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Numerical Simulation of Diffusion Flame in a Non-uniform Magnetic Field and Variations in Flame Shape, Temperature and NO, CO, CO_2

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ABSTRACT: The influence of magnetic field on combustion has attracted many researchers. Since the effect of the magnetic field on the gas flow and the combustion process is through volumetric electromagnetic force, the need for a numerical solution and electromagnetic simulation of the flow field is necessary to get the distribution of the magnetic field. The present study considers the numerical simulation of the diffusion flame in a non-uniform magnetic field and investigates the variations in the flame shape, temperature and NO, CO and CO_2 species. For this purpose, the electromagnetic equations and the fluid mechanics, heat transfer and the combustion equations are solved simultaneously. The results show that the volumetric magnetic force influences on paramagnetic substances (oxygen and air) and diamagnetic substances (methane and combustion products) and causes variations in the flame shape, flame temperature, and species emission. The volumetric magnetic force of decreasing magnetic field causes to slim and to elongate the flame shape and to increase in the flame temperature. Also, exerting an increasing magnetic field to a diffusion flame causes to make the flame length smaller (Mushroom-shaped) and decrease in the flame temperature. In addition to this, exerting a magnetic field to a diffusion flame can effect on pollutant emission. The results show that diffusion flame in a decreasing magnetic field produces less NO and CO pollutants. Therefore, by applying a non-uniform magnetic field, shape, temperature, and production of pollutants of a diffusion flame can be controlled.

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1- Introduction

The application of a magnetic field has recognized as a means of controlling the flow field and the kinetics of combustion to increase in efficiency and reduce in the emission of pollutants [1]. The first time, Faraday observed the effect of a magnetic field on a candle flame [2].

There are three different types of magnetism: diamagnetism, paramagnetism, and ferromagnetism. Diamagnetic substances are repelled by both poles of a magnet. In paramagnetic materials, such as oxygen, the magnetic dipole moments of the material get lined up with the external magnetic field to produce a net magnetic dipole moment and are slightly attracted to the magnets. Oxygen (O_2), as a paramagnetic matter, plays a major role in determining the behavior of air in the magnetic field [3].

This study seeks to investigate the claim that the magnetic field can control the combustion phenomenon, flame shape, flame temperature and pollution emission.

2- Mathematical Formulation

Flow and Energy [4]

Continuity:

$$div\left(\rho u\right)=0 \tag{1}$$

Momentum:

$$\frac{\partial}{\partial y}\left(\rho u\Phi\right)+\frac{1}{x}\frac{\partial}{\partial x}\left(x\,\rho v\,\Phi\right)=\frac{\partial}{\partial y}\left(\Gamma\frac{\partial\Phi}{\partial y}\right)+\frac{1}{x}\frac{\partial}{\partial x}\left(x\,\Gamma\frac{\partial\Phi}{\partial x}\right)+S_{\Phi} \tag{2}$$

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Energy:

$$\rho\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\frac{k}{C_p}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-\frac{1}{C_p}\sum_{i=1}^{N}h_i w_i+\frac{1}{C_p}\rho\sum_{i=1}^{N}Y_i f_i V_i \tag{3}$$

Equations of species:

$$\rho\left(u\frac{\partial Y_i}{\partial x}+w\frac{\partial Y_i}{\partial y}\right)=\rho D_i\left(\frac{\partial^2 Y_i}{\partial x^2}+\frac{\partial^2 Y_i}{\partial y^2}\right)+\omega_i \tag{4}$$

Magnetic field [5]

$$F_{mag}=\frac{X}{\mu_0}\vec{\mathrm{B}}.\nabla\vec{B} \tag{5}$$

3- Methodology

Two OpenFOAM software solvers have been interrelated to solve the electromagnetic equations and flow field and combustion equations. The magnetic field solver calculates the volumetric magnetic forces and these forces bring to momentum equations as source terms. The system used to run simulations has a 48GHz CPU and 256GB RAM. The time of each solution was about 72 to 168 hours, equivalent to 3 to 7 days. The flame behavior investigated in different positions of the magnetic field.

4- Results and Discussion

4- 1- The effect of non-uniform magnetic field on flame shape and temperature

Fig. 1 illustrates the methane diffusion flame shape and temperature without a magnetic field (a) and with increasing and decreasing magnetic fields (b, c respectively).

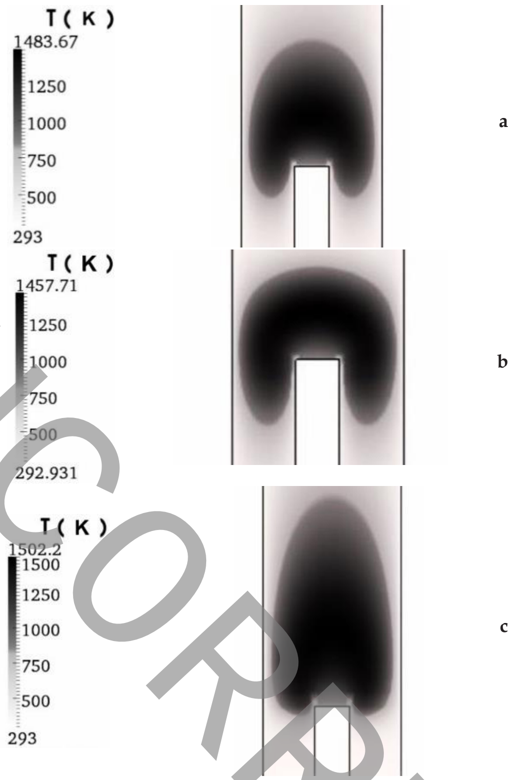

Fig. 1. a) Methane flame shape without a magnetic field, b) Methane flame shape with an increasing magnetic field, c) Methane flame shape with a decreasing magnetic field

The magnetic field attracts air into the stronger magnetic field and repels the combustion products to the weaker magnetic field. This behavior is related to the paramagnetic and diamagnetic specification of substances in the magnetic field. In the decreasing magnetic field, the flame elongates and the temperature rises. Also, exerting an increasing magnetic field to a diffusion flame causes to make the flame length smaller (Mushroom-shaped) and decrease in the flame temperature.

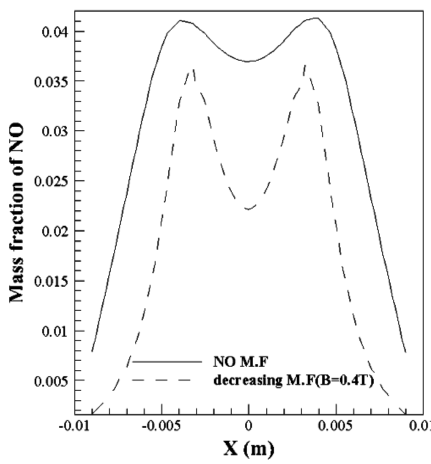

Fig. 2. The effect of a decreasing non-uniform magnetic field on NO emission without and with a magnetic field of 0.4 Tesla

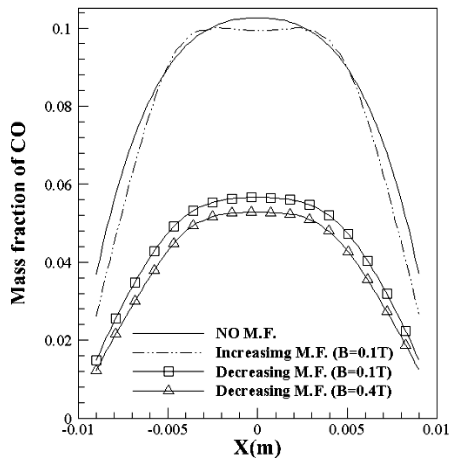

Fig. 3. The effect of non-uniform magnetic field on CO emission

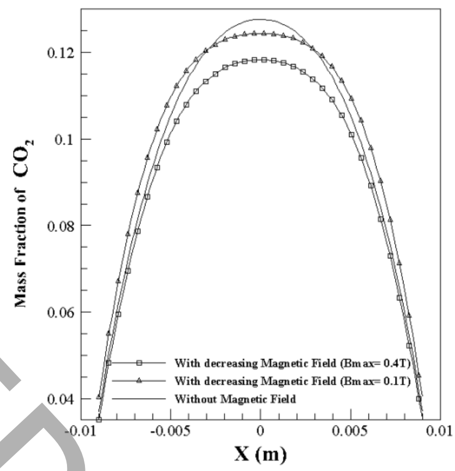

Fig. 4. The effect of reducing magnetic field with intensity of 0.1 and 0.4 Tesla on CO_2 mole fraction

4- 2- The effect of non-uniform magnetic field on NO, CO, and CO_2 emission

Fig. 2 depicts NO mass fraction along the horizontal axis in the vicinity of the fuel outlet (*X*) with a decreasing magnetic field and without a magnetic field. This figure shows that the magnetic field gradient leads to a decrease in NO emission.

Fig. 3 is the comparison of CO mass fraction emission of two different decreasing non-uniform magnetic fields and one increasing non-uniform magnetic field, with exerting no magnetic field.

Fig. 4 shows the effect of decreasing magnetic field with a maximum magnitude of 0.1 and 0.4 Tesla on the production of CO_2. It makes known that the non-uniform magnetic field with the maximum strength of 0.1 Tesla causes to increases in the volume average of CO_2 production and makes the more uniform profile of CO_2 distribution.

5- Conclusions

- The volumetric magnetic force of decreasing magnetic field causes to slim and to elongate the flame shape and to increase in the flame temperature.
- An increasing magnetic field causes to make the diffusion flame length smaller and to decrease in the flame temperature.
- Exerting a magnetic field to a diffusion flame can effect pollutant emission.
- The diffusion flame in a decreasing magnetic field produces less NO and CO pollutants.
- Applying a non-uniform magnetic field can control the flame shape, temperature, and production of pollutants of a diffusion flame.

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