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Research paper

CFD simulation 3D premixed combustion of methane: influence of the excess air

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Abstract

Methane is one of the most widely used fuels especially for combustion in gas turbine. The utilization of methane for application in gas burner requires a design step**.** A part of a design can be done on CFD simulation. This simulation aims to see the mechanism of premixed flame and the influence of excess air on temperature, CO_2 and NO_X concentrations inside of the gas burner. The 3D computational fluid dynamic was used in this simulation. The combustion reaction was carried out with the spices transport model. The excess air was varied each of 0%, 20%, 40%, and 60%. The simulation results showed the preheat zone occurred at a distance from 0 mm to 300 mm and the reaction zone occurred at a distance above 300 mm in combustion chamber. The increasing of the excess air decreased the temperature distribution as well as the concentration of CO_2 and NO_X but increased the concentration of O_2.

Keywords:*CFD-3D; Premixed Combustion; Methane; Excess Air.*

1. Introduction

The utilization of methane as fuel for gas burner has been widely used. The direct testing of the gas burner usually requires amount of cost and have a risk to failure. The CFD simulation is one way to overcome this problem. ANSYS Fluent is one of the most widely used software for simulating of combustion process. Spices transport is a model that could be used to predict a phenomenon on premixed combustion. Many researchers have simulated on 2D premixed combustion methane using spices transport model. Masatkar et al. [1] have simulated 2D premixed flame of methane-air and syngas-air using spices transport model, the results showed the highest temperature occurred on equivalence ratio of 0.9 and CO_2 decreased with increasing of air velocity.Powel et al. [2] have simulated 2D premixed combustion using spices transport to predict a combustion phenomenon of methane, hydrogen and ethane on the gas burner, the results showed the flame position of methane closer to the gas burner outlet, the velocity and the mass fraction can be compared with the results of the testing. Chen et al. [3] have implemented spices transport on 2D simulation of premixed methane-air, the results showed the thermal conductivity of wall burner influenced combustion process.
In this simulation, premixed combustion methane-air was done on 3D to investigate the influence of the excess air to the temperature and mass fraction of CO_2, NO_x, and O_2

2. Methodology

Simulations were performed using ANSYS Fluent with mass conservation, momentum conservation, energy conservation, standard turbulent, spices transport, finite rate/eddy dissipation, thermal and prompt NOx equations. The stoichiometric combustion equation reaction of methane is shown in equation 1.

$$CH_4 + 2\,(O_2 + 3{,}76\,N_2) \rightarrow CO_2 + 2\,H_2O + 7{,}52\,N_2 \quad (1)$$

The step of NO_X reaction was used as shown in equation (2) to (8) [4].
Thermal NOx Process

$$O + N_2 \rightleftharpoons N + NO \quad (2)$$

$$N + O_2 \rightleftharpoons O + NO \quad (3)$$

$$N + OH \rightleftharpoons H + NO \quad (4)$$

Prompt NOx Process

$$CH + N_2 \rightleftharpoons HCN + N \quad (5)$$

$$N + O_2 \rightleftharpoons NO + O \quad (6)$$

$$HCN + OH \rightleftharpoons CN + H_2O \quad (7)$$

$$CN + O_2 \rightleftharpoons NO + CO \quad (8)$$

The spices transport equation was used for the combustion reaction as shown in equation (9) [4].

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla(\rho \vec{v} Y_i) = -\nabla.\bar{J}_i + R_i + S_i \quad (9)$$

The calculation domain was premixed gas burner with a diameter of combustion chamber of 200 mm, a length of combustion chamber of 400 mm, a diameter of premixed chamber of 50 mm, a length of the premixed chamber of 250 mm, a diameter of fuel inlet of 20 mm and a diameter of air inlet of 30 mm as shown in Fig 1.

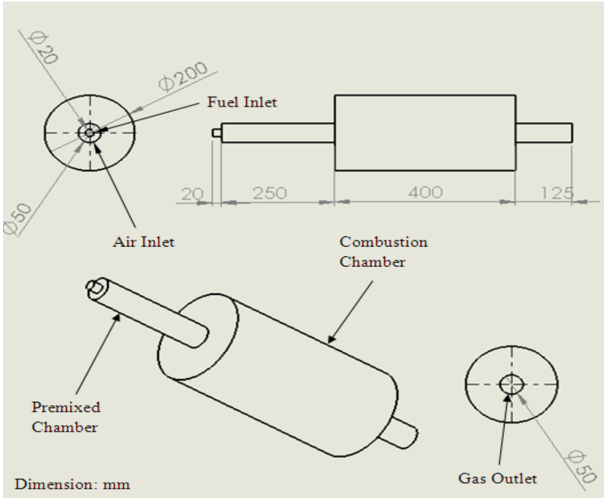


Fig. 1: Solid of Calculation Domain.

The mesh generating for solving numerical calculation is shown in Fig 2. The boundary condition was used in this simulation is shown in Table 1.

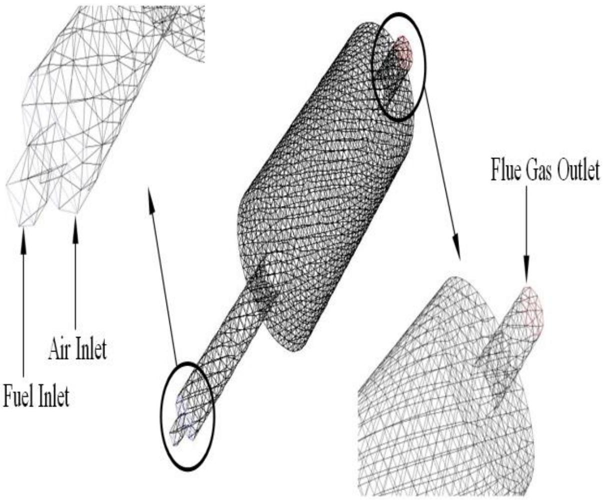


Fig. 2: Mesh Generation of Calculation Domain.

Table 1: The Boundary Condition

Excess Air (%)	V (m/s)	T (ºC)	Mass Fraction O_2	Mass Fraction N_2
0	3,0464	27	0,23	0,77
20	3,65568			
40	4,26496			
60	4,87424			

3. Results and discussion

3.1. The mechanism of change of temperature, reactant and product

Fig 3 shows the mechanism of change of reactants, products and temperature along axial direction at the center of the combustion chamber on the gas burner. The concentration of CH_4 (reactants) decreased with increasing in the CO_2 concentration (product) during the reaction process. The heat was released in the reaction could be identified on an increase of the temperature (axial direction). The point crossing of the line of a decrease of reactant (CH_4) and an increase of temperature is a point to divide the preheat zone (preflame zone) and reaction zone (visible flame zone) on gas burner [5]. The preheat zone existed in the range of combustion chamber length of 0 mm to 300 mm and the reaction zone existed in combustion chamber length above 300 mm.

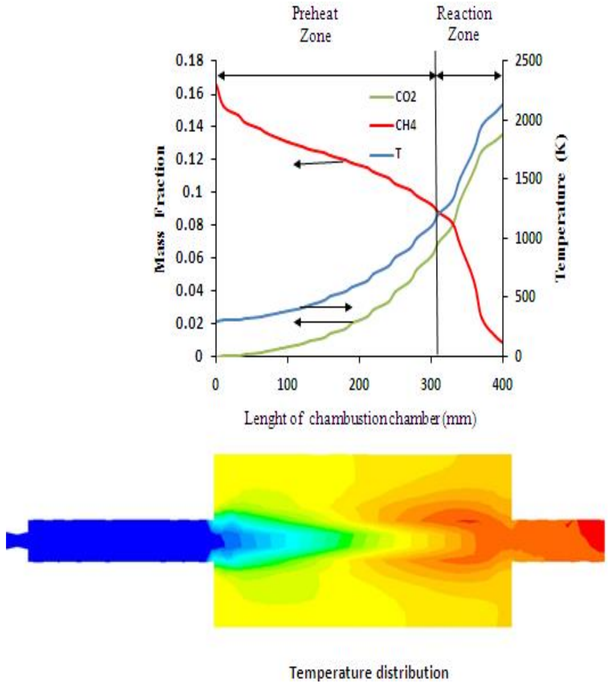
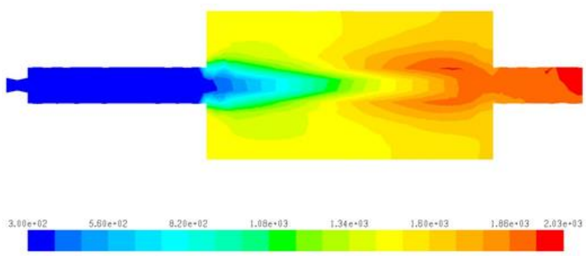


Fig. 3: The Distribution of CH_4, CO_2 and Temperature at A Length of Combustion Chamber.

3.2. The effect of the excess air on the temperature inside the gas burner

Fig 4 shows the temperature distribution inside the gas burner, an increase of the excess air tended to decrease the temperature distribution inside of the gas burner especially in the reaction zone. It was caused by an increase of nitrogen as result of the excess air. The nitrogen would absorb heat released by a combustion reaction. An increase of excess air of 20%, the temperature decreased in the preheat zone was lower in the range of 3 K to 7 K than in the reaction zone in the range of 120 K to 160 K. The maximum of temperature at each of the excess air were 2030 K, 1870 K, 1740 K and 1620 K. The temperature distribution on radial direction is shown in Fig 5-6. According this figure at preheat zone the temperature tended to increase from inner to outer was caused by the high unburned gas at center of the flame. It was contrary at reaction zone, the temperature tended to decrease from inner to outer on radial direction due to all fuel completely burn. This distribution has similarity to the distribution that explained by El-Mahallawy [5].



(a)

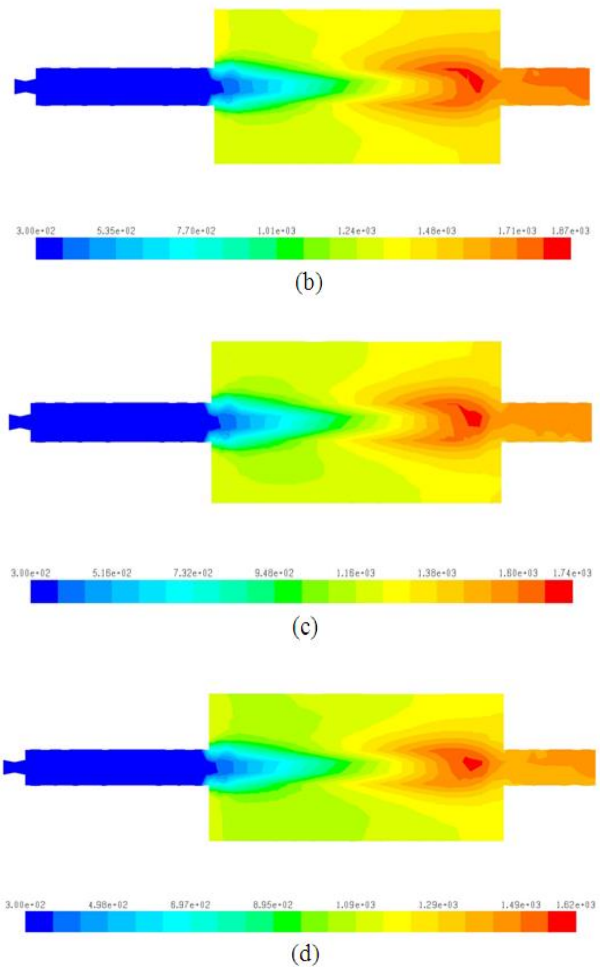


Fig. 4: The Temperature Distribution (K) With Variation of Excess Air; (A) 0%, (B) 20%, (C) 40%, (D) 60%.

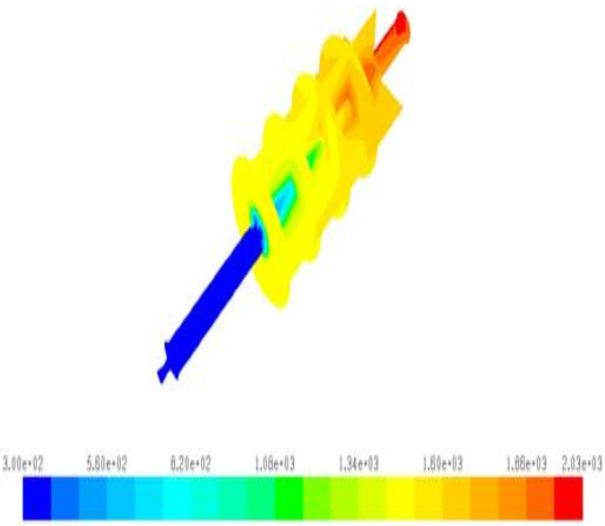


Fig. 5: The 3D of Temperature Distribution on A Axial and A Radial Direction (K).

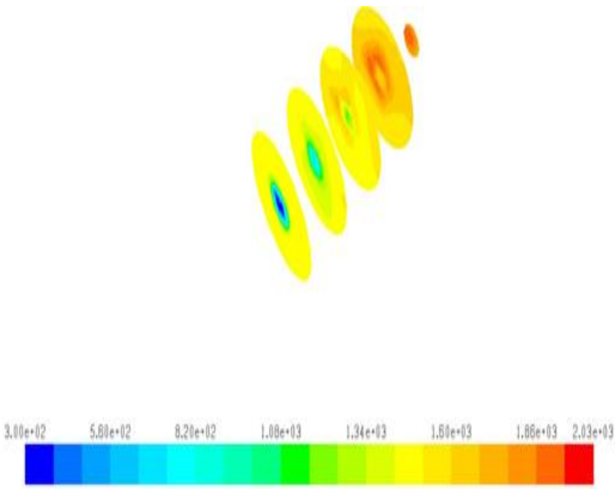
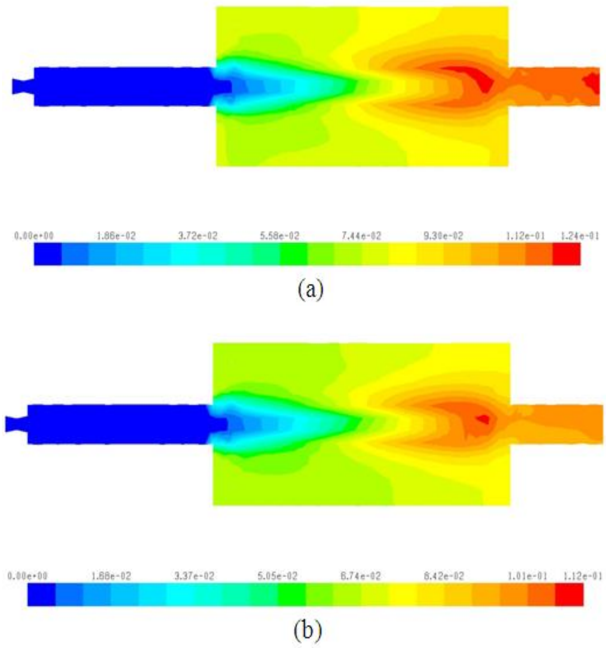


Fig. 6: The 3D of Temperature Distribution on A Radial Direction (K).

3.3. The effect of the excess air on CO2 inside the gas burner

Fig 7 shows the effect of the excess air on the distribution of CO_2 mass fraction inside of the gas burner. The CO_2 mass fraction decreased with an increase of the excess air.Due to the constant mass of CO_2 produced by the combustion process, while amount of the mass of the product increased as resulted an increasing in the mass of oxygen and nitrogen in the product. This result has a same trend to the reported of Wasser et al. [6] and Vidian et al. [7].The magnitude of a decrease in the CO_2 mass fraction at an increase of 20% of the excess air were about 0.0003 at the preheat zone and about 0.017 at the reaction zone. The maximum of CO_2 mass fraction concentration at each of the excess air were 0.13523, 0.11892, 0.10164 and 0.08844 in combustion chamber center at a length of 400 mm. The distribution of CO_2 tended to increase from inner to outer at preheat zone due to have unburned fuel at center of flame, but the distribution of CO_2 tended to decrease from inner to outer at reaction zone was caused by all fuel has been completely burn.



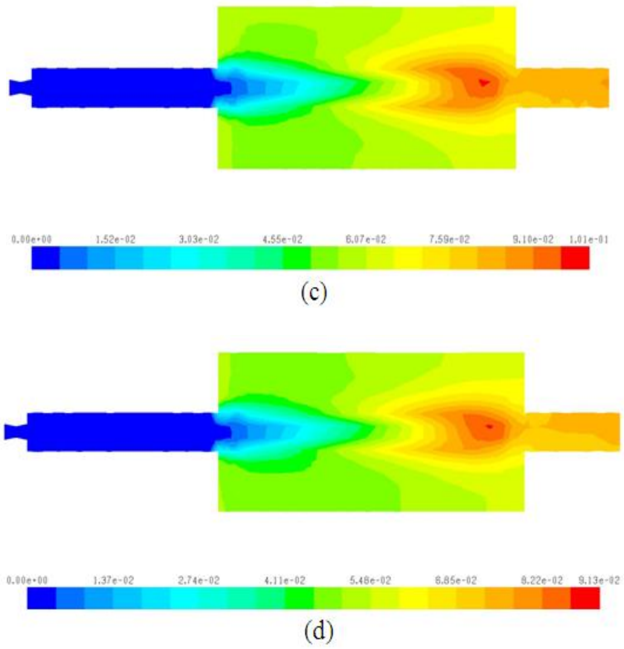
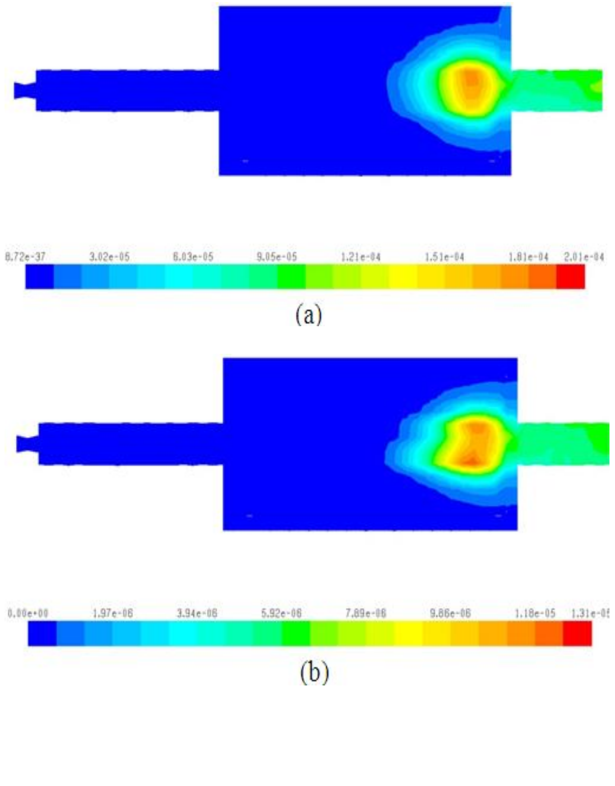


Fig. 7: The Mass Fraction of Carbon Dioxide Distribution with Variation of Excess Air; (A) 0%, (B) 20%, (C) 40, (D) 60%.

3.4. The effect of the excess air on NO_x inside the gas burner

Fig 8 shows the effect of the excess air in NO_x concentration. In generally, the NOx concentration on each the excess air would occur at zone with a length between 300 mm to 400 mm (reaction zone) in combustion chamber. At this zone, the temperature was above 1000 K that would produce NOx [8]. The increase of the excess air would decrease the concentration of NO_x due to decrease on the temperature as resulted on increasing of the excess air. The NO_x mass fraction for each the excess air were 1.287 x 10^{-4}, 9.332 10^{-6}, 7.740 10^{-7} and 4.690 10^{-8} in combustion chamber center at a point with the length of 400 mm. In the radial direction, the concentration of NO_x tended to decrease from inner to outer due to follow the trend of the temperature as shown in Fig 4-6.



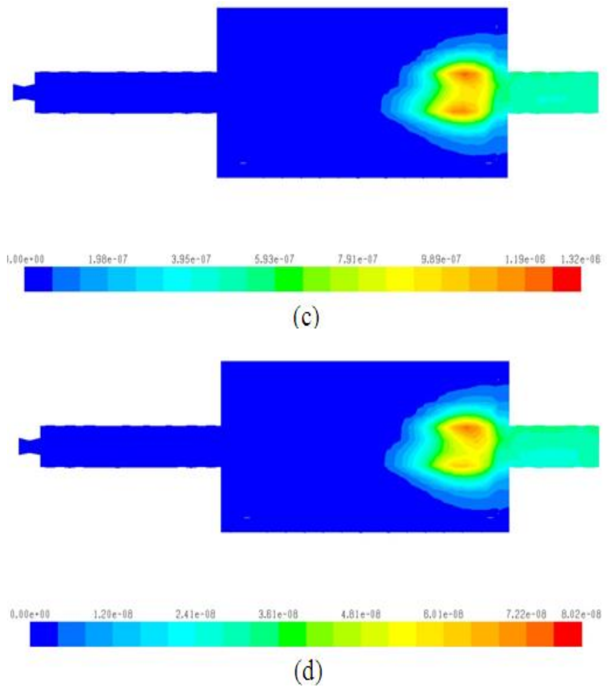
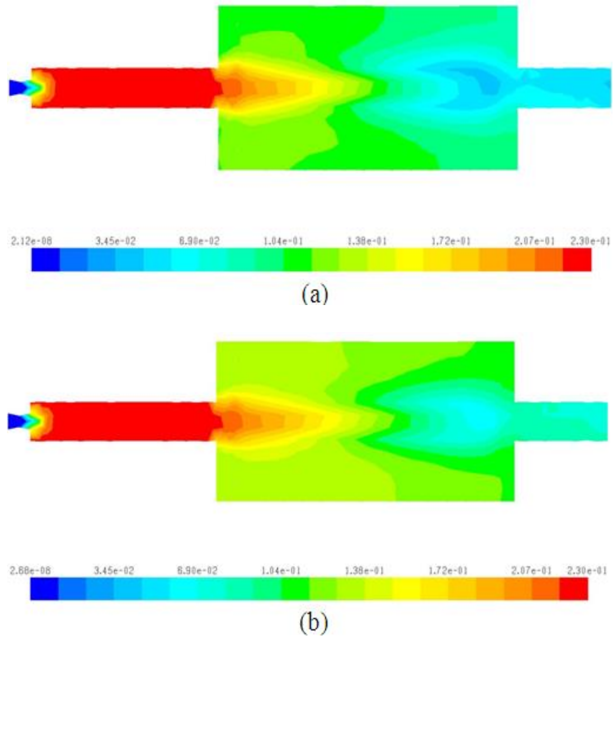


Fig. 8: The Mass Fraction of Nitrogen Oxide Distribution with Variation of the Excess Air; (A) 0%, (B) 20%, (C) 40%, (D) 60%.

3.5. The effect of the excess air on oxygen inside the gas burner

Fig 9 shows the influence of excess air to oxygen distribution inside of the gas burner. For each of the excess air, the highest of oxygen concentration occurred at the premixed zone due to the reaction did not happened yet, furthermore it gradually decreased from the preheat zone to the reaction zone. In the reaction zone, an increase of the excess air would increase excess oxygen that would become a product. The maximum of oxygen mass fraction at each of the excess air were 0.0201, 0.04636, 0.0732 and 0.09363 in the center of combustion chamber at the length of 400 mm. In the radial direction at preheat zone, the concentration O_2 tended to decrease from inner to outer due to more of fuel unburned at center of flame, but at reaction zone the concentration O_2 tended to decrease from inner to outer due to complete combustion of fuel.



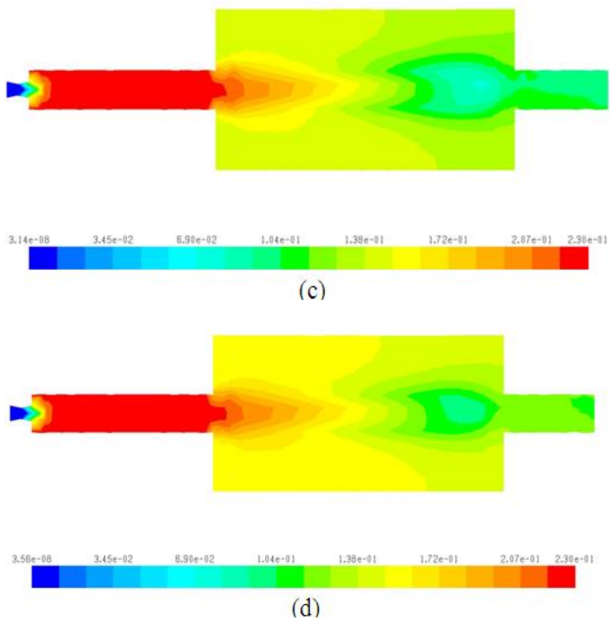


Fig. 9: The Mass Fraction of Oxygen Distribution with Variation of the Excess Air; (A) 0%, (B) 20%, (C) 40%, (D) 60%.

4. Conclusion

The simulation results shown the preheat zone (preflame zone) occurred at a distance of 0 mm to 300 mm, the reaction zone (visible flame zone) occurred at a distance above of 300 mm. The increase of the excess air tended to decrease the temperature, the CO_2 concentration and the NO_x concentration. The increase of the excess air tended to increase the O_2 concentration. The significant of temperature differences occurred in combustion chamber centre at a length above 300 mm (reaction zone), where the formation of NO_x occurred at this position.

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