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Porosity effects in flame length of the porous burners

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ABSTRACT

Furnaces are the devices for providing heat to the industrial systems like boilers, gas turbines and etc. The main challenge of furnaces is emission of huge air pollutants. However, porous burners produce less contaminant compared to others. The quality of the combustion process in the porous burners depends on the length of flame in the porous medium. In this paper, the computational fluid dynamic (CFD) is used to investigate the porosity effects on the flame length of the combustion process in porous burner. The simulation results demonstrate that increasing the porosity increases the flame length and the combustion zone extends forward. So, combustion quality increases and production of carbon monoxide decrease. It is possible to conclude that temperature distribution in low porosity burner is lower and more uniform than high porosity one. Therefore, by increasing the porosity of the burner, the production of nitrogen oxides increases. So, using an intermediate porosity in the burner appears to be reasonable.

Keywords: Burner, Porous media, Flame, Simulation

INTRODUCTION

Environmental crisis is one of the main problems that the world is facing today. One of the strategies for controlling the air pollution is increasing the combustion efficiency for reducing the fuel consumption. So, a burner should control the combustion of fuel for producing the heat.

Porous burners consume low value of fuels for producing the heat. This may be a solution to reduce the production of carbon dioxide. Weinberg, [1]. Howell *et al*., [2] studied the porous materials and their convective, conduction and radiative properties. They described the flame stabilization within a porous burner and showed that the porous matrixes have higher burning speeds and lower flammability limits than open flames.

Yoshizawa *et al.* [3] numerically simulated one-dimensional porous burner by considering one-step kinetics. They studied the effects of the heat transfer on the burning rate and flame structure. Barra *et al.* [4] numerically studied a one-dimensional two-layered porous burner. They showed that the first layer should have a low volumetric heat transfer coefficient, low conductivity, and high radiative coefficient. The second layer should have a high volumetric heat transfer coefficient, high conductivity, and medium radiative coefficient.

Xie *et al.* [5] investigated the performance of a porous media burner with reciprocating flow. They showed that structure and material of porous burner significantly affect the burner performance.

Francisco Jr *et al.* [6] studied the combustion of hydrogen rich gaseous fuels with low calorific values in a porous medium burner. They showed that the flame stability and pollutant emissions are a function of fuel gaseous mixtures of CH_4, H_2, CO_2, CO, and N_2.

Zheng *et al.* [7] investigated the combustion of low calorific values gases in silicon carbide (SiC) foam. They showed that higher temperatures were obtained in SiC foams of 30 PPI (pores per inch).

Mujeebu *et al.* [8] studied two premixed LPG burners based on submerged and surface combustion modes in porous medium and compared their combustion and emission characteristics with conventional burner. They observed that NOx emission is reduced by 76% and 75% by the use of submerged and surface combustion modes, respectively, compared with the conventional burner.

Yu *et al.* [9] experimentally studied the thermal efficiency and the emission properties of porous burners. They investigated three kinds of porous burners; metal fiber (MF), ceramic (CM) and stainless steel fin (SF). They showed that the MF and SF burners had the lowest and highest CO emissions between the three types of burner, respectively. However, The MF and SF burners had the highest and the lowest NOx emission between the burners, respectively.

Li *et al*. [10] experimentally studied the liquid fuel combustion in a porous media burner. They showed that the flame of porous burner is affected by the airflow velocity.

Afsharvahid *et al.* [11] evaluated the impact of surface reactions on the NO_X production within a porous burner. They found that the presence of surface reactions significantly influence the NO_X reduction efficiency.

Ismail *et al.* [12] investigated the application of porous medium burner with micro cogeneration system. They showed that very low NOx emissions were produced in this burner for domestic burner applications.

Gao *et al.* [13] investigated the premixed combustion of methane/air mixtures in different pickings. They studied the flame temperature profiles, pressure drop, and pollution emissions for carbon monoxide, hydrocarbon, and NOx. They showed that CO emission was significantly affected by the flame temperature; however, the HC emission was mainly influenced by the mixing uniformity of fuel/air.

In this paper, the effects of porosity on the flame length in porous burners are investigated.

Governing equations

Porous burner system is composed of two parts: 1) solid matrix and 2) void space saturated by fluid. Therefore, the continuity and momentum equations are written for gas phase and energy equation is written for both phases. In this paper, the steady two-dimensional system is considered. The effect of gravity force is neglected. So, the governing equations are as following (Hackert *et al.*, [14] :

The continuity equation:

1) $-\nabla.(\rho v)=0$

The momentum equations:

2) $$\nabla.(\rho v v_i) = \nabla.(\mu \nabla v_i) - \frac{\partial P}{\partial x_i}$$

Gas phase energy equation:

3) $$\nabla.(\rho v h) = \nabla.\left(\frac{k}{c_p}\nabla h\right) + h_c R_A$$

Solid phase energy equation (Hsu *et al*. [15]:

4) $$\nabla.(k\nabla T) + h(T - T_s) - \nabla.(q_r) = 0$$

Where, ρ is fluid density (kg/m3), RA is reaction rate (kg fuel/m3/sec), μ is fluid viscosity (kg/m/sec), h is specific enthalpy (J/kg), hc is heat of combustion (J/kg fuel), k is thermal conductivity (W/m/K), h is convective heat transfer coefficient, qr is radiative heat transfer per area, P is pressure (Pa), and v is gas velocity (m/sec).

Material and methods

Geometry of porous burner is generated using Gambit 2.0 software. The dimensions of simulated burner are 4*12mm. In order to obtain grid independent results, different uniform grid numbers, 20 × 120, 40 × 240 and 50 × 300 are tested for porosity of 0.5. It is noticed that the difference between the length of concentration fully developed zone predicted based on 40 × 120 and 50 × 150 grids is insignificant (<1%). The length of concentration fully developed zone for the tested grid points is 9.276, 9.301 and 9.305 for grids 20 × 120, 40 × 240 and 50 × 300 respectively. Thus 40 × 240 grid is used for generating the results. The model equations are solved using commercial flow simulation software, FLUENT 6.0.1.

Temperature of the inlet stream is 300 Kelvin and the velocity is 0.2m/s. The studied reaction is combustion of methane with 20% excess air as following:

$$CH_4 + Air \rightarrow CO_2 + 2H_2O$$

The above equations are solved for 7 different porosities: 0.10, 0.25, 0.40, 0.55, 0.70, 0.85, and 1.00.

RESULTS AND DISCUSSION

In order to verify the validity of the results, temperature of the center line of the porous burner with porosity of 0.5 is compared with the experimental results presented in the literature. As it is seen in figure 1, the simulation results are in line with experimental results (Durst and Trimis, [16].

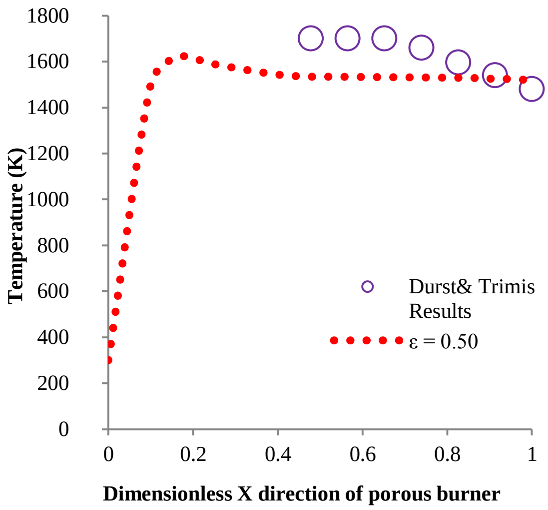

Fig. 1: The effect of porosity on the temperature distribution in the centerline of porous burner

Figure 2 shows the effects of porosity on the temperature distribution in the porous burner. As it is seen, an increase of porosity rises the maximum temperature of the flame. Whereas, in low porosities, due to faster heat conduction, temperature throughout the porous medium is lower and more uniform than high porosities.

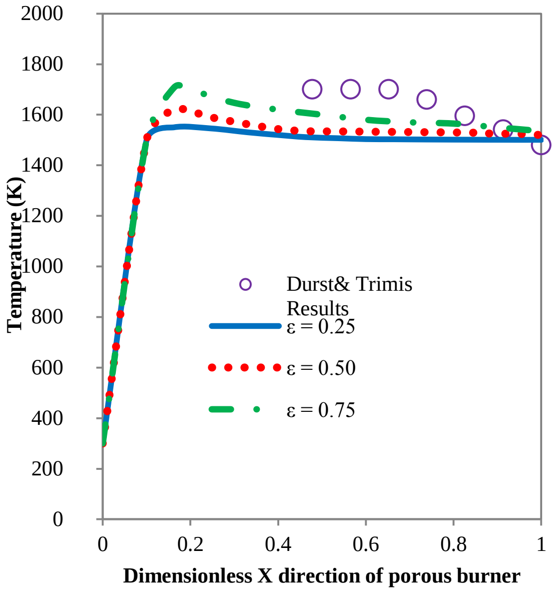

Fig. 2: The effect of porosity on the temperature distribution in the porous medium burner

Figure 3 and 4 illustrated the temperature and concentration distribution of methane in different porosities. It is seen that by increasing the porosity the flame length raises.

Figure 5 displays the fully developed length of concentration in the different porosities. As it is seen, the porosity increasing extends the combustion process zone forward and increases the concentration fully developed length. In the other word, combustion takes place in the greater part of the burner, so, the efficiency of process increases and the conversion of methane to carbon monoxide decrease.

Figure 6 displays the fully developed length of temperature in the different porosities. It is seen that increasing of porosity increase the temperature fully developed zone. It means that in the low porosity, temperature is more uniform than high porosity, so, the probability of NOx production decreases, however, the production of CO increases (Afsharvahid *et. al*, [17].

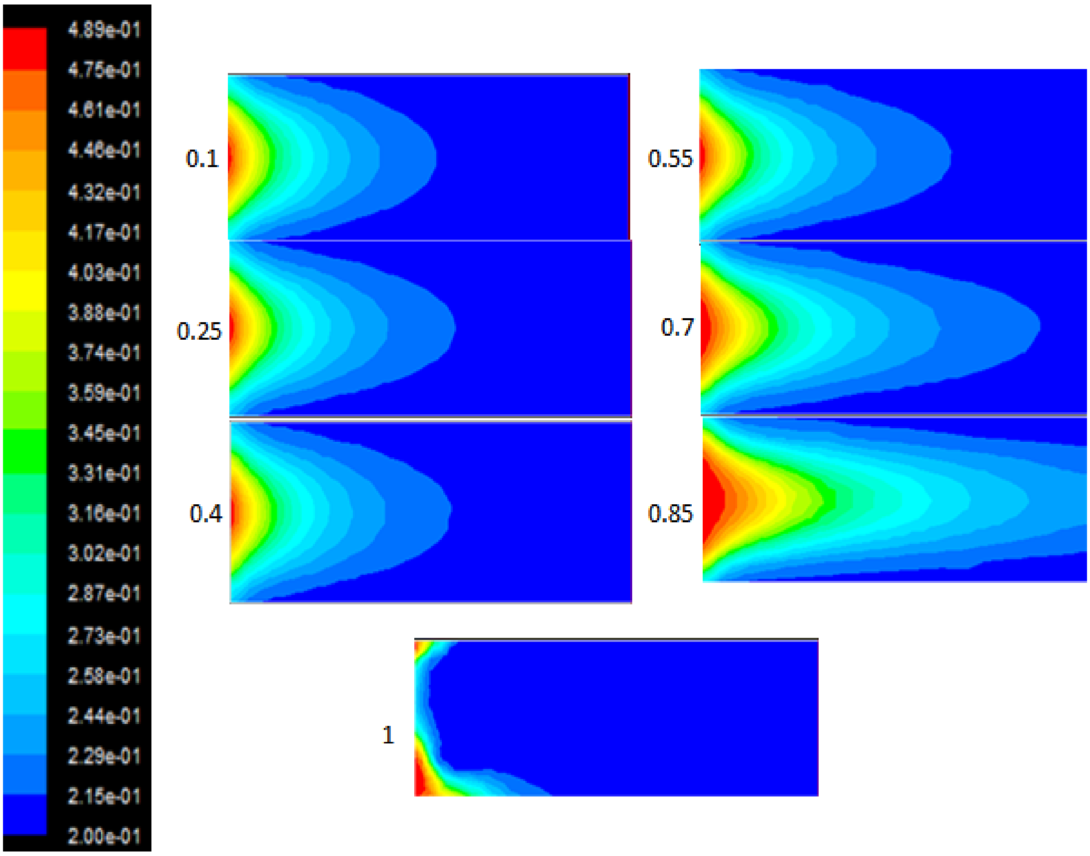

Fig. 3: porosity effects on concentration distribution of methane in porous burner

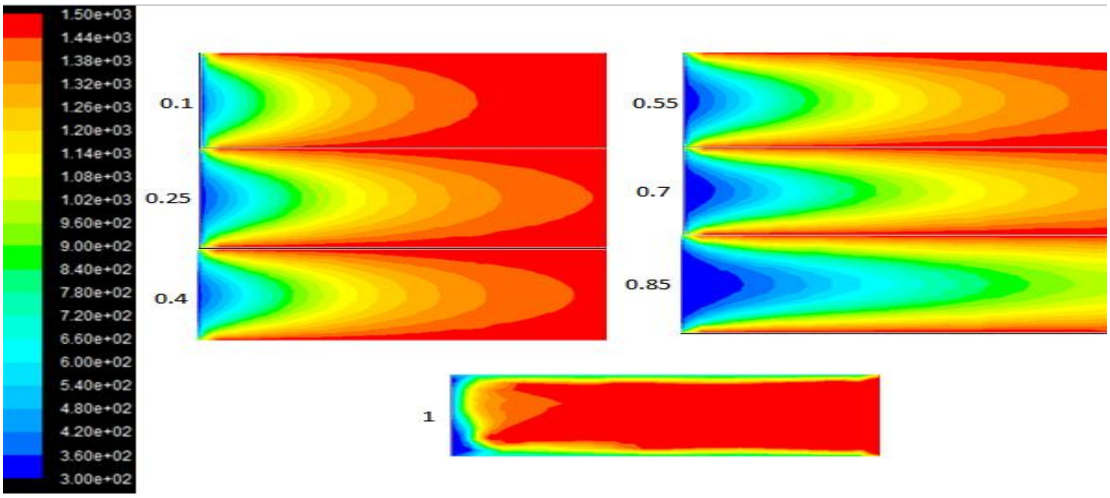

Fig. 4: porosity effects on temperature distribution in porous burner

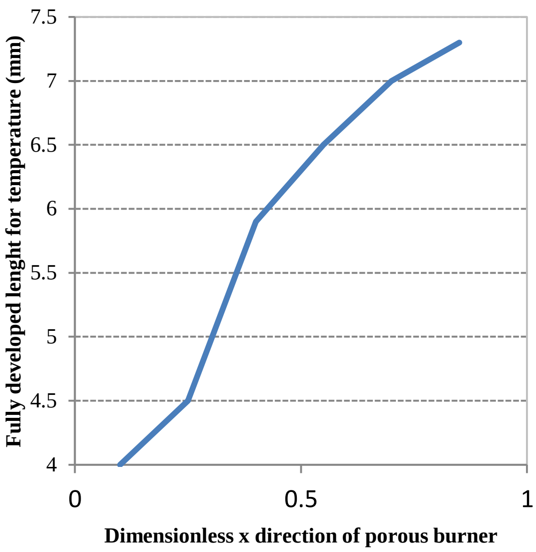

Fig. 5: Fully **d**eveloped length of concentration versus porosity

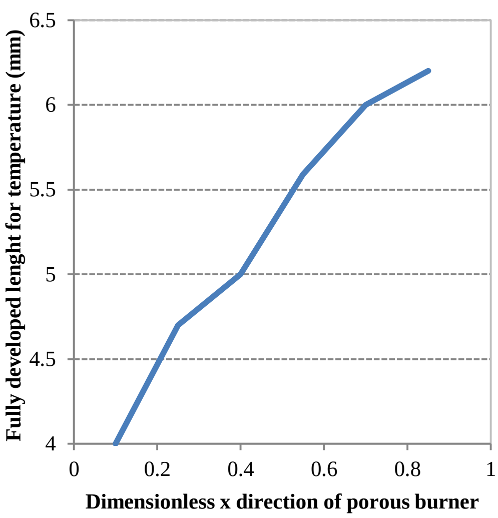

Fig. 6: Fully developed length of temperature versus porosity

It is concluded that the pollutants emission in furnaces can be controlled by selection of the correct porosity for the porous burner. In the other word, using an intermediate porosity reduces the emission of pollutants.

Conclusion

In this paper, prediction of the flame length of a porous burner is numerically simulated by CFD commercial package, fluent. Finite volume method is used to investigate the porosity effects on improving the combustion process. It is observed that by increasing the porosity of burner, maximum and average flame temperature increase and uniformity of the temperature decreases. In addition, by increasing the porosity, flame length increases. At constant operating pressure and relative air ratio, the NOx emissions are influenced by the operating temperature (Bakry *et. al.* [18, 19], then decreasing the burner porosity reduces the NOx emission. Moreover, high temperature causes reduce the conversion of methane to CO. So it is noticed that an intermediate porosity improve the emission of pollutants.

The comparison of the simulated temperature for porosity of 0.5 with those in the literature shows the good agreement between our simulated results and the measured temperature by Durst and Trimis [16].

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