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## **Analysis of a Mesoscale Fuel Reformer with Heat Recirculation and Porous Surface Stabilized Flame**

*William C. Thompson and Ajay K. Agrawal*

*Department of Mechanical Engineering, University of Alabama,  
Tuscaloosa, Alabama 35401, USA*

### **Abstract**

Syngas, or synthetic gas, is composed primarily of hydrogen (H<sub>2</sub>) and carbon monoxide (CO). Carbon monoxide and hydrogen store chemical energy, thus syngas can be used as a fuel source. Fuel reformation is the process used to convert an existing fuel source, such as methane or diesel, into synthetic gas. In this study, thermal partial oxidation is used for fuel reformation to eliminate the need for the catalyst. Thermal partial oxidation employs thermal energy to partially oxidize the fuel to produce syngas. The major drawback to this method of fuel reforming is the significant heat loss associated with the procedure. Further, fuel reforming at the mesoscale is difficult because of the short residence time available. In this study, a fuel reformer with a counterflow annular heat exchanger for heat recirculation and porous inert media to stabilize the flame is presented. These design features address the issue of major heat loss and make the process much more efficient. A detailed computational analysis is presented to evaluate design features and show thermal and combustion characteristics of the system. The analysis is based on conservation equations of mass, momentum, and species mass conservation in an axisymmetric domain. The computational analysis includes simulations under rich conditions at ambient pressure. Chemkin and Fluent software were integrated to simulate rich methane-air combustion at different equivalence ratios using a detailed chemical kinetic mechanism. Analysis reveals the effects of reactant inlet temperature and fuel reformer operating conditions on fuel to syngas conversion. Ultimately this study shows that thermal oxidation for fuel reforming can be a viable and efficient process.

### **I. Introduction**

As energy demands increase around the world, more viable fuel sources must be found and utilized. Fuel flexible combustion devices must also be developed to satisfy energy demands in the commercial and industrial sectors. Hydrogen is a clean fuel that contains more energy per unit mass than any hydrocarbon fuel. Hydrogen also generates minimum emissions when burned and no emissions when electro-chemically converted to electricity in a fuel cell [1]. Fuel reforming is used to produce hydrogen, which is the main reactive component in synthetic gas, or syngas. More broadly, syngas is primarily composed of hydrogen (H<sub>2</sub>) and carbon monoxide (CO), along with carbon dioxide (CO<sub>2</sub>), unburned hydrocarbons (UHC), and several other minor species. Syngas is combustible and can be used as a fuel source in internal combustion engines and gas turbines.

Syngas is produced by three major methods: carbon dioxide reforming, water steam reforming, and partial oxidation (POX). Typically, methane is used in these fuel reforming processes but

other hydrocarbon fuels such as diesel, glycerol, bio-diesel, and vegetable oil can also be used to produce syngas [2]. Steam reforming is an endothermic process that occurs at a temperature range of 700°C to 850°C, and because of its low temperature range, coking can be an issue. Partial oxidation reforming is an exothermic reaction that can be achieved through the use of a catalyst or thermally with the use of heat. Catalytic partial oxidation (COPX) reforming occurs in a temperature range of 800°C to 1000°C. CPOX can also be combined with steam reforming in a process called autothermal reforming (ATR).

Thermal partial oxidation (TPOX) reforming occurs above a temperature of 1100°C. Because of the high temperature associated with TPOX, heat loss can be a problem that can decrease the efficiency of the reforming process significantly [3]. This study investigates partial oxidation reforming to produce syngas, specifically TPOX reforming. Numerical simulations using detailed chemical kinetics analysis and computational fluid dynamics analysis integrated with detailed chemical kinetics are presented to show the effect of equivalence ratio, reactant inlet temperature, and pressure on syngas production, specifically the production of hydrogen and carbon monoxide. Methane was the fuel studied for TPOX reforming, but other hydrocarbon fuels could be employed in the future.

Figure 1 shows a schematic of the combustor used for the simulations. It utilizes an annular design to recirculate heat to the incoming reactants and a porous inert media (PIM) to homogenize the mixture, as well as to stabilize the flame and preheat the incoming reactants.

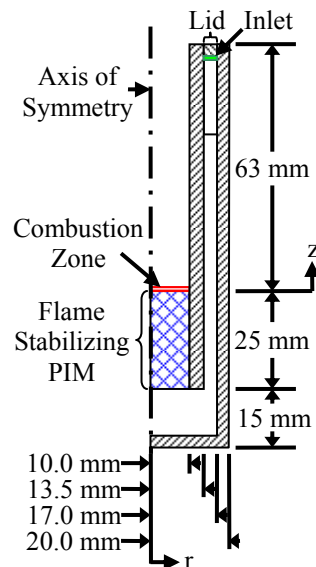


Figure 1. Combustor Schematic

The PIM stabilizes the flame and anchors the flame to the surface at the matrix interface of the PIM, which allows for higher burning speeds. PIM also creates a super adiabatic effect, i.e. higher adiabatic flame temperature locally versus the adiabatic flame temperature of a free flame at the same equivalence ratio. The sensible enthalpy from the products is recirculated through convection from the hot gas to the inert media, which then transfers heat through conduction and radiation to the media upstream of the reaction zone to preheat the incoming reactants. The high

thermal conductivity of the solid matrix compared to the conductivity of the gas enhances heat transfer from the products to the reactants. Thus, the overall effect is a substantial preheating of the incoming reactants. The preheating as well as the heat recirculated through the annulus allow for faster kinetics, higher flame speed, and extended flammability limits of the fuel/oxidizer mixture. The higher temperature compared to the free flame conditions allows initiation and chain-branching mechanisms to occur at ultra-rich equivalence ratios. The extended rich flammability limit allows partial oxidation conditions to be established, thus allowing the stripping of the hydrogen from the original fuel molecule to produce syngas [4]. These advantages allow TPOX to be a viable approach for syngas production. Several simulations are presented to show how these advantages affect syngas production.

## II. Methods

Chemkin-Pro and Ansys Fluent were used to simulate methane-air combustion. Chemkin was used to run a perfectly-stirred reactor (PSR) model at various inlet temperatures, equivalence ratios, and operating pressures. Chemkin was also used to run a premixed burner-stabilized flame model. A commercial computational fluid dynamics (CFD) software (Fluent) was integrated with detailed a chemical reaction mechanism to simulate the coupling among fluid dynamics, chemical kinetics, and heat transfer. PSR and burner-stabilized models were used to calculate the optimum operating conditions for the system. The CFD model was used to investigate the overall trend of syngas production. All three model results are presented in sequence, each model with increasing complexity to account for flow and chemical kinetics of the problem.

Perfectly Stirred Reactor (PSR) Model. The simplest model, used to obtain baseline data, is the PSR model. PSR model is a homogenous reactor model in which the contents are assumed to be nearly spatially uniform due to high diffusion rates, and the reactor is assumed to be perfectly mixed to describe the spatially averaged properties, or bulk properties. Because of the homogeneous nature of the mixture, the conversion of reactants to products is controlled by reaction rates and not by the mixing processes. This model consists of a chamber, which may allow for heat loss, with inlets and outlets. The general conservation equations in this model as implemented in the Chemkin software include the conservation equations of mass, energy, and species. Figure 2 depicts a schematic representation of a generic perfectly stirred reactor. [5]

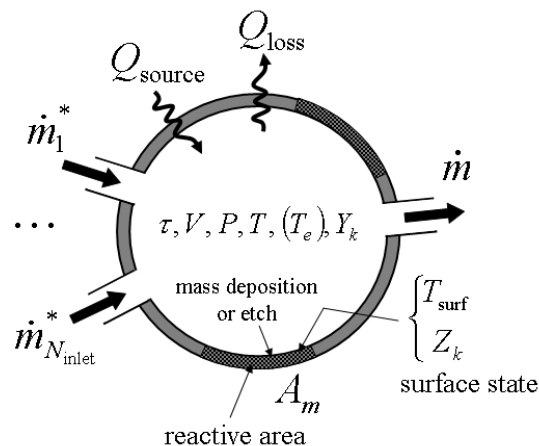


Figure 2. Schematic Representation of a Perfectly Stirred Reactor

This study uses a single PSR reactor with one inlet and an outlet at steady state. This model can evaluate steady state systems and transient systems, but steady state was chosen to obtain product gas properties for a fixed residence time. The inlet and outlet serve as a means for mass to enter and leave the system. A major parameter for this simulation that must be specified is a nominal residence time ( $\tau$ ), which is calculated using the nominal density of the mixture, mass flow rate, and reactor volume. A sufficiently large residence time of 0.5 s was used in this study to achieve near equilibrium conditions at the reactor exit. The reactor volume and mass flow rate are arbitrary values while the density remains constant. Other parameters that must be specified are inlet temperature, pressure, equivalence ratio, heat loss, surface temperature, the species of fuel and oxidizer. In this study heat loss was assumed zero, the surface temperature was considered to be equal to the gas temperature, and methane-air combustion was used for reactant and product species. A parametric study was conducted by varying equivalence ratio, operating pressure, and reactant inlet temperature. The equivalence ratio was varied from 1 to 3 in increments of 0.5. The pressure was varied from 1 atm to 5 atm in increments of 1 atm. The inlet temperature was varied from 300 K to 600 K in increments of 50 K. This simulation was used to calculate the optimum operating conditions when most syngas is effectively produced.

*Premixed Burner Stabilized Flame Model.* The premixed burner-stabilized flame model is a 1-D premixed laminar flame model. This model is often used to study the chemical kinetics of a problem in a combustion environment. This simulation has the ability to model the chemical kinetics and transport processes that occur inside the flame to understand the combustion process itself. Like the PSR model, the general conservation equations of mass, energy, and species are used. In addition, the conservation of momentum in 1D is also used [5]. This model can be run by solving the energy equation or by specifying the gas temperature profile to account for the heat loss. Regardless, the model has to have a temperature profile, generated or specified, to complete the simulation. In this study, the energy equation was solved by neglecting the heat loss [6]. A sufficiently large unbunt gas temperature of 600 K was specified because optimum results occur when the reactants enter the combustor at a high temperature (higher than ambient). An equivalence ratio of 2.5 was used to maximize syngas production. This analysis was conducted only at 1 atm since pressure effects observed from PSR models would also be viable for this model. Methane-air combustion simulation was performed to determine how the product species of hydrogen and carbon monoxide develop axially. Further, the temperature profile will be generated for the analyzed length (10 cm), and along with profiles of the product species, the reaction zone can be determined.

*Computational Fluid Dynamics-Chemical Kinetics Model:* This detailed model, though preliminary at this stage, combined CFD analysis with chemical kinetics analysis. The computational domain was assumed to be axisymmetric to approximate the actual hardware. For steady, laminar flow, the governing equations of mass, momentum, and energy are presented in Equations 2 through 5.

Mass conservation equation:

$$\frac{\partial}{\partial z}(\rho v_z) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = S_m \quad (2)$$

Momentum conservation equation in the axial (z) direction:

$$\begin{aligned} \frac{1}{r} \frac{\partial}{\partial z} (r \rho v_z v_z) + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v_r v_z) = -\frac{\partial P}{\partial z} + \frac{1}{r} \frac{\partial}{\partial z} \left[ r \mu \left( 2 \frac{\partial v_z}{\partial z} - \frac{2}{3} \bar{\nabla} \cdot \bar{v} \right) \right] \\ + \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial v_z}{\partial r} + \frac{\partial v_r}{\partial z} \right) \right] + S_z \end{aligned} \quad (3)$$

Momentum conservation equation in the radial (r) direction:

$$\begin{aligned} \frac{1}{r} \frac{\partial}{\partial z} (r \rho v_z v_r) + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v_r v_r) = -\frac{\partial P}{\partial r} + \frac{1}{r} \frac{\partial}{\partial z} \left[ r \mu \left( 2 \frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} \right) \right] \\ + \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( 2 \frac{\partial v_r}{\partial r} - \frac{2}{3} \bar{\nabla} \cdot \bar{v} \right) \right] \\ - 2 \mu \frac{v_r}{r^2} + \frac{2}{3} \frac{\mu}{r} (\bar{\nabla} \cdot \bar{v}) + \rho \frac{v_z^2}{r} + S_r \end{aligned} \quad (4)$$

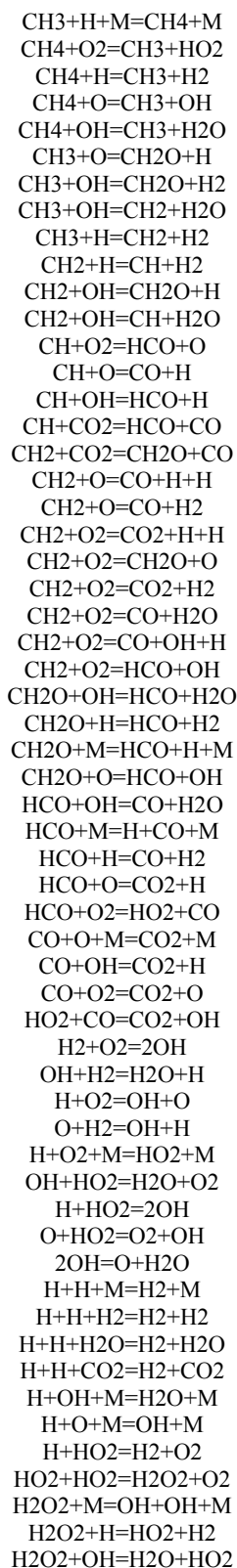
Energy conservation equation:

$$\frac{1}{r} \frac{\partial}{\partial r} \left( r \rho v_r c_p T + r \rho v_r \frac{v^2}{2} \right) + \frac{\partial}{\partial z} \left( \rho v_z c_p T + r \rho v_z \frac{v^2}{2} \right) = \frac{1}{r} \frac{\partial}{\partial r} \left( k_r r \frac{\partial T}{\partial r} \right) + \frac{\partial}{\partial z} \left( k_z \frac{\partial T}{\partial z} \right) + S_E \quad (5)$$

Here  $v$  is the total velocity and  $v_r$  and  $v_z$  are the radial and axial components of velocity, respectively [7]. The governing equations are solved in Fluent software. The chemical reactions were represented by a 60-step reaction mechanism for methane-air combustion typically used to calculate laminar flame speed in Chemkin software. The elements associated with this kinetics input file are hydrogen (H), oxygen (O), carbon (C), and nitrogen (N). The associated 19 species are CH<sub>4</sub>, CH<sub>3</sub>, CH<sub>2</sub>, CH, CH<sub>2</sub>O, HCO, CO<sub>2</sub>, CO, H<sub>2</sub>, H<sub>2</sub>O<sub>2</sub>, O, OH, HO<sub>2</sub>, H<sub>2</sub>O<sub>2</sub>, H<sub>2</sub>O, and N<sub>2</sub>. Table 1 shows the reactions involved in the 60-step reaction mechanism.

The computational domain was divided into various zones including the inlet, porous media zone, and combustion zone. Boundary conditions were specified for each of these zones, such as mass flow rate into the combustor, the porosity of the porous media, and total reactant inlet enthalpy. These are just a few examples of the many boundary conditions specified for this problem. Reactions were turned off everywhere except in the porous media zone and combustion zone for this simulation, which was comprised of domain including PIM and the combustor downstream of it. Source terms to specify the mass flow rate into the system. Three volumetric mass source terms were used in this simulation, the total mass source term, the methane mass source term, and the oxygen mass source term. The mass source terms were based on a  $\dot{m}_{\text{total}} = 7.911\text{e-}4$  kg/s, a  $\dot{m}_{\text{CH}_4} = 1.041\text{e-}4$  kg/s, and a  $\dot{m}_{\text{O}_2} = 1.602\text{e-}4$  kg/s. It is possible to use a radiation model with this simulation, but it was not used for simplicity. The energy model and species transport models were the main models utilized for this simulation. The mixture properties are specified or calculated in the species transport model. These properties must be correct to ensure correct simulation.

Table 1. Reactions for 60-Step Methane Reaction Mechanism



The solution methods used for this problem consisted of the SIMPLEC pressure-velocity coupling scheme, and QUICK and power-law differencing schemes. Different schemes were used for energy, momentum, species, etc. The power law scheme was exclusively used for species equations, while the energy and momentum utilized the QUICK scheme. All species and the energy equations were under-relaxed by a factor of 0.5, and the momentum equation was under-relaxed by a factor of 0.7. Convergence criterion (mostly 0.001) were specified and the solution was initialized with initial guesses for the species and temperature. Temperature was guessed to be 500 K everywhere, and the mole fractions of H<sub>2</sub> and O<sub>2</sub> were specified to be 0.0548 and 0.21933, respectively.

Methane-air combustion was analyzed with this simulation at an equivalence ratio of 1.0 and 1.25. Because of the simplifications made for this problem, such as turning off the radiation model and not refining the grid at high velocities inside the combustor, the simulation at an equivalence ratio of 1.5 reached blow-off. Blow-off would not have occurred if fewer assumptions were made. From experimental work, it is known that stable methane-air combustion easily occurs at an equivalence ratio of 1.5. Thus, these assumptions that simplify problem also introduce errors because some of the realism is removed. However, the model used shows the trend of how hydrogen and carbon monoxide are produced as the reactants become rich with increasing equivalence ratio. The assumptions made were necessary to reduce the complexity brought to the simulation with detailed chemical kinetics, and although these assumptions introduced error, they still produce viable initial results that can be used to interpret the behavior of the system.

### III. Results and Discussion

*PSR Model.* PSR model provided data showing the optimum operating conditions for this system. Figure 3 depicts the adiabatic flame temperature versus pressure for different reactant inlet temperatures. Reactant inlet temperature was varied from 300 K to 600, the pressure was varied from 1 atm to 5 atm, and the equivalence ratio was varied from 1 to 3. From Figure 3, it can be seen that the adiabatic flame temperature decreases as equivalence ratio increases, and adiabatic flame temperature increases as pressure increases. Some of the temperature profiles appear constant, because of the scale of the plot. As inlet temperature increases, the adiabatic flame temperature also increases, as expected. These results just verified what was expected of the system. Figure 4 shows how the adiabatic flame temperature decreases with increasing equivalence ratio for reactant inlet temperature of 300 K. The mole fraction of hydrogen and carbon monoxide are of the greatest interest because they are the primary reactants in syngas. Figure 5 shows how hydrogen and carbon monoxide production are affected by equivalence ratio and reactant inlet temperature for operating pressure of 5 atm.

Syngas production increases with increasing reactant inlet temperature. As seen in Figure 5, hydrogen production starts to decrease after an equivalence ratio of 2.5, and carbon monoxide production starts to decrease after an equivalence ratio of 2.0. Syngas production efficiency is sometimes defined as seen in equation 6:

$$\eta_{syngas\ production} = \frac{H_{2,production}}{CO_{production}} \quad (6)$$

According to this definition, the most efficient operating conditions are at an equivalence ratio of 2.3. Thus, from this simulation it is shown that the optimum operating conditions for optimum syngas production are at a high inlet temperature and an equivalence ratio of 2.3. Since the optimum syngas production occurs at an equivalence ratio of 2.3, the effect of pressure was investigated for equivalence ratios between 2 and 3 and varying the pressure from 1 atm to 5 atm. Figure 6 shows how production of hydrogen and carbon monoxide are affected by pressure at an inlet temperature of 600 K.

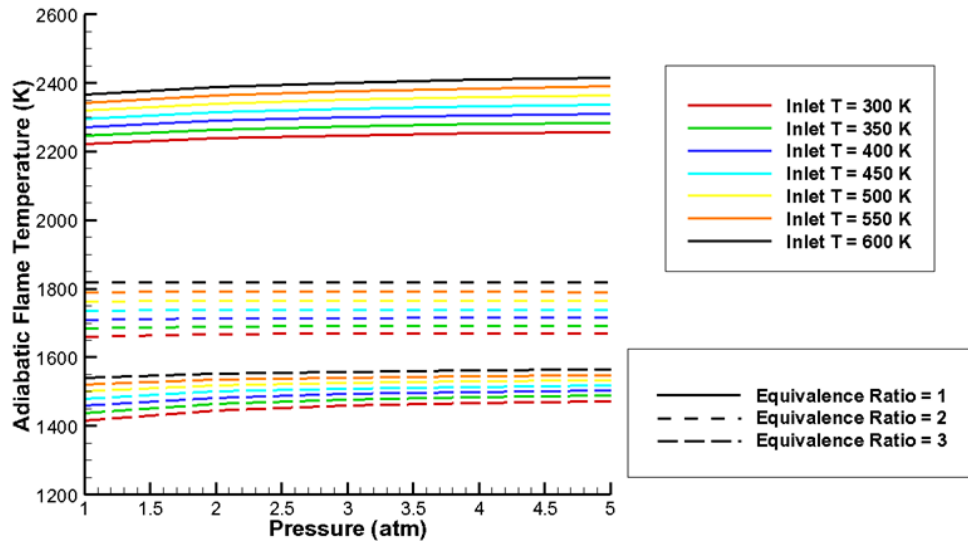


Figure 3. Adiabatic Flame Temperature as a Function of Pressure and Inlet Temperature

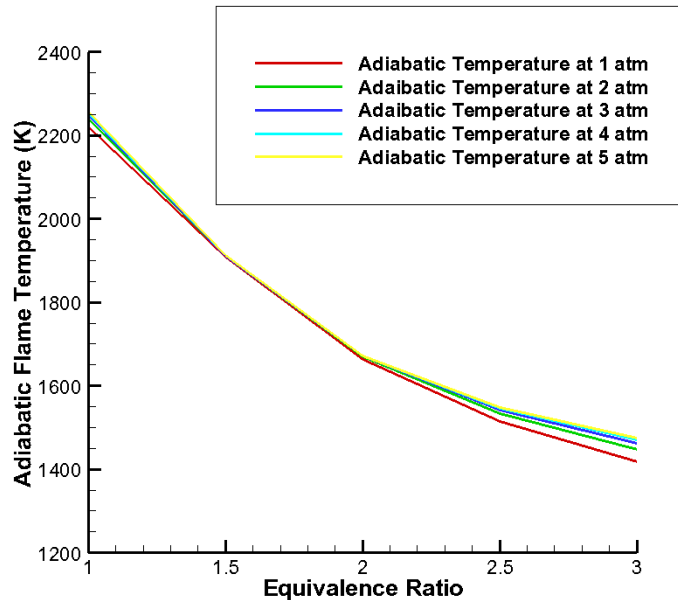


Figure 4. Equivalence Ratio versus Adiabatic Flame Temperature at Inlet Temperature of 300 K



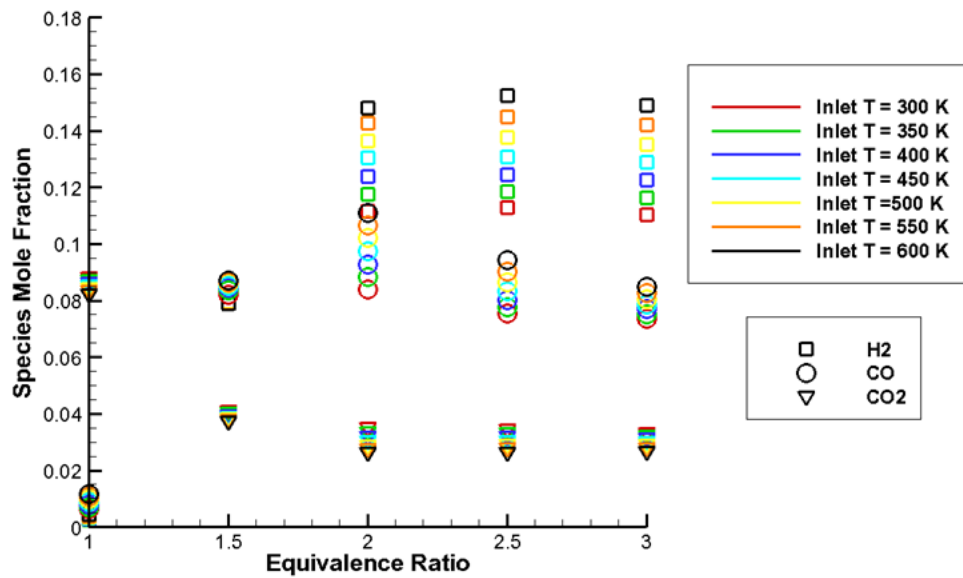


Figure 5. Species Mole Fraction as a Function of Equivalence Ratio and Inlet Temperature

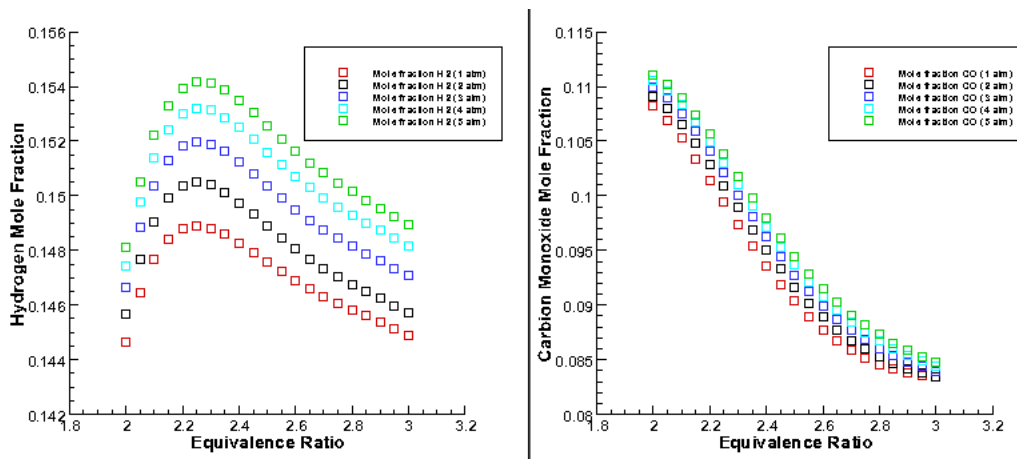


Figure 6. Hydrogen and Carbon Monoxide Production between Equivalence Ratios of 2 and 3 Ranging From a Pressure of 1 atm to a Pressure of 5 atm

Figure 6 further states that the optimum operating conditions occur at an equivalence ratio of 2.3. This is where the maximum hydrogen production to carbon monoxide production ratio occurs. This figure also shows that hydrogen production and carbon monoxide production both increase with increasing pressure. Thus, the optimum conditions for syngas production occur at a high inlet temperature, an equivalence ratio of 2.3, and high pressure.

*Premixed Burner Stabilized Model.* The premixed burner-stabilized model was used to determine how hydrogen and carbon monoxide are produced axially as the reactions progress through the combustor. The temperature profile was also generated for the length examined (10 cm). Figure 7 shows hydrogen and carbon monoxide profiles along the 10 cm length of the burner-stabilized adiabatic flame. Figure 7 shows that the reactants enter the combustion zone, react in the first 0.5 cm of the combustor, and increase the temperature to 1655 K. Carbon monoxide mole fraction remains fairly constant after the reaction zone, and while hydrogen mole fraction increases along the length examined. This result shows that the reactions that produce the hydrogen extend past the reaction zone, while reactions producing carbon monoxide occur mainly within the reaction zone. This simulation was only carried out at 1 atm only because as the pressure increases, a similar trend of pressure on species mole fractions as the PSR model is expected for the burner-stabilized model.

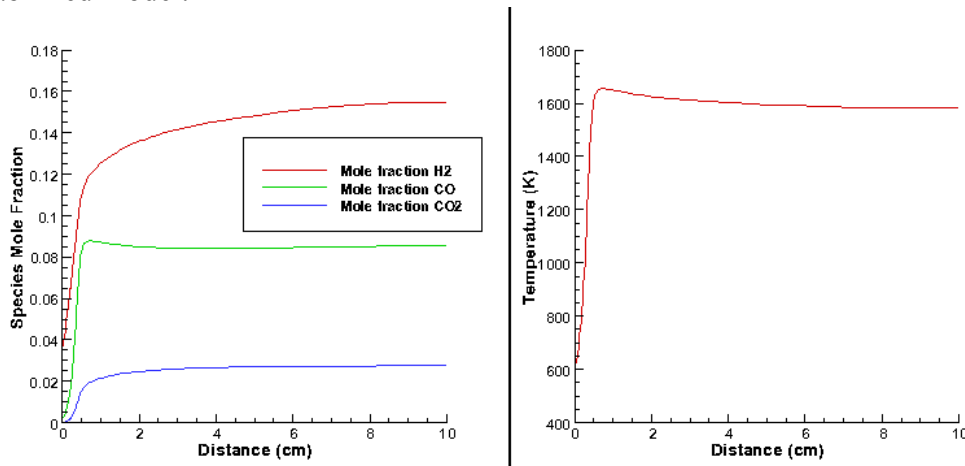


Figure 7. Burner-Stabilized Model Results

*Computational Fluid Dynamics-Chemical Kinetics Model:* Figure 8 compares the temperature contours from detailed CFD simulations at equivalence ratio of 1.0 and 1.25. As Figure 8 depicts, the porous media plays a vital role in preheating the reactants. Heat from the reaction is conducted into the porous media, which is in contact with the combustor wall, and in turn is conducted through the wall into the incoming reactants. In the reaction zone, boundary layers are formed, which tend to insulate the reactants in the annulus from the high temperature reaction zone of the combustor. Thus, most of the preheating of the reactants takes place around the porous media. Less heat is conducted in the case where the equivalence ratio equals 1.25 because the adiabatic flame temperature is less than in the case where the equivalence ratio equals 1.0. The reactant inlet temperature for both cases is around 400 K and the combustor pressure was specified as atmospheric. More efficient syngas production will occur at the optimum conditions specified earlier, but this simulation was carried out at a lower inlet temperature, pressure, and equivalence ratio to gain basic understanding of the coupling effects between fluid flow, heat transfer, porous media, and chemical kinetics. The heat transfer pathways would also be influenced by radiation which could be significant in some regions of the system, but ignored in this preliminary study.

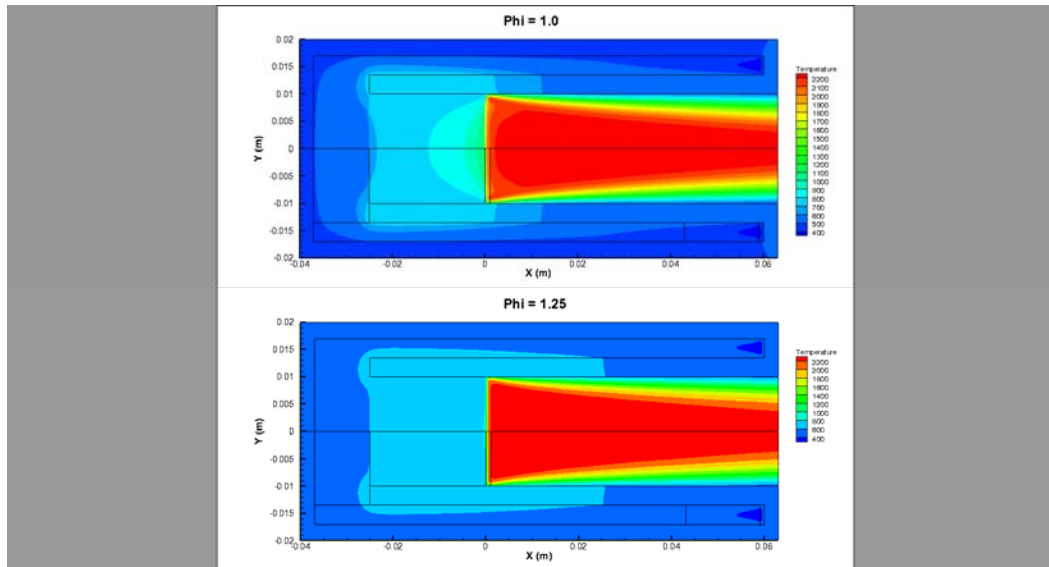


Figure 8. Temperature Contours for CFD-Detailed Kinetics Simulation

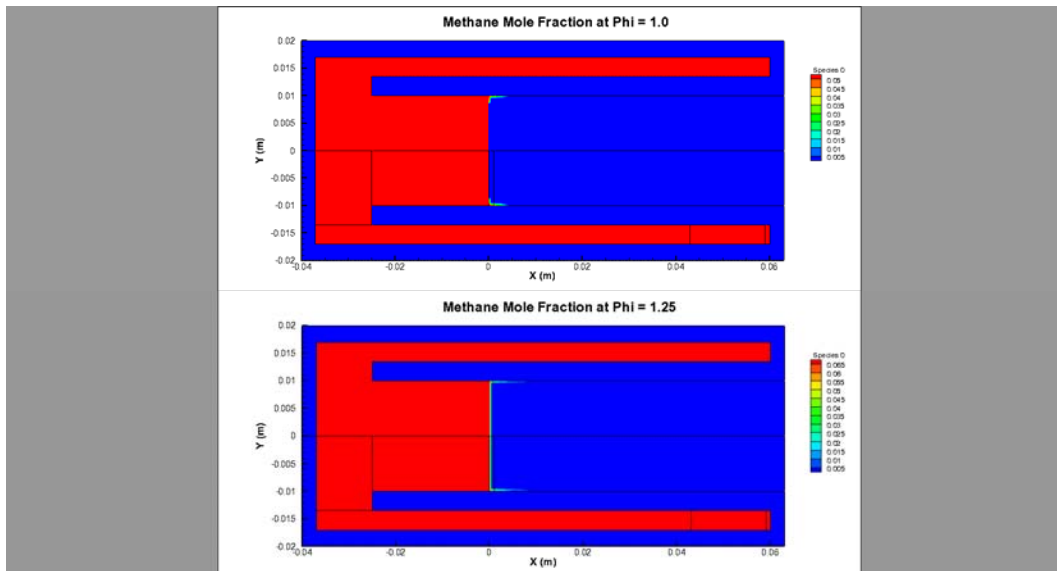


Figure 9. Methane Mole Fraction Contours for CFD-Detailed Kinetics Simulation

Figure 9 depicts the methane ( $\text{CH}_4$ ) mole fraction. The simulation specified where reactions could take place, which is only in the porous media, flame and exhaust zones. Figure 9 shows no methane present in these zones, signifying complete oxidation of the original fuel. The same can be said for Figure 10, which shows the oxygen ( $\text{O}_2$ ) mole fraction. Both cases for Figures 9 and 10 are the same because the total mass flow rate was held constant. Next, the radical production was examined to understand how it affected the reaction zone. Oxygen radical ( $\text{O}$ ) and hydrogen radical ( $\text{H}$ ) are generated at the plane just downstream of the porous media, and are confined to a narrow but intense flame zone. These radicals help sustain reactions that would eventually produce product species including  $\text{H}_2$  and  $\text{CO}$  in case of fuel-rich combustion. Figure 11 shows contours of the mole fractions of oxygen radicals ( $\text{O}$ ) produced in this system. Similarly, Figure 12 and 13 show contours of the mole fraction of hydrogen radicals ( $\text{H}$ ) and hydroxyl radical ( $\text{OH}$ ) produced in the system.

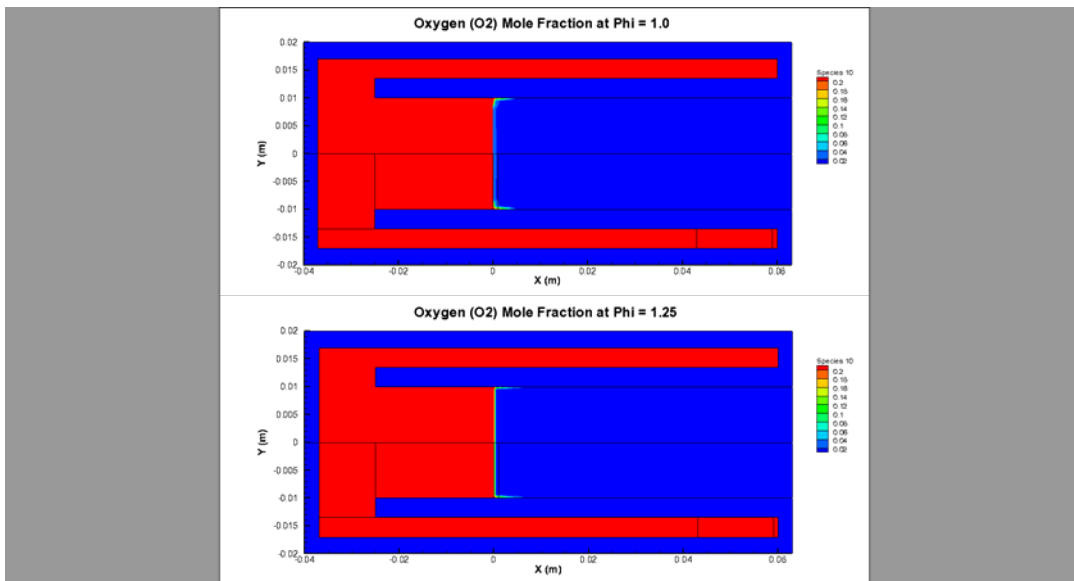


Figure 10. Oxygen ( $O_2$ ) Mole Fraction Contours for CFD-Detailed Kinetics Simulation

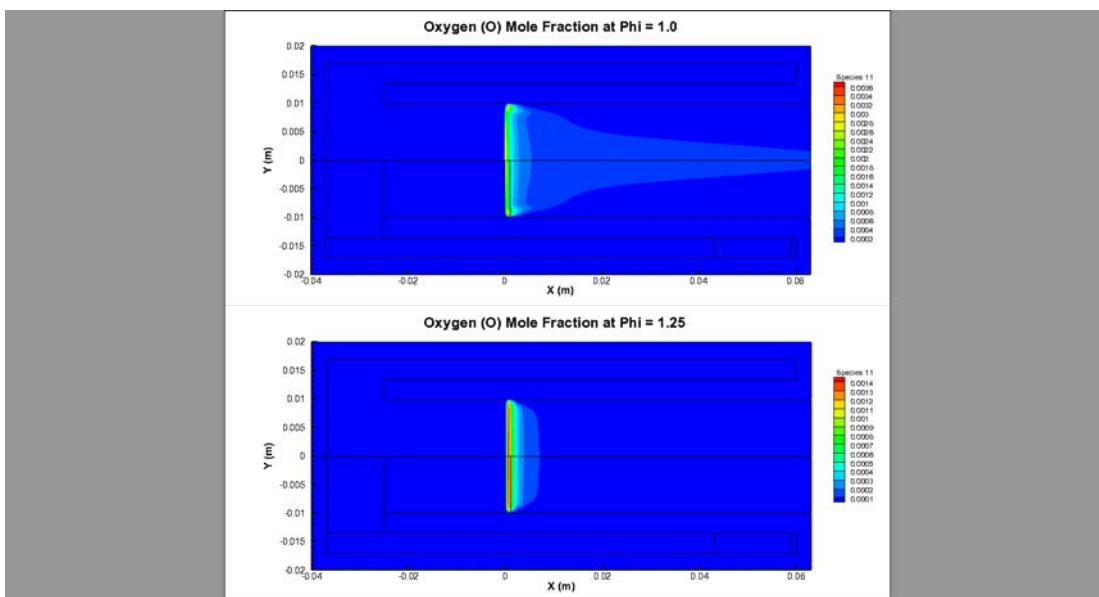


Figure 11. Oxygen Radical (O) Mole Fraction Contours for CFD-Detailed Kinetics Simulation

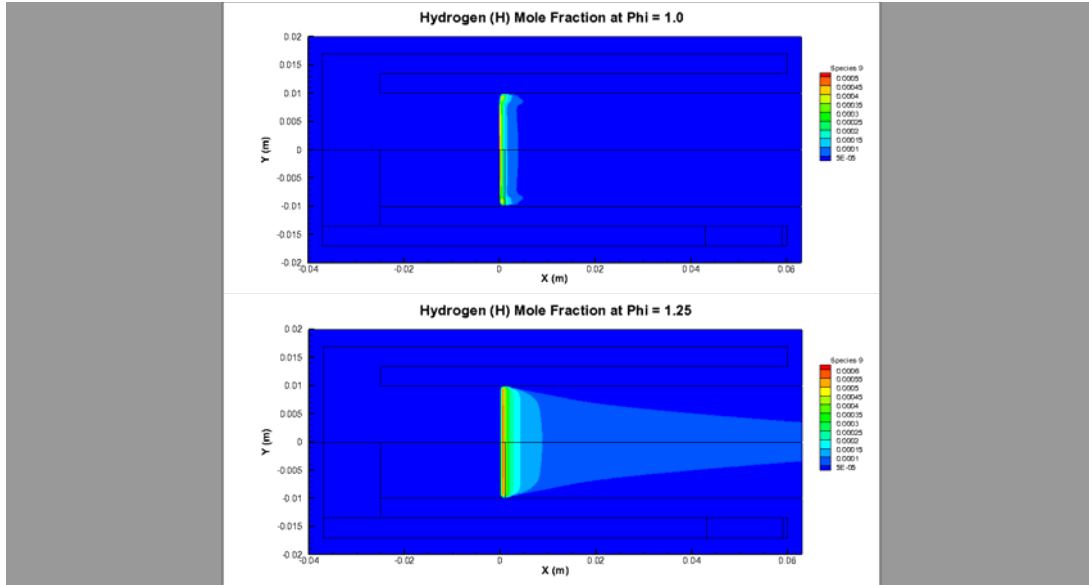


Figure 12. Hydrogen Radical (H) Mole Fractions for Fluent Simulation

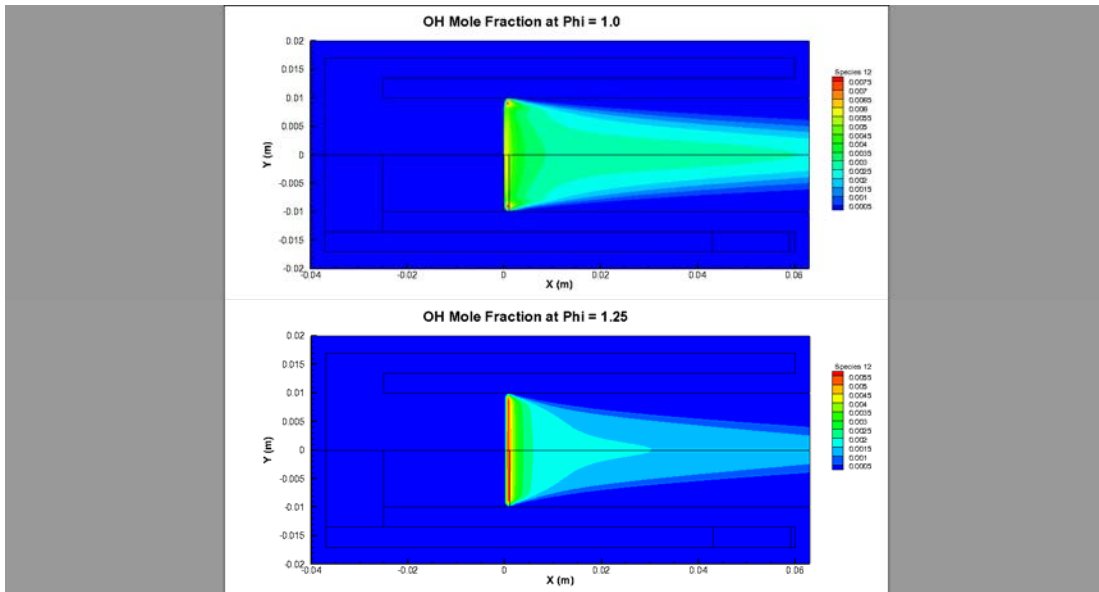


Figure 13. OH Mole Fractions for Fluent Simulation

Figures 11, 12, and 13 show that at stoichiometric conditions ( $\phi=1.0$ ) more radicals are produced compared to the fuel-rich combustion at  $\phi=1.25$ . Radical concentration related to the reaction zone temperature, which is higher for  $\phi=1.0$ . These results also identify the axial and radial extent of radical production zones, although complete reliance on these results will require a fully grid-independent solution which has not been attained in the present study because of the large computational requirements. Still, these results offer unparalleled insight into the reaction zone and its coupling with various fluid flow and heat transfer phenomena evident in the present system.

Next, CFD results are examined to evaluate production of  $H_2$  and  $CO$ . Figure 13 depicts the contours of hydrogen ( $H_2$ ) mole fractions for this system. As the equivalence ratio increases past stoichiometric condition and the mixture becomes fuel-rich,  $H_2$  production can be expected to increase as inferred from PSR and burner-stabilized models. Present simulations replicate this trend, and also show increased  $H_2$  in the boundary layer region where the temperature is lower for the  $\phi = 1.25$  case. Figure 14 shows the contour plots of  $CO$  mole fraction for this system. A similar trend as observed for the  $H_2$  mole fractions is also observed for the  $CO$  mole fraction. More  $CO$  is produced for fuel-rich conditions as expected. Under rich conditions excess fuel is present, and since methane's molecular make up is of carbon and hydrogen, more hydrogen and carbon become available in the form of unreacted products.

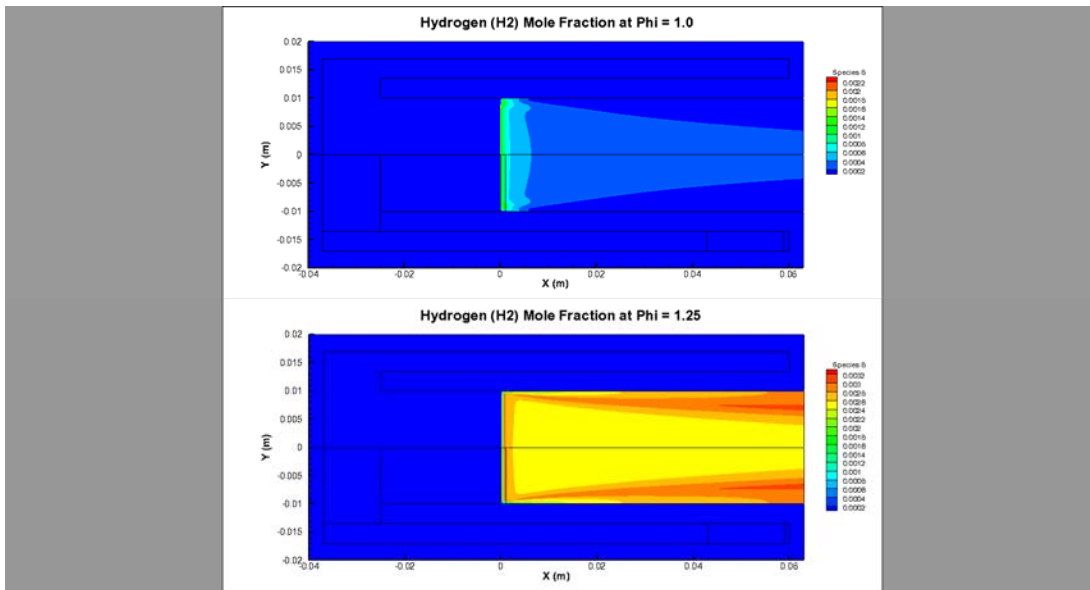


Figure 14.  $H_2$  Mole Fractions for Fluent Simulation

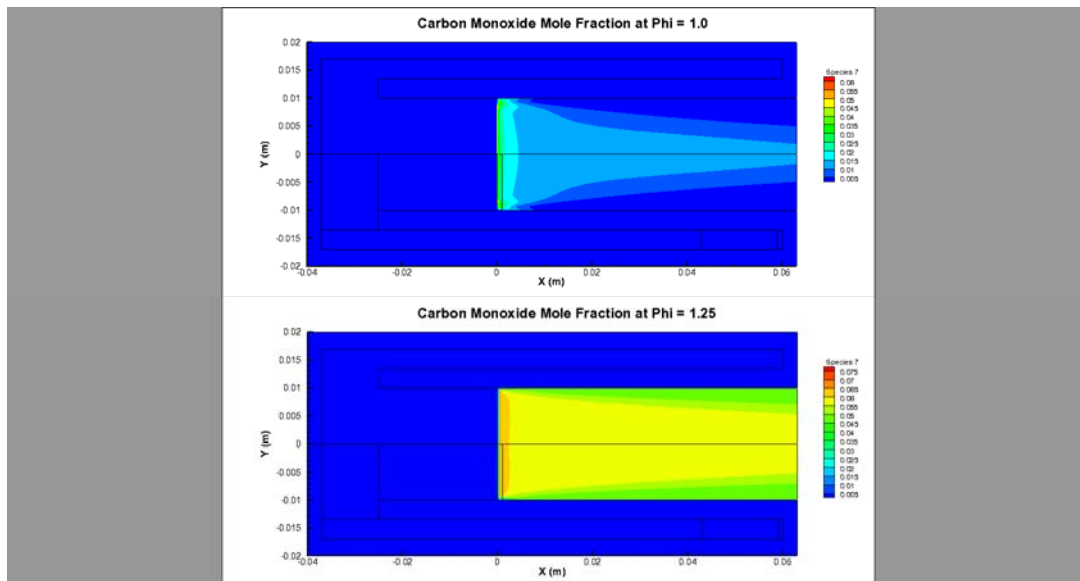


Figure 15.  $CO$  Mole Fractions for Fluent Simulation

Finally, Figure 16 shows the contour plot of CO<sub>2</sub> mole fraction in the system. Results show that more CO<sub>2</sub> is produced outside of the flame in the boundary layer, and more CO is produced within the flame zone. This effect can be explained by increased dissociation in the high-temperature reaction zone.

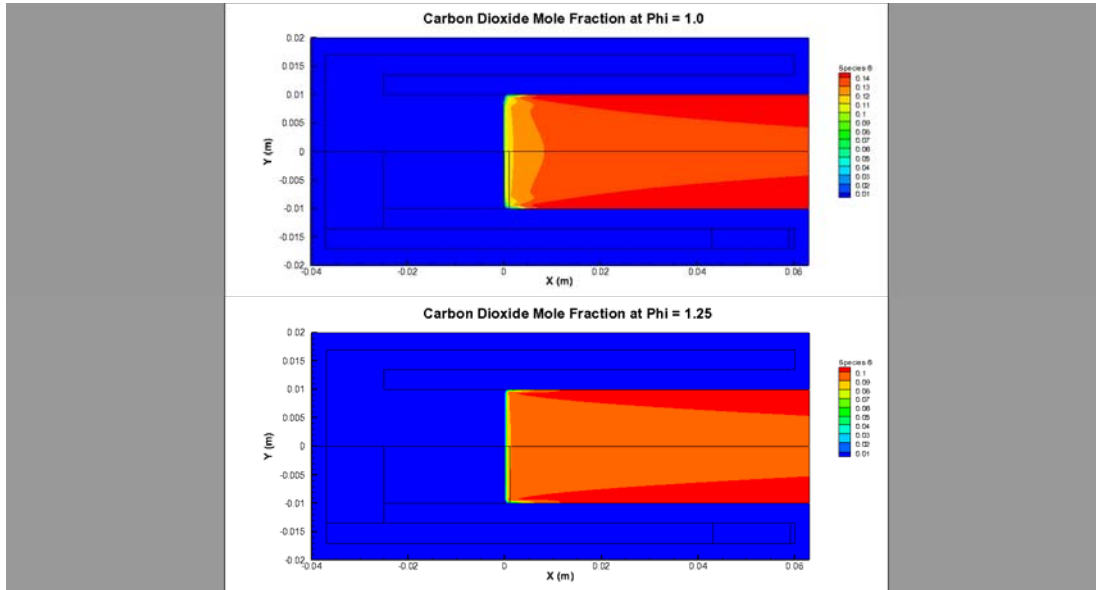


Figure 15. CO<sub>2</sub> Mole Fractions for Fluent Simulation

#### IV. Conclusions

Three models with increasing complexity were used to investigate fuel-rich combustion of methane to produce syngas containing hydrogen (H<sub>2</sub>) and carbon monoxide (CO). Simple PSR model provided results that allowed the optimum operating conditions for syngas production to be determined. These optimum conditions were at high operating pressure, high inlet temperature, and an equivalence ratio of around 2.3. The burner-stabilized model showed how the product species, specifically H<sub>2</sub> and CO, were produced in the reaction zone, as well as the pre-reaction zone and post-reaction zone. Most H<sub>2</sub> was produced in the reaction zone, but these reactions continued downstream to further increase H<sub>2</sub> production. The CO was produced mainly in the reaction zone, and downstream of this zone, CO was consumed by further oxidation reactions. CFD analysis with detailed chemical kinetics revealed the complex coupling among fluid flow, heat transfer, porous media, and chemical reactions. From this simulation it was found that most of the preheating of the reactants occurs in the porous media region. Because of the simplification introduced (e.g., no radiation), the heat transfer model is not completely accurate, but the trend observed with the porous media is consistent with previous experimental observations. Simulations revealed that fewer radicals are produced in the reaction zone as the mixture becomes fuel-rich. Simulations also identified how H<sub>2</sub> and CO production is affected by the local temperature. H<sub>2</sub> production increases in the boundary layer for the fuel-rich reactant mixture. CO<sub>2</sub> production also increased in the boundary layer because of low temperature and less dissociation. These trends offer unparallel insight into combustion processes inside this system. However, future studies will focus on fully validated, grid independent solution incorporating detailed chemical kinetics with thermal radiation for a range of operating conditions to optimize the system performance.

## V. Acknowledgments

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