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

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

INTRODUCTION

This quarterly technical progress report describes work performed under DOE Grant No. DE-FG22-94MT94011 during the period Septemer 1, 1996 to December 31, 1996 which covers the nineth quarter of the project. The objective of this investigation is to characterize the operation of a fan powered infrared burner (IR burner) at various gas compositions and ambient conditions 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 NO_X emissions in a controlled geometric space [1]. As the environmental regulations become more stringent, infrared burners are receiving increasing interests.

The burner tested in this project is installed in a deep fat fryer. It consists of a pressurized air supply, an air/fuel mixing chamber, and a porous ceramic radiant tile., see Figure 1. Combustion takes place on the surface of the perforated ceramic tile creating a radiant heat source. One main reason for the present interest in this type of burner is its low NOx 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. Applications of 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 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 project consists of both experimental research and numerical analysis. To conduct the experiments, an experimental setup has been developed and installed in the Combustion Laboratory at Clark Atlanta University, see Figure 2. This setup consists of a commercial deep fat fryer that has been modified to allow in-situ radiation measurements on the surface of the infrared burner via a view port installed on the side wall of the oil vat. Proper instrumentation including fuel/air flow rate measurement, exhaust gas emission measurement, and radiation measurement has been developed. Since accurate IR radiation measurement plays a critical role for the success of this project, various instrumentation to measure the radiant output from the infrared burner have been evaluated. In the developed experimental setup, an FTIR, System 2000 from Perkin Elmer is used for in-situ measurements of the radiant output from the surface of the burner. A blackbody with temperature range of 50 to 1200 degree C (model IR-564 from Graseby Infrared) is used to calibrate the FTIR. A set of Horiba gas analyzers is used to measure the emissions from the burner. Experiments were 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 are tested to study the effect of fuel mixtures on the performance of the radiant burners. The performance of the burner are investigated in terms of its radiant efficiency (ratio of radiative flux generated by the burner to the total energy input by fuel) and gaseous emissions at various gas composition and air/fuel ratio.

Progress in Experimental Studies

To date, the experimental tests have been completed. Tests have been 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 are tested to study the effect of fuel mixtures on the performance of the radiant burners. The performance of the burner are investigated in terms of its radiant efficiency (ratio of radiative flux generated by the burner to the total energy input by fuel) and gaseous emissions at various gas composition and air/fuel ratio.

Radiant Efficiency

The radiant efficiency of the infrared burner is defined as the ratio of the radiative flux escaping the burner to the heat released by combustion. Test results for methane, methane and propane, and methane and hydrogen fuels were obtained for equivalence ratio from 0.7 to 1.3. Experiments for methane/propane mixture were performed in which the propane content was 1.22% in volume. Experiments for methane/hydrogen mixture were performed in which the hydrogen content was 5.74% in volume. The results are shown in Figure 3. It is found from the test results that, in general, radiant efficiency increases steadily first and then decreases. The maximum is at or close to the stoichometric. The methane/propane mixture produced the highest radiant efficiency which is close to 40%, compared to 30% for the methane alone.

Gaseous Emissions

Gaseous emissions from the IR burner were measured using Horiba gas analyzers. Test results were obtained for equivalence ratio from 0.7 to 1.3. To elucidate the effects of fuel compositions upon the emissions from the burner, pure methane and mixtures of methane/propane and methane/hydrogen were employed as fuels. Experiments for methane/propane mixture were performed in which the propane content was 1.22% in volume. Experiments for methane/hydrogen mixture were performed in which the hydrogen content was 5.74% in volume. Tests results for CO, NOx, CO_2 are presented in Figures 4, 5, and 6, respectively. As shown in Figure 4, the CO concentration in the exhaust stream remained lower than 50 ppm for all three fuels when equivalence ration is under 1, namely, the fuel lean operating conditions. Under fuel rich operating conditions, the CO concentration increased dramatically and exceeded the upper limit of the measurement instrument. This dramatic increase of CO concentration indicated incomplete combustion of the fuels. Figure 5 shows the NOx emissions when different fuels were burnt. It is interesting to note that both the pure methane and the methane/propane mixture produced very similar NOx emissions with maximum just over 20 ppm. In comparison, the methane/hydrogen mixture reached its NOx maximum of 15 ppm, which is significantly lower. In all these cases, the NOx maximum always occurred close to the stoichiometric but under fuel rich conditions. The CO_2 emissions are shown in Figure 6. As expected they reach their maximum at the equivalence ratio of 1.

Effects of Operating Altitude

To determine the effects of the operating altitude upon the burner performance, tests were conducted at three different altitudes, which rang from 800ft to 6800ft. These tests were conducted in Utah area, using a mobile lab facility. Figure 7 and 8 show the CO and NOx emissions from the burner. Instead of equivalence ratio, excess air is used in these figures. Examination of these figures indicates that effect of operating altitude upon the CO emissions was not significant. When there was twenty percent or more excess air, the CO emissions were all close to zero. However, the NOx emissions varied significantly from the low altitude to the high. The test at the altitude of 4350ft produced a much lower NOx emission compared to the tests at 800ft and 6800ft, see Figure 8. This can be explained by studying the tile temperature measurement results, which is shown in Figure 9. It can be seen that the tile temperature when the burner is operated at 4350ft was always about 100F lower than that when the burner is operated at 800ft. As a result, the thermal NOx produced was lower. The exact reason why the tile temperature is lower at this altitude is still under investigation.

In summary, the effects of fuel compositions and operating altitude upon the gaseous emissions and radiant efficiency are studied. Analysis of the results has indicated following conclusions:

1. The radiant efficiency is strongly dependent upon the fuel composition. Addition of a small amount of propane in methane produced a significant increase of radiant efficiency.
2. Compared to CO and CO_2, the NOx emissions from the burner are strongly affected by the fuel compositions.
3. Operating altitude plays a significant role in the NOx emissions from the burner. The tile temperature also varied significantly. Detailed analysis is needed for this effect.

Progress in Numerical Analysis

A physical model of the infrared burner can be described as follows: the mixture of air and fuel enter the perforated ceramic tile of approximately 13 mm thick, the mixture is gradually heated and combusted while it is flowing through the tile. The enthalpy of combustion released in the gas phase heats the ceramic tile which then emits thermal radiation to a heat load. This process has been modeled by researchers using conduction, convection, radiation, combustion (heat generation), and premixed flame model for one or more outputs such as surface temperature, gas temperature, temperature within the porous layer, flame speeds/flame locations, radiant output, efficiency, and emissivity [1]-[6].

Research collaboration with Energy International (EI) to successfully complete the modeling effort in this project has been initiated in the fall of 1996. Engineers at EI conducted a separate literature review on the radiant burner modeling and came to the same conclusion CAU made previously; i.e., the most sophisticated model reported in the literature was developed by Sathe et. al. [1] at Arizona State University (ASU). The model developed at ASU incorporates the effects of convection, conduction, radiation, and combustion on the performance of radiant burners. The flow is assumed to be one-dimensional, steady, and laminar. The solid matrix is assumed to be gray and to emit, absorb, and scatter radiant energy. Gaseous radiation is neglected compared to solid radiation. Non-local thermal equilibrium between the gas and the solid phase is accounted for by considering separate energy equations for the two phases. Details of the governing equations and solution algorithm can be found in the paper by Sathe et al.

In the current investigation, the model developed by Sathe et al. has been acquired from ASU. The model is being modified to account for variable fuel composition, aeration effects, and operation at altitude. The existing model has been coupled with the most recent version of CHEMKIN (currently known as CHEMKIN-II), which provides the necessary capabilities for the model to account fuel composition, aeration, and altitude, as well as improve solution convergence. The updated version of PREMIX also provides improved convergence over the original version used in the existing code. This improved convergence and stability provided by the updated PREMIX significantly decreased the computational cost associated with obtaining a converged solution.

SUMMARY AND CONCLUSIONS

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

1. Experimental study at CAU has been completed. The data are now under detailed analysis and will be reported in next quarterly report.
2. Theoretical formulation and analysis of the PIR burner performance model are continued. Preliminary results have been obtained.
3. A paper will be presented at the Fifth Annual HBCU/Private Sector/Fossil Energy Research and Development Technology Transfer Symposium, March 5, 1997.

4. An astract of paper has been submitted for presentation at Spring Technical Meeting of the Central Stats Section of the Combustion Institute, Point Clear, Alabama, April 27-29, 1997.

PLANS FOR THE NEXT QUARTER

The major task remaining is to complete the numerical analysis and modeling of the burner. This part of research has been initiated and will continue. It is expected that significant progress will be obtained in next quarter.

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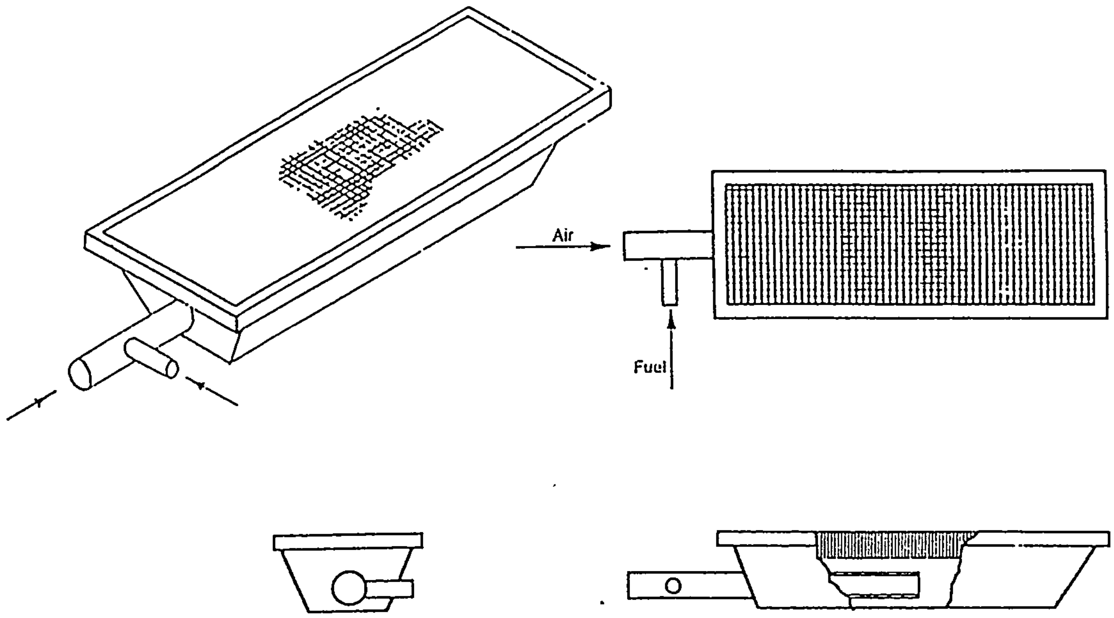

Figure 1 A schematic of the infrared burner.

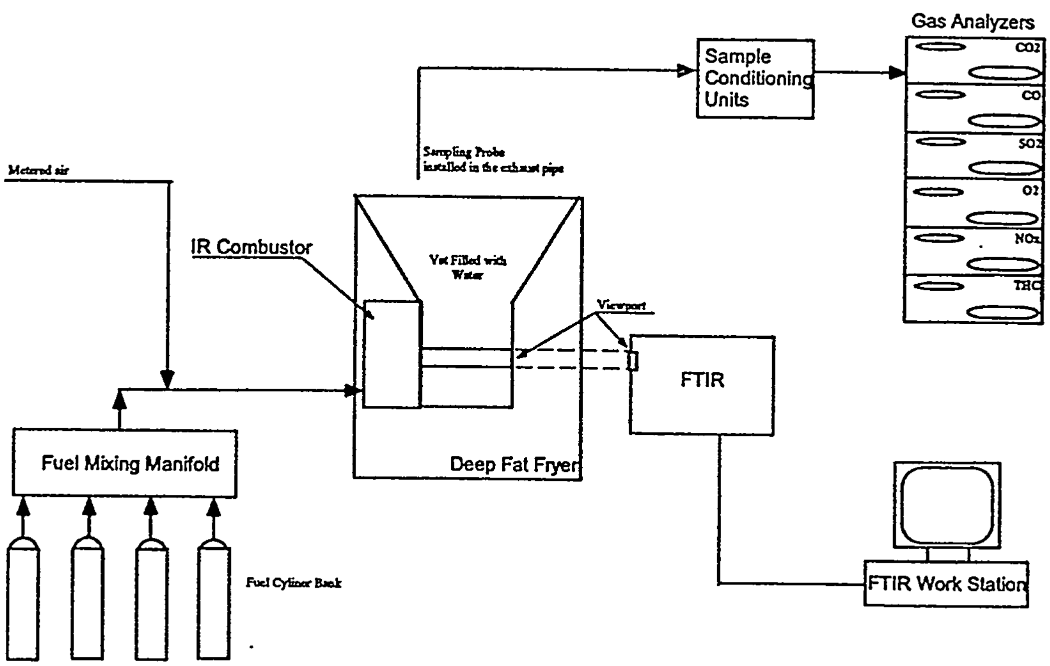

Figure 2 A schematic of the experimental setup.

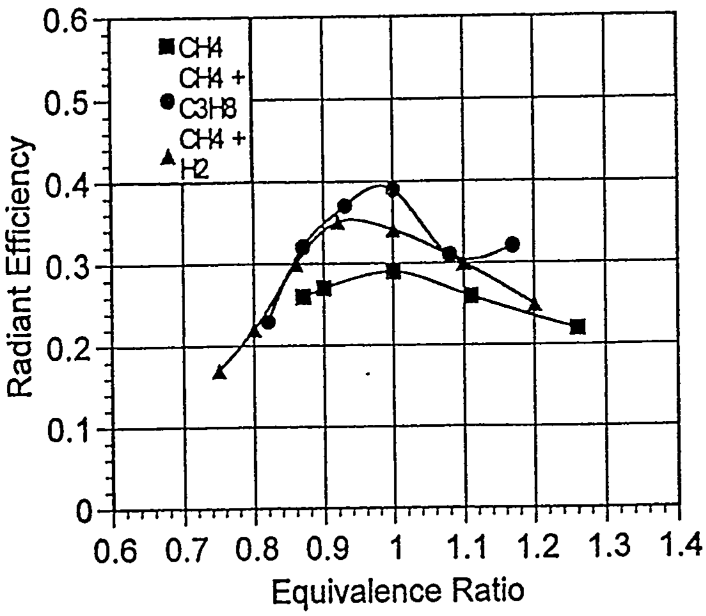

Figure 3 Effects of fuel compositions upon the radiant efficiency.

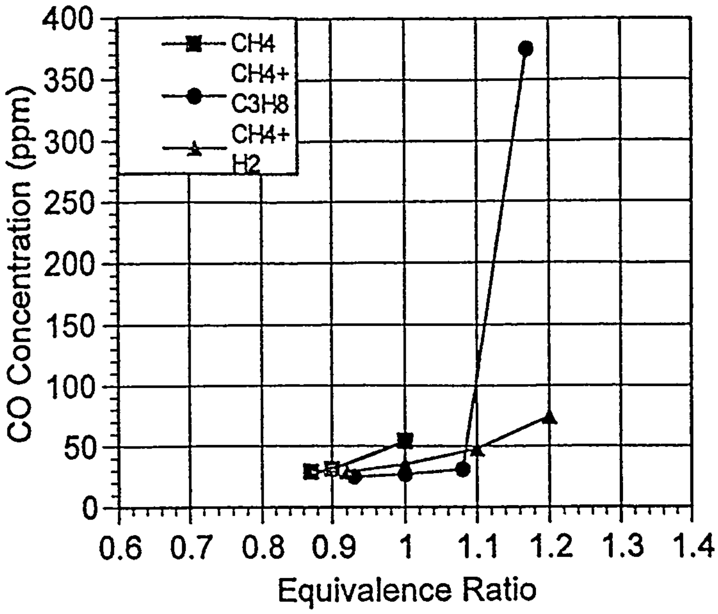

Figure 4 Effects of fuel compositions upon the CO emissions.

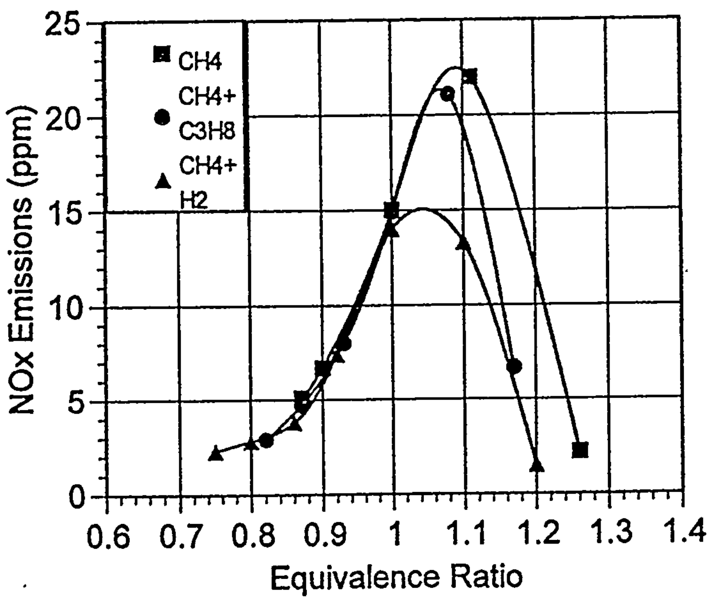

Figure 5 Effects of fuel compositions upon the NOx emissions.

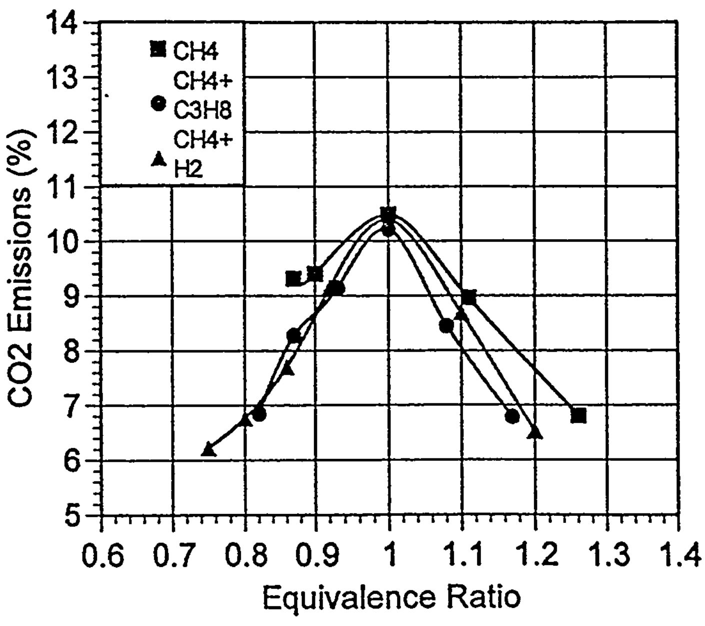

Figure 6 Effects of fuel compositions upon the CO_2 emissions.

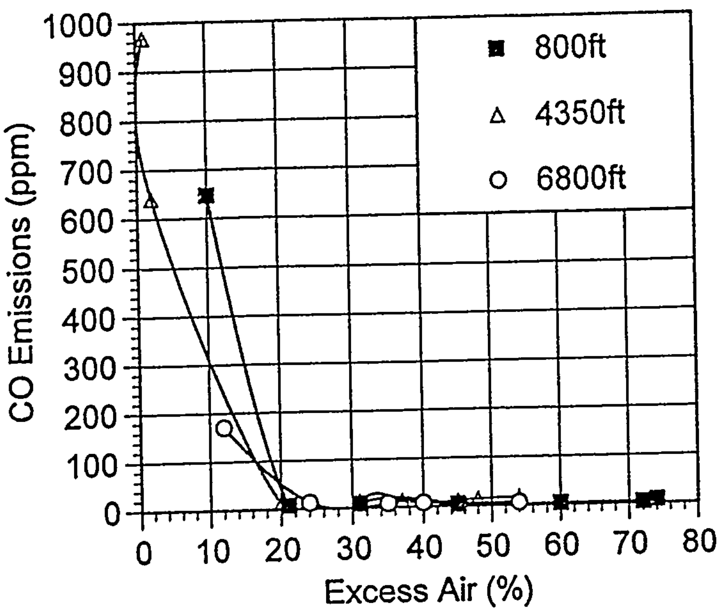

Figure 7 Effects of operating altitude upon the CO emissions.

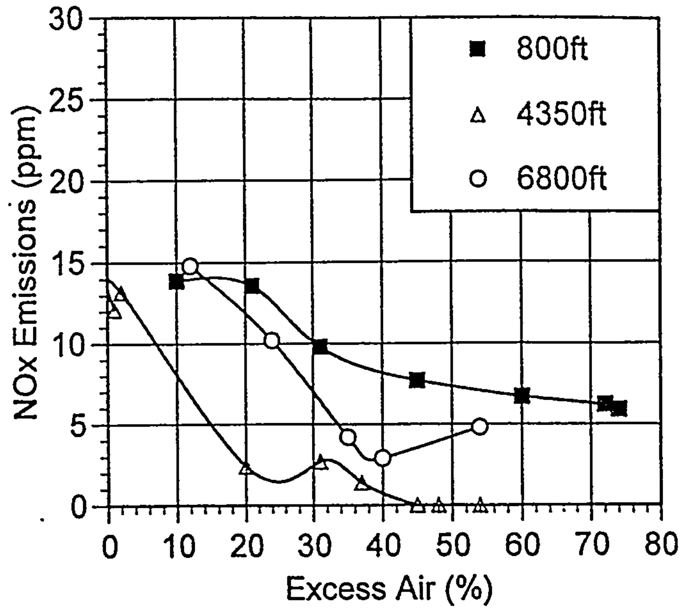

Figure 8 Effects of operating altitude upon the NOx emissions.

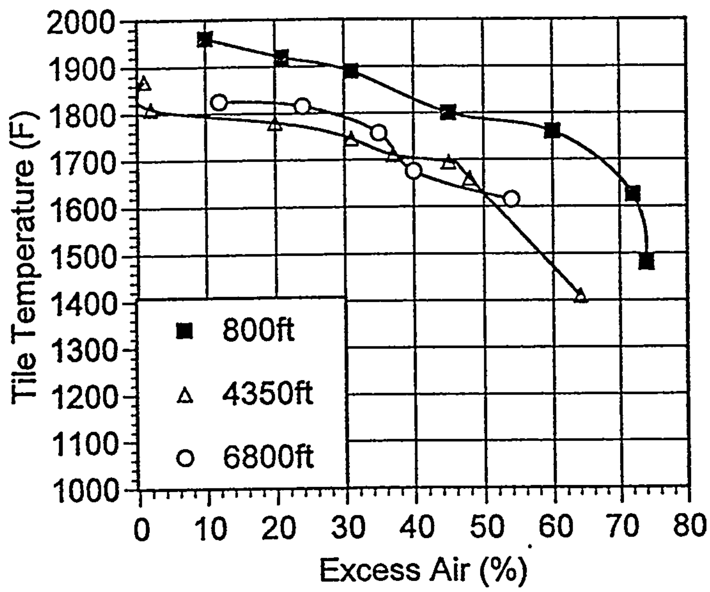

Figure 9 Effects of operating altitude upon the tile temperature.