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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 October 1, 1995 -- December 31, 1995

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INTRODUCTION

This quarterly technical progress report describes work performed under DOE Grant No. DE-FG22-94MT94011 during the period October 1, 1995 to December 31, 1995 which covers the fifth quarter of the project.

Infrared (IR) burner is a surface combustor that elevates the temperature of the burner head to a radiant condition. Applications of the radiant burners include boilers, air heaters, deep fat fryers, process heaters, and immersion heaters. 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].

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. 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 [2]. The composition of the natural gas supplied by gas companies varies 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. Fuel 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 being speed of flame propagation. 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. 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. The objective of this investigation is to characterize the operation of IR burner at various gas compositions and develop a baseline theoretical analysis to predict the behavior of these burners to the change in fuel compositions. In this program, a unique measurement system is developed at CAU's Combustion Laboratory to study the effects of gas compositions upon the performance of IR radiant burners. Radiation and emission measurement capabilities of the CAU burner system are tested in this quarter and found to be satisfactory.

PERIMENTAL METHODS

An infrared radiant burner measurement system was devised and built. The experimental is capable of measuring the combustion product output, as well as providing a means by ch the radiant heat output of the porous radiant burner can be measured (see Figure 1).

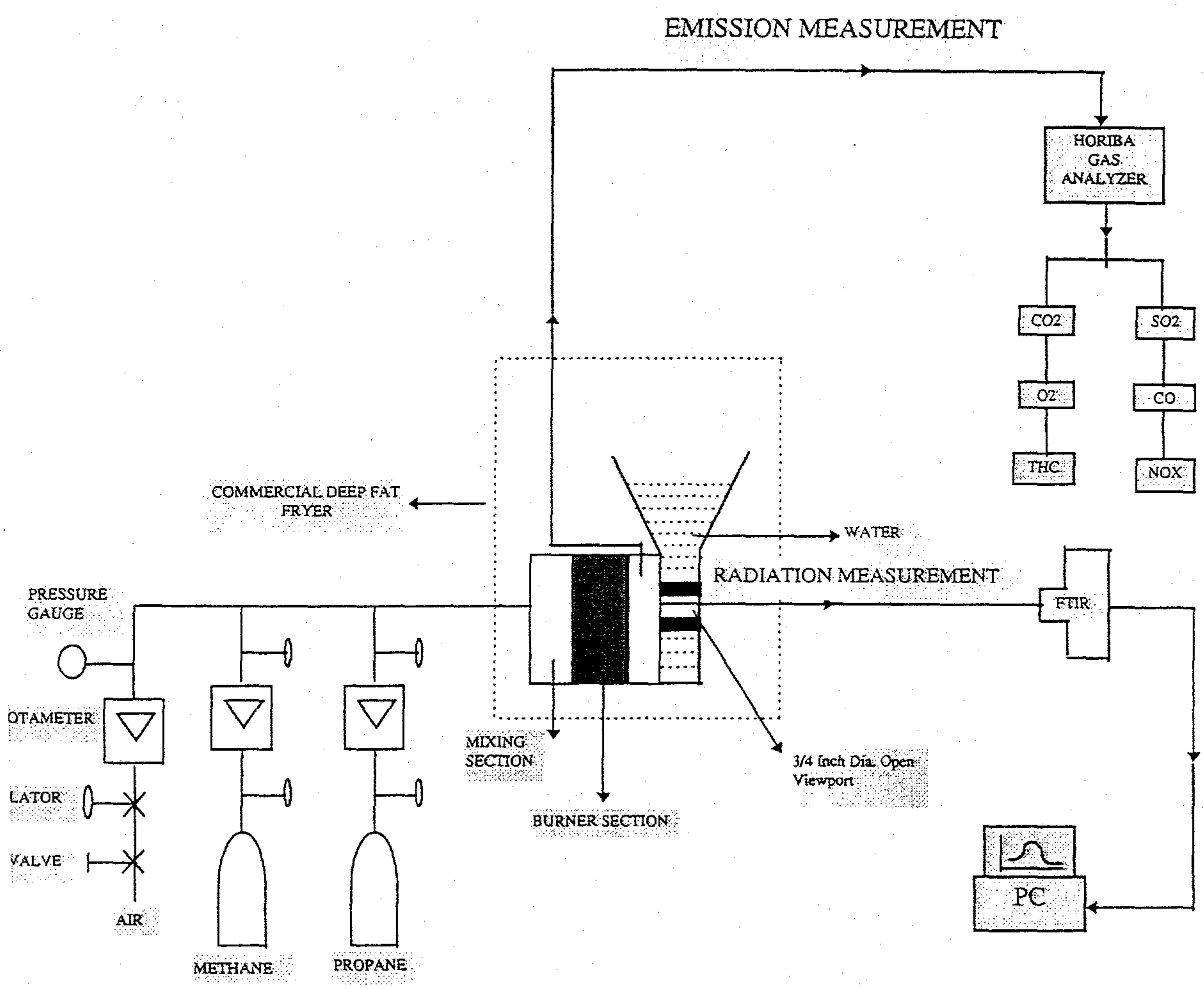

Figure 1. Schematic of the CAU Radiant Burner System

An existing commercial deep fat fryer was selected and was modified to allow in-situ ion measurements on the burner surface through a view-port. Water was used as a heat nedium. An FTIR system 2000 from Perkin Elmer was positioned in-line with the view-ınd is employed to measure the spectral radiance of the burner. A blackbody with a rature range of 50 to 1200 degree C (model IR-564 from Graseby Infrared) was used to ıte the FTIR. The burner was replaced with the blackbody during calibration. An exhaust ɔld was designed and fabricated to collect emission gas from the burner surface. On hand Horiba gas analyzer to measure the composition of the flue gas. The gas analyzer was ıted using gases of known composition.

A test matrix of gas composition was developed based on European standards for test gases. Three base limit gases, methane/propane (sooting), methane/hydrogen (lightback), and methane/nitrogen (flame lift), along with two propane-air peakshaving gas mixtures were chosen to represent the full range gas supply variation. .

In this quarter, methane was used to test the measurement capabilities. Radiant output for various methane/air stoichiometric ratios ranging from 0.4 to 1.35 were measured using the FTIR. The composition of the flue gas was analyzed for NO_x, CO_2, CO and unburnt hydrocarbon using the Horiba gas analyzer.

RESULTS AND DISCUSSION

The blackbody was set at a known temperature and the radiant output from the blackbody was measured by the FTIR. The resultant curve of relative intensity versus wavelength represented the spectral distribution of the radiant energy. The area under the curve represented the total normal radiation emitted by the blackbody at the set temperature. The experiment was repeated for an increment of 50 degrees in temperature from 750 to 1200 degree C. A calibration equation for radiant output as a function of spectrum area (see Figure 2: Y = 0.00952 X - 7.53 with an R squared value of 0.999) was then developed. Using this equation, the energy radiated by the porous burner for various fuel compositions can be determined with the FTIR without actually knowing the temperature or emissivity of the burner.

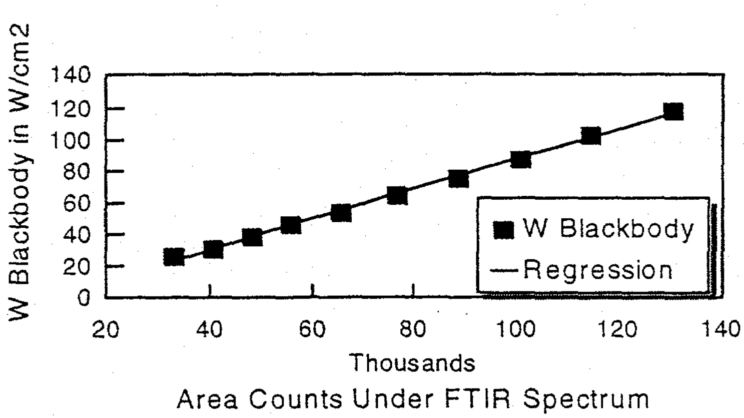

Figure 2. Calibration of Radiant Energy as a Function of FTIR Spectrum Area Counts

Radiation and emission measurement capabilities of the CAU IR burner system were tested using methane at various equivalence ratios (stoichiometric air/methane ratio / actual air/methane ratio) ranging from 0.45 to 1.35. The output radiative efficiency of the burner, defined as the ratio of the radiative flux escaping the burner to the heat released by combustion, ranged from 0.6 to 61 percent with the peak value at equivalence ratio equal to one (Figure 3). Sathe et al. [3] reported a maximum radiant efficiency of 40 % for these burners, however, our observation that leaner mixtures produced higher efficiencies is consistent with their work. The 21% excess radiant output measured by the FTIR was in large part attributed to the fact that the emission gases such as CO_2 and water also radiate heat to the FTIR. The energy spectrums obtained by the FTIR in our experiments clearly showed the peaks and surges due to CO_2 and water gases. It is consistent with the finding by Alzeta corporation [4] that the contribution of radiant energy by flue gases could go up to 25%. CO_2 and NO_x emissions showed a steady increase up to equivalence ratio one and decreased through equivalence ratio 1.35. Unburnt hydrocarbon (UHC) emission continued to increase as the mixture got richer in fuel.

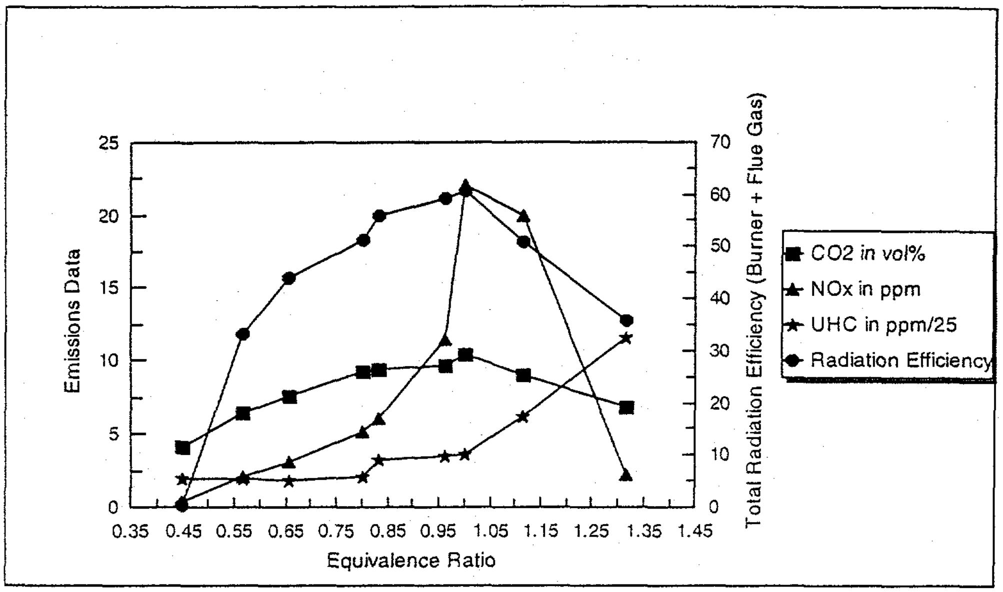

Figure 3. Radiant Efficiency and Emission Levels as a Function of Equivalence Ratio

SUMMARY AND CONCLUSIONS

A porous radiant burner testing facility was built, consisting of spectral radiance as well as flue gas composition measurements. The measurement capabilities were tested using methane and the test results were found to be consistent with the literature.

WORK IN PROGRESS

Above measurement capabilities of the CAU burner system are being applied to evaluate the effect of fuel blends on the performance of the burner and its associated behaviors such as stability limits.

Flue gas temperature measurements to determine the radiant contribution by flue gases is in progress.

A detailed heat transfer model capable of predicting the burner behavior to the change in fuel compositions is also being implemented.

ACKNOWLEDGMENTS

This project is supported by U.S. Department of Energy, through Contract No. DE-FG22-94MT94011. Modified deep fat fryer and some associated flow-line instruments were provided and installed by American Gas Association Research (AGAR) who are our partners in this research. Technical discussions provided by AGAR are also greatly appreciated.

OUTCOME OF THIS QUARTER

A paper is written on the measurement capabilities of the CAU burner system for presentation at the Fourth Annual HBCU/Private Sector - Energy Research and Development Technology Transfer Symposium sponsored by PETC/DOE at North Carolina A&T on April 2, 1996.

REFERENCES

1. Williams, A., Woolley, R., and Lawes, M., Combustion and Flame 89: 157-166 (1992).
2. American Gas Association Laboratories, GRI-82/0037, Topical Report, 1978-1982.
3. Sathe, S. B., Kulkarni, M. R., Peck, R. E., and Tong, T. W., Twenty-Third Symposium (International) on Combustion/The Combustion Institute, 1990/pp. 1011-1018.
4. Alzeta Corporation, Basic Research on Radiant Burners, GRI-92/0181, Final Report, 1987-1992.