Combustion of Gaseous Fuels with High Temperature Air in Normal- and Micro-gravity Conditions

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Summary

The objective of this study is determine the effect of air preheat temperature on flame characteristics in normal and microgravity conditions. We have obtained qualitative (global flame features) and some quantitative information on the features of flames using high temperature combustion air under normal gravity conditions with propane and methane as the fuels. This data will be compared with the data under microgravity conditions. The specific focus under normal gravity conditions has been on determining the global flame features as well as the spatial distribution of OH, CH and C_2 from flames using high temperature combustion air at different equivalence ratio.

Introduction

The highly preheated air combustion is a new concept on combustion and heat transfer technology, and its application is enormous including furnaces for various industrial purposes and combustion engines. In furnaces it can reduce the fuel consumption by up to about 50%, reduce the size of the equipment or increase the throughput for the same size of the equipment, and reduce the emission of pollutants by about 30% (including CO_2) without any adverse effort on thermal loading or performance of the system. In this method low oxygen concentration air is used for the combustion of fuels. In order to explore the potential of highly preheated air combustion, we examine the basic differences in the combustion behavior of theses flames under normal and microgravity conditions. The flame characteristics have been found to be significantly different using high temperature combustion air as compared to the results obtained with normal temperature combustion air.

Normal Gravity Studies

In the normal gravity experiments, the combustion air is preheated to temperatures from 900 °C to 1100 °C. The oxygen concentration in the combustion air is varied from 21% to about 2% to produce ultra-lean mixtures. Under normal temperature conditions it is normally not possible to stabilize the flame at such fuel-lean mixtures. The results have been obtained with methane and propane as the fuels. The results showed that as the air preheat temperature is increased, the flame color as well as the flame volume changes significantly. The flame volume is significantly larger at reduced oxygen concentration of oxygen in air. The flame color changes from yellow to blue to bluish-green to green with propane as the fuel over the range of conditions examined (see Fig.1). In contrast, with methane as the fuel colorless or flameless oxidation of the fuel was observed (see Fig. 2). The flame volume is much larger at low O_2 and high air-preheat temperatures. These unique features of the flames with high temperature combustion air have not been reported before. The distribution of C_2 in flames at different air preheats temperature and O_2 concentration in air is presented in Fig. 3. The results show that the gradients of C_2 at low O_2 concentration air and high air preheat temperatures are much less as compared to its counterpart. The spectral characteristics showed significant peak at the swan band for C_2 (at 516.5 nm, see Fig. 4) at high temperatures for the propane flame. This peak is directly responsible for the observed green color flame of propane flame. The experiments conducted under normal gravity conditions provide guidelines for the design and experiments under microgravity conditions. The usual philosophy is that with an increase in combustion air temperature the formation of NO_X will be higher. However if the oxygen concentration in air is reduced the NOx emission can be reduced significantly under high temperature air conditions. The experiment performed under normal gravity has shown that the use of high temperature combustion air provides uniform distribution of temperature in the flame and hence a uniform heat flux distribution in the combustion zone.

Microgravity Combustion Studies

The experimental facility for use in microgravity combustion conditions has been designed. Various parts for the facility have been assembled. The burner assembly consists of a cylindrical burner in which the fuel is injected on the central axis surrounding which high temperature combustion air is injected. The high temperature is produced by electrically heating the air. The tests conducted showed that the temperature air could be raised to about 1100°C using electrical heating elements. This raised the issue of touch temperature of the other parts in the facility. Calculations revealed that the one can run the facility in excess of 10 minutes before the temperature in the drop rig can be 40°C. Therefore one can run the tests in the drop tower and aircraft for several seconds without having concern on the touch temperature rise in the experimental rig. The oxygen concentration in the combustion air will be varied using bottled gas having desired composition of the O_2 and N_2 mixture. This procedure will also allow us to easily change the N_2 in the air with CO_2. The reason for changing the N_2 with CO_2 is that in our normal gravity experiments significant differences were found in the flame combustion characteristics between the two gases. The flame global features will be observed using an CCD and digital cameras. The data will be stored on a computer in the rig and then transferred to an external computer after the tests for further processing the data. Tests will be conducted with combustion air preheat temperatures in the range of approximately 900 to 1100°C. The O_2 concentration in the combustion air would be varied from 21% down to 2% in discreet steps at any air preheat temperature. Nitrogen or CO_2 will be used as the dilution gas to reduce the concentration of oxygen in the combustion air.

The microgravity studies will be conducted first in the NASA 2.2 second drop tower facility and then in the KC 135 for longer duration tests. The drop rig would consist of an air preheater, burner, combustion chamber, gas cylinders, CCD and digital cameras and associated lens, filters and associated optical mounts, battery packs and a computer. An electrical heater will be used to preheat the air to the desired temperature. A schematic diagram of the preheater used for microgravity studies is presented in Fig.5. The flame obtained is given in Figure 6. The combustion chamber shown in Figure 7 is used for the microgravity studies.

Specify measurements to be made at micogravity will include measurements similar to those conducted under normal gravity conditions, namely, flame size and shape, and time resolved spatial distribution of OH, CH and C_2 from the flames. These data will then be analyzed to determine the role of microgravity on the flame behavior. Our studies will further provide means of controlling the flame signatures and flame radiation in addition to providing a database for model validation and model development.

Acknowledgements

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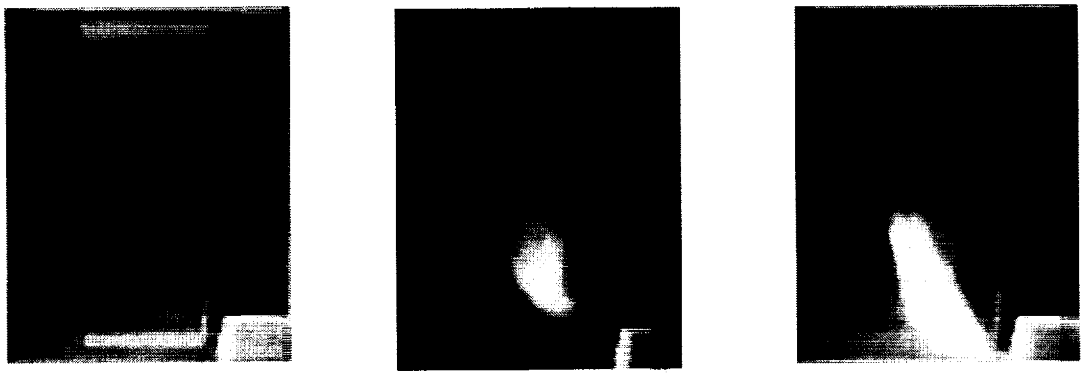
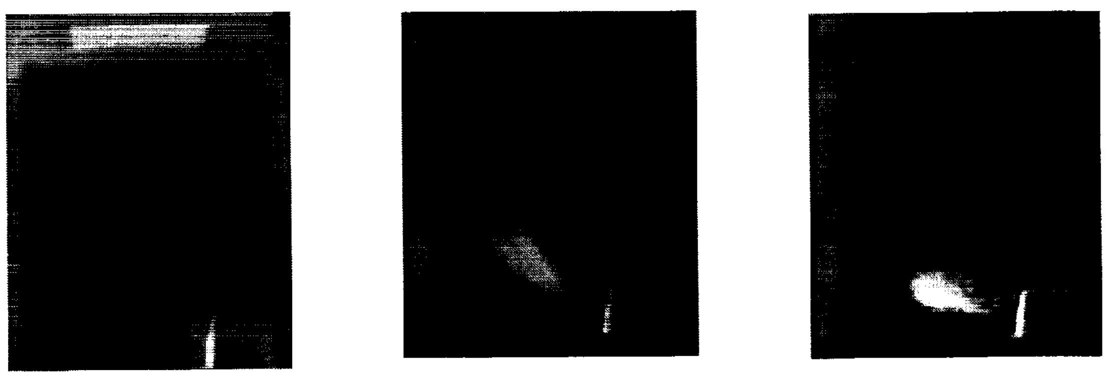


2% (Φ=0.83)
EGR=949%
1100 °C

8% (Φ=0.21)
EGR=163%
950 °C

21% (Φ=0.079)
EGR=0%
900 °C

Figure 1: Propane Flame (note the green color at low O_2 concentration in air)

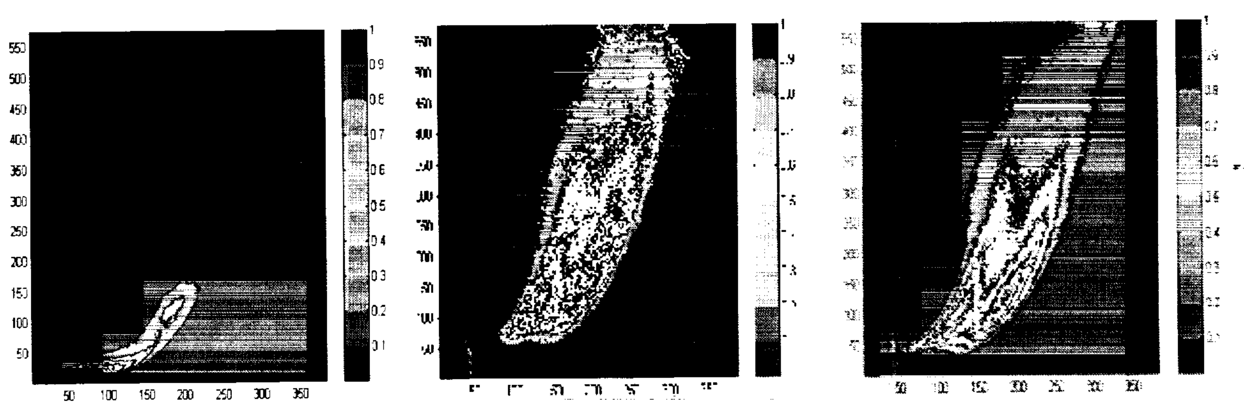


2% (Φ=0.3)
1100°C

8% (Φ=0.08)
950°C

21% (Φ=0.031)
900° C

Figure 2: Methane Flame (Note the flameless/colorless oxidation of fuel at low O_2 conc. in air)



C2 (15%) 980 °C

C2 (15%) 1070 °C

C2 (15%) 1160 °C

Figure3. Effect of Air Preheat Temperature on the Distribution of C_2 in Flames

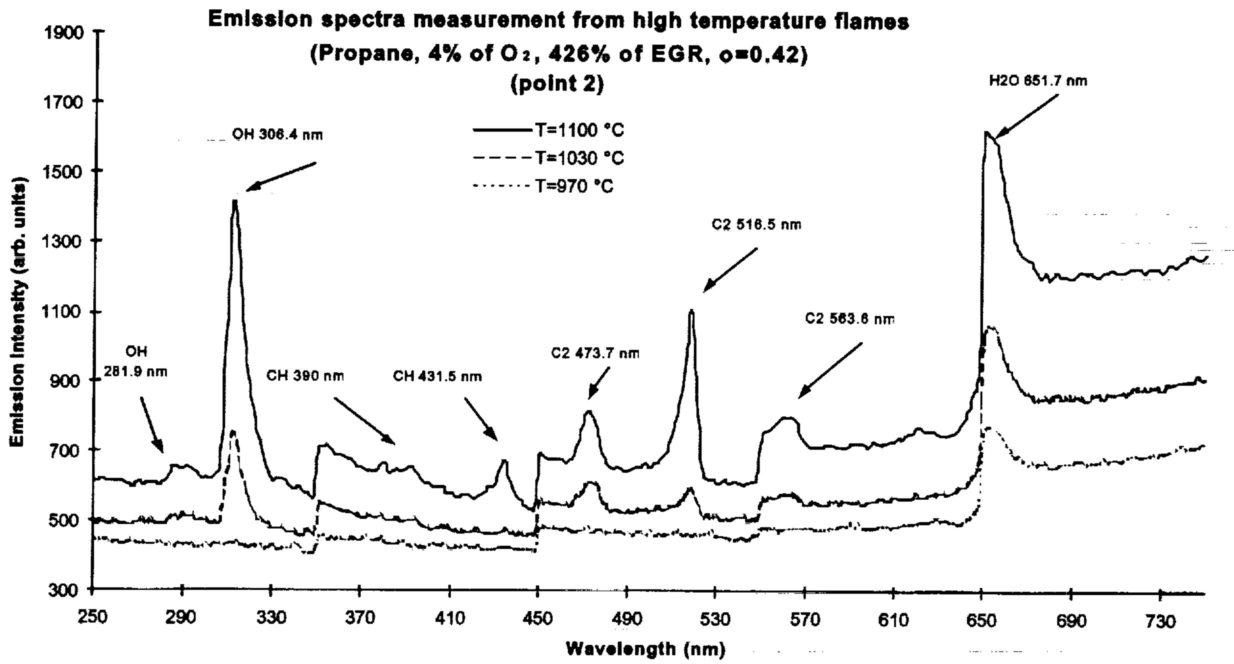


Figure 4. Emission Spectra of Propane Flame at Normal Gravity

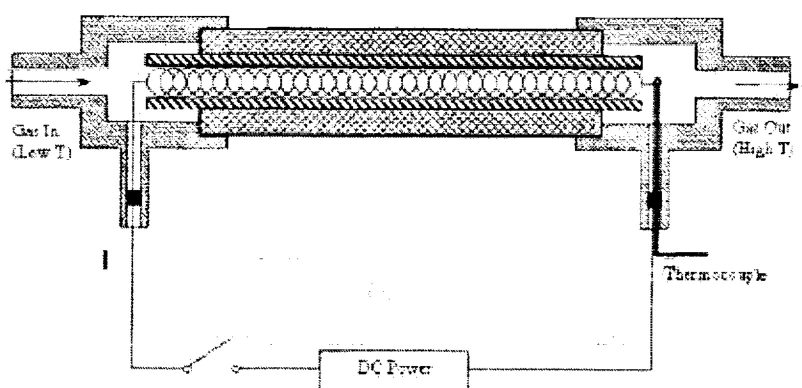


Figure 5. Air Preheater Assembly

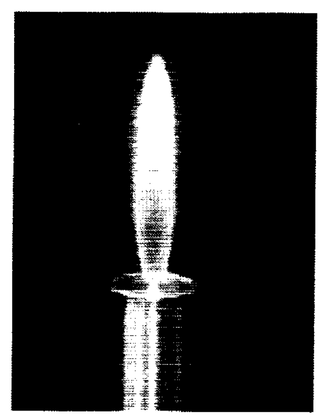


Figure. 6. Flame at 1g

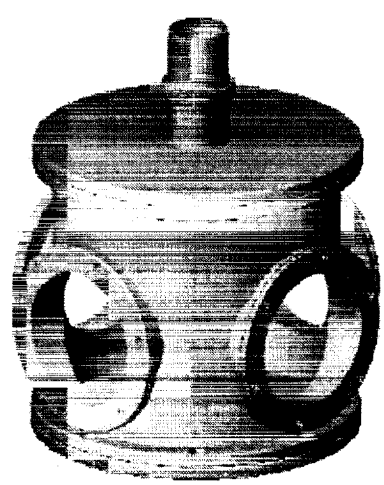


Figure 7. Combustion Chamber for the µg Rig