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Measurement of Fuel Flow Behavior of Propane Diffusion Flame by Dimensionless Numbers under Magnetic Field Application

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Abstract : In this paper the interaction of fuel flow with magnetic fields and the various dimensionless numbers that are used for the characterization of the effects of the magnetic field on diffusion flames are discussed. The interaction of the magnetic field with the combustion processes occurring in a diffusion flame can be characterized by the conservation equations

Key words - Dimensionless number, Reynolds number, Grashoff number, Froude number, Temperature

1. Introduction

A diffusion flame is the area of focus since it simulates most of the combustion characteristics found in various industrial applications. Reynolds number is the ratio of the momentum forces to the viscous forces and is used to characterize the fuel flow as being laminar or turbulent. The Froude number is defined as the ratio of the initial jet momentum force to the buoyancy force and is used to ascertain if the flame is buoyancy or momentum controlled. The flame behavior with and without the application of the magnetic field and to characterize the fuel flow was assessed by dimensionless numbers such as Reynolds number, Grashoff number and Froude number.

2. Experimental set-up

Experiment is carried out in the presence of an applied magnetic field created by an electromagnet situated around the burner system and compared to a case of no applied field.

Fig.1. Experimental set-up

The various components that constitute this set-up are; the electromagnet that produces a non-uniform magnetic field, burner system which sustains the diffusion flame and thermocouple for temperature measurements of the flame. The experimental setup is shown in Fig.1.

The magnetic field is generated in the air gap of the electromagnet. A DC power supply has been used since it produces a static magnetic field. The power supply can produce voltages in the range (6V d.c–24V d.c); thus the current through the coil and hence the intensity of the magnetic field can be varied. The current through the coil and the magnetic field intensity is measured by using a multi meter and a Gauss meter with a transverse probe respectively, to accurately monitor the field intensity during the experiment. Platinum versus Platinum-10% Rhodium S type thermocouple with a bead diameter of 0.2mm was used to measure the flame temperatures. The thermo physical properties have been evaluated at room temperature and atmospheric pressure.

3. Calculation

The flame behavior with and without the application of the magnetic field was assessed by Considering the Froude number and the buoyancy force acting on the flame, the magnetic force via the dimensionless numbers. The fuel gas flow rate was monitored continuously to ensure consistency in recorded values and the following data was analyzed to ensure laminar flow conditions. All parameters are discussed in the following sections.

3.1 Reynolds number

The Reynolds number of the hot gases is determined by Eqn. 1 It is to be noted that both the fuel mass fraction ($Y_{F,\,Stoic}$) and the flame length (L_F) are included in this definition.

$$Re = V_F\, I\, Y_{F,\,Stoic}\, L_F / v \qquad (1)$$

Where; V_F is the mean burner port exit fuel velocity (m/s), (I) is the ratio of actual initial momentum to that for uniform flow, ($Y_{F,\,Stoic}$) is the fuel mass fraction, and (v) is the kinematic viscosity of the flame gases (m^2/s).

3.2 Froude number

Diffusion flames may be either buoyancy controlled (*Fr* << 1) or momentum controlled (*Fr* << 1) or in a transition region (Fr ≈ 1) The flame length has been considered as the characteristic dimension since the effect of the magnetic field is applied along the length of the flame.

$$Fr = (V_F\, I\, Y_{F,\,Stoic})^2 / \alpha\, L_F \qquad (2)$$

In the above equation the mean buoyant acceleration (α) may be determined by the following equation

$$\alpha = 0.6\, g\, (T_f/Tox - 1) \qquad (3)$$

Here, T_f is the flame temperature (K) and T_{0X} is the oxidizer temperature (K) under ambient conditions.
Temperature measurements were made in the radial direction. The thermocouple was mounted on the measurement platform and aligned along the central axis of the burner. A propane/ air diffusion flame was established for different flow rates and the temperature profiles were measured as a function radial distance at the height 5 cm, above the burner surface. These measurements were conducted both in the absence and presence of the magnetic field around the flame. A comparison was made for the maximum temperatures noted along the flame axis for the case of no applied field and with applied magnetic field. An increase of 68 K was reported for the flow velocity of 0.9cm/sec.

Fujita, et al. defined magnetic Grashoff number as the parameter to identify the regime where fluid motion due to the presence of a magnetic field would occur.The magnetic Grashoff number Gr_m is defined as the ratio of magneto buoyancy forces to viscous forces i.e.

$$Gr_m = (X_f - Xox)B\, dB/dz\, L_f^{\,3} / \mu_0\, \rho\, v^2 \qquad (4)$$

X_f is the volume magnetic susceptibility of the flame, Xox is the volume magnetic susceptibility of the flame, B is the magnetic field intensity (*Tesla*), dB/dz is the magnetic field gradient Tesla/m, L_f is the flame length (m), μ_0 is the permeability of vacuum. ρ is the density of the initial fuel jet. v is the kinematic viscosity of the initial fuel jet. This is analogous to the Grashoff number since it is expected that the differences in the magnetic forces acting on the combustion gases and the surrounding air causes a buoyancy like effect on the flame system.

Magnetic Froude number as the ratio of Reynolds number squared to the magnetic Grashoff number by including Reynolds number of the flame as given under in Eqn 5

$$Fr_m = Re^2 / Gr_m \qquad (5)$$

Table shows the calculated values of parameter for the characterization of flow field.

Velocity	Reynolds no.	Magnetic Froude no.	Magnetic Grashoff no.
0.90	0.05	1.16×10^{-6}	2.33×10^{3}

4. Conclusion

The dimensionless numbers characterizing the flame-field interaction show that the behavior of flame is affected by magnetic field's influence. The experimentally examined Reynolds number indicates that the flame gases were laminar in nature. The Froude numbers clearly indicate that they were buoyancy Controlled and the range of magnetic Froude numbers number indicate that the magneto buoyancy forces are significant as compared to the momentum forces. Further, the magnetic Froude numbers were of the order of 10-6. Also, the magnetic Grashoff number indicates that the flames lie in a region where the non-uniform field could affect combustion. These results are consistent with the Froude number calculations where it was determined that the flames are buoyancy controlled.

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