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STUDY OF THE EFFECTS OF AMBIENT CONDITIONS UPON THE PERFORMANCE OF FAN POWERED, INFRARED, NATURAL GAS BURNERS

Quarterly Technical Progress Report

For the Period January 1, 1995 -- March 31, 1995.

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TABLE OF CONTENTS

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INTRODUCTION

This quarterly technical progress report describes work performed under DOE Grant No. DE-FG22-94MT94011 during the period January 1, 1995 to March 31, 1995 which covers the second quarter of the project. The objective of this investigation is to characterize the operation of fan powered infrared(PIR) burner at various barometric pressures (operating altitude) and gas compositions and develop design guidelines for appliances containing PIR burners for satisfactory performance.

The fan powered infrared burner is a technology introduced more recently in the residential and commercial markets. It is a surface combustor that elevates the temperature of the burner head to a radiant condition. A variety of metallic and ceramic materials are used for the burner heads. It has been demonstrated that infrared burners produce low CO and NOx emissions in a controlled geometric space. As the environmental regulations become more and more stringent, infrared burners are receiving increasing interests.

In this program, the theoretical basis for the behavior of PIR burners will be established through analysis of the combustion, heat and mass transfer, and other related processes that determine the performance of PIR burners. Based on the results of this study, a burner performance model for radiant output will be developed. The model will be applied to predict the performance of the selected burner. The model will also be modified and improved through comparison with experimental results.

To conduct experimental study, an experimental setup will be devised and built. This experimental rig will be capable of measuring the combustion product output, as well as providing a means by which the radiant heat output can be measured. The burner will be selected from an existing commercial appliance that is compatible with the laboratory facilities in the Combustion Laboratory at Clark Atlanta University.

During this period, laboratory facilities that are necessary for conducting this research are completed. The student research assistants have started working in the laboratory. The selection of the test burner has completed. The preparation and instrumentation of this test burner is underway. The theoretical analysis and modeling of the fundamental combustion process of the PIR burner is progressing well. A study of the existing models are being conducted, which will yield specific direction and recommendations for the new model to be developed.

PROGRESS TO DATE

This report period covers the second quarter of the project. Two major tasks scheduled for this period are theoretical analysis and formulation of the PIR burner performance model, and the development of the experimental facilities, respectively. These tasks were started in the previous quarter and are progressing well.

PIR Burner Performance Model Development

The infrared burner, see Figure 1, is designed to use minimum air (10%-20% excess air) to achieve the maximum flame temperature and at the same time maintain stable combustion. Although this design can achieve high intensity radiation, it sacrifices the flexibility of a burner with high aeration. This results in sensitivity of its performance to fuel composition changes and other factors, including barometric pressure and humidity.

The composition of the natural gas supplied by gas companies various with time. This is mainly due to the effort for these gas companies to meet the changing demands from users including industrial, commercial and domestic gas applications. To meet the peak demand in the most economic way, it is a common practice to supplement the existing supply with a gas that can be readily obtained from available raw materials. In many situations large quantities of coke oven gas are available and may be employed for mixing with base natural gas. Mixtures of the liquefied petroleum gases, water gas, producer gas, or oil gas also offer possible choices. Generally, the gas company must make sure that the standby fuel will, when mixed with the base natural gas in the maximum proportion to which it is to be utilized, permit the continued satisfactory functioning of appliances in service. It is also the manufacturers' responsibility to design appliances capable of performing more satisfactorily under reasonably wide variations in gas composition while retaining desirable efficiencies and operation. Therefore, to study the effect of gas composition upon the performance of gas appliance is obviously of extreme importance for gas companies to evaluate the interchangeability of any supplemental gas and for manufacturers to produce

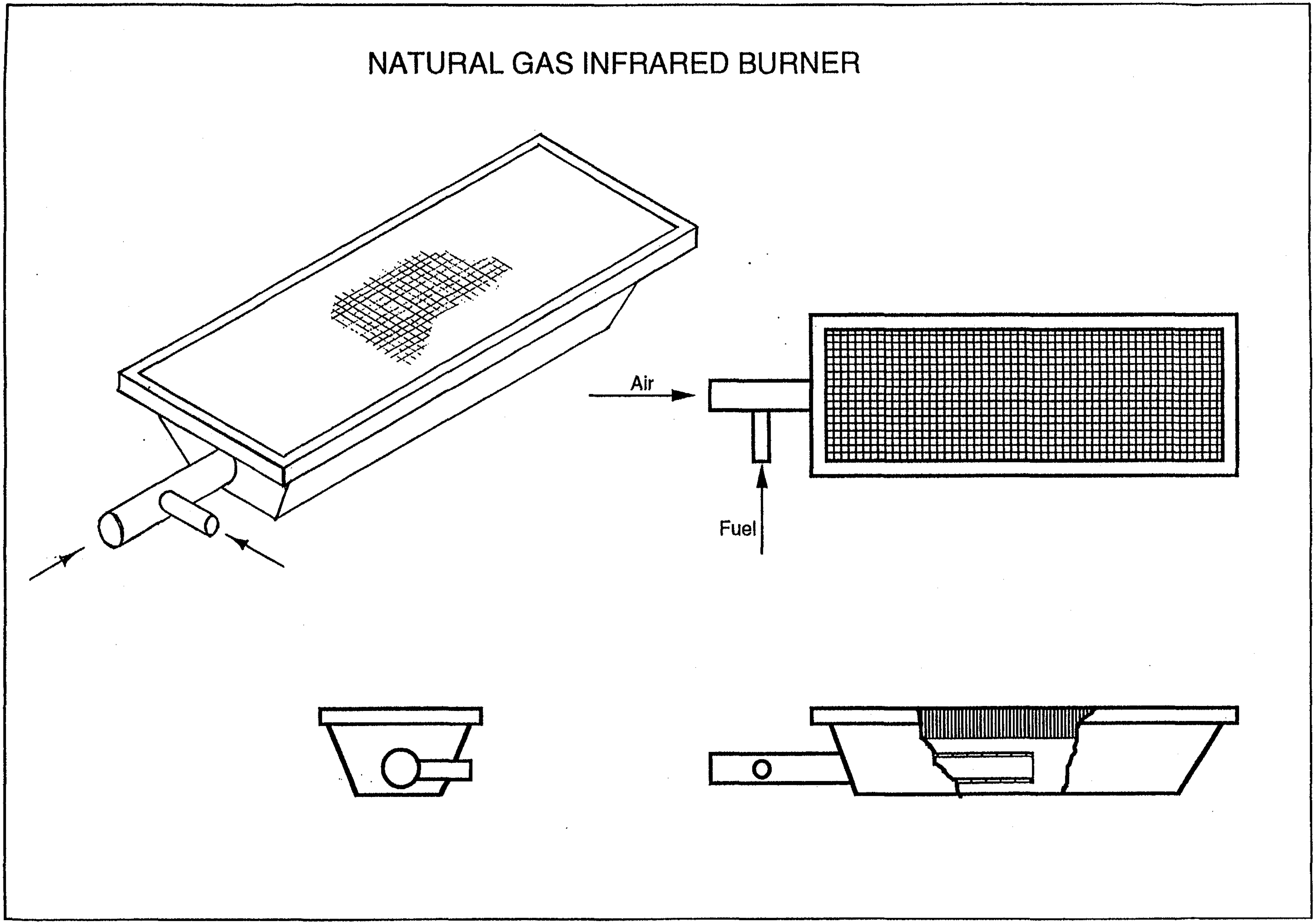

Figure 1 A schematic of the natural gas infrared burner.

more flexible gas appliances capable of accommodating variations in gas composition without readjustment.

Gas composition variations generally change the input rate, primary air injection, and flame characteristics. Changes in input rate and primary air injection are functions of the heating values and specific gravity of the gases, whereas differences in flame characteristics are dependent on changes in their chemical composition. Therefore, the study of the effects of gas composition upon the burner performance can be conducted through studying the burner's performance at various gas heating values, specific gravity and chemical compositions. Theoretical basis for the effects of gas compositions upon the performance of IR burners needs to be established through analysis of the combustion, heat and mass transfer, and other related processes. The equations that define flame speed, quench length, and adiabatic flame temperature needs to be formulated. These equations are dependent on gas heating values, specific gravity, and chemical compositions, and are commonly referred to as the interchangeability equations. By analyzing these equations, the effects of gas compositions upon the performance of the IR radiant burner can be determined.

In the following, changes in input rate, primary air injection and flame characteristics resulting from variations in gas heating values, gas specific gravity, and gas chemical composition are discussed.

The Effect of Gas Heating Values and Specific Gravity

The input rate"Q", flow of gas through an orifice in Btu per hr, varies directly as the heating value "h" of the gas, and inversely as the square root of its specific gravity "ρ", at constant pressure. This relationship is called the "input rate factor".

$$Q = \dot{m}h$$

$$\dot{m} = \rho v a$$

$$\text{input rate factor} = \frac{h}{\sqrt{\rho}}$$

Atmospheric burner is designed based on the principles of the Bunsen burner. The primary air is entrained into the mixing tube of the burner by momentum of the gas stream issuing from a orifice. The change in the thermal input rate to a burner invariably affects primary air injection, which is defined as the amount of primary air injected expressed as a percentage of air theoretically required for complete combustion. Although the volume of primary air injected remains constant for a given orifice and pressure at which it is supplied, primary air injection expressed as percentage of air theoretically required for complete combustion changes since input rate in Btu per hr varies according to the ratio $h/(\rho)^{0.5}$, assuming air required for complete combustion per unit Btu is the same for the gases. The primary air injection is directly proportional to the square roots of the gas's specific gravities and inversely proportional to their heating values, assuming air required for complete combustion per unit Btu is the same for the gas. This relationship may be regarded as the "primary air factor".

$$\text{primary air factor} = 1000\frac{\sqrt{\rho}}{h}$$

The Effect of Gas Chemical Composition

Fuel composition can dramatically influence a infrared burner's performance. A reduction of radiation output, up to 15% is reported by British Gas by switching from reference gas (100% methane) to the gas having low flame speed and requiring less air for complete combustion.[5] This is due mainly to the gas composition change, which results in the air/fuel ratio change and reduces the flame temperature. The change of fuel composition may also affect completeness of combustion and other emissions in combustion products, such as NOx.

Natural gases have as principal constituents hydrocarbons of the paraffin series, these being usually methane and ethane. In all cases, non-combustibles such as CO_2, O_2, and N_2 are found in natural gas in varying concentrations. Heating values of natural gases range generally from 1,000 to 1,150 Btu per cu ft, although in some few instances gases are distributed having a higher or lower heating value. Specific gravities vary from slightly more than 0.55 for gases comprised predominantly of methane to about 0.8 for natural gases containing large percentages of inerts (usually nitrogen).

Gases having different heating values or specific gravities invariably have different chemical compositions. Accordingly, burning characteristics of such gases will differ in important respects, one of the most important being speed of flame propagation.

The Effects of Ambient Pressure, Temperature and Humidity

The sensitivity to barometric pressure temperature and humidity is mainly due to changes in flame characters and mass and heat exchange between the flame and the environments. Low barometric pressure (high elevation) can also affect flame stability, which is observed in the AGA high altitude study.[6][7] An unstable flame burns away from the surface, reducing surface temperature and radiant output, and increasing convective output.

The ignition performance of PIR burners is also sensitive to ambient condition changes. The ignition process is affected by the flow variables such as the pressure and velocity and the fuel parameters such as air/fuel ratio and gas composition. Related studies on gas turbine combustion show that pressure and air/fuel ratio, which changes with elevation and gas composition, have a pronounced effect on minimum ignition energy.[9][10] This energy is defined as the amount of energy needed to heat to its adiabatic flame temperature the smallest volume of gas whose minimum dimension is equal to the quench distance.

The effect of ambient temperature and humidity on gas burners has been largely qualitative although a limited amount of quantitative measurements in regards to effect on emissions is reported in Sheridan (1994).[8]

Development of the Experimental Facilities

Laboratory facilities that are necessary for conducting this research are completed in this reporting period. Natural gas line and pressurized air line have been installed in the laboratory. The gas analysis station which consists of six(6) analyzers and two(2) sampling units have been installed and now are being calibrated.

The instrument that is to be used to measure the radiation from the burner has not been ordered yet. Several options are being compared. It is expected that a decision will be made soon.

The installed gas analysis station consists of sampling probes, sample conditioning units, and analyzers of CO, CO_2, SO_2, NO_x, O_2, and Total Unburned Hydrocarbon (THC). The CO, CO_2, and SO_2 analyzers are Horiba VIA-510 series non-dispersive infrared analyzers. The NO_x analyzer is a Horiba CLA-510S chemiluminescence analyzer. The O_2 analyzer is a Horiba MPA-510 magnetopneumatic analyzer. And the THC analyzer, Horiba FIA-

510, is based on the principle of hydrogen flame ionization. The analyzers are now under calibration. It is expected that the analysis station will be in operation in May.

SUMMARY AND CONCLUSIONS

In summary, the project is progressing well. The scheduled tasks for this period of time are being conducted smoothly. Specifically:

1. Laboratory facilities that are necessary for conducting this research are completed. Natural gas line and pressurized air line have been installed in the laboratory. The gas analysis station which consists of six(6) analyzers and two(2) sampling units are being calibrated.
2. The selection of the test burner has completed. The preparation and instrumentation of this test burner is underway.
3. The theoretical analysis and modeling of the fundamental combustion process of the PIR burner is progressing well. A study of the existing models are being conducted, which will yield specific direction and recommendations for the new model to be developed. Theoretical analysis and formulation of the PIR burner performance model are progressing well.
4. The student research assistants have been selected and started working in the laboratory.
5. The Advisory Committee of the project has held its first meeting. The project PI reported the progress and the future plan. The committee discussed various technical aspects of the projects. Advice from the committee has been integrated into the working plan for next period.

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