World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:6, No:8, 2012

Numerical Study on CO_2 Pollution in an Ignition Chamber by Oxygen Enrichment

Zohreh Orshesh

***Abstract*—**In this study, a 3D combustion chamber was simulated using FLUENT 6.32. Aims to obtain accurate information about the profile of the combustion in the furnace and also check the effect of oxygen enrichment on the combustion process. Oxygen enrichment is an effective way to reduce combustion pollutant. The flow rate of air to fuel ratio is varied as 1.3, 3.2 and 5.1 and the oxygen enriched flow rates are 28, 54 and 68 lit/min. Combustion simulations typically involve the solution of the turbulent flows with heat transfer, species transport and chemical reactions. It is common to use the Reynolds-averaged form of the governing equation in conjunction with a suitable turbulence model. The 3D Reynolds Averaged Navier Stokes (RANS) equations with standard k-ε turbulence model are solved together by Fluent 6.3 software. First order upwind scheme is used to model governing equations and the SIMPLE algorithm is used as pressure velocity coupling. Species mass fractions at the wall are assumed to have zero normal gradients.Results show that minimum mole fraction of CO_2 happens when the flow rate ratio of air to fuel is 5.1. Additionally, in a fixed oxygen enrichment condition, increasing the air to fuel ratio will increase the temperature peak. As a result, oxygen-enrichment can reduce the CO_2 emission at this kind of furnace in high air to fuel rates.

***Keywords*—**Combustion chamber, Oxygen enrichment, Reynolds Averaged Navier- Stokes, CO_2 emission

I. Introduction

DUE to increased demand for energy, clean cut fossil fuel resources, and growing concern over environmental pollution and global warming, mainly caused by the greenhouse effect is an urgent need for advanced energy systems to provide efficient power, with harmful consequences there is less environmental. Oxy-fuel firing is more energy efficient and environmental friendly than conventional air-fuel firing and its application to reheating furnaces has begun since 1990s [1]. Combustion air can increase the oxygen in the exhaust gases and reduce energy loss and increase the efficiency of heating systems.

The main objective of this study was to compare the amount of air to fuel ratio of CO_2 consumption, including and without oxygen enrichment.

Today, oxygen enrichment combines with oxidizer in the chemical reaction. The benefits of oxygen enrichment are: lower emissions, increase efficiency, increase productivity, and improve temperature stability and heat transfer, and reduce costs of fuel consumption and pollutants [2].

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So, Combustion engineers have focused their attention to develop many strategies to reduce CO_2 emission. There are two general methods for reduction useless pollutants: improvement combustion cycle, treatment exhaust gases. In the present study, oxygen enrichment is used to reduce CO_2 in order to improvement combustion cycle. The main goal of this thesis is to compare CO_2 pollution for different air-fuel ratio, including the oxygen enrichment and without it.

Oxygen enrichment reduces or eliminates the need for combustion air, resulting in less nitrogen oxide production. Oxy-fuel combustion also increases the flame temperature without increasing fuel cost [2].

Benefits of oxygen enrichment are [3]: lower emissions, increase efficiency, increase productivity, improve temperature stability and heat transfer, and reduce costs of fuel consumption and pollutants.

Hamzeh Jafar Karimi, Mohammad Hassan Saidi [5] had done computational method on a type reheating furnace in which combustion air was enhanced by oxygen. The results showed that the best range of oxygen enrichments was between 21% and 45% by volume, as the higher slope of flame temperature and production increase occurs in this range.

II. Governing Equation

Combustion simulations typically involve the solution of the turbulent flows with heat transfer, species transport and chemical reactions. FLUENT [8] uses finite volume to resolve physical equations (energy, continuity, momentum equations).

Continuity Equation

$$\frac{\partial}{\partial t}(\rho)+\nabla.(\rho V)=S_m \quad (1)$$

Momentum Equation

$$\frac{\partial}{\partial t}(\rho V)+\nabla.(\rho VV)=\nabla.((\mu+\mu_t)\nabla V)+F \quad (2)$$

Energy Equation

$$\frac{\partial}{\partial t}(\rho E)+\nabla.(\rho VE)=\nabla.((k+k_t)\nabla T)+\nabla.(\tau.V)-\nabla(pV)+S_r+S_h \quad (3)$$

It is common to use the Reynolds-averaged form of the governing equation in conjunction with a suitable turbulence model. The 3D Reynolds Averaged Navier Stokes (RANS) equations together with standard k turbulence model [9] are solved by Fluent 6.3. In finite volume method, integrated physical equations are used.

$$\frac{\partial}{\partial t}(\rho k)+\nabla.(\rho V k)=\nabla.\left(\frac{(\mu+\mu_t)}{\sigma_k}\nabla k\right)+G_k-\rho\varepsilon \quad (4)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\nabla.(\rho V \varepsilon)=\nabla.\left(\frac{(\mu+\mu_t)}{\sigma_\varepsilon}\nabla \varepsilon\right)+C_{1\varepsilon}\frac{\varepsilon}{k}G_k- C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \quad (5)$$

Where

$C_{1\varepsilon}=1.44$
$C_{2\varepsilon}=1.92$
$\sigma_k=1$
$\sigma_\varepsilon=1.31$

III. Combustion Modeling

Before simulate the problem by FLUENT 6.32, the geometry is modeled in GAMBIT. The computational domain is a cubic rectangle which is 60 cm wide, 90 cm high and 190cm long (figure 1).

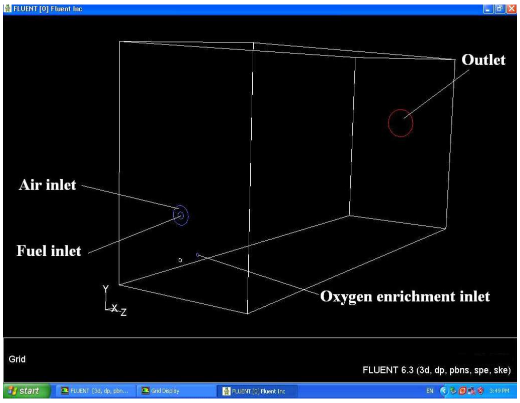


Fig. 1 problem geometry

The enriching oxygen inlet is 10 cm long placed under the torch at 16 cm high from the bottom of ignition chamber (figure 2).

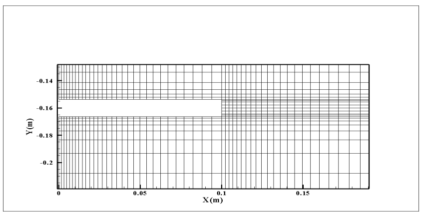


Fig. 2 view of oxygen inlet

Fluent software uses two resolutions, namely pressure based and density based resolutions. In this study modeling is based on pressure. In order to resolve the chemical reaction and its modeling, species are selected from species transport in models menu.

In reaction, volumetric option is selected. Then, inlet diffusion, diffusion energy source, full multi component diffusion, thermal diffusion options are all checked and eddy-dissipation is selected in turbulence-chemistry interaction menu. From Material menu, density option, incompressible gas is selected. Then, by clicking species, all components of reaction can be observed.

Independence and the turbulence model and the turbulence were investigated and finally with 83320 grid cells were chosen as the computational grid (figure 3) and standard k-ε were decided to be used as the turbulence model.

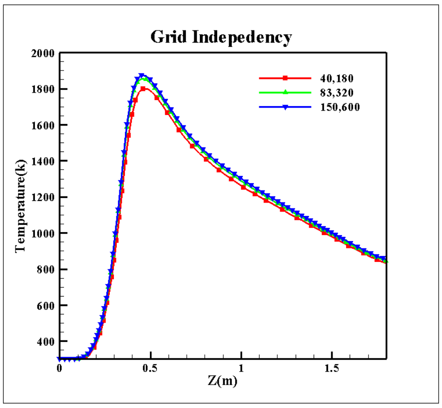


Fig. 3 Computational grid

The regions close to the burner were meshed into smaller control volumes in order to enhance forecast accuracy (figure 4).

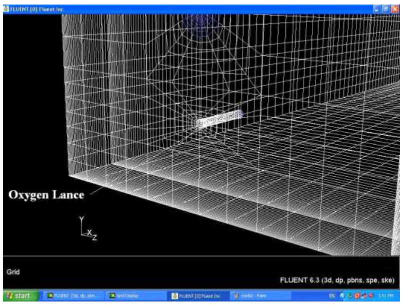


Fig. 4 meshing of oxygen inlet

IV. Numerical Calculation

A standard k-ε turbulence model is used in this combustion. The descritization model is first order upwind scheme by using SIMPLE algorithm.

After writing chemical reaction of methane combustion in stoichiometric and use from thermodynamic tables, adiabatic flame temperature calculates 2320°K. When the residual comes down to near zero and reach convergence, solution will be finish.

V. Boundary Condition

Flow conditions are steady, turbulent flow, heat transfer and chemical reactions, also under flow condition; Mach number is very low; hence, the flow in assumed incompressible. The inlet temperature is 300°K for all inlets.

Since the fuel and air inlets are totally separate, this model can be used efficiently. In mixture material menu, methane-air is selected since methane-air reactions are involved. In reaction, volumetric option is selected.

VI. RESULT AND DISCUSSION

After numerical calculation, it is easy to see results. By plotting the CO_2 mole fraction vs. X, according to figure 5, with the increase of AF ratio, CO_2 decreases. It is obvious Minimum amount of CO_2 mole fraction in combustion, happens at highest AF ratio (5.1).

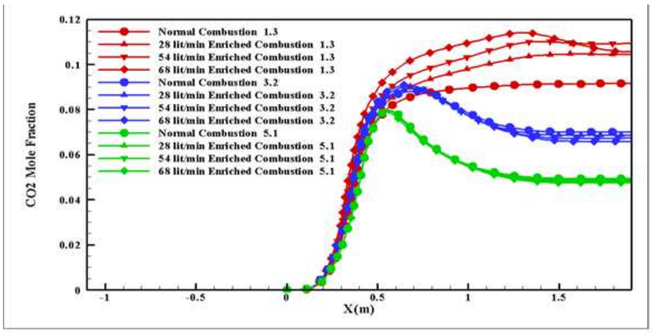
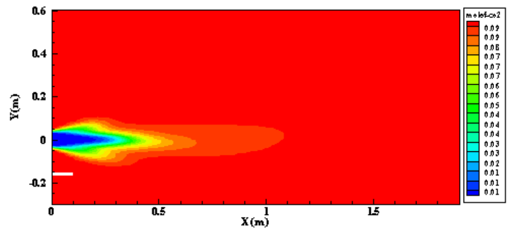
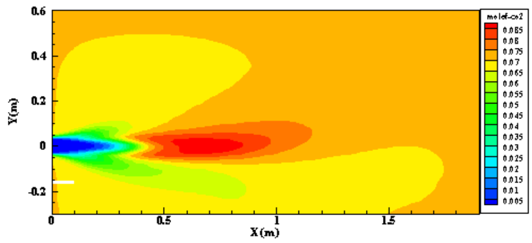


Fig. 5 Comparison of CO_2 mole fraction along centerline of combustion

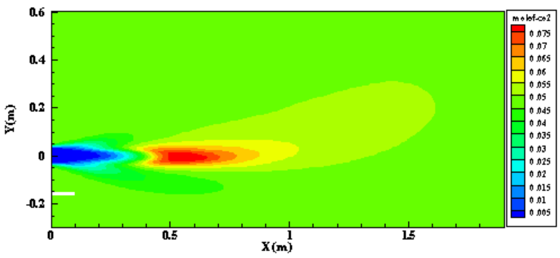
The contours also confirm these facts. For example, figure 6 show comparisons of CO_2 mole fraction contours, when there is normal combustion.



(a)



(b)



(c)

Fig. 6 CO_2 mole fraction normal combustion, (a) AF = 1.3 (b) AF = 3.2, (c) AF =5.1

At the first sate (AF=1.3), by increasing enriched oxygen, CO_2 mole fraction increases. The increase of incoming oxygen discharge, has a little effect on curve of CO_2 mole fraction at state AF=3.2 and has approximately no effect on amount of CO_2 in 5.1.

In 2005, M. Darbandi, A. Banaeizadeh and G. E. Schneider had been done numerical simulation on reacting flow [11] and compared their results with experimental data results and other numerical results which is gotten by Elkaim, D., Reggio, M., and Camarero, R and Smoot, J.L, and Lewis, H.M. Fig. 7 plotted those results and results of this study and shows comparison between them. According to this figure, there is good agreement between all of results.

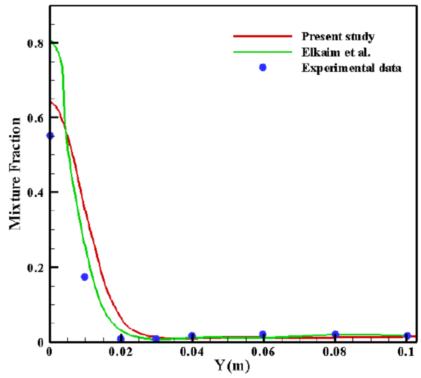


Fig. 7 Mixture fraction distribution of species and a comparison between present study, Elkaim et al. [12] and experimental data [13]

Finally, there is a comparison between all of temperatures.

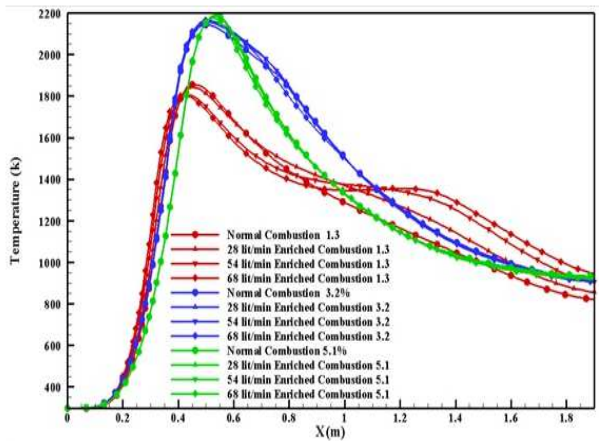


Fig. 8 compares temperature along the torch centerline with different air-fuel inlets and oxygen enrichment

With the increase of air-fuel ratio, the maximum torch flame increases too. According to figure 8, this increase is very drastic from air-fuel ratio of 1.3 to 3.2. The temperature becomes uniform along the torch centerline. By enriching oxygen, variations are observed in maximum temperature of AF ratio of 1.3. As the oxygen inlet increases, the temperature decreases noticeably. However, with AF ratio of 3.2. Changes in oxygen enrichment are negligible in AF ratio of 3.2 and 5.1.

VII. Conclusion

Computational results for the pollutant emissions resulting from combustion of fuel are evaluated.

A 3D combustion chamber was simulated using FLUENT6.32 software. AF ratio is flexible as 1.3, 3.2 and 5.1 and the oxygen enriched flow rates are 28, 54, 68 lit/min. The results show that for AF=1.3, increasing oxygen flow rate, increases the CO_2 emission. Minimum amount of CO_2 mole fraction in combustion happens at AF=5.1. Finally, we can say oxygen-enrichment can reduce the CO_2 emission at this kind of furnace.

Acknowledgment

Author thanks from hydropower and dam research office at Khuzestan water and power authority.

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