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STACK GAS MEASUREMENT OF BURNING PROPANE GAS FOR AN EXPERIMENTAL FIRE FIGHTING TRAINER

Edmund Swiatosz

Naval Training Equipment Center
Orlando, Florida

June 1974

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The Navy's fire fighting training facilities include burning diesel oil which results in a multitude of chemicals and present pollution and health hazard problems. A possible solution is replacement of diesel fuel with a relatively clean burning gaseous fuel. To determine this feasibility, stack gas measurements were made from a 4 million btu per hour gas burner facility under a fire fighting training environment. The concentrations of stack gases were found to be sensitive to various test parameters including air-fuel ratio (primary air),

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stack exhaust size and draft inlet openings (secondary air). These concentrations were determined as controllable and within acceptable safe limits for fire fighting training application.

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SECTION I

INTRODUCTION

STACK GAS MEASUREMENT OF BURNING PROPANE GAS FOR AN EXPERIMENTAL FIRE FIGHTING TRAINER

The Navy's fire fighting training facilities include burning diesel oil which results in objectional volumes of thick, black smoke particulates or soot along with gaseous pollutants. Recent data[1] indicate that these oil fires may present a severe potential health hazard particularly to instructor personnel exposed to the multitude of chemicals in the soot.

The current methods used to reduce smoke emissions from oil fires are the water spray systems and the after burner. Both methods retain diesel oil as fire source with questionable performance to meet possible future restrictions on environmental pollution and occupational safety.

The use of a gaseous fuel has been proposed [2] in conjunction with a logic control circuit as an alternate method of reducing pollution. In addition to providing a clean burning fuel with relatively few gaseous products, this system would have several potential advantages. These include quick start up and shut down capabilities; and flexible control of extinguishment and reflash control. The feasibility of this system has been studied under NAVTRAEQUIPCEN Task 1734 [3]. As part of this task the stack gas analysis of burning propane under experimental field conditions are presented herein to determine the extent of the concentration of products obtained from burning a gaseous fuel for fire fighting training.

1. Hill, T.A., Siedle, A.R., and Roger Perry, Navy Preventive Medicine Unit 2, Norfolk, Va, Hazards of a Fire-Fighting Training Environment, American Industrial Hygiene Association Journal, June 1972, p. 423-430.
2. Wolff, H.H., Patent No. 3,675,342, Fire Fighting Trainer, July 1972.
3. NAVTRAEQUIPCEN Report, Task 1734, Fire Fighting Simulation (in progress).

SECTION II

STATEMENT OF THE PROBLEM

The burning of a gaseous fuel such as propane or natural gas will have products of combustion including Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydrocarbons (HC) and Nitrogen Oxides (NOx). The concentration of these gases should not exceed limits established for environmental standard and occupational safety for fire fighting trainers. It is intended to determine concentrations comparable to a training environment. It is also the intent to determine how these quantities will vary with changes to various parameters such as air-fuel ratio, top stack exhaust opening, bottom draft opening, and application of hose water.

SECTION III

METHOD OF PROCEDURE

A large size horizontal burner [4] equipped with an air blower and rated for 4 million btu per hour was selected for experimental tests. The burner, as shown in figure 1, was purchased as a prepackaged unit and normally has a constant air-fuel ratio feature. This was deleted in order to manually set the various air-fuel ratios for individual tests. Propane gas was supplied under a two stage reduction to 7-inch water pressure at the burner. The fuel is mixed with the primary air supply from the blower prior to ignition. Fuel quantities were selected to provide a flame area coverage up to about 4 by 4 foot area and up to about 10-foot flame height.

To facilitate stack gas measurements and control of the secondary air conditions, a 6 by 6 by 13 foot high enclosure was constructed as shown in figure 2. This would enclose a single flame comparable to one of the burners in a multiple array required for a full size prototype trainer. The enclosure permitted the measurements of stack gas concentrations as they exited out at the top opening. Initially a water spray was used around the outside of the burner enclosure to protect the structure from the intense heat. Roof doors were opened to 6 by 6 foot maximum stack exit opening for these initial tests. As a result of these initial tests it was found necessary to add a 1-inch thick ceramic fiber insulation to the interior chamber to avoid temperature reduction effects on the products of combustion. The enclosure roof was also modified to provide stack exhaust opening of 10 inches, 15 inches, 20 inches, and 24 inches diameters.

The test set up as shown in figure 3 included metering of the gas and air supply to the burner. Gas and air temperatures and thermocouple measurements within the flame enclosure were also provided. These provided the means for obtaining parameters of gas rates, air-fuel ratios and effects of bottom draft and upper roof opening on stack gas measurements.

The stack gases were initially measured using a "Fisher-Orsat Gas Apparatus" for CO, CO_2 and O_2 gases. Subsequent measurements given in this report were made using "National Mine Service" detector tubes which provided additional NOx and hydrocarbon measurements as well as capability for measuring smaller concentrations. Samples were taken 10 feet above the burner nozzle centerline at the exhaust exit opening of the enclosure except during open air tests when the sample tube was 6-1/2 feet above the burner nozzle.

4. Eclipse Bulletin H-89, Eclipse Gas Burner No. 140-IP, Eclipse Fuel Engineering Co., Rockford, Illinois.

SECTION IV

RESULTS

Measurements of CO are shown graphically in figures 4, 5, 6, and 7. CO ranged from .001 percent to .1 percent for estimated normal fire fighting training conditions having sufficient primary and secondary air provisions. For abnormal conditions of extreme low air-fuel ratio (low primary air) and/or small stack exhaust opening (low secondary air) CO ranged from 1 percent to 2 percent. Increases in CO also occurred with applications of hose water as shown in figure 8. The CO readings for open air tests varied from about .0005 percent at the high air-fuel ratios to about .01 percent at the lower air-fuel ratios, for lower level (6-1/2 feet) sample probe location.

CO_2 results shown in figures 8 and 9 indicate an increase in CO_2 with reduction in stack exhaust openings for secondary air. CO_2 did not change appreciably with changes in air-fuel ratio or primary air.

Oxygen measurements were generally about 15 percent depending on the amount of secondary air provided. No measurements of O_2 were obtained where high concentrations of HC or CO affected the oxygen detector tube readings.

The NOx measurements are shown in figure 10. These decreased from a high of 30 ppm to less than 2 ppm when primary air was decreased and/or secondary air increased.

The hydrocarbon (propane) measurements shown in figure 11 indicate a significant increase due to reduction of secondary air and hose water application.

SECTION V

DISCUSSION

TEST EQUIPMENT AND PARAMETER EFFECTS ON EMISSIONS.

The test data indicate the general sensitivity of the emissions to the test equipment design and the test parameters. The generation of CO was especially sensitive to the heat transfer from the flames during initial tests. This was due primarily to the relatively high ratio of the flame enclosure surface to the enclosed volume and the use of a water spray on the outside surface to protect the structure from the intense heat. In order to obtain meaningful data on the emissions due to other parameters, it became necessary to offset the dominating effect of the heat transfer from the flames to the immediate surroundings. Hence the chamber interior was insulated to obtain a heat transfer condition comparable to a full sized fire fighting trainer. The effect of heat transfer on combustion in flames is noted in literature [5,6] which indicates the complexity of the flame mechanism particularly for fuel-rich flames. However, the basic theory explains qualitatively the dramatic reductions in CO and HC with increasing primary and secondary air provisions. For example, propane is decomposed in the initial phase of the flame to form CO but its chemical bond energy is relatively high. Hence high flame temperature and sufficient oxygen is required to decrease the CO concentration. The conversion of CO to CO_2 is enhanced by longer residence time since this is a relatively slow reaction compared with CO formation.

CARBON MONOXIDE EMISSIONS.

As previously mentioned, during initial testing a considerable amount of heat was being absorbed from the flames by the surrounding uninsulated enclosure. This resulted in relatively high initial CO gas measurements ranging from 1 percent to 6 percent. Subsequent insulation of the chamber interior provided a means for attaining levels of CO within the acceptable .15 percent for fire fighting training [7]. After minimizing the heat transfer effects, it was evident that the variation of the CO level, within the acceptable level, was sensitive to the primary and secondary air parameters as well as hose water effects.

5. Fristrom, R.M., The Mechanism of Combustion in Flames, Chemical and Engineering News, Oct 1963.

6. National Air Pollution Control Administration Publication No. AP-65, Control Techniques for CO Emissions from Stationary Sources, U. S. Department of Health, Education and Welfare, Mar 1970.

7. Memorandum, BUMED-7321-DAM;jbw, 26 Sep 1973, Information on Carbon Monoxide Inhalation Effects; reply to request to, Bureau of Medicine and Surgery.

The effect of increasing secondary air CO reduction by increasing the stack exhaust opening is shown in figures 4 and 5. These indicate a CO reduction by two orders of magnitude from .45 percent for a 10-inch diameter stack opening to about .005 percent by increasing the stack diameter to 24 inches. Maximum CO values occurred as the air-fuel ratio was decreased from a high of 24:1 to about 4:1. Further reduction of an air-fuel ratio to extreme low values resulted in a decrease in CO from the maximum value as the burning became less complete.

Increases in CO occurred when 69 gpm of high velocity fog water was applied to the flames as shown in figure 8. Since these measurements were made under steady state conditions with a continuous flame, they will tend to be higher than with actual training conditions. In an actual training situation the fire would be extinguished by valve closure and the increase in CO due to the applied water would be momentary. Nevertheless, CO readings for the 24-inch stack exhaust diameter were still better than the acceptable safe limit. A reduction in secondary air with a 10-inch diameter resulted in an increase in CO between .20 percent to .5 percent with the hose water. On the basis of an acceptable CO level for the 24-inch diameter exit opening a ratio of stack opening area to surface flame area of about .1 minimum would be necessary.

NITROGEN OXIDE

Nitrogen oxide (NOx), as with CO, requires careful consideration from a toxicity standpoint. The Threshold Value Limit (TVL) [8] for NOx is 5 ppm compared with 50 ppm for CO. The acceptable limit for NOx for a short time (10 minutes) fire fighting training situation would be about 30 ppm. The NOx readings as shown in figure 10 ranged from 1 ppm for the open air tests to about a maximum of 30 ppm for the combined extremes of high air-fuel ratio and low secondary air provisions. It is apparent that the cooling effect of increasing the secondary air reduces NOx while increasing air-fuel ratio tends to raise the flame temperature and subsequently the NOx. This trend appears to be in accordance with literature[9] citing the increase of NO with flame temperature. It is also noted that NOx is reduced considerably when hose water is applied to the flames.

HYDROCARBONS

Increases in HC (propane) and carbon particles (smoke) were evident for the simultaneous reduction in secondary air with the extreme low air-fuel ratios. These increases probably replace the formation of some CO in the flame process and hence would account for the reduction in CO for extreme low air-fuel ratio mentioned previously. However, as cited in literature (5) the fuel rich burning flame is a complex process which is as yet not completely understood.

8. Sax, N.I., Dangerous Properties of Industrial Materials, page 3, 2nd edition, 1963.

9. Crynes, B.L., and Maddox, R.N., Status of NOx Control from Combustion Sources, Chemical Technology, Aug 1971.

The HC detector tubes used for test measurements were not direct readings as were the detector tubes for the other gases, and were found to be a relatively long time-consuming process. For this reason, the readings shown in figure 11 are most probably conservative in tending to give higher readings than the actual case. However, HC like methane is considered an asphyxiant and only dangerous when preventing sufficient quantities of oxygen to be available. These generally have a TVL of about 1,000 ppm. (This is unlike hydrocarbons from a fuel such as JP-5 which has tentative emergency levels of about 5 mg/liter for 10 minutes.) On this basis the percent of HC as indicated in these tests should not present any problem for fire fighting training.

EXCESS AIR EFFECTS ON CO_2 AND O_2

The measurements of CO_2 shown in figures 9 and 10 indicate excess air conditions. Also, the concentration of CO_2 decreased as the primary and secondary air was increased. This is to be expected since theoretically the CO_2 readings would decrease in proportion to the amount of excess air beyond the stoichometric burning at 16 percent CO_2. Since CO_2 levels did not appear to vary significantly with the air-fuel ratio, it would indicate that the control of the percentage of CO_2 and O_2 would depend primarily on the exhaust opening effects on secondary air. It was noted that levels of CO_2 less than 3.5 percent with O_2 levels greater than 15 percent were obtained with a 24-inch diameter stack opening. As expected, the O_2 levels were reduced to about 10 percent or less for smaller stack openings approaching 10-inch diameter.

SECTION VI

CONCLUSIONS

Propane gas and probably similar gaseous fuels can be safely used for fire fighting training. The resulting emissions would be within present safe toxic limits if adequate primary air (air-fuel ratio) and secondary air (stack and bottom draft) are provided.

The generation of CO is particularly sensitive to parameters of air-fuel ratio and stack bottom draft opening, providing the dominating effect of heat transfer cooling to the flames is minimized.

The concentration of the percentage of CO_2 depends primarily on the exhaust stack opening and bottom draft opening.

Hose water on the flames increased the CO and HC emissions while decreasing NOx and CO_2. The effect of the water spray would not significantly effect the use of propane for fire fighting training.

SECTION VII

RECOMMENDATIONS

The use of propane or similar gaseous fuel could be used as an acceptable fuel for fire fighting simulation. Natural gas being less expensive would be recommended in lieu of propane.

An air-fuel ratio between a minimum of 4.0 and a maximum of 12 should be used for non-toxic and realistic flames for fire fighting simulations.

The stack exhaust and inlet draft openings should be a minimum of 10 percent of the flame area for adequate secondary air.

Similar tests should be made using natural gas as an alternate to propane.

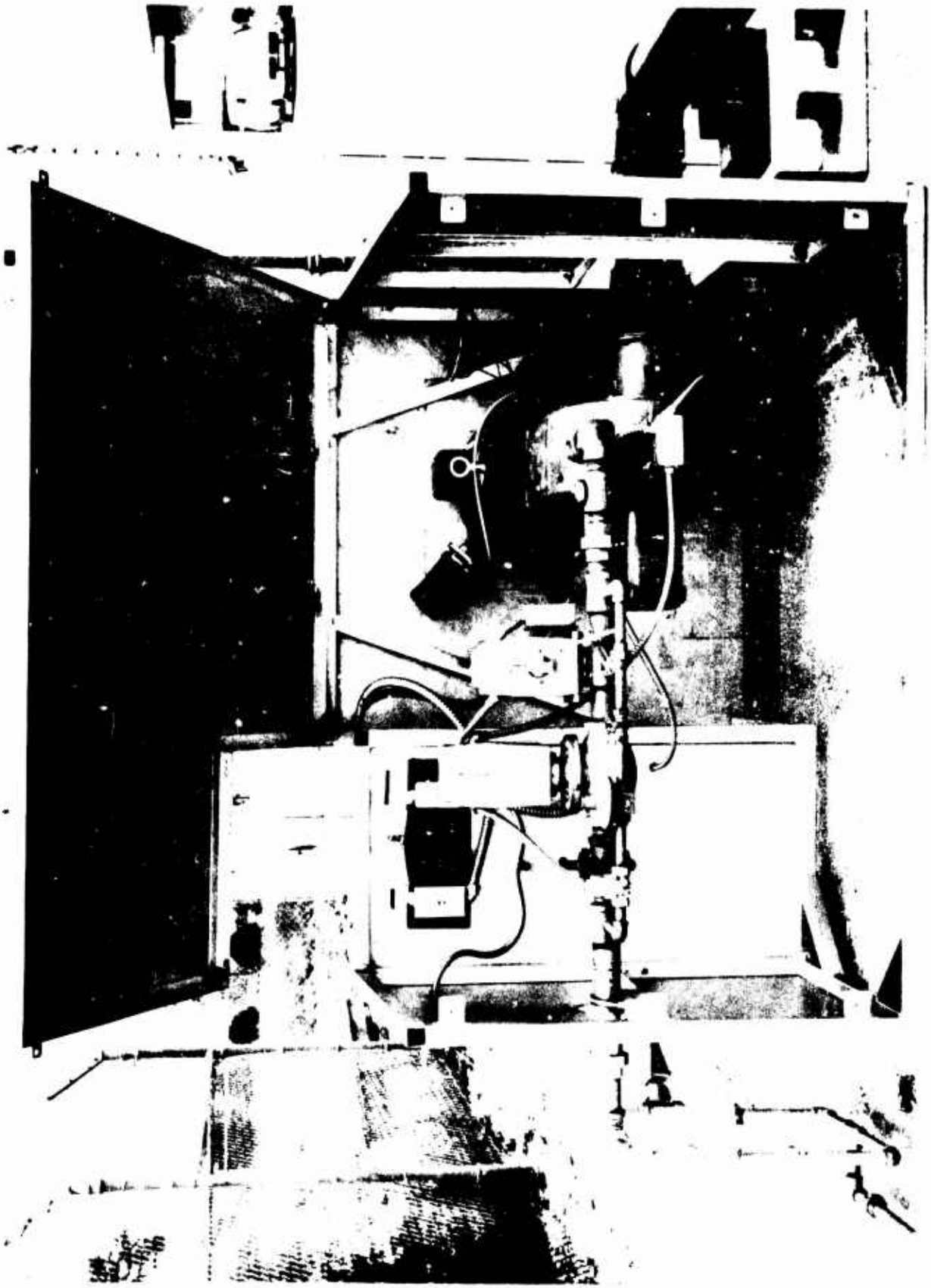

Figure 1. Burner and Control Assembly

Figure 2a. Burner Enclosure Arrangement

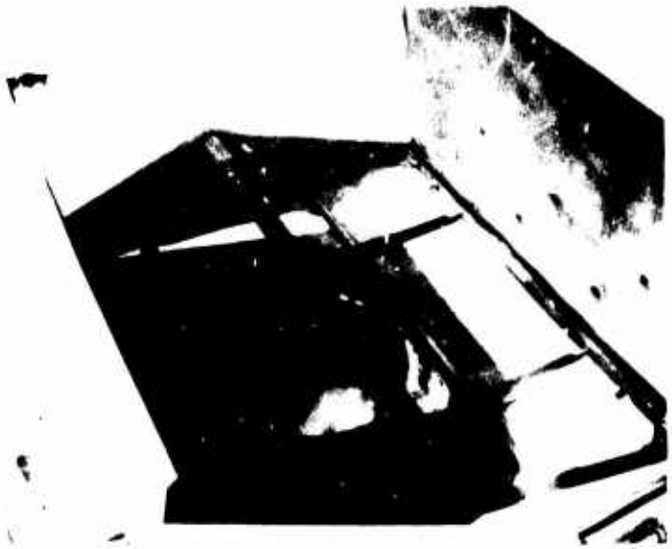

Figure 2b. Top View of Burner Enclosure Showing 24" Diameter Stack Exhaust and Sampling Tube

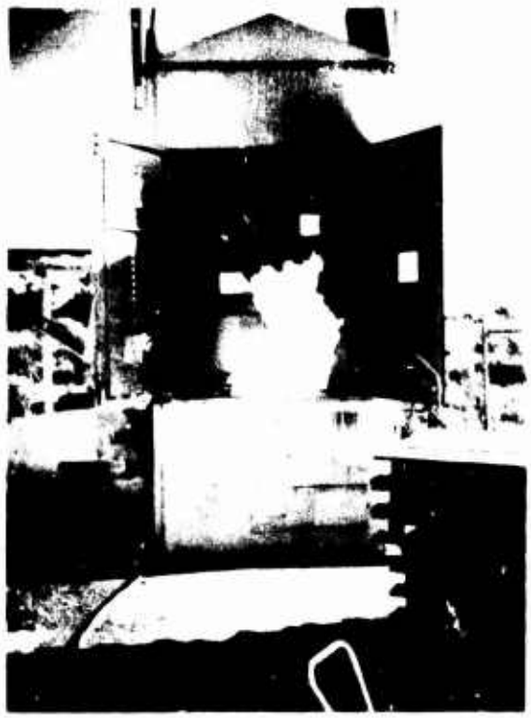

Figure 2c. Propane Flame for Horizontal Burner

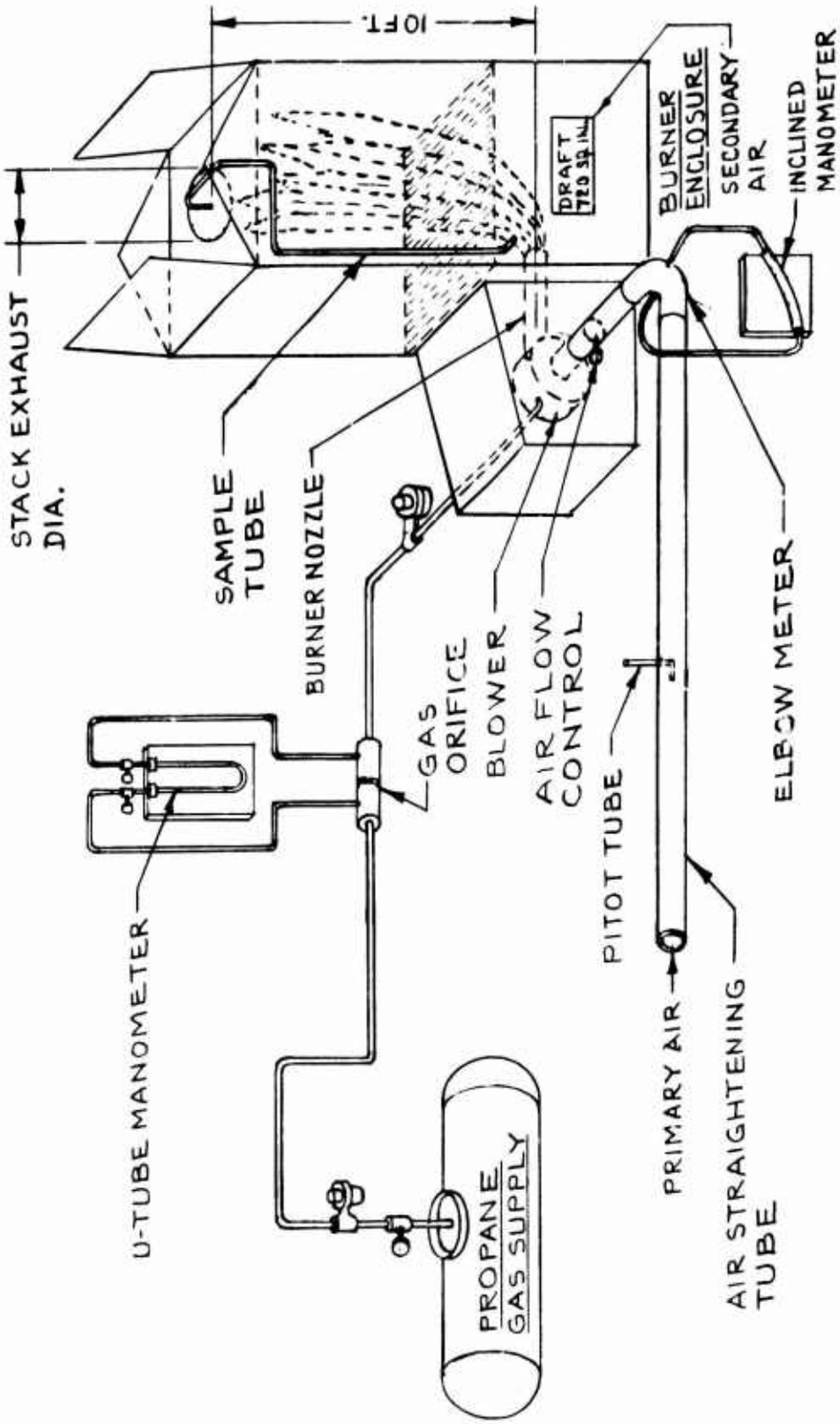

Figure 3. Schematic of Test Set-Up for Stack Gas Measurements

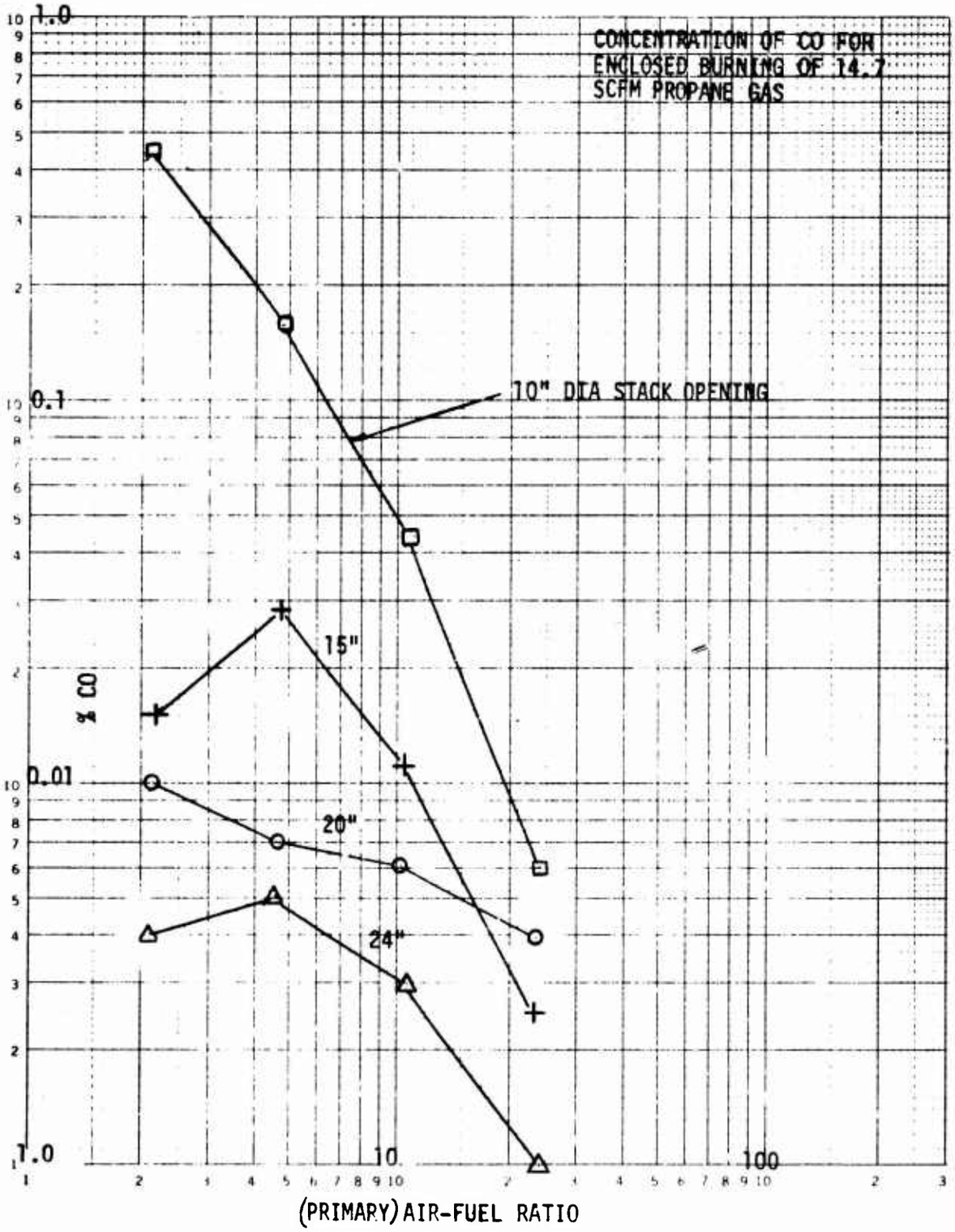

Figure 4. Concentration of CO for Enclosed Burning of 14.7 scfm Propane Gas

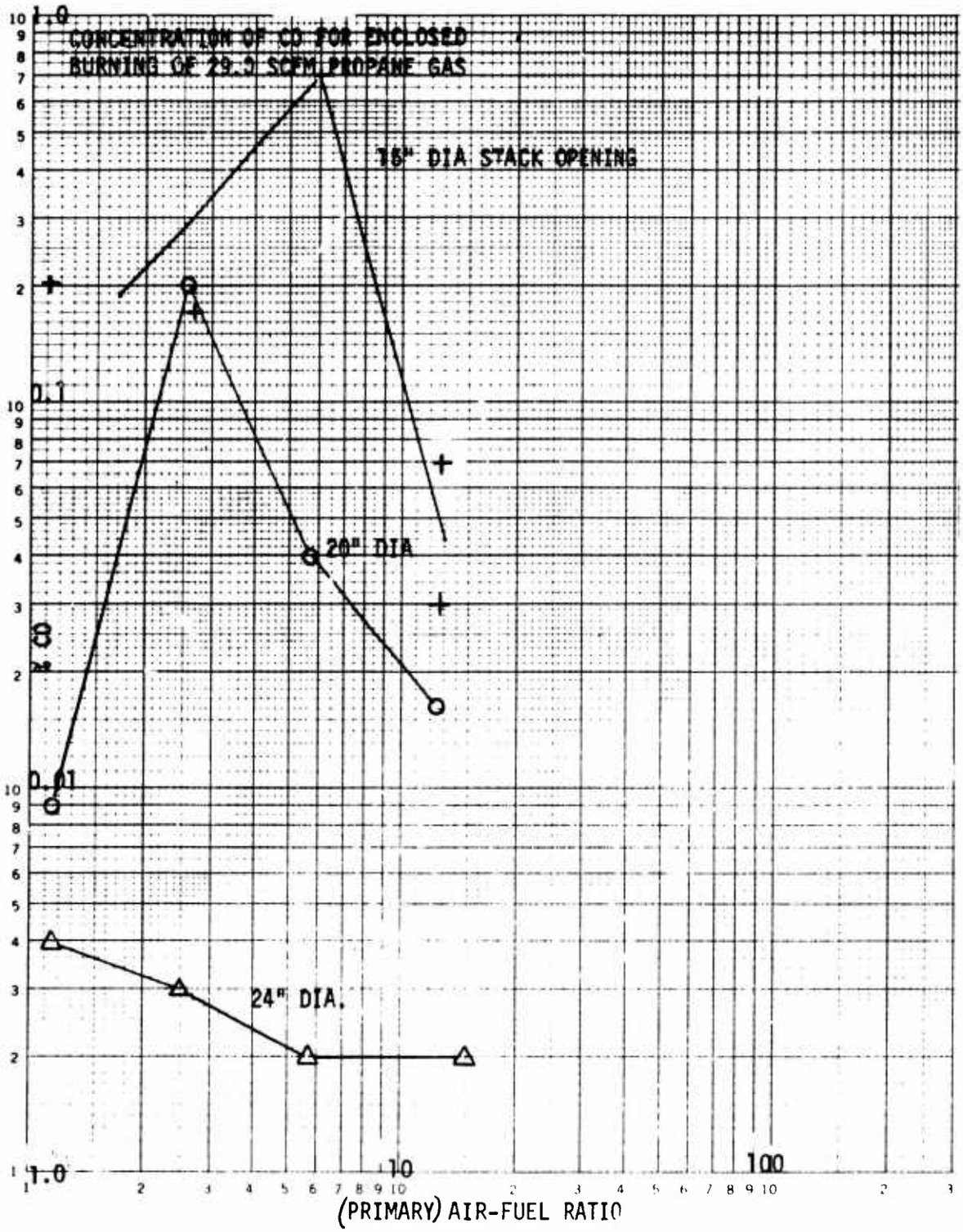

Figure 5a. Concentration of CO for Enclosed Burning of 29.0 SCFM Propane Gas

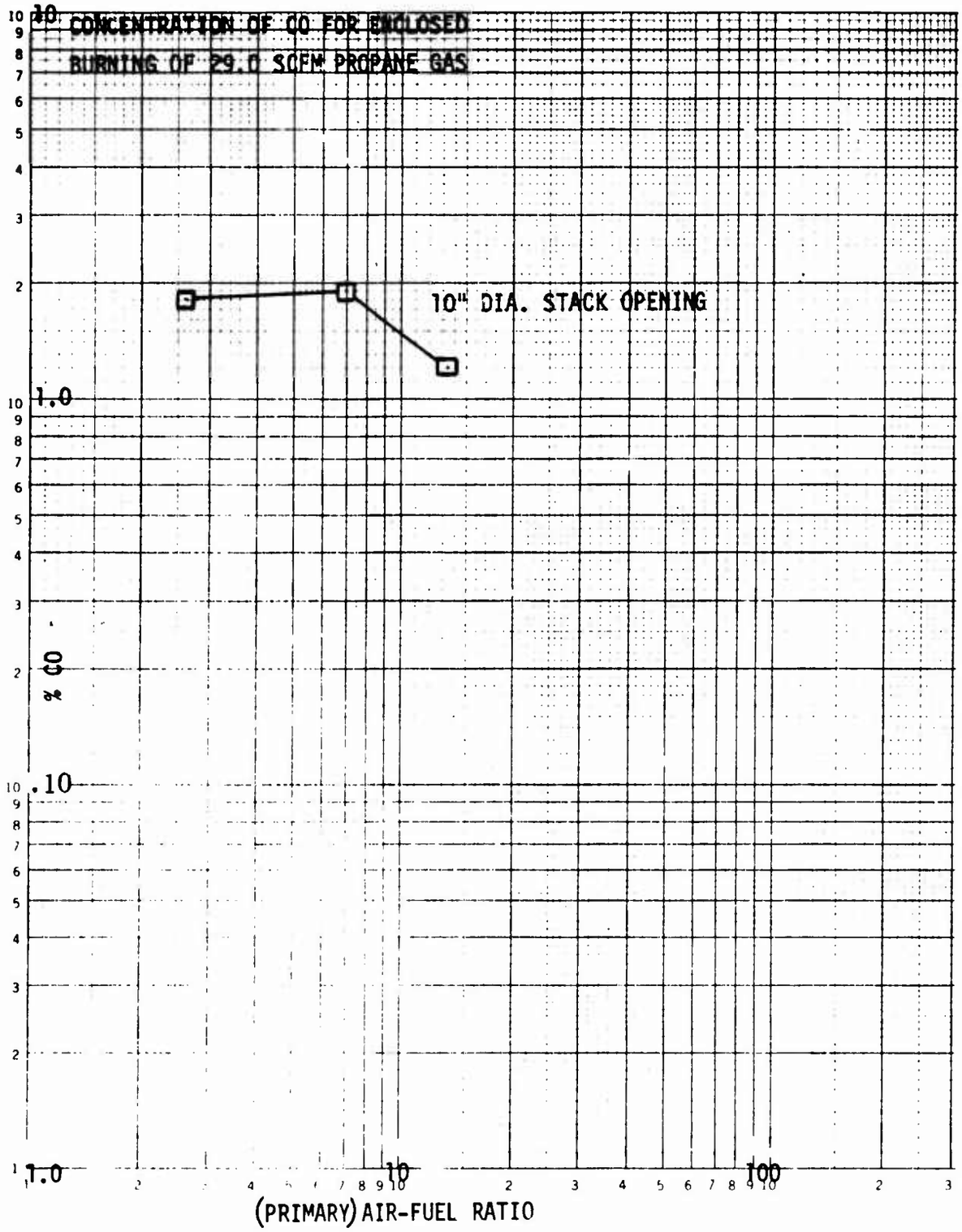

Figure 5b. Concentration of CO for Enclosed Burning of 29.0 scfm Propane Gas

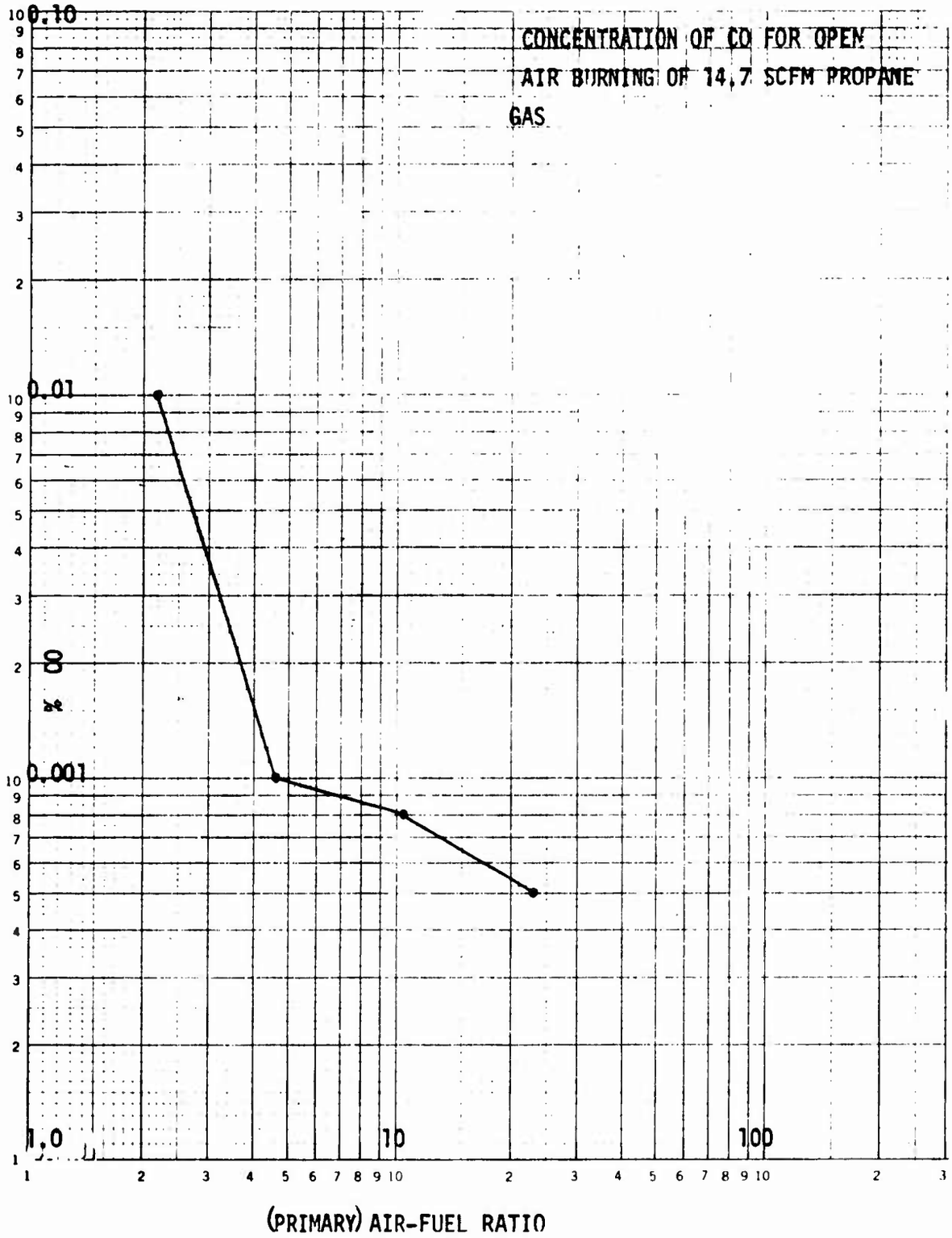

Figure 6. Concentration of CO for Open Air Burning of 14.7 SCFM Propane Gas

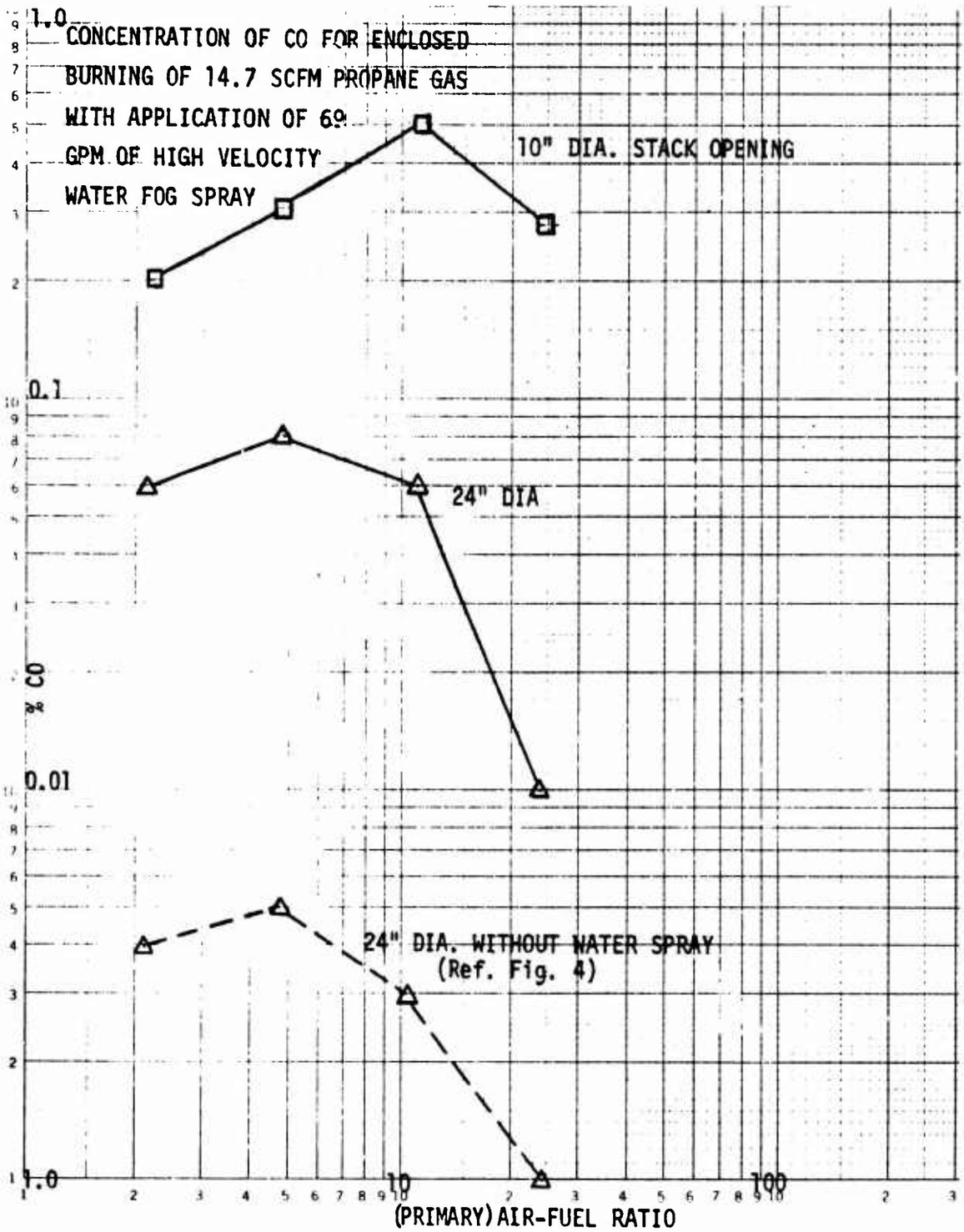

Figure 7. Concentration of CO for Enclosed Burning of 14.7 scfm Propane Gas with Application of 69 gpm of High Velocity Water Fog Spray

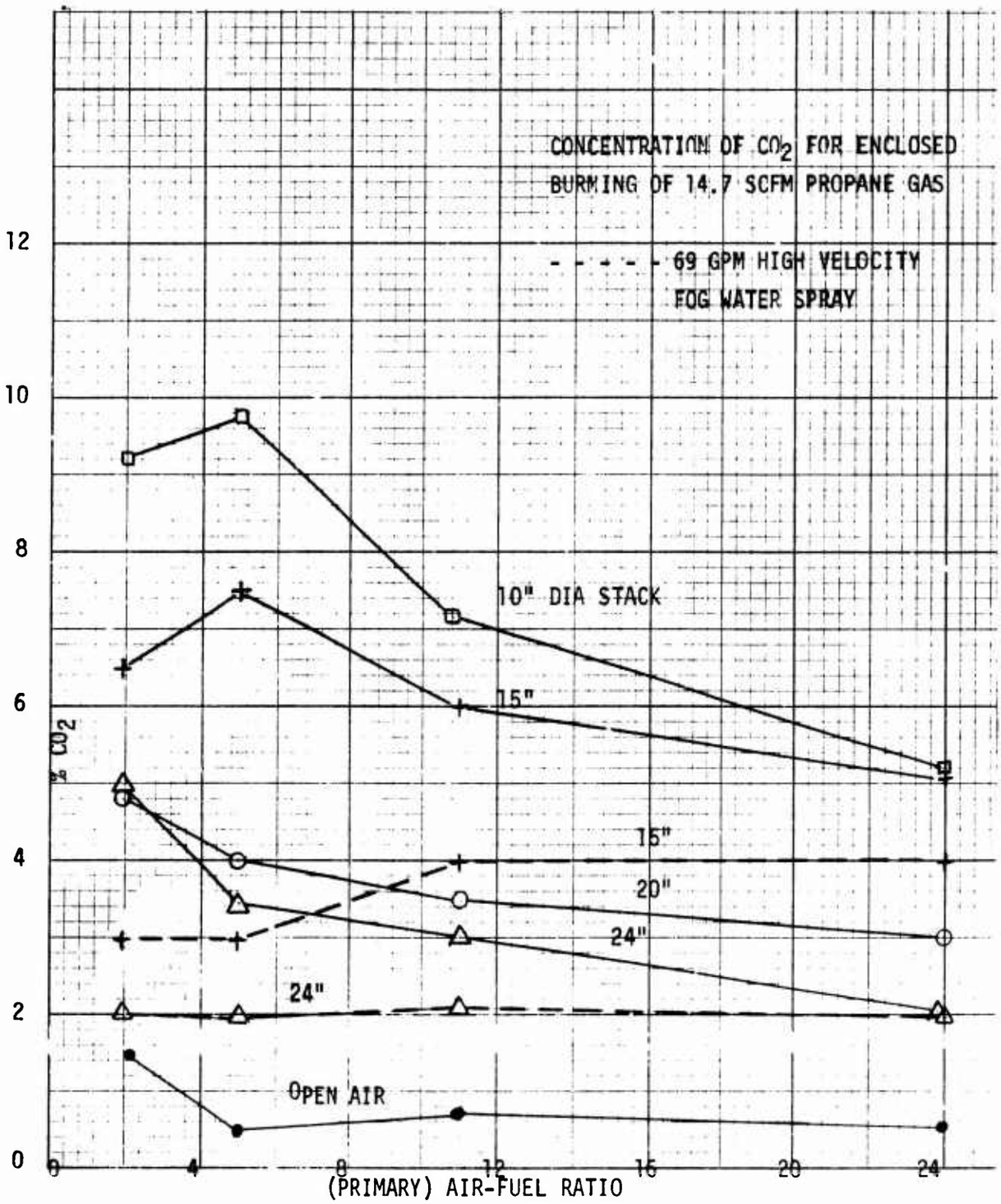

Figure 8. Concentration of CO_2 for Enclosed Burning of 14.7 scfm Propane Gas

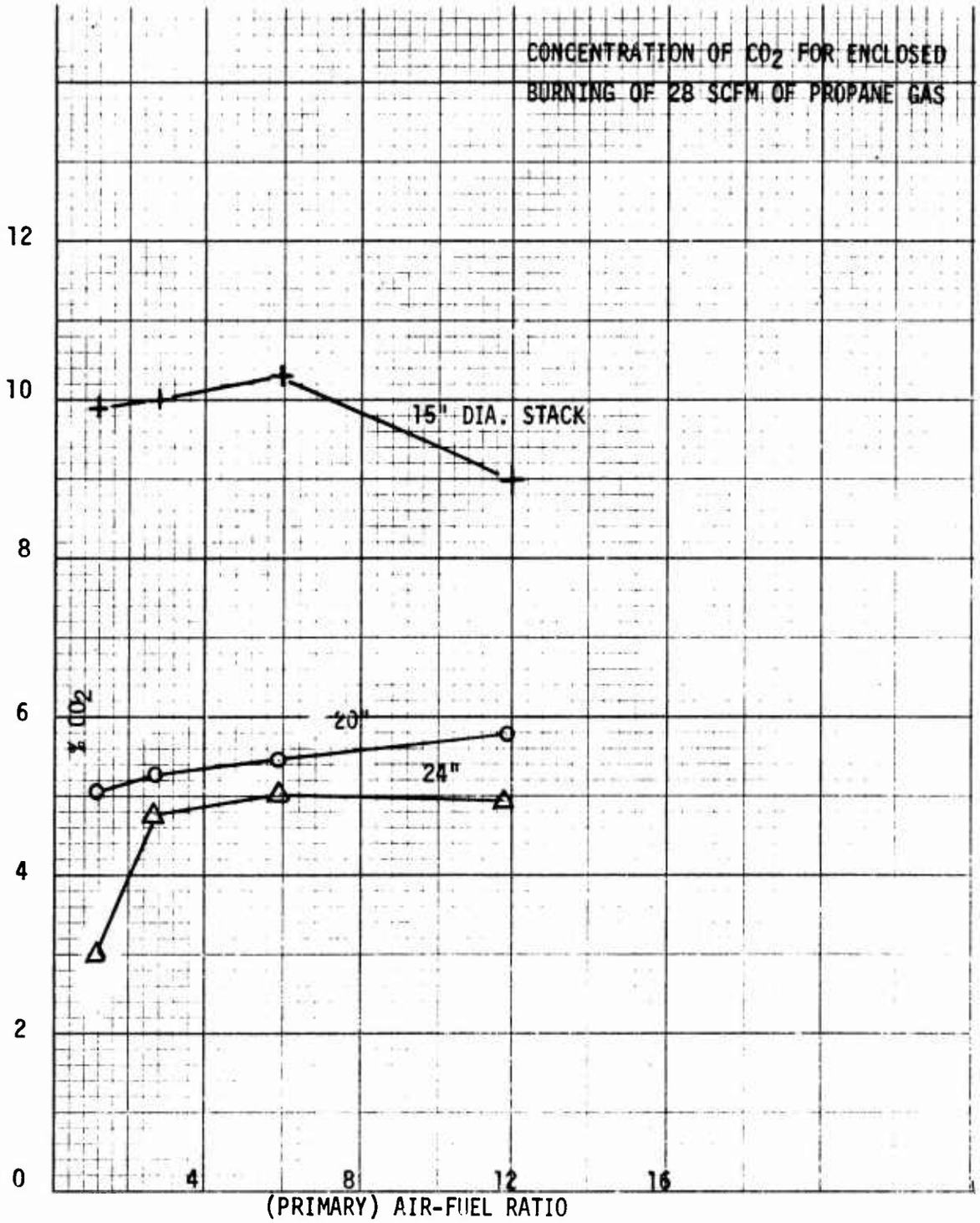

Figure 9. Concentration of CO_2 for Enclosed Burning of 29.0 scfm Propane Gas

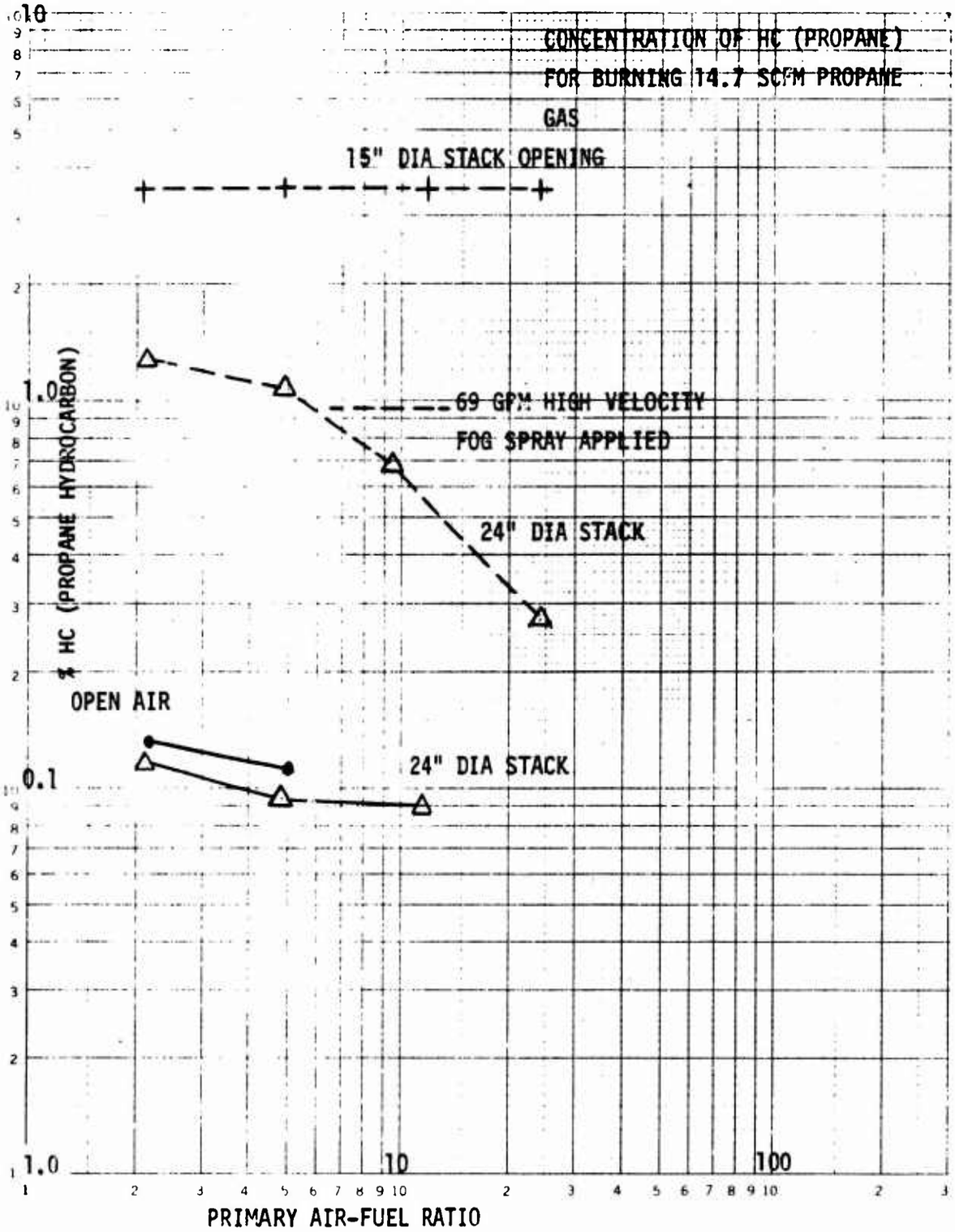

Figure 10. Concentration of HC (Propane) Burning 14.7 scfm Propane Gas

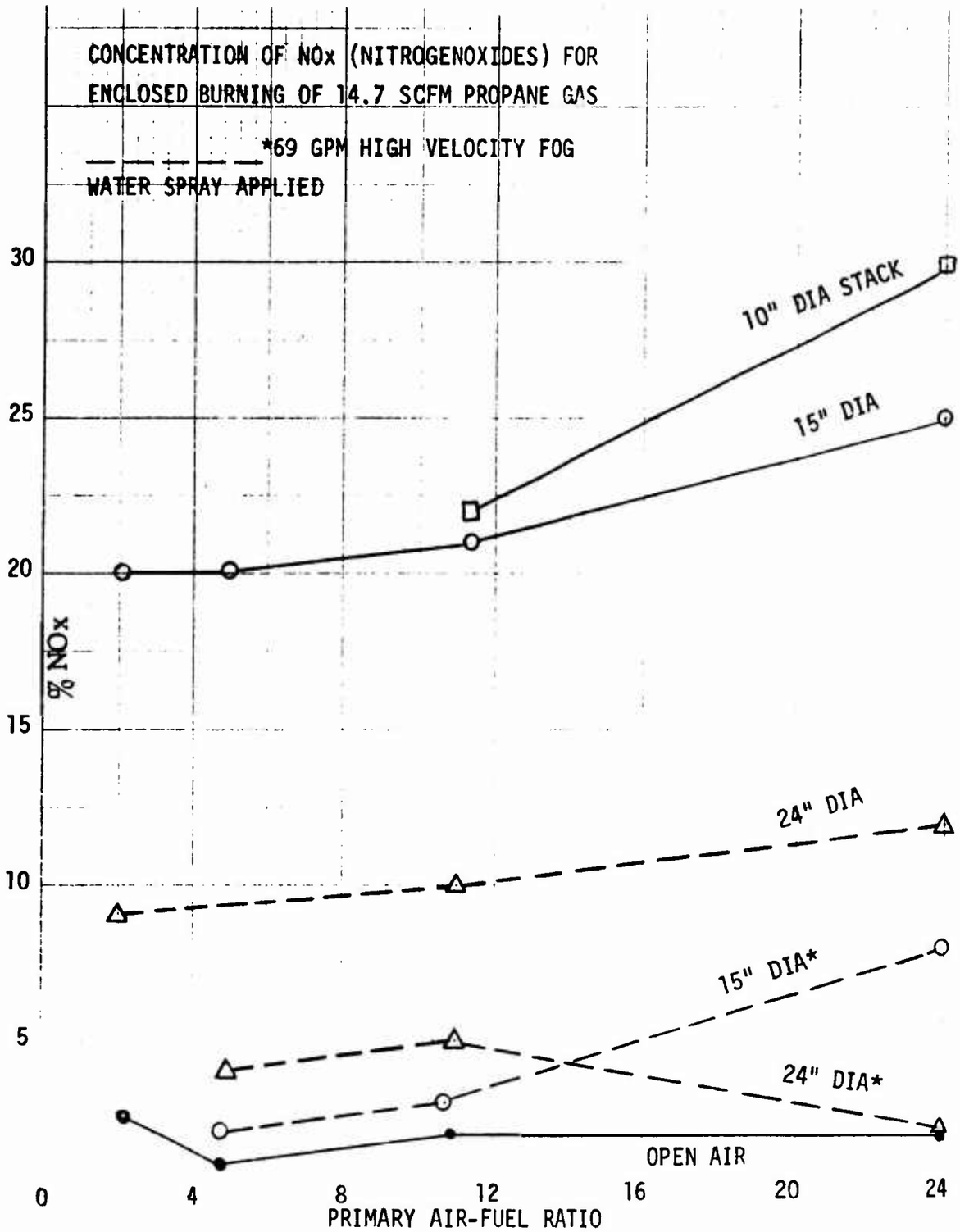

Figure 11. Concentration of NOx (Nitrogen Oxides) for Enclosed Burning of 14.7 scfm Propane Gas

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2. Wolff, H.H., Patent No. 3,675,342, Fire Fighting Trainer, July 1972.

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5. Fristrom, R.M., The Mechanism of Combustion in Flames, Chemical and Engineering News, Oct 1963.

6. National Air Pollution Control Administration Publication No. AP-65, Control Techniques for CO Emissions from Stationary Sources, U. S. Department of Health, Education and Welfare, Mar 1970.

7. Memorandum, BUMED-7321-DAM:jbw, 26 Sep 1973, Information on Carbon Monoxide Inhalation Effects; reply to request to, Bureau of Medicine and Surgery.

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