Simulation of Methane Partial Oxidation
in Porous Media Reactor for Hydrogen Production

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ABSTRACT: *The enactment of strict laws on reducing pollution and controlling combustion has given rise to the necessity of considering a new approach to energy supply in the future. One such approach is the use of hydrogen as an alternative to fossil fuels. Hydrogen and synthesis gas are typically produced through the partial oxidation of methane in porous media. This process was theoretically simulated in this study through the modeling of a tubular reactor filled with a porous medium. With a view to achieving increased hydrogen production, the investigation focused on the following tasks: The best equivalence ratio of fuel to air was determined, and the effects of reactor diameter and length were examined to identify the most favorable reactor size for hydrogen production. The effects of fuel flow rate and porous media properties, such as grain size and porosity, on hydrogen production, were also investigated.*
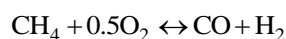
INTRODUCTION

The global consumption of fossil fuels has been constantly on the rise has given the need to satisfy the industrial demand for energy. Such excessive consumption may later deplete already limited fossil fuel reserves. In addition, emissions from the combustion processes involved in fuel production drastically affect the environment and threaten human health. In response to these issues, governments have imposed stringent laws to reduce combustion pollutants and control the release of chemical and radioactive substances into the atmosphere. These issues have highlighted the cruciality of adopting a new approach to energy supply. For this purpose, hydrogen has been discussed as a next-generation fuel given that it is a very environment-friendly gas that produces only water when reacting with oxygen.

Hydrogen also has the highest energy density among all fuels and energy carriers. Its energy yield is 122 kJ/kg, which is 2.75 times greater than those of other hydrocarbon fuels [1]. Another advantage of hydrogen is that it can be produced from hydrocarbon fuels, such as methane, through steam reforming, partial oxidation, and auto-thermal reforming. Fig. 1 illustrates different methods of methane conversion to syngas (H_2 + CO).

The partial oxidation of methane involves the use of a porous-media reactor, where the incomplete combustion of methane produces syngas. Process conditions are controlled in the reactor to produce hydrogen and an exothermic reaction takes place as follows.

$$CH_4 + 0.5O_2 \leftrightarrow CO + H_2$$
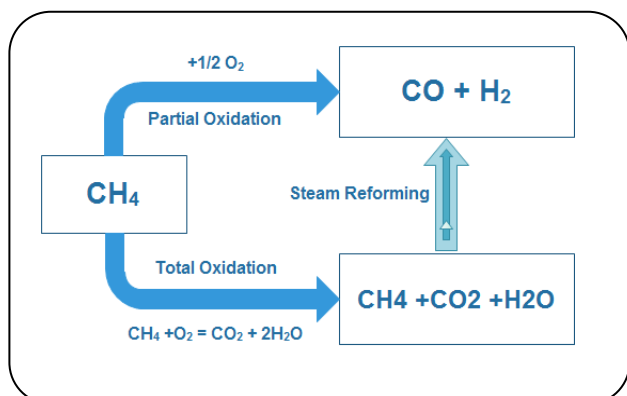
Fig. 1: Different methods for methane conversion to Syngas.

Fig. 2: Variations in the temperature of gas and porous solid along the flame length [3].

Partial oxidation presents many advantages over other reforming technologies. The process does not require an external heat source or excess fluid, such as water. It also provides an ideal dynamic response, thereby enabling the handling of light and heavy hydrocarbon fuels. Small-scale partial oxidation systems have been widely applied because of the compact dimensions of these systems, their low sensitivity to fuel diversity, and their rapid response times. These features have made incomplete combustion suitable for variable-load systems, such as fuel cells.

Gas mixture combustion in porous media substantially differs from free flame homogeneous oxidation. In free flame propagation, the dominant mechanism for heat transfer is convection from hot combustion products. Given the poor heat transfer properties of gas mixtures, combustion occurs inside a thin layer of reaction, thereby causing poor upstream heat transfer. Increased transfer of total heat can be achieved by placing a solid porous material in combustion media; the increase is made possible by the thermal radiation and thermal conductivity that result from the thermal properties of the solid matrix [2]. Correspondingly, upstream flame enthalpy is partially transferred through radiation and conduction, thus improving the stability of oxidation. Fig. 2 shows variations in gas and porous solid temperatures along the flame length.

To theoretically explore the partial oxidation of methane in porous media, this study modeled a tubular reactor filled with a porous medium. With a view to achieving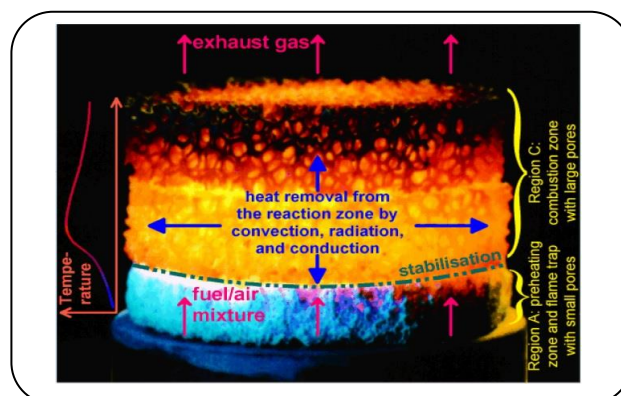 increased hydrogen production, the research focused on examining the effects of the following factors: (1) porous media properties (e.g., structural properties, such as particle diameter and porosity), (2) physical changes in reactors (including changes in diameter and length), and (3) the fuel-to-air equivalence ratio generated by inlet flow rate.

Relevant literature

Numerous experimental and numerical studies have been conducted on hydrogen production based on porous media. Such literature revolves around the effects of reactor design, the structure of porous media materials, equivalence ratio, flow rate, and partial oxidation in porous media. Some researchers used the Péclet number as a basis in examining the incomplete heat combustion of liquid and gas hydrocarbon fuels in the inert base reformer of a porous medium [4]. Babkin investigated the incomplete combustion of methane in two porous media, namely, silicon carbide foam and aluminum oxide, which have different thermal conductivity and radiation properties [5].

In an experiment using the stability parameter of the Péclet number, *Pedersen et al.* examined the rich combustion of methanol, methane, octane, and gasoline in an inert porous medium in a quartz or porcelain tube, where hydrogen production can take place [6, 7]. The authors also employed various types of porous media with different properties, including aluminum oxide foam and aluminum oxide grains, and differently sized solid granules of aluminum oxide and silicon carbide foam.

Hsu et al. found that heat transfer rates and radiation coefficients significantly affect the prediction of gas and solid phase temperatures in porous media [8]. Achieving accurate results in a numerical simulation necessitates the application of porous media properties on the basis of accurate empirical data. *Howell et al.* characterized porous media with several properties, such as effective conductivity, permeability coefficients, and vanishing coefficients, on the basis of empirical tests [9]. *Miguel et al.* numerically investigated the thermal partial oxidation of methane within a small-scale inert porous media-based reactor to explore the operating conditions and possible procedures for maximizing reforming efficiency and minimizing soot formation [10]. *Stelzner et al.* employed laser-induced fluorescence to visualize flame stabilization during porous media combustion. The authors observed that the position of maximum OH concentration is almost independent of excess air ratio for the same thermal loads in a stable operation regime [11]. Their results also revealed that the length of the flame zone decreases with increasing excess air ratios. For low excess air ratios and thermal loads of 200 kW/m^2, the flame stabilizes directly downstream of a flame trap, whereas, for high thermal loads (up to 800 kW/m^2), the flame moves further downstream into the blow-off region at high excess air ratios. In between these two regimes, the height of flame position is almost independent of thermal load and/or excess air ratio; such feature reflects the advantages of internal heat circulation in Porous Inert Media (PIM) for premixed combustion [11]. *Han et al.* optimized a detailed reaction mechanism of methane combustion for the partial oxidation of methane on the basis of the results of an experiment involving a flow reactor [12]. The authors indicated that the optimized mechanism can accurately predict CO and H$_2$ production during the partial oxidation of methane.

Brenner et al. explored the laminar and turbulent permeability properties and emission intensities of porous media in the form of polynomial functions in terms of temperature [13]. Using several experiments and numerical results, Pan et al. obtained the effective conductivity of porous media for a few types of ceramics [14]. *Malico* and *Pereira* explored the effects of the radiation properties of porous media on the functioning of cylindrical porous torches in a two-dimensional scenario [15]. They found that temperature distribution strongly depends on radiation parameters, particularly on the scattering phase function. Regardless of radiation, however, the results agree well with available experimental data.

Other empirical studies on incomplete combustion n porous media include that of *Al-Hamamre et al.,* who probed into the effects of different parameters, such as inlet speed (heat load), equivalence ratio, and porous material properties (thermal conductivity and specific heat) [16]. The authors cooled the output products from a reactor using an exchanger and then directed the products as dry gas into a gas chromatograph or gas analyzer system. The product compositions were analyzed for H$_2$, CO, CO$_2$, N$_2$, O$_2$, CH$_4$, and C$_2$H$_2$. *Zhdanok* conducted several tests on different porous materials and different porous media geometries [17].

Numerically, a variety of tools have been employed to predict the behavior of rich combustion. Henneke and Ellzey, for instance, used numerical tools to predict the oxidation of enriched fuel in a porous solid matrix [18]. Most relevant studies concentrated on numerical simulations in predicting product compositions, temperature distributions, and the effects of various performance parameters on incomplete combustion in porous media reformers. Similar to that proposed in [19], numerous numerical tools have thus far been adopted to predict the adiabatic flame temperature in the incomplete combustion of H$_2$S. *Hsu* and *Matthews* explored exact chemical kinetics to predict the temperature fields and concentrations of chemical species [20].

Ehsani et all modeled the Oxidative Coupling of Methane over Mn/Na$_2$WO$_4$/SiO$_2$ Catalyst using an artificial neural network. He studied the operating conditions, such as temperature, Gas Hourly Space Velocity (GHSV), CH$_4$/O$_2$ ratio and diluents gas on ethylene production by oxidative coupling of methane in a fixed bed reactor at atmospheric pressure [21].

Combustion in porous media

Combustion requires three conditions:

- A fuel and an oxidizer of an appropriate ratio should be used.

- The fuel and oxidizer should be mixed.

- An ignition temperature should be achieved in the above-mentioned mixture

Before exploring combustion in a porous medium, we first provide a few related definitions.

Porous medium

A porous medium is composed of a heterogeneous system that is made of a solid matrix with an empty space filled by fluids. It contains a number of pores between a few phase particles inside a duct or control volume, where the sum of volume fractions, (i.e., the empty volume fraction, occupied by pores) and that of solid volume fractions are identical. Computational technology focuses primarily on volume fraction particles and not on mass fraction. In volume fraction, solid particles are normally removed easily similar to a concentrated volume or concentrated solid, thus leaving an empty space known as pores.

Porous media are characterized by certain parameters that constitute the properties of porous materials. These parameters include the following:

- Porosity equal to the ratio of empty space volume (V_p) to the total volume of a porous material V

- Throughput as a fraction of the cross-sectional area of pores.

- Pore tortuosity factor equal to average pore length with a thickness of a porous body.

- Pores specific surface and shape

The viscosity and inertia of porous materials

- The physical and mechanical properties of porous materials

Oxidation in porous media

Oxidation in porous media can be classified into two processes, namely, stationary and non-stationary oxidation. The former can be achieved by stabilizing the flame at a specific zone in a porous medium, whereas in the latter, the combustion wave travels in an alternating forward and backward movement in a porous solid matrix. Flame stability in porous media can be achieved through many techniques:

- A porous structure is cooled in a specific zone where flame propagation is prevented.

- Speed stability is derived, which involves the use of flow rate (where a medium and a flame move at the same speeds) to stabilize the flame in a porous medium .

- Stability is ensured through thermal radiation, which reduces flame temperature and, subsequently, flame speed.

- The stability of the Péclet number is obtained through the formation of a no-combustion zone with pores of small diameters (Pe < 65) and a combustion zone with pores of large diameters (Pe > 65). In this scenario, a flame is stabilized between the two zones. This rule was first proposed in [22] with the introduction of the modified and critical Péclet numbers .

The critical Péclet number (Pe$_c$) for methane oxidation in inert porous media is 65, calculated as follows:

$$Pe = \frac{S_L \times d_m}{\alpha} \qquad (1)$$

Where S_L is the laminar flame speed, d_m denotes the equivalent pore diameter and α represents the thermal diffusion coefficient of a gas mixture. Concentrated heat transfers in porous media, in the upstream direction and preheats a cold fuel/oxidizer. It then determines flame propagation and improves flame stability [23]. Fig. 3 shows a schematic of heat transfer during the physical and chemical process of combustion in a PIM [24].

Fuel-to- air ratio

The mass ratio of fuel to air is called Fuel-to-Air (FA) ratio represented as follows:

$$FA = \frac{m_f}{m_a} \qquad (2)$$

Where m_f and m_a are the mass of fuel and mass of air, respectively.

The fuel-to-air ratio plays a crucial role in the quality of combustion, which will not occur if such ratio is excessively large or small. In between two boundaries, however, this ratio should be selected on the basis of certain conditions until the highest efficiency is achieved.

Equivalence ratio

The equivalence ratio is obtained from the division of an actual fuel-to-air ratio by a theoretical fuel-to-air ratio. For an air–fuel mixture, three potential ratio scenarios are possible:

• Stoichiometric mixture: In this case, the air in the mixture is equal to the minimum air required to enable complete combustion. The equivalence ratio in this mixture is 1.

• Lean or poor mixture: A mixture is called lean or poor when the actual fuel-air ratio is greater than the theoretical fuel-to- air ratio. In this scenario,
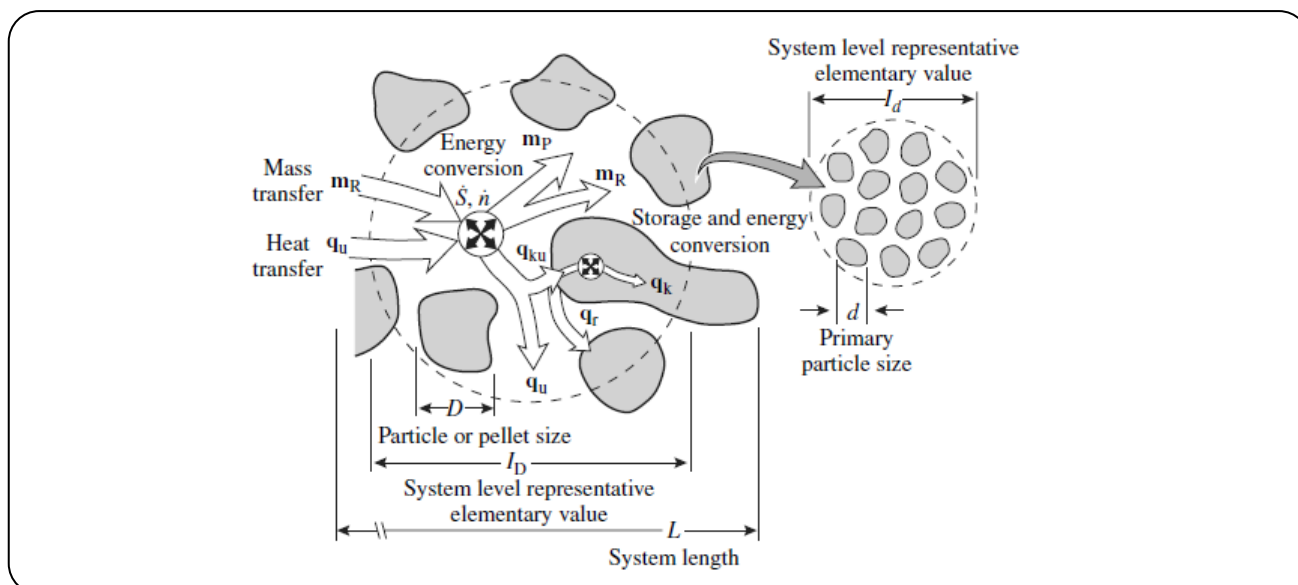
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Fig. 3: Schematic of physicochemical processes in a porous buried flame burner depicting microscale processes in a PIM [24].

the equivalence ratio is lower than 1. A lean mixture is normally used to achieve complete combustion and reduce the pollutants.

•Rich mixture: A mixture is called rich when the actual fuel-to-air ratio is smaller than the theoretical fuel-to-air ratio. The equivalence ratio in the mixture is higher than 1.

Numerical modeling of partial methane oxidation in a porous medium

As previously stated, incomplete combustion in porous media reactors is affected by numerous parameters, such as fuel-to-air ratio, the properties of porous materials, the mass flows of air and fuel, and a reactor's physical parameters. Investigating these parameters in an experimental study is extremely costly and time-consuming. As an alternative, modeling can be employed to examine a system's operating conditions as this approach involves minimal effort in examining all parameters involved. A numerical model can also be used to evaluate system performance, which is difficult to test in experiments .Accordingly, this study used a reactor filled with a porous medium in which incomplete combustion occurs. The reactor consists of a cylindrical shell made of quartz and is filled with granules of aluminum oxide as the porous medium. Fig. 4 shows a schematic of the reactor's layout. Having passed through a porous ceramic plate, the oxygen and rich methane

mixture was conveyed into the main chamber of the reactor. At this stage, combustion was initiated using electrode sparks. Partial oxidation was then induced through the injection of fuel and air. The internal diameter of the cylindrical tube was covered with ceramic heat insulation to compensate for thermal expansion in the compacted bed and cylinder and to prevent thermal reactions between these two components. The insulation was also intended to minimize conduction heat loss from the tube wall due to insulation outside the cylinder.

MATHEMATICAL MODEL

Several equations were employed to model the predicted behaviors of incomplete combustion in the porous medium used in this work; these equations were those for the conservation of mass, momentum, energy, and chemical species for laminar and non-isothermal flow in a chemical reactant mixture of ideal gases. Two models of heat transfer in porous media were used: the thermal equilibrium model and the thermal non-equilibrium model. In the former, the fluid phase and the solid phase of the porous medium were assumed to be in thermal equilibrium, requiring only an energy equation to predict heat transfer behavior. The thermal equilibrium assumption was applied to fluid flow inside the porous medium at a low flow rate and a high coefficient of local heat transfer between two phases. As for the thermal non-equilibrium model, the fluid and solid phases
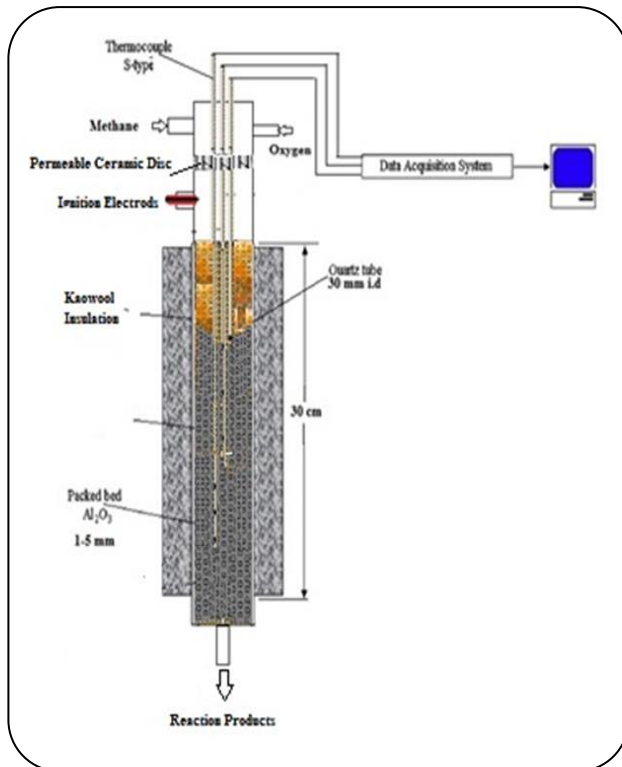
Fig. 4: Schematic of the partial oxidation reactor for hydrogen production.

did not exhibit thermal equilibrium, indicating different temperatures. In this case, one of the energy equations was applied to the fluid and the other equation was applied to the solid matrix; the equations were paired through the conversion of terms. The non-equilibrium condition is valid when the temperature difference between the fluid and solid phases is considerably smaller than the temperature created in an entire system.

The general model for combustion in the porous medium in this work was based on the following assumptions:

- The fluid behaves similar to how an ideal gas does.
- Pressure remains constant along the reactor.
- No temperature equilibrium exists between the fluid phase and the solid medium.
- The solid phase is homogeneous and isotropic, with properties that vary across temperatures.
- Only radiative heat transfer is considered in the solid phase.

The modeling was conducted in a two-dimensional medium. Therefore, the continuity equation and the momentum balance equation for the gas phase were as follows [25]:

- Continuity equation

$$\nabla \cdot \left(\varepsilon \rho_f v \right) = 0 \tag{3}$$

- Momentum balance equation for the gas phase

$$\varepsilon \rho_f v \cdot \nabla v = -\varepsilon p + \varepsilon \mu_f \nabla \cdot \left(\nabla v \right) - \left(\nabla p \right)_p \tag{4}$$

With respect to the equilibrium between the fluid and solid phases, two separate energy equations were formulated as follows:

- The energy equation for the gas phase

$$\varepsilon \rho_f c_{p \cdot f} v \cdot \nabla T_f = \varepsilon \Delta \left(k_f \cdot \nabla T_f \right) + \tag{5}$$

$$h_v \left(T_s - T_f \right) - \varepsilon \sum_{k=1}^{N_{sp}} \omega_K M_K h_K$$

- The energy equation for the solid phase

$$\left(1 - \varepsilon \right) \nabla \cdot \left(k_s \nabla T_s \right) - h_v \left(T_{fs} - T_f \right) - \left(\nabla \cdot q_r \right)_p = 0 \tag{6}$$

In the equations above, ε represents the porosity, ρ_f is the fluid density, v is the speed vector, k_s denotes the conductivity factor of solid material, T_s represents the temperature of solid material, T_f is the fluid temperature, q_r is the radiation coefficient of heat transfer in the solid material, h_v is the heat transfer coefficient for volume displacement and M_k is denoting the molar weight in the k_{th} component.

The production or dissipation rates of gases can be associated with chemical reactions, with the use of gas energy equations and chemical species (Equation (7)).

$$\dot{\omega}_K = M_K \sum_{l=1}^{N_R} \left(v''_{kl} - v'_{kl} \right) K_1 \times \tag{7}$$

$$\left(\prod_{reactants} c^{v'_{kl}} - \frac{1}{K_C} \prod_{products} c^{v''_{kl}} \right)$$

Where N_R is the number of chemical reactions, M_K is the molecular weight, v''_{kl}, v'_{kl} is the stoichiometric coefficients of A_k in a chemical reaction mechanism and K_C is the chemical equilibrium constant.

$$\sum_{K=1}^{N_s} v'_{kl} A_k \leftrightarrow \sum_{K=1}^{N_s} v''_{kl} A_k \tag{8}$$

The specific speed constant in k_1 reaction was defined through the Arrhenius equation as follows.

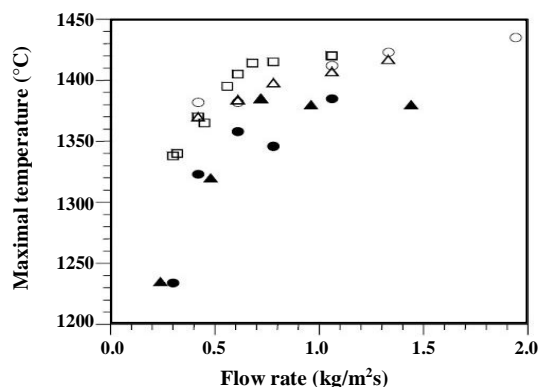$$k_1 = k_1^0 T^{\beta_1} \exp \left(-\frac{E_1}{RT} \right) \tag{9}$$

Fig. 5: Variation in combustion wave maximal temperature with flow rate [25].

Fig. 6: Comparing the presented model and experimental test by Zhdanok for Al2O3 spheres (3 mm).

Collision frequency k_1^0, temperature power β_1 and activation energy E_1 were specified for each reaction in the selective combustion mechanism.

This study used the chemical kinetics model GRI 3.0 for methane oxidation. This model assumes an irreversible process and two reversible processes.

Model validation

Before presenting the results, it is necessary to evaluate the accuracy of the presented model. The best research in this field performed by *Zhdanok* [26]. This research is an experimental test. A set up consist of a tabular rector with 66-cm length and 42 mm diameter was used. Aluminum oxide granular with a diameter of 3 mm was one of the material in this test. In Fig. 5 the variation of maximum temperature with flow rate for different material are shown. Based on the physical characteristics for mentioned system, CFD simulation is carried out. In Fig. 6 the result for Al2O3 spheres (3 mm) is compared with the presented model in this paper. As it is observed, the obtained numerical results agree well with available experimental data of the reference article.

RESULTS AND DISCUSSION

As mentioned earlier, this study modeled a tubular reactor filled with a porous material while theoretically exploring the partial oxidation of methane in the medium. To ensure increased hydrogen production, this study focused on the effects of porous media properties (including structural properties, such as particle diameter and porosity), the physical changes in a reactor
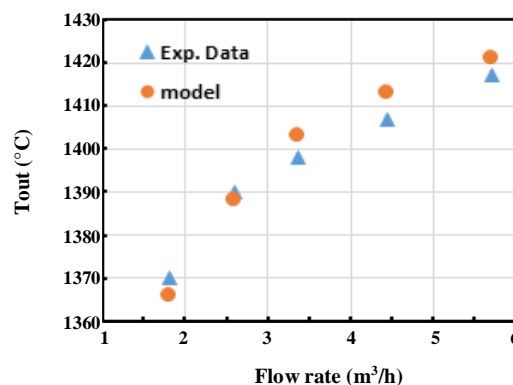
(e.g., changes in diameter from 20 to 40 mm and changes in reactor length from 20 to 40 cm), and the equivalence ratio of fuel to air generated by the rate of fuel and oxygen flow through an inlet.

Effect of equivalence ratio

The equivalence ratio [(λ) fuel-to-air equivalence ratio/φ = 1] significantly affected the product mix, the temperature in the reactor, and reaction stability. The range of stable performance decreased as φ increased. As φ increased, the energy released by the reaction per unit mass of fuel declined because less oxygen was available to complete the reaction. In this scenario, less energy was available to preheat incoming gases. As a result, flame speeds decreased, thus limiting the range of stable performance.

The insufficient oxygen led to the partial oxidation of hydrocarbons, which in turn, formed CO, H_2, and hydrocarbons of low molecular weights. Fig. 5 presents the results on the performance of two reactors with two different diameters and a reactor length of 30 cm. The highest hydrogen output volume was achieved at an equivalence ratio of 1.5. It is seen that the highest hydrogen output volume was achieved when at an equivalence ratio of 1.5.

Effect of the mass flow rate

From the perspectives of stationary time, temperature distribution, and heat load, the mass flow rate affected incomplete thermal combustion in the porous medium. A high mass flow rate reduces stationary time in a reactor, suggesting that a reactant has a shorter time to complete
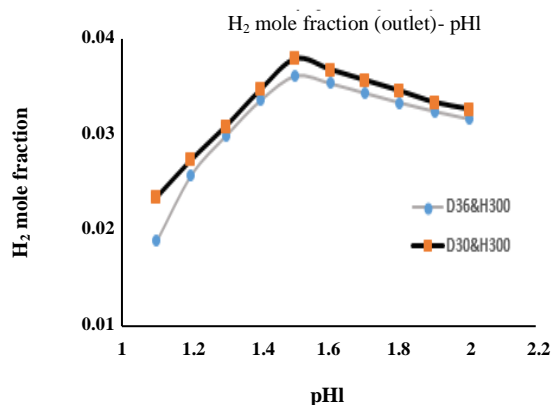
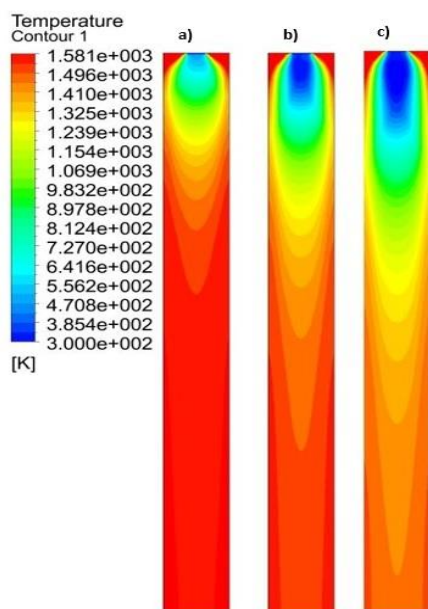*Fig. 7: Variation of hydrogen mole fraction with equivalence ratio.*

Fig. 8: Temperature distribution at equivalence ratio =1.5, D=30mm & L= 30cm. a) Q=100 lit/h b) Q=200lit/h c) Q=300lit/h.

a reaction. A high mass flow rate of fuel/air is also coupled with a high degree of distribution, thus covering a heat load higher than that covered under low mass flows. However, if a reactor is built for a wide range of fluctuations (as are porous medium reactors), stationary time exerts effects on the degree of conversion that are smaller than the effects of the turbulence and heat released in a porous structure. Hydrogen concentrations in high thermal loads are therefore expected to be greater than those in low thermal loads, despite the existence of

short stationary times. This phenomenon is attributed to the fact that lower relative heat loss occurs in high thermal loads than in low ones. It also implies that a small portion of heat is transferred, thereby preheating incoming gases toward upstream flow. In low-power scenarios, then, hydrogen products are low, and low temperature is expected in a reactor. Fig. 8 shows the temperature distribution in the reactor with a diameter of 30 mm, a length of 30 cm, and an equivalence ratio of 1.5 at different flow rates. Fig. 9 displays the temperature variations at the reactor outlet, Fig. 8 shows the mole percentage of hydrogen, and Fig. 10 illustrates the mole percentage of carbon monoxide in the reactor output at different flow rates.

In the next stage, we investigated the effects of flow variations. Because the equivalence ratio was fixed ($\varphi=1.5$), changes in the flow of methane and oxygen were identical. Figs. 11 and 12 show the variations in outlet temperature and the mole fraction of hydrogen at different Diameters and Lengths (D/L) and fuel flow rates.

Effect of material diameter

As stated earlier, a high rate of heat transfer in porous bodies is caused not only by high thermal conductivity but by numerous pores in porous bodies; these characteristics increase a heat transfer surface and, subsequently, heat transfer. A parameter that is effective in this process is the diameter of granules in a porous medium. In our modeling, particle diameter was set between 1 and 5 mm given the thermos-physical properties of aluminum oxide. Fig. 13 shows the temperature variations in the reactor outlet with aluminum oxide granules in the reactor with a diameter of 30 mm, a length of 30 cm, and an equivalence ratio of 1.5. Fig. 14 displays the changes in the mole percentage of hydrogen, along with the changes in granule diameter. As can be observed, the lower the granule diameter, the greater the mole percentage of hydrogen. This result is attributed to the effect of the surface area of the porous structure on fuel conversion in the partial oxidation process. Aluminum oxide granules with small diameters expand a surface area, create more tortuous paths for gas flow in a porous matrix, and intensify prorogation. These effects, in turn, lead to greater heat transfer between gas and solid porous matrices, thereby enabling greater fuel conversion.
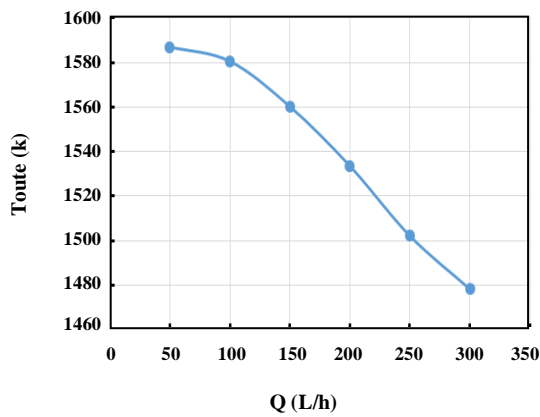
Fig. 9: Temperature variation with fuel flow rate at equivalence ratio= 1.5, D=30mm & L= 30cm].
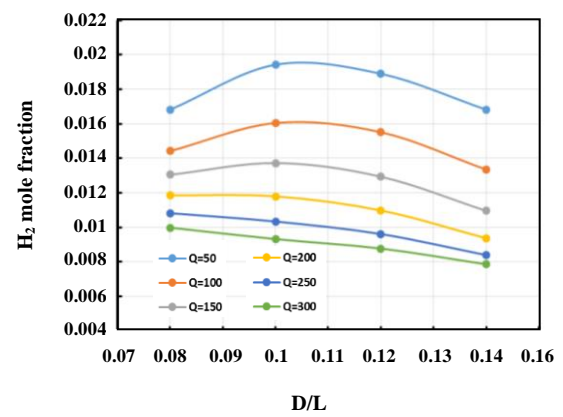

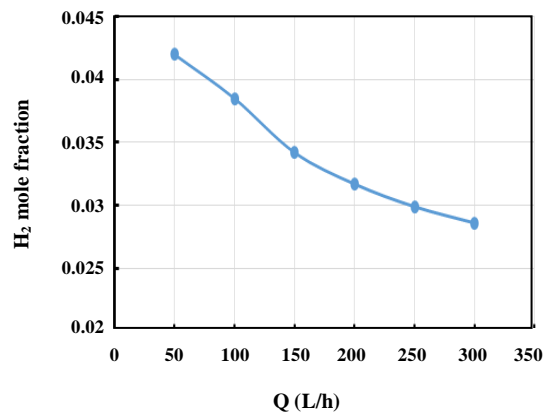*Fig. 12: Variation of H2 mole fraction in outlet with different D/L and fuel flow rate.*

Fig. 10: Hydrogen mole fraction variation with fuel flow rate at equivalence ratio =1.5, D=30mm & L= 30cm.
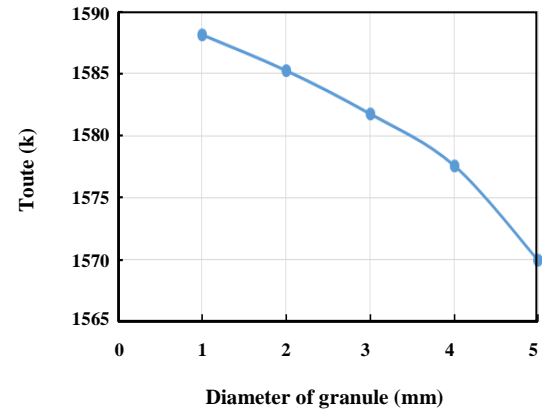

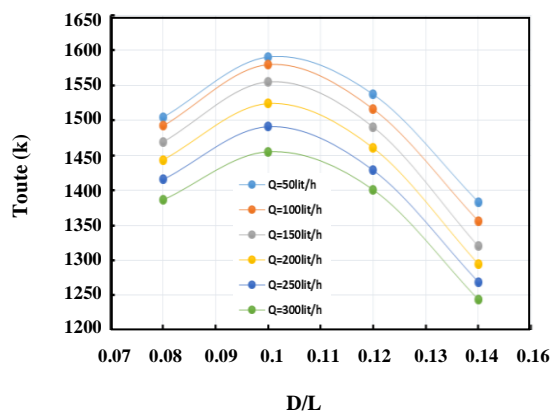*Fig. 13: Temperature variation with diameter of granule at equivalence ratio =1.5, D=30mm &   L= 30cm.*

Fig. 11: Variation of outlet temperature with different D/L and fuel flow rate.
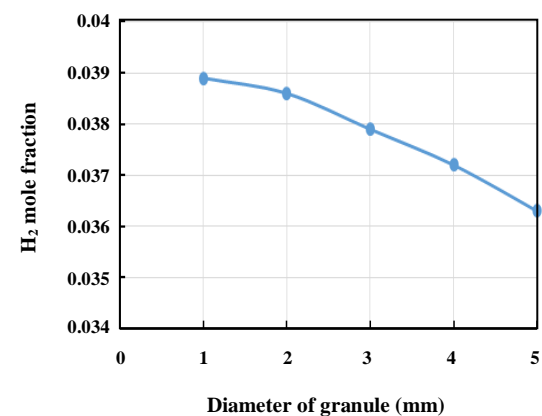

Fig. 14: Hydrogen mole fraction variation with diameter of granule at equivalence ratio= 1.5, D=30mm & L= 30cm.
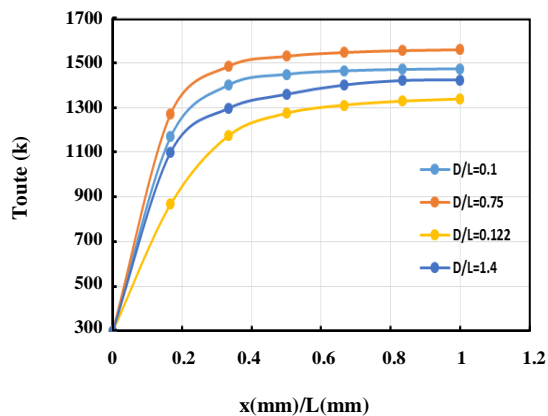
Fig. 15: Variation of temperature distribution in rector with different diameter, Height= 300 mm, Q methane =100 L/h, Q Oxygen = 100 L/h.

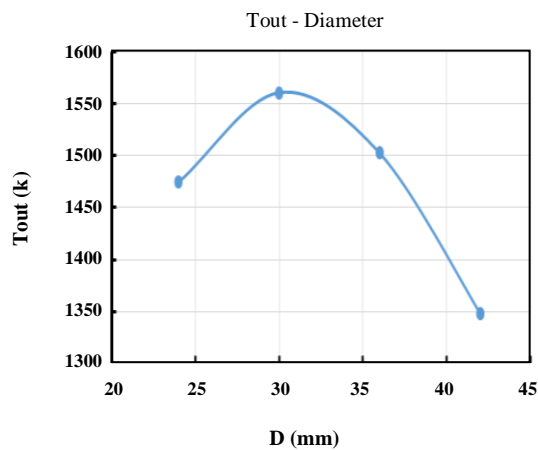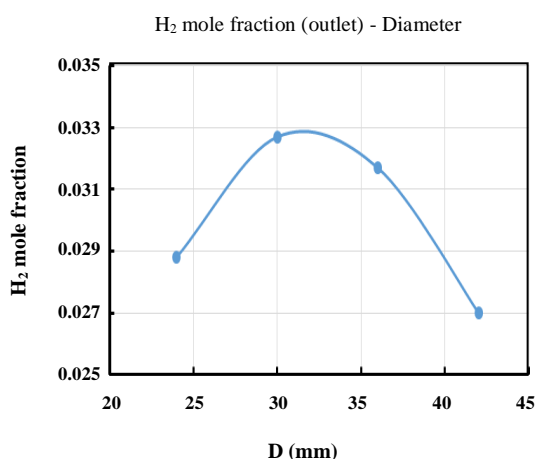*Fig. 16: Temperature variation with diameter of reactor at equivalence ratio= 1.5, D=30mm & L= 30cm.*

Fig. 17: Hydrogen mole fraction variation with diameter of reactor at equivalence ratio= 1.5, D=30mm & L= 30cm.

Effect of reactor diameter

The physical specifications of the reactor also contributed to the optimization of hydrogen production in the partial oxidation process. An example of such specifications is reactor diameter. Fig. 15 shows the variations in temperature distribution in the reactors with different diameters. As indicated in the figure, the maximum temperature began at an X/L equal to 0.5 and in the remaining segment of the rector without any changes. Note that this result was achieved at a methane and oxygen flow rate of 100 lit/h. The equivalence ratio in this model was 1.5.

Figs. 16 and 17 illustrate the temperature variations and mole percentage of hydrogen in the reactor outlet under a modified reactor diameter and an equivalence ratio of 1.5. The reactor length was 30 cm, which was identified as the best diameter for a 1.5 fuel-to-air equivalence ratio. Under such diameter, a higher temperature and, subsequently, a higher mole percentage of hydrogen occurred in the reactor outlet.

CONCLUSIONS

This research modeled a reactor tube filled with a porous medium. For the purpose of achieving increased hydrogen production, the investigation focused on the determination of the best fuel to equivalence ratio and also the possible effect of reactor diameter as well as length on hydrogen production. The optimal equivalence ratio for hydrogen production was found to be 1.5 at the presence of porous medium. The findings indicated that the reactor having a porous medium with a granule diameter of 1 mm exhibited superior performance. Further to that the best hydrogen production was achieved in a reactor with a diameter of 30 mm for an equivalence ratio of 1.5. Also the model showed that the maximum temperature began at the half of the length of reactor and in the remaining segment of the rector were without any changes. Also it was found that D/L= 0.1 was the optimum size of reactor for hydrogen production.

Nomenclature

C_p	Specific heat
E_1	Activation energy
FA	Fuel-air ratio
K_c	Chemical equilibrium constant
k_1^0	Collision frequency
K_s	Conductivity factor of solid material

M_k	Molar weight in the k_{th} component
NR	Number of chemical reaction
Pe	Péclet Number
q_r	Solid heat transfer radiation coefficient
T_s	Solid temperature
T_f	Fluid temperature
ν	Speed vector
ν'_{kl} , ν''_{kl}	Stoichiometric coefficients of A_k

Greek letters

β_1	Temperature power
ε	Porosity
λ	Fuel- air ratio
μ	Dynamic Viscosity, kg/m.s
ρ	Gravity, kg/m^3
φ	Equivalence ratio

subscripts

f	Fluid
s	Solid

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