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

Project 8985 Special Report No. 2

KILN BURNER

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ABSTRACT

Data were gathered to determine the performance of a kiln burner when retrofit with three low-Btu gases. The burner was fired on the IGT pilot-scale test furnace with a load simulating the calcining and reaction zones of a cement kiln. The low- and medium-Btu gases simulated for these combustion trials were Koppers-Totzek oxygen, Wellman-Galusha air, and Winkler air fuel gases. Koppers-Totzek oxygen fuel gas was an excellent substitute fuel, exhibiting equal or better performance than natural gas. Wellman-Galusha air and Winkler air fuel gas both exhibited flame stability problems on the unmodified burner. These two fuels also gave lower thermal efficiencies than natural gas and Koppers-Totzek oxygen fuel gas when fired on a modified fuel injector.

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OBJECTIVE

The use of low- and medium-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- and medium-Btu gases.

Eight types of industrial burners will be tested using three different low- and medium-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 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 kiln burner. The burner size and firing rate were chosen to simulate the firing density (Btu/CF-hr) in the calcining and reaction zones of a cement kiln because detailed temperature and heat transfer data were readily available for this process.

While firing natural gas, the furnace load was adjusted to absorb the same fraction of the furnace heat input that occurs in these sections of a kiln. 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 sq ft. 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.

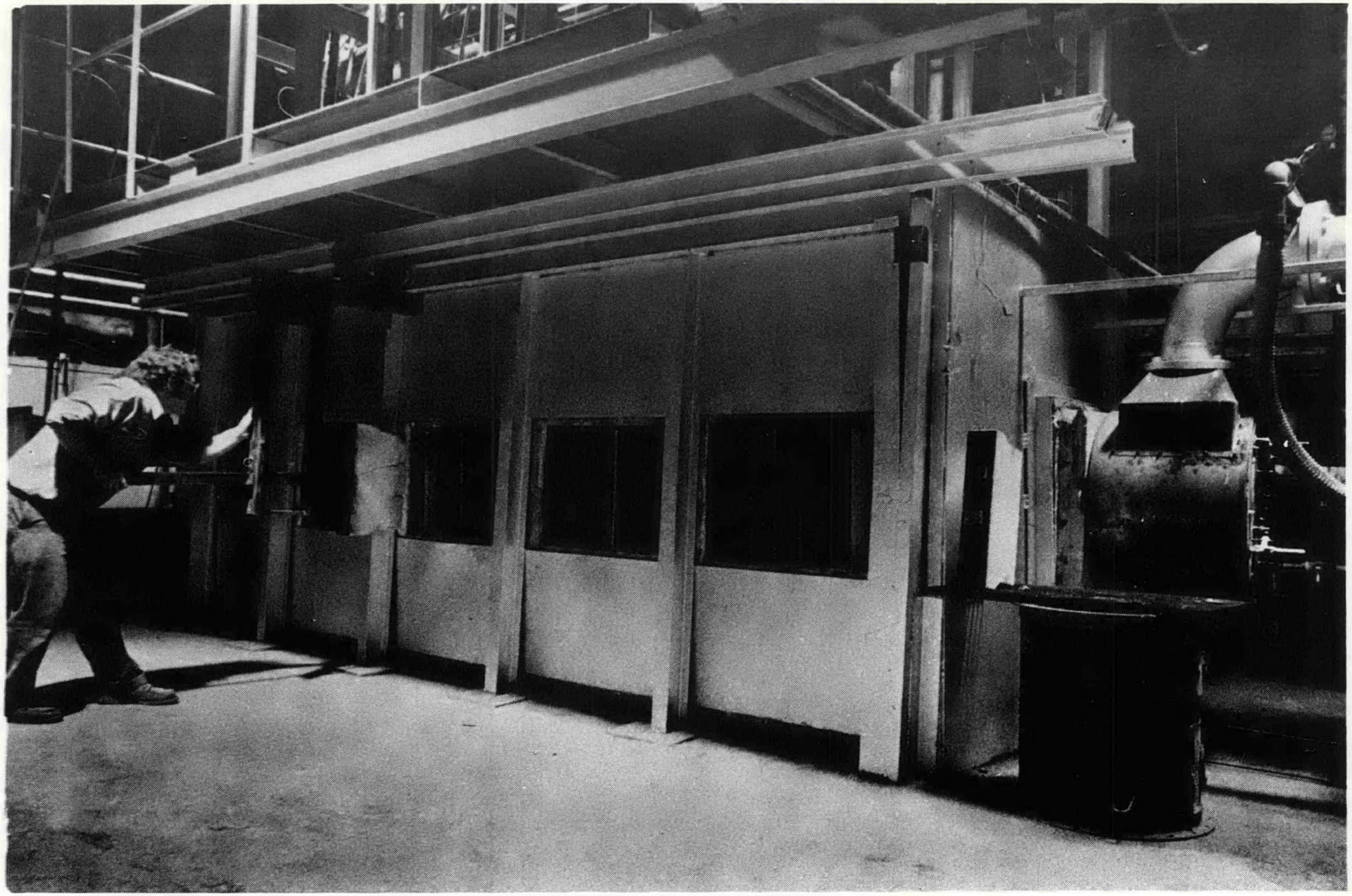

Figure 1. PILOT-SCALE TEST FURNACE

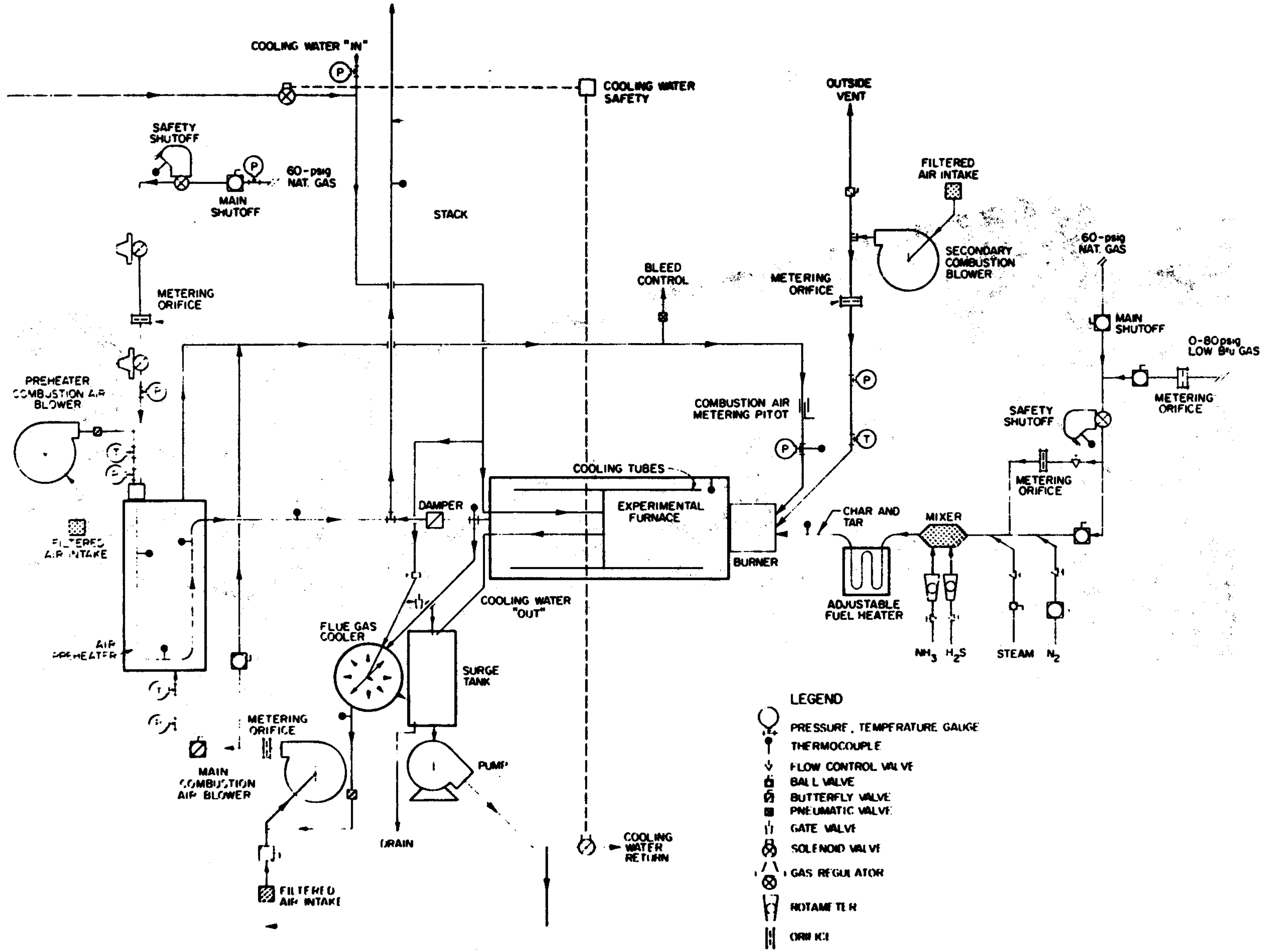

Figure 2. OVERALL FURNACE SYSTEM

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- AND MEDIUM-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	53.0	34.3	9.3	0.5	1.0	1.9	287	3767	0.68
Wellman-Galusha Air	26.9	14.3	7.4	2.6	46.9	1.9	160	3228	0.83
Winkler Air	21.1	13.0	6.9	0.6	56.5	1.9	116	2932	0.85

* 10% excess air at 650°F. The adiabatic flame temperature for natural gas is 3672°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

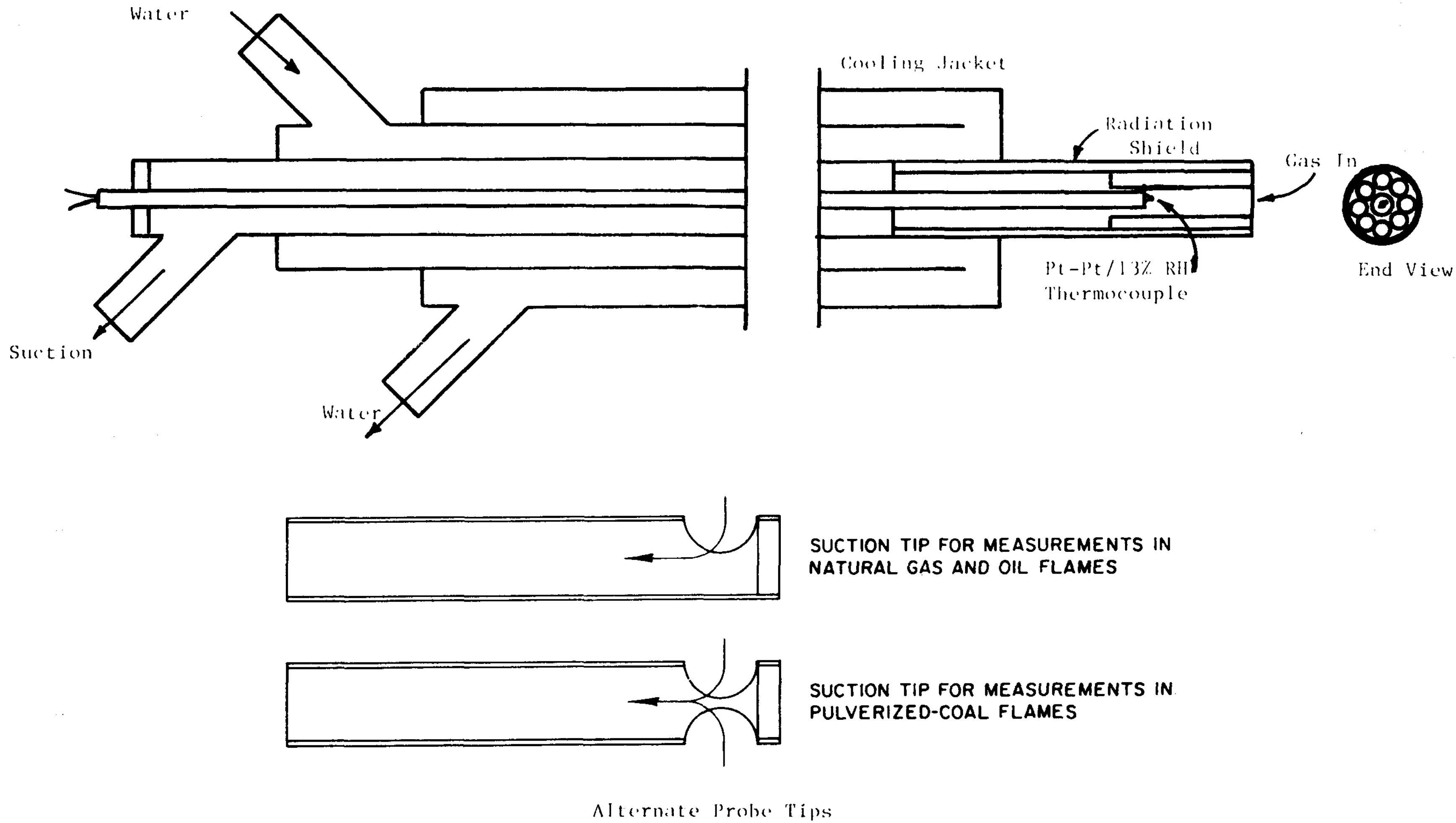

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Figure 3. ASSEMBLY DRAWING OF THE SUCTION PYROMETER

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 dewpoint 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 Flourescent Sulfur Dioxide (SO_2)
- Hewlett-Packard Thermoconductivity Chromatography, Hydrogen (H), Nitrogen (N_2), Argon (A_2), CO, CO_2, C_1 to C_5, Oxygen (O_2)
- Beckman Chemiluminescent NO-NO_2
- Data Integration System.

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.

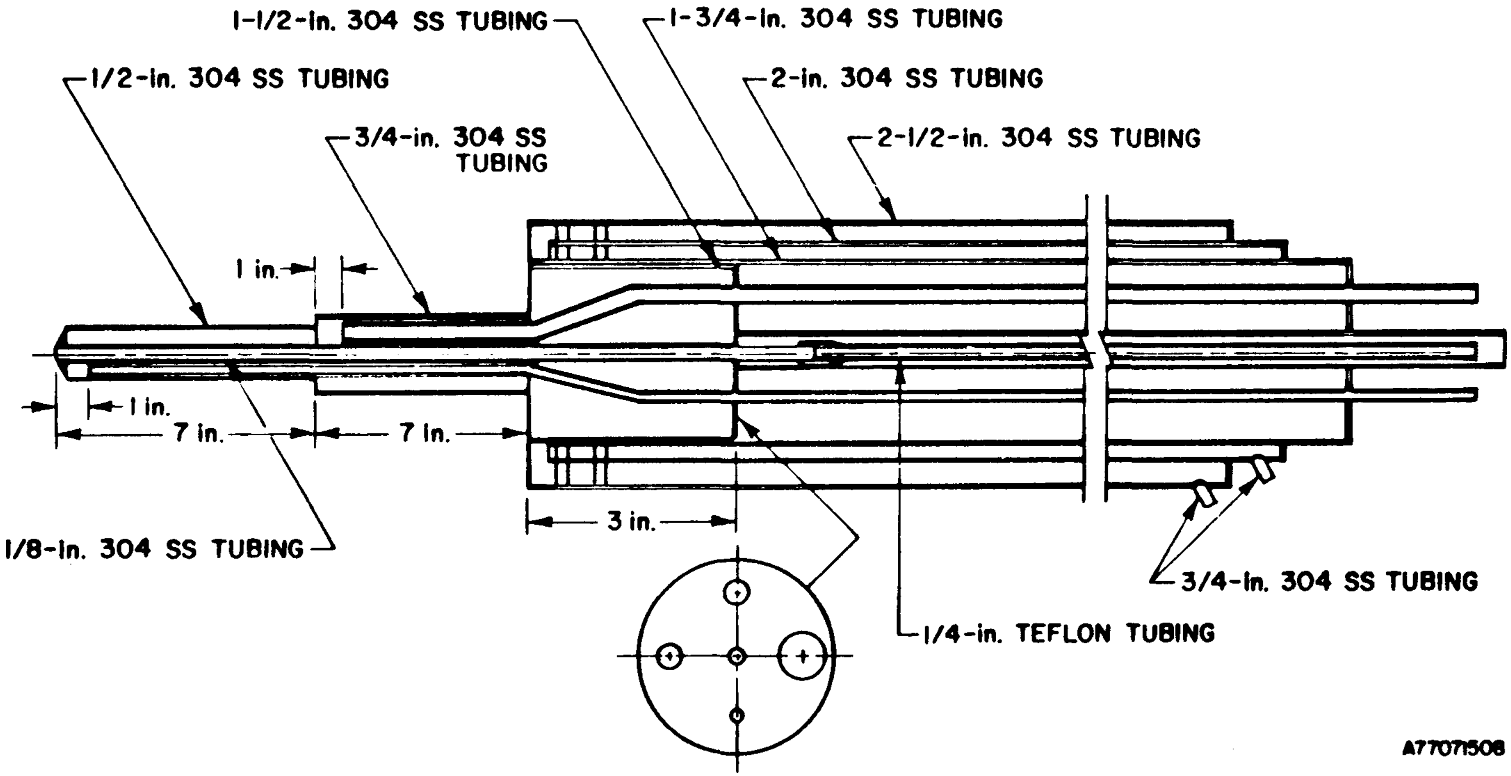

Figure 4. ASSEMBLY DRAWING OF GAS SAMPLING PROBE

BURNER TEST

Natural Gas Base-Line Data

Figure 5 illustrates the kiln burner that was used and Figure 6 is a schematic diagram of the fuel injector used with this burner. The air flow velocity, approximately 10 ft/s, is low compared with the fuel velocity. The fuel can be split between axial and radial flow and variation of the axial/radial ratio will control the flame length. The radial fuel exit area is adjustable to insure that the flow enters at sonic velocity, while the axial flow area is not adjustable and the velocity depends on the amount of axial flow with a maximum velocity of 85 ft/s for 100% axial natural gas flow.

After mounting the burner, the test facility was set up to specifically simulate a cement kiln. The critical operating parameters are 1) a length sufficient to simulate the calcining and reaction zones, 2) the firing density, and 3) the heat absorption profile.

A typical kiln,[1,3,5,6,7] shown schematically in Figure 7, consists of heating calcining, reaction, and cooling zones. The cross-sectional area (20 sq ft) and length (14 ft) of the IGT pilot furnace allow for a near-ideal simulation of the two zones of primary importance: the calcining and reaction zones. It is the heat transfer in these zones that is sensitive to fuel type. In the calcining zone, calcium and magnesium carbonate are decomposed to calcium and magnesium oxide. In the sintering or reaction zone, several complex reactions occur, and among these the oxides combine with SiO_2 to form silicates. These two zones occupy about one-third of the overall kiln length, with the calcining zone being twice the length of the sintering zone. The flame usually extends three-quarters the length of these zones.

Firing densities in rotary kilns range from 10,000 to 20,000 Btu/hr-cu ft.[1,3,5,7] A firing density value of 12,500 Btu/hr-cu ft will be used for our tests and is typical of many kilns. This requires a firing rate of 3.5 million Btu/hr for our furnace volume. Cement kilns require about 5 to 7 million Btu/ton of

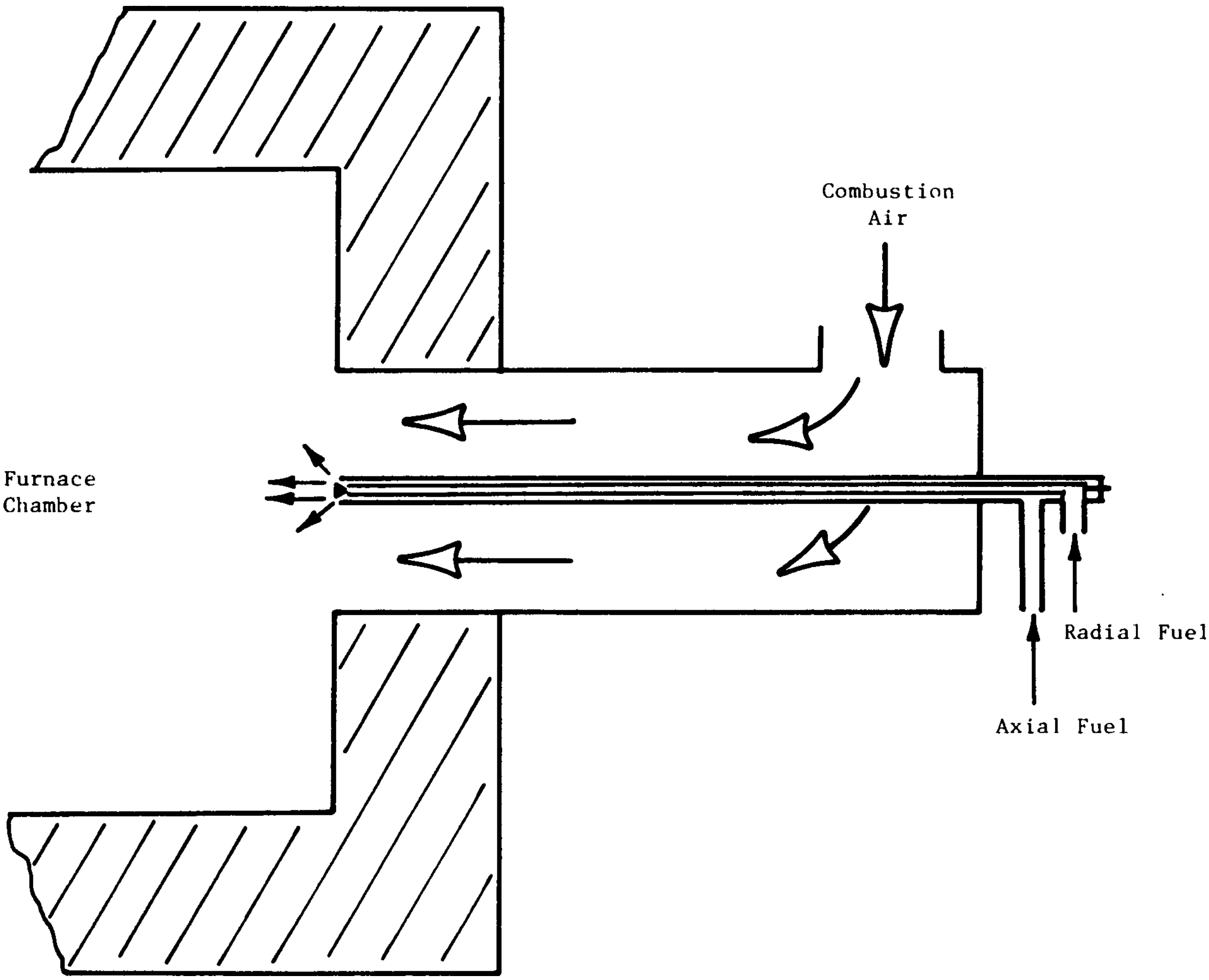

Figure 5. SCHEMATIC DRAWING OF KILN BURNER

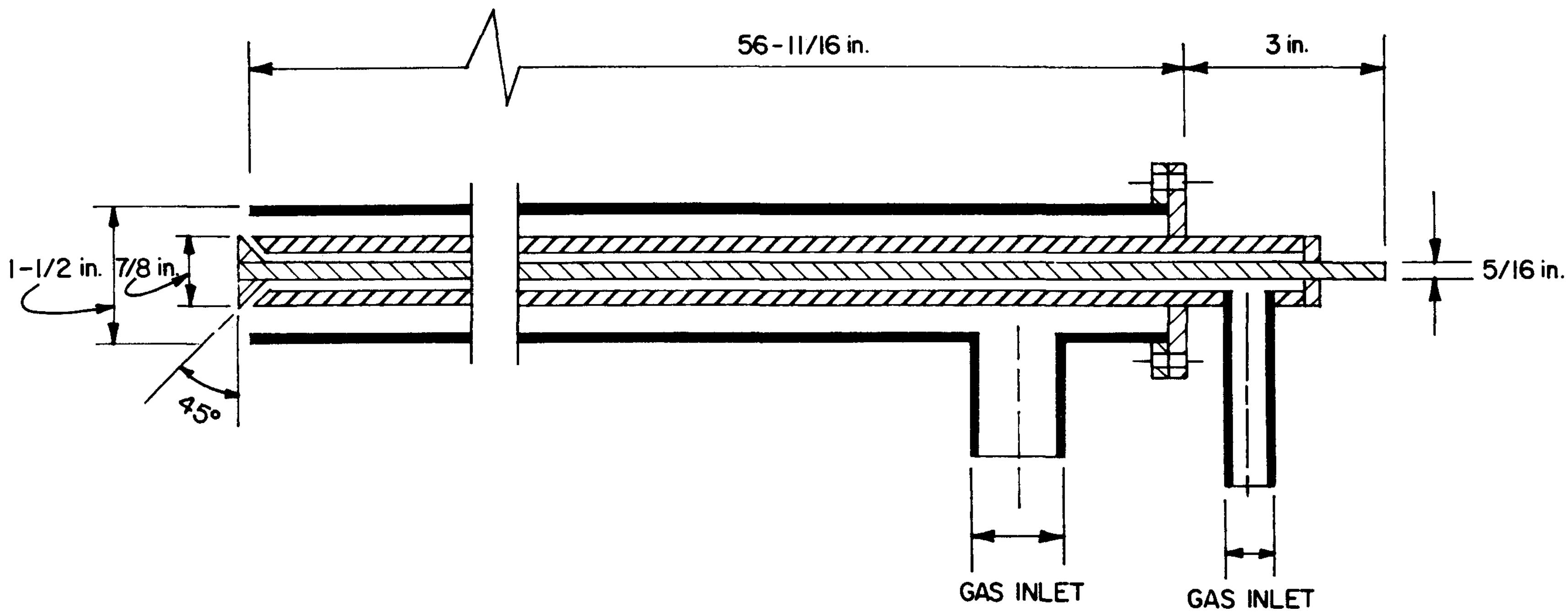

Figure 6. SCHEMATIC DIAGRAM OF THE KILN BURNER FUEL INJECTOR

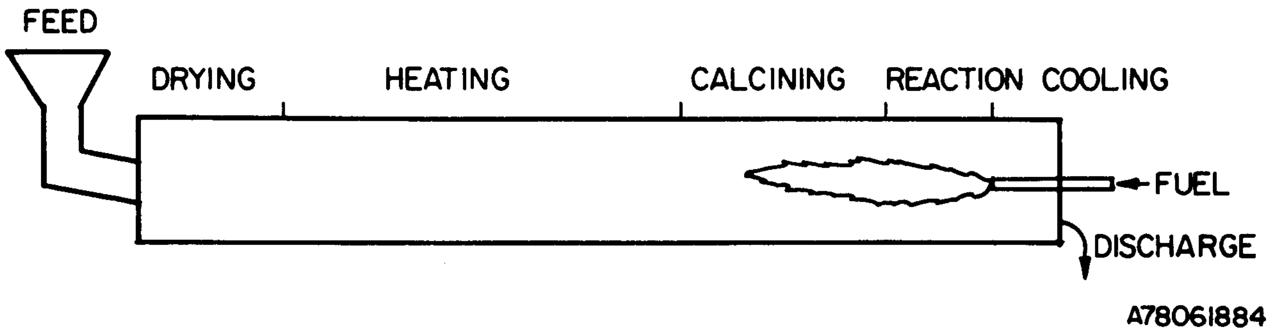

Figure 7. SCHEMATIC DRAWING OF A ROTARY CEMENT KILN

clinker.[1,3,5,6,7] Assuming 6 million Btu/ton, our furnace would simulate a production rate of 1150 lb/hr.

In order to determine the heat absorption profile, we must consider the temperature variation of the solid material (clinker) in the kiln. Figure 8

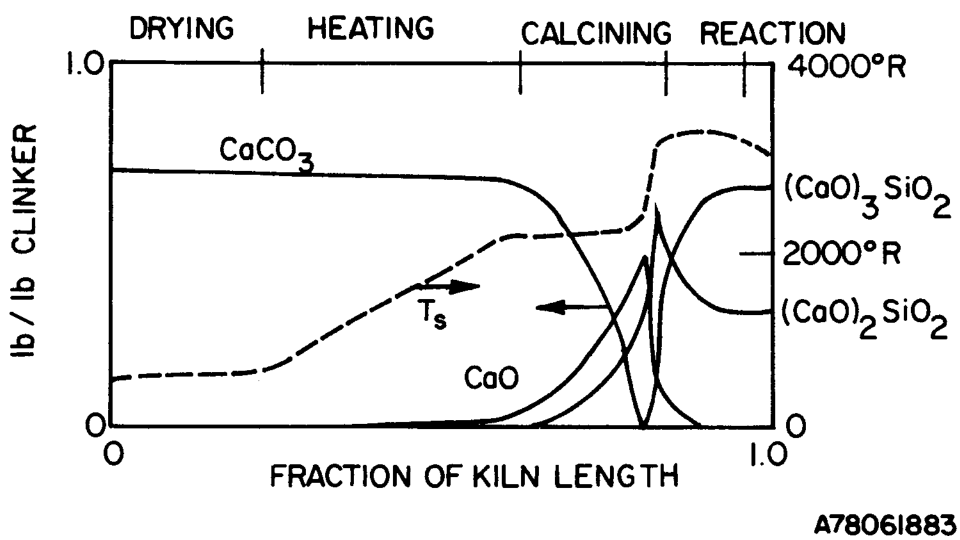

Figure 8. TEMPERATURE AND COMPOSITION IN A TYPICAL CEMENT KILN[1,5]

shows a typical plot for this temperature. This plot shows that the clinker temperature is relatively constant through the calcining zone and then rises rapidly as it enters the reaction zone. In the calcining zone, calcium and magnesium carbonate decompose by an endothermic reaction to calcium and magnesium oxide;

$$CaCO_3 = CaO + CO_2 \quad - 1350 \text{ Btu/lb CaO}$$
$$MgCO_3 = MgO + CO_2 \quad - 1264 \text{ Btu/lb MgO}$$

With a composition of about 68% CaO and 1.5% MgO, the heat requirement in the calcining zone is 950 Btu/lb of clinker produced. Therefore, the thermal load in the IGT furnace for the calcining section must be 950 Btu/lb times the 1150 lb/hr simulated production rate or 1.1 million Btu/hr, absorbed relatively uniformly throughout the section.

In the reaction zone, the temperature of the solid (clinker) materials increases rapidly by about 900°F because of the completion of the calcining reactions and the onset of the exothermic reactions. The overall effect is exothermic, releasing approximately 200 Btu/lb of clinker produced which is equivalent to 230,000 Btu/hr on the IGT test furnace. The increase in the temperature of the materials requires 233,000 Btu/hr (1150 lb/hr X 0.225 Btu/lb-°F X 900°F), so virtually no heat is transferred by the flame in this zone.

Figure 9 shows the required heat absorption profile. The flame length should be about 10.5 ft, and the total thermal loading of the furnace should be 1.1 million Btu/hr.

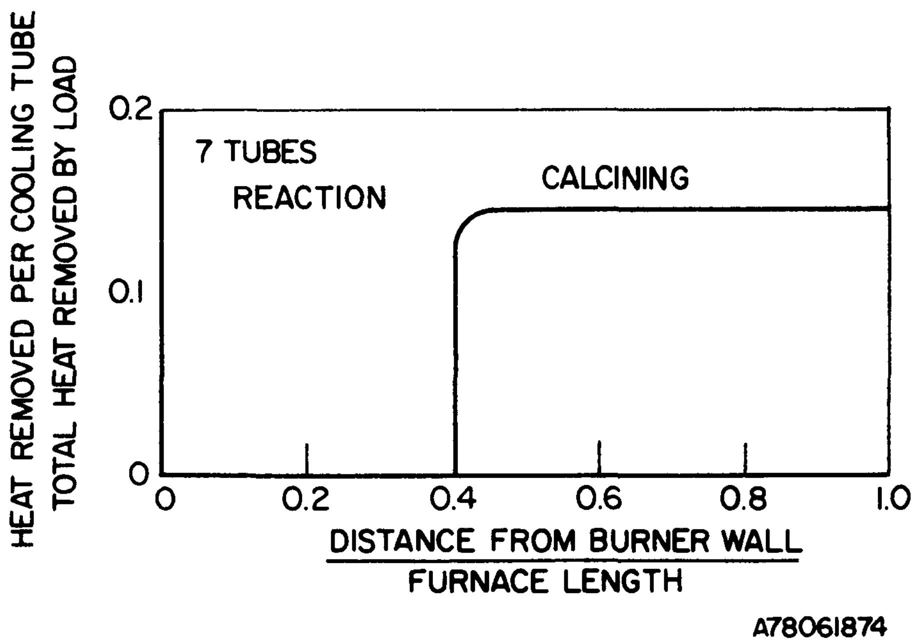

Figure 9. HEAT ABSORPTION PROFILE

Figure 10 shows a scaled drawing of the pilot-scale test furnace with the locations of the 58 water-cooling tubes, which can be placed within the furnace, indicated by circles. The filled-in circles show the locations of the water tubes that were used to simulate the kiln load. These locations were chosen to give a heat-absorption profile approximating the ideal profile shown in Figure 9. The total heat removed by the water-cooling tubes for the natural gas flame was 1,040,000 Btu/hr with a fuel enthalpy input of 3,502,000 Btu/hr, giving a thermal efficiency of 31%. Figure 11 shows the shape of the natural gas flame. These data were collected by making radial gas analysis measurements at selected axial positions using the gas sampling probe and the carbon monoxide and oxygen analyzers. The envelope shown in Figure 12 depicts the boundaries within which 99% of the combustibles were consummed.

Temperature data were collected as a function of axial and radial furnace positions using the suction pyrometer. These temperature data were used to generate the isothermal profiles given in Figure 12. The peak temperature measured for natural gas was 1580°C (2876°F) at 60 cm from the burner wall.

Figure 13 shows the flow direction profile measured for the natural gas flame. The flow direction was measured using a water-cooled, three-hole Hubbard probe, a Datametrics Barocel pressure transducer, and a Datametrics CGS electric manometer. The furnace flow profiles from this burner are very similar to those found with the forward-flow baffle burner, except that the recirculation zones are less intense because the total entering momentum (fuel plus air) is lower for the kiln burner.

Noise-level measurements were made adjacent to the furnace 2 feet from the side at the mid-point of the furnace and 1 foot from the burner. These measurements were made with the flame off to determine the background and on to determine the level of noise due to fuel flow through the burner and combustion in the furnace. The background noise level was 90 db with the fuel turned off. There was a 4-db increase at the burner with the flame. At the side, the noise level increased 10 db with the flame, both with and without a sampling door removed.

Post flame emissivities were also measured by the Schmidt method[20] using the radiometer and water-cooled target. Three radiant flux measurements are required:

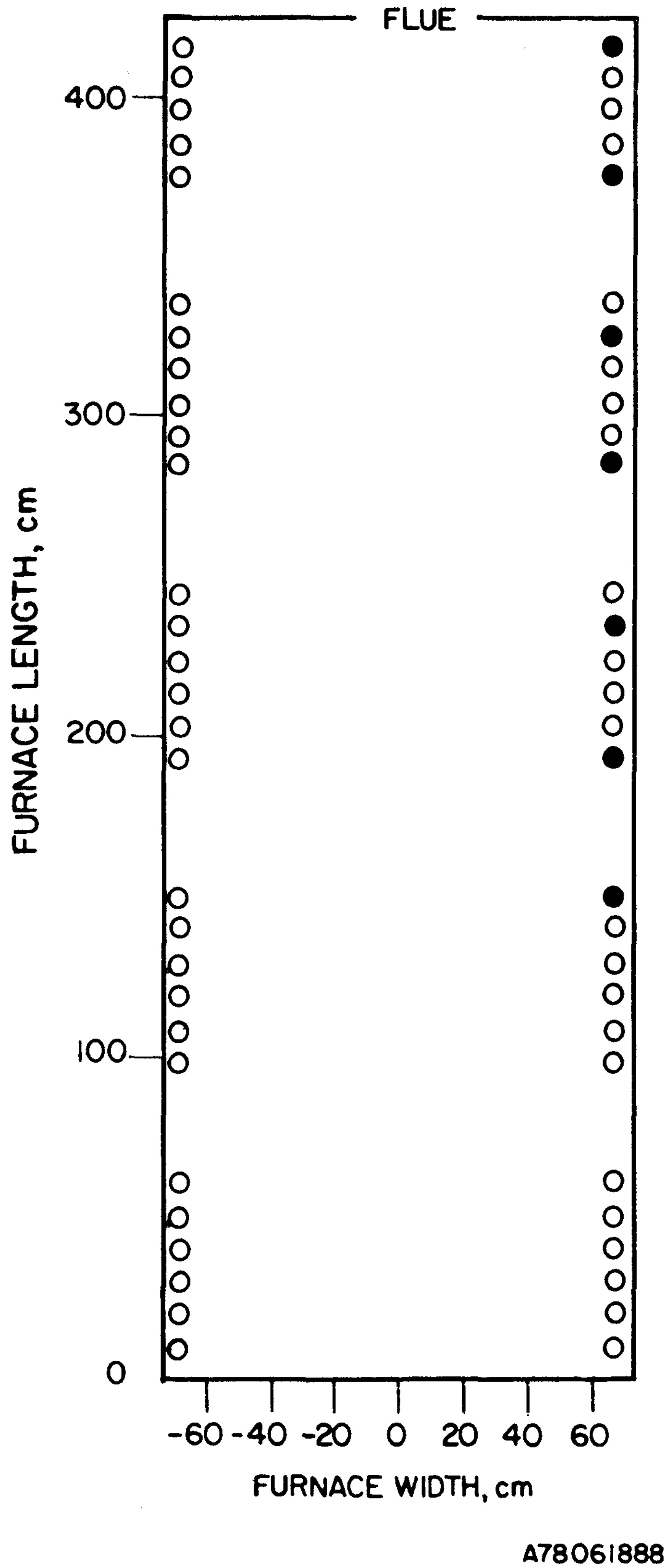

Figure 10. SCALED DRAWING OF TEST FURNACE WITH COOLING-TUBE POSITIONS

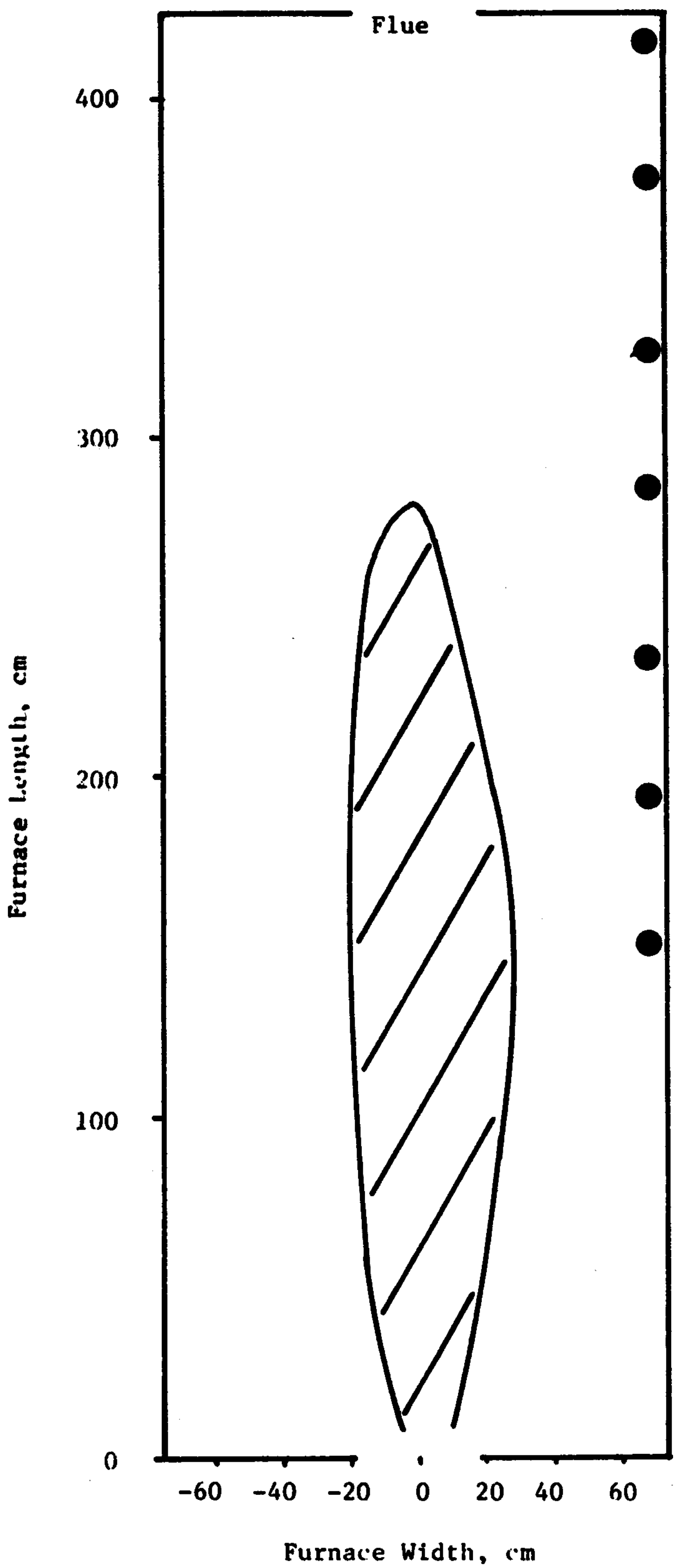

Figure 11. FLAME SHAPE FOR NATURAL GAS ON THE KILN BURNER

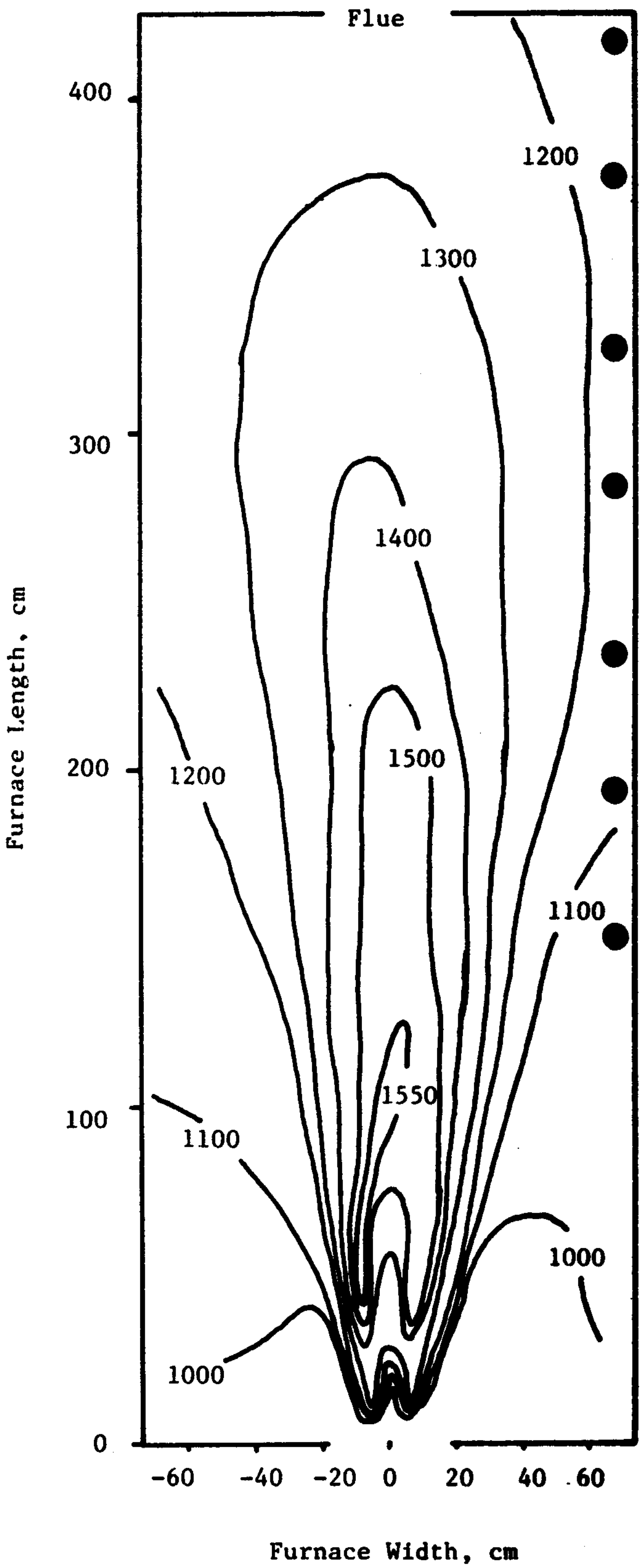

Figure 12. TEMPERATURE PROFILES (°C) FOR NATURAL GAS ON THE KILN BURNER

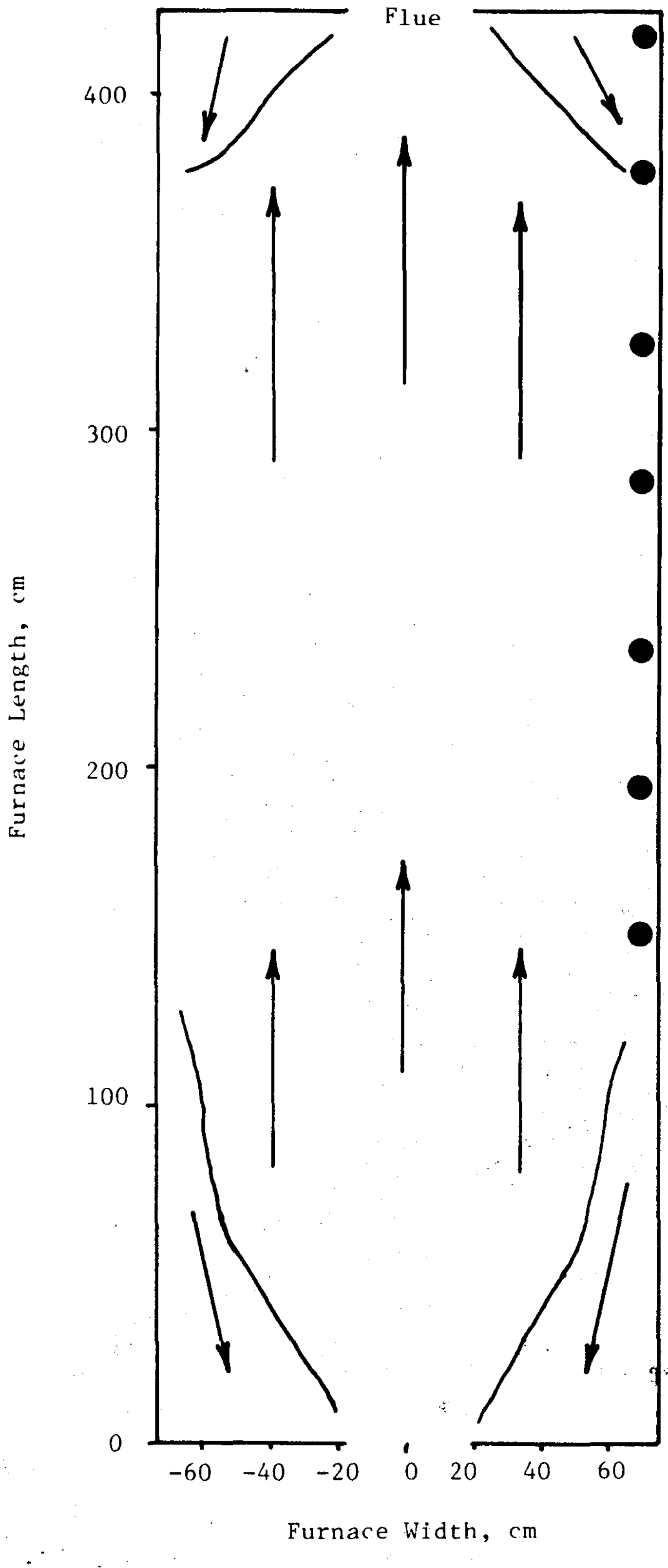

Figure 13. NATURAL GAS FLOW DIRECTION PROFILE

R_1 = Radiation intensity of the flame alone, obtained by viewing a cold target through the flame

R_2 = Radiation intensity of the refractory wall viewed through the flame

R_3 = Radiation intensity of the refractory wall without the flame.

The flame absorptivity is then—

$$\alpha = 1 - \frac{R_2 - R_1}{R_3} \tag{1}$$

The relationship between gas emissivity and absorptivity in a furnace, when the refractory is not a black body, can be determined from radiation theory.[4] The result is—

$$\alpha_f = 1 - (1 - \varepsilon_f)\ \{\varepsilon_r + \rho_r\ [\frac{\varepsilon_f T_f^4}{T_r^4} + (1 - \varepsilon_f)(\frac{\varepsilon_r + \frac{\rho_r \varepsilon_f T_f^4}{T_r^4}}{1 - \rho_r(1 - \varepsilon_f)})]\} \tag{2}$$

where ρ_r and ε_r are the reflectivity and emissivity of the refractory. T_r and T_f are the temperatures of the refractory and combustion products. The results of the gas emissivity measurements were given in Table 2. The values measured lie between the values that can be calculated by the method given in Reference 4 and the procedure proposed by Leckner (Combustion and Flame 19, 33, 1972).

Low-Btu Fuel Gas Tests

Flame Stability Tests

After completion of the natural gas work, flame stability tests began with the substitute fuel gases. The tests were initiated by attempting to stabilize a low-Btu gas flame at a volumetric flow rate equal to the natural gas flow rate. The low-Btu gas flow rate was then increased until either the flame became unstable (lifted or blew off) or until the enthalpy input reached that of the natural gas tests. For the Koppers-Totzek oxygen (KTO) fuel gas, no flame instability was encountered. The fuel injector could be fired at the 3.5 million Btu/hr input used for natural gas. However, Wellman-Galusha air (WGA) only reached a level of 1 million Btu/hr before blowing off and Winkler air (WA) could not be stabilized when fired on a cold furnace. Decreasing the excess air did not effect stability. Increasing the air preheat to 800°F did not make Winkler air fuel gas stable and only allowed the Wellman-Galusha air fuel input to be increased to 1.5 million Btu/hr before the flame became unstable. Because of the construction of this burner, it was not possible to increase the air preheat beyond 800°F. Because of the flame stability problem, a large kiln fuel injector was fabricated to reduce the Wellman-Galusha air and Winkler air fuel velocities.

Koppers-Totzek Oxygen Fuel Gas Tests

Table 2 compares the data collected for the low-Btu gases with those for natural gas. The low heating value per cubic foot for the substitute fuels requires that the fuel volume flow rate be increased relative to natural gas. With many burners, this can cause problems with flame length and shapes; however, with the kiln fuel injector it was still possible to obtain a flame length similar to that of natural gas by adjusting the axial-to-radial volume flow ratio.

The thermal efficiency (heat to the load divided by fuel enthalpy input) for the furnace when fired with Koppers-Totzek oxygen fuel gas was 33% compared with the 31% that was set for natural gas. This is not too surprising, since the adiabatic flame temperature for KTO is about 90°F higher than that of natural gas. With the KTO flame shape, shown in Figure 14 adjusted to be approximately the same as that of natural gas, the heat transfer should be relative to the radiative characteristics which are dominated by the flame temperatures. Figure 15 shows the temperature profiles measured for KTO. In general, they are similar to those of the natural gas flame with a peak temperature of 1580°C (2876°F) found at 120 cm with our measurements. Figures 16 and 17 show the results of the radiation measurements. Figure 16 shows the radiant flux from the flame plus the combustion products along the length of the furnace for all the fuels tested, while Figure 17 shows the radiation from the flame alone. The radiant flux was measured with a narrow angle radiometer sighted down a water-cooled tube at a water-cooled target. For the measurements of radiant flux from the flame and combustion products, the water-cooled probe was placed on one side of the furnace and the target on

Table 2. RESULTS OF KILN BURNER TRIALS

Fuel Type	Fuel Flow,[b] SCF/hr	% Radial	Air Flow, SCF/hr	Axial Fuel Velocity, ft/s	Air Velocity,[c] ft/s	Flue Temp, °F	Vol Flow Flue Prod, SCF/hr	Flame Length, cm	Thermal[d] Efficiency, %	Post Flame Emissivity	Flue Gas Analysis for Kiln Burner Trials: NO_x, ppm	CO, ppm	CO_2, %, Dry Basis	O_2, %, Dry Basis	N_2, %, Dry Basis
Natural Gas	3,400	95	35,800	5	11.6	2250	39,150	282	31	0.21	80	150	10.2	2.1	87
Koppers-Totzek Oxygen	12,400	17	27,500	290	8.9	2420	34,600	302	33	0.21	110	300	23.1	1.9	75
Wellman-Galusha Air[a]	21,800	33	28,230	75	10.0	2223	45,700	292	24	0.20	26	200	20.1	1.3	78
Winkler Air[a]	29,700	14	28,130	131	10.0	2254	52,900	312	22.5	0.20	23	70	18.0	1.2	80

a Used a 4-inch kiln injector rather than the 1-1/2-inch natural gas injector.

b Fuel flow adjusted to give 3.50 ± 0.05 million Btu/hr fuel enthalpy input to furnace. (Fuel heating value varied from nominal value due to slight variations of actual fuel composition.)

c At 650°F air preheat.

d Efficiency defined as the load divided by the product of the fuel volume flow and fuel heating value.

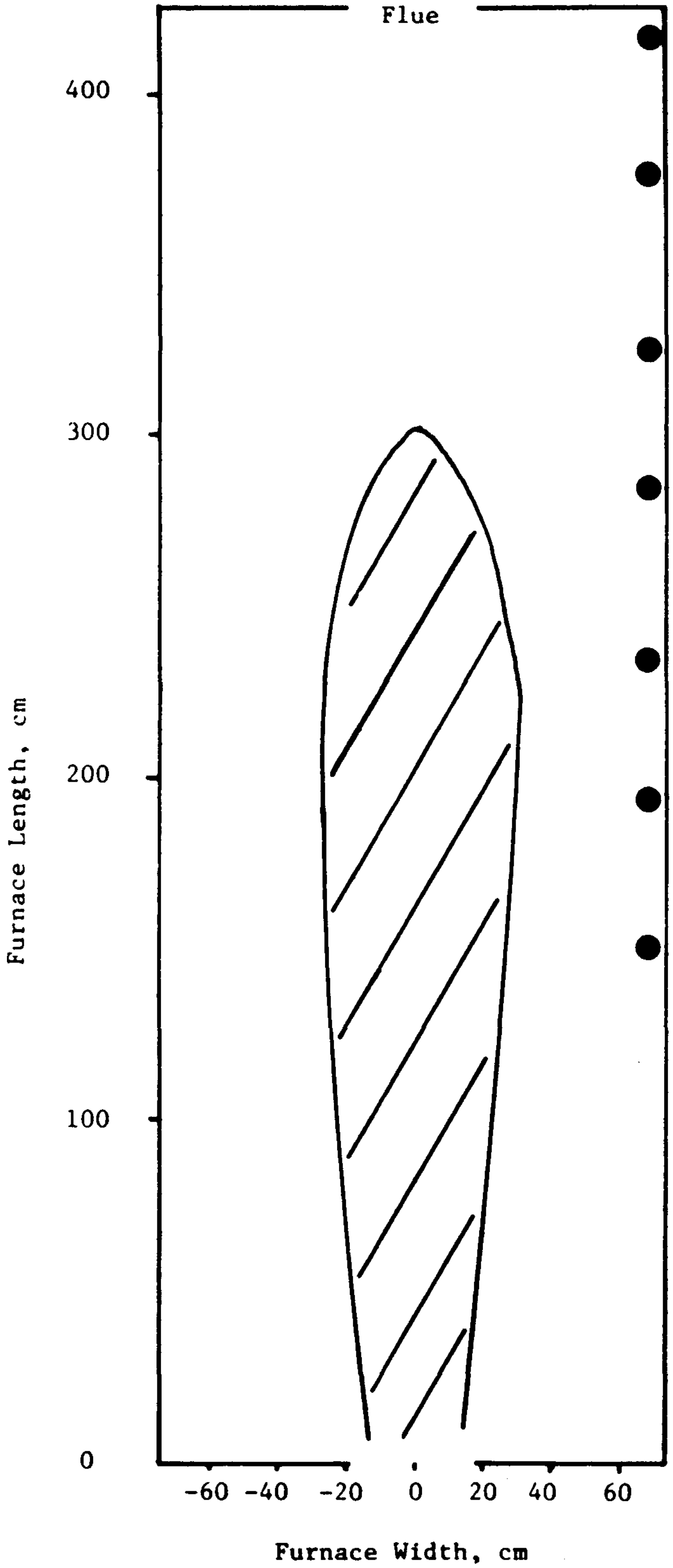

Figure 14. FLAME SHAPE FOR KOPPERS-TOTZEK
OXYGEN FUEL GAS ON THE
KILN BURNER

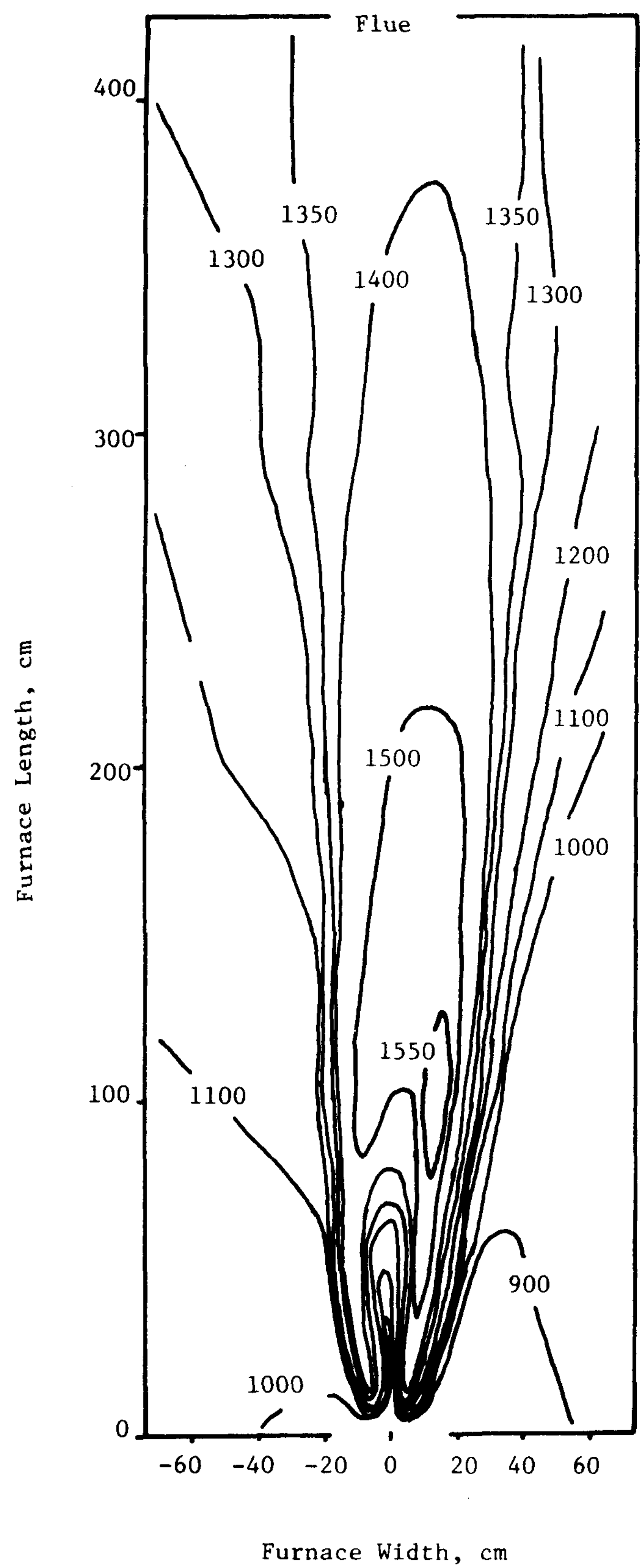

Figure 15. TEMPERATURE PROFILES (°C) FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE KILN BURNER

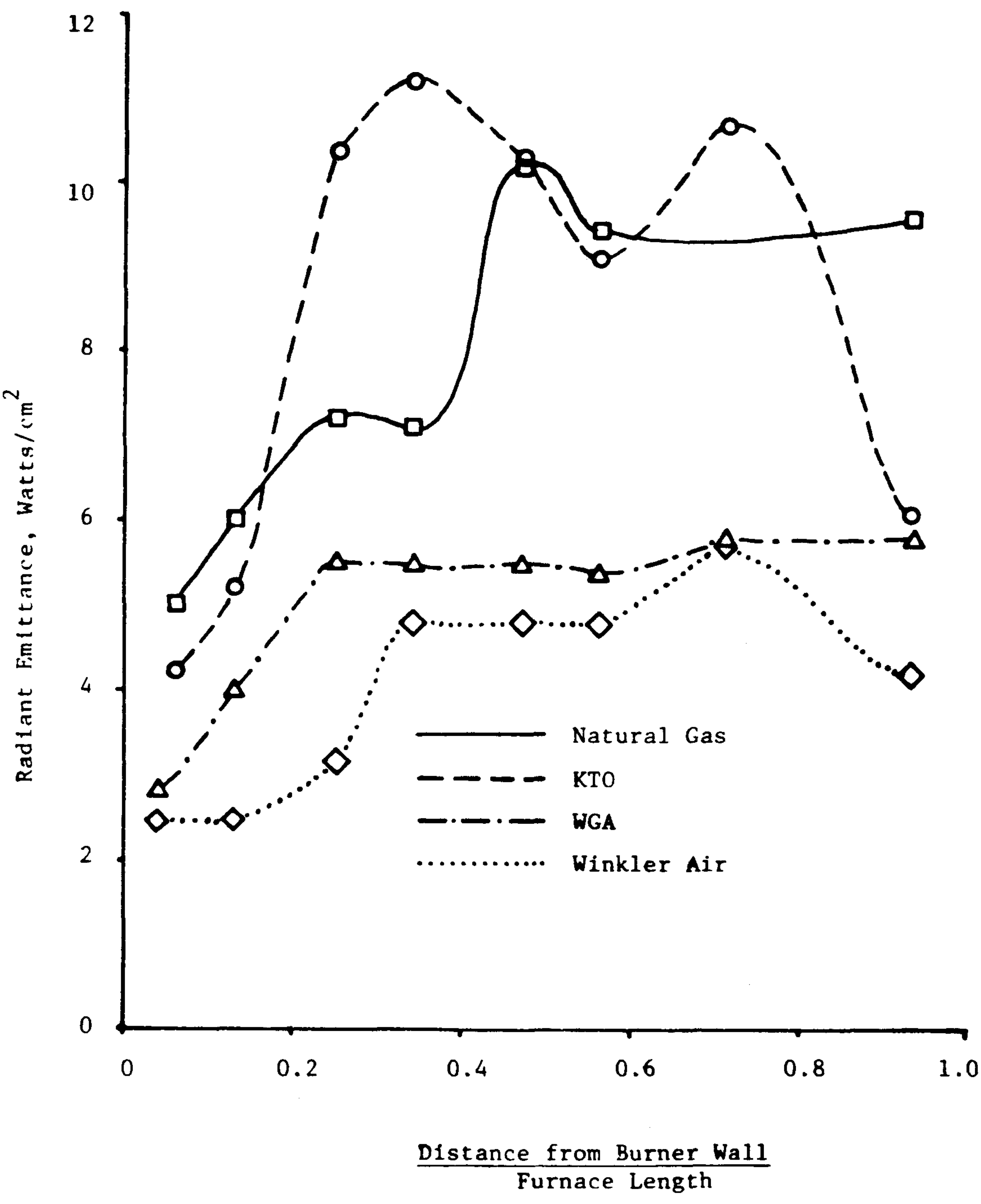

Figure 16. RADIANT EMITTANCE FROM FLAME PLUS COMBUSTION PRODUCTS FOR KILN BURNER

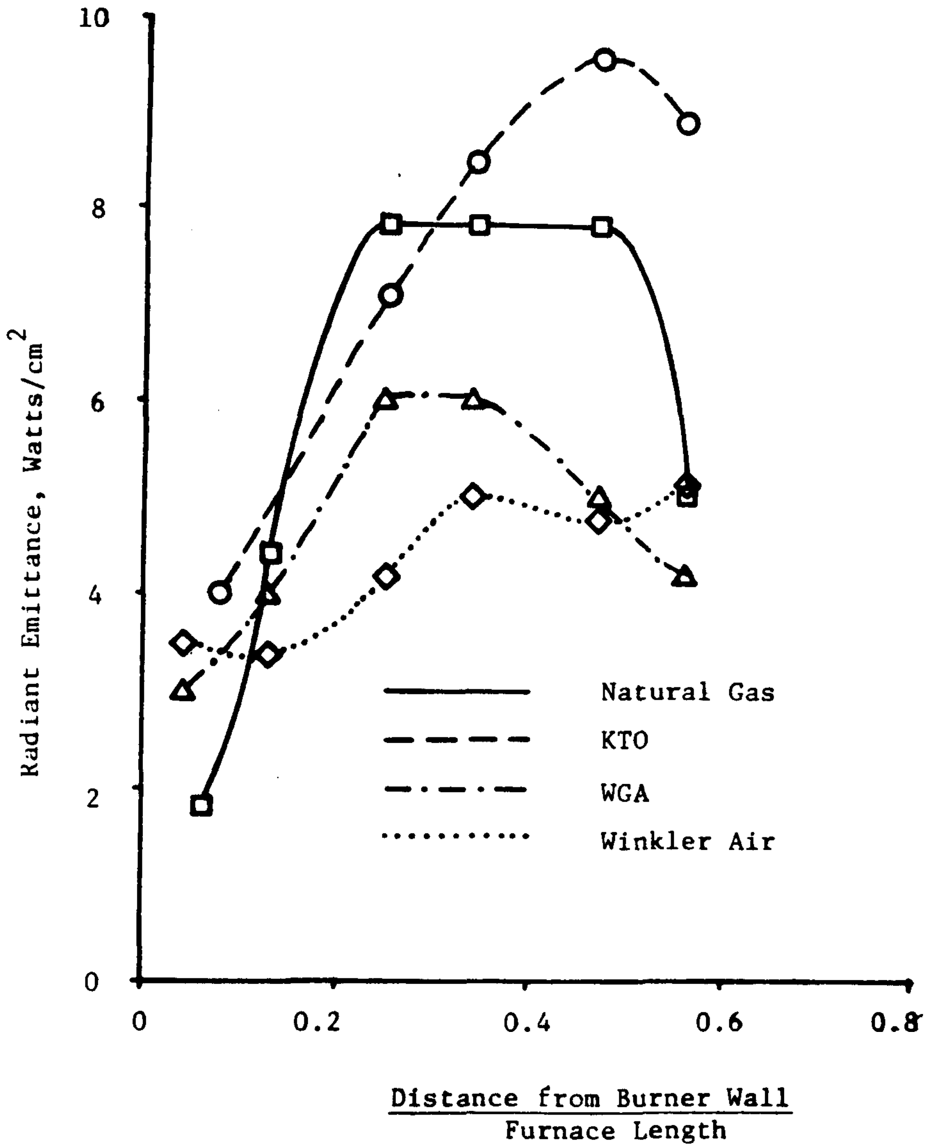

Figure 17. RADIANT EMITTANCE FROM FLAME FOR KILN BURNER

the other side. For the flame radiation measurements, the water-cooled probe was positioned at the near flame boundary and the water-cooled target at the far flame boundary.

In Figure 16, the radiant flux for KTO rises rapidly to a peak, drops near the center of the furnace, and peaks again before falling off toward the flue. For the greater part of the furnace length, the KTO radiant flux is greater than or equal to that measured for natural gas. This would suggest that the KTO flame should transfer more heat to the load which, indeed, was the case.

Figure 18 compares the heat-absorption profile for KTO with that of natural gas. Considering the process involved, the KTO heat-absorption profile is similar enough to be no practical problem. The flow direction profile for KTO was the same as that seen for natural gas which is the flow direction profile to be expected from a burner with a high velocity central fuel jet surrounded by a low velocity coaxial air flow.

Sound level measurements were taken for KTO in the same manner as was done for natural gas. During the KTO tests, the background noise level was 89 db. When KTO was fired, there was a 5-db increase at the burner, a 7-db increase at the side of the furnace with the furnace closed, and a 9.5-db increase when a sample door was removed.

Koppers-Totzek Oxygen Fuel Gas Retrofit Conclusions

The test results for KTO suggest that a medium-Btu gas, such as this, with a high adiabatic flame temperature retrofits very well on a kiln burner. The thermal efficiency and flame temperatures were similar to natural gas and flame stability was no problem. By adjusting the axial/radial gas flow ratio we were able to obtain a flame length similar to the natural gas flame length. Thus, the most important considerations — stability, efficiency, flame temperature and flame size — are all comparable to the natural gas case.

Wellman-Galusha Air Fuel Gas Tests

Data from the WGA tests are also included in Table 2. WGA was fired on a larger, 4-inch injector in order to produce a stable flame at a 3.5 million Btu/hr fuel enthalpy input.

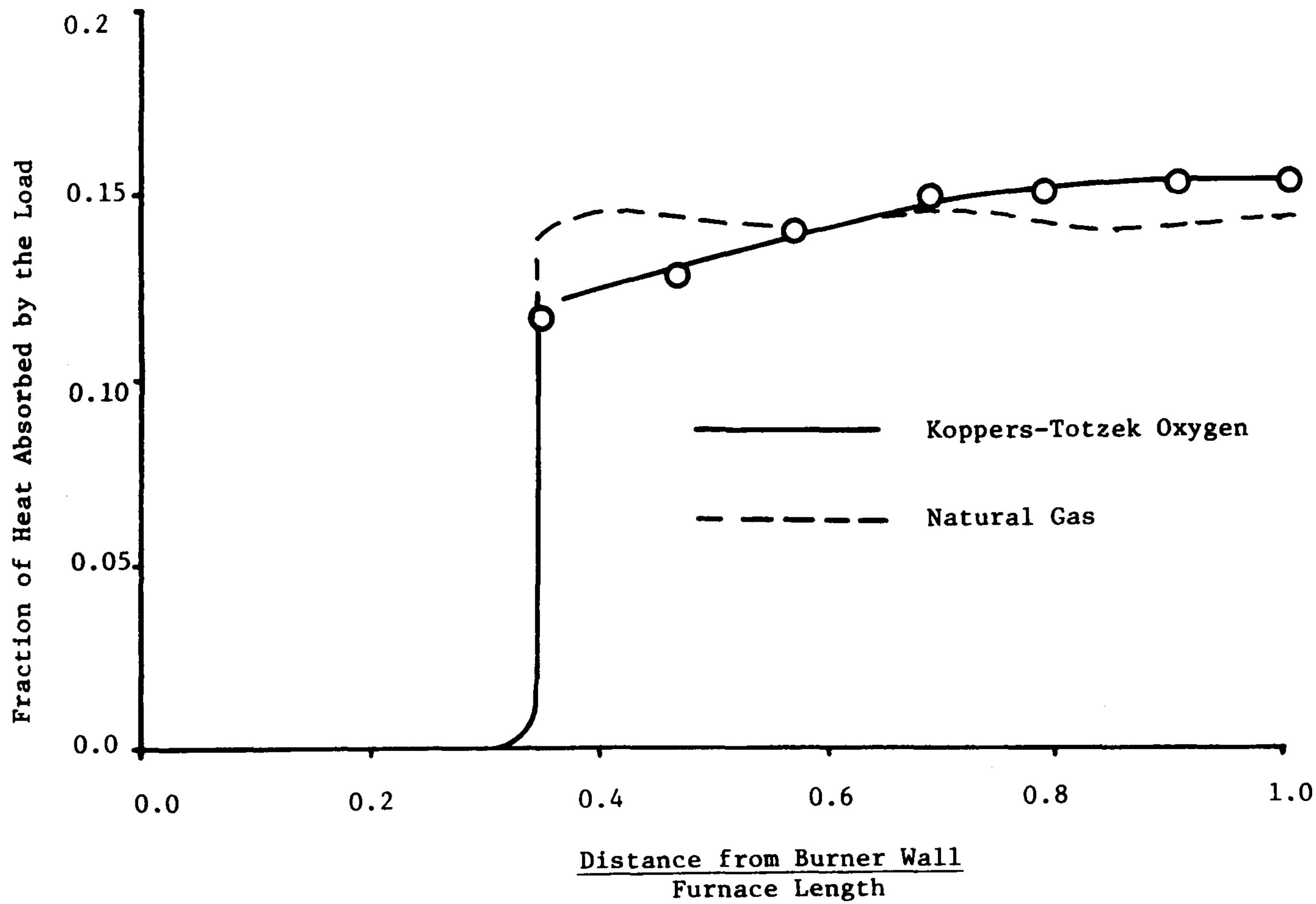

Figure 18. HEAT ABSORPTION PROFILE FOR NATURAL GAS AND KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE KILN BURNER

With this fuel, the furnace thermal efficiency was 24%. This is considerably less than the 31% with natural gas. Figure 19 shows the temperature profiles observed with WGA. The peak temperature measured was 1422°C (2592°F) at 200 cm. Figure 20 shows the flame shape, which was adjusted to have a length equal to the natural gas flame length by adjusting the fraction of axial gas flow through the fuel injector.

The radiation measurements shown in Figures 16 and 17 help to explain the reduced thermal efficiency when firing WGA. The radiant flux from the flame and from the flame plus combustion products for WGA is considerably less than that measured for natural gas or KTO. Figure 21 shows the heat-absorption profile for WGA. The WGA profile is similar enough to the natural gas base-line heat absorption profile to be no practical problem. The flow direction profile, measured for WGA was similar to the other gases.

Sound level measurements were also taken during the WGA trials. The background noise level was 80 db. When the furnace was fired with WGA, there was a 7-db increase at the burner. The increase at the side of the furnace was 5 db with the furnace closed and 8 db when one of the sampling doors was removed.

Wellman-Galusha Air Fuel Gas Retrofit Conclusions

Since WGA was only stable at 1 million Btu/hr when fired on the natural gas fuel injector, we cannot say that it could be retrofit without modification. When the injector was modified (made larger to reduce the fuel velocities), flame stability was attained. Flame length was no problem because the kiln fuel injector design allows this adjustment. However, flame temperatures and thermal efficiency were reduced for WGA relative to both the natural gas and KTO flames.

Thus, the burner would be seriously derated if WGA were retrofit directly on the burner. When modified to allow the fuel enthalpy input to be increased, the thermal efficiency and flame temperatures were low, relative to the natural gas flame, meaning that the burner would still have to be derated. If the fuel could be sufficiently preheated, the efficiency and flame temperature problems might be solved.

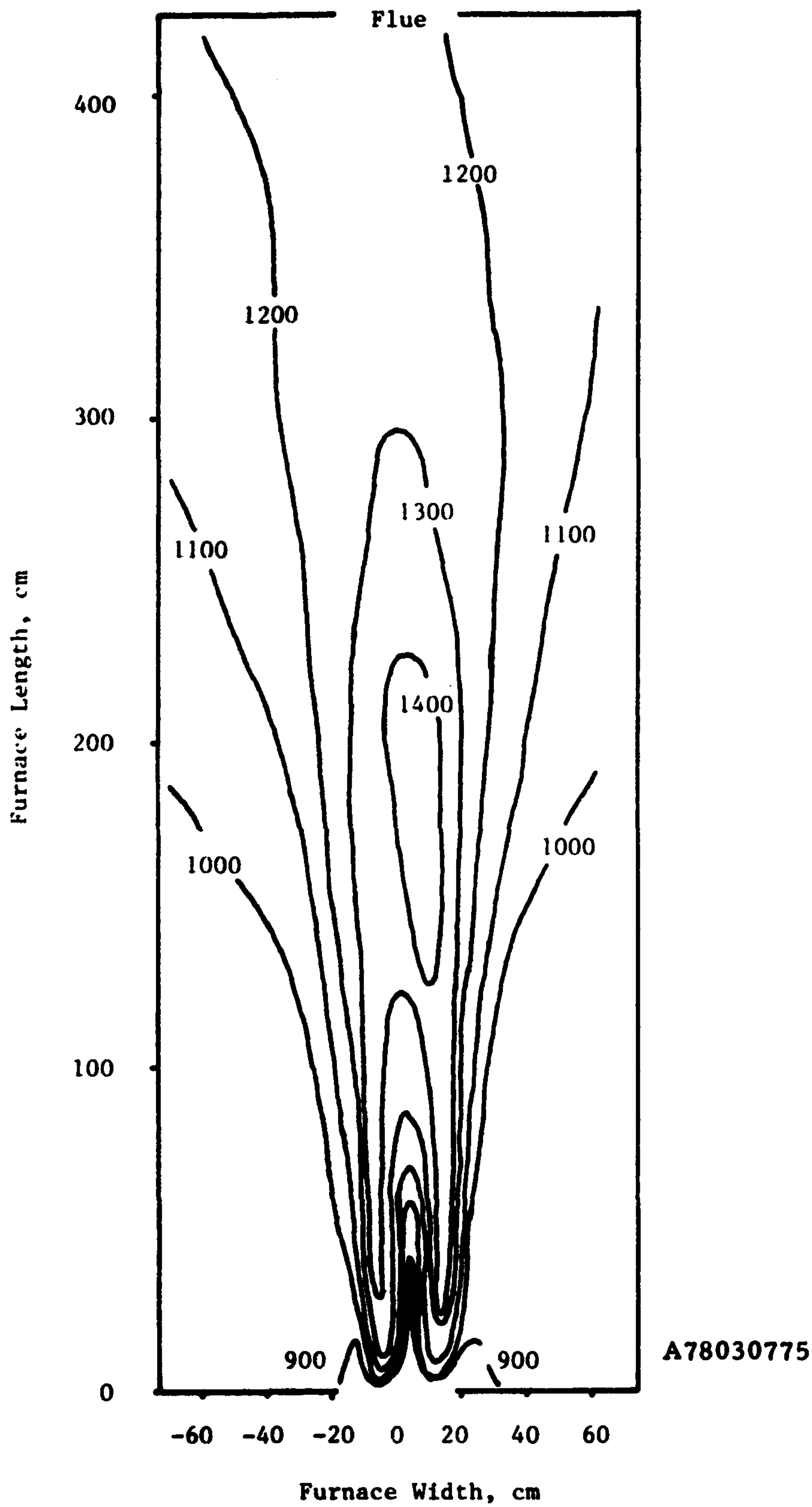

Figure 19. **TEMPERATURE PROFILES (°C) FOR WELLMAN-GALUSHA OXYGEN FUEL GAS ON THE KILN BURNER**

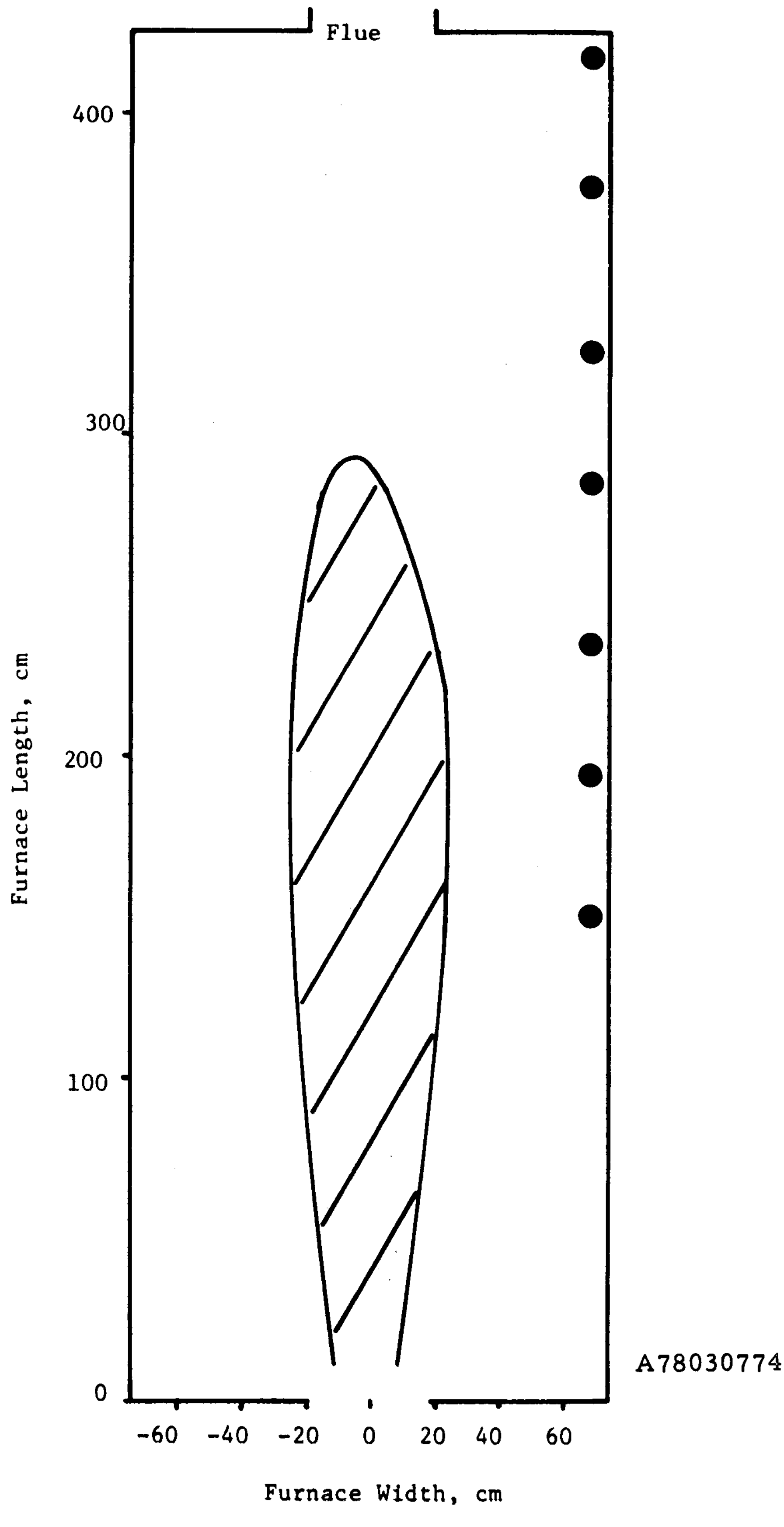

Figure 20. **FLAME SHAPE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE KILN BURNER**

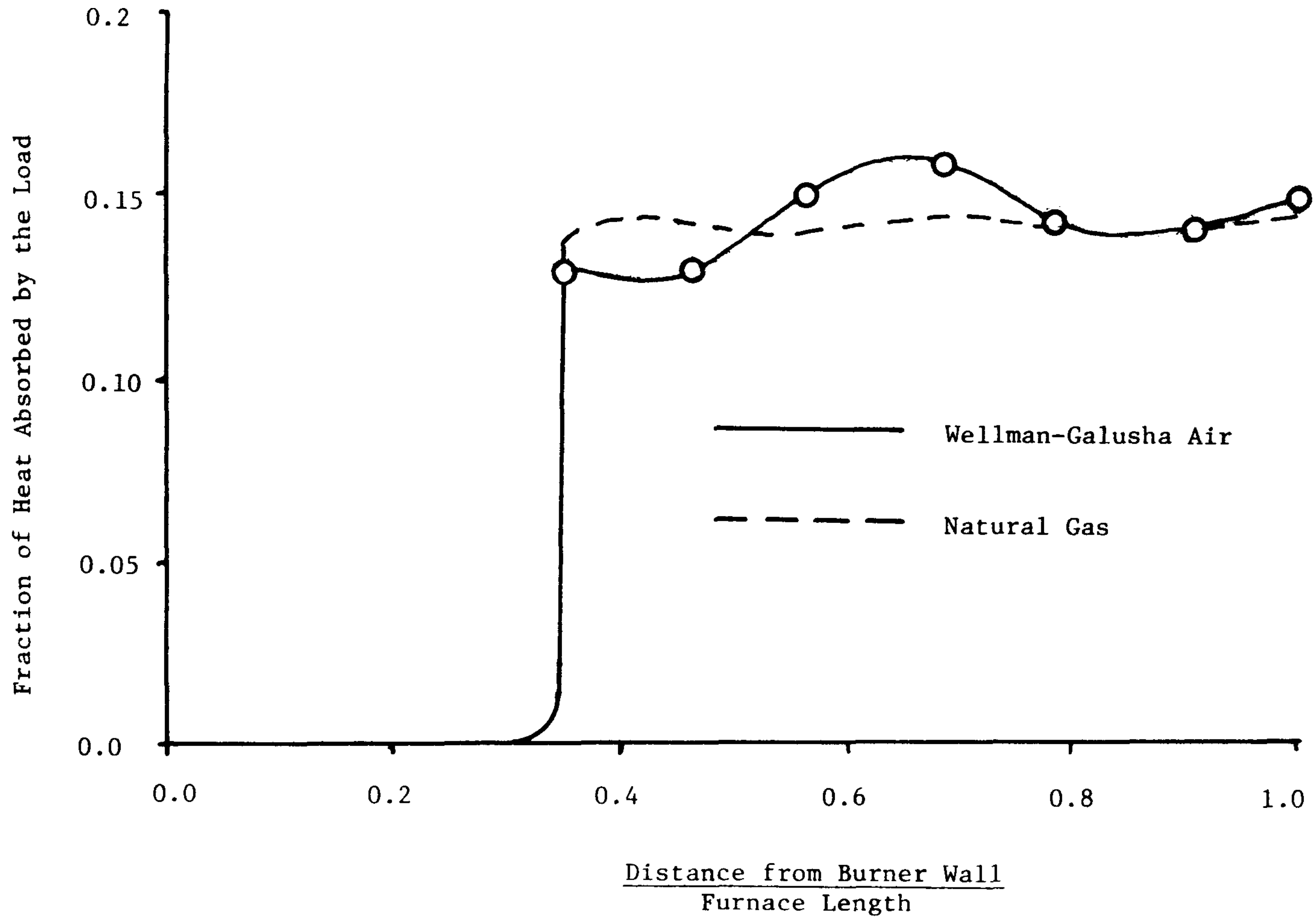

Figure 21. HEAT ABSORPTION PROFILE FOR WELLMAN-GALUSHA AIR FUEL GAS COMPARED WITH NATURAL GAS ON THE KILN BURNER

Winkler Air Fuel Gas Tests

Table 2 also gives results from the Winkler air fuel gas trials. This fuel, as with WGA, required a larger fuel injector to have a stable flame. With the 4-inch injector, no flame instability was encountered and the burner could be fired at the required 3.5 million Btu/hr fuel input. At this rate, the furnace thermal efficiency (load divided by fuel enthalpy input) was 22.5%. This is the lowest efficiency of all the fuels. This is not surprising because WA has the lowest adiabatic flame temperature of the four fuels. Figure 22 is a plot of the measured thermal efficiency versus adiabatic flame temperature to the fourth power for natural gas, KTO, WGA, and WA fuel gases. The relatively good correlation is not surprising because flame radiation is the dominant heat-transfer mode, and the adiabatic flame temperature and the real flame temperatures are closely related. Figure 23 is a plot of the temperature profiles measured for WA. The peak temperature observed was 1337°C (2439°F) at 200 cm. These are the lowest temperatures of all the fuels tested. These low temperatures explain the low radiant flux measurements shown in Figures 16 and 17.

Figure 24 shows the flame shape and Figure 25 shows the heat-absorption profile. The flow direction profile was similar to the other gases tested. During the Winkler air sound level measurements, the background noise level was 77 db. There was a 20-db increase at the burner when WA was fired. The increase at the side of the furnace was 14 db with the furnace closed and 18 db when one sampling door was removed.

Winkler Air Fuel Gas Retrofit Conclusions

The Winkler air retrofit conclusions are similar to the conclusions for WGA except that it was not possible to stabilize a WA flame even at a 1 million Btu/hr fuel input. With a modified (larger) fuel injector, WA fuel gas was stable at 3.5 million Btu/hr and could be adjusted to the same flame length as natural gas. The thermal efficiency and flame temperatures, however, were the lowest of all the fuels. For this reason, WA would not be an ideal fuel for retrofitting on a kiln burner. Preheating the fuel would help the efficiency and flame temperature problems; however, the increase in fuel volume due to temperature and thus the increase in fuel velocity could cause flame stability problems.

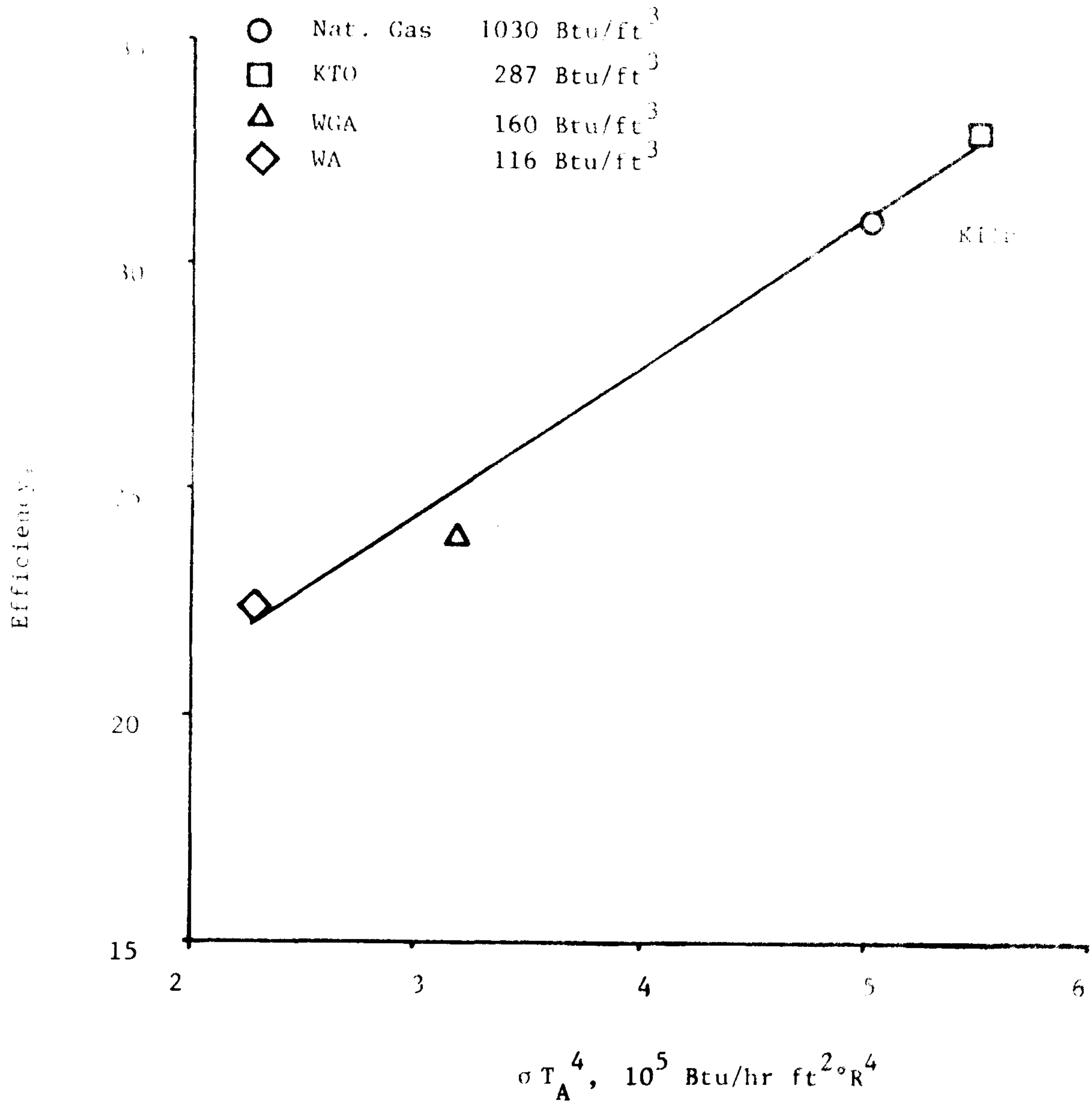

Figure 22. **EFFICIENCY VERSUS ADIABATIC FLAME TEMPERATURE TO THE FOURTH POWER**

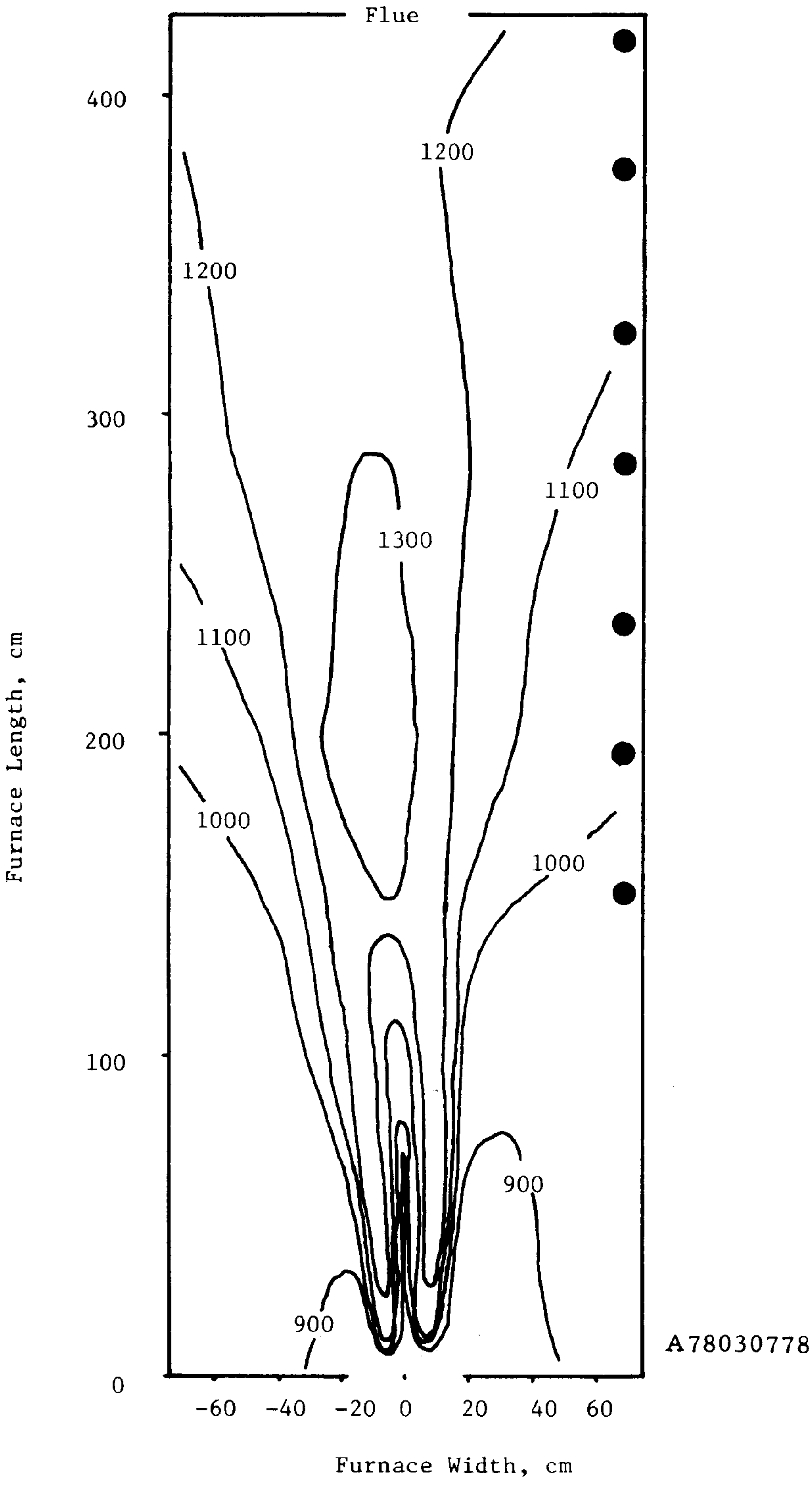

Figure 23. TEMPERATURE PROFILE (°C) FOR WINKLER AIR FUEL GAS ON THE KILN BURNER

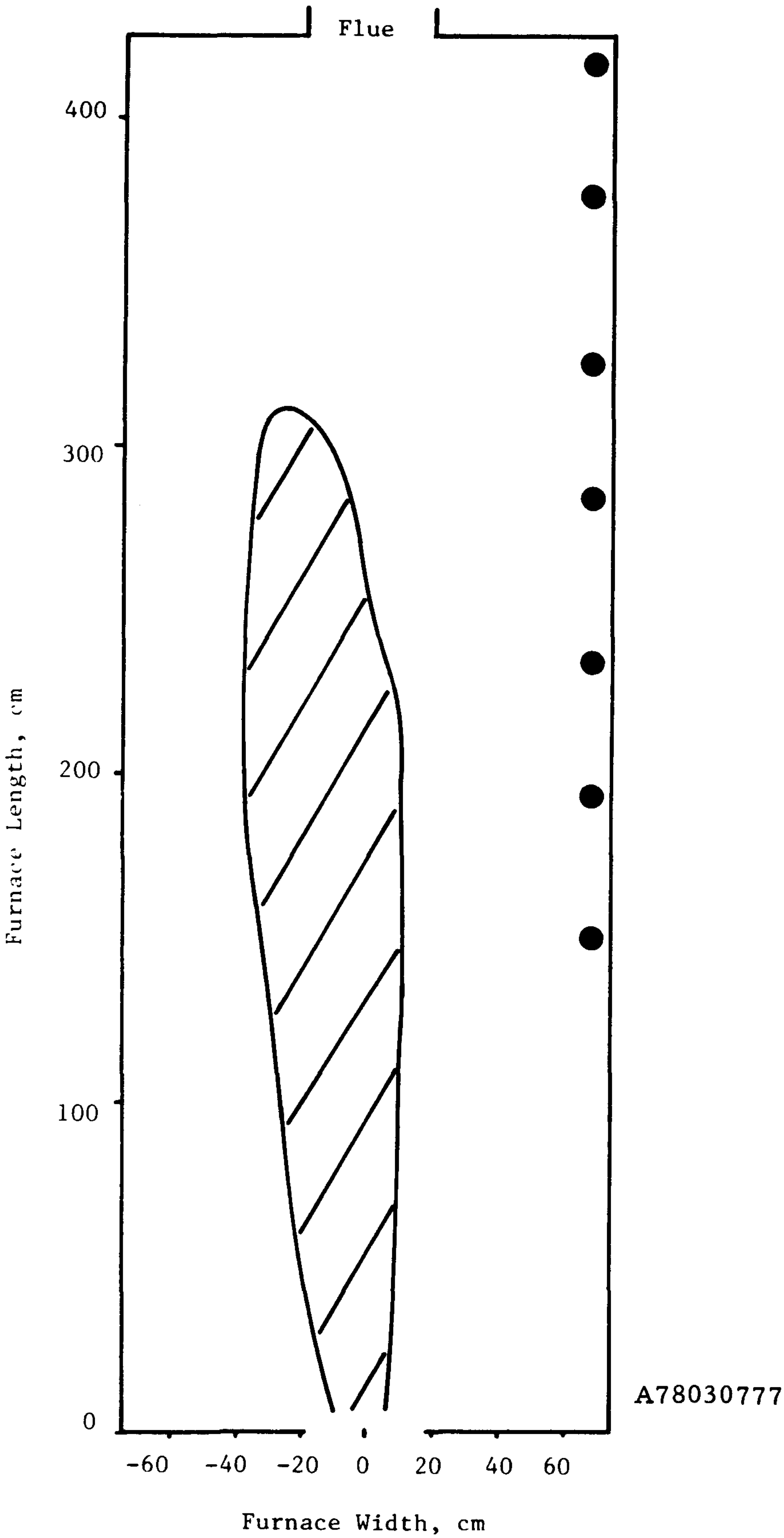

Figure 24. FLAME SHAPE FOR WINKLER AIR FUEL GAS ON THE KILN BURNER

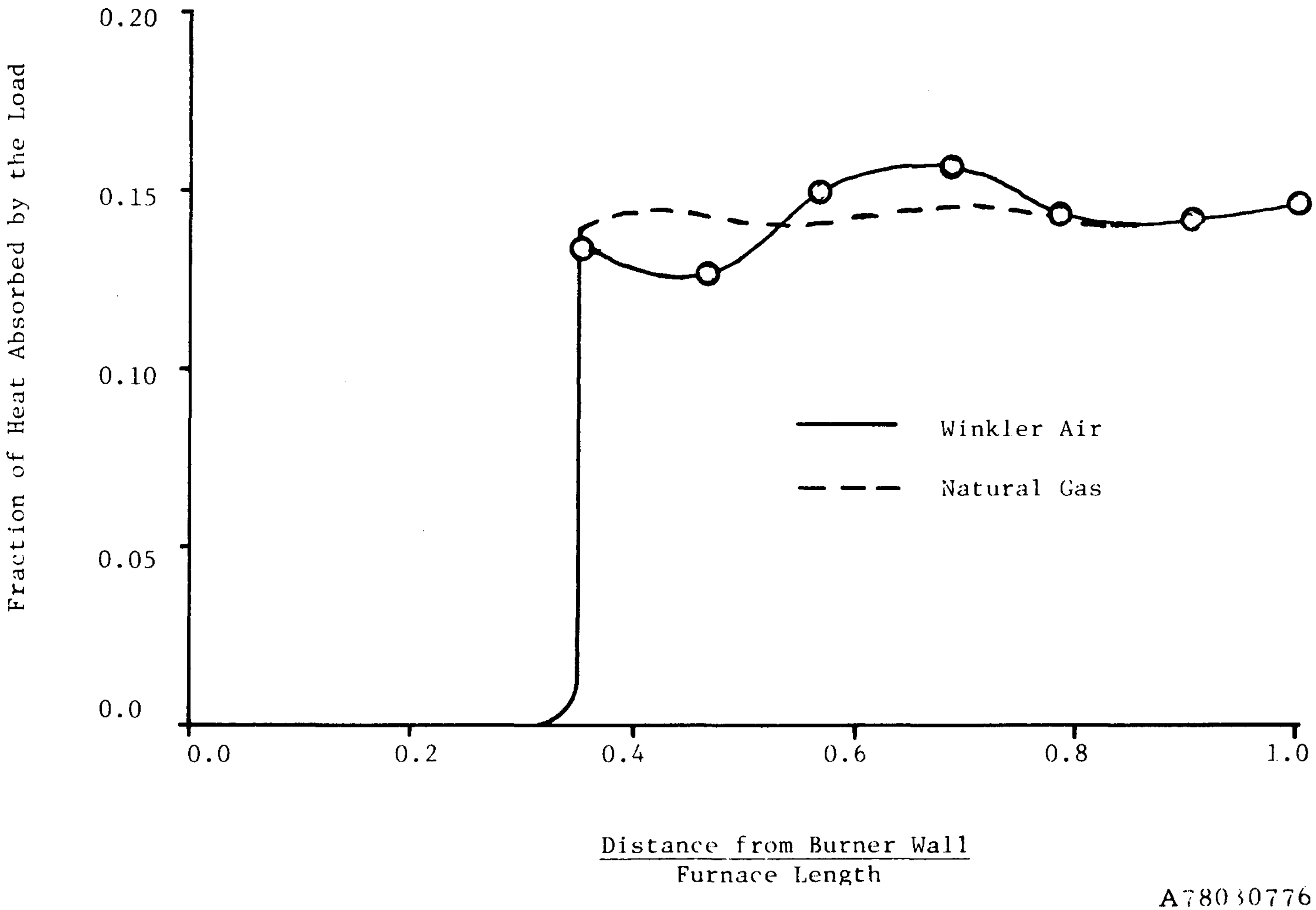

Figure 25. HEAT ABSORPTION PROFILE FOR WINKLER AIR FUEL GAS COMPARED WITH NATURAL GAS ON THE KILN BURNER

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