Influence of Gradient Magnetic Field on Quenching and Elongating Diffusion Flame

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Abstract – DC magnetic fields influence on quenching and elongating kerosene diffusion flame is experimentally studied by different magnetic fields. The results show that magnetic field promotes the combustion and cause to different variations in the flame front area and height. Applying magnetic field cause to decrease flame front area especially for the flame position below the magnets center line. Also, the flame height decreases below the magnets center line. For the flame above the magnets center line, decreasing product of the magnetic induction and its gradient cause to elongate the flame and then the flame height and front area decrease. These results clarify the effect of a sharp magnetic field on flame volume and height. Therefore, applying magnetic field can be considered as a flame controller.

Keywords – Diffusion Flame, Kerosene, Magnetic Field, Quenching, Elongating.

I. INTRODUCTION

Gases in the air or combustion products are either diamagnetic or paramagnetic. Diamagnetic and paramagnetic materials have different behavior in the magnetic fields. Diamagnetic materials, such as Carbon dioxide, nitrogen and most products of combustion, are repelled by both poles of a magnet. In paramagnetic materials, such as oxygen, the magnetic dipole moments of the material line up with the external magnetic field to produce a net magnetic dipole moment and slightly attracted to magnets [1].

Different values of the magnetic susceptibility of gases cause to create different magnetic body forces. The magnitude and direction of the magnetic body force follow Kelvin’s equation:

\[ F_{mag} = \frac{1}{2} \frac{x_i}{\mu_0} \nabla B^2 \quad (1) \]

Here, B is the magnetic induction or magnetic flux density measured in Tesla (T), xi is the magnetic susceptibility of gas species i and \( \mu_0 \) is the magnetic constant defined with a value of \( 4\pi\times10^{-7} \) Henrys per meter.

Table 1: Volumetric Magnetic Susceptibility of Gas Components (Room Temperature and 1 atmosphere)

<table>
<thead>
<tr>
<th>Gas</th>
<th>( X(\times10^{-9}/\text{mL}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{O}_2 )</td>
<td>152</td>
</tr>
<tr>
<td>( \text{N}_2 )</td>
<td>-0.54</td>
</tr>
<tr>
<td>( \text{H}_2\text{O} )</td>
<td>-0.58</td>
</tr>
<tr>
<td>( \text{CO}_2 )</td>
<td>-0.11</td>
</tr>
</tbody>
</table>

Table 1 shows \( x_i \) concerning combustion at room temperature [2]. The magnetic susceptibility of \( \text{O}_2 \), which is paramagnetic gas, is much larger than that of a diamagnetic gas. According to equation (1) the uniform magnetic field has no effect on the dia or paramagnetic gases [3].

The direction of magnetic body force \( (F_{mag}) \) depends on the sign of the magnetic susceptibility of gas species. Paramagnetic gas has positive magnetic susceptibility \( (X>0) \) and the direction of the magnetic force is toward the higher intensity field, while with diamagnetic gases \( (X<0) \), the force is toward the opposite direction.

In gas components present in a combustion field, O\(_2\) has the largest magnetic susceptibility. Therefore, a gas containing more O\(_2\), such as air, tends to move toward the stronger magnetic-field direction, and a gas with less O\(_2\), such as fuel or combustion gas, tends to move toward the weaker magnetic field. Based on this principle, it may be possible to utilize a magnetic field to control the flow field of the combustion region to improve the combustion characteristics [4]. Diffusion flame, which is exposed to inhomogeneous magnetic field, bends so as to escape from the magnetic fields of higher intensities [5]-[8]. This is due to the role of oxygen. Oxygen gas as a paramagnetic molecule is aligned so as to make a “wall of oxygen”. Uno proposed “magnetic curtain” or “air curtain” as a wall of air which is formed by magnetic field [6].

Oxygen or nitrogen mixed oxygen can be attracted by a magnetic field [9]. In contrast, nitrogen gas escaped from magnetic field of high intensities. Wakayama concluded that both magnetic promotion of combustion and magnetic deflection of flames can be explained by considering the flow of air caused by gradient field [10]. “Magnetoaerodynamics” was the word which used to refer the possibility of magnetic control of combustion and air flow [10].

The present paper focuses on the experimental investigation of DC magnetic fields influence on quenching and elongating kerosene diffusion flame. For these purpose, a kerosene diffusion flame put in the middle of magnet poles in the increasing and decreasing magnetic field respectively. By applying magnetic inductions to the flame, its shape will be studied experimentally.

II. EXPERIMENTAL SETUP AND MEASUREMENTS

Fig. 1 illustrates the experimental setup, schematically. The kerosene diffusion flame position in the middle of the magnet poles is depicted by fig. 1.
Experiments were carried out in ambient air at atmospheric pressure and the temperature was T=293K.

The gap of the electromagnet was 1.5cm. The magnetic field induction was measured along the vertical axis using a Gauss meter (BM421 Brochaus Messtechnik). For all measurements the expanded uncertainty was calculated according to 95% confidence level (or coverage factor k=2). A Sony Cybershot digital camera was used to record the flame. An IR filter was made and applied to block all visible light letting only infrared light pass. The Matlab image processing toolbox was then used to process each picture to evaluate and measure the variations of the flame surface and height.

III. RESULTS AND DISCUSSION

The maximum of the magnetic induction (B\(_{\text{Max}}\)), current in the magnet poles (I) and maximum of the product of the magnetic field induction (B) and its gradient (dB/dZ) is given in Figure 2. The kerosene diffusion flame was situated inside the magnetic field ±2.5 cm of the poles center.

Figure 3 illustrates the distribution of the magnetic field induction (B) and its gradient (dB/dZ) along the vertical axis. It is obviously seen that (dB/dZ)\(_{\text{Max}}\) is around ±20 mm.

Fig. 4 shows the effect of increasing magnetic field on normalized flame front area and flame height. In this experiment, the flame was below the magnets center line. For BdB/dZ=73 (T\(^2\)/m) normalized flame front area is equal to 0.37 and normalized flame height 0.23.

The figure depicts that both flame front area and flame height decrease significantly by increasing product of the magnetic induction and its gradient.

Reduction in the flame area and height is a result of the magnetic field effect on oxygen as a paramagnetic gas and diamagnetic gases. These results clarify the effect of a sharp magnetic field on flame volume. Therefore, applying magnetic field can be considered as a flame controller to decrease flame volume.

Fig. 5 depicts the effect of decreasing magnetic field on normalized flame front area and flame height. In this experiment, the flame was above the magnets center line.

This figure shows that decreasing product of the magnetic induction and its gradient cause to elongate the flame and then the flame height and front area decrease. The maximum of normalized flame height is 1.17 for BdB/dZ=-43 (T\(^2\)/m) and the maximum of flame front area equal to 1.16 for for BdB/dZ=-45.8 (T\(^2\)/m). This phenomenon is due to the magnetic body force. Oxygen as a paramagnetic material attracts to the stronger field and gas combustion products repel by magnetic field.

Pictures of quenching and elongating the kerosene diffusion flame by increasing and decreasing magnetic field are shown in fig. 6. In quenching, the flame behavior is similar to the flame under low gravity.
Fig. 4. Effect of increasing magnetic field on normalized flame front area and flame height

Fig. 5. Effect of decreasing magnetic field on normalized flame front area and flame height

Fig. 6. Quenching and elongating the kerosene diffusion flame by increasing and decreasing magnetic field

CONCLUSION

In this study experimental measurement and investigation of DC magnetic field effects on quenching and elongating kerosene diffusion flame were done. Experiments were carried out in ambient air at atmospheric pressure and the temperature was T=293K. The following conclusions were reached from the analysis of the results:

- Increasing magnetic field decrease kerosene diffusion flame front area and flame height significantly. For BdB/dZ=73 (T²/m), normalized flame front area decreases 63% and normalized flame height 77%.
- Applying decreasing magnetic field on kerosene diffusion flame cause to elongate and shorten the flame respectively. Magnetic body force act on Oxygen oppose sum of free convection force and magnetic body force act on diamagnetic gases. Therefore, the net force causes to change the flame height in the force direction.

- Oxygen has the major role on “magnetoaerodynamics” and can be considered as a special paramagnetic substance to control diffusion flames.

REFERENCES


AUTHOR’S PROFILE

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