INTERACTION BETWEEN A TURBULENT DIFFUSION JET FLAME AND A LATERAL WALL INFLUENCE OF MATERIAL PROPERTIES

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ABSTRACT- We study in this situation the interaction between a lateral wall and a diffusion flame for different methane, propane, butane fuels and for one Reynolds number and for different wall materials conductivities variation like Ceramics, Cooper and Stainless-Steel in order to examine the rate of heat flux spreading to the wall interaction. Therefore, the main objective of the present research is to study dynamic process of the diffusion flame-wall interaction and the effects of the interaction on turbulent diffusion flame structure and heat transfer to the wall with different fuel properties. On the other hand, the interaction of a flame and a lateral wall can be found in furnaces and hazardous fire propagation along the wall. The lateral wall may provide variations in flame structure interaction this sort of interaction constitutes the fundamental configuration of extracting energy from the flame and fire hazard. The stagnation flame sustained by a fuel jet impinging on the wall provides a useful flame structure for basic flame studies [2].
Key words: - Turbulent flow / Diffusion flame / Impinging flow / Fuel properties / Jet combustion.

NOMENCLATURE

C_p	specific heat	(kJ.kg^{-1}.k^{-1}).	D	jet diameter	(m).
f	mixture fraction.		K	kinetic turbulent energy	(m^2.s-^{2}).
m_j	$_j$ mass species	(kg).	P	pressure	(Pa).
t	time	(s).	U_I	velocity from x_i	(m.s^{-1})
U_j	velocity from x_j	(m.s^{-1})	Z_i	$_i$ Species fraction.	
$Z_{i,car}$	fuel fraction.		$Z_{i,ox}$	oxydant fraction.	
x_i	coordinate from I direction.		x_j	coordinate from j direction.	

Greek symbols

ε	viscosity dissipation.		ν_t	turbulent viscosity	(m^2 .s^{-1}).
ν	kinetic viscosity	(m^2 .s^{-1}).			

Subscripts

p	pressure constant.	car	carburant
ox	oxydant		

1. INTRODUCTION

Impinging premixed gas fired flame jet heat transfer has been well established as a high performance technology for heating, cooling and drying processes due to its very high heat and mass transfer for both industrial and domestic applications [1-3]. A non premixed flame gas fired emitted from a circular nozzle with a diameter of d, and a velocity of V impinges vertically parallel to a plan surface mounted parallel to the flame, which is held at a different distance of L/d from a nozzle to a plate surface. After impinging on the plate, the flame and combustion production extend radially outwards along the surface with formation of a thermal

and dynamic boundary layer. Due to the complexity of the heat transfer characteristics of the interacting flame to a lateral wall, this may involve thermal conduction, convection, radiation and thermo chemical heat release (TCHR), reports on relevant previous studies in this area are rather rare [4-5]. Moreover, current design and application of impinging flame jets mainly rely on the practical experience, rather than scientific analysis.
Although some experimental studies have been performed, very few prediction models for evaluation of the thermal performance and the interaction of fluid dynamics and a lateral wall. The aim of the present study is therefore to validate prediction experimental model of [2] for the interaction between a non premixed flame and a lateral wall. The simulation was performed with different fuel CH_4, C_3H_8, C_4H_{10}. And using different wall thermal conductivity material properties. We study the interaction between the flame and the lateral wall for different L/d distance.

2. TURBULENT GOVERNING EQUATIONS

2.1 Numerical simulation

The present study, FLUENT [7] (commercial CFD software) was used to model the flow field and heat transfer for diffusion turbulent flame using a reduced reaction mechanism (8 species are considered). The momentum equations couples with the K Epsilon turbulent model as follows:

$$\frac{\partial \overline{U}_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial(\rho v_x \phi)}{\partial x} + \frac{\partial(\rho v_y \phi)}{\partial y} = \frac{\partial}{\partial x}\left(\Gamma \frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Gamma \frac{\partial \phi}{\partial y}\right) + S_\phi \tag{2}$$

$$\frac{\partial}{\partial x_i}(U_i k) = \frac{\partial}{\partial x_j}\left[\left(\nu + \frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G - \varepsilon \tag{3}$$

$$\frac{\partial}{\partial x_i}(U_i \varepsilon) = \frac{\partial}{\partial x_j}\left[\left(\nu + \frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{k}(C_{\varepsilon 1} G - C_{\varepsilon 2}\varepsilon) \tag{4}$$

Where $G = -u_i u_j \frac{\partial U_i}{\partial x_j}$ et $\nu_t = C_\mu \frac{k^2}{\varepsilon}$

S_ϕ is a source term.

The model constants: $C_\mu = 0.09$, $C_{\varepsilon 1} = 1.44$, $C_{\varepsilon 2} = 1.92$, $\sigma_k = 1.0$ and $\sigma_\varepsilon = 1.0$.

2.2 Modeling Non Premixed Combustion

In non-premixed combustion, fuel and oxidizer enter the reaction zone in distinct streams. This is in contrast to premixed systems, in which reactants are mixed at the molecular level before burning.

In order to resolve the turbulent chemistry interaction we are focused to use Pre PDF model based on the resolution of Favre mean mixture fraction $\overline{f}$ equation (5) and a conservation equation for the mixture fraction variance $\overline{f'^2}$ equation (6) [7].

$$\frac{\partial}{\partial t}\left(\rho \overline{f}\right)+\nabla.\left(\rho \vec{v}\,\overline{f}\right)=\nabla.\left(\frac{\mu_t}{\sigma_t}\nabla \overline{f}\right) \quad (5)$$

$$\frac{\partial}{\partial t}\left(\rho \overline{f'^2}\right)+\nabla.\left(\rho \vec{v}\,\overline{f'^2}\right)=\nabla.\left(\frac{\mu_t}{\sigma_t}\nabla \overline{f'^2}\right) \quad (6)$$

The species fractions considered in this investigation are $C_3H_8, C_4H_{10}, CH_4, O_2, N_2, H_2O, NO, CO_2, CO, OH$.

3. COMPUTATIONAL DOMAIN

The dimension of the combustion chamber is (800 X 500) mm^2, the diameter of the fuel jet is 10 mm. the boundary conditions in all faces are: face (1) velocity inlet (fuel), velocity inlet (air), face (3) wall, face (4) symmetry, face (5) outflow. The number of mesh nods is 160000, figure (1).

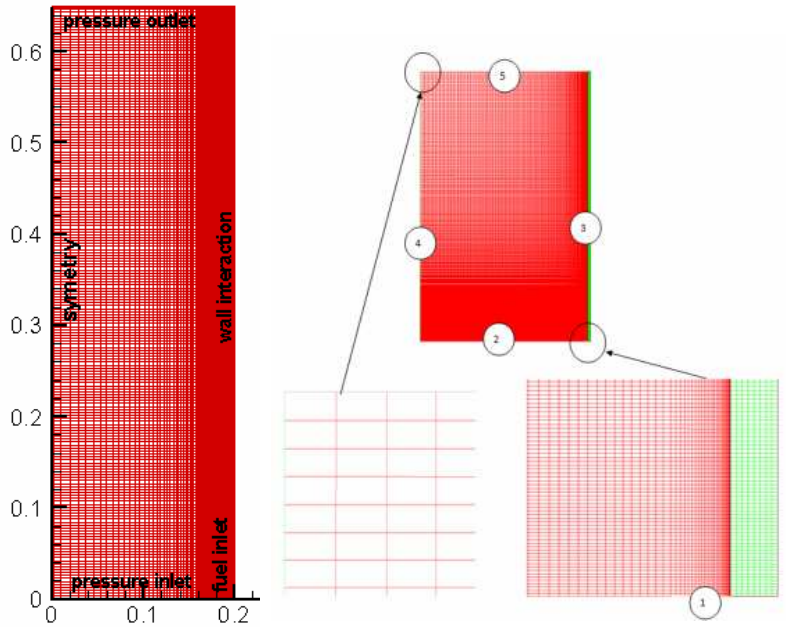

Figure1. Schematic of mesh domain and boundary conditions for jet diffusion flame.

4. NUMERICAL RESULTS

The simulation were carried out for the different fuels properties the first one is the Methane fuel CH_4, the second is the propane C_3H_8 and the third fuel is the Butane C_4H_{10}.

This fuel varies from in adiabatic temperature, molecular weight… temperature distribution of the flame under Reynolds numbers of 8000 were measured by the experimental work of Yei-Chin Chao and al. [6]. For this simulation the Reynolds number is that of the fuel jet. We are used a one Reynolds number, in order to minimise the data plots.

The energy extracted from the flame is highly related to its temperature level and temperature distribution. And this level of temperature is varied with the type and chemical properties of fuels. The shape of a flame will be highly modified with the interaction with a lateral wall. The part of the flame far from the lateral wall will be less affected, while the part of the flame

approached to the lateral wall will be highly affected, the flame spreading vertically along the plate is different for different fuels properties, highly degrees obtained for methane and moderately degrees for propane. This spreading is decrease with the increasing of molecular weight figure 2 and figure 3.
For steady diffusion flame figure 4 and figure 5 shows profiles for the flame attached on a lateral wall, for Reynolds number equal to Re = 8000.
It shows that this type of diffusion flame can be consider as making up of an entrainment zone at the root of the flame, of about 10 mm through the flame's high, and a subsequent mixing and combustion zone. The whole flame has a visible length of 80 mm. In the entrainment zone, the fuel is drawn to the central air jet due to the low pressure created by the high fuel velocity jet. Initial air fuel mixing and combustion occurs in this zone. In the mixing and combustion zone, rapid mixing of air and fuel, and combustion occurs for methane fuel. The flame maintains the characteristic yellowish colour of a diffusion flame but some regions of bluish flame is also observable at the base, at the top and inside the flame experimental results of [6].
The temperature contours in figure 4, figure 5 shows the temperature of the flame and fuels concentration species profiles for different hydrocarbon fuels CH_4, C_3H_8, C_4H_{10} at 8 stations along the flame's high of 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 mm at the y-direction respectively figure 7 to figure 11. The flame was assumed to be attached to the wall from the jet exit to the front of the flame. For the flame generated by the propane fuel the flame is very similar to the experimental results obtained by [6], for the methane flame the maximum temperature is about 1400K, but for propane flame the maximum temperature is about 1700 K, and for butane flame the maximum temperature is about 1300 K, the discussion of this levels that the butane not completely burned on this physical conditions, hence only a portion species mass fraction of butane exit from the fuel jet has been burned with the air partially surrounding the flame, due to the molecular structure of the butane fuel and mass weight, the mixing of the air surrounding the fuel occur just in the surface of the jet in this situation butane is partially mixed with the surrounding air.
High temperature started to occur in the entrainment zone, indicating that combustion occurred in this zone also and propagated a long the lateral wall. The maximum temperature measured was about 1650 K, which occurred in the middle of the combustion region at a distance about midway between the fuel exit and upper front of the flame, indicating that the most intense combustion occurred in this part of the flame corresponding to the higher temperature levels destructing energy from the fuel is very high figure 5.
It can be observed that in the entrainment zone with y < 150 mm, the temperature was the lowest at the centre of the flame, increasing to a peak at about 5 mm away from the centerline, and then dropped gradually further forwards more a long the impinging plate.
At y = 400 mm, the temperature was about 1400 K for the propane flame but it vary from the fuel to another at the middle of the reaction zone, increased further forwards the impinging plate to a maximum of about 1400 K for butane and methane fuel but we observed a three picks occurred between y = 50 mm and 200 mm with a maximum temperature of 1700 K and then dropped quickly further for y > 450 mm.
After the ejection zone, air fuel jet velocity is very high and the profiles are quasi parabolic in shape due to interaction to the lateral wall. Thus the jet velocity is higher at the centreline than that on the edge of the burner. The fuel cannot diffuse into the centreline of the flame but mixes with the air surrounding the reaction zone this is very quite for butane flame. But the ambient air is easy to mixer with the fuel for methane flame for the same Reynolds number.
An increase in the fuel consumption with the decreasing in molecular weight in figure 7, figure 8, figure 9 the mass fraction of propane is very significant than that for methane flame,

it's very useful to use methane flame in this situation in order to get a rich flame than for propane flame.
The ratio of fuel consumption is varied when we varying fuel characteristics. The length of the reaction zone increased slightly with the decreasing in molecular weight, while the length of the mixing and combustion zone varied significantly with jet fuel supply.
In this situation the enlarged of reaction zone, was more appearance with the methane fuel which is corresponding to well fuel mixing with the entrainment air. However, the increase in fuel supplied will tend to increase the length of the flame, resulting in a net increase in the flame length. For the butane flame at the same Reynolds number, resulting little consumption of fuel which increase the production of an unburnt pollutant NO.
At the same Re number for methane and propane flame the thermal mechanism NO production will increase more than for butane flame at the same boundary conditions, which results in a more significant increase in fuel consumption.
The influence of the lateral wall on the flame structure is that the wall makes an obstacle to the mixing of the fuel supply from the jet with the entrainment surrounding air. The wall breaking the axisummitry of the round jet and the changing of the flame shape occurred.

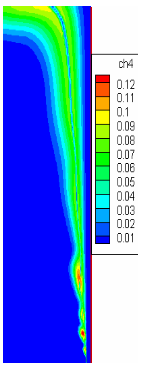

Figure 2. Mass fraction of methane CH_4 .

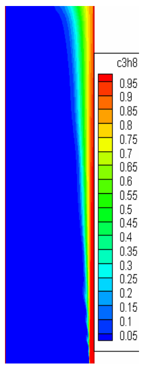

Figure 3. Mass fraction of propane C_3H_8.

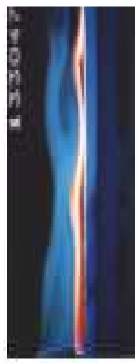

Figure 4.Temperature experimental field [8].

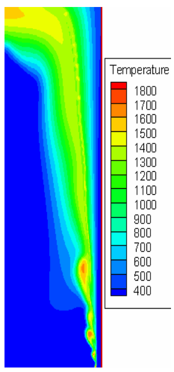

Figure 5. Temperature field for propane flame wall interaction.

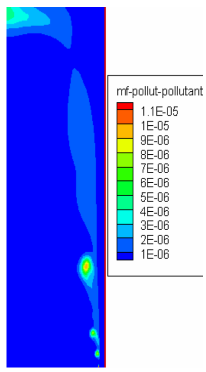

Figure 6. Polluant NO mass fraction.

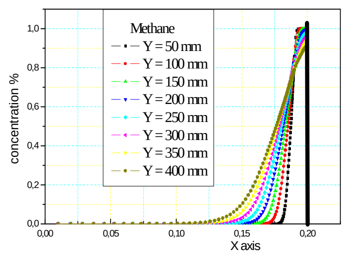

Figure 7: CH_4 concentration for methane flame

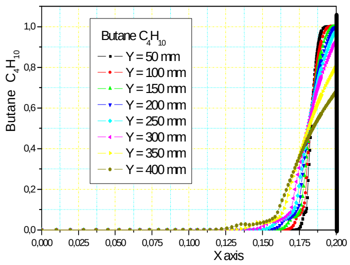

Figure 8: C_4H_{10} concentration for Butane flame

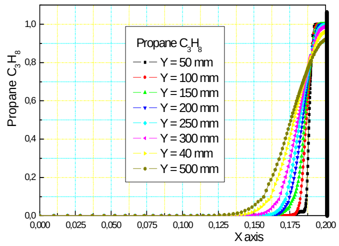

Figure 9: C_3H_8 concentration for Propane flame

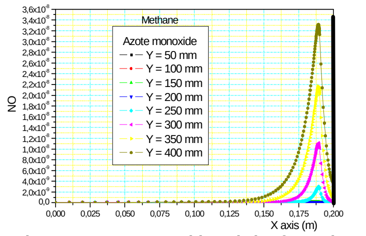

Figure 10: Azote_monoxide variation for methane flame.

5. CONCLUSION

In the present study, the temperature distribution and the mass fraction for chemical species distribution of a diffusion flame interaction with a lateral wall for different fuel jet ejection was investigated. The following results were obtained.

- The fuel properties influenced the flame structure and the maximum level of temperature is differing for methane, propane, and butane.
- The temperature profiles at different sections of the flame show a cool region behind the wall at low flame high. At high flame the cool core disappear and the maximum temperature zone occurred at the centre and dropped steadily away from the centre.
- In the next studies we will discuss the stagnation point heat flux for a lateral wall situation when the heat fluxes were greatly affected by three factors: Re, U, and the nozzle to plate distance.

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