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, 1996 -- March 31, 1996

Tiejun Bai (PI), Yaw D. Yeboah, and Ramanathan Sampath

April 1996

Grant No. DE-FG22-94MT94011

For

U.S. Department of Energy
Pittsburgh Energy Technology Center
Attn: Document Control Center
P.O. Box 10940, MS 921-143
Pittsburgh, PA 15236-0940

By

Department of Engineering
Clark Atlanta University
Atlanta, GA 30314

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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, 1996 to March 31, 1996 which covers the sixth ? quarter of the project. The objective of this investigation is to characterize the operation of fan powered infrared burner (PIR) at various gas compositions and ambient conditions and develop design guidelines for appliances containing PIR burners for satisfactory performance.

PIR burners consist of a pressurized air supply, an air/fuel mixing chamber, and a porous metallic or ceramic radiant tile. Combustion takes place within the porous tile creating a radiant heat source. One main reason for the present interest in this type of burner is its low NO_x emissions. This is attributed to the fact that a large proportion of the heat of combustion is given out as radiation from the burner surface. This results in relatively low gas temperature in the combustion zone compared to that of a conventional free-flame burner. As a consequence, such burners produce less NO_x mainly by the so called prompt- NO mechanism [1]. Applications of the radiant burners include boilers, air heaters, deep fat fryers, process heaters, and immersion heaters.

The performance of natural gas-fired heating and cooking equipment is strongly dependent on ambient conditions and natural gas composition. In the United States, ambient temperature, pressure, and relative humidity vary significantly by location and season. Also, natural gas compositions supplied by local gas distribution companies exhibit seasonal and regional variations. These variations can cause reliability and performance problems in gas-fired equipment. In service, IR burners have had reliability and performance problems, especially when exposed to various gas compositions, operating altitudes, and other ambient conditions like temperature and humidity. These parameters also effect the composition of the gaseous emissions from these burners. Burning characteristics will also differ in important respects, one of the most being speed of flame propagation. It is the responsibility of the manufacturers to design appliances capable of performing more satisfactorily under reasonably wide variations in gas composition while retaining desirable efficiencies and operation.

There have been very limited studies to investigate the effects of gas composition upon the performance of radiant burner. Due to the lack of data and fundamental understandings, the IR burner product development in the industry is empirical in nature, and is conducted with one gas composition. This project characterizes the operation of IR burner at various gas compositions and ambient conditions and develops a baseline theoretical analysis to predict the behavior of these burners to the change in fuel compositions.

PROGRESS TO DATE

This report covers the sixth quarter of the project. In this project, a unique radiation and emission measurement system has been developed at CAU's Combustion Laboratory to study the effects of gas compositions upon the performance of porous radiant burners. It consists of a PIR commercial deep fat fryer that was modified to allow in-situ radiation measurements on the

surface of the infrared burner via a view-port installed through the oil vat. A system 2000 FTIR from Perkin Elmer is used for in-situ measurements of the radiant output from the surface of the burner. A blackbody with a temperature range of 50 to 1200 degree C (model IR-564 from Graseby Infrared) was used to calibrate the FTIR. A set of Horiba gas analyzers are used to measure the emissions from the burner. Experiments are being conducted for an extensive test matrix of fuel gas mixtures that represent the complete range of gas compositions usually encountered in the United States. Methane is used as the baseline fuel. Mixtures of methane/propane, methane/hydrogen, and methane/nitrogen along with two propane-air peakshaving gas mixtures were designed to study sooting, flashback, and lift-off conditions. The performance of the burner is being examined for stability limits, radiant efficiency (ratio of radiative flux escaping the burner to the heat released by combustion), and gaseous emissions at each gas composition and air/fuel ratio.

A number of published research papers on modeling of porous burners were reviewed. The physical mechanism and theoretical analysis of the combustion process of the PIR burner were formulated. The numerical modeling and implementation of a PIR burner code at CAU's computing facility is in progress.

WORK PERFORMED DURING THIS QUARTER

An extensive test matrix of fuel gas mixtures was prepared to represent the complete range of gas compositions found in the United States (Table 1). In this matrix methane is the baseline fuel. Mixtures of methane/propane (sooting), methane/hydrogen (lightback), and methane/nitrogen (flame lift) along with two propane-air peakshaving gas mixtures have been designed to simulate variations in gas compositions. The air/fuel ratio in terms of theoretical combustion air (TA) is designed to vary between 90% -170% for each fuel mixture. The baseline TA is set at 130%.

Test results for methane/propane/air mixtures were obtained for TA ranging from 80% to 170%. Experiments were performed for various methane/propane mixtures (82/18, 88/12, 91/9, 94/6, and 97/3). For any mixture in general, radiant efficiency, CO₂ and NO_x emissions showed a steady increase up to stoichiometric and decreased through air/fuel ratio of 1.7 (see Figure 1 through 3). Unburned hydrocarbon emission continued to increase as air/fuel ratio decreased from 1 (see Figure 4).

A fuel gas mixing station (see Figure 5) was designed and constructed to supply a continuous flow of repeatable, accurate fuel gas mixtures to the fryer during the fuel composition variability testing. This mixing station consisted of four rotometers with different flow ranges connected in parallel to a mixing manifold. The constituents for the fuel mixtures, supplied by compressed gas cylinders, were mixed together in the desired volumetric ratios via the mixing station, and piped to the fryer for continuous operation. By continuously mixing the fuel mixtures from inexpensive gas constituents, the high cost for specially mixed gases would be avoided and test durations would not be limited.

A project review meeting was held at CAU to which gas companies and DOE funders were invited. Minutes were distributed under separate cover.

SUMMARY AND CONCLUSIONS

A porous radiant burner testing facility consisting of a commercial deep-fat fryer, an FTIR based spectral radiance measurement system, a set of flue gas analysis components, and a fuel gas mixing station was constructed. The measurement capabilities of the system were tested using methane and the test results were found to be consistent with the literature. Various gas mixtures were tested. Results indicated that the stability limits of the burner and emissions vary with fuel gas composition and air/fuel ratio. However, the maximum radiant efficiency of the burner remained constant. Results obtained from this study can be useful to develop optimum design guidelines for PIR burner manufacturers. Such guidelines are important for progress in natural gas utilization technologies.

OUTCOME OF THIS QUARTER

An abstract for the paper entitled "An Experimental Study of the Effects of Natural Gas Composition Variations on Fan Powered Infrared (PIR) Burners" has been submitted for presentation at the 1996 American Flame Research Committee (AFRC) International Symposium, September 30 - October 2, 1996, Baltimore, Maryland.

PLANS FOR THE NEXT QUARTER

Remaining experiments planned in the test matrix covering methane/hydrogen, methane/nitrogen, and peakshaving gases will be completed in the next quarter. Data analysis and the evaluation of the effect of fuel blends on the performance of the burner and its associated behaviors will be completed.

Environmental chamber test runs and experiments will be conducted at AGAR, Ohio.

Modification of a heat transfer model [2] to predict the burner behavior to the change in fuel compositions will be completed.

ACKNOWLEDGMENTS

This project is supported by PETC/DOE through Contract No. DE-FG22-94MT94011 and gas companies. Gas mixing station was designed, fabricated and provided by American Gas Association Research (AGAR) who are our partners in this project. Technical discussions provided by AGAR are also greatly appreciated.

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Table 1 cont'd

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Figure 1

Figure 2

C₃H₈ ↑ NO_x ↑

Figure 3

Figure 4

Gas Mixing Station

Figure 5