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

Project 61004 (Formerly 8985) Special Report No. 4

HIGH-FORWARD-MOMENTUM BURNER

Richard T. Waibel
Edward S. Fleming

Prepared by
Institute of Gas Technology
IIT Center, 3424 S. State Street
Chicago, Illinois 60616

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ABSTRACT

Data were gathered to determine the performance of a high-forward-momentum burner when retrofit with three low-to-medium-Btu gases. The burner was fired on the IGT pilot-scale test furnace with a load simulating one zone of a continuous refractory kiln or one instant during the heat-up of a batch kiln. The low-and medium-Btu gases simulated for these combustion trials were Koppers-Totzek oxygen, Wellman-Galusha air, and Winkler air fuel gases. All of the substitute fuels exhibited stable flames when directly retrofit on the burner. Koppers-Totzek oxygen gave a thermal efficiency slightly greater than that for natural gas, but Wellman-Galusha and Winkler air fuel gases each had lower efficiencies. Koppers-Totzek oxygen and Wellman-Galusha air fuel gases had flame lengths longer than that for natural gas, whereas Winkler air fuel gas had a flame length comparable to the natural gas flame.

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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 North American Manufacturing Co. Tempest burner, which is representative of the high-forward-momentum (HFM) burner type. The burner size and firing rate were chosen to simulate the firing density (Btu/CF-hr) in a refractory kiln.

While firing natural gas, the furnace load was adjusted to absorb the same fraction of the furnace heat input that occurs in one section of a continuous kiln or one instant during the heat-up of a batch 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.

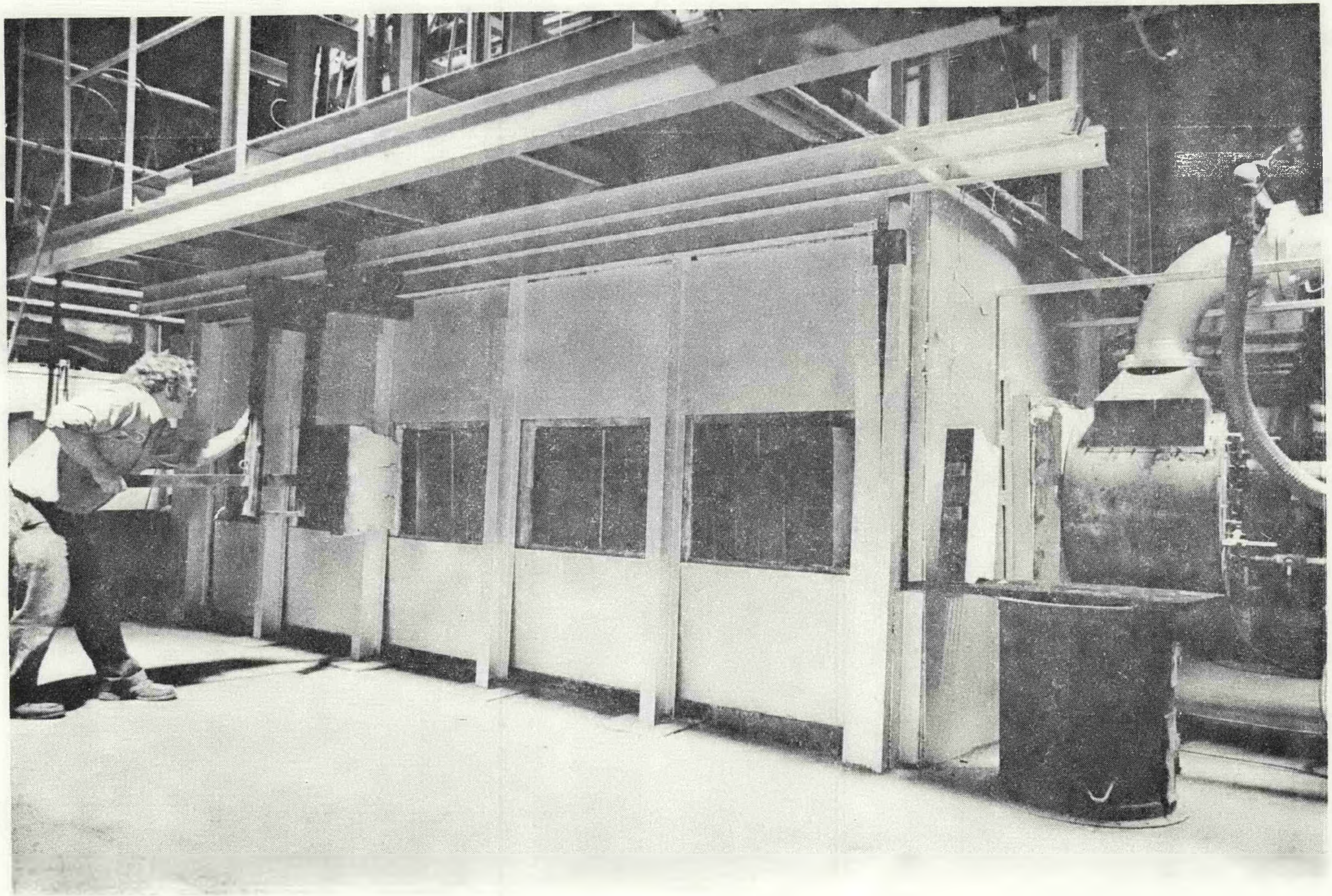


Figure 1. PILOT-SCALE TEST FURNACE P78103213

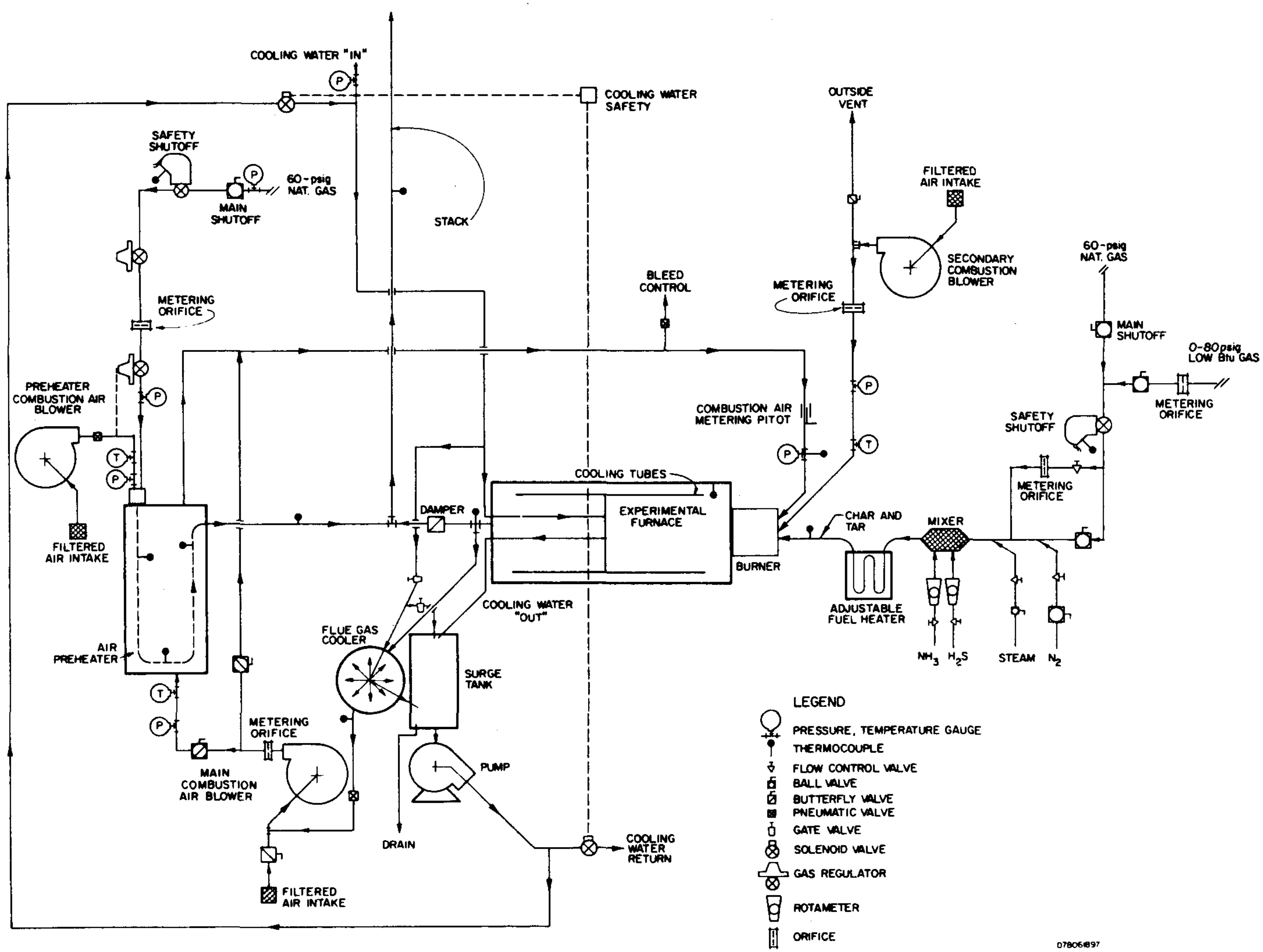


Figure 2. OVERALL FURNACE SYSTEM

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- AND MEDIUM-Btu GASES TESTED

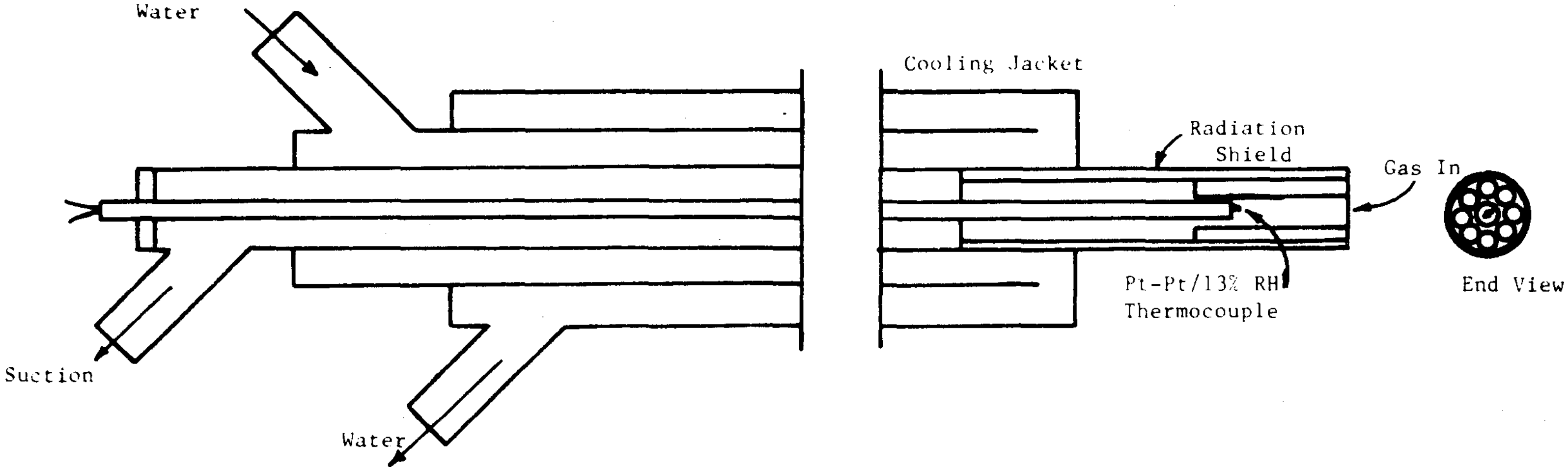
Fuel	CO	H_2	CO_2	CH_4	N_2	H_2O	Heating Value, Btu/SCF	Adiabatic Flame Temp,* °F	Specific Gravity
Koppers-Totzek Oxygen	53.0	34.3	9.3	0.5	1.0	1.9	287	3570	0.68
Wellman-Galusha Air	26.9	14.3	7.4	2.6	46.9	1.9	160	2990	0.83
Winkler Air	21.1	13.0	6.9	0.6	56.5	1.9	116	2700	0.85

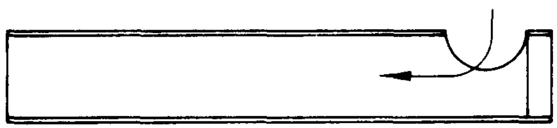
* 10% excess air at ambient temperature. The adiabatic flame temperature for natural gas is 3380°F for the conditions.

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





Suction Tip for Measurements in Natural Gas and Low- and Medium-Btu Gas Flames

Alternate Probe Tip

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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 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-NO_x
- 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.

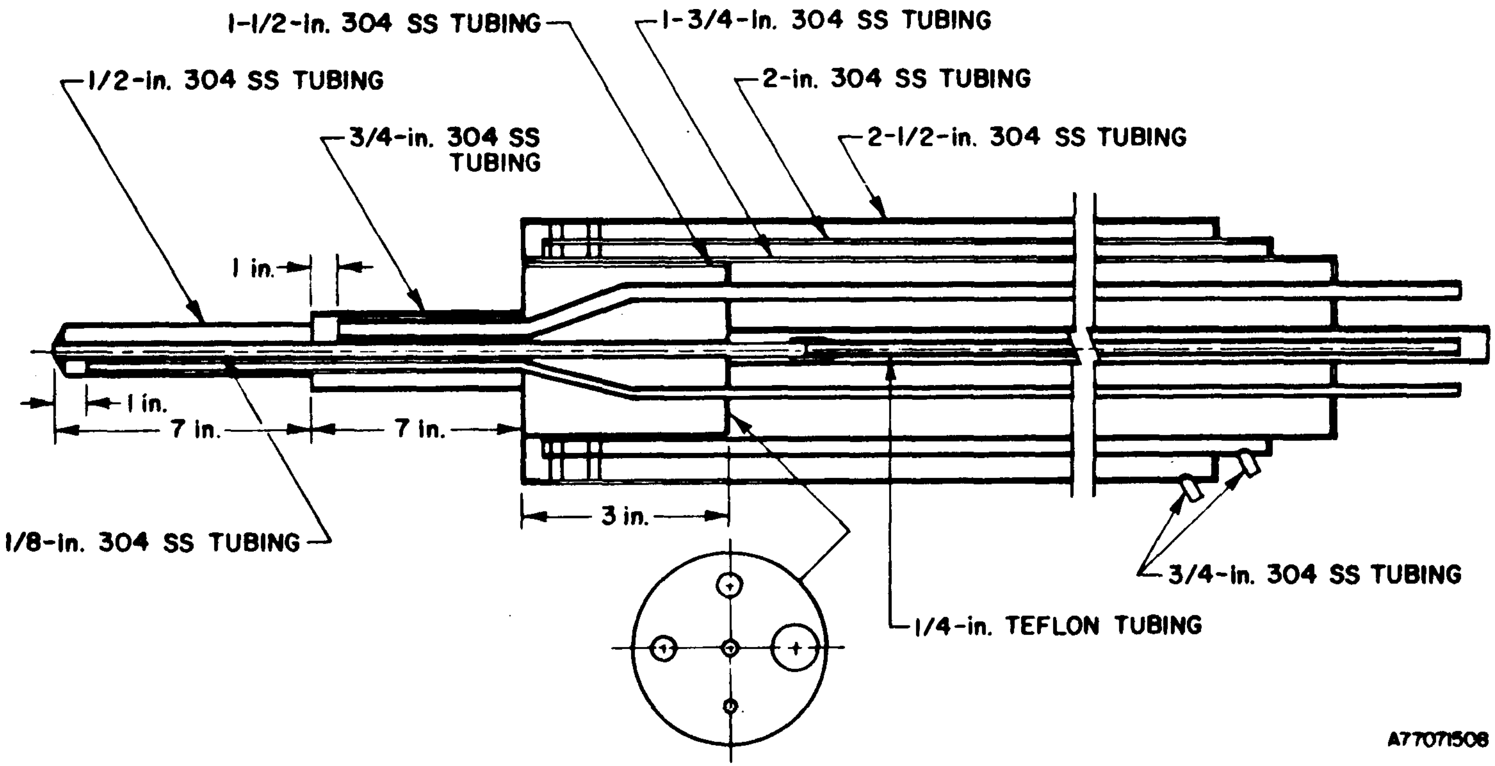


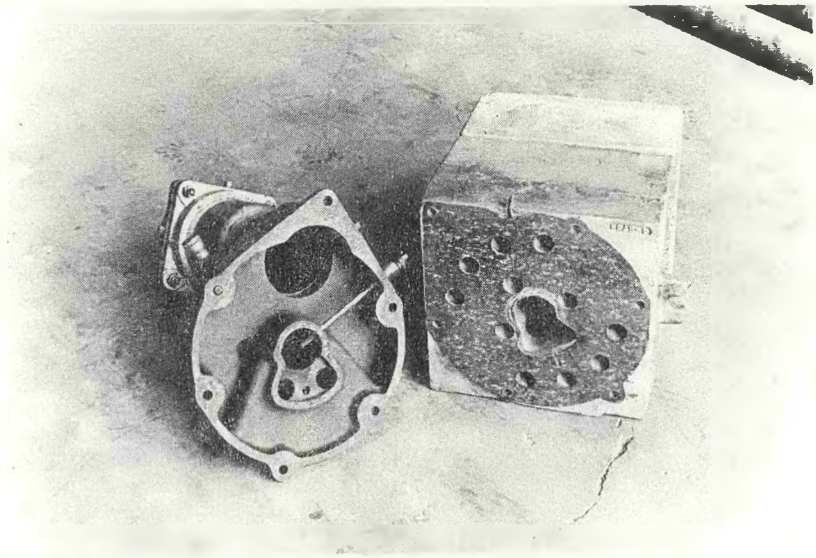
Figure 4. ASSEMBLY DRAWING OF GAS SAMPLING PROBE

BURNER TESTS

High-forward-momentum (HFM) burners are designed to produce a very strong stirring action in the furnace chamber in order to provide a uniform temperature throughout much of the furnace volume. Figure 5 shows two views of the North American Manufacturing Tempest burner, chosen to represent the HFM burner type, and Figure 6 is a schematic cross-sectional view of the burner. These figures show the small chamber where the fuel and air combine, and combustion is initiated, before the partially burned fuel and air exit the burner mouth at high velocity. This high-velocity flame "jet" entrains combustion products from the furnace, setting up the recirculation patterns that produce the stirring and the resultant uniform furnace gas temperatures. The burner utilized in our tests was an N.A. Model 4442-7 with a maximum rated capacity of 3 million Btu/hr. It is typically operated with 10% excess air and without air preheat.

There are many uses for the HFM burner, the most popular being for batch and continuous car-bottom kilns for firing ceramic and refractory pieces. In the batch-type kiln, the load starts at ambient temperature, is slowly heated to the temperature required to fire (bind and solidify) the refractory material, is held there, and is then cooled before being removed from the furnace. In the continuous kiln, the pieces being fired are placed on car-bottoms and moved through a long tunnel furnace. The cars pass through "zones" in the furnace where the load attains higher and higher temperatures until the desired maximum temperature is reached. The cars are held at the maximum temperature for a sufficient length of time and then pass through a cooling zone before exiting the furnace.

Because we require long periods of stable furnace operation to collect all of the data necessary for our comparisons, we simulated only one instant in the transient operation of a batch-type kiln or one zone of a continuous tunnel kiln. A large amount of heat can be transferred from the flame to the load in the early stage of the temperature cycle. Later when the load temperature is not changing during the high-temperature "soak" portion of the temperature cycle, little heat is transferred to the load. We chose to simulate an intermediate point in the load temperature cycle when about 35% of the energy input was transferred to the load.



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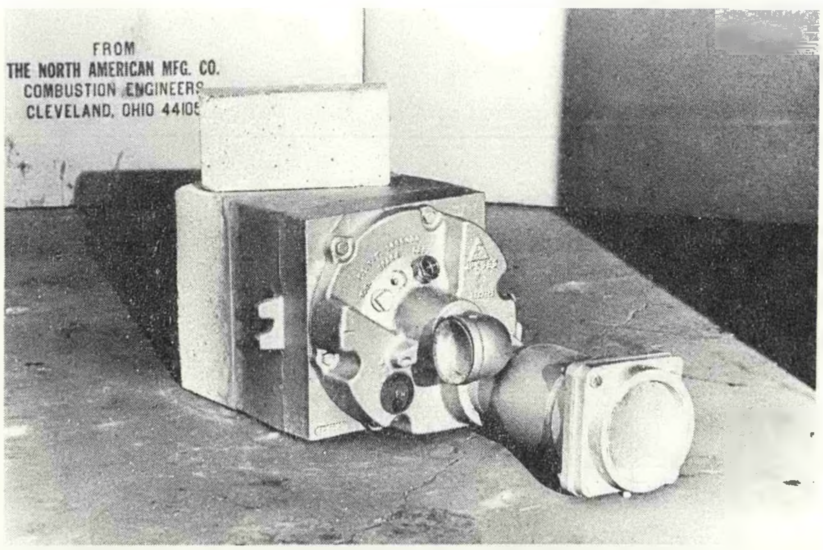
a. Disassembled Unit



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b. Assembled Unit

Figure 5. PHOTOS OF THE NORTH AMERICAN MANUFACTURING CO. TEMPEST BURNER

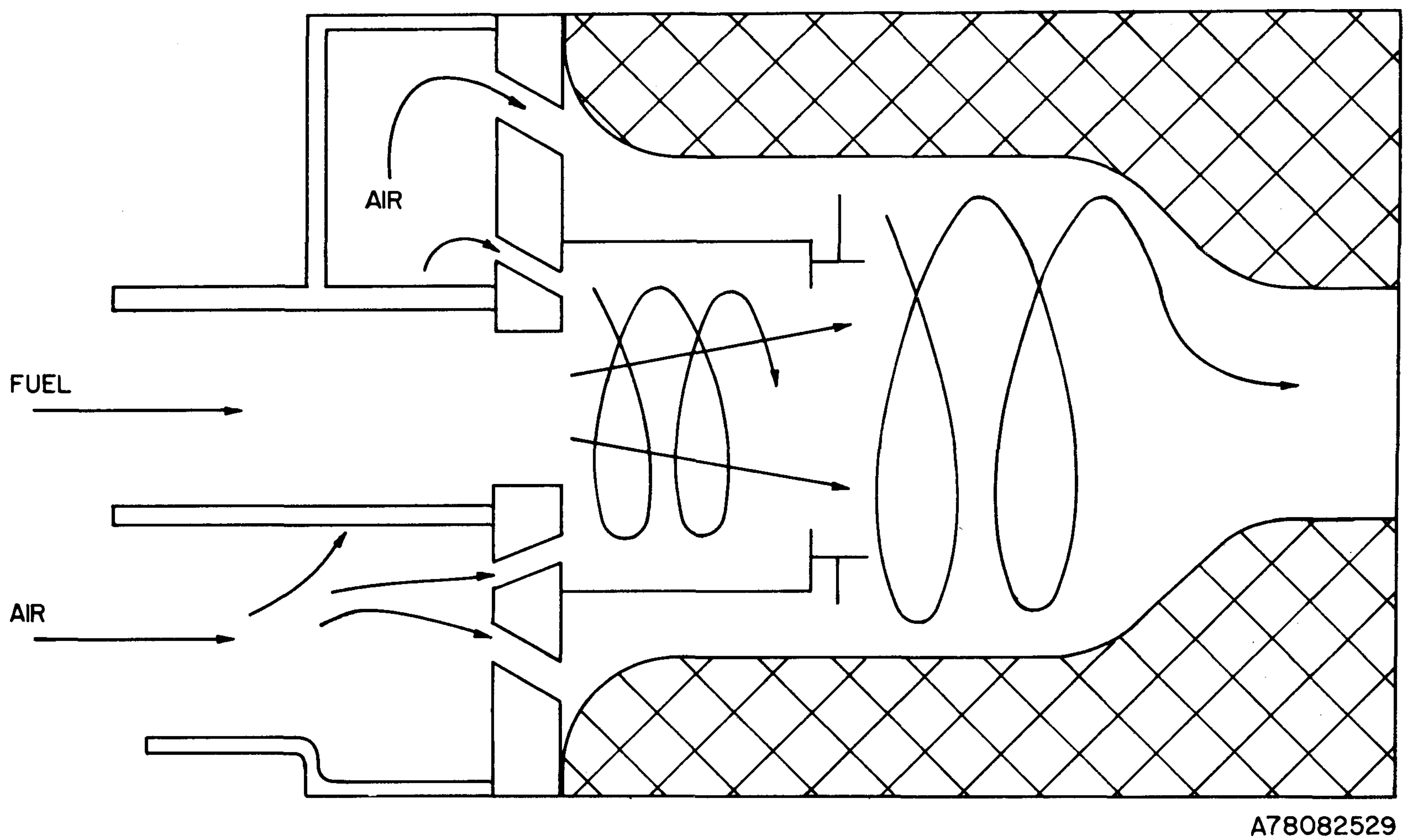

Figure 6. SCHEMATIC CROSS SECTION OF HIGH-FORWARD-MOMENTUM BURNER

Baseline Natural Gas Tests

At the beginning of the natural gas baseline tests, the cooling tubes in the furnace were adjusted until 34% of the thermal input to the furnace was absorbed by the load. This was considered to be sufficiently close to the desired value of 35%. The nine tubes used were about equally spaced along one wall of the furnace. Figure 7 shows the locations of the tubes and also the flame shape found for the natural gas flame. The flame shape is determined by measuring the gas composition at various points across the furnace at several locations along the furnace axis. The envelope depicted represents the zone within which 99% of the fuel is consumed. This is obtained by analysis of the carbon monoxide and oxygen levels.

Table 2 contains a summary of the natural gas baseline data. Figure 8 shows the temperature profiles found in the test furnace for the natural gas baseline conditions. The peak temperature was 1652°C (3006°F) at 36 cm from the burner wall. There is a narrow high-temperature region approximately 40 cm wide and 200 cm long with temperatures above 1200°C (2192°F); however, the bulk of the furnace is between 1100° and 1200°C.

Figure 9 shows the flow direction profile for the natural gas flame. As expected, the recirculation patterns are very large with this burner because of the high velocity of the flame jet issuing from the burner. This same flow pattern was found with all of the flames on this burner.

Sound level measurements were made during the natural gas baseline tests. At a point 1 ft from the burner, the background noise level was 88 db due to the combustion air fan. When the burner was firing, the noise level increased by 2 db. Alongside the furnace the background noise level was 80 db. When the burner was fired, this noise level increased by 8 db with the furnace closed and by 17 db with a sampling door removed.

Post flame emissivities were also measured by the Schmidt method[1] using the radiometer and water-cooled target. Three radiant flux measurements are required:

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

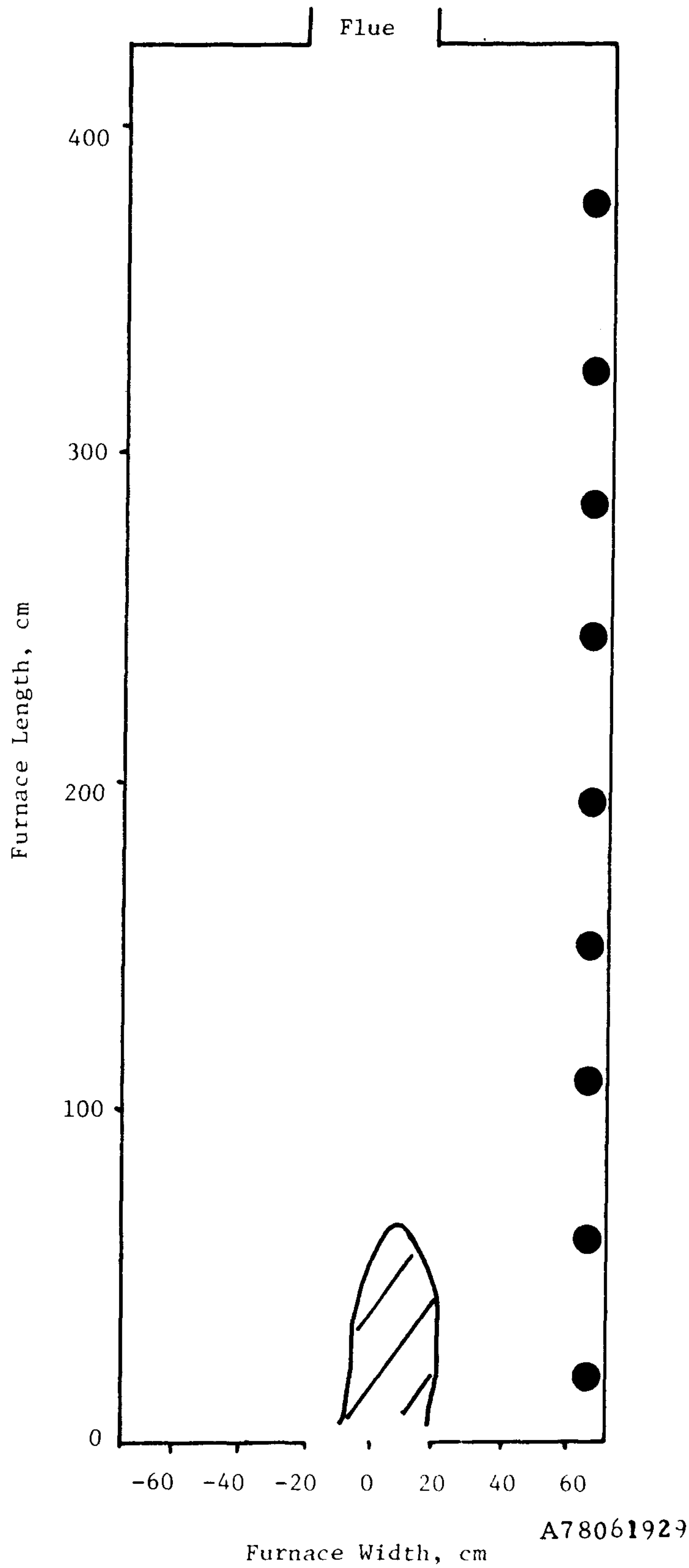

Figure 7. FLAME SHAPE FOR NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

Table 2. FURNACE AND HIGH-FORWARD-MOMENTUM BURNER OPERATION CONDITIONS

Fuel Type	Fuel[a] Flow, SCF/hr	Air[b] Flow, SCF/hr	Fuel[c] Velocity, ft/s	Air Velocity, ft/s	Flue Gas Temperature, °F	Volume Flow Flue Gas, SCF/hr	Flame Length, cm	Thermal[d] 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	30,670	231	200	2069	33,540	66	34	0.23	49	20	10.8	1.9	87
Koppers-Totzek Oxygen	10,550	24,350	838	158	2139	30,330	111	35.5	0.24	25	35	23.9	1.9	74
Wellman-Galusha Air	17,190	24,650	1364	160	1949	38,090	111	30	0.23	12	10	20.2	1.3	78
Winkler Air	23,210	24,300	1842	158	1954	43,130	70	27	0.22	12	10	17.0	1.1	82

[a] Fuel flow adjusted to give 3.0 ± 0.1 million Btu/hr fuel enthalpy input. (Fuel heating value varied within ± 8% of the nominal value due to slight variations in the fuel composition from the nominal composition.)

[b] 10% excess air at ambient temperature.

[c] Velocity calculated as fuel volume flow rate at standard conditions (1 atm,60°F) divided by fuel nozzle outlet area.

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

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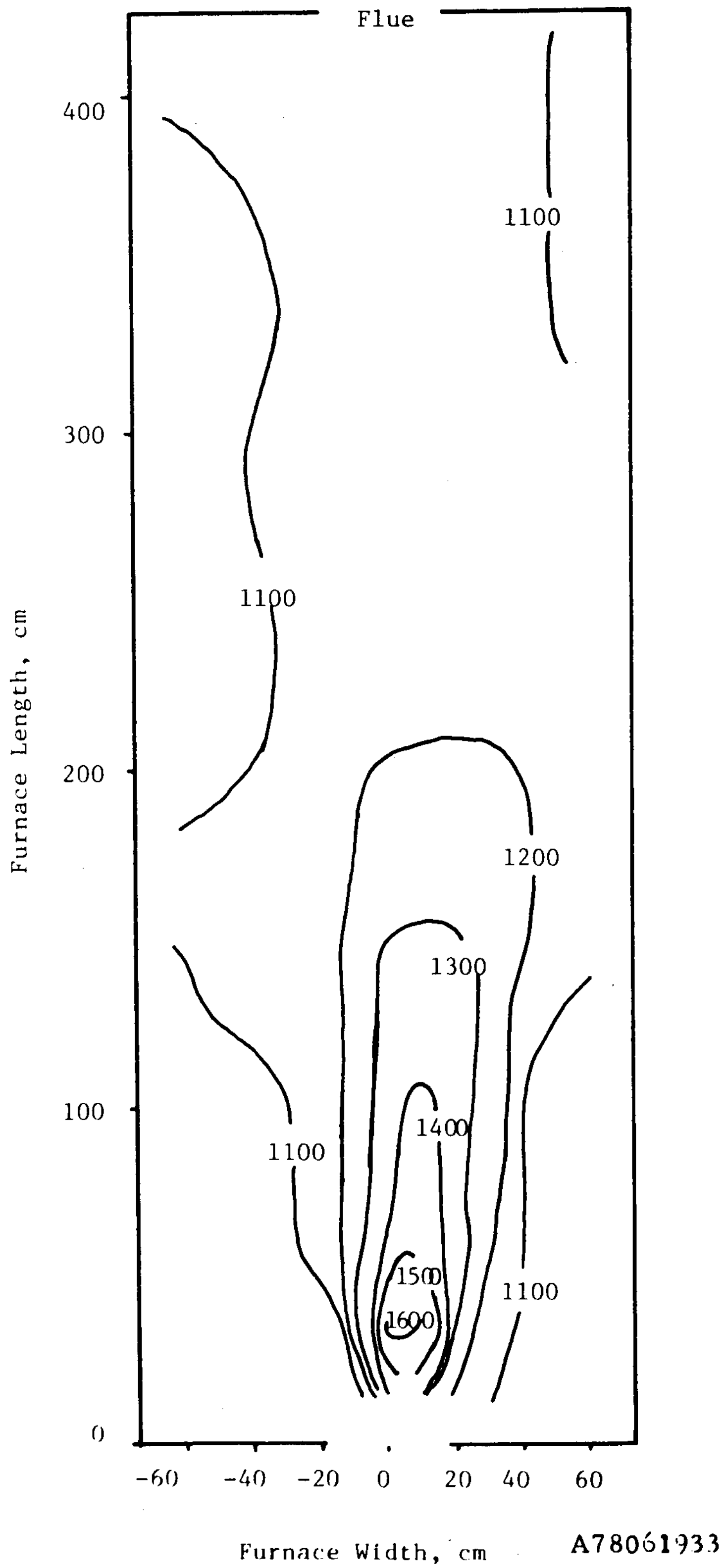

Figure 8. TEMPERATURE PROFILES (°C) FOR NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

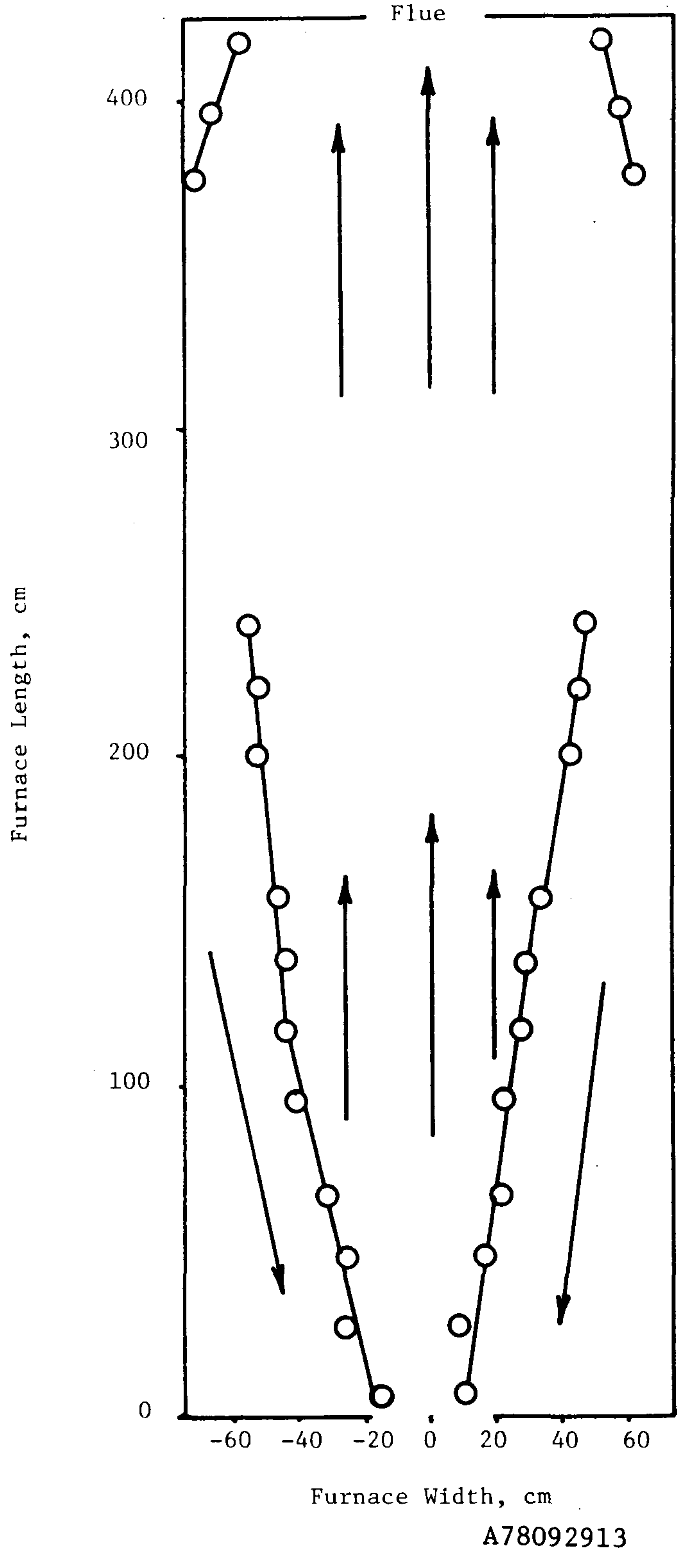

Figure 9. FLOW DIRECTION PROFILE FOR NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER (Note: The Circles Represent Data Points Showing the Location of Flow Direction Reversal.)

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 blackbody, can be determined from radiation theory.[2] 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, and 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 2 and the procedure proposed by Leckner.[3]

The flame radiation and heat absorption profiles measured for natural gas will be presented later in the report along with similar measurements made for the substitute fuel gases.

Low-Btu Gas Tests

Flame Stability Tests

After completion of the natural gas baseline trials, flame stability trials began with the substitute fuel gases. The trials were initiated by attempting to stabilize a low- or medium-Btu gas flame at a volumetric flow rate equal to the natural gas flow rate. The fuel flow rate was then increased until either the flame became unstable (lifted or blew off) or until the fuel enthalpy input reached that of the natural gas tests. For all three of the low- and medium-Btu gases, no flame instability was encountered and the fuels could be fired at the 3 million Btu/hr rate used for the natural gas baseline trials.

Koppers-Totzek Oxygen Fuel Gas Tests

Following the flame stability trials, the furnace was fired with KTO fuel gas and the furnace load, exit gas temperature, and wall temperature were monitored to determine when the furnace reached thermal equilibrium. When equilibrium was attained, data collection began. Table 2 contains a summary of the data collected.

With KTO the thermal efficiency (heat absorbed by the load divided by the fuel enthalpy input) was 35.5%, as compared with 34% for natural gas. The flame length, however, increased from 66 cm to 111 cm. Figure 10 shows the flame shape for KTO.

Figure 11 compares the heat absorption profile for KTO and natural gas. The profiles are similar because the flame is small relative to the size of the furnace and the area over which the load is distributed.

The flame temperature profiles are plotted in Figure 12. The temperatures measured for the KTO flame are similar to those found for natural gas. In most of the furnace volume the temperatures are between 1000° and 1200°C. The peak temperature measured for KTO was 1629°C (2964°F) at 15 cm from the burner wall, as compared with 1652°C (3006°F) at 36 cm for natural gas.

Figure 13 shows the radiation from the flame plus combustion products at points along the length of the furnace. The measurements were made by sighting a narrow-angle radiometer across the furnace toward a water-cooled target at the opposite wall. The measurements show the thermal radiation from the natural gas flame to be slightly higher than from the KTO flame. The heat absorption profiles show that the KTO flame transferred less heat in the first half of the furnace than the natural gas flame and more in the second half. A comparison of the temperature profiles near the wall show the KTO temperatures to be higher than natural gas in the second half of the furnace, suggesting that convective heat transfer in that half may have led to the improved performance by KTO.

Figure 14 shows the thermal radiation from the flame alone. This was measured by placing a water-cooled target at the far-flame boundary and sighting the radiometer down a water-cooled tube placed at the near-flame boundary. The flame radiation for KTO was less than that measured for natural gas.

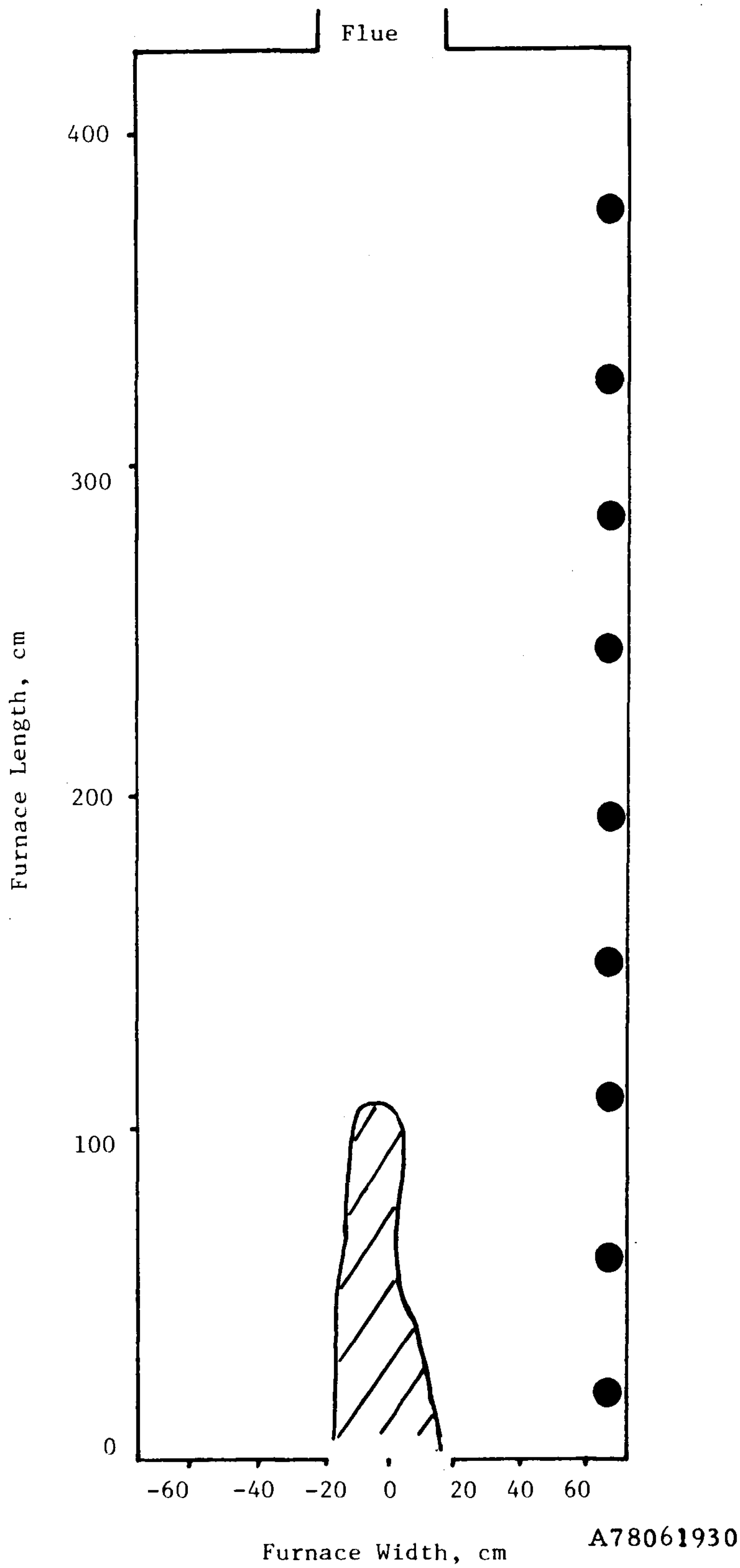

Figure 10. FLAME SHAPE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

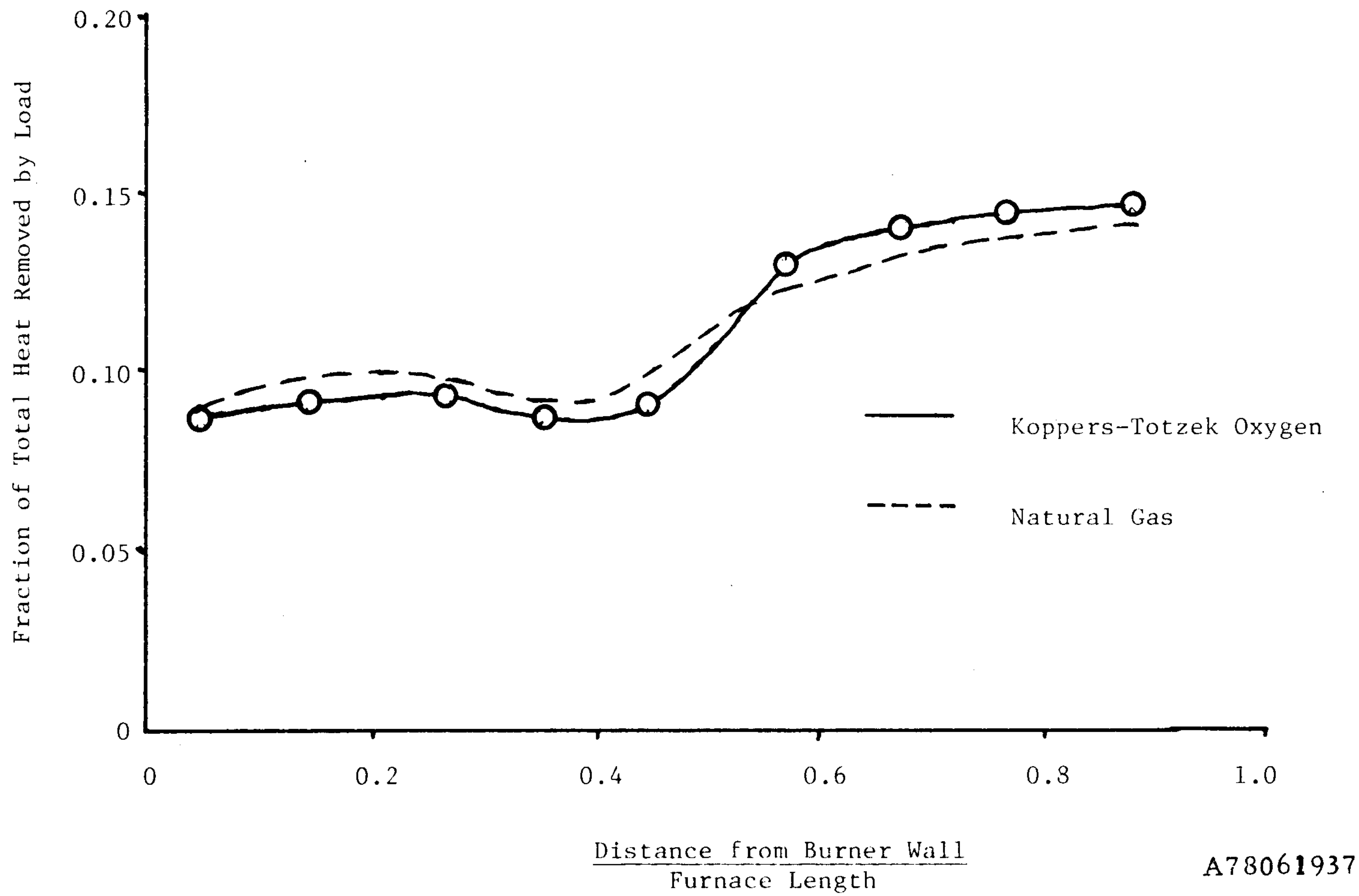

Figure 11. HEAT-ABSORPTION PROFILES FOR KOPPERS-TOTZEK OXYGEN AND NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

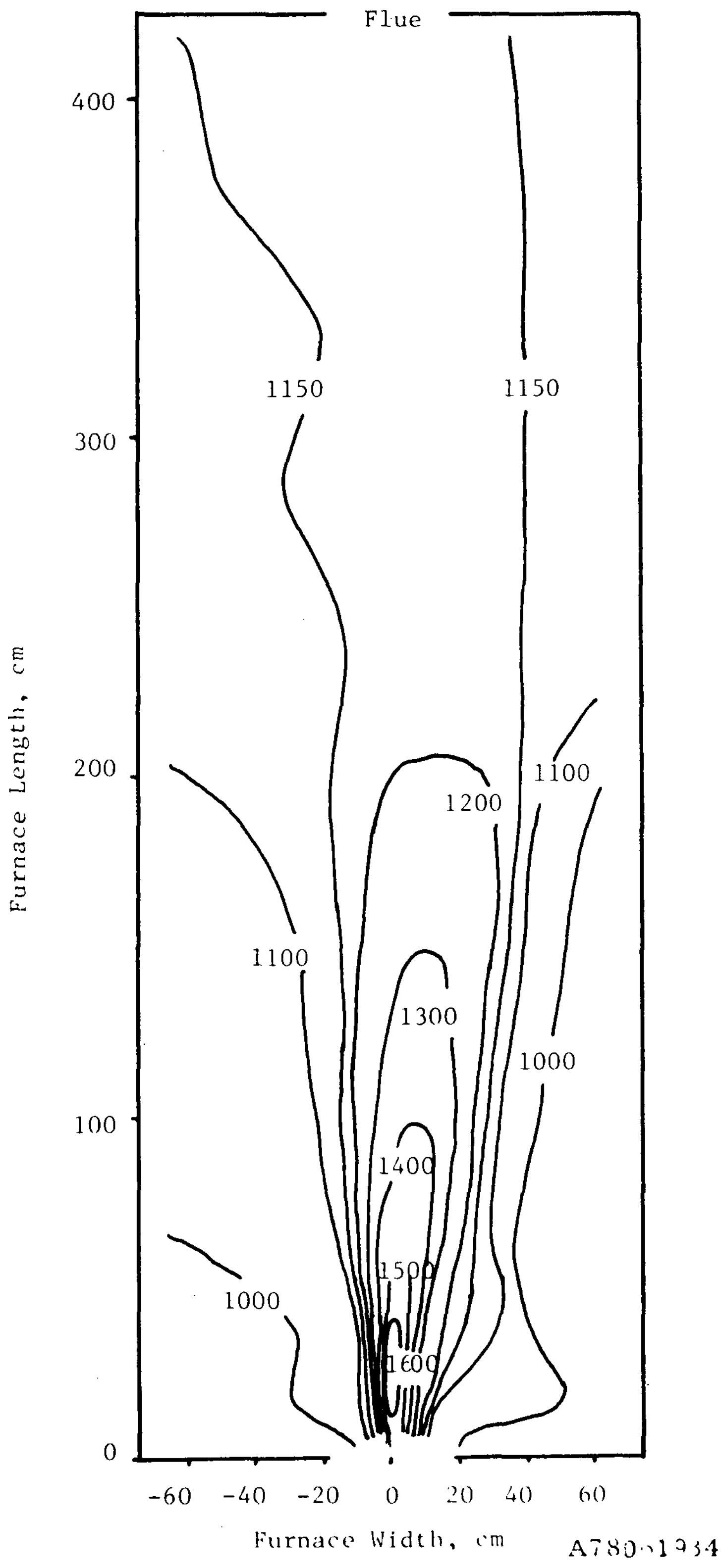

Figure 12. TEMPERATURE PROFILE (°C) FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

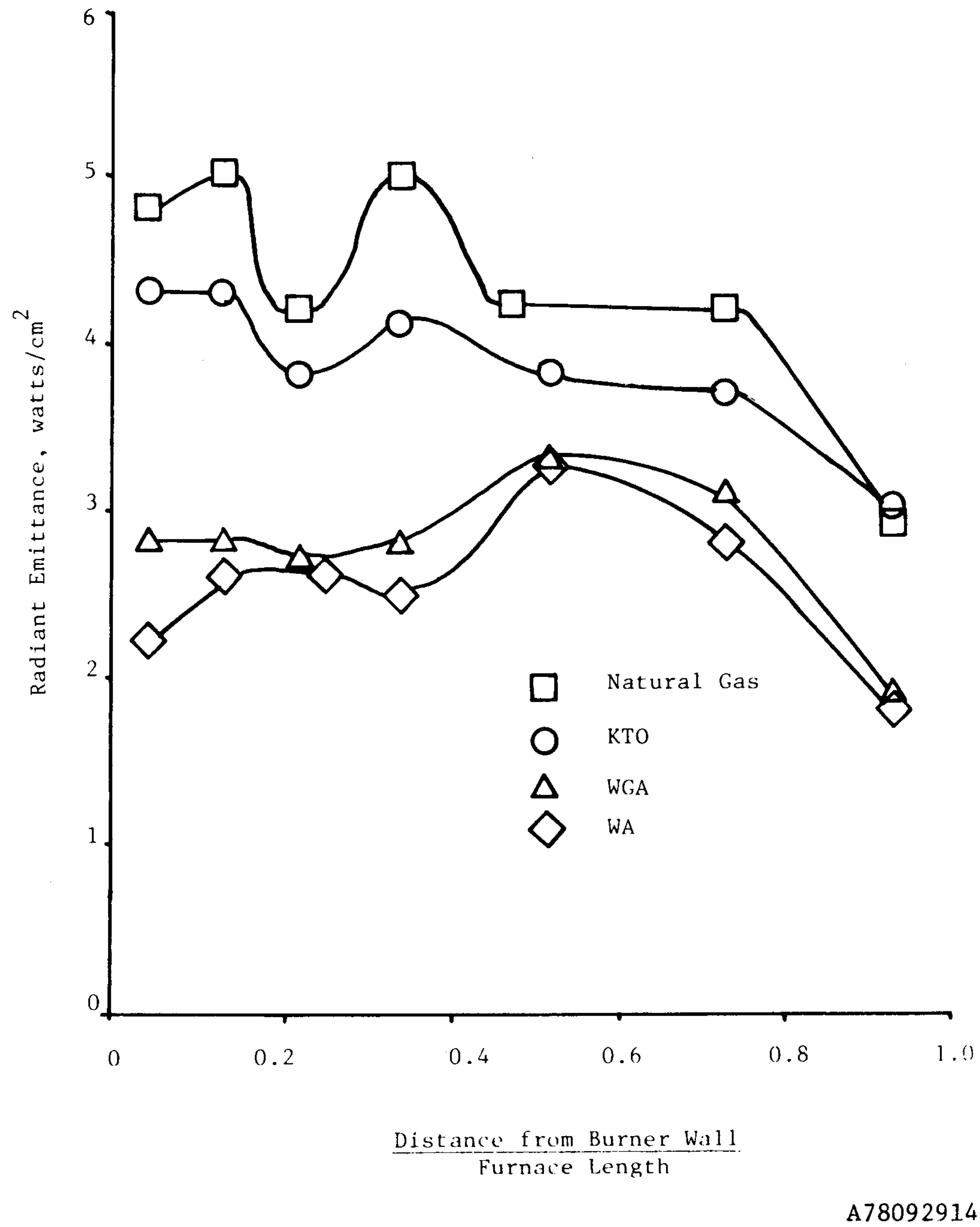

Figure 13. THERMAL RADIATION FROM THE FLAME PLUS COMBUSTION PRODUCTS FOR THE HIGH-FORWARD-MOMENTUM BURNER

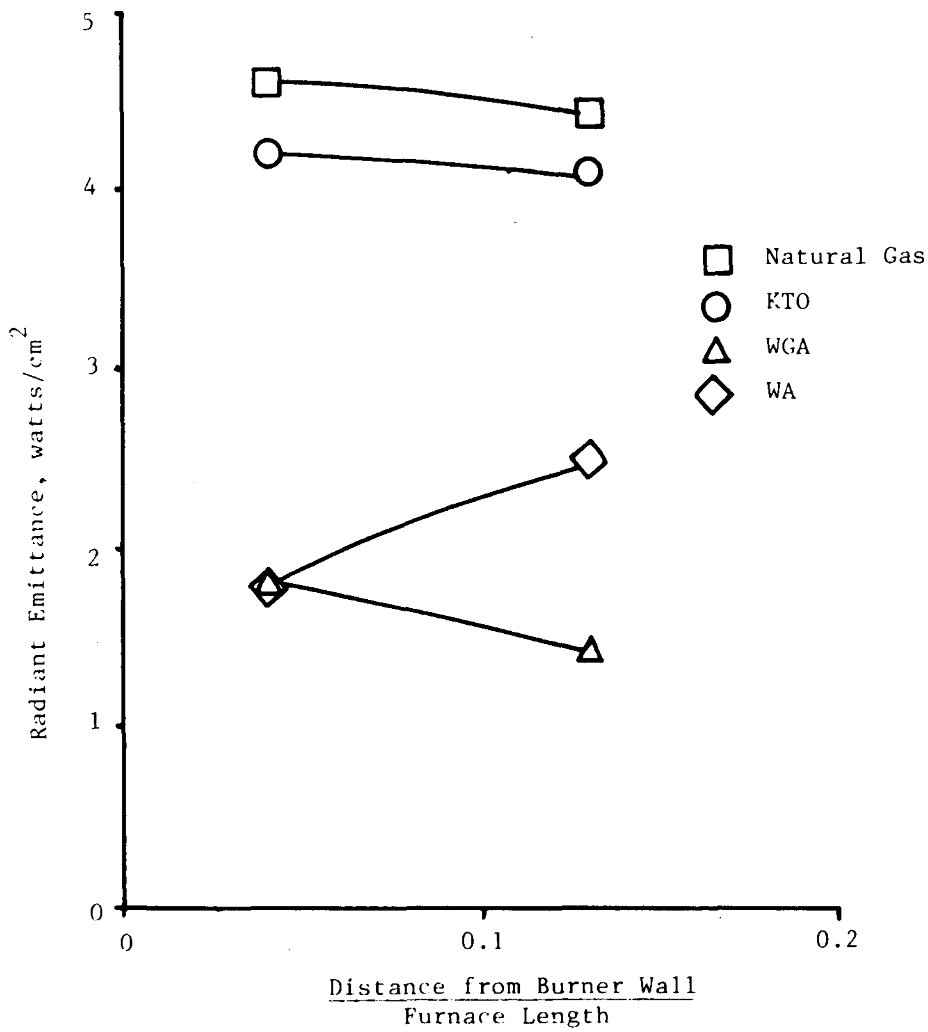

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Figure 14. THERMAL RADIATION FROM THE FLAME FOR THE HIGH-FORWARD-MOMENTUM BURNER

Sound level measurements were made during the KTO fuel gas trials. The background noise level at the burner was 94 db. This increased 9 db to 103 db when KTO was fired on the burner. At a point 2 ft from the side of the furnace, the background noise level was 86 db. When KTO was fired on the burner, the noise level increased 19 db with the furnace closed and 27 db with one sampling door removed.

As noted earlier the KTO flow direction profile was nearly identical to the profile determined for natural gas.

Koppers-Totzek Oxygen Fuel Gas Retrofit Conclusions

KTO will give few problems when retrofitted to this burner if the extended flame length (111 cm vs. 66 cm) is acceptable. This will probably be the case for many applications of this burner. The thermal efficiency, flame temperatures, and heat absorption profile are all similar to those measured for natural gas.

Wellman-Galusha Air Fuel Gas Tests

Following the Koppers-Totzek oxygen fuel gas trials, the furnace was fired with Wellman-Galusha air fuel gas and allowed to attain thermal stability. The results of this test are also summarized in Table 2.

The thermal efficiency for WGA was 30%, as compared with 34% for natural gas. This change in efficiency is typical of the type of decrease found with previous burners when natural gas and WGA fuel gas were compared.

The flame length with WGA fuel gas was 111 cm, compared with 66 cm for natural gas. Figure 15 shows the shape of the WGA flame. The peak flame temperature measured was 1352°C (2466°F) at 15 cm from the burner wall. Figure 16 shows the flame temperatures measured for the WGA tests. The furnace temperatures are very uniform throughout the combustion chamber, similar to the natural gas and KTO tests, although the temperatures are about 100°C lower. Figure 17 shows that the furnace load heat absorption profile during the WGA fuel gas tests was nearly identical to the baseline natural gas profile.

Figures 13 and 14 show the radiation profiles measured during the WGA tests compared with the measurements from the tests with the other fuels. The WGA radiation emission levels are significantly lower than those found

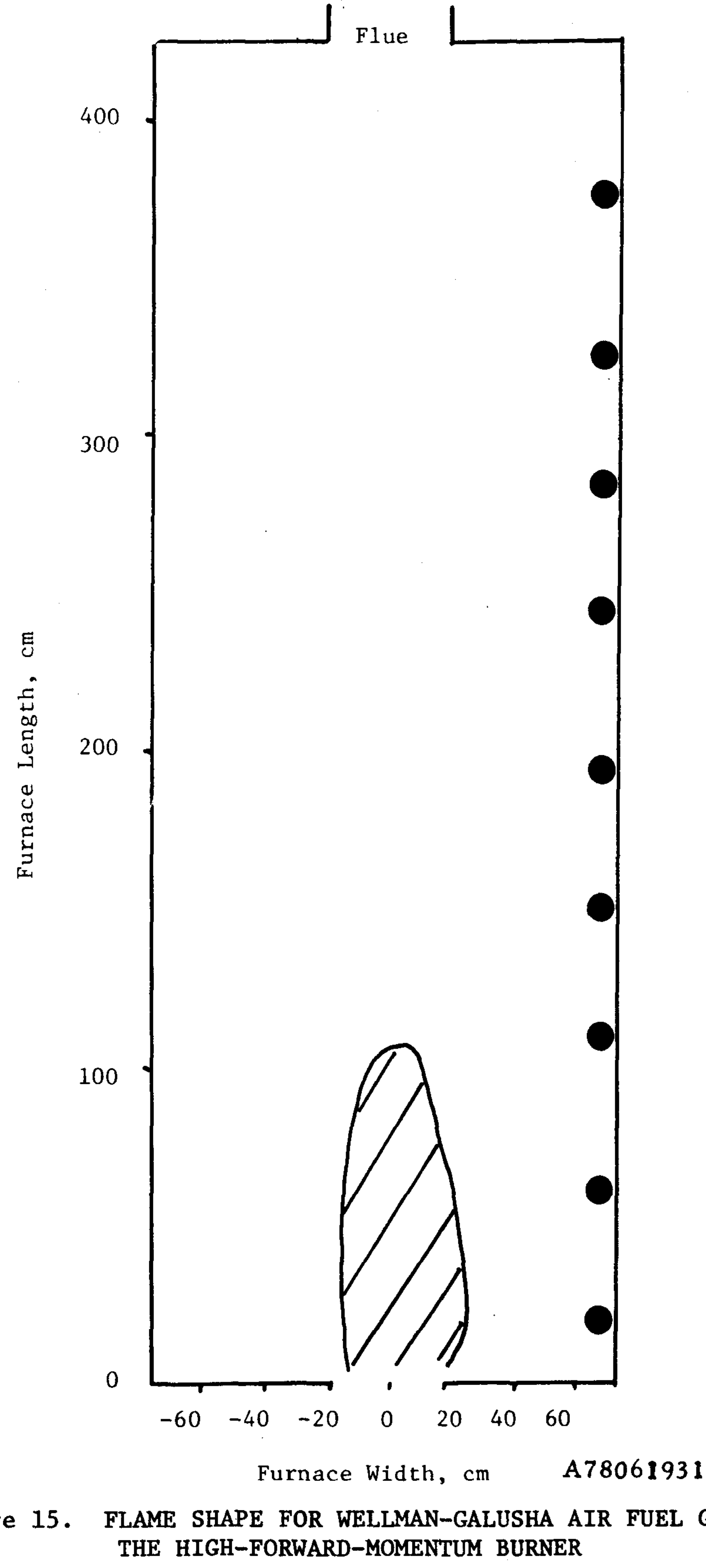

Figure 15. FLAME SHAPE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

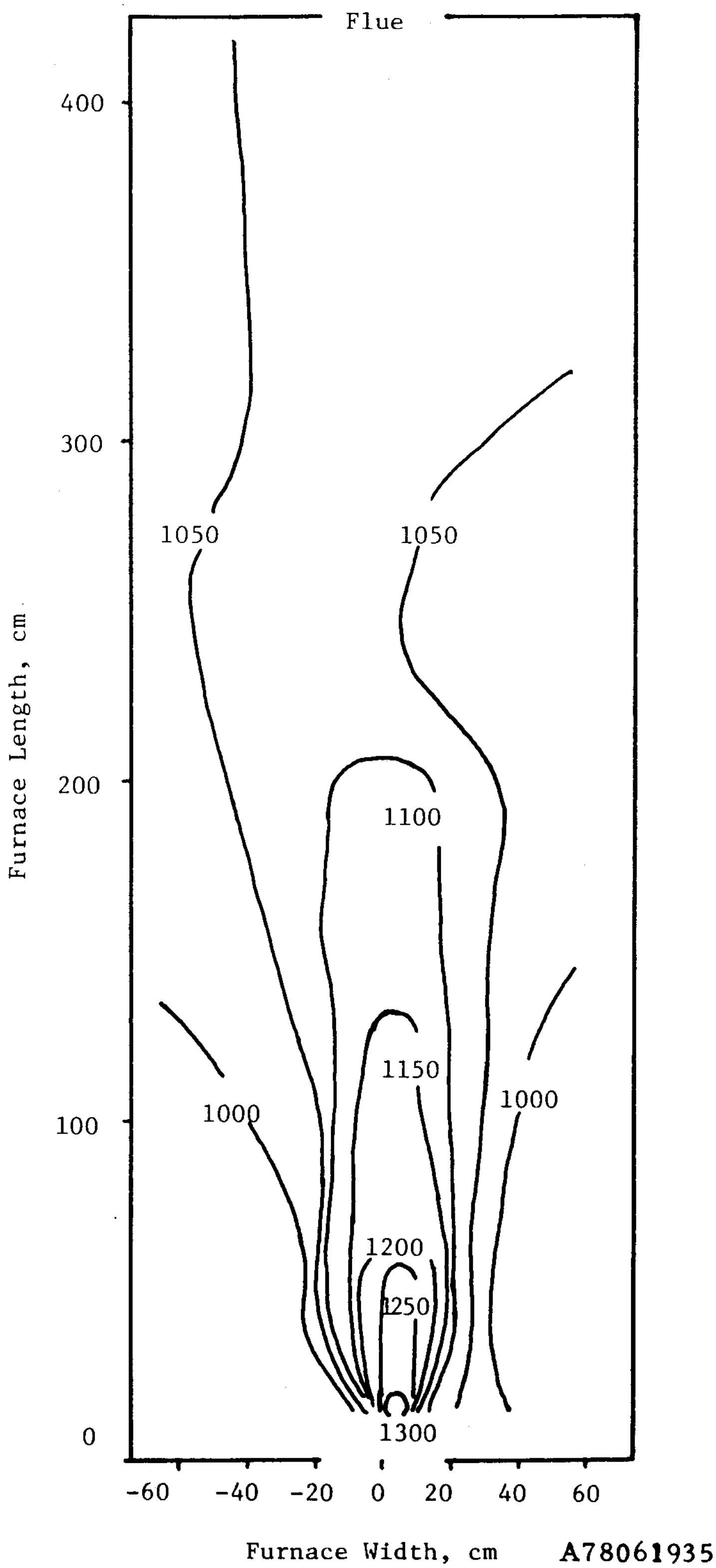

Figure 16. TEMPERATURE PROFILE (°C) FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

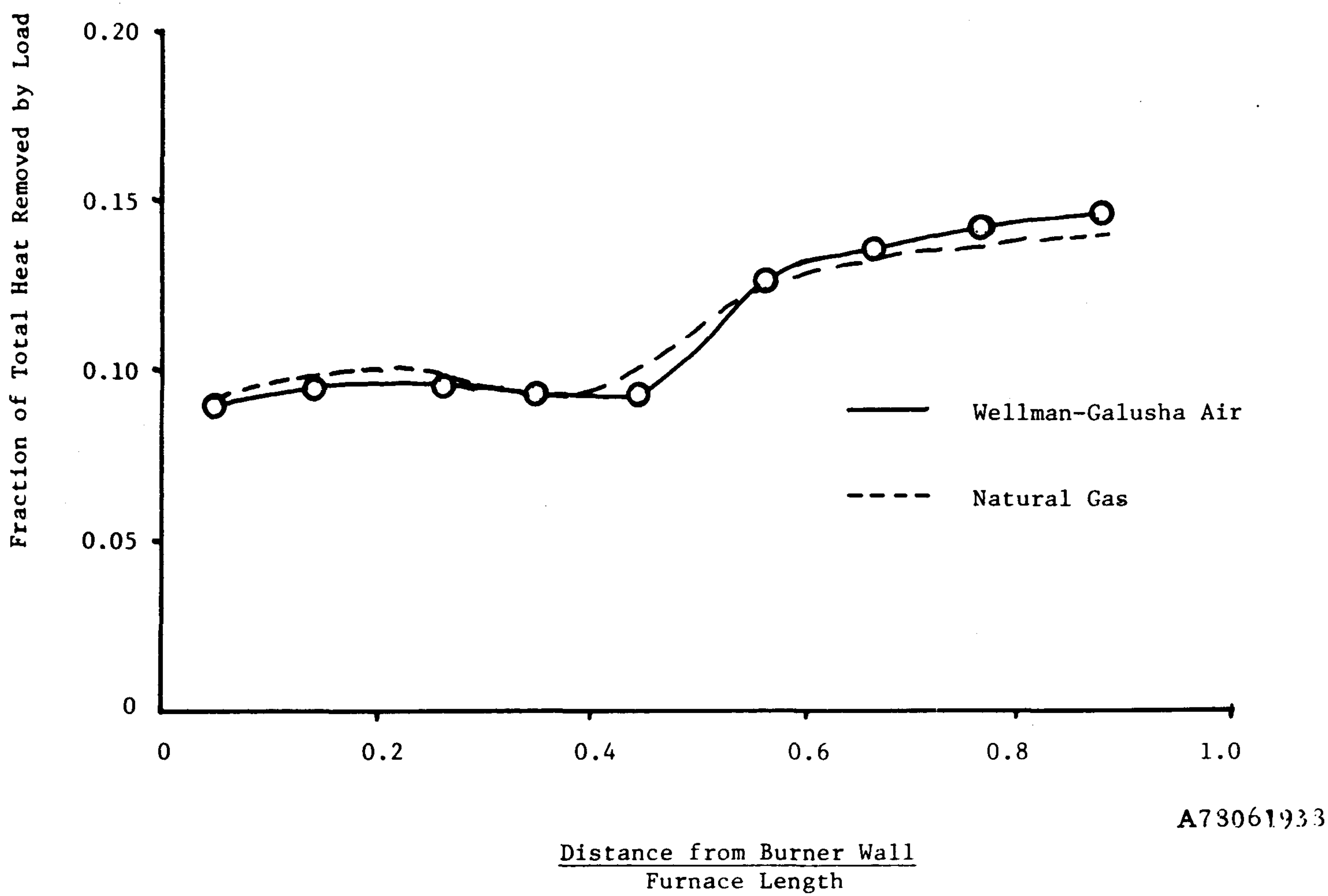

Figure 17. HEAT-ABSORPTION PROFILES FOR WELLMAN-GALUSHA AIR FUEL GAS AND NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

for natural gas and KTO. These measurements are consistent with the flame temperature measurements, and they help to explain the lower thermal efficiency found for WGA.

Since WGA fuel gas transferred less heat to the load than natural gas, additional tests were made to determine the natural gas firing rate that would transfer the same amount of heat to the load. To do this, additional thermal efficiency measurements were made for natural gas at input rates of 2.0, 2.3, and 2.55 million Btu/hr. The results of these tests are shown in Figure 18. These data show that natural gas at a firing rate of 2.4 million Btu/hr would transfer as much heat to the load as WGA fuel gas at 2.9 million Btu/hr.

The sound levels with WGA fired on the high-forward-momentum burner were very high. The background level was 94 db near the burner and 86 db at the side of the furnace. The noise level increased to 102 db at the burner when WGA was fired. It increased to 104 db at the side of the furnace with all of the sampling doors in and jumped to 121 db with one sampling door removed.

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

Wellman-Galusha Air Fuel Gas Retrofit Conclusions

Although the WGA heat absorption profile compared very well with the natural gas profile, the WGA thermal efficiency and flame temperatures are both lower than those found for natural gas. Tests showed that WGA at an input of 2.9 million Btu/hr transferred only as much heat to our water-tube load as natural gas at 2.4 million Btu/hr. This is an approximately 20% increase in fuel consumption, or a 16% reduction in production. Also, the low peak flame temperature may limit the performance of this fuel in high-temperature applications.

Thus, although WGA showed no flame stability or heat absorption profile problems when retrofitted to this burner, there were significant problems in terms of thermal efficiency and flame temperature.

Winkler Air Fuel Gas Tests

The results of the WA fuel gas trials are summarized in Table 2 along with those of the other fuels. The furnace thermal efficiency with WA fuel gas was only 27%. Figure 18 shows that the heat transferred to the load

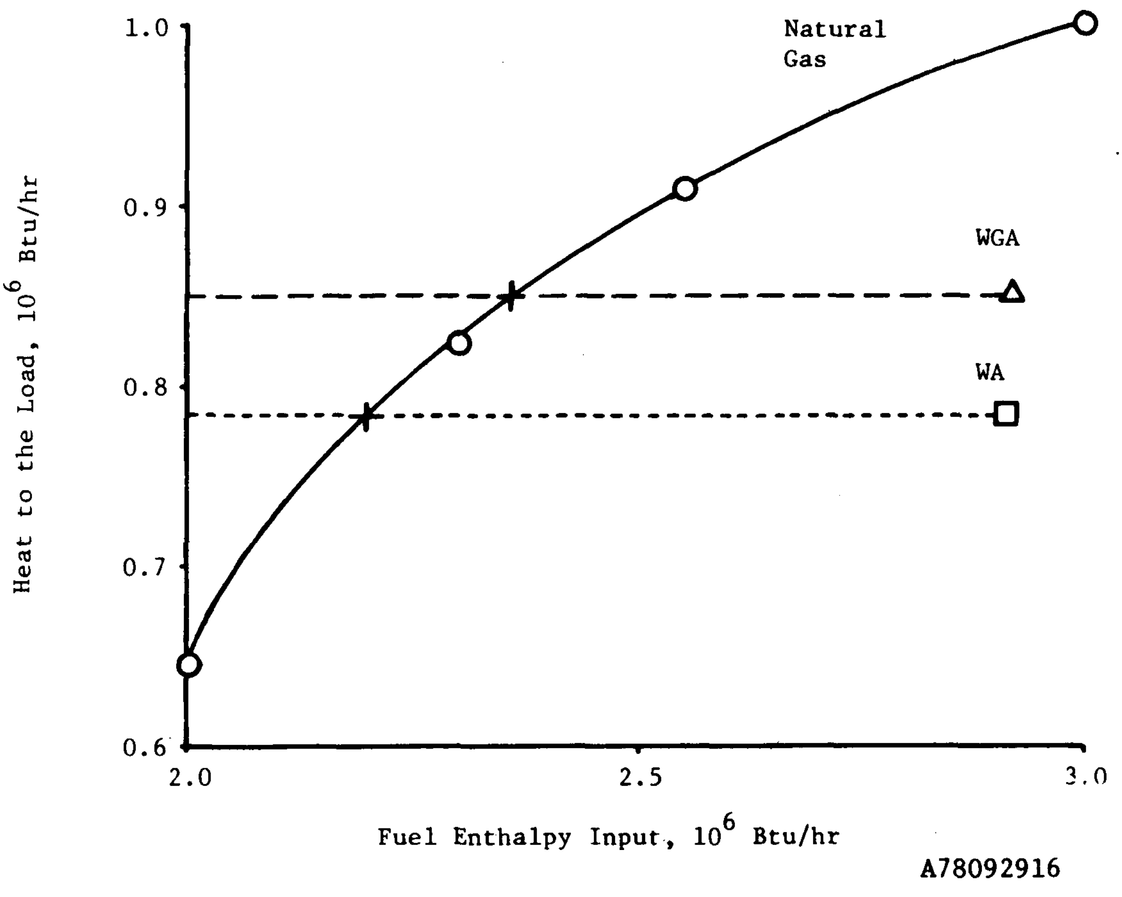

Figure 18. LOAD VS. FIRING RATE FOR NATURAL GAS AND LOW-Btu GAS

with this fuel at a fuel enthalpy input of 2.9 million Btu/hr corresponded to the load for natural gas at 2.2 million Btu/hr.

The flame length for the WA fuel gas flame was 70 cm long, as compared with 66 cm for natural gas. The flame shape is shown in Figure 19. Figure 20 shows the load heat absorption profile compared with the natural gas profile. The WA profile is nearly identical to the natural gas profile. The WA flow direction profile was also the same as that shown in Figure 9.

The peak flame temperature measured for WA fuel gas was 1345°C (2453°F) at 36 cm from the burner wall. Figure 21 shows the temperature profiles in the furnace during the WA test. The figure shows the same type of temperature uniformity that was found during the tests with the other fuels. The WA and WGA flame temperatures are very similar, and this is reflected in the thermal radiation measurements shown in Figure 13.

Sound level measurements during the WA trials showed a background noise level of 100 db at the burner and 92 db at the furnace sidewall. The level rose 7 db at the burner when WA was fired. The level rose to 105 db at the side with the furnace closed and to 115 db when a sampling door was removed during operation of the burner.

Winkler Air Fuel Gas Retrofit Conclusions

Winkler Air fuel gas gave no flame stability, flame length, or heat absorption profile problems when retrofitted on this burner; however, the thermal efficiency dropped from 34% to 27% and the peak flame temperature dropped by 300°C (540°F). WA at 2.9 million Btu/hr transferred about 783,000 Btu/hr to the load. This load rate could be sustained by natural gas combustion at an input of 2.2 million Btu/hr. Thus, WA would require a 32% increase in energy consumption. Compared with natural gas at a 2.9 million Btu input, use of WA would result in a 25% decrease in production.

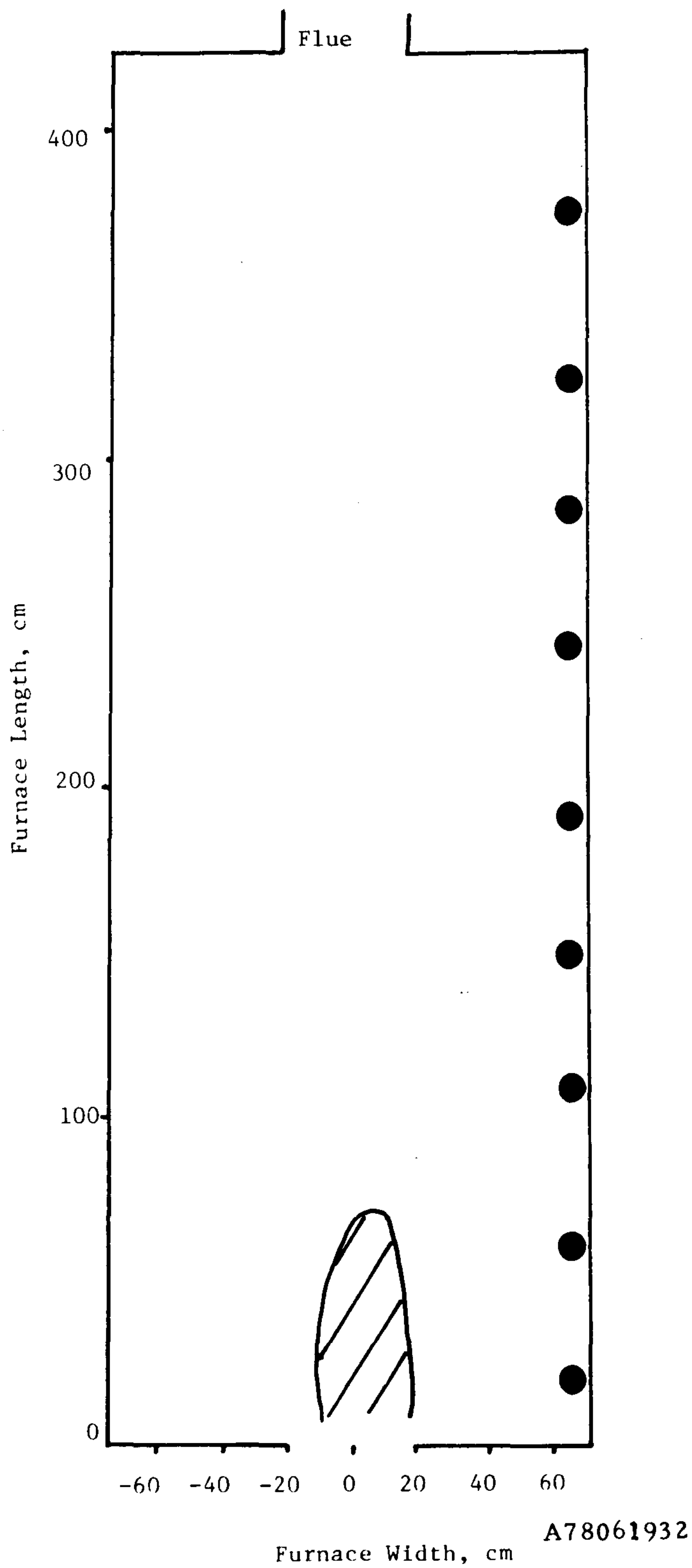

Figure 19. FLAME SHAPE FOR WINKLER AIR FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

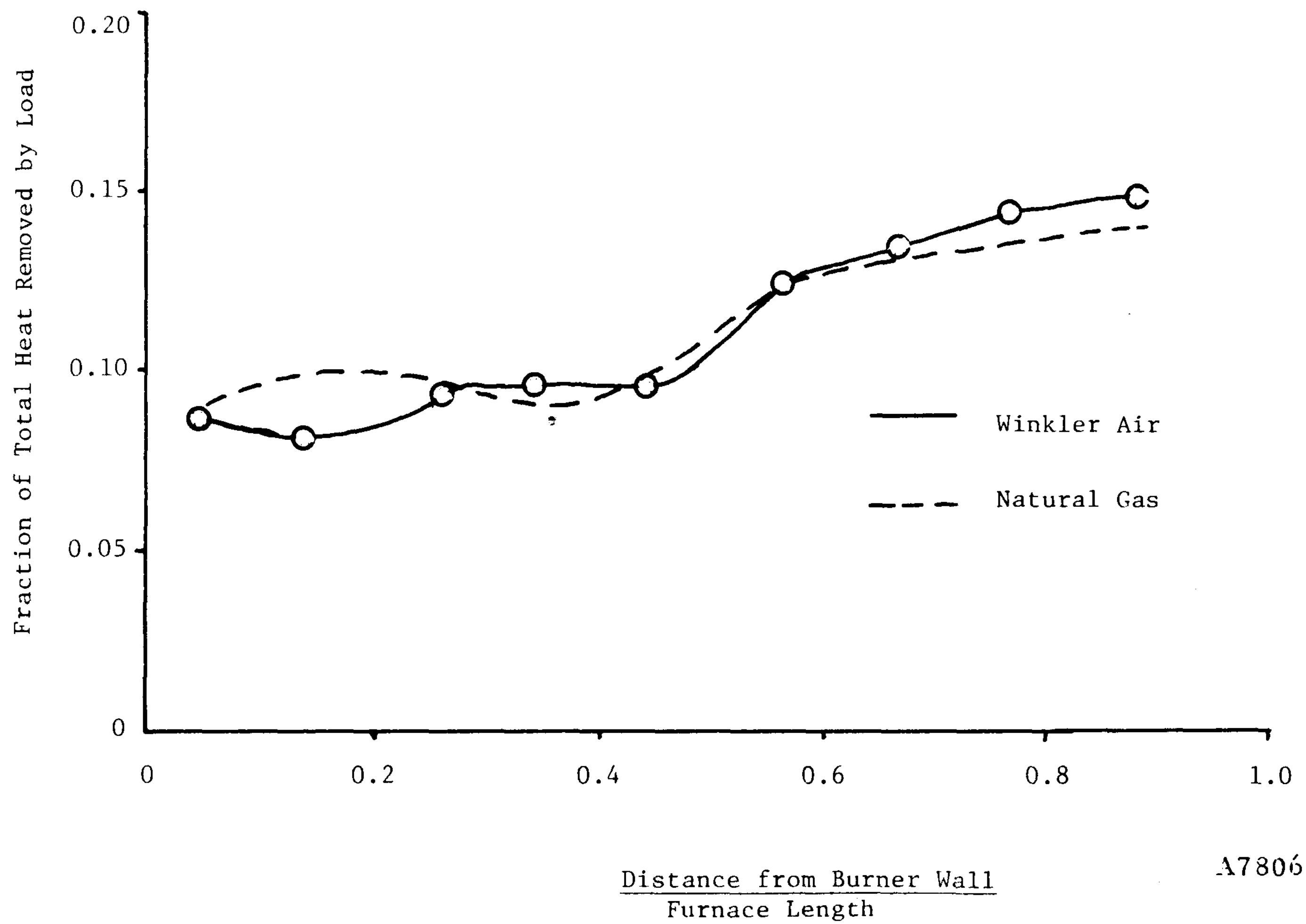

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Figure 20. HEAT ABSORPTION PROFILES FOR WINKLER AIR FUEL GAS AND NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

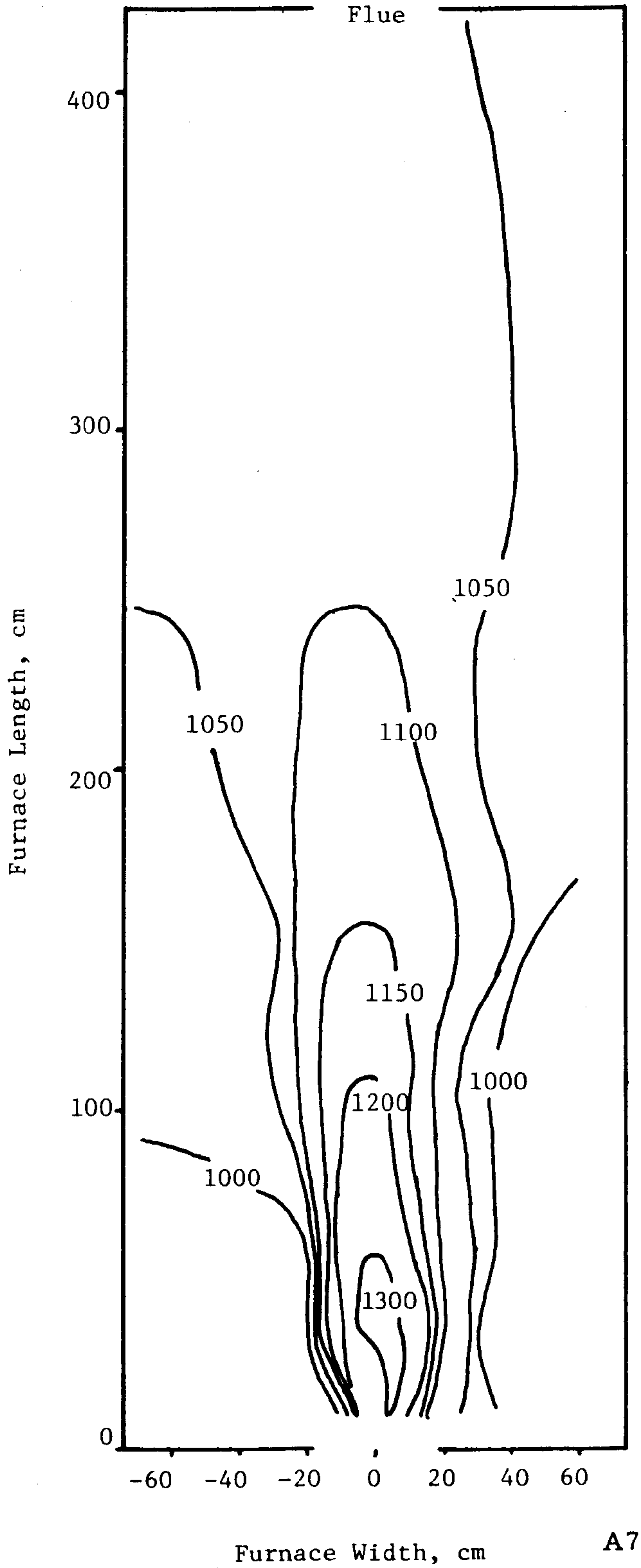

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Figure 21. TEMPERATURE PROFILES (°C) FOR WINKLER AIR FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER

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