Characteristics of Gaseous Diffusion Flames With High Temperature Combustion Air in Microgravity

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Abstract

The characteristics of gaseous diffusion flames have been obtained using high temperature combustion air under microgravity conditions. The time resolved flame images under free fall microgravity conditions were obtained from the video images obtained. The tests results reported here were conducted using propane as the fuel and about 1000°C combustion air. The burner included a 0.686 mm diameter central fuel jet injected into the surrounding high temperature combustion air. The fuel jet exit Reynolds number was 63. Several measurements were taken at different air preheats and fuel jet exit Reynolds number. The resulting hybrid color flame was found to be blue at the base of the flame followed by a yellow color flame. The length and width of flame during the entire free fall conditions has been examined. Also the relative flame length and width for blue and yellow portion of the flame has been examined under microgravity conditions. The results show that the flame length decreases and width increases with high air preheats in microgravity condition. In microgravity conditions the flame length is larger with normal temperature combustion air than high temperature air.

Introduction

Study of laminar diffusion flames has important role to understand and utilize their thermal and chemical behavior in practical combustion systems. The flame length and width is an important property of laminar flames. No previous data are available on the effect of combustion air preheat in microgravity conditions. Combustion with high temperature air is a relatively new concept and has many practical benefits [1,2]. Some of the benefits of using high temperature air for combustion that have been demonstrated include (i) energy savings of about 30%, (ii) pollution reduction, including NO_x and CO_2, by about 30%, (iii) 25% reduction in the size of the equipment, and (iv) far uniform thermal field in the combustion zone. In this study we provide information on the behavior of flames formed with high temperature combustion air in microgravity.

Experimental

The experiments were conducted using a 1 sec drop tower facility. The experimental burner consisted of a 0.686 mm diameter fuel jet that was centrally located in a 12.7 mm diameter air jet. The combustion air could be preheated up to about 1100°C using electrical heating. The experiment test rig consisted of burner, voltage regulator, electrical air preheater, combustion chamber, color CCD camera, digital camcorder, and gas cylinders for fuel, combustion air and burner cooling, see Figure 1. The flame images were captured using a CCD camera in the emission mode at a framing rate of 30 frames per second and then recorded onto a digital camcorder. Experiments were conducted under microgravity conditions at normal pressure and normal oxygen concentration air using propane as the fuel at a flow rate 0.02 SCFH. The flame photographs, recorded with the color CCD camera and camcorder, were analyzed to determine the flame shape (length and width) and color.

Results and Discussion

The results are presented at two air preheat temperatures of 900^{o}C and 1000^{o}C. A sequence of diffusion flame photographs using propane as the fuel in microgravity conditions for experiments # 3 and 4 are shown in Fig. 2. In this paper results from two specific experiments with combustion air preheats at 900^{o}C (for expt. # 3) and 1000^{o}C (for expt. # 4) are reported to provide the effect of air preheat temperature on flame size, shape and color (hybrid) under microgravity and normal gravity conditions. The time sequence photos of flame during drop were recorded onto the video camera at a speed of 30 frames/s. The results show that in both cases the flames are of hybrid color consisting of initial blue color flame followed by a yellow color flame downstream of the burner. The length of the yellow color flame is higher at higher air preheat temperature (compare flame photos from experiments # 4 with # 3). The yellow portion of the flame with experiments # 4 (having higher air preheat temperature) is higher. A close examination of the entire flame length (blue and yellow portion) shows that the length of flame in experiment # 4 is shorter as compared to flames produced in experiment # 3.

The flames photographs were further analyzed with respect to the total length and width as well as the length and width of the blue and yellow portion of the flames during the entire time duration in the microgravity environment. The results for the total length and width are shown in Fig. 3. The results show shorter flame at higher air preheats temperatures (compare flame lengths in Fig. 3 for experiments # 3 and 4 at t = 0 to about t = 0.1 sec). Immediately after the onset of drop (very low microgravity conditions) the flame length for experiment # 4 (with high air preheats) is smaller. This suggests that higher temperature air reduces the flame length in microgravity. Our results obtained at 1-g conditions also showed that the flame length decreases with increase in air preheats [2] using normal O_2 concentration in air. In contrast the flame width increases with increase in air preheats under microgravity conditions (compare flame width from t =0 to about t = 0.1 for the two cases). At the onset of microgravity the flame with high air preheat temperature experiences a rapid increase in flame width (experiment # 4) as compared to low temperature air case (experiment # 3). The rate of increase of flame width is higher with higher air preheats at t =0.1 to about t = 0.2. After t = 0.2 sec both flames reach the maximum width due to lower gravity field. The change in gravity with time during the drop was calculated by balancing the force on the entire drop package (i.e., drag and gravity = mass x acceleration). At higher residence times (t) under microgravity conditions the flame length increases because of the drag and hence a higher gravity values as compared to that obtained at the onset of drop. This suggests that under microgravity conditions the flames are smaller and wider with increase in air preheats.

A comparison of the blue and yellow portion of the flame for the two experiments is shown in Figure 4. At higher air preheats the yellow portion of the flame becomes higher and the blue portion of the flame becomes smaller. Hotter flames (with higher air preheats) affect both the length and width in microgravity. The initial trend observed for the entire flame length and width applies to both flames with even greater differences in blue portion of the flame length at the two airs preheat. Global features on the change in flame length and width as affected by gravity and air preheat temperature are summarized in Figure 5. They show that high air preheats further widens the flame width and reduces the flame length in microgravity conditions.

Conclusions

Flame length decreases and the width increases under microgravity conditions. At higher air preheat temperatures the flame length decreases under microgravity conditions. Under microgravity conditions at high air preheat temperature, the flame width is even wider as compared to normal temperature air and normal gravity conditions. The flame luminosity as measured by the yellow color of the flame increases with increase in air preheats temperature under microgravity conditions. The data obtained provides useful information for model validation and model development.

Acknowledgments
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References
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2. Gupta, A. K.: Flame Characteristics and Challenges with High Temperature Air Combustion, Invited Lecture, Proc. 2nd International Seminar on High Temperature Combustion in Industrial Furnaces, Stockholm, Sweden, January 17-18, 2000.

Fig. 1. A photograph of the experimental facility.

T=0.000 sec T= 0.033 sec T=0.066 sec T=0.166 sec

T=0.000 sec T=0.033 sec T=0.066 sec T=0.133 sec

Fig. 2. Flame photos with 900°C (upper row, expt. # 3) and 1000°C (lower row, expt. #4) air preheat temperature.

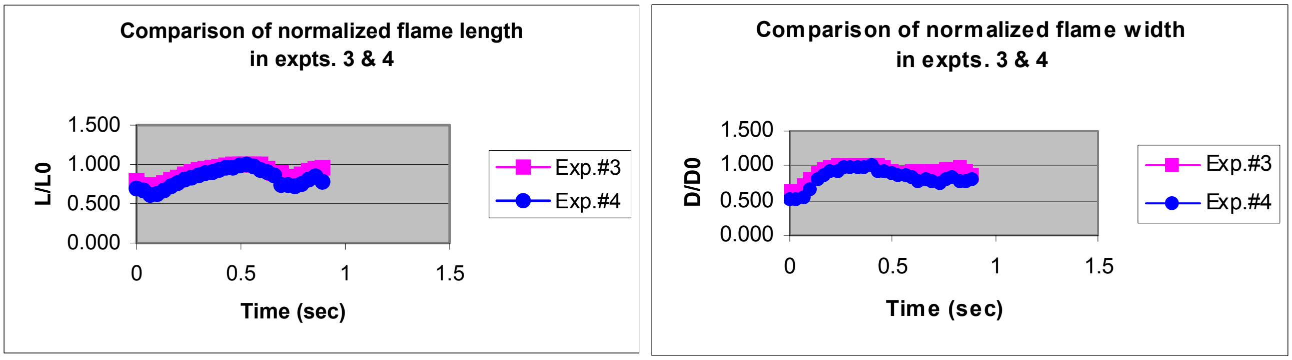


Fig. 3. Change in normalized flame length (left) and width (right) during the experiments.

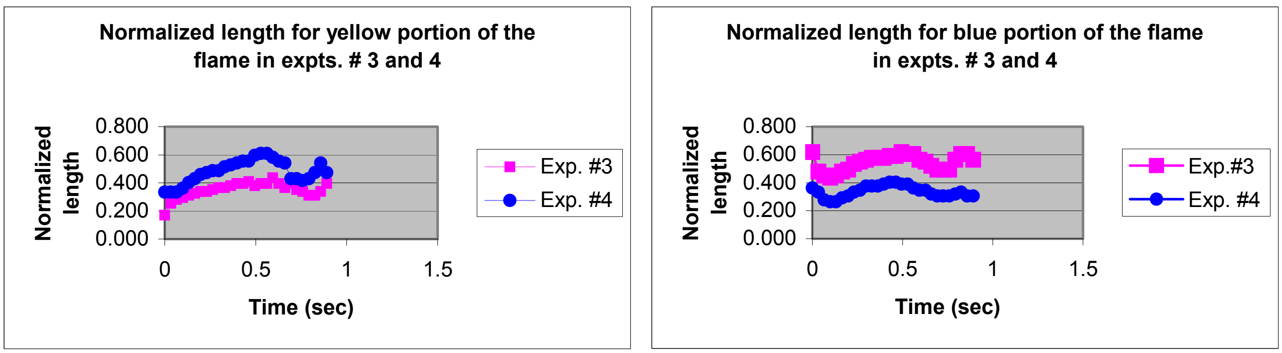


Fig. 4. Change in normalized yellow (left) and blue (right) portion of the flame length.

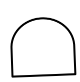
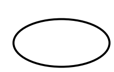
Gravity	Normal Temp. Air	High Temp. Air
1-g	 Flame shape	 Decreased flame length
μ-g	 Small and wider flame	 Smaller and even wider flame

Fig. 5. A schematic representation of the effect of air preheats temperature and microgravity on the global flame shapes.