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

Project 8985 Special Report No. 1
FORWARD-FLOW BURNER TYPE

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ABSTRACT

Data were gathered to determine the performance of a Bloom baffle burner when retrofit with three low-Btu gases. The baffle burner is representative of the forward-flow type of burner and was fired on a furnace with a load simulating the preheat zone of a steel reheat furnace — a typical use for this burner. The low-Btu gases simulated for these combustion trials were Koppers-Totzek oxygen, Wellman-Galusha air, and Winkler air. All of the low-Btu gases exhibited problems when fired on an unmodified burner. Each had a flame length longer than the natural gas flame and a thermal efficiency lower than the efficiency with natural gas. Burner modifications could alleviate some of the retrofit problems. With these modifications Koppers-Totzek oxygen medium-Btu fuel gas would be an acceptable substitute for natural gas. The other two low-Btu gases would still not be ideal substitutes.

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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 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 Bloom baffle burner, which is representative of the forward-flow burner type. The burner size and firing rate were chosen to simulate the firing density (Btu/CF-hr) in the preheat zone of a steel reheat furnace.

While firing natural gas, the furnace load was adjusted to absorb the same fraction of the furnace heat input that occurs in a reheat furnace. 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.

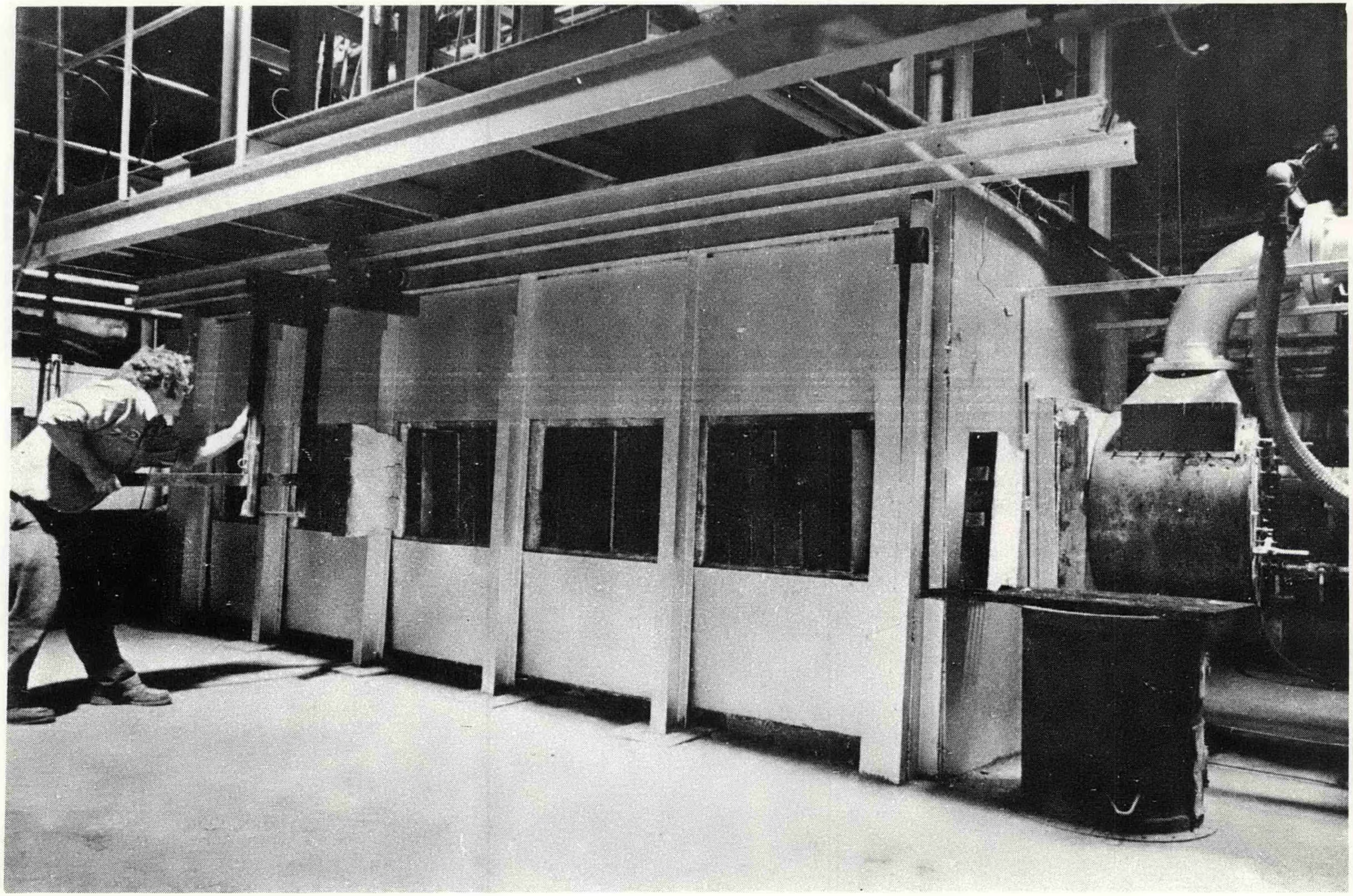


Figure 1. PILOT-SCALE TEST FURNACE

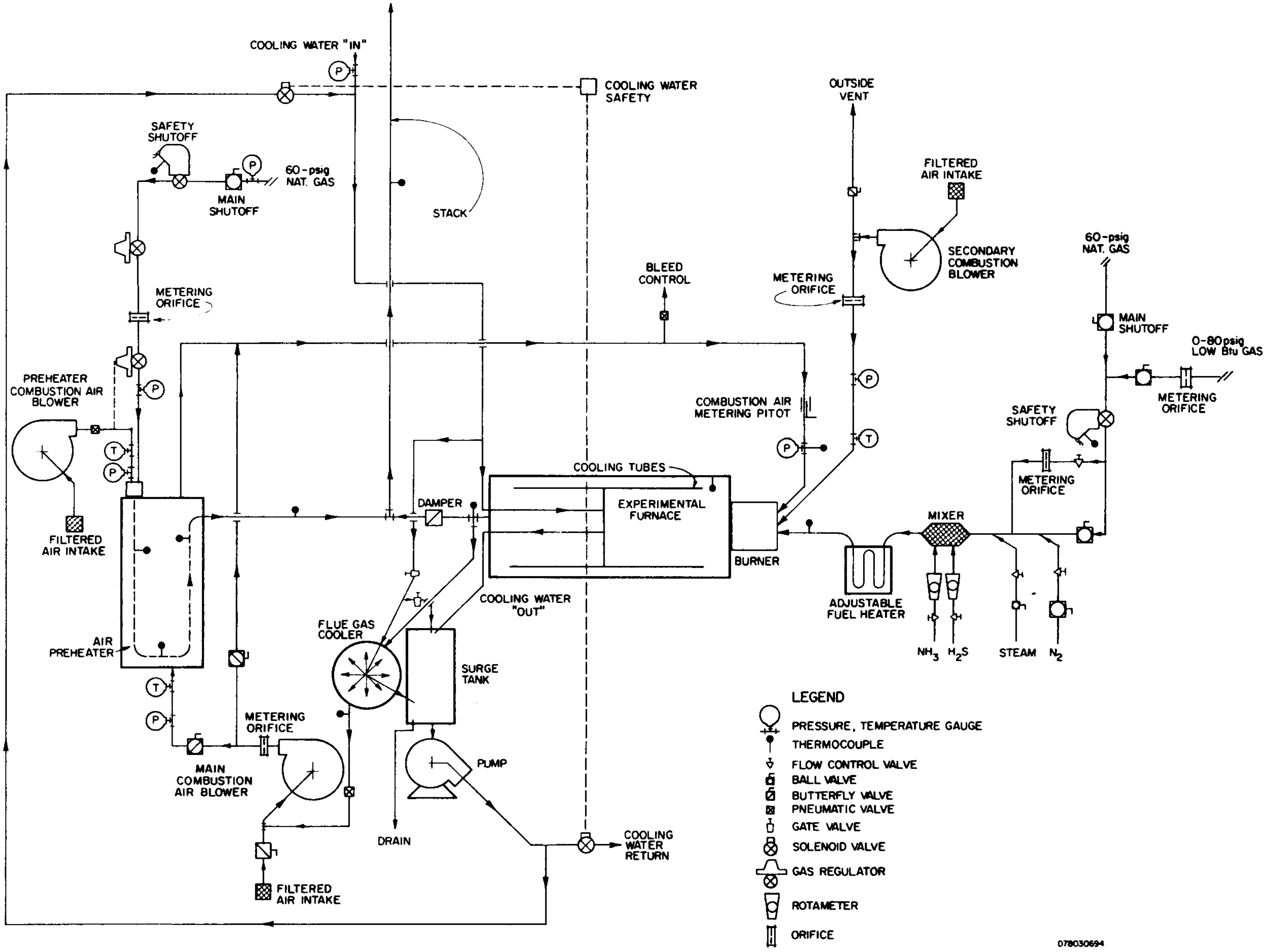


Figure 2. OVERALL FURNACE SYSTEM

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

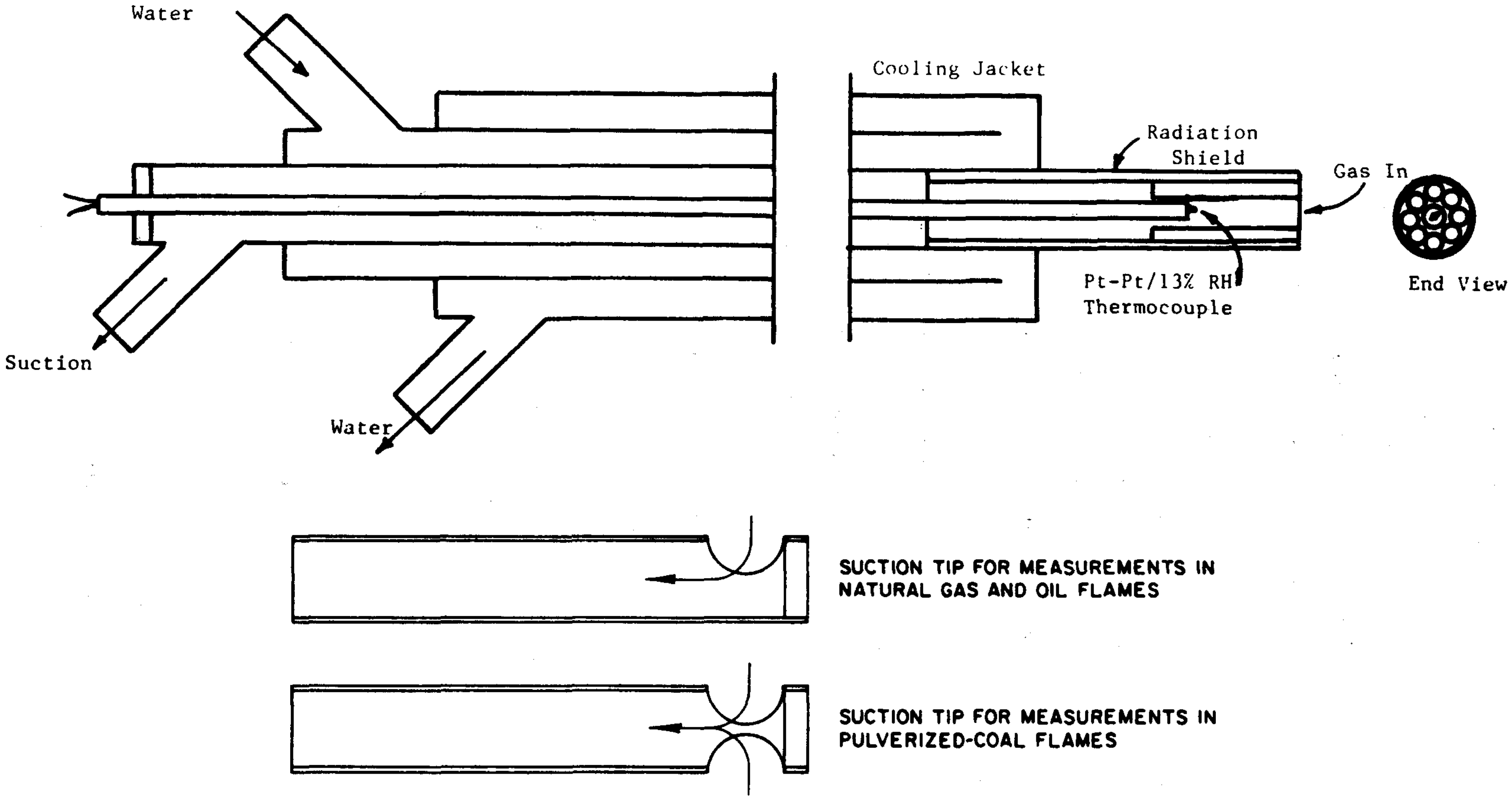
Fuel	CO	H_2	CO_2	CH_4	N_2	H_2O	Heating Value, Btu/SCF	Adiabatic Flame Temp,* °F
Koppers-Totzek Oxygen	53.0	34.3	9.3	0.5	1.0	1.9	287	3767
Wellman-Galusha Air	26.9	14.3	7.4	2.6	46.9	1.9	160	3228
Winkler Air	21.1	13.0	6.9	0.6	56.5	1.9	116	2932

* 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



Alternate Probe Tips

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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.

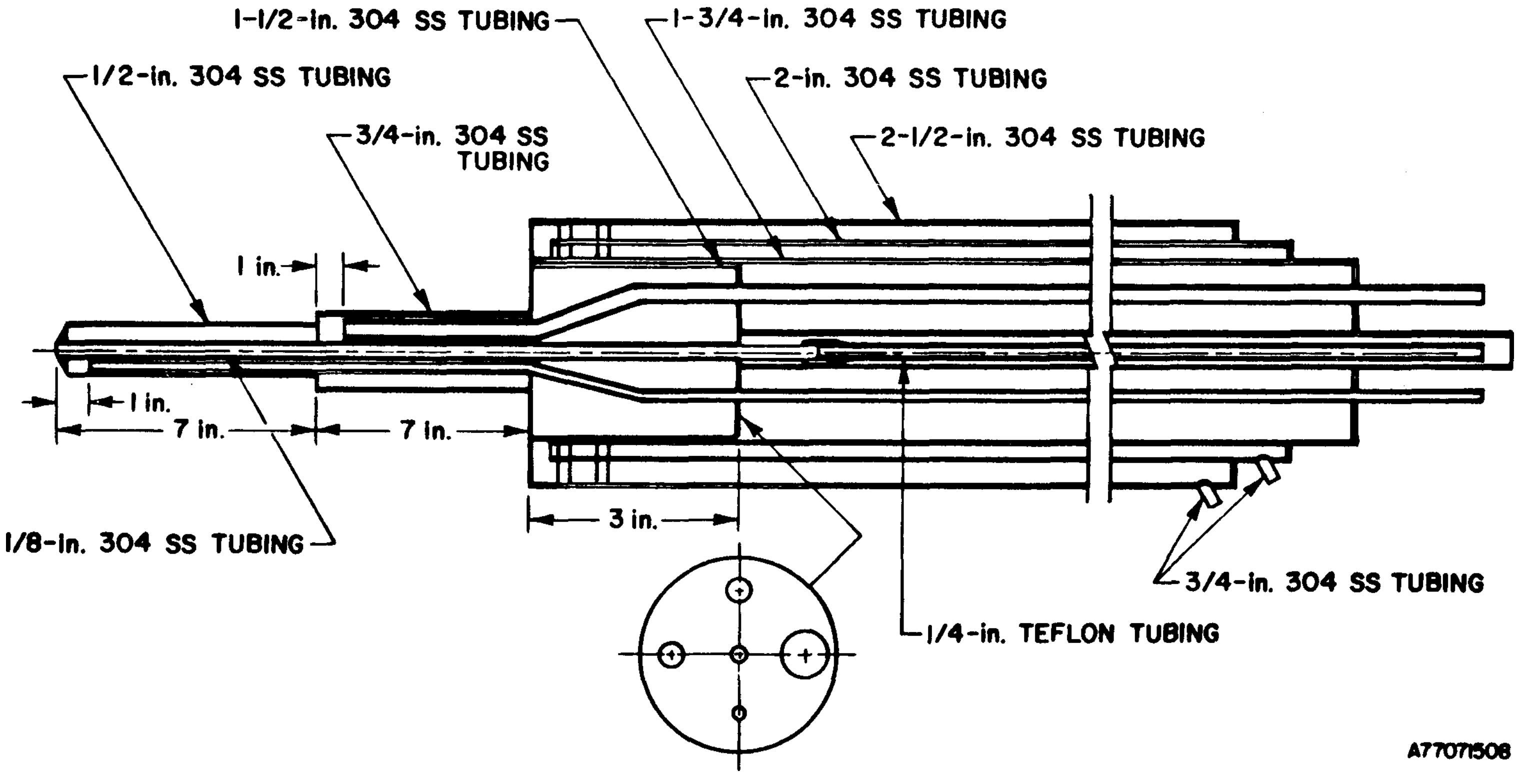

Figure 4. ASSEMBLY DRAWING OF GAS SAMPLING PROBE

BURNER TEST

Natural Gas Base-Line Data

The first burner to be tested, a baffle burner illustrated in Figures 5 and 6, was installed on the pilot-scale test furnace. The burner is full scale and available as an off-the-shelf item from the manufacturer. The burner consists of a centrally located gas nozzle, surrounded by a high-temperature refractory baffle that has ports for the injection of combustion air into the furnace. The flame patterns produced by this burner can be altered by inserting baffles with air ports of differing diameter or angle.

This type of burner is found on many large-scale industrial process heating furnaces such as steel reheating, batch glass melting, aluminum holding, and tunnel kilns. The baffle design selected for testing produces a flame-to-test furnace length ratio equal to the flame-to-preheat section length ratio found in a five-zone steel slab reheat furnace. Figure 7 illustrates a five-zone steel slab reheating furnace.

Steel slabs are produced from ingots in a primary rolling operation, called slabbing. Slabs are oblong in shape, usually 4 to 12 inches thick, 60 to 74 inches wide, and up to 30 feet in length. After reheating, the slabs are rolled into plates or strips.

More than 60% of the fuel used in a reheat furnace is consumed in the preheat section.

Modeling the preheat section of a reheat furnace requires that the burner operating conditions be as close to industrial practice as possible. The baffle burner selected for testing has a maximum fuel input capacity of 7.2 million Btu/hr, with 10% excess air preheat to 650°F. The fuel nozzle is a 2-1/2-inch Schedule 40 pipe. The burner was test fired at 72% of its maximum capacity (5.25 million Btu/hr), which is typical of industrial practice. This fuel input produces a firing density (firing rate divided by furnace volume) of 17,564 Btu/cu ft-hr, which is within the range (10,000 to 25,000 Btu/cu ft-hr) of industrial firing densities. The baffle used to produce the desired flame-to-furnace length ratio has eight holes, 2.2 inches in diameter, oriented to give a 15-degree swirl.

The rate of heat absorption and efficiency of the furnace preheat section were simulated on the pilot-scale furnace by inserting water-cooling

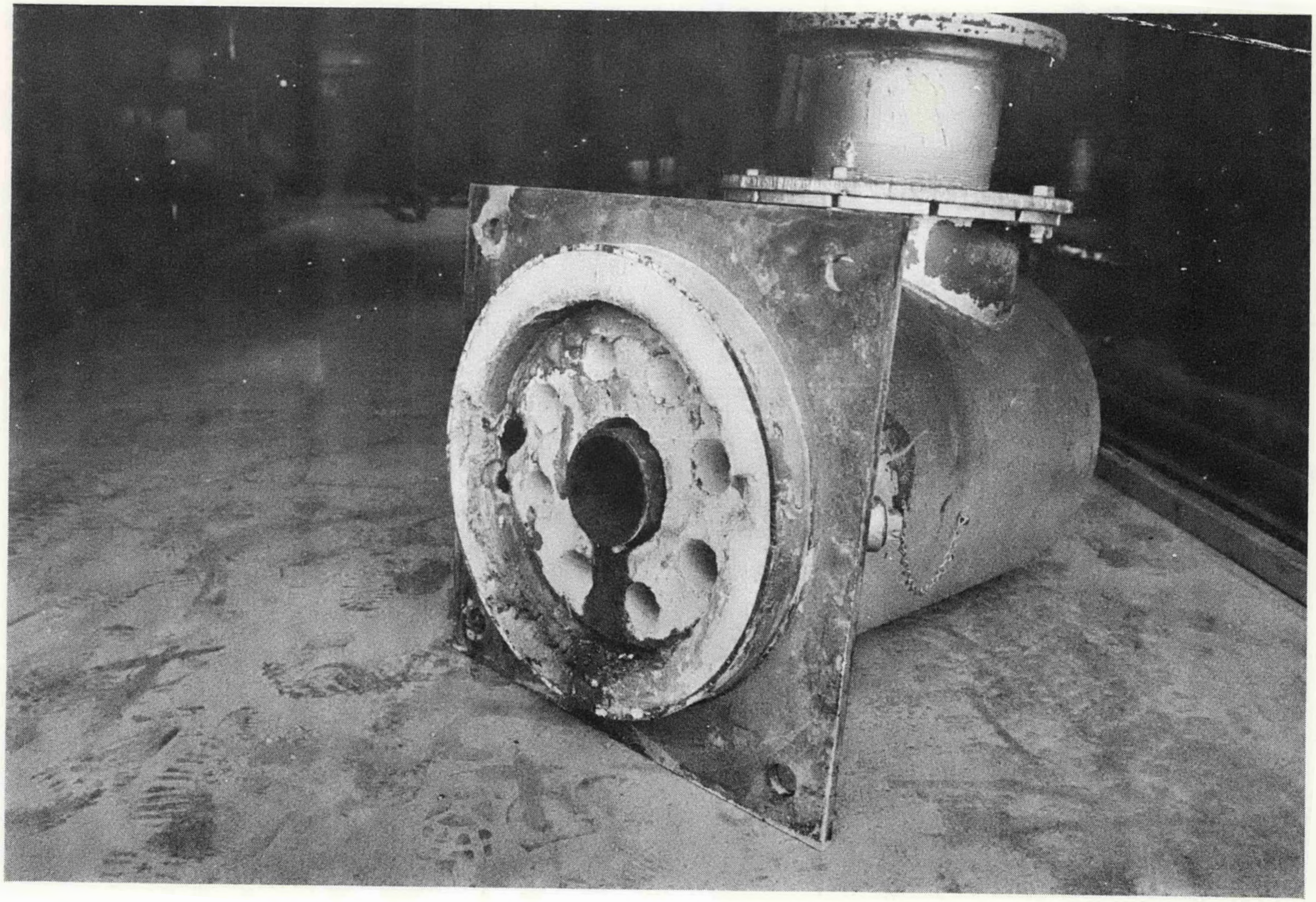

Figure 5. BLOOM BAFFLE BURNER

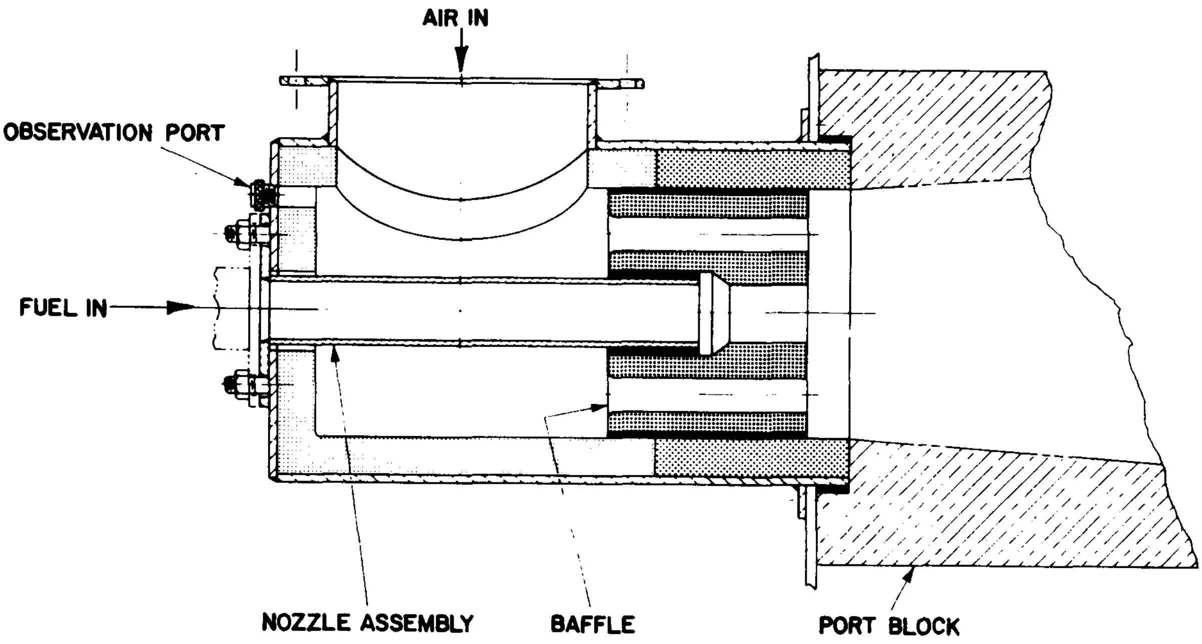

Figure 6. ASSEMBLY DRAWING OF BAFFLE BURNER

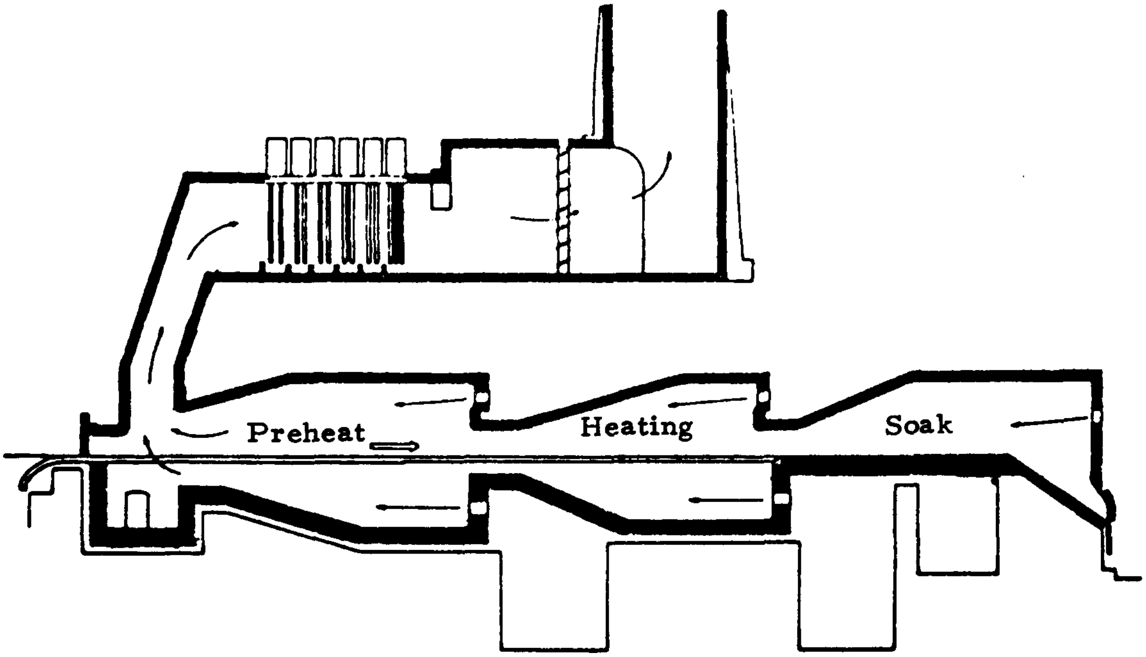

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Figure 7. PROFILE OF FIVE-ZONE REHEATING FURNACE WITH OVERHEAD METAL RECUPERATOR

tubes along the furnace sidewalls. A scaled drawing of the test furnace is shown in Figure 8. The locations of the 58 water cooling tubes, which can be placed within the furnace, are indicated by circles. The heat absorption profile typical of a five-zone reheat furnace preheat section is given in Figure 9. The curve has been plotted in dimensionless units to make scaling easier. In addition to attempting to reproduce this heat absorption profile, the furnace also must be operated with a thermal load efficiency (heat absorbed by water cooling tubes divided by the fuel input enthalpy) between 30% and 40%. To achieve this efficiency and heat absorption rate, nine cooling tubes were inserted into the furnace. These tubes are denoted in Figure 8 by the filled-in circles. The heat absorption curve of Figure 9 was reproduced by adjusting the cooling surface area of each heat sink. This is accomplished by altering the length of each cooling tube exposed within the furnace. The entire thermal load was placed on the right furnace sidewall, which would simulate the hearth of the reheat furnace. The pilot-scale furnace is rotated 90 degrees relative to a reheat furnace. Thus all temperature, radiation, gas composition, and flow direction profile data represent variations in the vertical plane of the reheat furnace. If the flame were symmetrical about the burner axis, the relative orientation of the test furnace to the reheat furnace would not matter. Photographs show that the flame is asymmetrical. Thus, when reviewing profile data, it is important to interpret the results as viewing the combustion process from the roof of a reheat furnace.

The total heat removed by the water-cooling tubes was 1,867,500 Btu/hr. The enthalpy input was 5,294,000 Btu/hr of fuel and 585,500 Btu/hr of combustion air preheat. Thus, the thermal load efficiency was 35%. This efficiency and the heat-absorption profile with natural gas established the base-line condition for comparison with low-Btu gas combustion.

The second set of natural gas firing data collected determined the shape (width and length) of the natural gas flame. These data were collected using the sample gas probe and the carbon monoxide and oxygen analyzers. Analysis of the data reveals the flame shape shown in Figure 10. This envelope depicts the boundaries within which 99% of the combustibles were consumed.

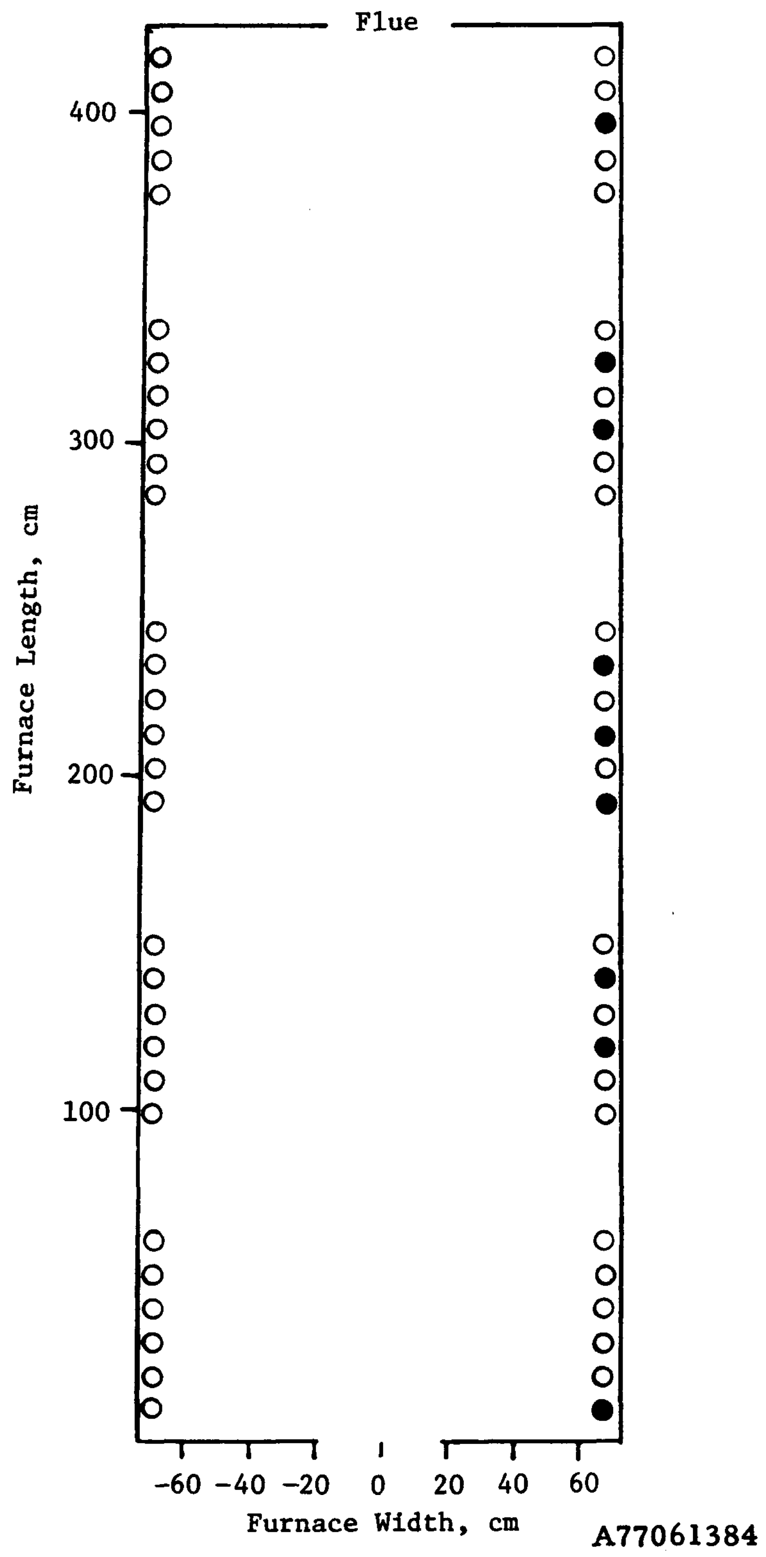

Figure 8. SCALED DRAWING OF TEST FURNACE
WITH COOLING-TUBE POSITIONS

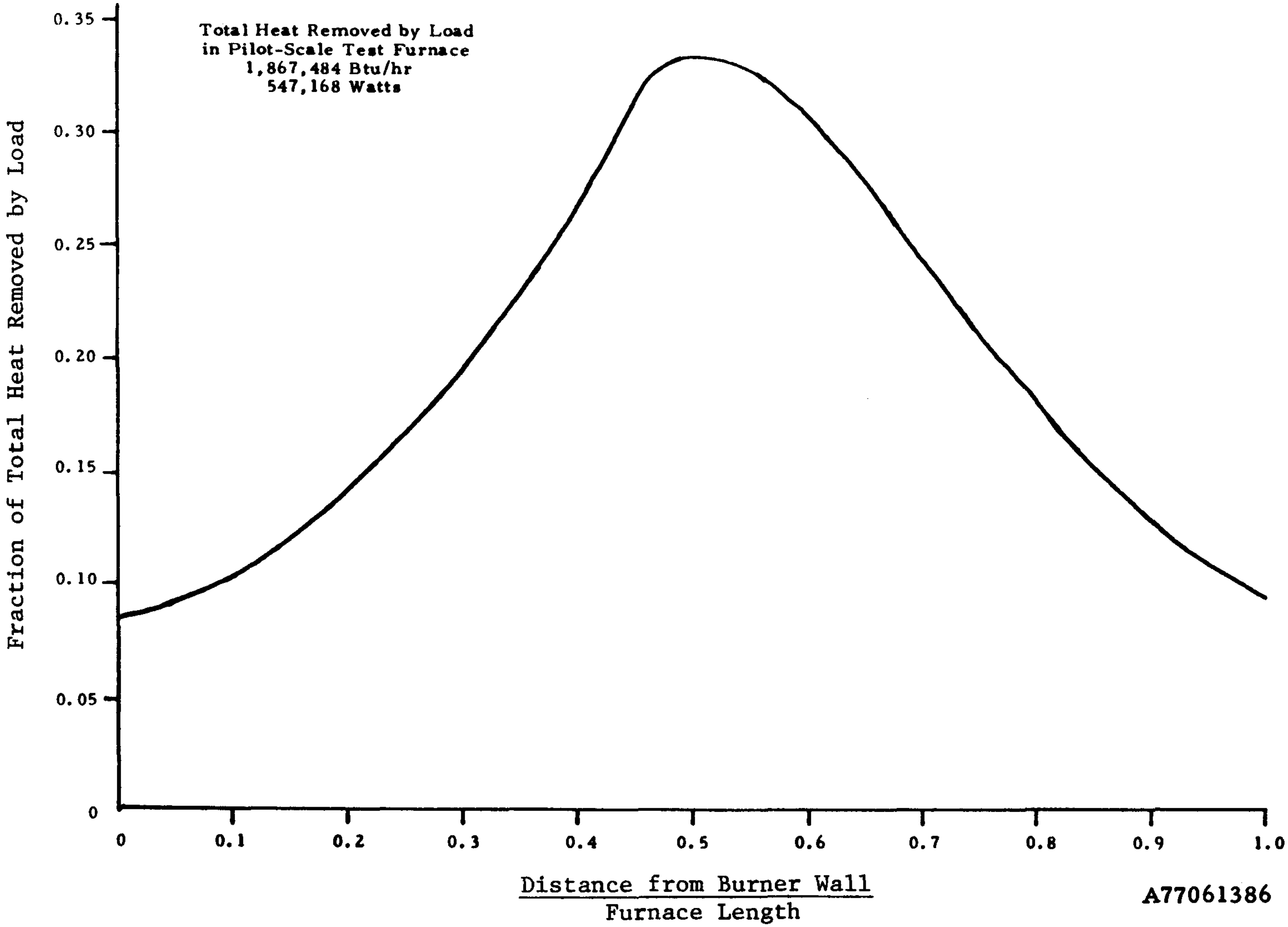

Figure 9. HEAT ABSORPTION PROFILE OF PREHEAT SECTION OF A FIVE-ZONE REHEAT FURNACE AS A FUNCTION OF FURNACE LENGTH

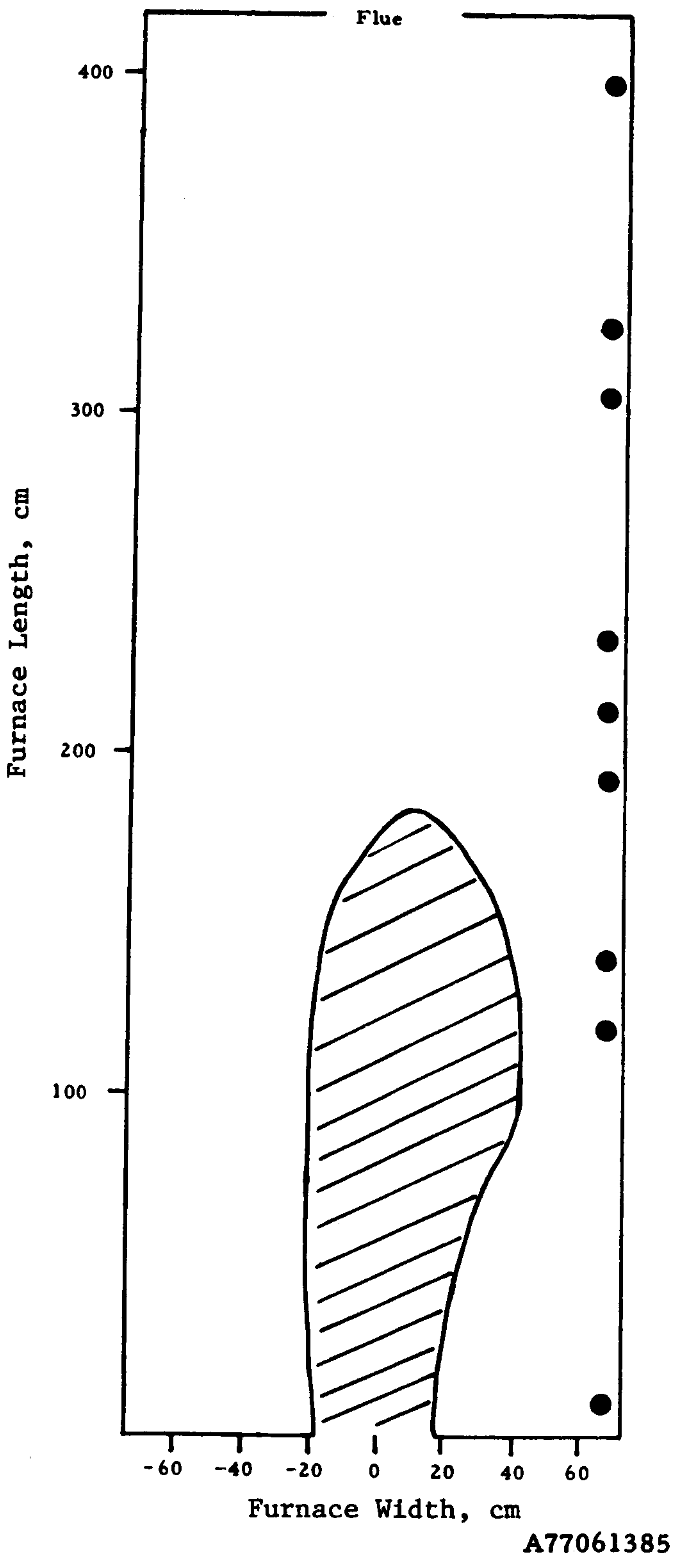

Figure 10. NATURAL GAS FLAME SHAPE FROM A BAFFLE BURNER

Temperature data as a function of axial and radial furnace positions were gathered using the suction pyrometer. These temperature data were used to generate the isothermal profiles given in Figure 11.

Figure 12 shows the flow direction profile measured for the natural gas flame. The flow direction was measured using a water-cooled Hubbard probe, a Datametrics Barocel pressure transducer, and Datametrics CGS electric manometer. The data show that the flow from this burner is "plug" flow through the furnace with recirculation zones in the corners. This is to be expected from a burner with such a low swirl angle (15 degrees).

Noise level measurements were made adjacent to the furnace along the side and at the burner. Measurements were made with the flame on and off to determine the level of noise due to the combustion process and fuel flow. With the flame off, the noise level was 75.5 db. The measurements for natural gas showed a 6.5 decibel increase due to combustion at the burner. An 8.5 decibel increase was measured along the side of the furnace with the furnace closed, and a 14.5 decibel increase due to combustion was measured when one of the sampling doors was removed.

In addition to these above data, radiant heat flux and post-flame emissivity data were collected.

Low-Btu Gas Tests

Flame Stability Tests

After completion of the natural gas work, flame stability tests began with the low-Btu 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 and Wellman-Galusha air fuel gases, no flame instability was encountered, and the burner could be fired at a rate equal to the natural gas firing rate.

During the tests with Winkler air fuel gas, the flame became unstable at a fuel input of 27,800 SCF/hr or about 3.2×10^6 Btu/hr enthalpy input. Varying the excess air level or axial position of the nozzle did not affect the flame stability problem. Increasing the air preheat temperature from 650° to 800°F produced a stable flame at a firing rate equal to the 5.25 million Btu/hr natural gas base-line input. Increasing the air preheat temperature would increase the bulk fuel-air mixture temperatures near the nozzle.

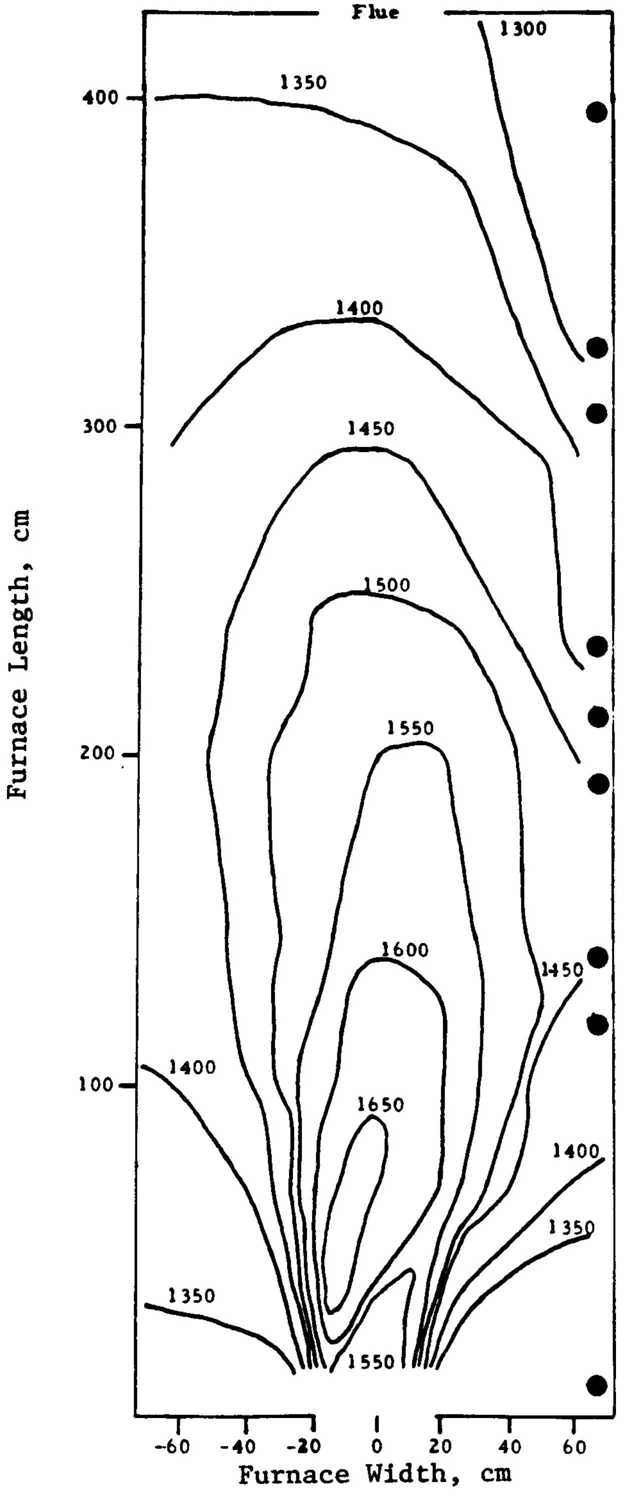

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Figure 11. ISOTHERMAL PROFILES (°C) AS A FUNCTION OF FURNACE POSITION FOR NATURAL GAS ON THE BAFFLE BURNER

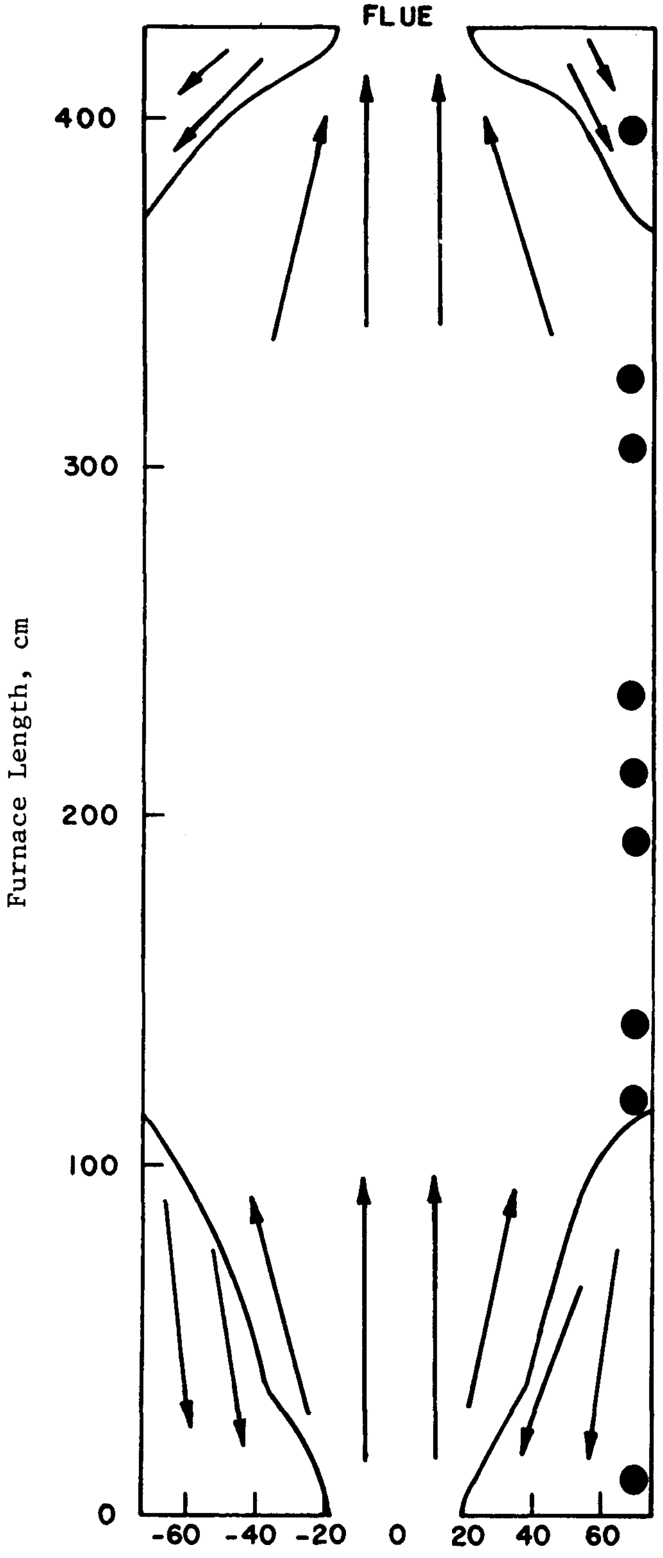

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Figure 12. FLOW DIRECTION FOR BLOOM BAFFLE BURNER WITH NATURAL GAS FUEL

The flame propogation velocity increases with mixture temperature, and this would explain the increase in flame stability.

Koppers-Totzek Oxygen Fuel Gas Tests

Table 2 compares some of the test results for the low-Btu gases with those for natural gas. The low heating value of the substitute fuels requires that the fuel flow rate and, consequently, the fuel velocity be greatly increased at the nozzle. For KTO, the fuel velocity is 168 ft/s compared with 43 ft/s for natural gas.

The flame length for KTO, 342 cm, is very much longer than the 180 cm measured for natural gas. The flame length for a turbulent diffusion flame is determined by the rate of mixing of the fuel and air. If a high-velocity fuel jet from the central nozzle is surrounded by a slow-moving air stream, the jet will rapidly entrain the surrounding air. The rate of mixing will depend on the fuel/air momentum flux ratio. The momentum flux is the product of the velocity times the mass flow rate. On the other hand, if the air velocity and therefore the air momentum flux is high compared with the fuel, there is also rapid mixing of the fuel and air. When the momentum fluxes of the fuel and air are comparable, neither stream can entrain fluid from the other, and mixing of the two streams is slow, resulting in a long flame. For the natural gas flame, the air momentum flux is very much greater than that of the fuel, resulting in good air/fuel mixing and a very short flame. For KTO, the air and fuel momentum fluxes are comparable, which explains the very long flame length.

The thermal efficiency for KTO is 26% compared with 35% for natural gas. This might be considered surprising because the adiabatic flame temperature for KTO is comparable to that of natural gas. The peak flame temperatures are also comparable with 1650°C (3002°F) measured at 240 cm for KTO and 1672°C (3042°F) at 36 cm for natural gas.

Figure 13 compares the heat absorption profiles for KTO and natural gas. The profile for KTO is displaced slightly toward the flue end of the furnace. Figure 14 shows the flame shape determined for KTO, and Figure 15 shows the temperature profiles measured for KTO. The flame shape and temperature profiles help to explain the displacement of the heat absorption profile.

Table 2. FURNACE AND BURNER OPERATING CONDITIONS

Fuel Type	Fuel Flow, SCF/hr	Air Flow, SCF/hr	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	CO	CO_2	O_2	N_2
										— ppm —		—%, dry basis—		
Natural Gas	5,140	53,960	43	151	2433	59,000	180	35	0.17	300	12	10.9	2.0	87
Koppers-Totzek Oxygen	20,100	42,800	168	120	2676	54,800	342	26	0.20	290	1000	24.1	1.8	74
Wellman-Galusha Air	34,200	44,300	286	124	2300	71,800	302	23	0.20	30	250	20.3	1.3	78
Winkler Air*	44,500	44,000	372	146	2328	80,900	240	22	0.185	14	54	18.0	1.2	81
Winkler Air†	44,500	44,000	140	164	2330	80,900	342	21	0.185	26	140	17.0	1.1	82

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* Air preheat 850° rather than 650°F as used with other tests.

† Used 4-inch fuel nozzle; all others used 2-1/2 inch nozzle.

‡ Efficiency based on load divided by fuel volume flow times heating value.

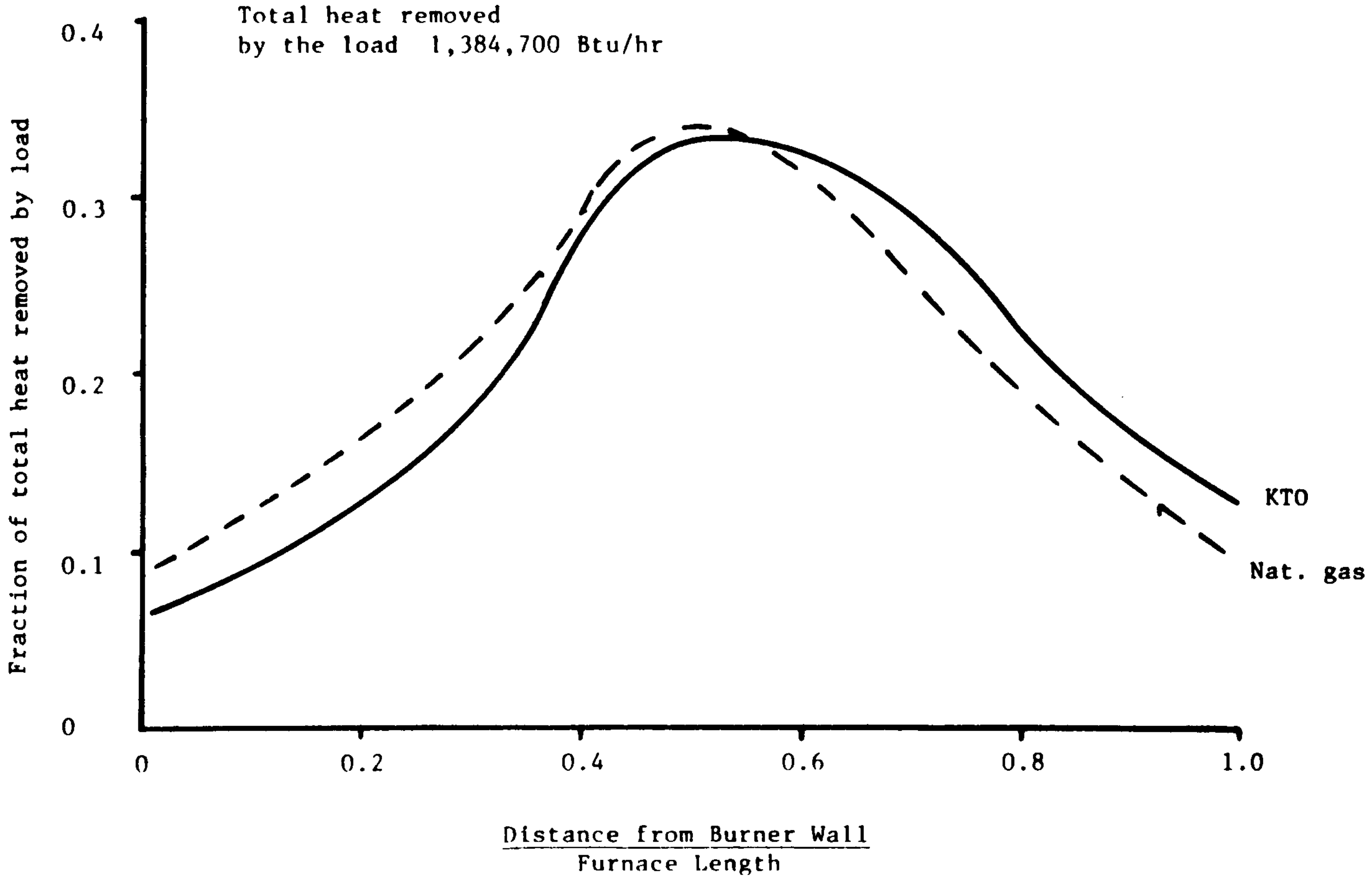

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Figure 13. HEAT-ABSORPTION PROFILE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE BAFFLE BURNER

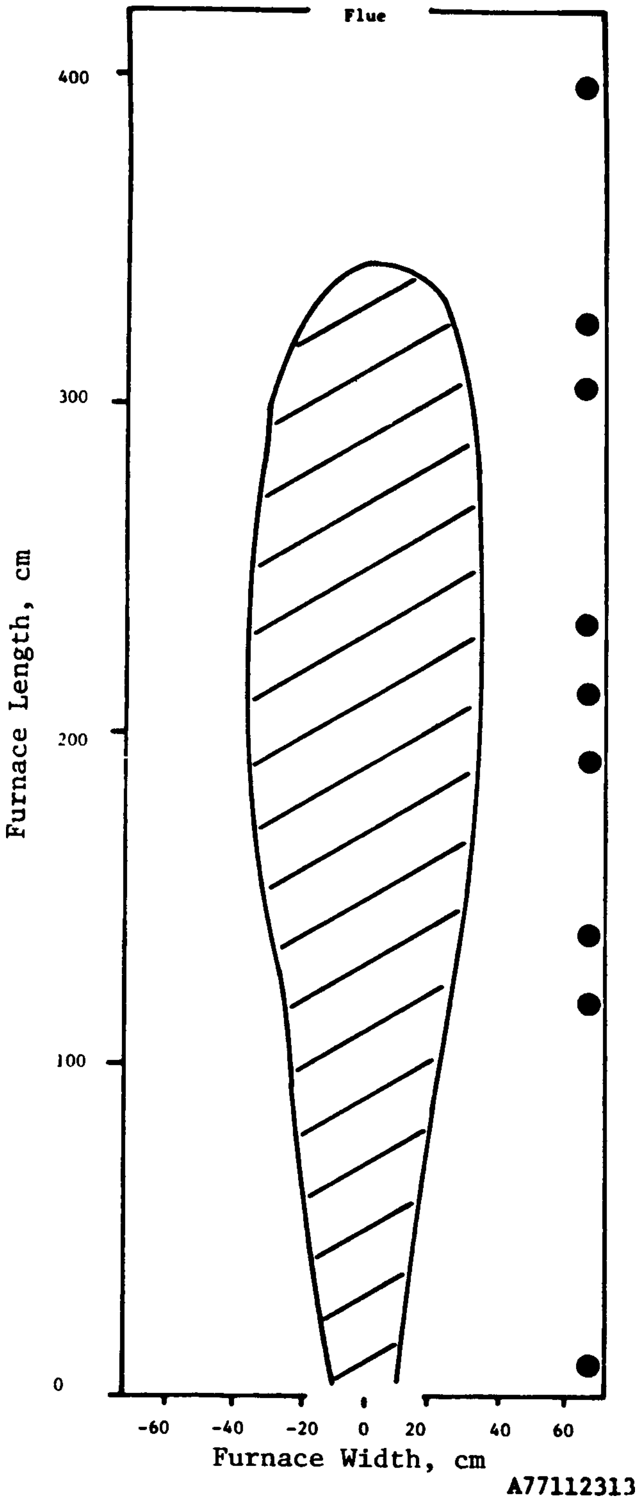

Figure 14. FLAME SHAPE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE BAFFLE BURNER

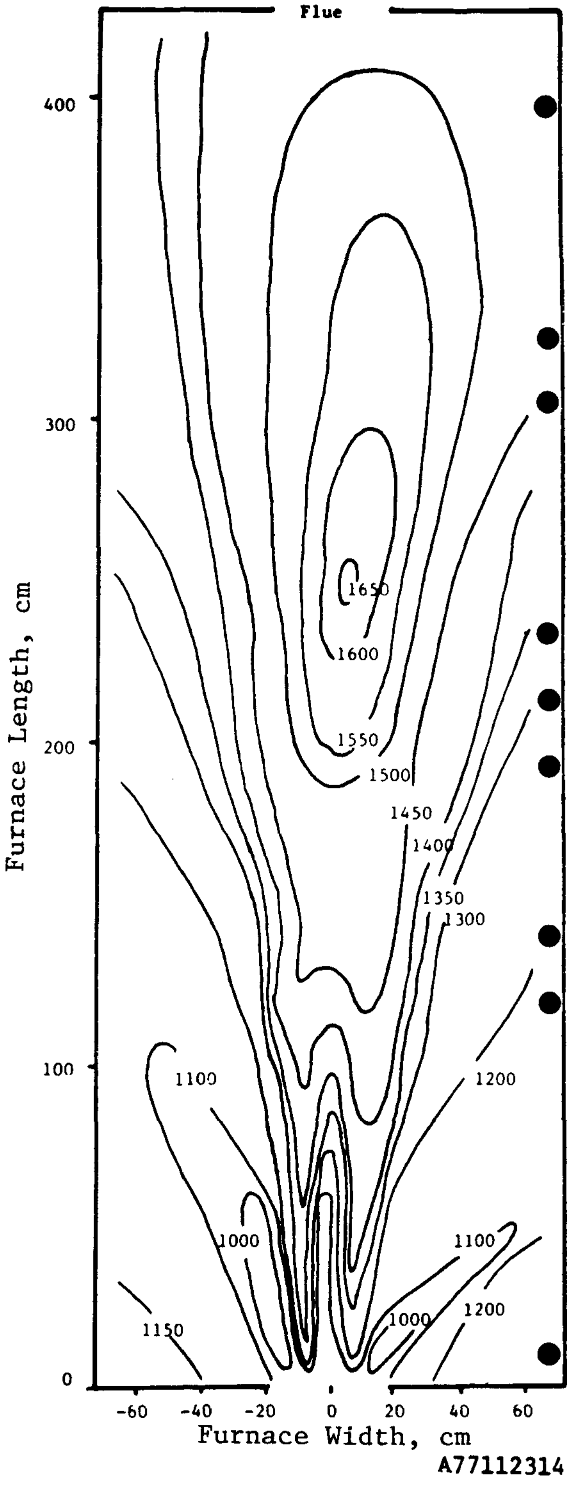

Figure 15. TEMPERATURE PROFILES (°C) FOR KOPPERS-TOTZEK OXYGEN ON THE BAFFLE BURNER

Because the flame is so long, the peak temperatures appear farther down the length of the furnace, and thus the heat is transferred from the flame to the load farther down the furnace than was the case for natural gas. Also, because the flame is so long, the hot combustion products are formed near the furnace exit and escape before they are able to transfer heat to the load, resulting in a loss of efficiency.

The flame radiation measurements confirm the shift in heat transfer from the front of the furnace for the low-Btu gases. 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 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 KTO radiant flux shows a steep rise from the burner and then a general leveling off from the middle to the end of the furnace. The hot combustion products increase in concentration toward the end of the furnace, and this explains the increase in the thermal radiation. The natural gas curve, however, shows a peak close to the burner (near the middle of the flame) because of the radiation from carbon particles formed during the thermal decomposition of methane and the higher hydrocarbons present in the natural gas. This causes a high radiant flux near the burner, with the emissions gradually decreasing toward the flue end of the furnace.

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

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

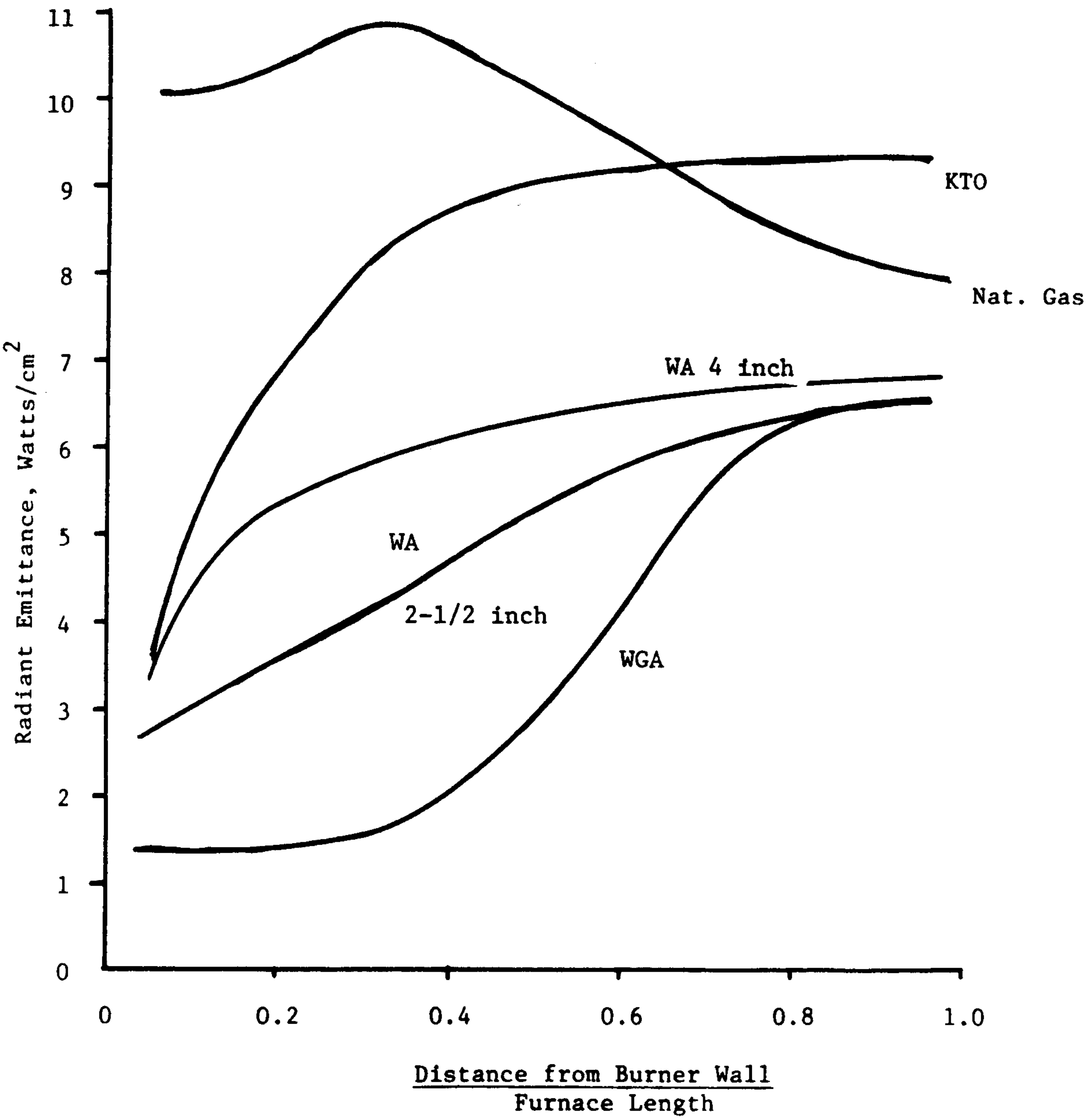

Figure 16. RADIANT EMITTANCE FROM FLAME PLUS COMBUSTION PRODUCTS FOR BAFFLE BURNER

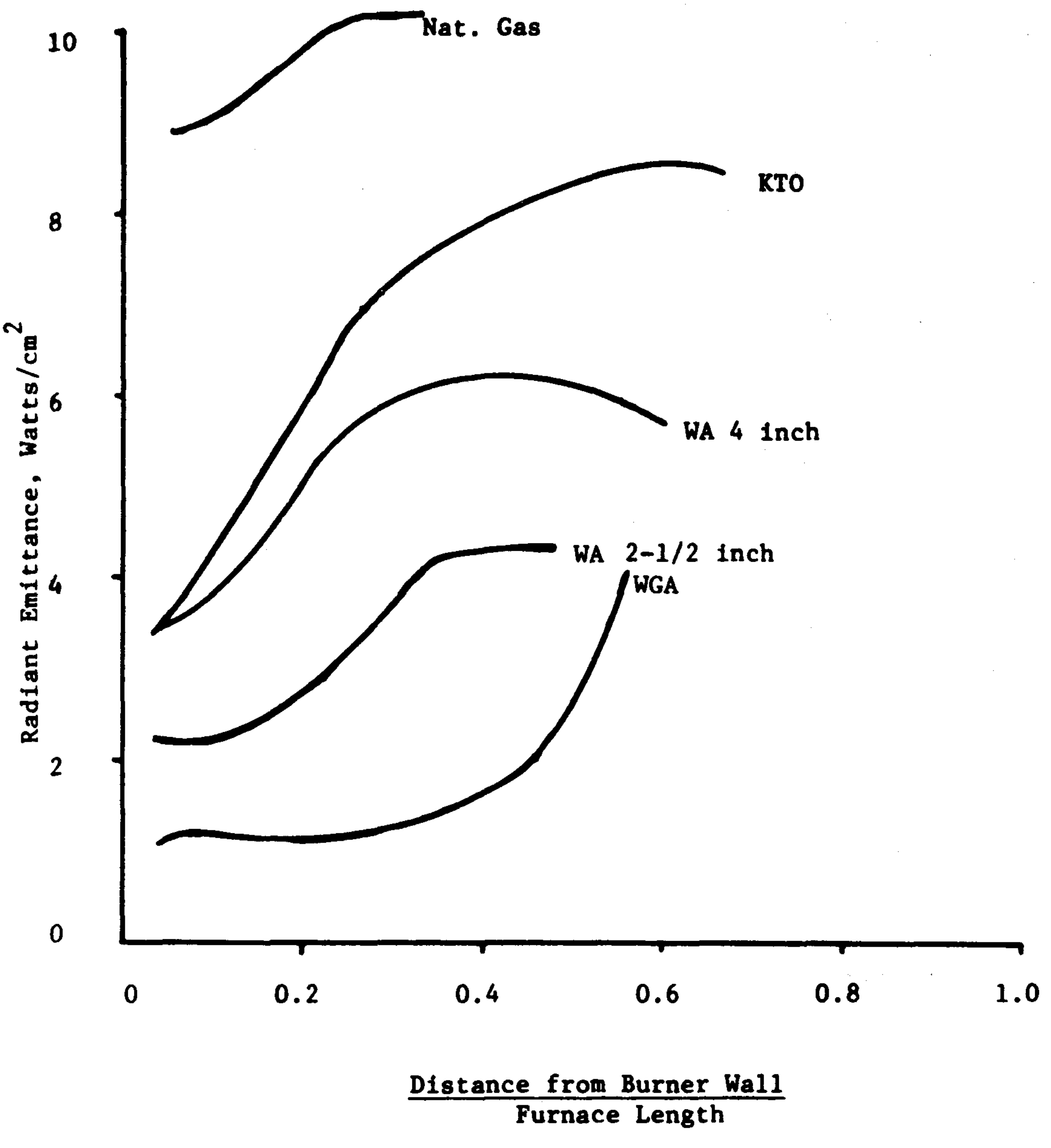

Figure 17. RADIANT EMITTANCE FROM FLAME FOR BAFFLE BURNER

The flame absorptivity is then—

$$\alpha = 1 - \frac{R_2 - R_1}{R_3} \qquad (1)$$

The relationship between gas emissivity and absorptivity in a furnace, when the refractory is not a black body, can be determined from radiation theory.[2] The result is—

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

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 emissivity measured for natural gas, 0.17, is higher than the 0.16 calculated using charts available in Reference 2 and also found in many engineering handbooks. The measured emissivity, however, is lower than the 0.18 calculated using the method proposed by Leckner (Combustion and Flame 19, 33, 1972). For KTO, the measured emissivity was 0.20. The value calculated from the Hottel and Sarofim charts was 0.18 and Leckner's calculation gave 0.21.

Sound-level measurements were taken at a location 1 foot from the burner air plenum and at another location 2 feet from the furnace at the center of the sidewall at an axial position halfway down the length of the furnace.

During the KTO tests, the background noise level was 88 db. The noise level increased by 7 db at the burner when the fuel was fired. The increase was 7 db at the sidewall. When a sampling door was removed, the noise level at the sidewall increased by 8 db.

Figure 18 shows the flow direction profile for KTO. The flows for this fuel are similar to the flows found for natural gas.

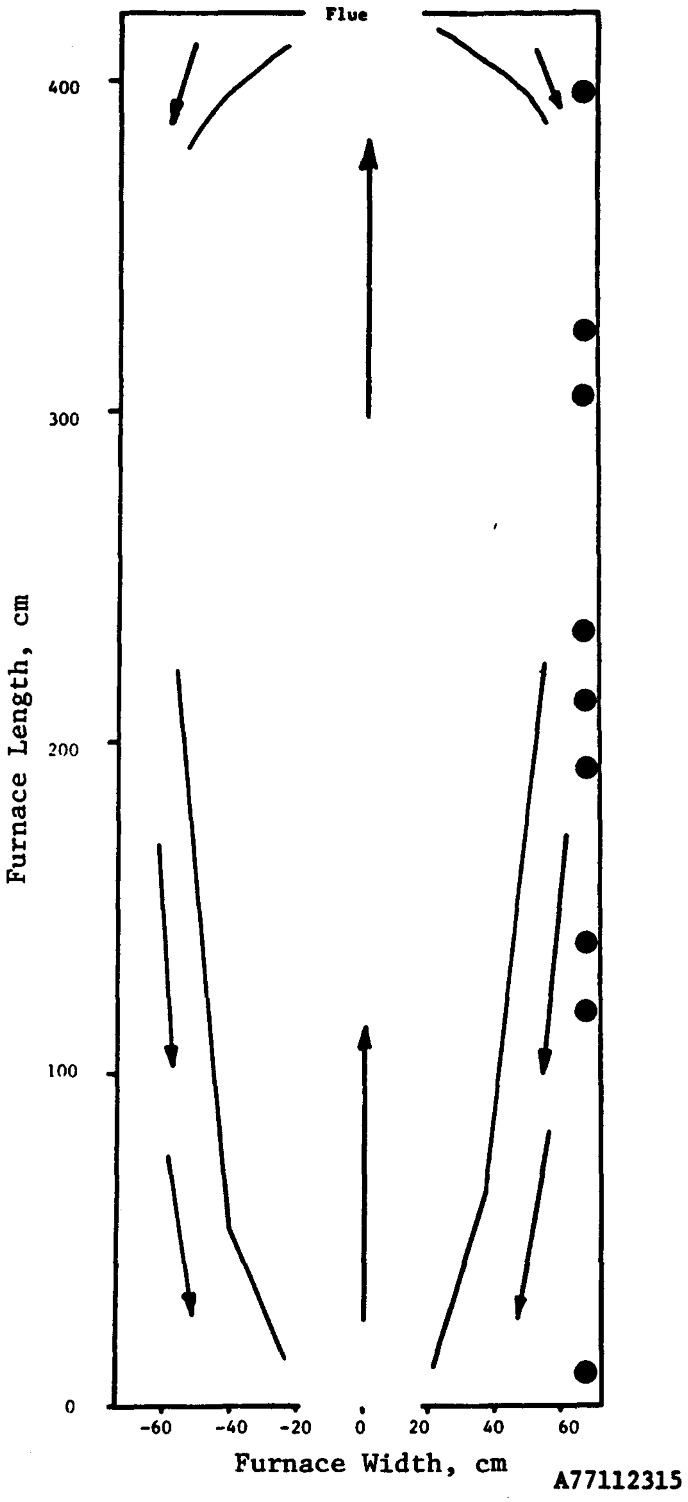

Figure 18. FLOW DIRECTION PROFILE FOR KOPPERS-TOTZEK OXYGEN ON THE BAFFLE BURNER

Koppers-Totzek Oxygen Fuel Gas Retrofit Conclusions

A direct retrofit of KTO on an unmodified baffle burner would be difficult because of the extended flame length. The long flame would probably impinge on the refractory backwall for most furnaces designed for natural gas firing. This would cause accelerated refractory wear and burnout. The heat absorption profile and flame temperature for KTO are acceptable and since the baffle burner is easily modified, the flame length problem can be solved. The flame was shortened by inserting a larger, 4-inch, fuel nozzle. The fuel velocity decreased and therefore the fuel momentum flux decreased relative to the air momentum flux shortening the flame length from 342 cm to 270 cm. Increasing the swirl would further shorten the flame. Shortening the flame and thus intensifying the heat release near the burner should also increase the thermal efficiency.

Thus, due to the excessive flame length, KTO does not directly retrofit well on the baffle burner. KTO, however, should be able to approach the same heat absorption profile, thermal efficiency, flame length, and flame temperature as natural gas with some burner modifications. These modifications are relatively simple with the baffle burner.

Wellman-Galusha Air Fuel Gas Tests

Table 2 also gives some of the results of the tests with WGA. The 160 Btu/CF heating value of WGA results in a very high fuel flow rate and thus a very high fuel velocity at the nozzle. In this case, the fuel momentum flux is about 1.5 times that of the air, and the resulting flame is 302 cm, which is shorter than that of KTO, but still longer than that of natural gas.

The thermal efficiency for WGA is 23%, which is considerably lower than the 35% for natural gas. The 1351°C (2464°F) peak flame temperature at the 240-cm axial position is considerably below the 1672°C (3042°F) measured for natural gas. This would explain the reduced heat transfer and thus reduced thermal efficiency.

Figure 19 compares the heat absorption profile for WGA with that of natural gas. The profile is slightly displaced toward the flue end. The

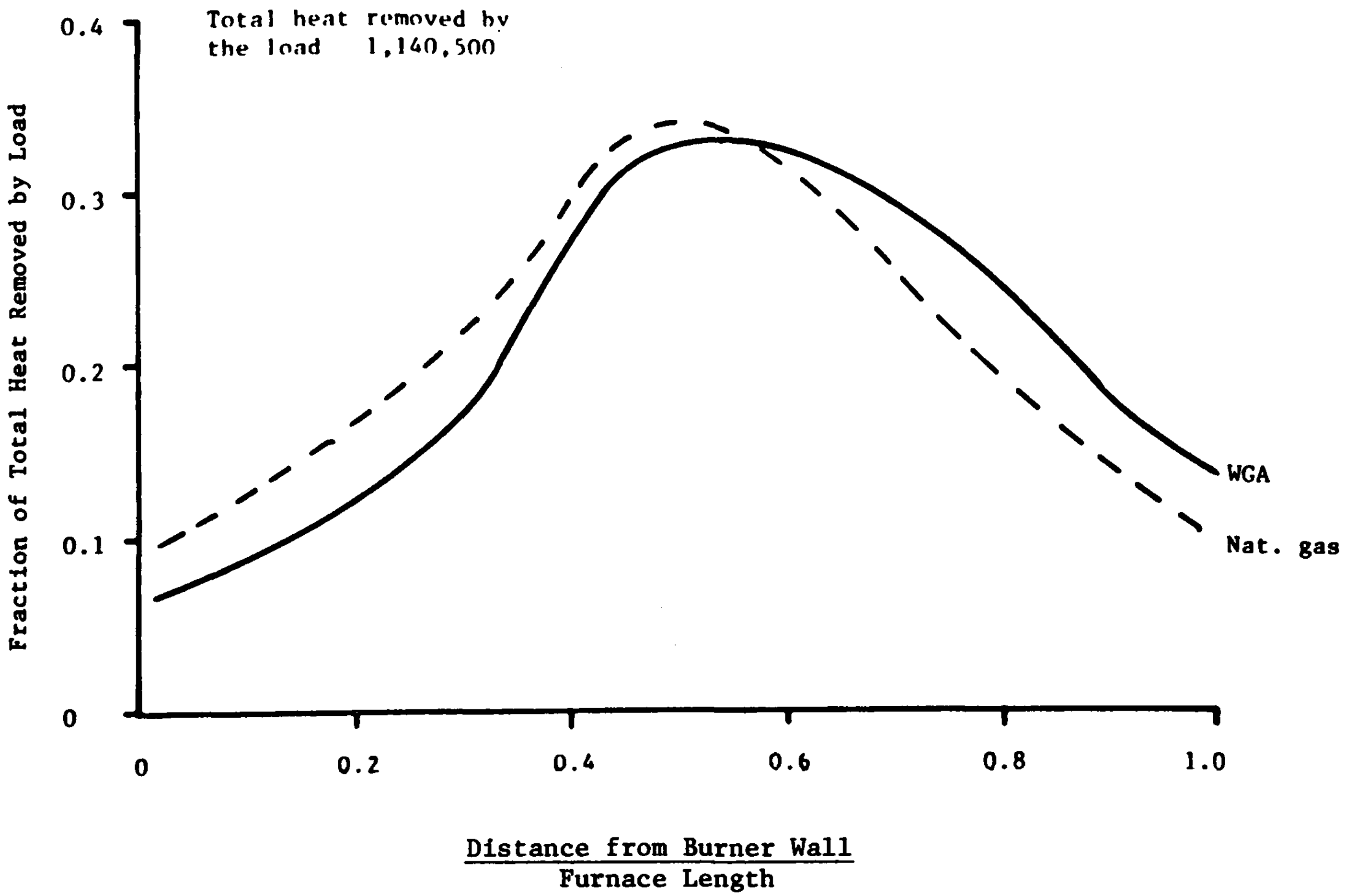

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Figure 19. HEAT-ABSORPTION PROFILE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE BAFFLE BURNER

shape is nearly identical to that of KTO. Figure 20 shows the flame shape for WGA; Figure 21 shows the temperature profiles, and Figure 22 shows the flow direction profiles. Again the flame shape and temperature profiles show that the heat is released farther down the furnace with WGA.

Figure 16, which shows the radiant flux from the flame and combustion products and Figure 17 which shows the radiant flux from the flame alone, also explain the shift in heat absorption profile from the burner end toward the flue end of the furnace. The radiant flux from WGA is considerably reduced compared with that of natural gas. This is mainly because of the reduced flame temperatures, since thermal radiation is proportional to the fourth power of the gas temperature. Also, the low-Btu gases, primarily carbon monoxide and hydrogen, do not burn with highly luminous flames, as was the case with natural gas where carbon formation increased the flame radiation. The post-flame emissivity measured for WGA was 0.20. The calculated value from Hottel and Sarofin was 0.18 and from Leckner was 0.21.

Sound level measurements were also made with WGA. During these tests, the background noise level was 83 db. The noise level increased by 9 db at the burner when WGA was fired. The increase was 10 db along the sidewall, both with and without a sampling door removed.

Wellman-Galusha Air Fuel Gas Retrofit Conclusions

A direct retrofit of WGA on the baffle burner would result in a long flame, though not as long as KTO. The flame length might be reduced by increasing the nozzle size, if there was space in the burner to do so. However, the peak flame temperature and the thermal efficiency are both considerably lower than that of natural gas. A flame temperature of 1351°C (2462°F) means that many high-temperature processes could not employ WGA unless the flame temperature was increased by preheating the fuel or increasing the air preheat. This would also increase the heat transfer in the furnace and bring up the thermal efficiency.

Thus, the long flame length, low thermal efficiency, and low flame temperature make WGA unattractive as a direct retrofit fuel on the baffle burner. To alleviate the flame length problem a larger burner casing and thus a new burner would probably be needed to accomodate a large enough nozzle. This could not solve the efficiency and flame temperature problems. These problems

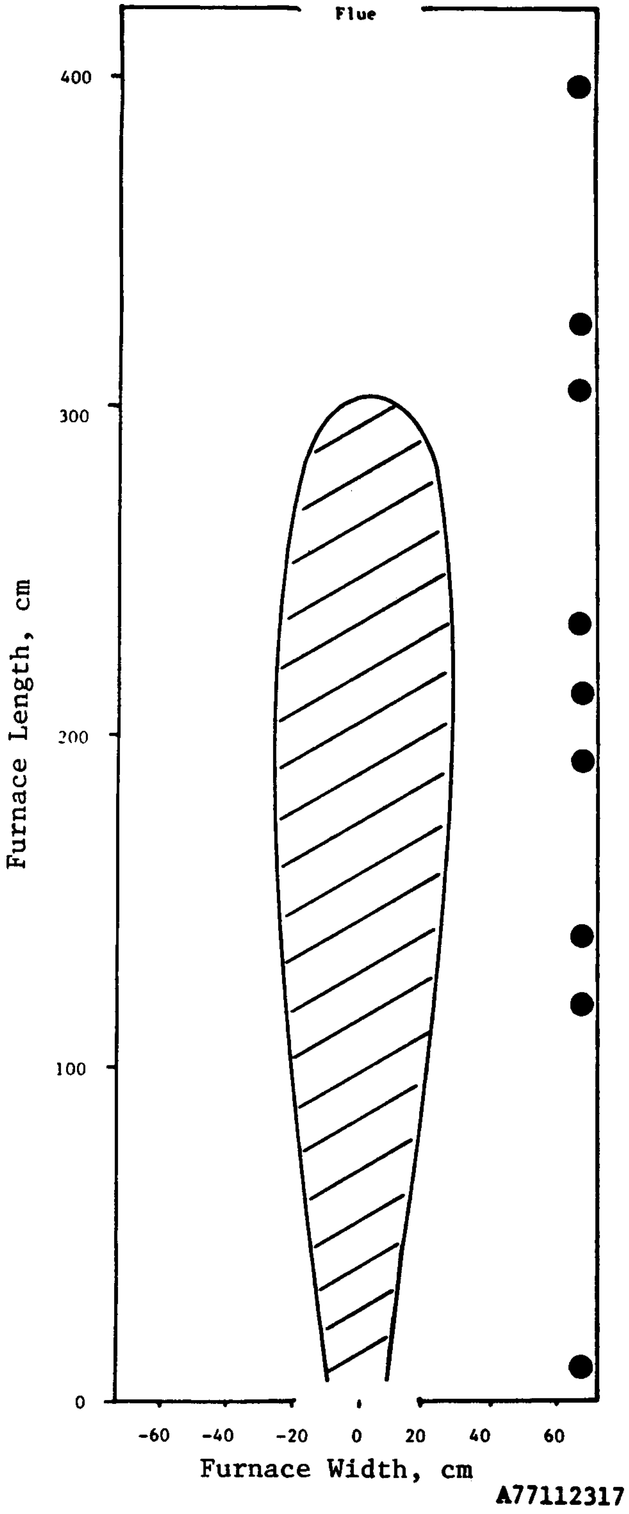

Figure 20. FLAME SHAPE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE BAFFLE BURNER

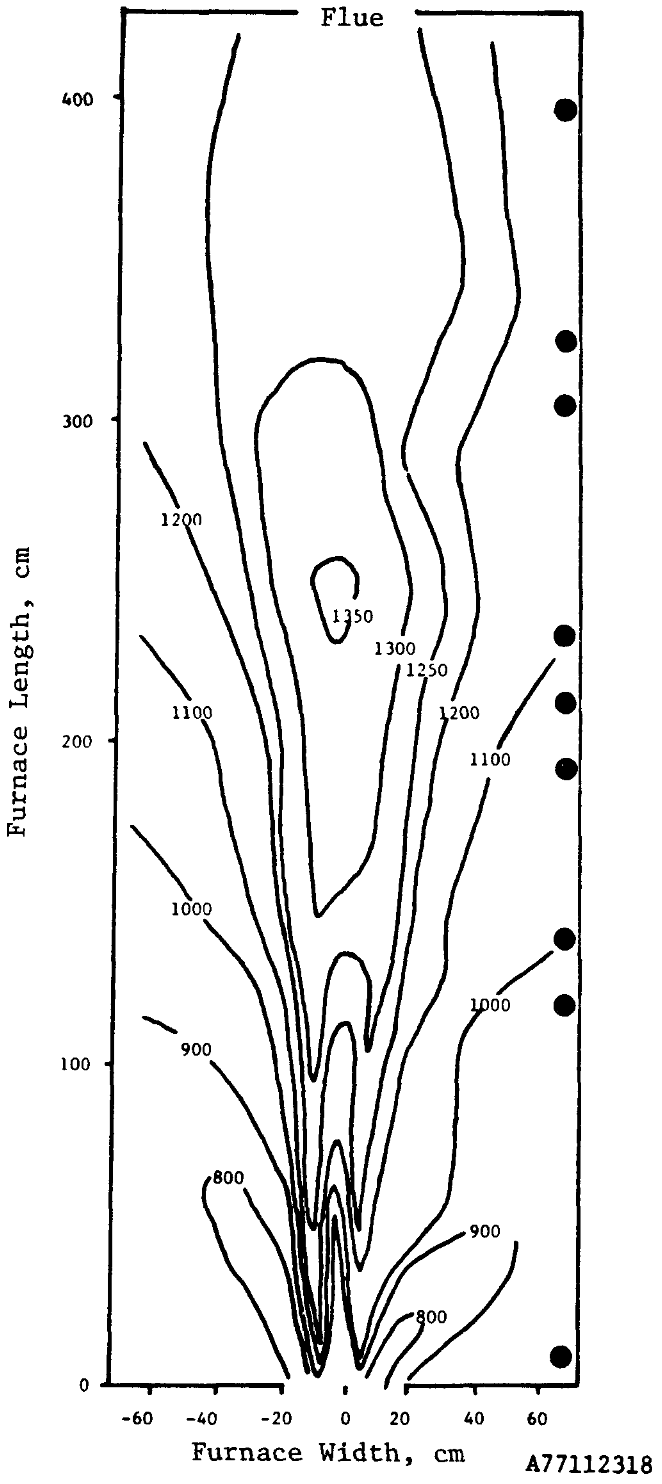

Figure 21. TEMPERATURE PROFILES (°C) FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE BAFFLE BURNER

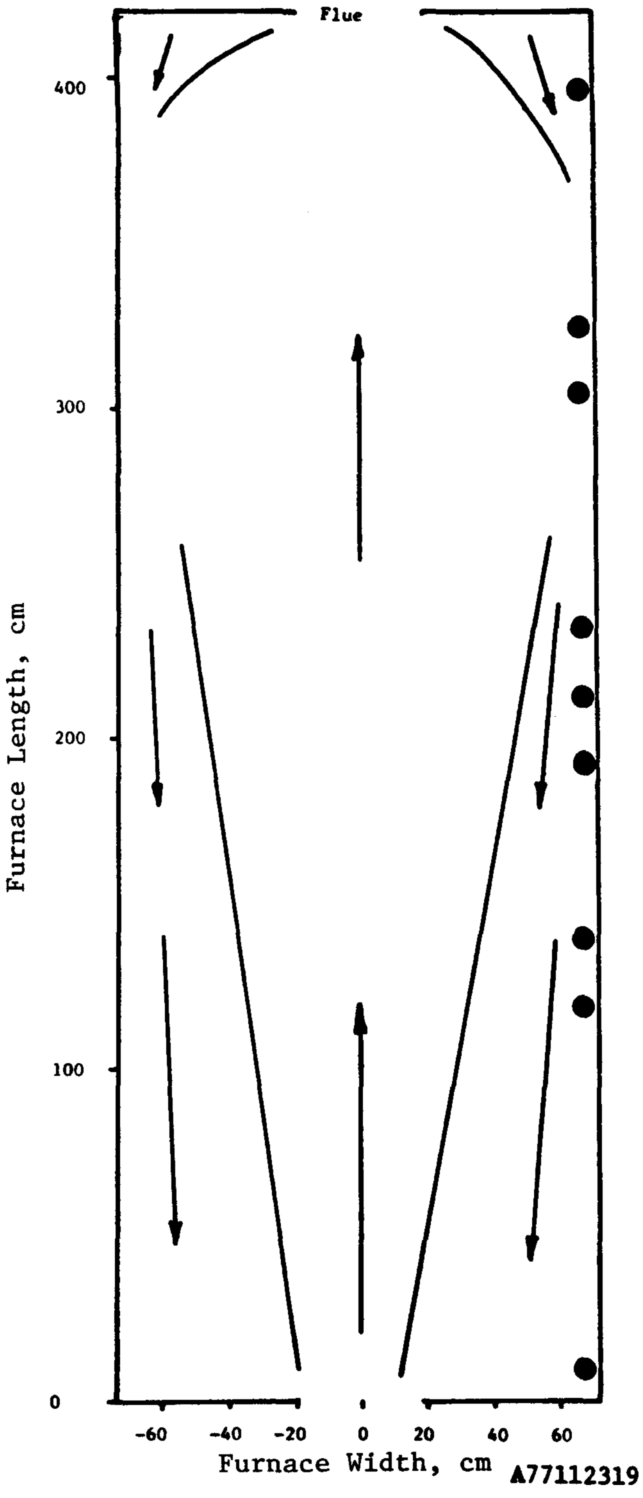

Figure 22. FLOW DIRECTION PROFILE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE BAFFLE BURNER

could be solved by sufficiently preheating the fuel or increasing the air preheat level. Thus, WGA would require major equipment changes to be utilized on furnaces designed for natural gas.

Winkler Air Fuel Gas Tests

The results of the WA tests are shown in Table 2 along with the other gases. Results are given for two cases: a 2-1/2-inch nozzle and a 4-inch nozzle. With the 2-1/2-inch nozzle used for the natural gas base-line tests, WA was not stable until the air preheat level was increased to 800°F. The fuel velocity for WA on the smaller nozzle was very high, 372 ft/s, resulting in a high fuel momentum flux relative to the air momentum flux. This explains the flame stability problem and the shortest flame length of the low-Btu gases.

The thermal efficiency for WA on the 2-1/2-inch nozzle is 22%, which is considerably lower than the 35% for natural gas. Figure 23 shows the heat-absorption profile. Figure 24 shows the flame shape, and Figure 25 shows the temperature profiles. Figure 26 shows the flow direction profile. The heat absorption profile for WA is distinctly displaced toward the flue end of the furnace. Again, the flame length and temperature profiles help explain the displacement of the heat absorption profile because the flame is still much longer than that of natural gas. The peak flame temperature of 1393°C (2540°F) and the low radiant flux are the reasons for the low thermal efficiency.

Figure 16, which displays the radiant flux from the flame plus combustion gases, and Figure 17, which displays the radiant flux from the flame alone, show the reason for the low rate of heat transfer. The radiant flux from the WA flame on the 2-1/2-inch nozzle is considerably lower than that of natural gas. It is low near the burner and increases toward the flue end of the furnace. This is due mainly to the low flame temperatures. The emissivity measured for Winkler air was 0.185. The Hottel and Sarofin charts gave a value of 0.17, while Leckner's calculation method gave 0.20.

During the sound level measurements with Winkler air on the 2-1/2-inch nozzle, the background noise level was 92 db. The noise level increased by 14 db at the burner, 5 db at the sidewall, and 6 db at the sidewall with a sampling door removed when the burner was fired.

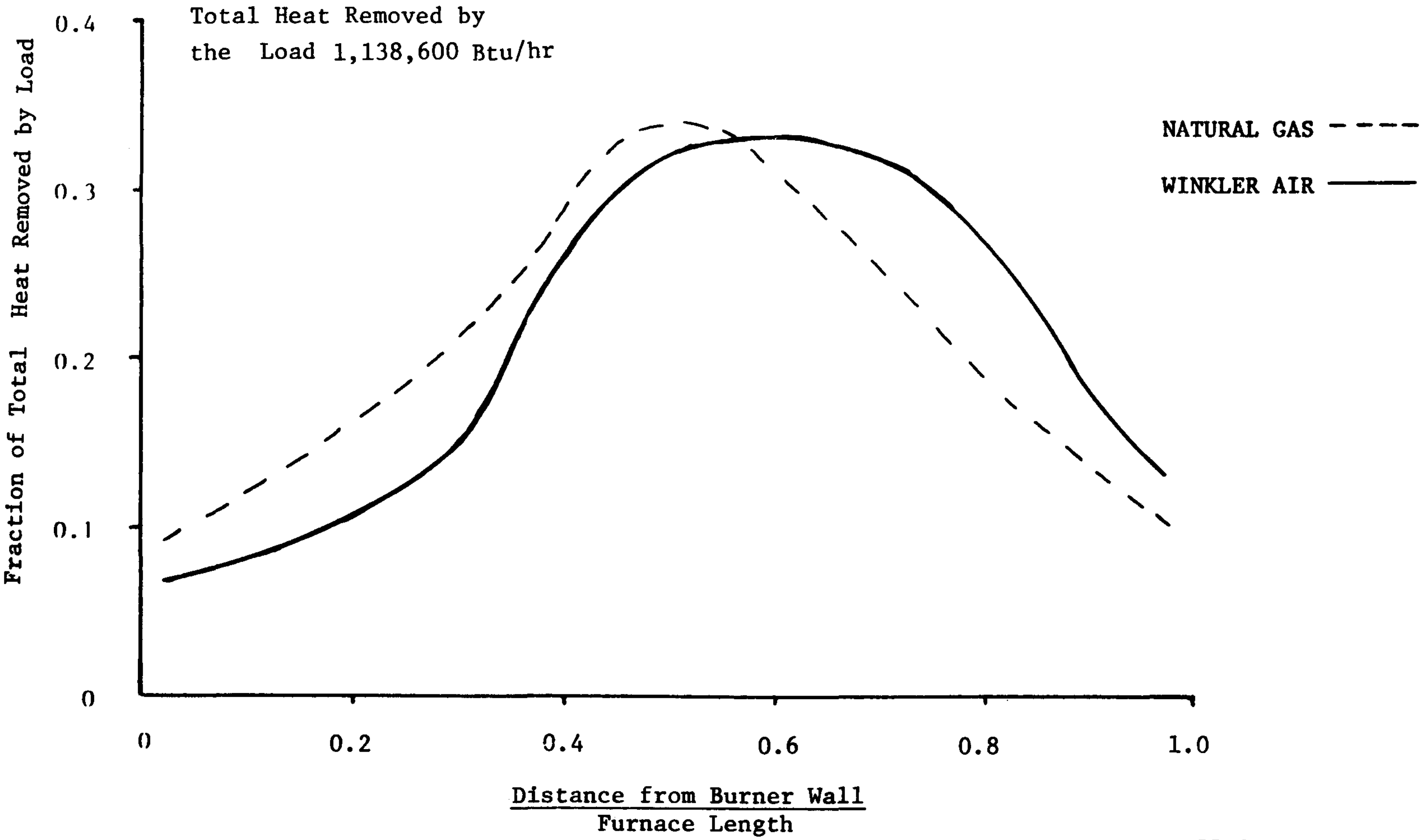

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Figure 23. HEAT ABSORPTION PROFILES FOR WINKLER AIR FUEL GAS ON THE BAFFLE BURNER

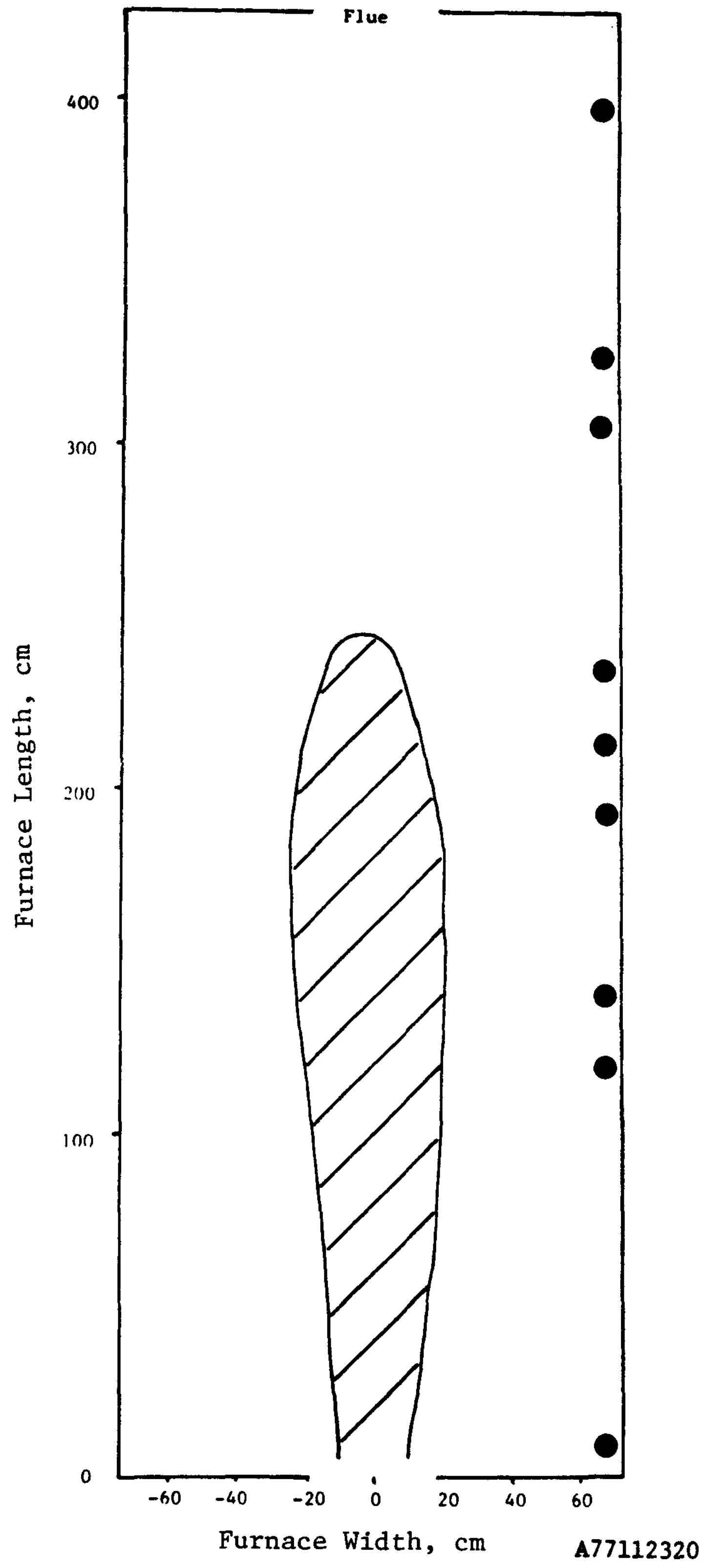

Figure 24. FLAME SHAPE FOR WINKLER AIR FUEL GAS ON THE BAFFLE BURNER

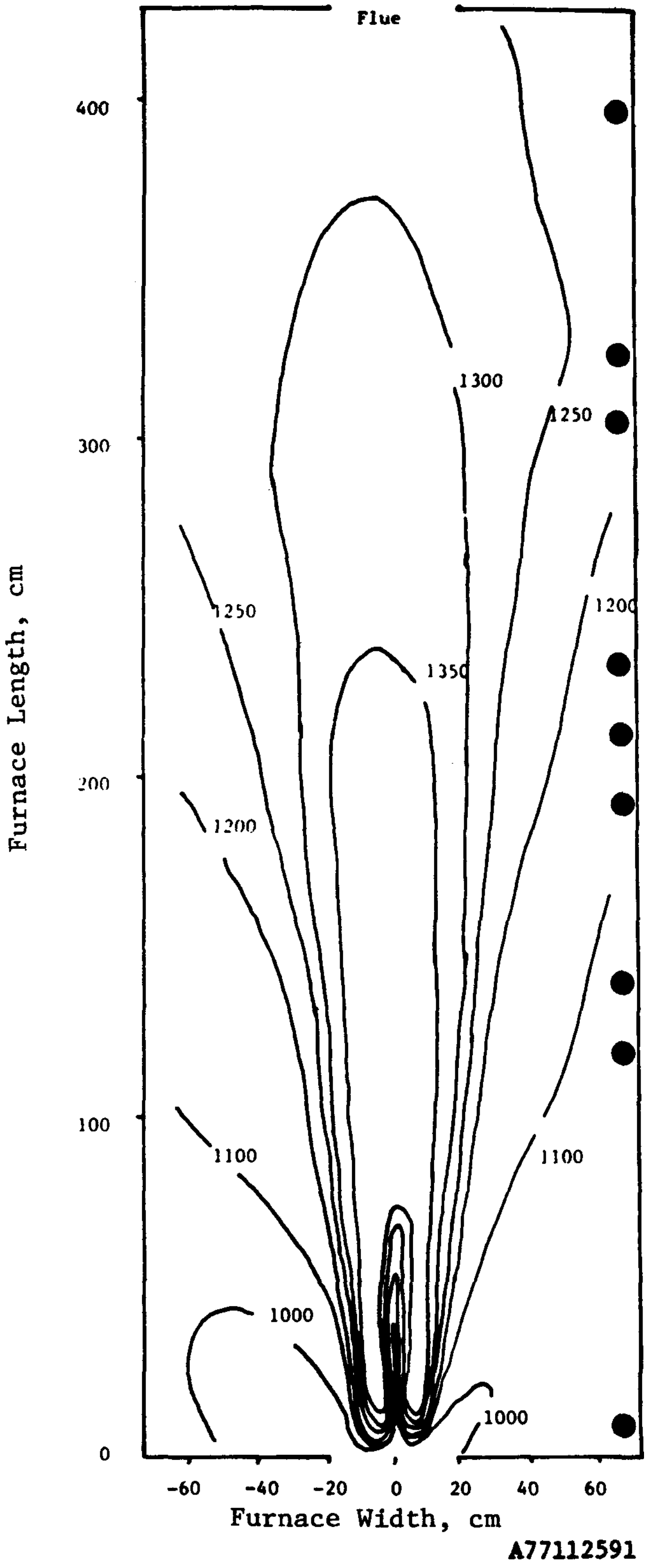

Figure 25. TEMPERATURE PROFILES (°C) FOR WINKLER AIR FUEL GAS ON THE BAFFLE BURNER

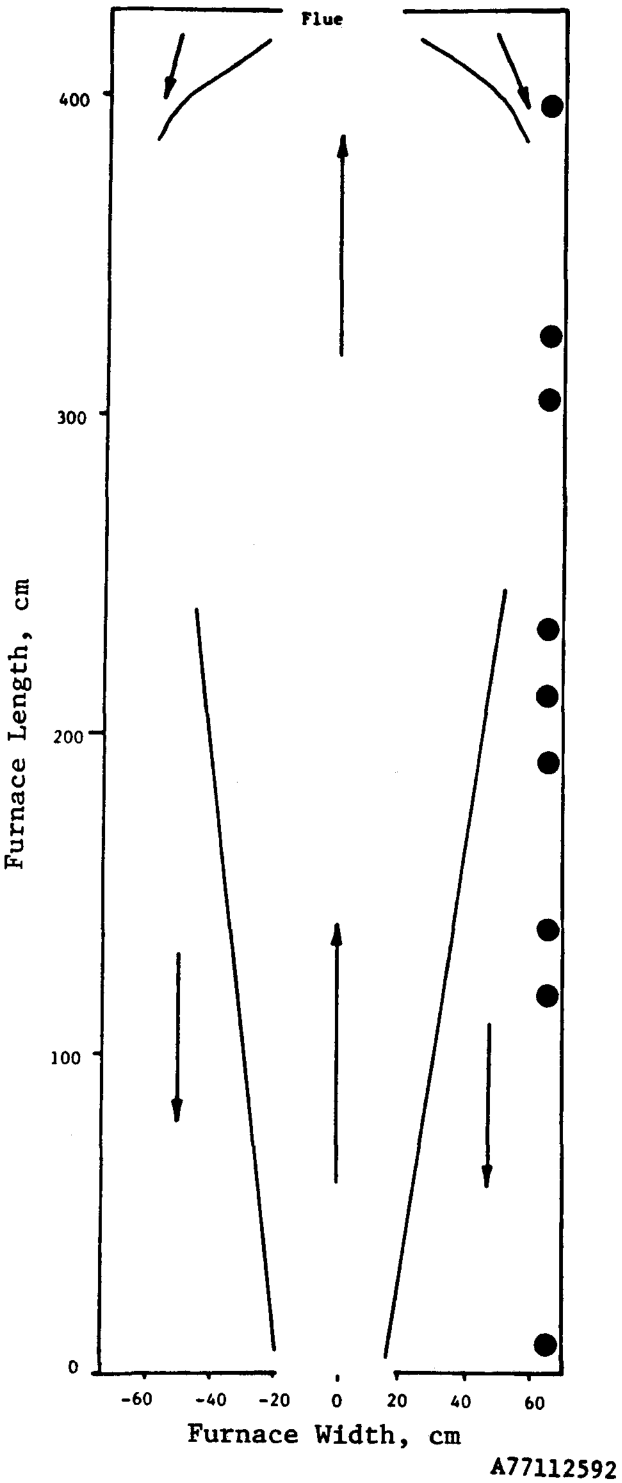

Figure 26. FLOW DIRECTION PROFILE
FOR WINKLER AIR FUEL GAS ON THE BAFFLE BURNER

Winkler Air 4-Inch-Nozzle Tests

Because the heat absorption profile and thermal efficiency were distinctly different from the natural gas base line and because of the flame stability problem, it was decided to fire WA on a modified nozzle and baffle. A 4-inch-diameter nozzle was the largest that could be accomodated. A suitable baffle was thus prepared, and the tests were conducted.

The results of these tests are also shown in Table 2. The flame stability problem was eliminated by the use of the larger nozzle. However, the flame length increased with the larger nozzle because the fuel momentum flux became comparable to the air momentum flux. Figure 27 shows a plot of the flame lengths of the various low-Btu gases versus the fuel/air momentum flux ratio. This plot shows that the flame is shortest when the fuel/air momentum flux ratio is very large or very small. For natural gas, the fuel momentum flux is low compared with that of the air, and the flame is short. For Winkler air on the 2-1/2-inch nozzle, the fuel momentum flux is large compared with the air momentum flux, and the flame is again short. One would expect the peak to occur where the flux ratio is equal to 1.0; however, the effect of the air swirl is to reduce the peak flame length and displace it to a value less than 1.0.

Figure 28 shows the heat absorption profile for WA with the 4-inch nozzle compared with WA and natural gas with the 2-1/2 inch nozzle. The profile is displaced toward the flue end of the furnace; however, the displacement is not as pronounced as WA with the smaller nozzle. Figure 29 shows the flame shape. Figure 30 shows the temperature profiles, and Figure 31 shows the flow direction profiles. The flame shape and temperature profiles depict the longer, broader flame, but do not explain the shift in the heat absorption profile.

Examination of Figure 16, which shows the radiant flux from the flame and combustion gases and Figure 17, which shows the radiant flux from the flame itself will explain the shift in the heat absorption profile. The radiant flux from the flame on the 4-inch nozzle is higher near the burner than was the case with the smaller nozzle. This would increase the heat

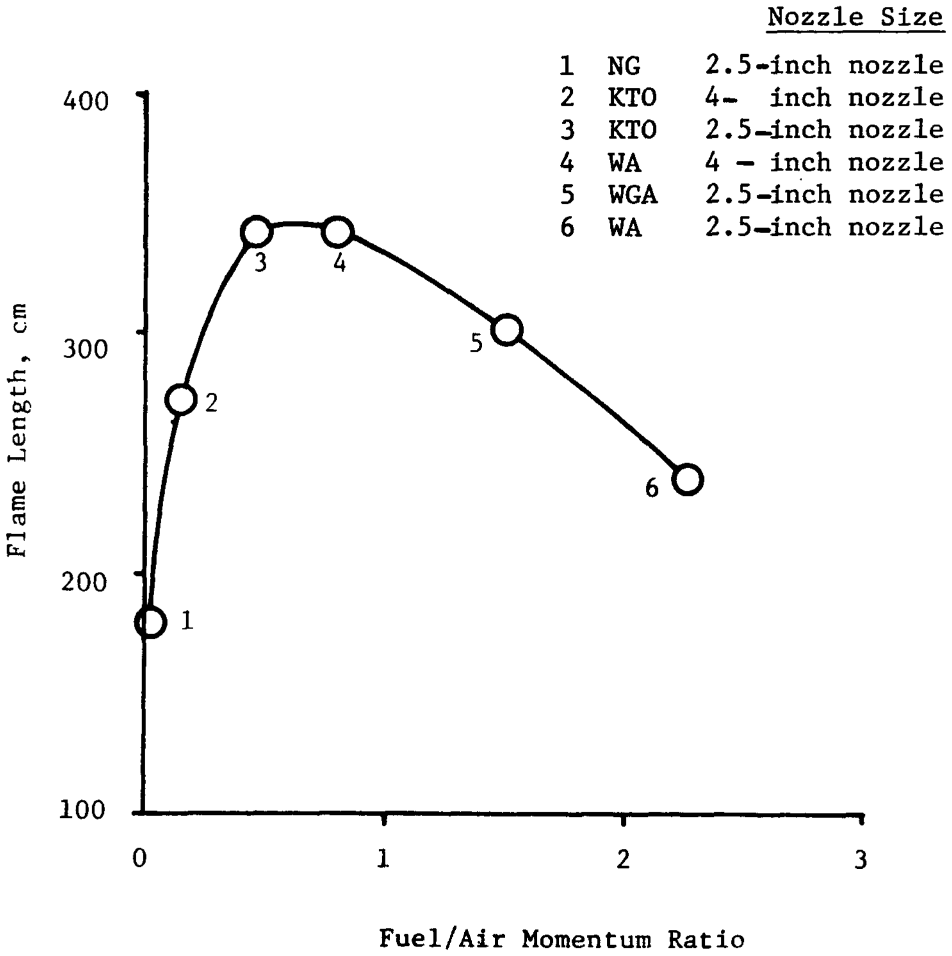

Figure 27. FLAME LENGTH VARIATION WITH FUEL/AIR MOMENTUM RATIO ON THE BAFFLE BURNER

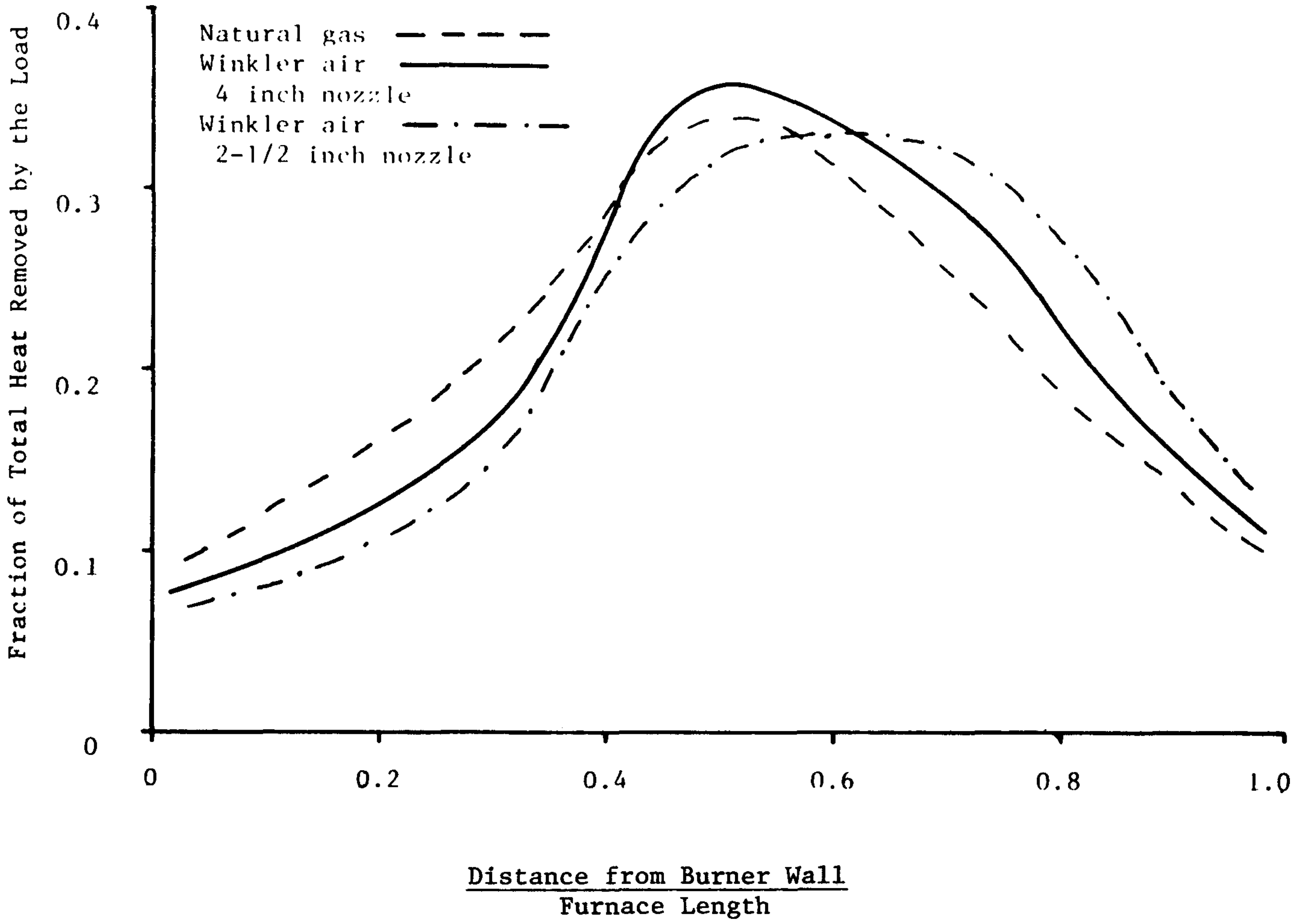

Figure 28. HEAT ABSORPTION PROFILE FOR WINKLER AIR ON THE BAFFLE BURNER

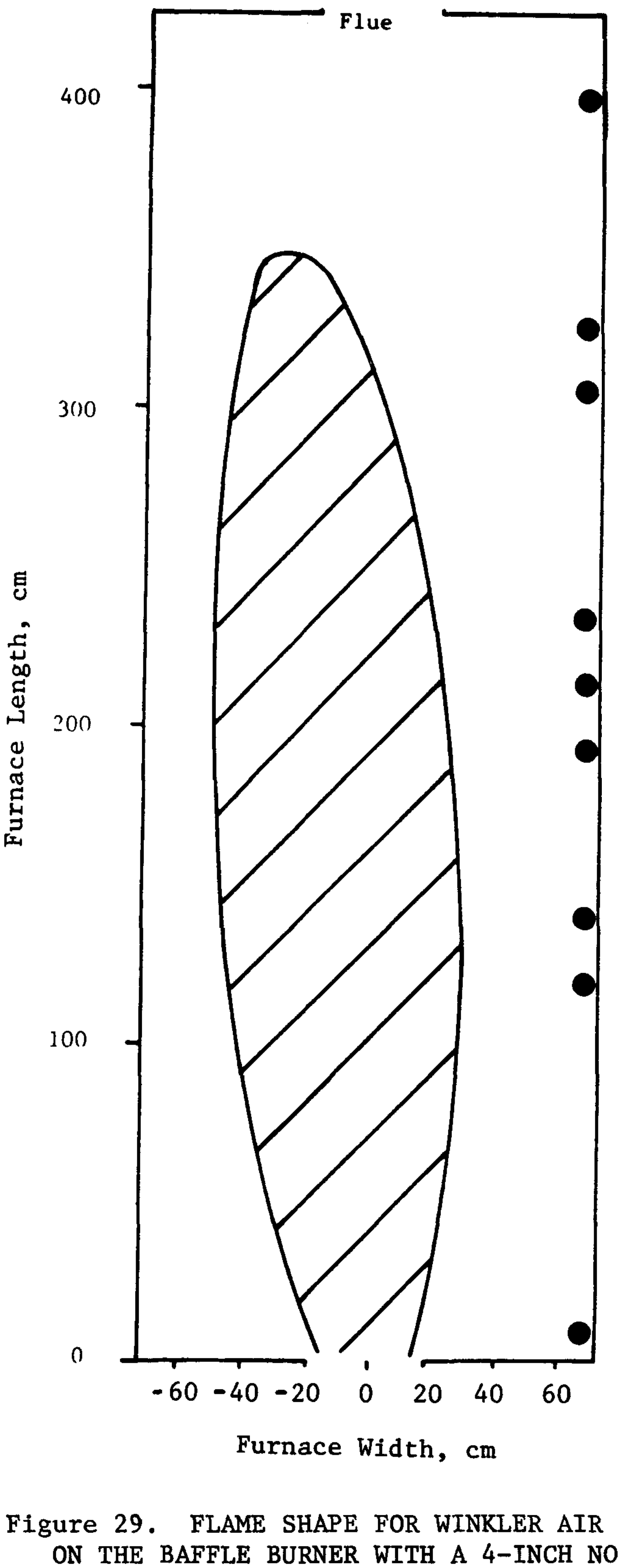

Figure 29. FLAME SHAPE FOR WINKLER AIR FUEL GAS ON THE BAFFLE BURNER WITH A 4-INCH NOZZLE

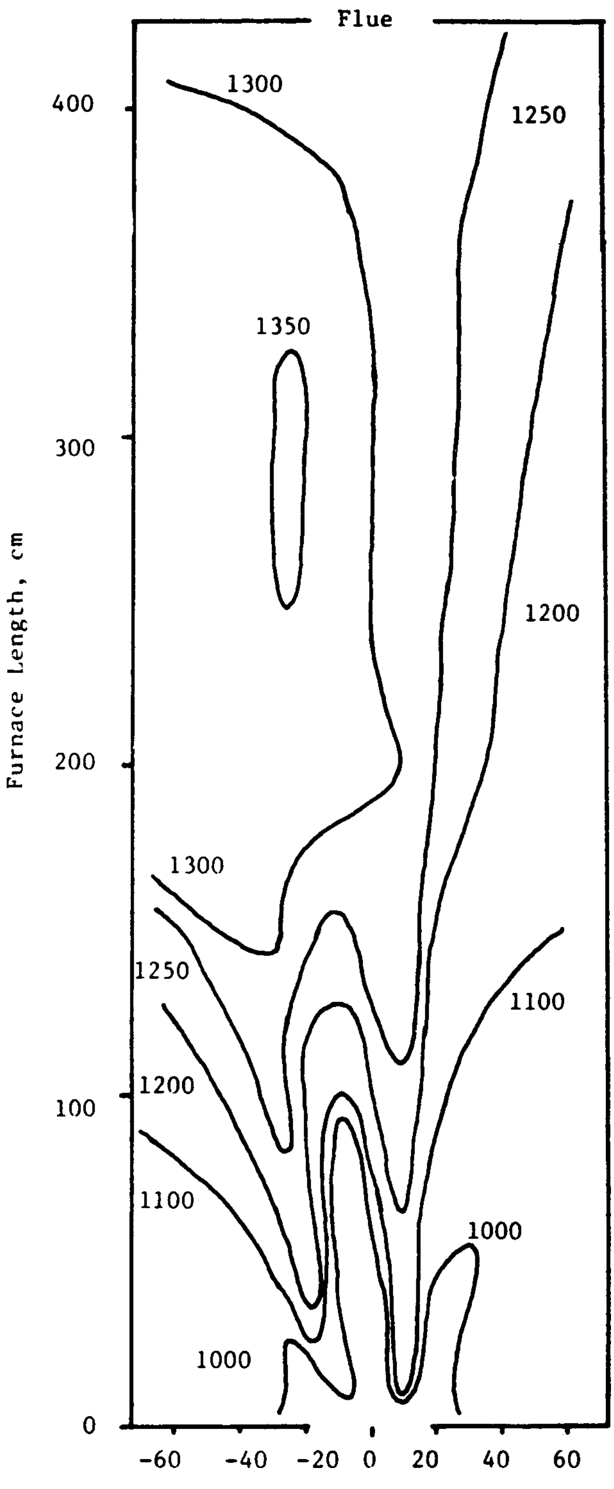

Figure 30. TEMPERATURE PROFILES (°C) FOR WINKLER AIR ON THE BAFFLE BURNER WITH A 4-INCH NOZZLE

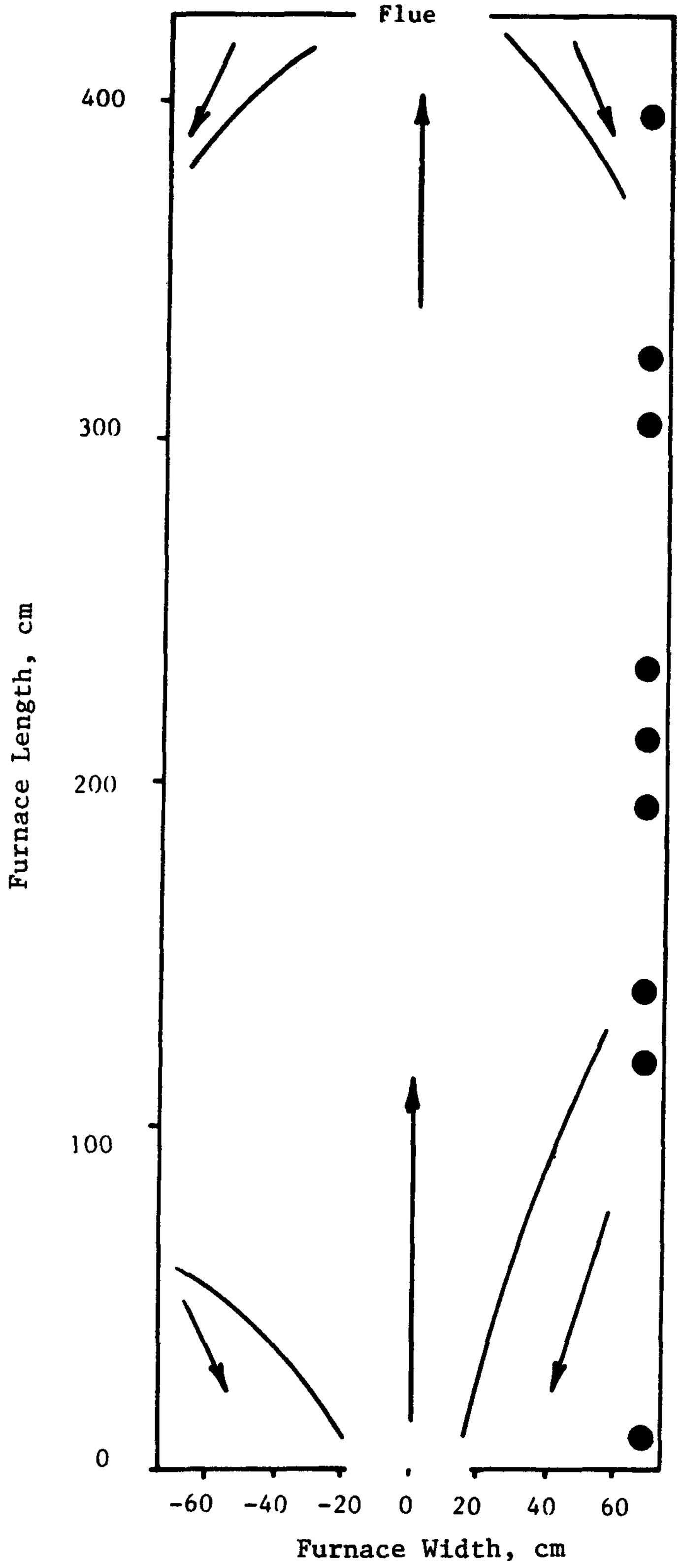

Figure 31. FLOW DIRECTION PROFILE FOR WINKLER AIR WITH A 4-INCH NOZZLE

transfer in this section of the furnace. The overall thermal efficiency for WA on the larger nozzle is 21%, which is comparable to the efficiency with the smaller nozzle. The peak flame temperature, 1351°C (2464°F), measured at 290 cm from the burner is a little lower than the 1393°C (2540°F) measured at 105 cm with the smaller nozzle.

Winkler Air Fuel Gas Retrofit Conclusions

Winkler air fuel gas has more retrofit problems than Koppers-Totzek oxygen and Wellman-Galusha air fuel gases. When retrofit directly, the fuel could only be fired at an input of 60% of the natural gas firing rate. This problem was alleviated by increasing the air preheat level; however, in many industrial applications, such a step might not be possible without major capital expenditure.

In addition, the heat absorption profile, thermal efficiency, and flame length were all distinctly different from natural gas. The heat absorption profile, flame length, and flame stability problems would not be alleviated by simple burner nozzle and baffle modifications. This is because the burner body is too small to accomodate the necessary changes. The thermal efficiency and flame temperature problems would not be solved even by increasing the burner size. The low flame temperature problems would eliminate WA as a fuel for high-temperature processes unless the temperature could be raised by fuel preheating or additional air preheating. The use of oxygen enrichment of the combustion air could also be considered to increase the flame temperature and consequently the thermal efficiency. Thus, Winkler air could not be directly retrofit on the existing burner. Increasing the burner size, air preheat,and fuel preheat might still not be sufficient to use Winkler air on many high-temperature furnaces.

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