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The Effects of a Magnetic Gradient on Lifted Diffusion Flames

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Abstract

Reducing pollution and increasing energy efficiency are two tests extensive studies for combustion. Methane is a fuel of choice; it releases a large amount of heat and its molecular simplicity allows it to produce less pollutants. In many systems, the use of methane combustion takes place by diffusion flame. In the present paper, we developed impact of a magnetic field gradient to develop a laminar flame with an axisymmetric actuator CH_4/air. Results are explained by the effects of magnetic force, and thermo magnetic convection which involves the thermal variation of magnetic susceptibility. The gradient of a magnetic field reduces the air velocity and the spatial gradient of the mass fraction of methane, which are important effects of reducing the lift-off height and increasing the propagation flame velocity.

Keywords: *Laminar Diffusion Flames CH4/Air, Magnetic Field, Lift-Off Height, Experimental Study, CFD.*

1. Introduction

To solve the equations assessments, FLUENT utilizes the finite volume method [1]. This method is to integrate on a control volume balance sheet equations [2]. After these equations were discredited, conditions for defined limits must solve the system of equations. Combustion process control is of a considerable interest at both scientific and economic levels, as it is connected with the problem of energy efficiency and ecological improvement. Among the numerous methods of combustion control, the application of a magnetic field is one of the most promising [3-6]. The authors have shown an increase of the combustion rate only in the specific configuration of combustion of solid propellant in rocket motors. Inducing a Lorentz force opposed to the flow of ionized gaseous products decelerated the flow leading to an increase of the static pressure from which the combustion rate directly depends. However, the amount of ionized species and their velocity are too small in ordinary diffusion flames to take into account the influence of the Lorentz force. Many researchers studied the direct effect of a uniform magnetic field up to 5T on chemical kinetics for a premixed laminar flame of propane/air. If high speed chemical reactions seem not to be affected, nitrogen oxide formation shows a slight difference under magnetic influence [7-12]. Action of the magnetic gradient on the air surrounding the flame explains the flame deformations and then the the changes of the temperature and the OH radical emissions. In 1996, Wakayama observed that the magnetic gradient promotes the combustion process, attributing this effect to an increase in the oxygen supply at the flame front by magneto convection due to the magnetic susceptibility difference between air and flame products. This shows how the magnetic field can sustain combustion in microgravity environment through this mechanism. A diffusion flame issued from a single jet of fuel in ambient air can have different behavior depending on the injection conditions: attached to the burner, lifted or blown out. The lift-off height is shown depending on both the flow rate and the flame propagation. Concerning the lifted flame, they suggested the triple flame configuration [13]. The flame is composed of three branches along the stoechiometric contour: a rich branch close to the fuel jet, a lean branch and, in the middle, a diffusion flame. These branches are issued from a point called the triple point. The unfastened from the laminar flame burner continue to be studied in order to identify the mechanisms that lead to the detaching (liftoff). In fact, the understanding of the mechanisms of stabilization of the flames jerked is of crucial importance as well for the fundamental studies for practical applications [14-15]. In the past, it was often used in fireworks to minimize or reduce this stall and, especially, in the turbulent flames. To operate this stabilization of flame, its coupling to the burner are used.

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Indeed, the flames require a change of the burner geometry, or assistance by plasma, electric field or magnetic field [16-17].

In the present paper, we are interested in the impact of a magnetic field gradient to develop a laminar flame with an axisymmetric actuator CH_4/air. The obtained flame is a laminar flame triple (triple flame) which can be lifted off the burner if the conditions of the speed of the flow are favorable. However, it should be recalled that the goal is not to ensure whether the market model in our simulations is good or bad; the goal is to study the effect of the magnetic field on the flame.

2. Geometrical Configuration

The configuration of the burner is schematized in Figure 1. This burner coaxial is composed of an inner tube of internal diameter D_i = 6 mm and of an annular tube of internal diameter of D_e = 18 mm. The inner tube is chamfered on its external part. The inner tube is powered by the methane (CH_4) and the external tube is powered by the air. The configuration of this burner allows us to carry out a study of an axisymmetric actuator around the central axis of the burner.

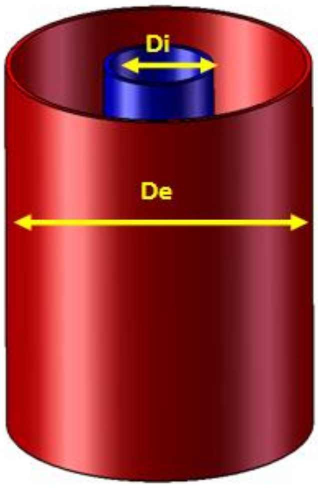

Figure 1. Configuration

The burner is composed of two coaxial jets from two concentric tubes. The center circle contains the jet fuel (CH_4) and the annular jet of air (Figure 2). The influence of the magnetic field, in the present study, was modeled by the addition of a volume equation within the strength of impulse. This strength is modeled on all the height of the object domain which is limited by the total width of the burner. The strength is in every stitch applied. The flow successively passes through a field gradient positive to y = 5 mm and a field gradient to negative 15 mm. The magnetic force is successively positive (pointing to the top according to y) then negative on the air.

We chose the following modes:

Quad: the mesh is structured by quadrilateral elements only.

Map: the mesh is regular.

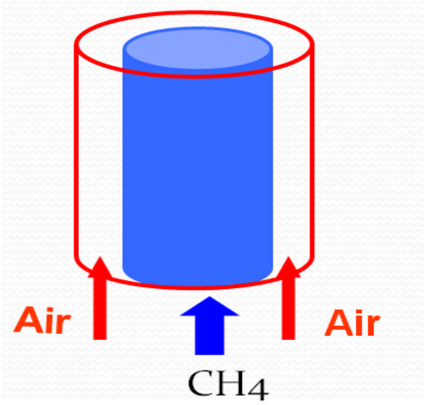

Figure 2. Burner composes

The selected interval is equal to 0.0072 m. The number of mesh is 5004 (Figure 3).

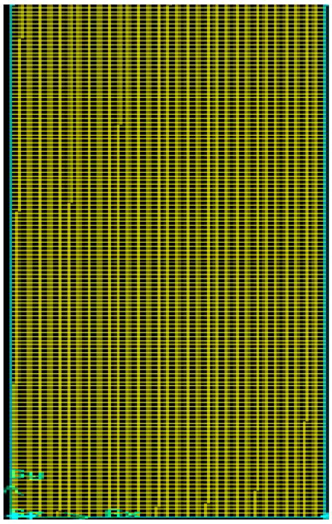

Figure 3. Geometry mesh

3. Numerical results

3.1. Current Lines

The current lines presented in Figures 4 and 5 provide the following information. In fact, we found the wake left by the inner wall of the burner and the Poiseuille flow conditions. The two jets are little changed. In fact, the current lines are slightly more spaced with field than without. The magnetic impact depends on the direction of the gradient. For $0 < y < 10$ mm, the current lines are more inclined and more tightened. For y >10 mm, the gap between the lines increases, and the slope is lesser. In the first gradient, which the maximum is at y = 5 mm, the jet of air is accelerated. Indeed, it was observed that the lines are more inclined and more tightened. For y > 10 mm, the gap between the lines increases, and the slope is lesser.

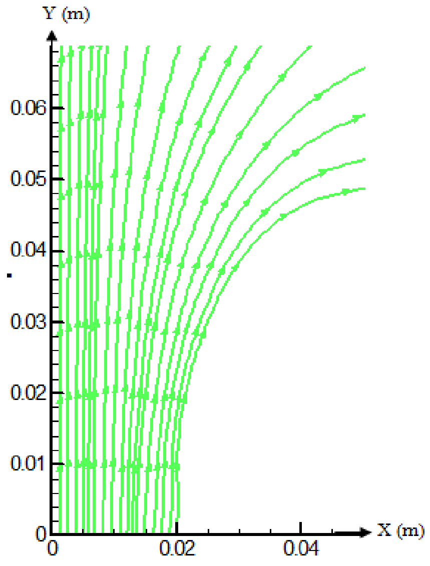

Figure 4. Current lines without magnetic field

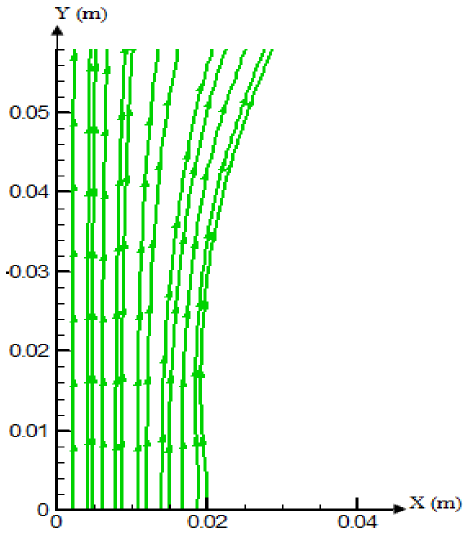

Figure 5. Current lines with magnetic field

3.2. Evolution Axial

Figure 6 presents a comparison between the evolution of the speed on the axial axis of symmetry with and without a magnetic field. The third areas of the flow are always presented. On the first area in the field, the least of the speed drop is noted, and on the second and third boxes, the velocity is low compared with the case without field. These comments are attributed to the fact that the magnetic force acts on the air, thereby slowing the annular jet and, thus, allowing the central jet to be less embarrassed by the annular jet. The annular jet reaches the pin with a lower speed cause by the action of the magnetic field.

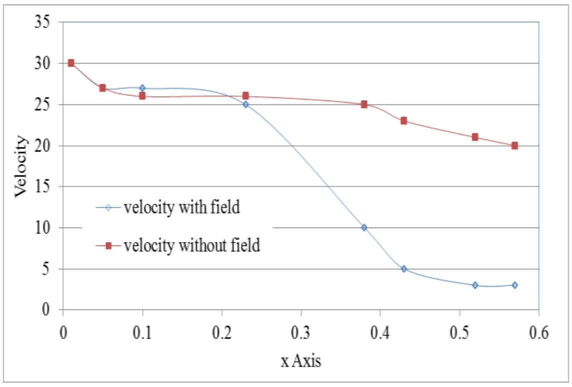

Figure 6. Variation of axial velocity

3.3. Evolution of Temperature

Figure 7 presents the variation of the temperature, according to these results. It was noted that, in the case of y= 0 mm, the magnetic field had a great effect on the evolution of the temperature. The temperature decreased with the presence of the magnetic field and allowed us to show that the height of the detaching decreased due to the magnetic field. Indeed, it was noted that the maximum temperature was equal to 2800 K. without field. The maximum temperature with the magnetic field was equal to 2400 K.

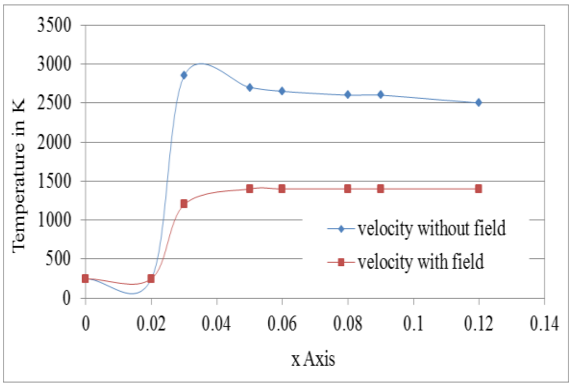

Figure 7. Variation of temperature

3.4. Evolution of the Radial Velocity

Figures 8, 9, 10 and 11 curves present the evolution of the radial velocity. According to the results, it was noted that the slope of the radial velocity was not changed by the magnetic field but the values were low. The magnetic field was observed in the area of the low velocity due to the wall of the injector. Indeed, it was noted that the slope of the speed was not changed by the magnetic field. In fact, the values were low, the magnetic field had an effect on the area of the low speed due to the injector wall. For y = 0 mm and y = 20 mm, the curves showed the effect of the magnetic field helping the annular jet by increasing its speed and disrupting the curve the mixed layer air/air. For y=100, the magnetic field opposed the mixture. For y=300, the magnetic field's effect on the mixed layer was by reducing velocity.

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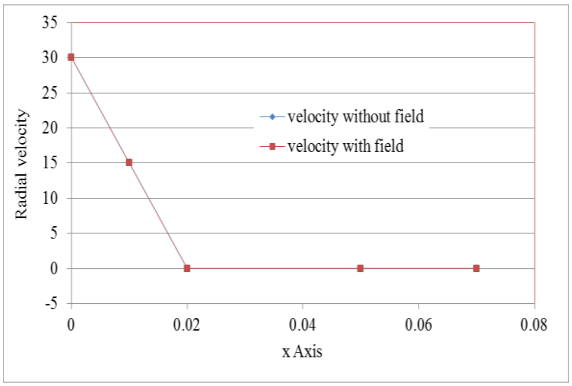


Figure 8 Radial velocity for y=0 mm

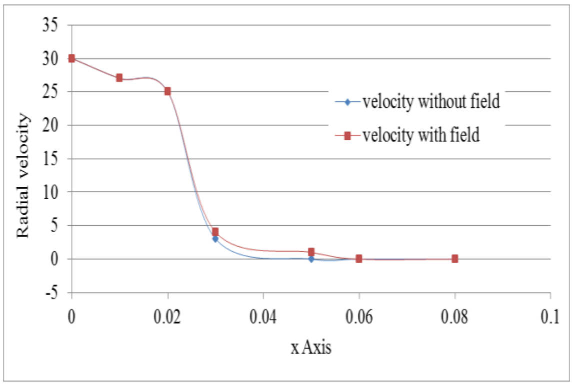


Figure 9 Radial velocity for y=20 mm

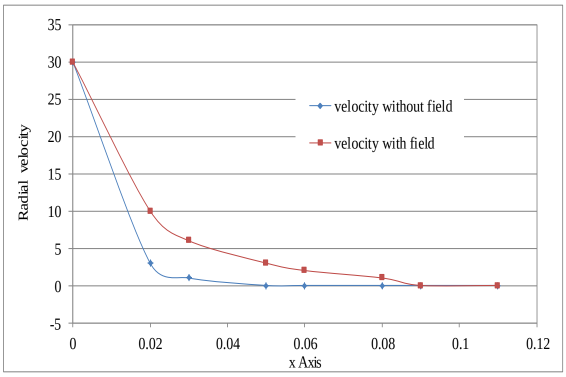


Figure 10 Radial velocity for y=100 mm

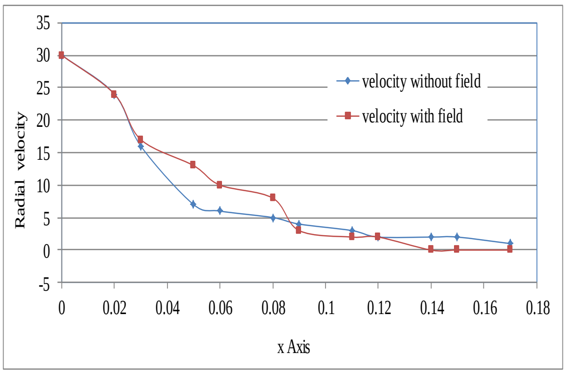
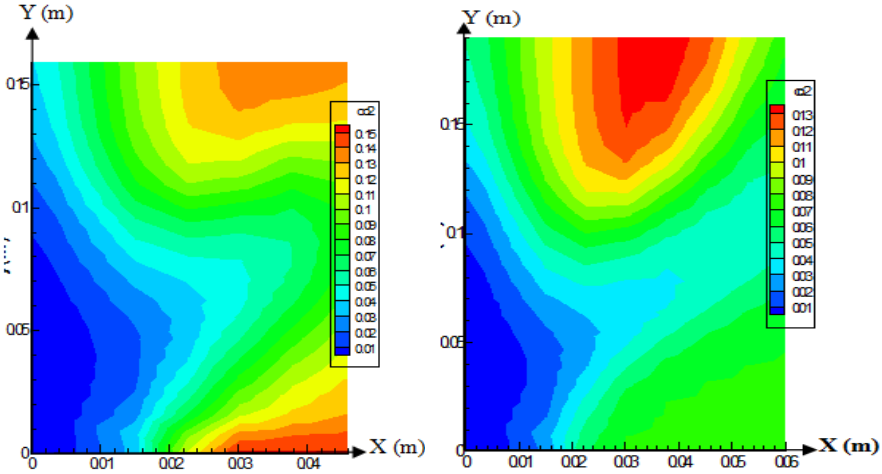


Figure 11 Radial velocity for y=200 mm

3.5. *Species Distribution*

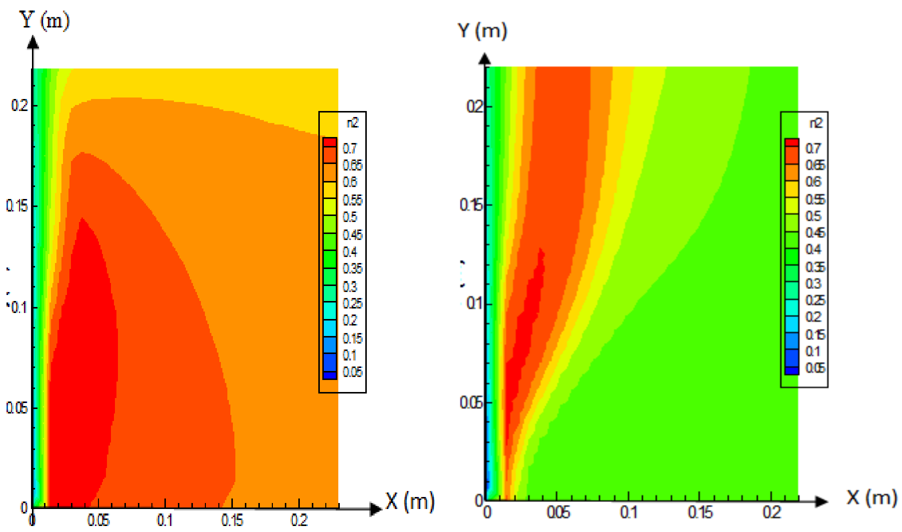
Figure 12 shows the species distribution with and without magnetic field. According to these results, it was noted that the CO_2 was more important in the case without the magnetic field. Particularity, the CO_2 was formed mainly at the level of the flame.

Figure 13 shows the species distribution with and without magnetic field. According to these results, it was noted that the N_2 was more important in the case without the magnetic field. Particularity, the N_2 was formed mainly at the level of the flame.



(a) Without field **(b)** With field

Figure 12 The distribution with and without magnetic field of CO_2



(a) Without field **(b)** With field

Figure 13 The distribution with and without magnetic field of N_2

4. Validation

We showed that the temperature decreased with the presence of the magnetic field, allowing us to show that the height of detaching declined due to the magnetic field, as described in the article by Baker *et al.*, for a low velocity. Air the flame is shorter with flame attached broader and bluer. The action of a magnet permanent place at the output of the burner to two different vertical positions shows that the height of lift is reduced by the action of magnetic field gradient which leads to an increase in the stability area. In fact, the air flows and methane, necessary for the extinction, are higher.

We have shown that the magnetic force acts on the air, thereby slowing the annular jet and, thus, allowing the central jet to be the least bothered by the annular jet. According to Wakayama *et al.*, it is possible to control the combustion on the flames of dissemination from a magnetic field. They deduced that the application of the magnetic field allows changing the dynamics of the ambient air, which have an effect on the dissemination flame.

5. Conclusion

A numerical study was carried out on the effects of a magnetic field gradient on lifted diffusion flames. The effects of a magnetic field gradient were considered to see the relevant physical aspects of the magnetic field and to validate the present numerical results when compared to other numerical data. The different laws that govern the system have been developed and the various changes made to the solver shown. The magnetic force and the dynamic equations have been established in the two dimensional stationary case. We have demonstrated that the application of the magnetic field allows reducing the velocity of the playground and the spatial gradient of mass fraction of methane; it also led to a decrease in the height of detaching and an increase in the speed of propagation of the flame.

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