# Impinging Diffusion Flame and NO Production

Nadjib Ghiti, Abed Alhalim Bentebbiche, and Samir Hanchi

***Abstract*—This paper reports a numerical investigation of an impinging diffusion flame on the pollutant emission for tree hydrocarbon fuels characteristics. The effects of the wall plate, the nozzle diameter, the Reynolds number on both thermal and prompt NO production. This work based on the Pre PDF simulation and K Epsilon models for study the reactive turbulent flow spreading on the lateral wall. We found that when the temperature increases the production of thermal NO increase, the NO production is more influenced by the hydrocarbon fuels.**

***Index Terms*—Simulation, combustion, diffusion flames, interaction, turbulent, NOx production.**

## I. Introduction

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 Reynolds number. According to the studies of [1], the non-premixed and partially non premixed flames jet interacting to a lateral wall heat transfer was very dependent on Reynolds number and equivalence ratio of the air fuel, distance between the orifice nozzle to a lateral wall, the wall roughness, and the wall properties (conductivity, emissivity). Effects of nozzle shape (circular or slot) and inclination of the impingement plate on heat transfer characteristics of the system under different flame conditions had been studied [2] studied the interaction of the lateral wall and a "V"-shaped flame stabilized by a thin wire.

Barlow and Carter [3] investigated experimentally the effects of temperature and mixture fraction on NOx emission in $H_2$ jet flames. Hayhurst and Lawrence [4] reported an experimental investigation of NOx emission in a fluidized bed combustor during burning of coal volatiles. Meunier and Carvalho [5] per-formed experimental and numerical investigations on NOx emissions from turbulent propane diffusion flames. Schlegel *et al.* [6] reported an experimental– numerical study on NOx emissions from catalytically stabilized lean premixed methane–air flames.
Poppe et al. [7] investigated control of NOx emissions from confined methane–air premixed flames by imposing oscillations. Many researchers have also focused on the development of appropriate NOx mechanisms for more detailed prediction and investigation of NOx emissions from flames. These include the Li and Williams mechanism [8], the Warnatz and Klaus mechanism [9], the Leeds mechanism [10], and the mechanisms discussed by Miller and Bowman [11].

However, there is no more previous researches of the pollutants emission by impinging diffusion flame, the simulation was performed with different fuels $CH_4$, $C_3H_8$, $C_4H_{10}$. Further, we will explore the relationship between pollutant emissions and different hydrocarbons components. Thus, the objective of this study is to investigate the NOx pollutant emission with one jet impinging on a vertical plate under atmospheric conditions. This paper reports the preliminary results, including the effects of the hydrocarbons fuel variation on the both thermal and prompts NO pollutants emission.

## II. Methods and Computational Domain

In order to resolve the turbulent flow problem we are used the tow dimensional equations of motion coupled with K –Epsilon turbulent RNG based model.

In order to resolve the turbulent chemistry interaction we are focused to use Pre PDF model based on the resolution of mean transport species equation and its variance [12].

In the model, the impingement surface is parallel to the fuel jet; the burner exit is represented by a tube with a 10 mm of diameter. The domain has 80000 quadrimap grids Fig.1.

## III. 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 based on the fuel jet diameter. For this simulation the Reynolds number is that of the fuel jet. We are used one Reynolds number, in order to minimise the data plot.

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 properties of fuels chemical properties. 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 approach the lateral wall will be highly affected, the form of the flame spreading vertically along the plate is different for different fuels properties, highly for methane and rather for propane this spreading is decrease with the increasing of molecular weight Fig. 2, Fig. 3.

Fig. 4 and Fig. 5 shows a profiles for a flame attached on a lateral wall, for a diffusion flame Reynolds number equal to

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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 in height, 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 occur for methane fuel. The flame maintains the characteristic yellowish color of a diffusion flame but some regions of blush flame is also observable at the base, at the top and inside the flame experimental results of [1].

Fig.4, Fig. 5 shows the temperature contours of the flame temperature and fuels concentration species profiles for different hydrocarbon fuels $CH_4, C_3H_8, C_4H_{10}$ at 8 height of 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 mm at the y-direction Fig.7-Fig.10. 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 by [1], 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 butane jet and 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 along 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 on this conditions Fig. 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 along 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 $y$ = 50mm and 200 mm with a maximum temperature of 1700 K and then dropped quickly further for $y >$ 450 mm.

An increase in fuel consumption with the decreasing in molecular weight in Fig. 7, Fig. 8, Fig. 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 fuel consumption is different for different fuel burner. The length of the reaction zone increased slightly with decrease 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 un-burnt 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 consumption of fuel.

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 axi-symmitry of the round jet and the shape of the flame.

In this section we use Species transport model for NOx prediction in this section we will extend our calculation to include the prediction of NO. We will first calculate the formation of both thermal and prompt NOx, and then calculate each separately to determine the contribution of each mechanism.

The partial-equilibrium model is used to predict the O radical concentration required for thermal NOx prediction. Fig. 12-Fig. 14.

The peak concentration of NO is located in a region of high temperature where oxygen and nitrogen are available.

The Mass-Weighted Average field will show that the exit NO mass fraction is approximately 0.004778 kgmol/m$^3$s.

Note that the concentration of NO is slightly lower without the prompt NO mechanism.

The Mass-Weighted Average field will show that the exit NO mass fraction with only thermal NO formation (i.e., with no prompt NO formation) is approximately 0.003529kgmol/m$^3$s.

The prompt NO mechanism is most significant in fuel-rich flames. In this case the flame is lean and prompt NO production is low.

The Mass-Weighted Average field will show that the exit NO mass fraction with only prompt NO formation is approximately 0.002346 kgmol/m$^3$s.

The individual thermal and prompt NO mass fractions do not add up to the levels predicted with the two models combined. This is because reversible reactions are involved. NO produced in one reaction can be destroyed in another reaction.

NO ppm will be computed from the following equation:

$$NOppm = \frac{NO\ molefraction \bullet 10^6}{1 - H_2O\ mole\ fraction}$$

The contours closely resemble the mass fraction contours Fig. 15, as expected. A comparison was made for a tow different turbulent combustion models in order to optimize

the NO prediction for a turbulent impinging diffusion flame:

These results are obtained with a pre Pdf turbulent model.

The peak concentration of NO is located in a region of high temperature where oxygen and nitrogen are available. If we compare the rate of NO production with species transport model, we look that the species transport model is over predicted than the pre Pdf model. Fig.16.

For the NO evaluated with ppm we observe that for NO ppm calculated with species transport is more than the NO ppm calculated with pre Pdf model. Fig.17, Fig.18, Fig.19.

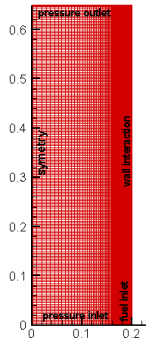


Fig. 1. Schematic of mesh domain and boundary conditions for jet diffusion flame.

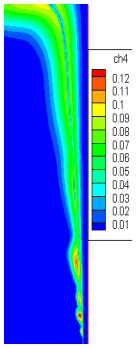


Fig. 2. Mass fraction of methane $CH_4$.

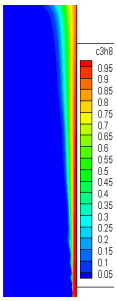


Fig. 3. Mass fraction of propane $C_3H_8$.

Fig.4. Experimental temperature field [2].

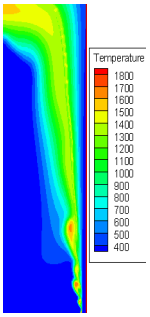


Fig. 5. Temperature field for propane flame wall interaction.

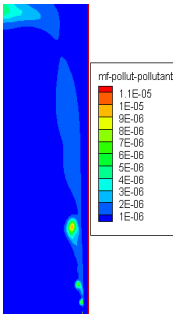


Fig. 6. Pollutant NO mass fraction.

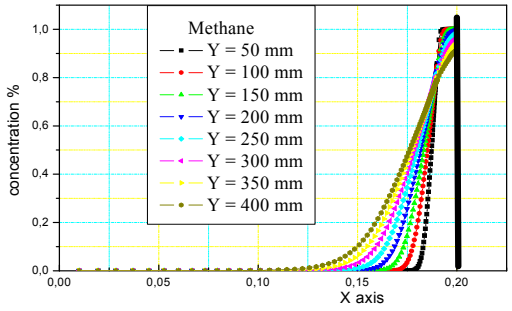


Fig. 7. CH4 concentration for methane flame.

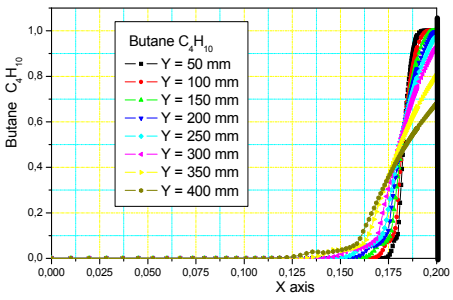


Fig. 8. C4H10 concentration for Butane flame.

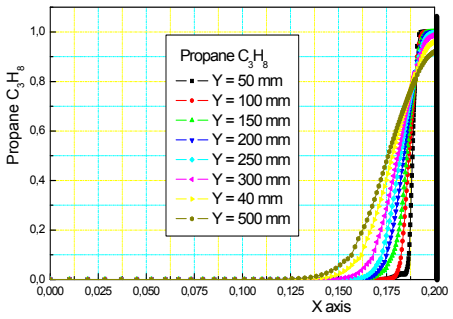


Fig..9. $C_3H_8$ concentration for Propane flame.

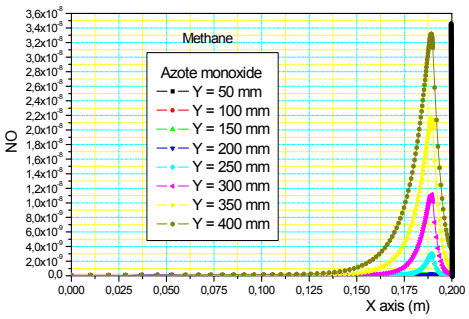


Fig. 10. Azote_monoxide variation for methane flame.

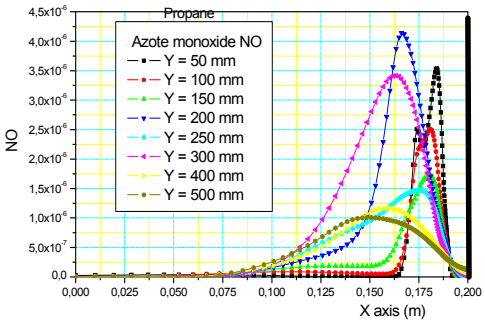


Fig. 11. Azote monoxide variation for propane flame.

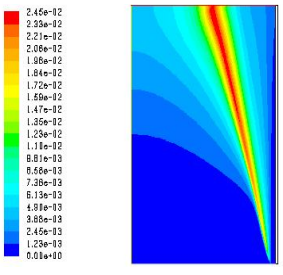

Fig. 12. Prompt and thermal nox Formation (kgmol/m$^3$s).

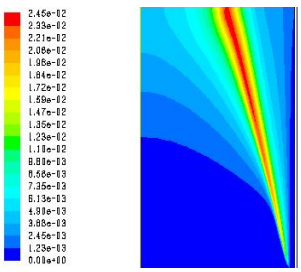

Fig. 13. Thermal nox formation (kgmol/m$^3$s).

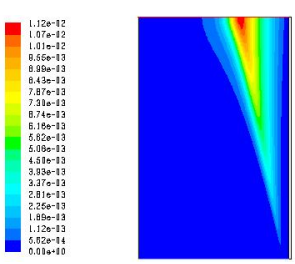

Fig. 14. Prompt nox formation (kgmol/m$^3$s).

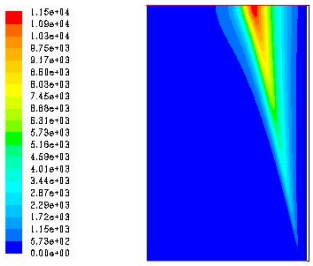

Fig. 15. Prompt nox formation (kgmol/m$^3$s).

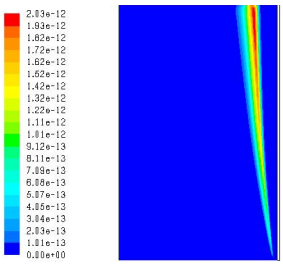

Fig. 16. NO ppm predicted with species transport model. Prompt and Thermal NO Formation.

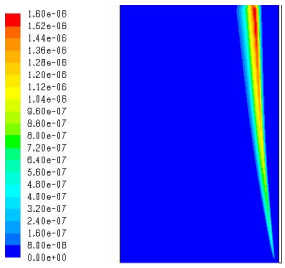

Fig. 17. NO ppm predicted with Pre Pdf model.

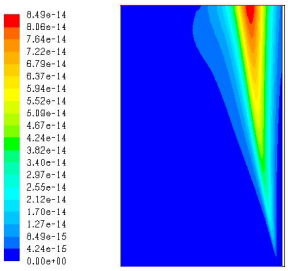

Fig. 18. Thermal NO predicted with pre pdf model.

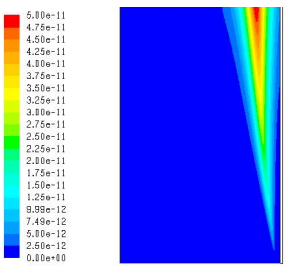

Fig. 19. Thermal NO predicted with species transport model.

## IV. 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 are obtained.

1) The fuel properties influenced the flame structure and the maximum level of temperature is differing for methane, propane, and butane.
2) The temperature profiles at different sections of the flame show a cool region behind the wall at low flame height. At high flame height the cool core disappear and the maximum temperature zone occurred at the centre and dropped steadily away from the centre.
3) The stagnation point heat flux is not appear in this case, but in the situation of horizontal plate the stagnation point is clear appearing heat flux greatly affected by three factors: Re, U, and the nozzle to plate distance.
4) The radial heat flux distribution is very affected by the fuel properties variation.

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