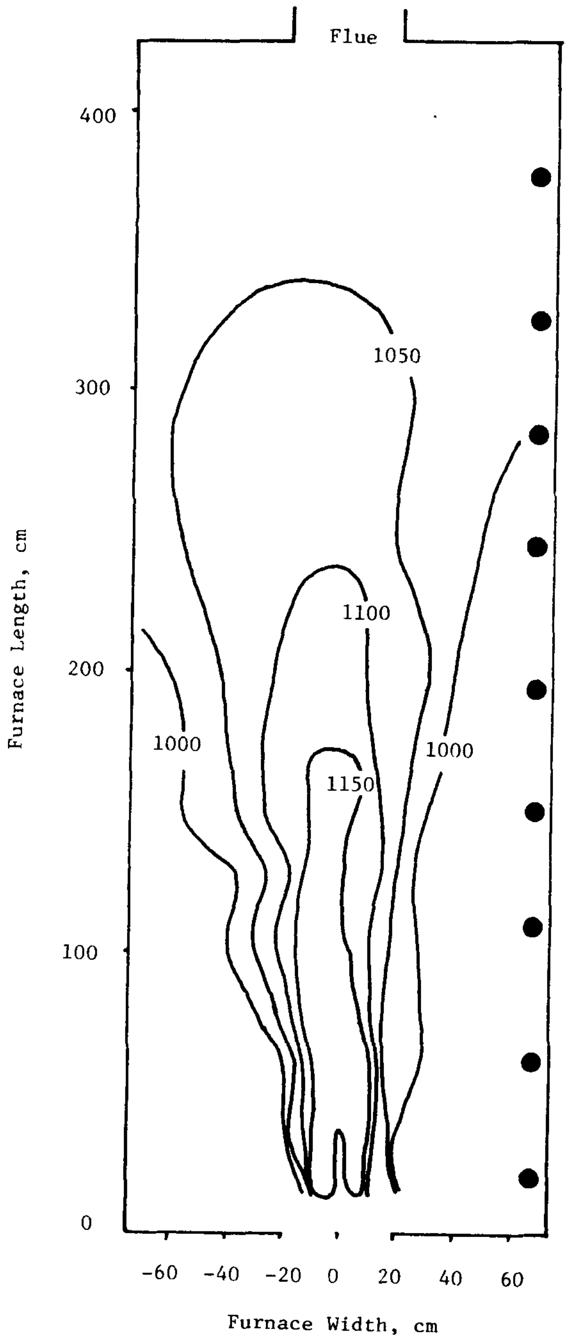

Figure 19. TEMPERATURE PROFILES (°C) FOR WINKLER AIR FUEL GAS ON THE HIGH-EXCESS-AIR BURNER

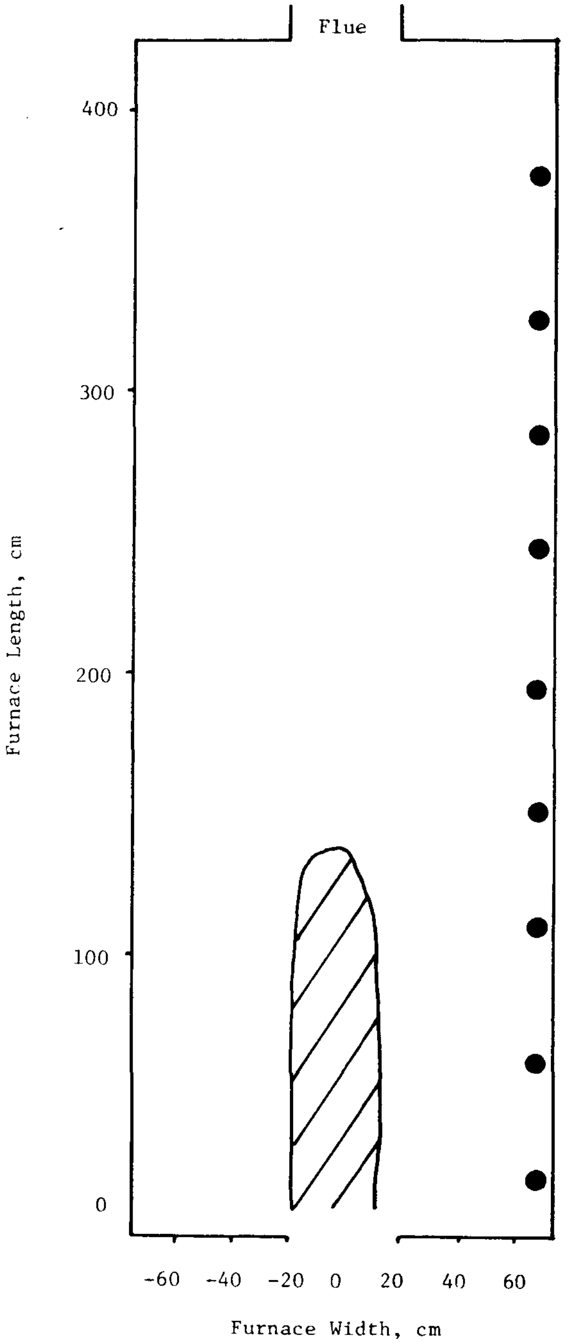

Figure 20. FLAME SHAPE FOR WINKLER AIR FUEL GAS ON THE HIGH-EXCESSS-AIR BURNER

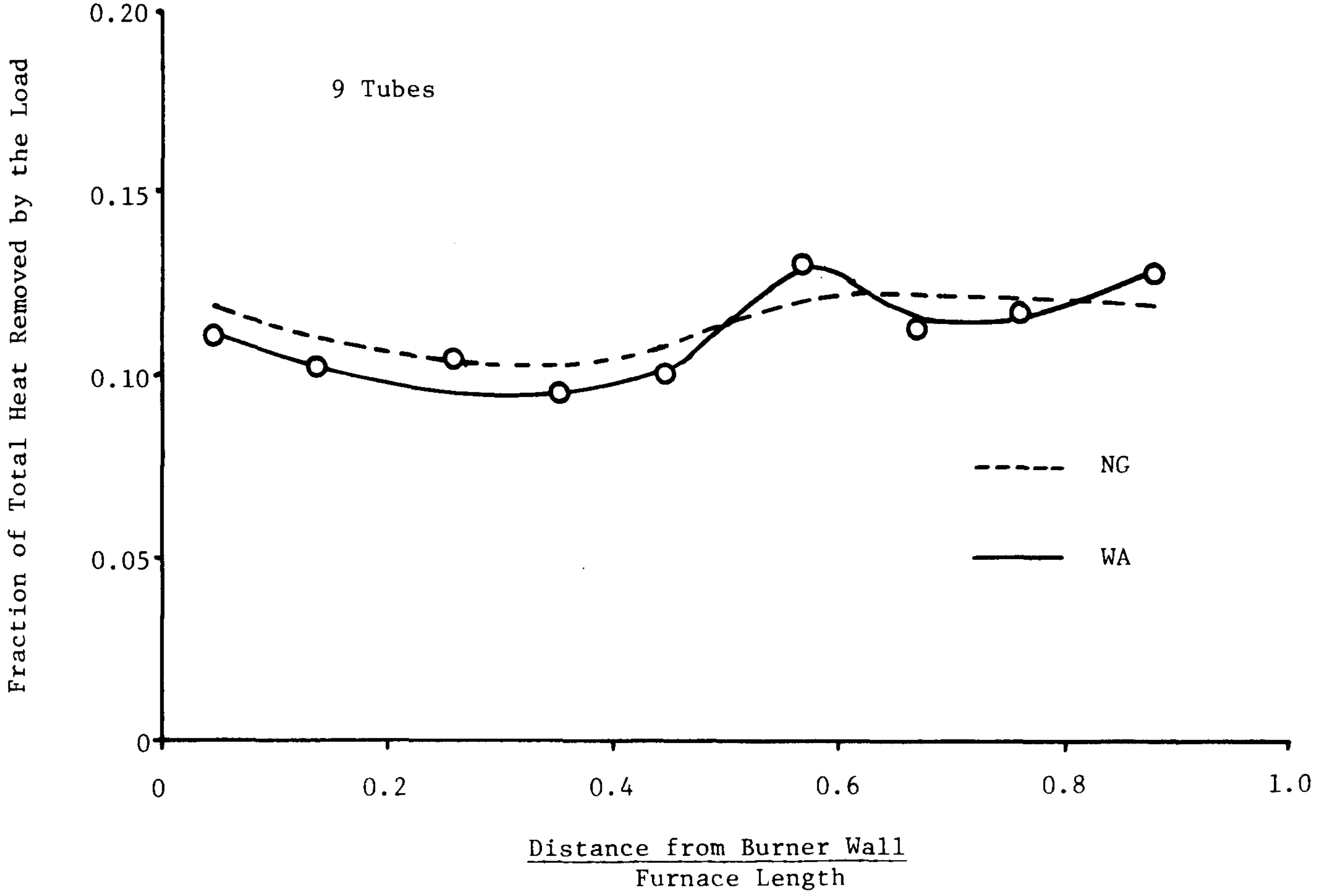

Figure 21. HEAT-ABSORPTION PROFILE FOR WINKLER AIR FUEL GAS COMPARED WITH NATURAL GAS ON THE HIGH-EXCESS-AIR BURNER

The flow direction profile was similar to Figure 9, shown for natural gas. The post-flame emissivity was measured as 0.22. The Hottel and Sarofim[1] calculation gave a value of 0.21 while the Leckner[2] calculation gave 0.24.

For WA, the background noise level at the burner was 96 db and 89 db at the furnace sidewall. The increases in noise levels with the burner operating were 1 db at the burner, 8 db at the side with the furnace closed, and 11 db at the side with a door removed.

Winkler Air Fuel Gas Retrofit Conclusions

Winkler air fuel gas could not be fired on this burner at 3.0 million Btu/hr at any excess air level down to 10% with or without a pilot because of blowoff. With a pilot, 2.5 million Btu/hr was stable with excess air levels as high as 97%.

This suggests that Winkler air fuel gas could be retrofit on this burner for many lower temperature heating or drying applications, but may not be suitable for higher temperature, high firing-rate applications.

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