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Enhancement of Hydrogen Production of Methane Incomplete Combustion through Porous Medium

MohammadReza Shahnazari*, Hedayat Mousavi, and Ali Saberi

Mechanics Engineering Department, K. N. Toosi University of Technology Tehran, Iran

Shahnazari@kntu.ac.ir

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INTRODUCTION

Hydrogen is referred as the fuel of the future, because the Hydrogen has many sources of production, the highest energy per mass unit and the lowest pollution in the combustion process [1]. It is also the reaction product of hydrogen and oxygen in the fuel cell is water, which is ideal for nature. The steam reforming, thermal partial oxidation (PO_X) and auto-thermal reforming are methods for producing hydrogen. Auto thermal reforming (ATR) is a combination of steam reforming and partial oxidation [2]. Compared with the other reforming technologies partial oxidation process has several advantageous. There is no need for external heat sources and additional feeds like water as in steam reforming. It has a good dynamic response, a very simple system design and can be applied to almost all hydrocarbons [3, 4].

Numerous experimental and numerical studies have been conducted on hydrogen production in porous media. A model for premixed combustion within porous inert media has been studied by Hsu and Matthews [5]. Their results have shown that single-step kinetics is adequate for predicting all the flame characteristics except the emissions for the very lean conditions. Numerical investigation of the thermal partial oxidation process of Methane in porous media based reformer performed by Al-Hamamre et al [6]. Their model was able to predict the temperature behavior in the reformer reasonably well. Also they mentioned that however the concentrations of H_2 and CO are under predicted while the H_2O concentration was over predicted. Also, Methane Thermal Partial Oxidation (TPOX) within a small scale Inert Porous Media (IPM) based reactor has been investigated by Miguel et al [7]. Moreover, a quasi-1D model of the TPOX reactor has been used by them to study the process and explore the operating conditions and possible procedures for maximizing the reforming efficiency and

minimizing the soot formation. Also, it has been found by them that a high preheating temperature of the reactants is beneficial for the process, and the effect of power input is negligible for the reforming efficiency.

EXPERIMENTAL PROCEDURE

The partial oxidation apparatus is shown in Figure 1 schematically. The apparatus consists of a combustion tube filled with a porous medium, fuel and air supply system and temperature measurement system. Also, a combustion tube with three internal diameters and wall thickness of 2 mm and the packed bed of 1, 3 and 5 mm solid Al_2O_3 spheres as the porous medium with different porosity has been used by us (Figure 2). It should be mentioned that the reactants are mixed in mixing chamber, and also a reservoir tank is provided to gather the gas after passing the gas cooling system for testing sample. Also, the measurement instruments are used to analyze the Oxygen, CO, CO_2 and CH_4, and also C-type thermocouples with the accuracy of ± 0.5% and ± 1.0% are installed at the center of the reactor to measure the temperature and are covered with a layer of A-type ceramic paper insulation to avoid damage.

GOVERNING EQUATION

In order to model and introduce the governing equations, the radiation of the gas phase is ignored. It is considered that the porous medium is homogeneous, so the continuum and momentum equations are as follows (Equations 1 and 2):

$$\frac{\partial}{\partial t}\rho_g + \nabla.(\rho_g u) = 0 \quad (1)$$

$$\frac{\partial}{\partial t}\rho_g + \nabla.\left(\rho_g u\right) = 0 \quad (2)$$

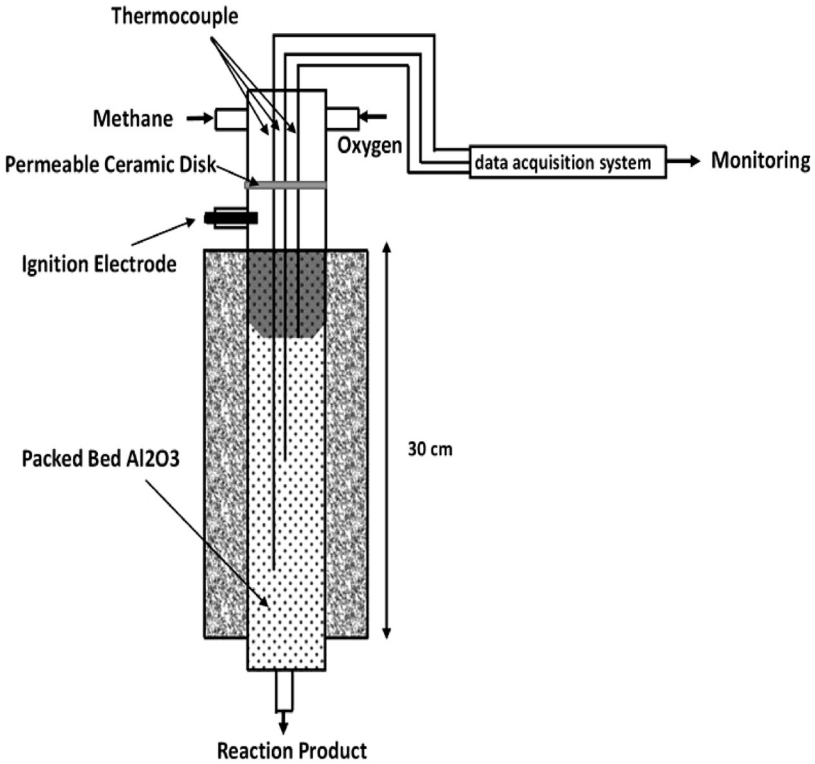

Figure 1: Schematic of the apparatus.

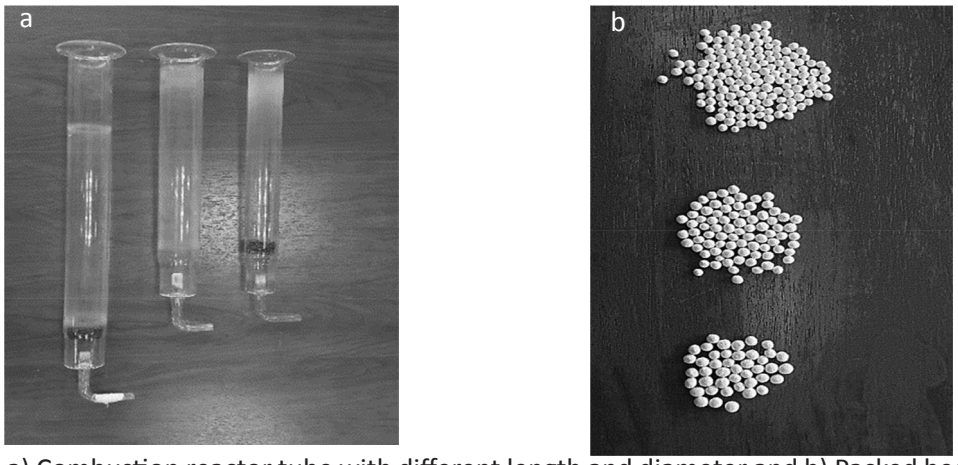

Figure 2: a) Combustion reactor tube with different length and diameter and b) Packed bed of 1, 3, and 5 mm solid Al_2O_3.

The energy equation for the gas and the solid phase is as follows (Equations 3 and 5):

$$\epsilon\left[\frac{\partial(\rho_g u)}{\partial t}+\nabla.\left(\rho_g u u_g\right)\right]=-\nabla.P+\nabla.(\mu\nabla u)+s \quad (3)$$

$$(1-\epsilon)\frac{\partial}{\partial t}(C_s\rho_s T_s)=\nabla.\left(k_{eff-s}\nabla T_s\right)+h_{sg}\left(T_g-T_s\right)+h_s(T_s-T_0) \quad (4)$$

It can be assumed that h_s is zero. By using Fick's law, it can be written:

$$\epsilon\frac{\partial\left(\rho_g y_i\right)}{\partial t}+\nabla.\left(\rho_g u y_i\right)=\nabla.\left(\rho_{gi}D_{m,i}\nabla y_i\right)+\epsilon\varepsilon_i(MW)_i \quad (5)$$

Where ρ, C and T are density, heat capacity and temperature, respectively. The parameter K*eff* is the effective thermal conductivity factor [8]. one can use a state equation (e.g., ideal gas) as an additional equation. In this study, despite the complexity of the GR13 mechanism to modeling the kinetic reactions, the combination of the CHEMKIN code and GR13 mechanism is used. The thermal conductivity of the porous material is temperature dependent. The governing equations are solved by a finite volume method and also the Piso algorithm is used. The rate of chemical reactions, thermo-physical and thermo-chemical properties are achieved by the CHEMKIN program and its basic information.

Results and Discussion

Figure 3, shows the experimental results of temperature distribution inside the reactor. As mentioned, the thermometer has been installed in different length of reactor to measure temperature. Figures 4 and 5 show the hydrogen and carbon monoxide mole fraction in the reactor outlet in different values of flow rete, respectively in the case where the diameter of the reactor is 30 mm, the length is 30 cm and the equivalence ratio is 2. It can be conclude that although the behavior of both curves is almost the same, they have a relative transitional position to each other. High heat transfer in porous medium is due to the presence of multiple pores in porous objects, which increases the heat transfer surface. The diameter of the granule is an effective parameter in this process. Figure 6 shows the temperature variations in the reactor output versus diameter of the aluminum oxide granule. Figure 8 shows the effect of input parameters on the H2 mole fraction.

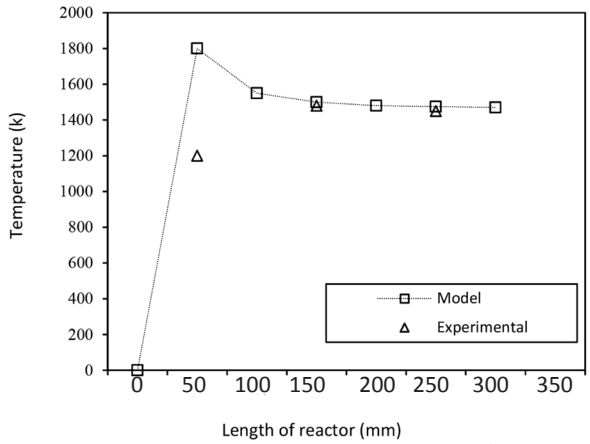

Figure 3: Variation of temperature in ϕ=2, $Q_{methane}$=100 lit/hour, Q_{Oxygen}=100 lit/hour.

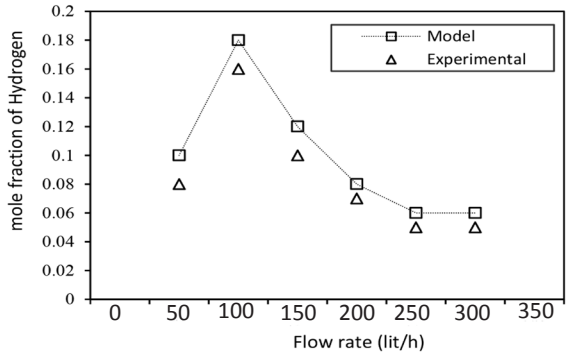

Figure 4: Mole fraction of Hydrogen versus flow rate in ϕ=2,D=30mm,L=30cm.

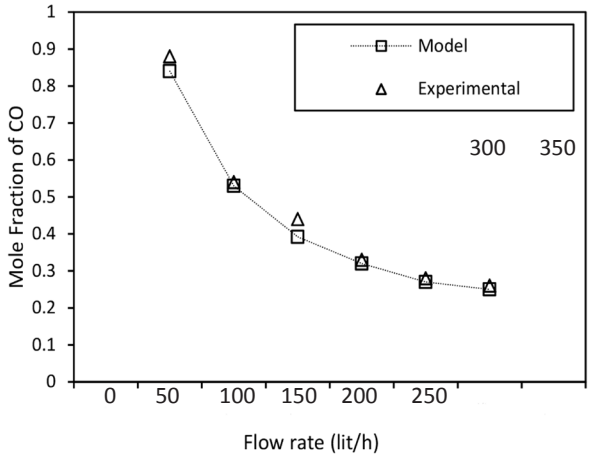

Figure 5: Mole fraction of CO versus flow rate in ϕ=2,D=30mm,L=30cm.

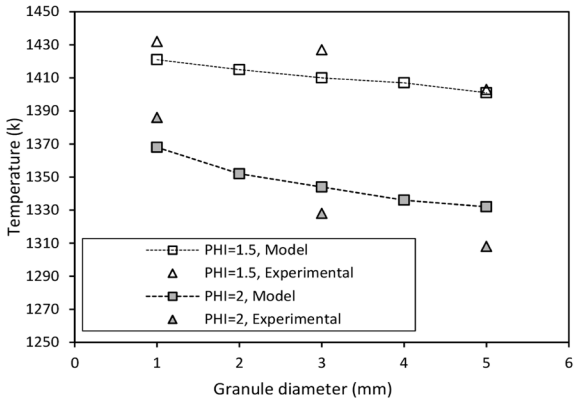

Figure 6: Variation of temperature versus Granule diameter in ϕ=1.5 and ϕ=2.

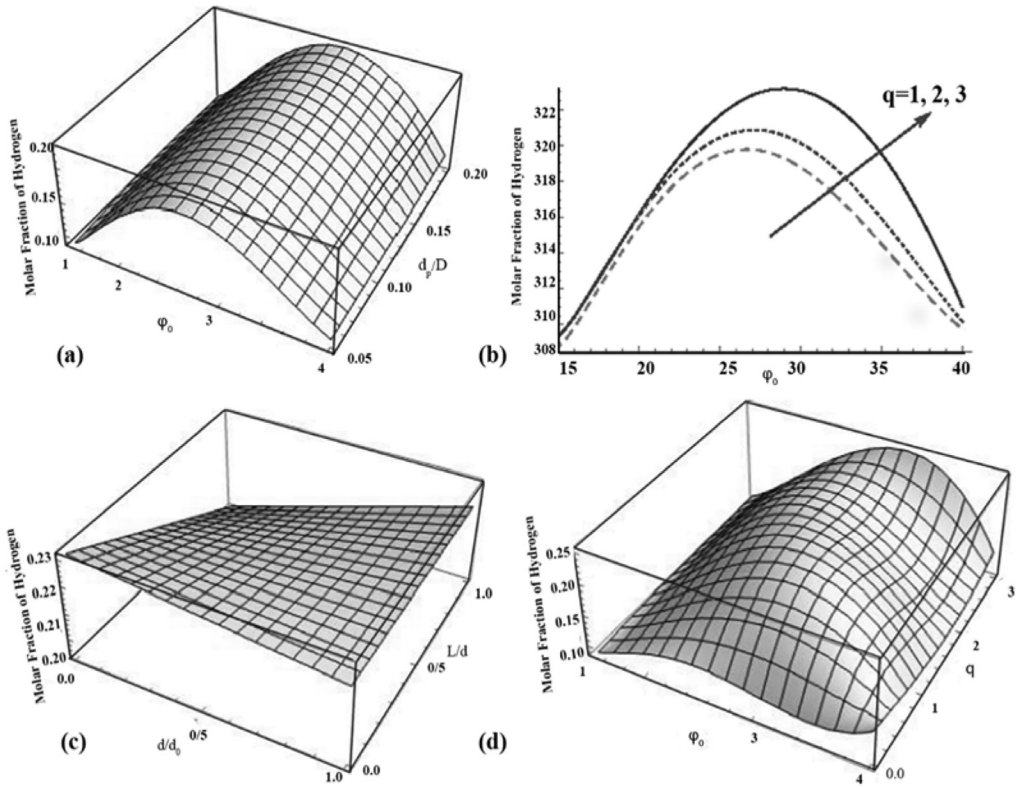

Figure 7: Variation of mole fraction with a) and b) equivalence ratio and d_p/D c) $q=Q/Q_0$ and equivalence ratio d) D/D_0 and L/.

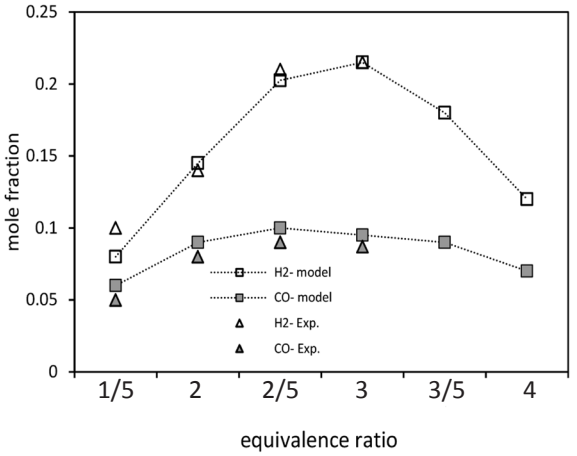

Figure 8: Mole fraction versus equivalence ratio d_p=6 mm,D=30 mm,and L=30 cm.

Figures (7-a) and (7-b) show the effect of the equivalence ratio and d_p/D. It can be conclude that the maximum mole fraction of hydrogen is in a second order form and increase as d_p/D increases. According to Figure 8-c, the best conditions to obtained optimal mole fraction of H_2 are D=30 mm and L/D=10. The simultaneous effects of φ and q on the mole fraction of produced hydrogen is shown in Figure 8-d. It is shown that $q=2.2$ in the maximum value of H_2 mole fraction.

As shown in Figure 8, the value of H_2 mole fraction increases as the equivalence ratio increase and in $\varphi \cong 2.9$ reaches to its maximum value ($H_{2,max}=2.2$).

CONCLUSION

In this paper, in order to investigate the effect of different input parameters, various sizes of reactors and spherical particles of alumina have been used experimentally. Also, the experiment tests have been carried out under different conditions of air and methane flow, and the results show a good agreement between the experimental and numerical methods.

For the first time, the optimal geometric parameters have been determined to reach maximum H_2 production. Also, it has been shown that the optimal equivalence ratio is function of input parameters. The optimum efficiency of the burner is calculated. Moreover, under good input conditions, the maximum hydrogen production can be achieved with a relatively optimal 75% energy efficiency. Moreover, the best conditions for obtaining the optimal mole fraction of H_2 are D=30mm, L/D=10, d_P/D=0.2, Q/Q_0=2.2, and ϕ=2.9. It can be concluded that despite incomplete combustion, using specific conditions lead to considerable energy efficiency.

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