

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

Project 8985 Special Report No. 3

NOZZLE-MIX BURNER

Richard T. Waibel  
Edward S. Fleming

NOTICE  
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

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

Date Published — August 1978

**MASTER**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EB

Prepared for the

**UNITED STATES DEPARTMENT OF ENERGY**

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

## **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

---

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

## ABSTRACT

Data were gathered to determine the performance of a nozzle-mix-type burner when retrofit with low- and medium-Btu gases. The burner, a Maxon Wide-Range Model WR-4, was fired on the IGT pilot-scale test furnace with a load simulating an instant during the heat-up cycle of an annealing furnace. The low- and medium-Btu gases simulated for these combustion trials were Koppers-Totzek oxygen (KTO), Wellman-Galusha air (WGA), and Winkler air (WA) fuel gases.

All three of these substitute fuel gases produced stable flames at the full rated burner input of 3.25 million Btu/hr, although, the Winkler air fuel gas flame would blow off with a small increase in excess air or a decrease in fuel heating value per cubic foot. Koppers-Totzek oxygen fuel gas performed as well as natural gas with the same thermal efficiency and even higher flame temperatures. The Wellman-Galusha and Winkler air fuel gases each exhibited lower thermal efficiencies and flame temperatures than natural gas.

## TABLE OF CONTENTS

	<u>Page</u>
OBJECTIVE	1
INTRODUCTION	2
FACILITIES	4
Description of Furnace Test Facility	4
Description of the Low-Btu Gas Generating System	7
Description of Instrumentation	7
BURNER TESTS	11
Base-Line Natural Gas Tests	16
Low- and Medium-Btu Gas Tests	21
Flame Stability Trials	21
Koppers-Totzek Oxygen Fuel Gas Trials	21
Koppers-Totzek Oxygen Fuel Gas Retrofit Conclusions	29
Wellman-Galusha Air Fuel Gas Trials	29
Wellman-Galusha Air Fuel Gas Retrofit Conclusions	33
Winkler Air Fuel Gas Trials	33
Winkler Air Fuel Gas Retrofit Conclusions	37
REFERENCES CITED	38

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
1	Pilot-Scale Test Furnace	5
2	Overall Furnace System	6
3	Assembly Drawing of the Suction Pyrometer	8
4	Assembly Drawing of Gas Sampling Probe	10
5	Maxon Wide-Range Burner	12
6	Schematic Cross Section of Wide-Range Burner	13
7	Schematic Cross-Sectional View of an Annealing Furnace	14
8	Load Time-Temperature Relationship for Batch Annealing Furnace	15
9	Flame Shape for Natural Gas on the Nozzle Mix Burner	17
10	Temperature Profiles ( $^{\circ}\text{C}$ ) for Natural Gas on the Nozzle-Mix Burner	19
11	Flow Direction Profile for Natural Gas on the Nozzle-Mix Burner	20
12	Blowoff Limits for Fuel Heating Value Versus Excess Air With Low-Btu Gases on the Nozzle-Mix Burner	22
13	Flame Shape for Koppers-Totzek Oxygen Fuel Gas on the Nozzle-Mix Burner	24
14	Heat Absorption Profile for Koppers-Totzek Oxygen Fuel Gas Compared With Natural Gas on the Nozzle-Mix Burner	25
15	Radiant Emittance from Flame Plus Combustion Products for the Nozzle-Mix Burner	26
16	Radiant Emittance from the Flame Alone for the Nozzle-Mix Burner	27
17	Temperature Profiles ( $^{\circ}\text{C}$ ) for Koppers-Totzek Oxygen Fuel Gas on the Nozzle-Mix Burner	28
18	Flame Shape for Wellman-Galusha Air Fuel Gas on the Nozzle-Mix Burner	30
19	Temperature Profiles ( $^{\circ}\text{C}$ ) for Wellman-Galusha Air Fuel Gas on the Nozzle-Mix Burner	31
20	Heat Absorption Profile for Wellman-Galusha Air Fuel Gas Compared With Natural Gas on the Nozzle-Mix Burner	32
21	Temperature Profiles ( $^{\circ}\text{C}$ ) for Winkler Air Fuel Gas on the Nozzle-Mix Burner	34
22	Flame Shape for Winkler Air Fuel Gas on the Nozzle-Mix Burner	35
23	Heat Absorption Profile for Winkler Air Fuel Gas Compared With Natural Gas on the Nozzle-Mix Burner	36

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1	Fuel Composition for Low- and Medium-Btu Gases Tested	7
2	Furnace and Burner Operating Conditions	18

## 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 are being tested during the program 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 Maxon Wide-Range burner, which is representative of the nozzle-mix burner type. The burner size and firing rate were chosen to simulate the firing density (Btu/CF-hr) in a batch annealing furnace.

While firing natural gas, the furnace load was adjusted to absorb the same fraction of the furnace heat input that occurs at one instant during the annealing furnace heat-up. 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.

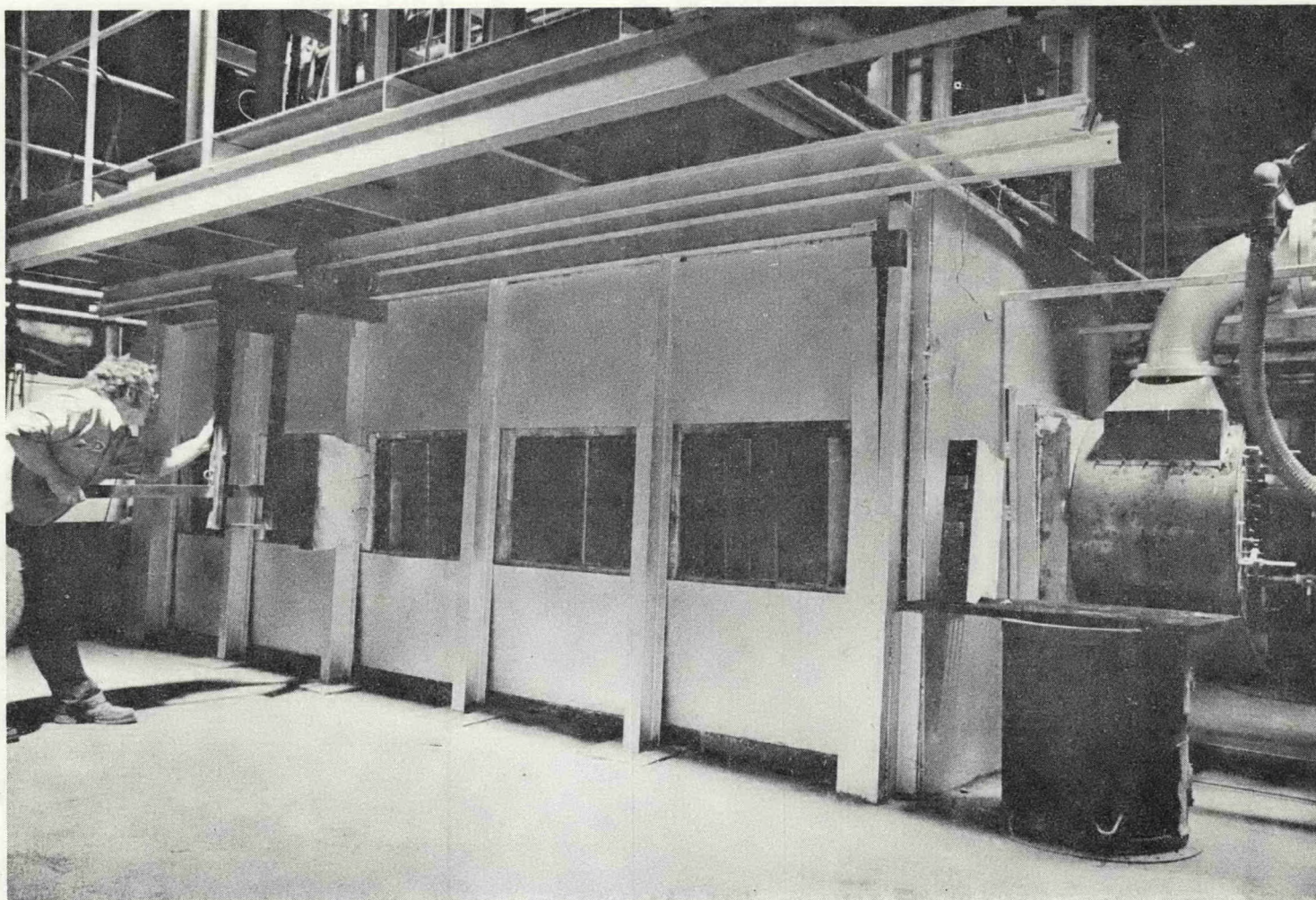
The furnace is also equipped with 58 water cooling tubes, each of which can be independently inserted through the roof, along the sidewalls. Varying the number of tubes, their location, and the depth of insertion allows control over the magnitude and character of the load that can be placed on the furnace. 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.



5

Figure 1. PILOT-SCALE TEST FURNACE



## 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

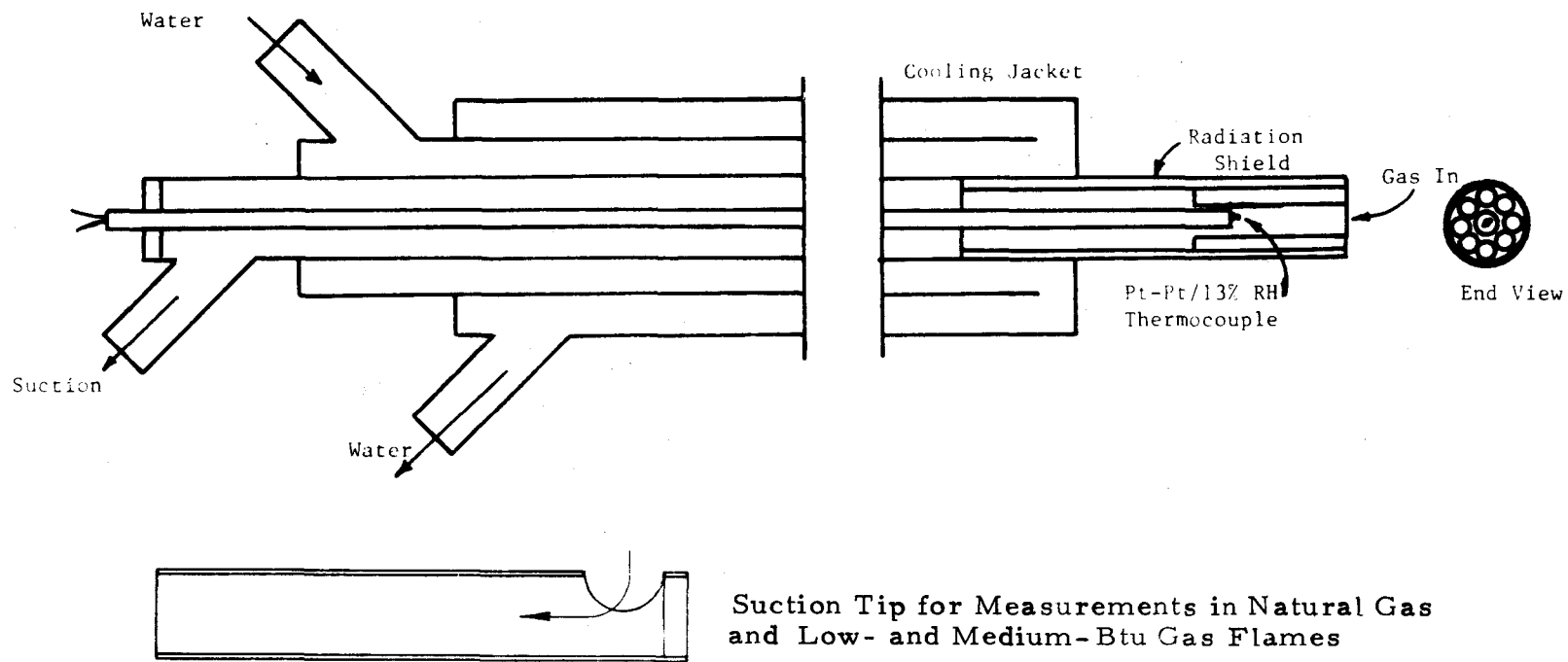
<u>Fuel</u>	<u>CO</u>	<u>H<sub>2</sub></u>	<u>CO<sub>2</sub></u>	<u>CH<sub>4</sub></u>	<u>N<sub>2</sub></u>	<u>H<sub>2</sub>O</u>	<u>Heating Value, Btu/SCF</u>	<u>Adiabatic Flame Temp,* °F</u>	<u>Specific Gravity</u>
Koppers-Totzek Oxygen	53.0	34.3	9.3	0.5	1.0	1.9	287	3570	0.68
Wellman-Galusha Air	26.9	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 70°F. The adiabatic flame temperature for natural gas is 3380°F for this condition.

## 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 Tip

A78082595

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.

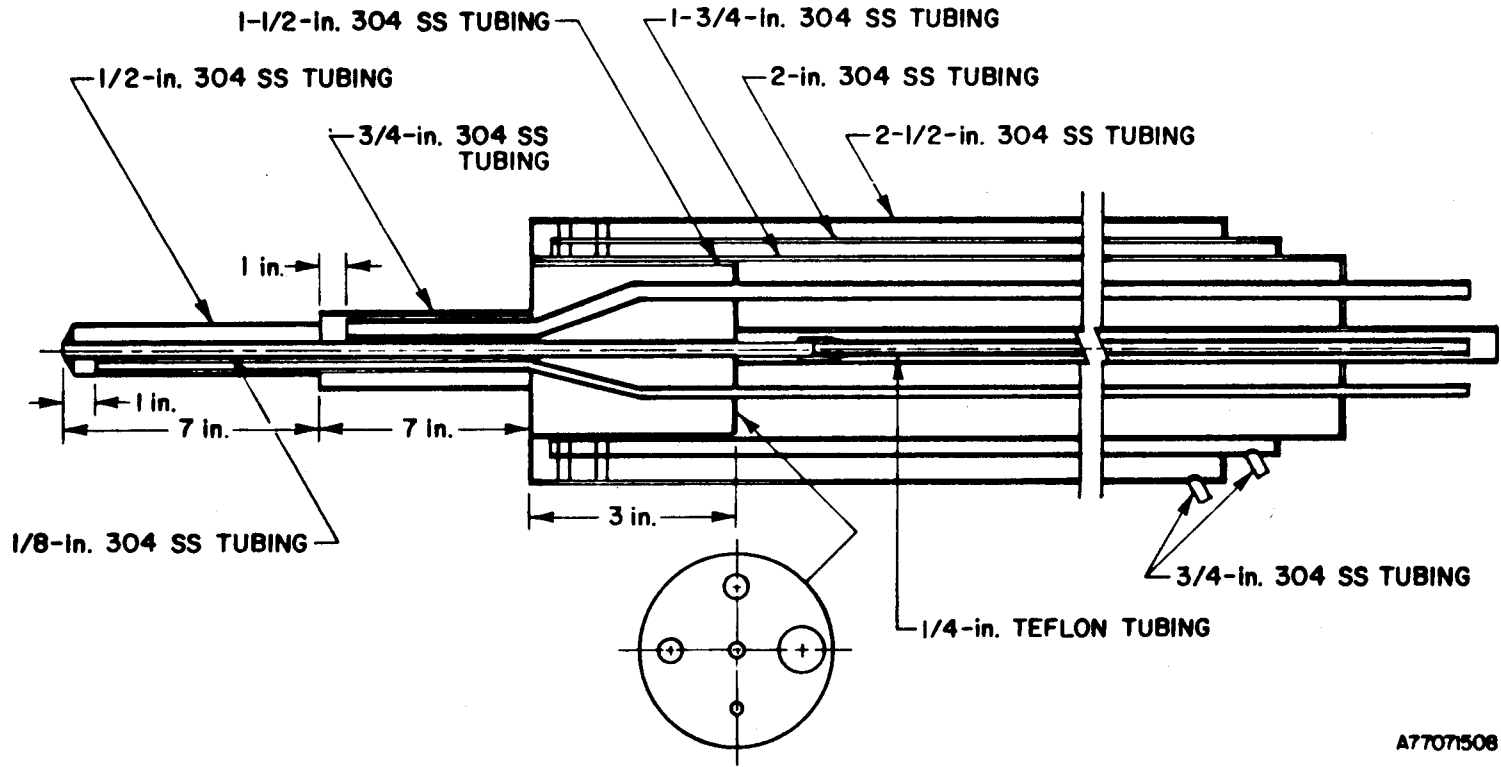
The flow direction was measured using a water-cooled Hubbard probe, with the upstream and downstream pressure taps connected to a Datametrix Barocel transducer and Datametrix CGS electric manometer.

Figure 4 shows the assembly drawing of the gas-sampling probe used in the flame and the flue. To minimize  $\text{NO}_2$  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  $190^\circ\text{F}$ , followed by a Millipore filter and a Permapure gas dryer. This dryer reduces the dew point to less than  $32^\circ\text{F}$ . 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 ( $\text{O}_2$ )
- Beckman Paramagnetic Oxygen ( $\text{O}_2$ )
- Beckman NDIR Methane ( $\text{CH}_4$ )
- Beckman NDIR Carbon Monoxide ( $\text{CO}$ )
- Beckman NDIR Carbon Dioxide ( $\text{CO}_2$ )
- Varian 1200 Flame Ionization Chromatograph (Total HC and  $\text{C}_2$  to  $\text{C}_9$ )
- Beckman NDIR Nitric Oxide ( $\text{NO}$ )
- Beckman UV-Nitrogen Dioxide ( $\text{NO}_2$ )
- Thermo Electron Pulsed Fluorescent Sulfur Dioxide ( $\text{SO}_2$ )
- Hewlett-Packard Thermoconductivity Chromatography, Hydrogen ( $\text{H}$ ), Nitrogen ( $\text{N}_2$ ), Argon ( $\text{A}_2$ ),  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{C}_1$  to  $\text{C}_5$ , Oxygen ( $\text{O}_2$ )
- Beckman Chemiluminescent  $\text{NO-NO}_2$
- 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 Molelectron 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  $500\ \mu\text{m}$ . 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.



A77071508

Figure 4. ASSEMBLY DRAWING OF GAS SAMPLING PROBE

## BURNER TESTS

The Maxon Wide-Range burner was chosen as a representative nozzle-mix burner. Figure 5 shows a photograph of the burner and an extra fuel nozzle insert. The fuel exits through the central, drilled holes while the air exits through the slots located radially around the fuel orifices. Figure 6 is a schematic, cross-sectional drawing of the burner. The burner utilized was a Maxon model WR-4 and has a maximum rated capacity of 3.25 million Btu/hr for natural gas with 16-oz combustion air.

Nozzle mix burners are popular in industry with many applications, including batch annealing. Batch annealing is the heat treatment of cold-reduced strip steel to restore the ductility which was lost during the reduction process.<sup>1,2</sup> In the cold-reduction process the grain structure of the steel is elongated in the direction of the rolling, which results in a highly stressed, very hard product lacking the ductility required for forming and stamping operations. Annealing is the process of heating the metal to a required temperature and holding this temperature (soaking) for the time required to obtain full recrystallization and to reduce the metal's hardness. The temperature range for annealing is 1100° to 1350°F. Figure 7 shows a cross-sectional view of a typical annealing furnace with a base, inner cover, and heating cover. The material being annealed, generally coils of steel sheet, is protected by the inner cover so that the steel can be heated in a reducing or neutral atmosphere. This atmosphere prevents oxidation of the metal surface. In some cases large odd shapes or special pieces may be stress-relieved without covers by adjusting the flames to provide a neutral or reducing atmosphere using less than stoichiometric air.

In a typical annealing operation the cold metal is loaded onto the furnace base and the inner cover is placed over the load. Next, the furnace or heating cover is placed on the base, the reducing or neutral gas to the inner cover is started, and the burners are lit. The furnace and load are brought up to temperature over about a 20-hour period, during which the burners are operated at maximum capacity. This is followed by a soak period, during which the burners are either turned down or modulated on and off to maintain the desired metal temperature. The soak period can last from 2 to 20 hours or more. A typical annealing furnace time-temperature chart is shown in Figure 8.

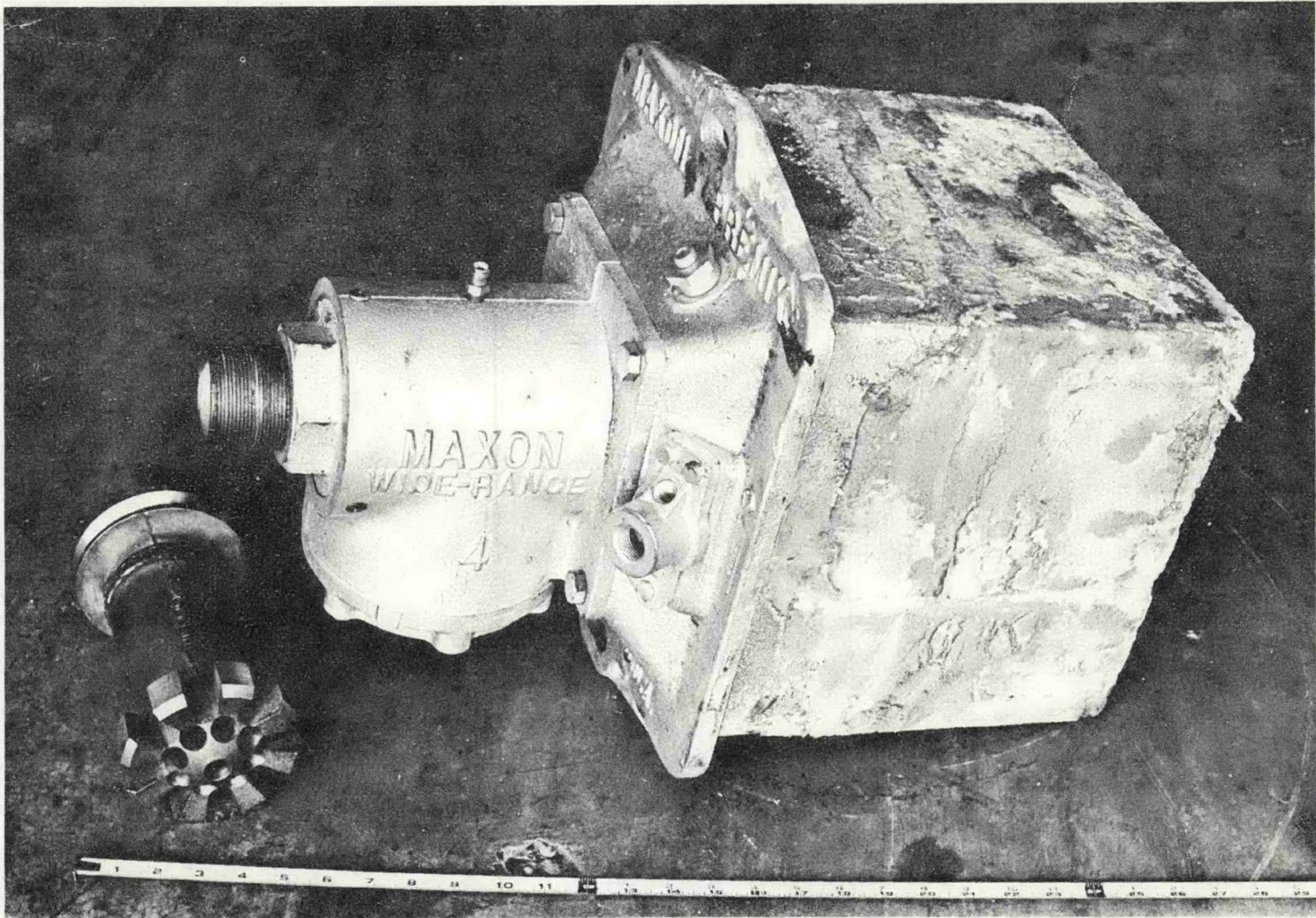
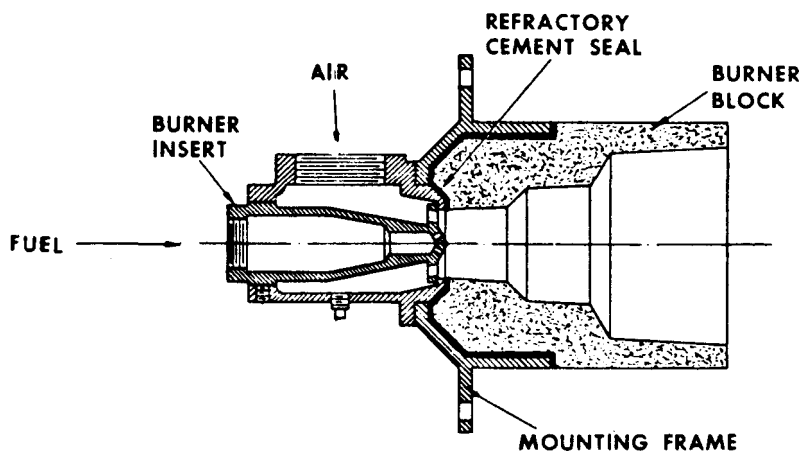
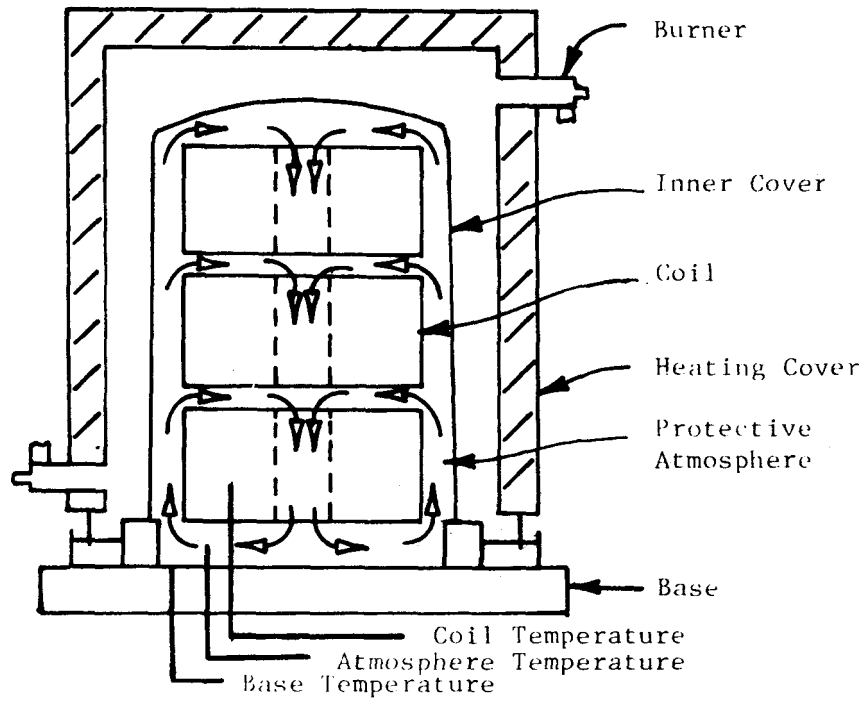


Figure 5. MAXON WIDE-RANGE BURNER



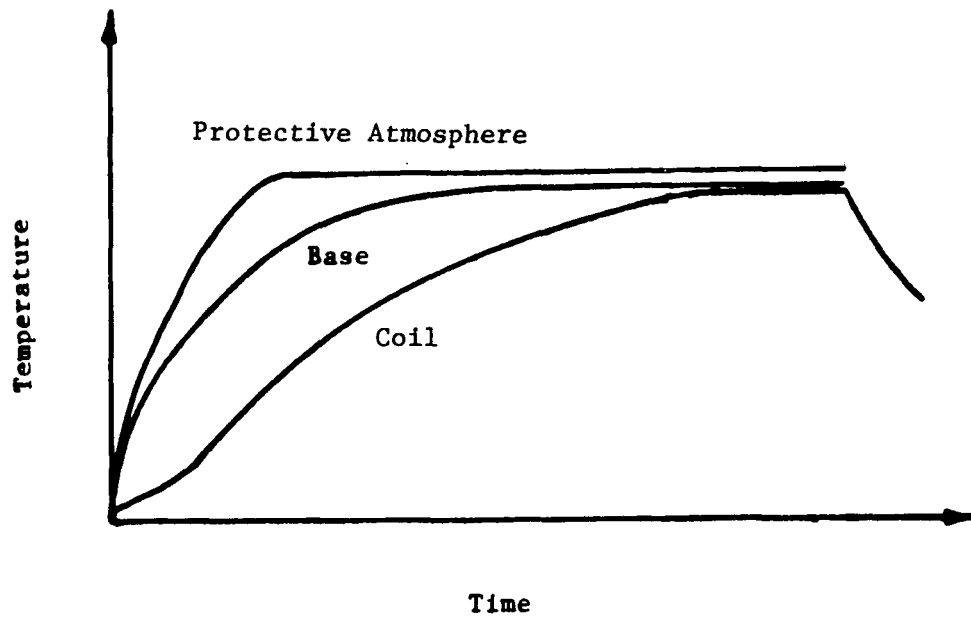
A78092686

Figure 6. SCHEMATIC CROSS SECTION OF WIDE-RANGE BURNER



A78092703

Figure 7. SCHEMATIC CROSS-SECTIONAL VIEW OF AN ANNEALING FURNACE



A78092687

Figure 8. LOAD TIME-TEMPERATURE RELATIONSHIP FOR BATCH ANNEALING FURNACE<sup>4</sup>

During the heat-up period the fraction of heat transferred from the flame to the load varies from an initially large value of 50% or more when the load is cold to a very low value near zero just before the firing rate is reduced for the soak period. We need a long period of stable operation in order to make our measurements; therefore, we simulated one instant during the heat-up cycle. We adjusted our load to remove 25% of the heat from the flame and placed the load, water-cooling tubes, uniformly along one side of the furnace. The placement of the tubes is shown in Figure 9. Annealing furnaces have multiple burners, so we only simulated a section of the furnace, namely a section at the top of the furnace with the burner firing over the covers just below the roof.

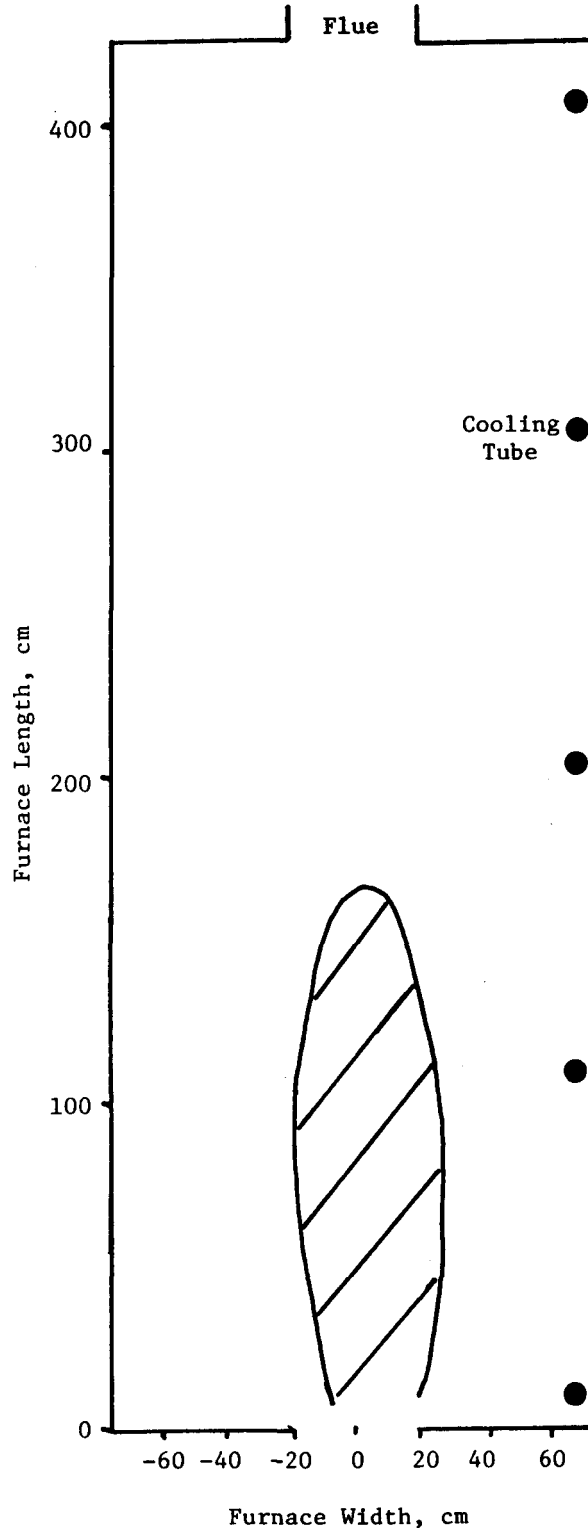
#### Base-Line Natural Gas Tests

After adjusting the cooling load, base-line data were collected for natural gas. The fuel input was 3.25 million Btu/hr with 10% excess air at ambient temperature. Table 2 contains a summary of these data and the data subsequently obtained for the low- and medium-Btu substitute fuels. The flame length measured for natural gas was 166 cm, and the shape of the flame is shown in Figure 9. The flame shape is determined by making radial scans of gas composition at selected positions along the flame axis. Analysis of the carbon monoxide and oxygen data is used to determine the zone within which 99% of the fuel is consumed.

Gas temperature measurements were made with the suction pyrometer on a horizontal plane through the flame axis. Figure 10 shows the temperature profiles through the furnace chamber. The peak flame temperature measured was 1607°C (2925°F) at 15 cm from the burner wall.

Figure 11 shows the flow direction profile of the nozzle-mix burner. Since this burner has no swirl, the shape is that typical of an enclosed jet. The shape shown for the natural gas flame is similar to that found for the low- and medium-Btu substitute fuels.

Noise level measurements were made adjacent to the burner and alongside the furnace chamber. During the natural gas tests, the background noise level was 92 db at the burner and 81 db alongside the furnace, due to the combustion air fan. At the burner, there was a 1 db increase when the burner was



A78092688

Figure 9. FLAME SHAPE FOR NATURAL GAS ON THE NOZZLE-MIX BURNER

Table 2. FURNACE AND BURNER OPERATING CONDITIONS

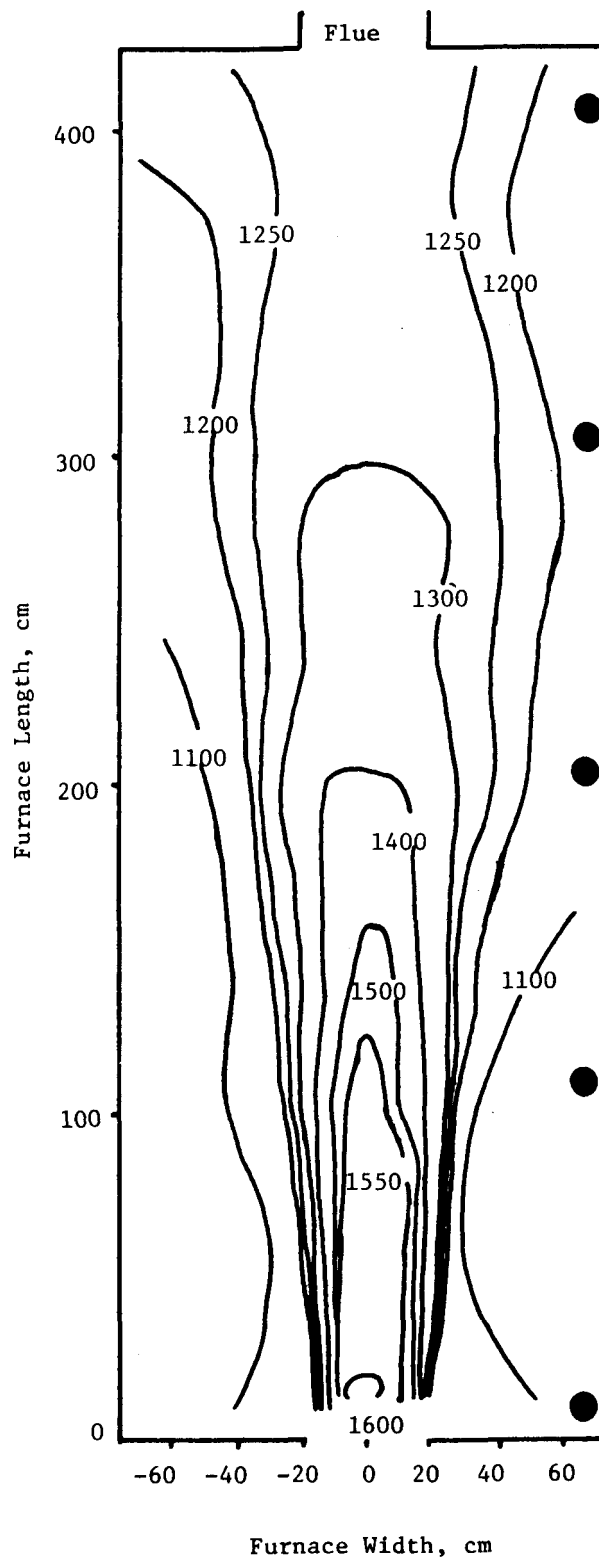
Fuel Type	Fuel* Flow, SCF/hr	Air Flow, SCF/hr	Fuel Velocity,** ft/s	Air Velocity, ft/s	Flue Gas Temperature, °F	Volume Flow Flue Gas, SCF/hr	Flame Length, cm	Thermal <sup>†</sup> Efficiency, %	Post Flame Emissivity.	Flue Gas Analysis				
										NO <sub>x</sub> — ppm —	CO —	CO <sub>2</sub> — % , dry basis —	O <sub>2</sub> —	N <sub>2</sub> —
Natural Gas	3,150	33,200	172	278	2,317	36,300	166	25	0.20	76	23	10.9	2.1	87
Koppers-Totzek Oxygen	11,700	27,200	636	227	2,371	33,800	100	25	0.21	90	50	24.1	1.8	74
Wellman-Galusha Air	20,010	27,700	1,090	232	2,179	43,500	100	21	0.21	15	30	20.3	1.3	78
Winkler Air	27,700	26,600	1,511	222	2,035	49,600	76	18	0.20	12	25	17.7	1.2	81

\* Fuel flow adjusted to give fuel enthalpy input of  $3.25 \pm 0.1$  million Btu/hr. (Fuel heating value varied  $\pm 5\%$  from nominal heating value due to slight variation of fuel composition from nominal composition.)

\*\* Fuel flow at standard conditions (60°F, 1 atm) divided by burner fuel orifice area.

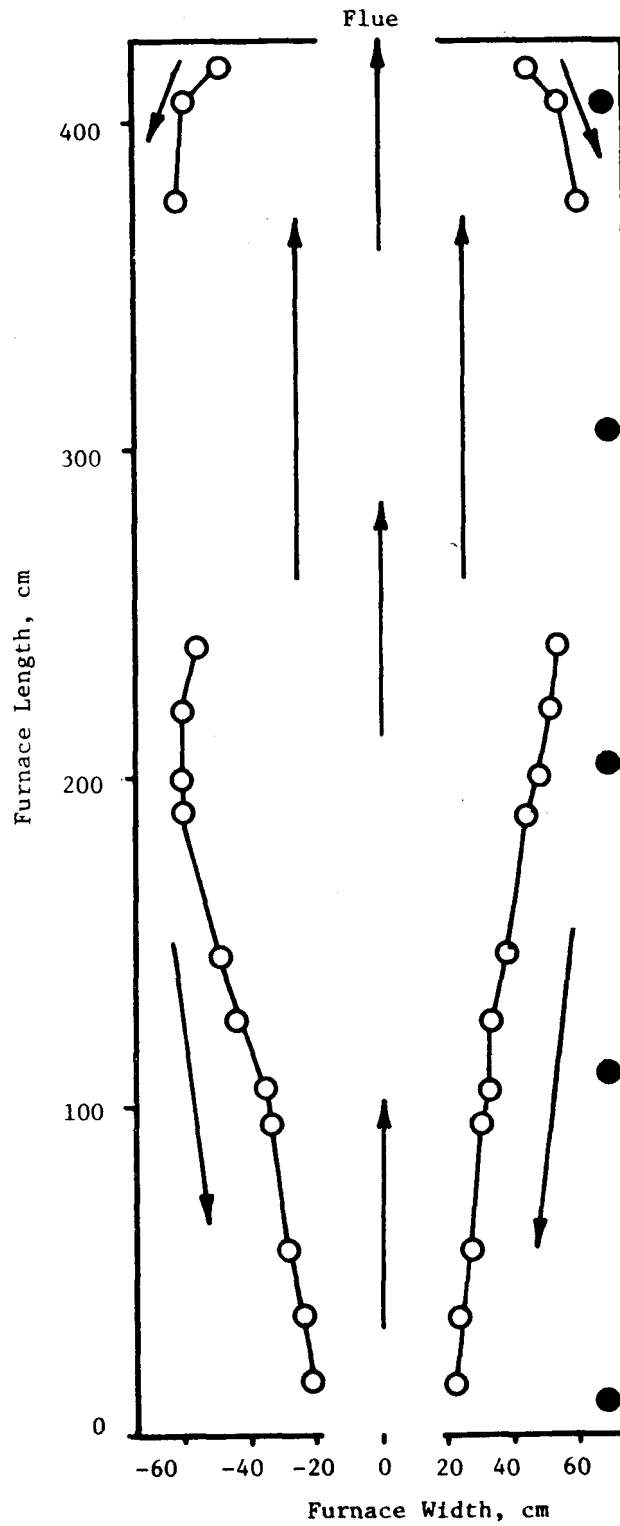
† Efficiency based on load divided by fuel volume flow times heating value.

B78092704



A78092689

Figure 10. TEMPERATURE PROFILES ( $^{\circ}\text{C}$ ) FOR NATURAL GAS ON THE NOZZLE-MIX BURNER



A78092690

Figure 11. FLOW DIRECTION PROFILE FOR NATURAL GAS ON THE NOZZLE-MIX BURNER

fired. At the side of the furnace, the increase during firing was 8 db with the furnace closed and 11 db when a sampling door was removed.

The natural gas flame radiant heat flux data will be presented with the low- and medium-Btu fuel data for comparison. The natural gas post-flame emissivity was measured to be 0.20. This is approximately the value that was calculated by the methods proposed by Hottel and Sarofim<sup>3</sup> and Leckner.<sup>5</sup>

#### Low- and Medium-Btu Gas Tests

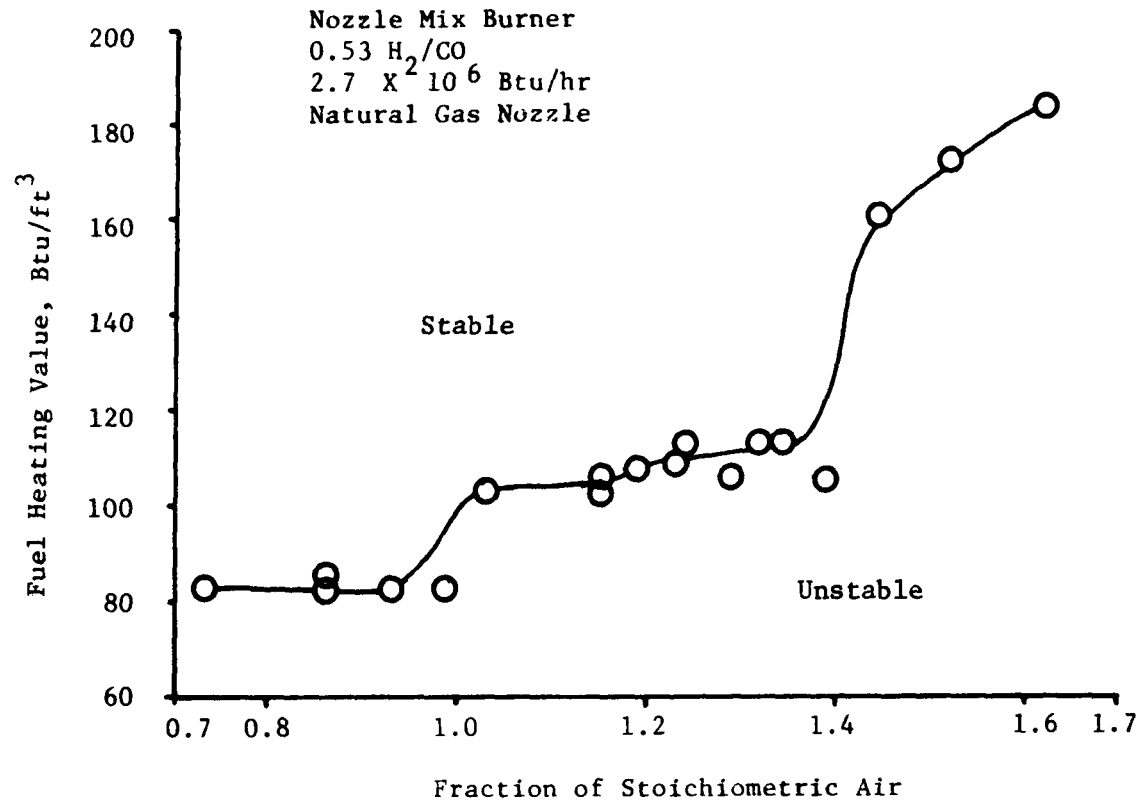
##### Flame Stability Trials

Flame stability trials were conducted in a cold furnace to determine if KTO, WGA, and WA fuel gases could be fired at 3.25 million Btu/hr. Each of the fuels was initially fed to the burner at a volume flow rate similar to the natural gas base-line flow rate. In each case, the flame was stable at this gas flow rate. The substitute fuel gas flow rate was then increased until the heat input reached 3.25 million Btu/hr. In each case, this level was reached with no flame instability problems. However, for Winkler air fuel gas, the flame would blow off if the excess air level exceeded about 20% or if the composition were not correct and the fuel heating value was less than about 110 Btu/SCF. In order to determine the extent of the blow-off problem, the fuel heating value was varied by nitrogen addition and the air flow was varied to determine the level of excess air at which blowoff occurred. Figure 12 shows the results of this study. This shows that, below about 100 Btu/SCF fuel heating value, the flame will blow off if the stoichiometric volume of air is supplied at the burner. The maximum allowable level of excess air increases with the fuel heating value.

Because the substitute fuels included in the program had stable flames at the rated burner heat input level, no burner modifications were necessary.

##### Koppers-Totzek Oxygen Fuel Gas Trials

After the flame stability trials, Koppers-Totzek oxygen fuel gas was fired on the burner and the furnace was allowed to heat up and attain thermal stability. Data were then collected similar to data obtained during the natural gas base-line trial. Table 2 compares some of the KTO data with the natural gas data. The KTO fuel volume flow rate is considerably greater than the natural gas flow rate because of the lower heating value per SCF for KTO. This also reflected in the fuel velocity at the burner outlet. The flame



A78092691

Figure 12. BLOWOFF LIMITS FOR FUEL HEATING VALUE VERSUS EXCESS AIR WITH LOW-BTU GASES ON THE NOZZLE-MIX BURNER

length for KTO, 100 cm, is shorter than that measured for natural gas, 166 cm. The KTO flame shape is shown in Figure 13.

The thermal efficiency measured for KTO was 25%, the same value that was adjusted for natural gas during the base-line trial. The oxides of nitrogen ( $\text{NO}_x$ ) and carbon monoxide (CO) emission levels for KTO were higher than those for natural gas.

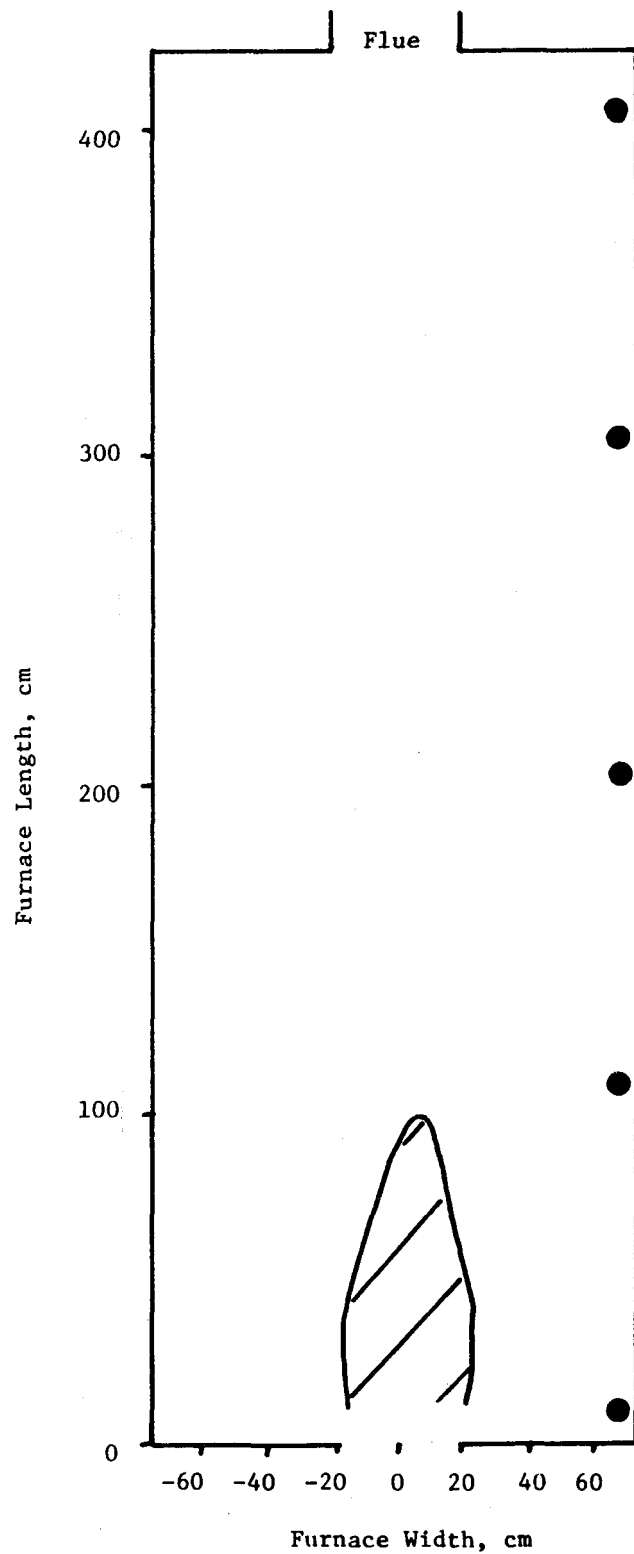
The heat absorption profile for KTO is compared with the profile for natural gas in Figure 14. The two profiles are nearly identical. This is because the flames for these two fuels are small relative to the overall furnace dimensions. Thus the flame shapes, although different for the two fuels, are sufficiently similar relative to the furnace dimensions to produce similar heat-transfer patterns.

Figure 15 shows the radiant emittance from the flame and combustion products for the low- and medium-Btu gases and natural gas. This measurement was made by placing a water cooled target on one side of the furnace and a narrow angle radiometer on the other side. Comparing the radiant emittance measurements for KTO and natural gas, it is not surprising that the thermal efficiency and heat-absorption profiles are so similar because the radiation levels are nearly identical.

Figure 16 shows the radiant emittance from the flame alone. The flames were so short that data could be obtained at only a few points. The KTO flame radiation was higher than that of natural gas. This is consistent with the flame temperature data.

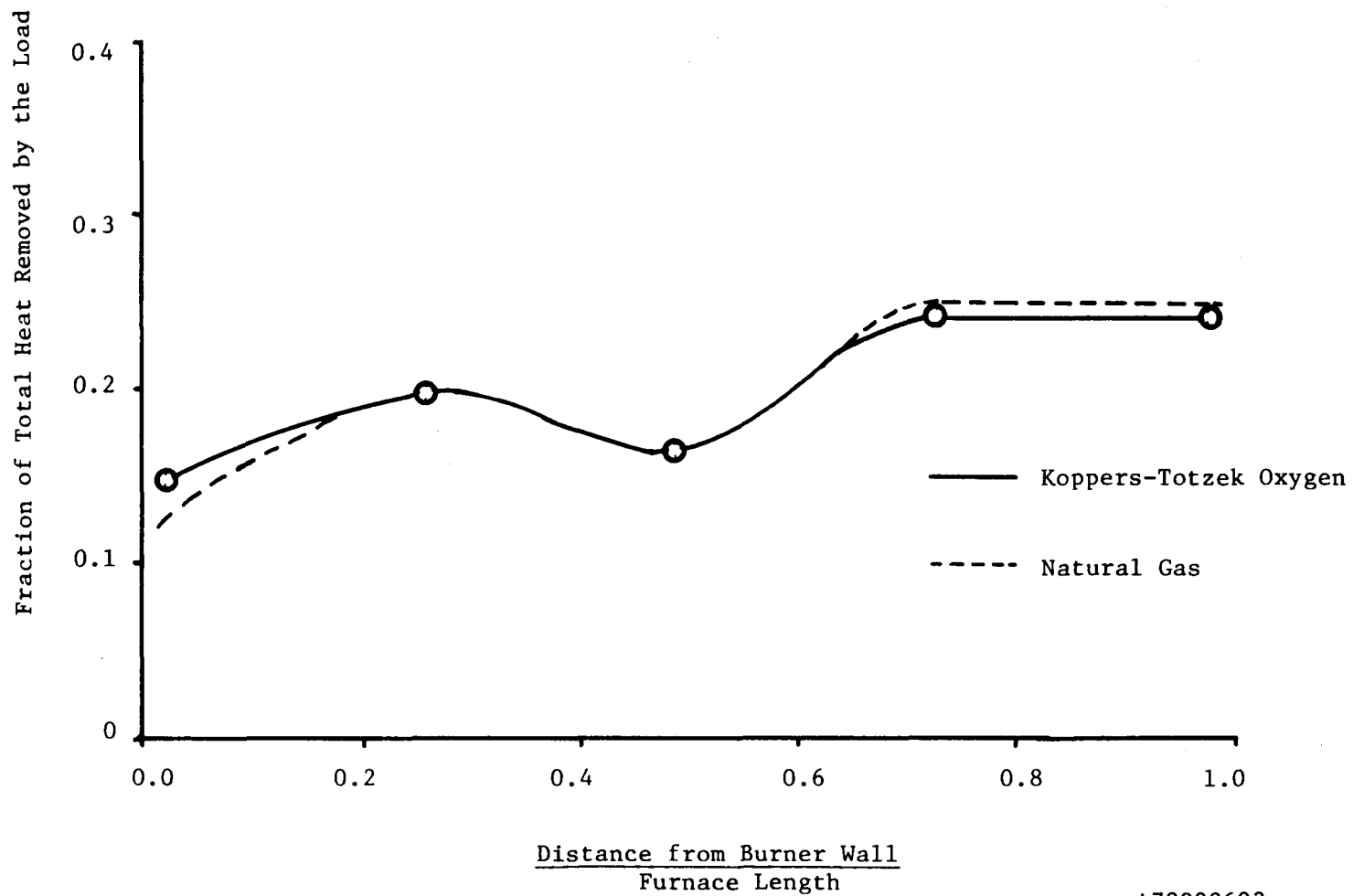
Figure 17 shows the temperature profiles measured for KTO. The profiles for KTO are similar to those measured for natural gas, however, the peak temperature found for KTO fuel gas was  $1732^\circ\text{C}$  ( $3150^\circ\text{F}$ ) at 36 cm. This is considerably higher than the  $1607^\circ\text{C}$  ( $2925^\circ\text{F}$ ) measured for natural gas. It is possible that the peak temperature for natural gas occurred at a point within the burner block or so close to the burner that it could not be detected. (See Figure 10.) The higher KTO flame temperatures found in the furnace chamber resulted in higher flame thermal radiation levels.

The post-flame emissivity was measured by the Schmidt method and has been described in a previous report.<sup>6</sup> The emissivity measured for KTO fuel gas is about that which would be calculated by the methods proposed by Hottel and Sarofim (0.20) or Leckner (0.24)



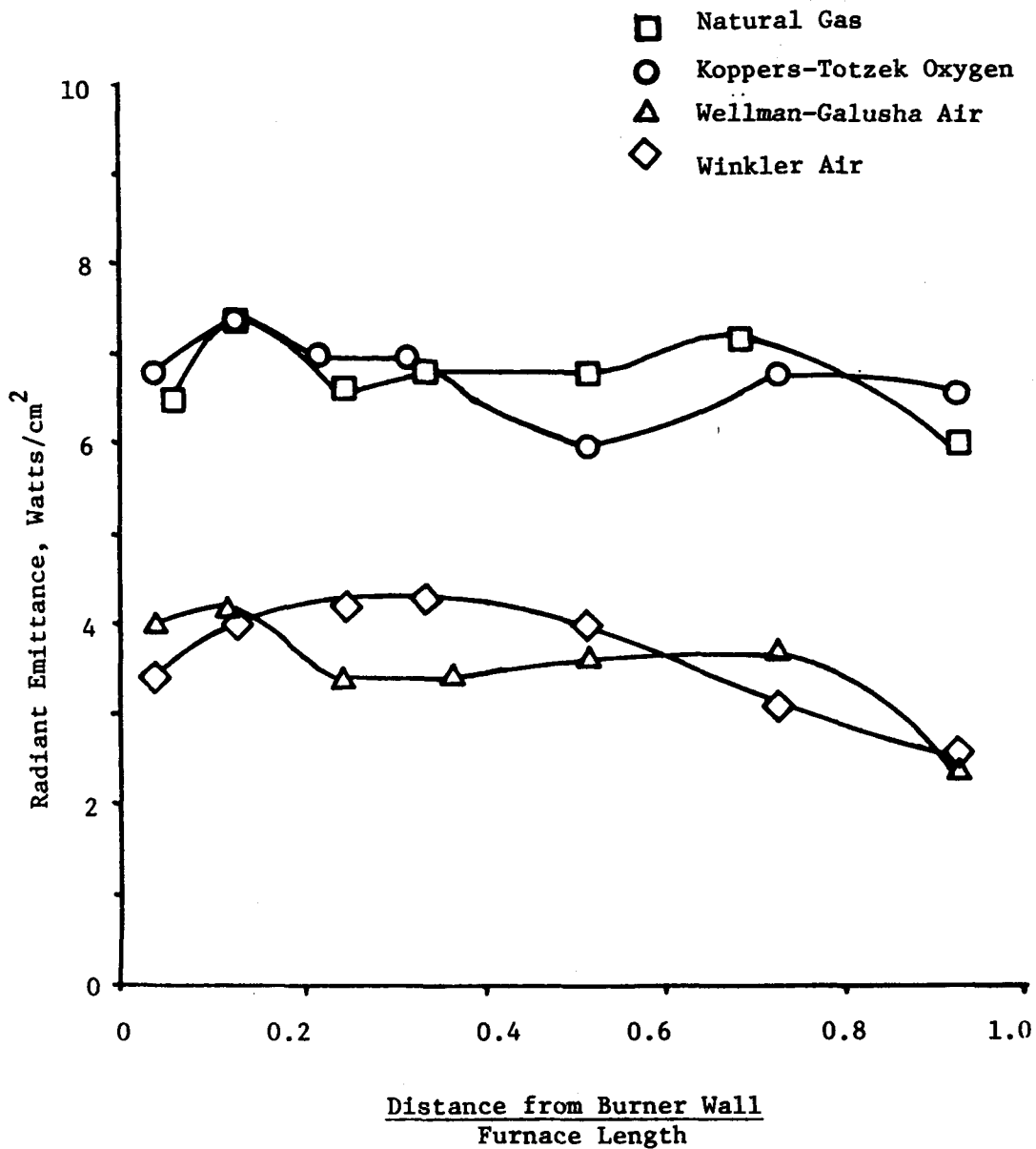
A78092692

Figure 13. FLAME SHAPE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE NOZZLE-MIX BURNER



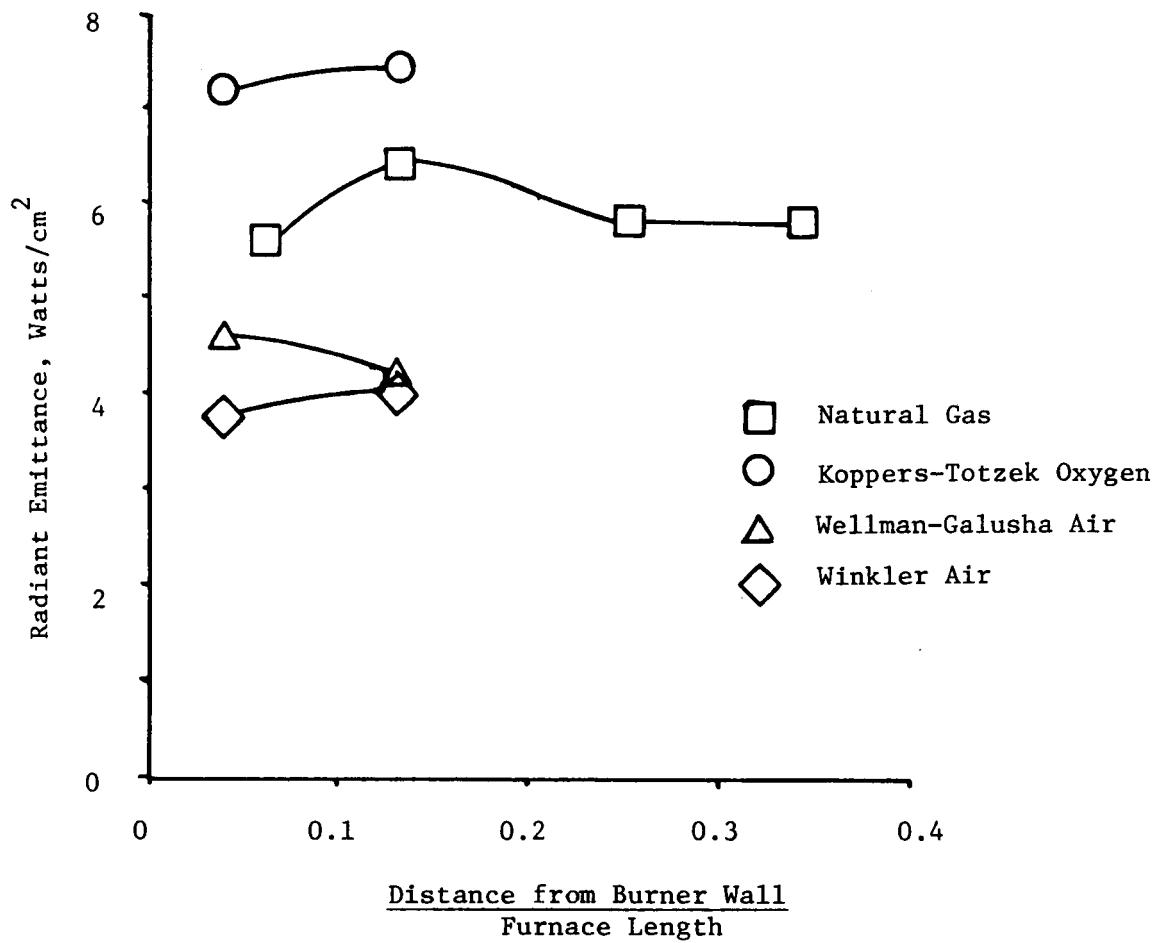
A78092693

Figure 14. HEAT-ABSORPTION PROFILE FOR KOPPERS-TOTZEK OXYGEN FUEL GAS  
COMPARED WITH NATURAL GAS ON THE NOZZLE-MIX BURNER



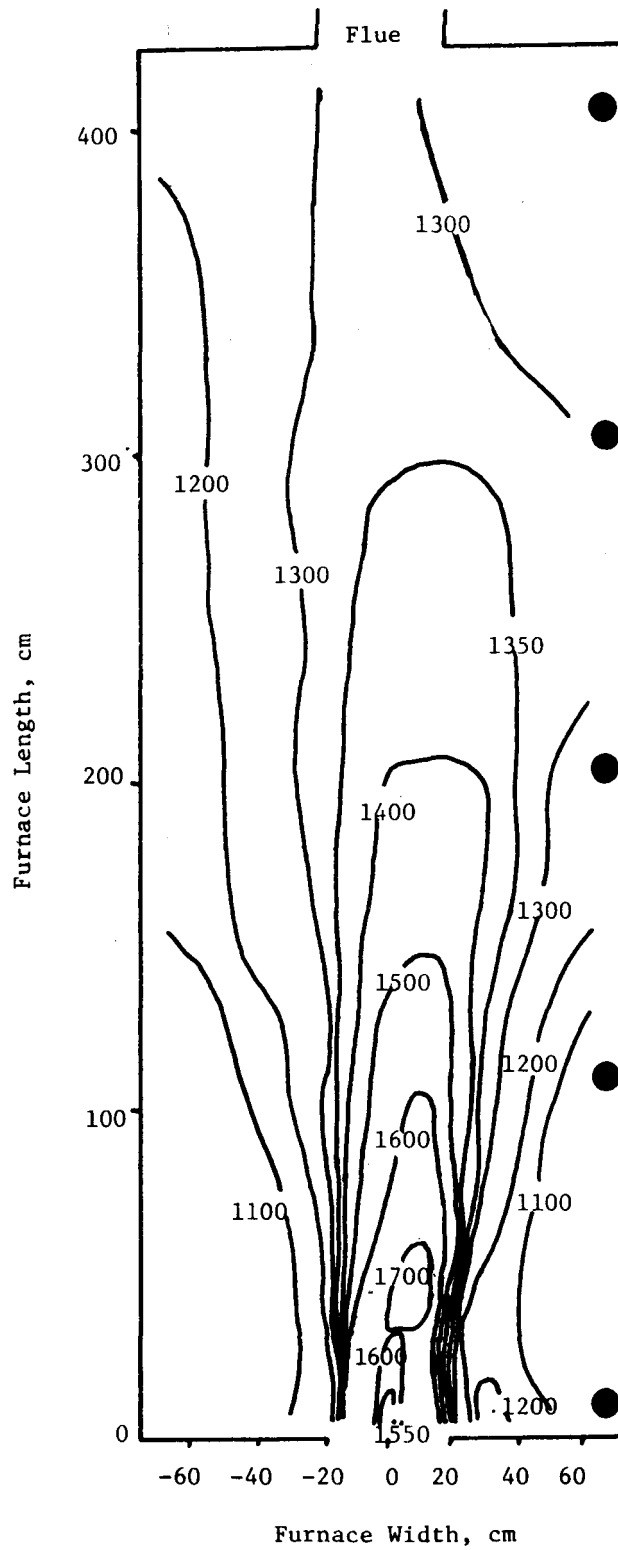
A78092694

Figure 15. RADIANT EMITTANCE FROM FLAME PLUS COMBUSTION PRODUCTS FOR THE NOZZLE-MIX BURNER



A78092695

Figure 16. RADIANT EMITTANCE FROM THE FLAME ALONE FOR THE NOZZLE-MIX BURNER



A78092696

Figure 17. TEMPERATURE PROFILES ( $^{\circ}\text{C}$ ) FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE NOZZLE-MIX BURNER

Sound level measurements were made for the KTO fuel gas. The background noise level was 93 db at the burner and 82 db at the side of the burner because of the combustion air fan. There was a 4 db increase at the burner, a 26 db increase at the side of the furnace with the furnace closed, and a 32 db increase at the side with a sampling door removed during firing.

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

#### Koppers-Totzek Oxygen Fuel Gas Retrofit Conclusions

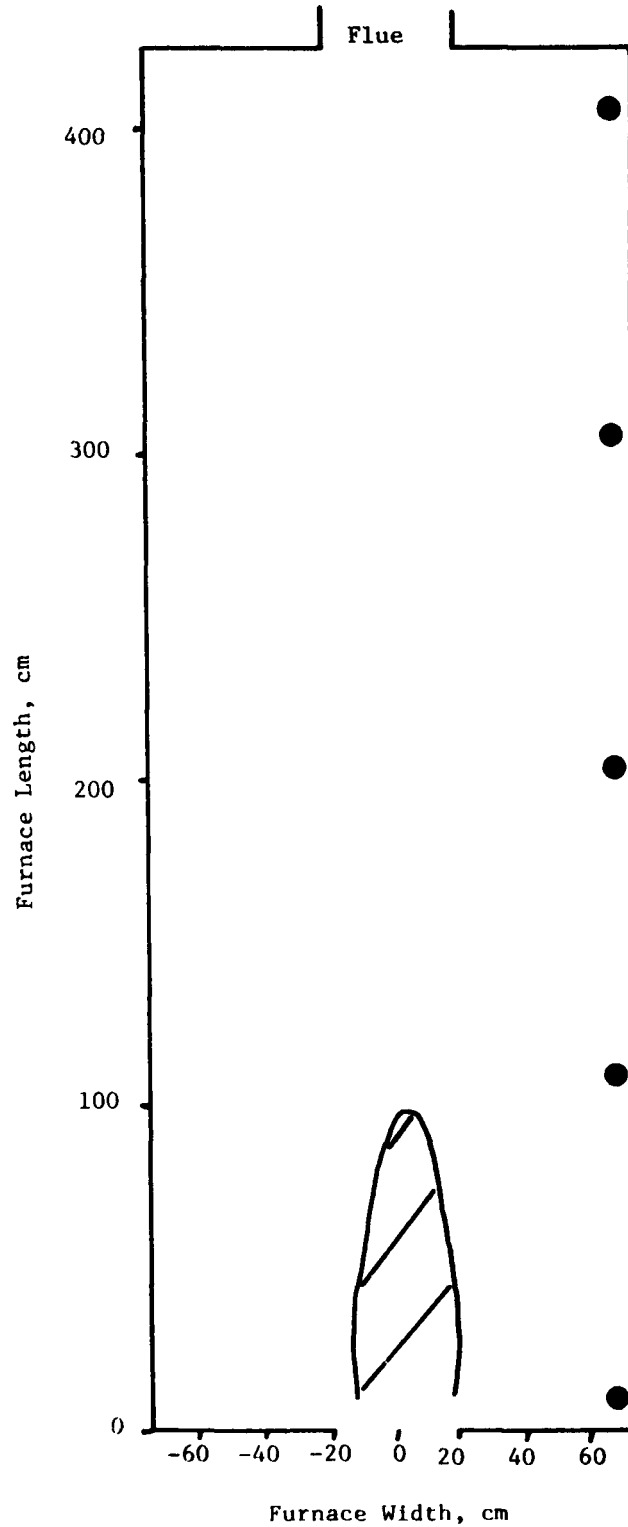
For Koppers-Totzek oxygen fuel gas the flame temperatures, thermal efficiency, and heat-absorption profile all indicate that this fuel will retrofit well on this type of burner. Although the flame length is reduced compared with natural gas, this did not affect the heat-transfer pattern to the load.

These results show that a medium-Btu gas, such as KTO fuel gas, can be expected to perform as well as natural gas on nozzle-mix-type burners.

#### Wellman-Galusha Air Fuel Gas Trials

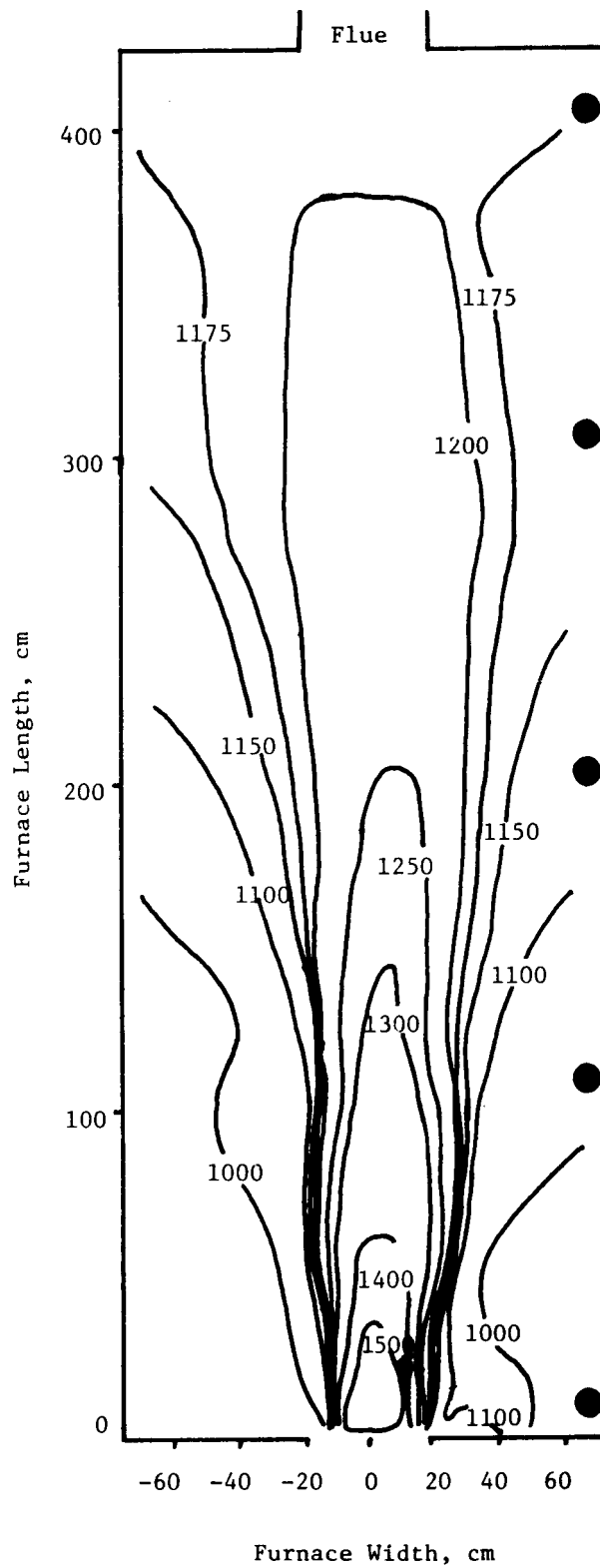
The results of the WGA fuel gas combustion trials are also included in Table 2. Since WGA has a low heating value per cubic foot, the fuel velocity at the burner is very high, although no flame stability problems were encountered. The flame length was 100 cm, the same as that measured for KTO. The flame shape is shown in Figure 18. The thermal efficiency for WGA fuel gas was 21%, which was somewhat below the 25% for the natural gas base-line trial. Figure 19 shows the flame temperature for WGA. The peak temperature occurred at 5 cm from the burner wall and was 1535°C (2795°F). This is lower than the temperature found for natural gas and KTO. Low flame temperatures result in low thermal efficiencies because of reduced heat-transfer rates.

The heat-absorption profile for WGA is compared with the natural gas profile in Figure 20. Although less heat was transferred to the load with WGA, we see that the profiles are nearly identical. Comparing the thermal radiation measurements shown in Figures 15 and 16, we see that the radiation



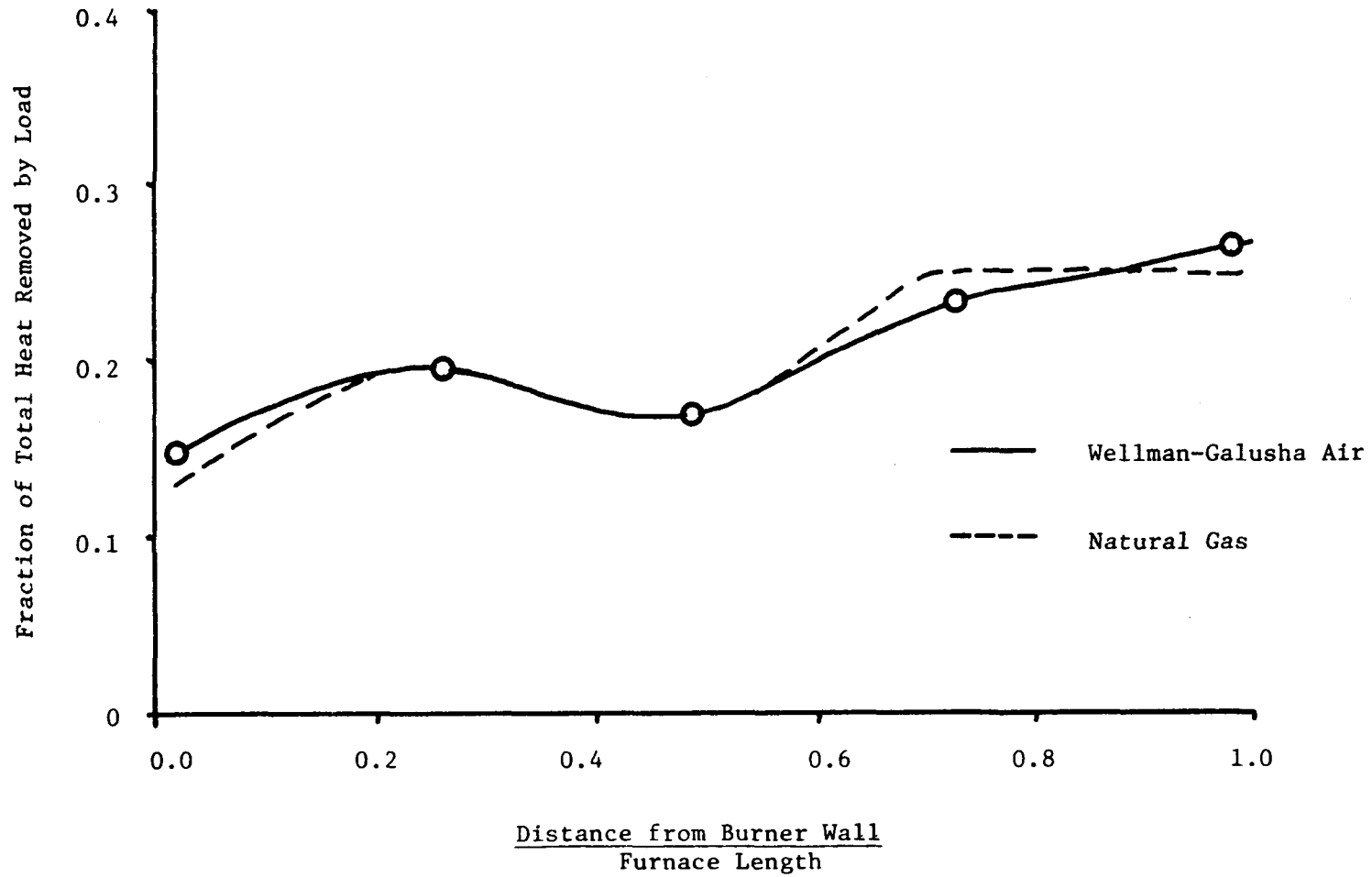
A78092697

Figure 18. FLAME SHAPE FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE NOZZLE-MIX BURNER



A78092698

Figure 19. TEMPERATURE PROFILES ( $^{\circ}\text{C}$ ) FOR WELLMAN-GALUSHA AIR FUEL GAS ON THE NOZZLE-MIX BURNER



A78092699

Figure 20. HEAT-ABSORPTION PROFILE FOR WELLMAN-GALUSHA AIR FUEL GAS COMPARED WITH NATURAL GAS ON THE NOZZLE-MIX BURNER

levels for WGA are lower than those for natural gas. This would be expected from the temperature measurements and explains the reduced thermal efficiency. The post-flame emissivity was measured as 0.21. The Hottel and Sarofim calculation gave a value of 0.20, while the Leckner calculation gave 0.23.

During the WGA sound level measurements, the background noise level at the burner was 90 db because of the combustion air fan. The noise level went to 95 db when the burner was fired. Along the side of the furnace, the background noise level was 80 db. The level increased 25 db with the furnace closed and 30 db with one sample door removed during firing.

The flow direction profile in the furnace was the same as shown in Figure 11 for natural gas.

#### Wellman-Galusha Air Fuel Gas Retrofit Conclusions

Wellman-Galusha air fuel gas can be fired with a stable flame at the maximum rated heat input on this burner. The flame shape and heat absorption profile are similar to those observed for natural gas. The thermal efficiency, flame temperatures, and thermal radiation levels show that the flame obtained with this fuel does not perform as well as natural gas in transferring heat to the load in a high-temperature furnace where radiation is the dominant heat-transfer mode.

#### Winkler Air Fuel Gas Trials

Using Winkler air fuel gas, the heat transferred to the load amounted to only 18% of the heat input compared with the 25% obtained for the natural gas base-line fuel. Figure 21 shows the temperature profiles obtained for WA. These are the lowest temperatures obtained for any of the fuels and are explained by the low heating value per cubic foot (116) for this fuel. The peak temperature measured was 1379°C (2514°F) at 5 cm from the burner wall.

WA fuel gas had the shortest flame, shown in Figure 22. The heat-absorption profile, seen in Figure 23, was virtually identical to the natural gas heat-absorption profile. The flow direction profile was similar to Figure 11, shown for natural gas.

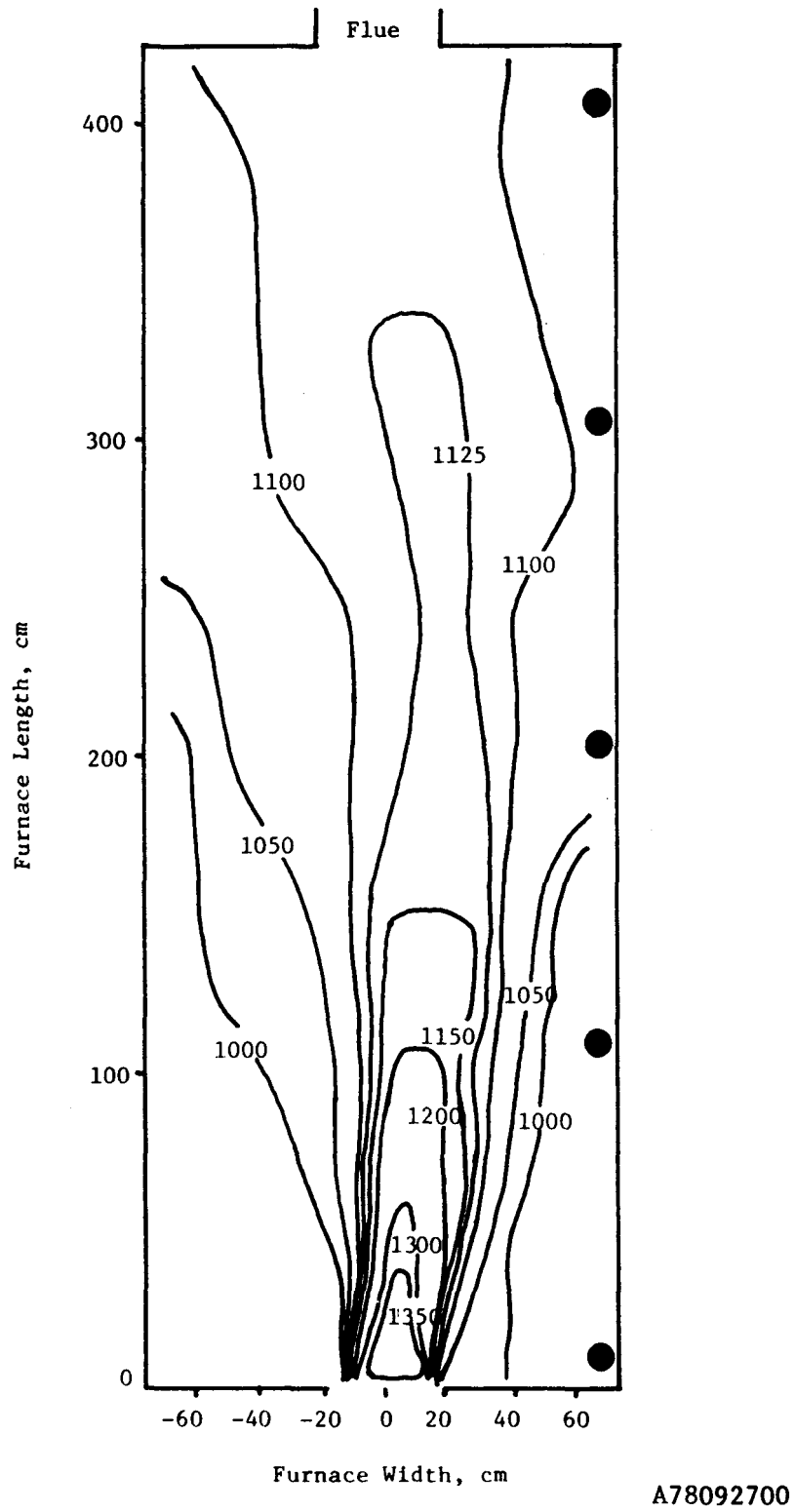
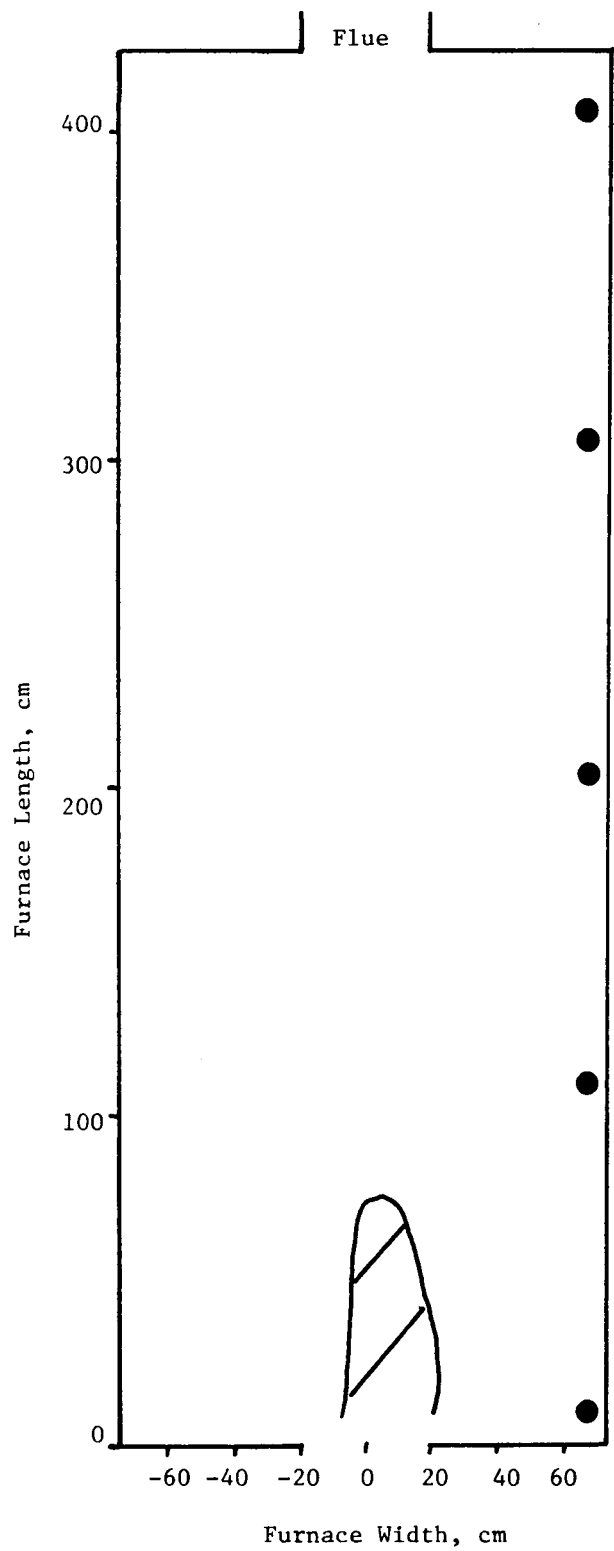
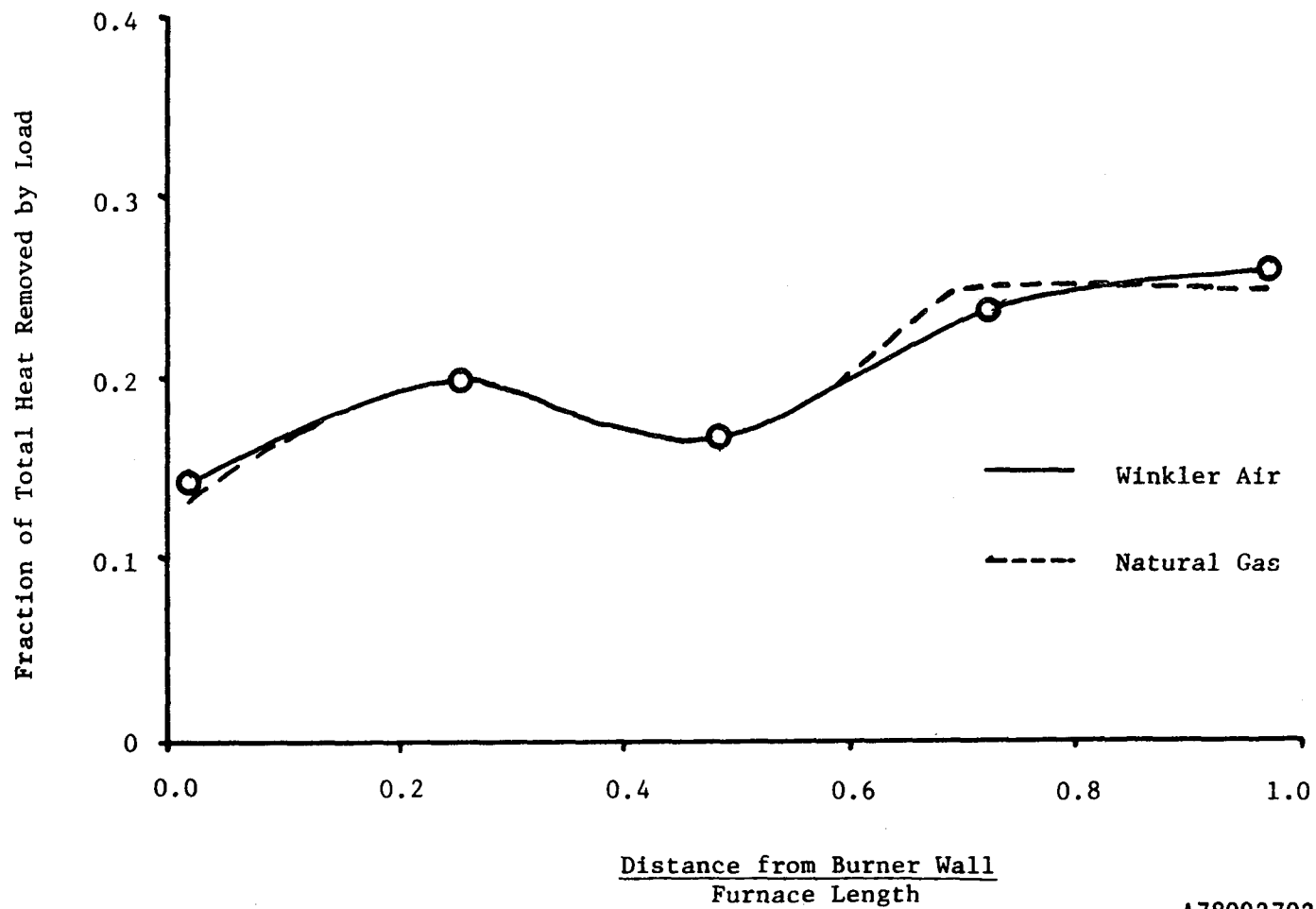


Figure 21. TEMPERATURE PROFILES ( $^{\circ}\text{C}$ ) FOR WINKLER AIR FUEL GAS ON THE NOZZLE-MIX BURNER



A78092701

Figure 22. FLAME SHAPE FOR WINKLER AIR FUEL GAS ON THE NOZZLE-MIX BURNER



A78092702

Figure 23. HEAT ABSORPTION PROFILE FOR WINKLER AIR FUEL GAS  
COMPARED WITH NATURAL GAS ON THE NOZZLE-MIX BURNER

For WA, the background noise level at the burner was 91 db and 80 db at the furnace sidewall. The noise level increases with the burner operating were 6 db at the burner, 24 db at the side with the furnace closed, and 31 db at the side with a door removed.

#### Winkler Air Fuel Gas Retrofit Conclusions

Winkler air fuel gas can be fired at the maximum rated heat input on this burner, although Figure 12 shows that a slight increase in excess air above 10% or a slight decrease in fuel heating value per cubic foot could cause the flame to blow off. Also, the flame temperatures, thermal efficiency, and thermal radiation levels indicate that WA flames will not transfer heat by radiation as well as natural gas flames. Thus, although WA can be successfully utilized, the production rate would have to be downrated. Also, the low flame temperatures would mean that the fuel could not be utilized for processes with high load temperature requirements.

#### REFERENCES CITED

1. American Gas Association, "Methods to Reduce Gas Consumption in Annealing Operations," Catalog No. M-50046. Arlington, Va., 1974.
2. Chedaille, J. and Braud, Y., Measurements in Flames. London: Edward Arnold, 1972.
3. Hottel, H. and Sarofim, A., Radiative Transfer. New York: McGraw-Hill, 1967.
4. Kranz, R.E., "Low Energy Batch Annealing." Paper presented at the IGT Symposium on Efficient Use of Fuels in the Metallurgical Industries, Chicago, December 9-13, 1974.
5. Leckner, B., Combustion and Flame, 19, 33, (1972).
6. Waibel, R.T., Development of Combustion Data to Utilize Low-Btu Gases as Industrial Process Fuels - Special Report No. 1, FE-2489-22 Institute of Gas Technology.