Development of a syngas-fired catalytic combustion system for hybrid solar-thermal applications

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Abstract: This paper describes the development and operation of a catalytic combustion system for use with syngas as an important component of a hybrid heating source for solar-thermal power generation. The reactor consists of a cylindrical ceramic monolith with porous alumina washcoat in which platinum is distributed as the catalyst. Two fuel-rich equivalence ratios were studied over a range of flow rates. The fuel-rich conditions permit low temperature combustion without the problem of hotspots likely to occur under fuel-lean conditions with hydrogen-containing fuels. Experimental data of temperature and species concentration at the exit of the reactor have been reported for a maximum fuel thermal input of 34 kW. The system exhibited quick start-up with a light-off time of around 60 seconds and a steady-state time of around 200 seconds as determined from the transient temperature profiles. The experimental results have also been complemented with detailed two-dimensional numerical simulations for improved understanding of the combustion characteristics in the reactor. The simulations suggest that the combustion system can be operated at a turn-down ratios far in excess of 1.67, which is the maximum value that has been investigated in the present setup. Stable operation, quick startup, and high turn-down ratio are some of the key features that enable the proposed combustion system to accommodate the transients in solar-thermal applications.

Keywords: solar-thermal, biomass, hybrid, catalytic combustion, syngas

1. Introduction

Hybridization of energy sources such as solar, wind and biomass are an effective strategy to accommodate the transients in renewable power generation [1]. Such systems are commonly referred to as Hybrid Renewable Energy Systems (HRES). The idea is to leverage the output from multiple sources against the intermittency of weather conditions. This reduces the cost of energy production and increases the reliability of the power generation system. Several hybridization schemes such as photovoltaics and wind [2, 3], wind and solar-thermal [4], solar-thermal and biomass [7- 9], and a combination of these [5, 6] have been proposed in the literature. In spite of hybridization, systems such as wind and solar usually require a fossil fuel backup for continuous operation. A promising renewable strategy for the elimination of fossil-fuel backup is hybridization with biomass. The focus of the present work is to develop a combustion system based on biomass-derived syngas for the continuous operation of solar-thermal power generation units.

Biomass is a versatile fuel due to its availability from multiple sources and several methods of utilization. One such established method for the generation of power is gasification. Gasification is a process in which the chemical energy of the solid biomass is converted into that of a gaseous fuel known as syngas or product gas. For air-blown gasification of biomass, the typical composition of

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syngas can be represented as 20% CO, 20% H₂, 2% CH₄, 12% CO₂ and 46% N₂ with a calorific value of around 5 MJ/m³ [7]. When compared to direct combustion of biomass, gasification offers the additional advantage of syngas storage and easy transportation from the point of production to the point of utilization. The capacity of a gasification unit is different for different types of gasifier and can vary from 1 MW to about 300 MW [10-12]. The efficiency of biomass to electricity conversion reported in the literature varies between 15 - 43%, with a mean value of 27% [13]. In comparison to fossil fuels such as coal, the cost of electricity from biomass is cheaper when environmental externalities such as human health, soil erosion, etc. are taken into account [14]. The highest reported CO₂ emission by a biomass electricity plant [15] is less than the lowest emitting natural gas plant by a factor of 3 and the lowest emitting coal power plant by a factor of 5 [10].

The primary considerations in the development and operation of a syngas combustion system for a solar-biomass hybrid system are the relatively lower temperature requirement, ultra-low pollutant emissions and startup time. Among these requirements, the achievement of low temperature relevant to solar-thermal technologies is particularly challenging. The maximum solar cycle temperature can be as low as 700 K for parabolic troughs to 1300 K for solar towers with central receivers [16, 17]. This temperature range is below the flammability limit of syngas and can only be achieved in conventional gas-phase combustion systems by the staging of air. Another technology that is particularly suitable for such low-temperature applications is catalytic combustion. In catalytic combustion, the fuel is oxidized in the presence of catalysts that help to extend the flammability limit by lowering the activation energy [18]. Catalytic combustion systems have the potential for near-zero NO_x emission levels and can facilitate quick startup when the inlet temperature is greater than the catalyst light-off temperature.

Catalytic combustion systems can be operated both under fuel-rich and fuel-lean conditions. For syngas and other hydrogen containing fuels, fuel-rich combustion is preferred as fuel-lean combustion can give rise to hot spots that are detrimental to the structural integrity of the catalyst substrate [20]. The excess fuel in the exhaust of a fuel-rich combustion system can be subsequently oxidized in a second-stage combustor possibly to feed other power cycles [21-23]. Thus, the motivation for the present work is to develop a catalytic combustion system for utilizing biomass-derived syngas typically associated with very low calorific value (~ 5 MJ/m³). Fuel-rich catalytic combustion of methane and coal-derived syngas for gas turbine applications has been studied by Etemad et al. [22, 23]. Experimental and numerical studies on rich catalytic combustion of hydrogen over catalysts such as platinum and rhodium have been reported by various authors [24-26]. Rich catalytic combustion of methane (also known as catalytic partial oxidation) is of special interest in the production of syngas from hydrocarbons [27-29]. Catalytic combustion of H₂/CO mixtures has been studied under fuel lean [30-31] and fuel-rich conditions [32] to understand the intrinsic chemical kinetics in such systems. However, fuel-rich catalytic combustion of biomass-derived syngas, with its particularly low calorific value, has not been reported in the literature. The present study also fills this gap in the literature.

The present study reports experimental results for the development and operation of a 34-kW syngas combustion system operating under conditions relevant to solar-thermal plants. This power level has been chosen to provide a hybrid heating source for a supercritical CO₂ Brayton cycle loop currently being setup as part of the SERIUS initiative [33]. The novelty in the current work concerns the application of catalytic combustion of biomass-derived syngas for the continuous generation of renewable power. Platinum has been chosen as the catalyst due to its superior activity with H₂ and CO. The experimental results have been complemented with detailed numerical simulations for gaining insight into the combustion process. The next few sections describe the details of the catalytic combustor, experimental setup, results from the experimental studies, numerical model, comparison of model predictions with data, followed by a summary of the findings from the present study.

2. Experimental work

2.1. Catalytic Combustor

The catalytic combustion system comprising of the reactor and the flow lines is shown in Figure 1. The diffuser is fitted with a perforated chamber containing stainless steel spheres of 3-mm diameter. This ensured a uniform velocity profile at the entrance of the monolith that varied within $\pm 5\%$ of the mean value. This was verified by measuring the exit velocity using a hot-wire anemometer. The perforated chamber also avoided possibility of any flashback of the flame in the premixed charge. The diffuser was followed by a flow-straightening section that consisted of a 20-mm thick cylindrical honeycomb made of Hastelloy. This was followed by the catalytic monolith, a converging section and the exhaust nozzle. The monolith was 150-mm long and 150-mm in diameter and consisted of square channels with a density of 400 cells per square inch. The substrate of the monolith was made of the ceramic material cordierite, while the inner walls of the channels were lined with a porous washcoat of alumina (Al₂O₃). Platinum was distributed in this porous washcoat. Table 1 gives the detailed specifications of the catalytic monolith.

2.2. Flow system

The air and fuel flow into the system were controlled by mass flow controllers (make: Alicat) with a range of 0-1000 SLPM with an accuracy of $\pm 1\%$ at the maximum flow rate. At startup, for the purpose of achieving catalyst light-off, the fuel was preheated in a 15-kW furnace-type heater with PID temperature control. The fuel was supplied from pressurized cylinders and had a volumetric composition of 20% CO, 12% CO₂, 20% H₂, 2% CH₄ and 46% N₂. A bypass line was incorporated to preheat the catalytic combustion system using air rather than fuel prior to starting the experiments in order to avoid wastage of fuel. After reaching a steady temperature, the bypass valve was closed and fuel and air were separately introduced into the mixing chamber. The preheated fuel was mixed with the air in the mixing chamber at a particular equivalence ratio determined by the flow rates. This fuel-air stream was subsequently oxidized in the catalytic monolith.

2.3. Instrumentation and data acquisition

For temperature measurements, sheathed K-type (chromel-alumel) thermocouples of 1.5mm diameter were used at the inlet and outlet of the catalytic monolith. The temperature was corrected for radiation losses and this correction was found to be around 30-40 K for the present work [34]. At the inlet, two thermocouples were placed (center and peripheral positions) 50-mm below the monolith. At the outlet, a total of eight thermocouples were placed at various radial locations (0mm to 70mm) about 50-mm above the monolith. Temperature data was acquired at a sampling frequency of 15 Hz using a data acquisition system (model: PXIe-4353, make: National Instruments). The species concentration data were acquired using an exhaust gas analyzer (make: MRU) that can measure CO (0-20% by vol.), CO₂ (0-20%), O₂ (0-25%), NO_x (0-2000 ppm) and hydrocarbons (0-20000 ppm), with an accuracy of $\pm 5\%$. The resolution for the measurement of CO, CO₂, O₂, NO_x and hydrocarbons are 0.01%, 0.1%, 0.01%, 1-ppm, and 1-ppm, respectively. The hydrocarbon measurement was calibrated for methane as chemical equilibrium analysis predicted negligible production of higher hydrocarbons (~ 0.1 ppm). In general, all measurements of temperature and species were repeatable within $\pm 2\%$. The temperature of the inlet air across all the experiments varied between ± 7 K.

2.4. Determination of experimental conditions

The experimental conditions were determined considering the maximum allowable temperature in the catalytic reactor and flashback in the premixed fuel-air mixture. For continuous operation, a maximum temperature of 1073 K was specified by the monolith manufacturer. The variation of adiabatic flame temperature as a function of equivalence ratio for the selected composition of biomass-derived syngas is shown in Fig. 2. The inlet temperature of 503 K is close to the reported light-off temperature for rich catalytic combustion of syngas [22]. The lowest equivalence ratio for the thermally safe operation was determined to be 4. The upper equivalence ratio considered for the present study was 5. For equivalence ratio values beyond, the temperature rise would be lower than the required value; moreover, it may lead to undesirable effects such as carbon deposition on the monolith.

Initial trials revealed that the phenomenon of flashback was a serious issue at low flow rates. The flow rates were then determined using laminar flame speed calculations. The detailed C₂/H/O mechanism of Warnatz et al. [35] was used to determine the laminar flame speeds at equivalence ratio of 4, P = 1 bar and unburned mixture temperature of 600 K. The unburned flame speed value obtained was 16 cm/s. Considering a factor of safety of 4, the minimum flow rate was determined to be 300 SLPM for $\Phi = 4$. The large factor of safety was incorporated to account for any local non-uniformity in the flow. The upper flow rate of 500 SLPM was selected to operate the reactor at a desired power level of 34 kW. An intermediate value of 400 SLPM has also been used in the present study. The Reynolds number in the monolith channels corresponding to the flow rates of 300, 400 and 500 SLPM was in the laminar regime, thereby justifying the use of laminar flame speed calculations. The complete set of experimental conditions is shown in Table 2.

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2.5. Experimental results

In this section, temperature measurements under both transient and steady-state conditions are reported and discussed. Additionally, catalytic light-off timescales and species measurements at the exhaust of the monolith are also reported.

2.5.1. Transient characteristics

Figure 3 shows the transient temperature profiles measured at the inlet and the exit of the catalytic combustion system for different flow conditions. The point of inflection on the exit temperature curve signified the light-off condition. For all the cases, it was observed that the time required for light-off was reduced with increase in the flow rate. The transient phase occurs after the light-off phase. The duration of the transient phase was also found to significantly reduce with increase in the flow rate. However, both these parameters were observed to be fairly insensitive to the equivalence ratio (Figure 4). The dependence is found to be more on the convective transport. The light-off time obtained was 50 seconds for 500 SLPM and 65 seconds at 300 SLPM. Overall, the system had a short startup time corresponding to less than 5 minutes at the lowest flow rate. This characteristic is highly desirable to quickly respond to the transients in solar-thermal power generation.

2.5.2. Temperature

Figure 5 shows the measured peak outlet temperatures as a function of the flow rate. For equivalence ratios of 4 and 5, the experimentally-observed temperature rise is 516 K and 449 K, respectively. It is interesting to note from Fig. 5 that there is no significant effect of flow rates on temperature rise for the range of flow rates studied. This indicates that the residence time available in the current reactor is sufficient for the completion of reactions under the given conditions.

Figure 6 shows the radial temperature profiles at the reactor outlet for equivalence ratios of 4 and 5, and a flow rate of 300 SLPM. The uncertainty in temperature measurements corresponds to a value of around $\pm 2\%$ which translates to only around ± 20 K for the measured temperatures. The observed trend in the radial variation of temperature is indicative of the heat loss to the walls of the reactor. It can be observed that the temperature variation over the central region of the monolith (radius of 30-mm) is around 40 K only. Thus, the temperature in this region is reasonably uniform. However, beyond this region and closer to the wall, there is a larger gradient, mainly driven by the heat loss to the walls. Even in this region, at a radial location of 60-mm, the temperature variation is of the order of 150 K. The sharp drop in temperature between 60-mm and 70-mm is due to proximity to the wall.

The average temperature of the exhaust obtained using the radial temperature profiles was used to estimate the heat loss from the system. The software, Refprop 9.0 [36], was used to calculate the enthalpy of the exhaust. The exhaust temperatures estimated from the adiabatic flame temperature calculations were used as a reference for the heat loss calculation. It was found to be in the range of

20-27% for both the equivalence ratios, as shown in Fig. 7. The decrease in the heat loss percentage with flow rate was due to the higher fuel thermal input associated with the increase in flow rate.

2.5.3 Measurements of Species Concentration

Figures 8 and 9 represent of the experimentally obtained product species variation with flow rates for equivalence ratios of 4 and 5, respectively. It is interesting to note that there is no significant change in the species concentrations over the range of flow rates studied. The minor variation observed with respect to the flow rate could also be due to variation in the initial composition of syngas (up to 2%) provided by the supplier. On the other hand, it is observed that the equivalence ratio has a significant influence on the product composition, indicating varying extent of consumption of the reactants. The species such as H_2 and CH_4 were consumed to a greater extent at $\Phi = 4$ as compared to that at $\Phi = 5$. The results also suggested that there was a net production of CO and CO_2 and consumption of CH_4 and H_2 . The production of CO is the result of the partial oxidation ($CH_4 + 0.5 O_2 \rightarrow CO + 2H_2$) and steam reforming ($CH_4 + H_2O \rightarrow CO + 3H_2$) reactions of methane. It is important to note that there is a decrease in CH_4 in products as the flow increases from 300 to 400 SLPM and then an increase at 500SLPM. This is explained as follows. From Fig. 5, one can observe that the exit temperature increases as the flow rate increases from 300 SLPM to 400 SLPM and remains almost same at 500 SLPM. This is to be expected as the temperature would increase with increase in heat input. However, between 400 SLPM and 500 SLPM, the increased heat input may be balanced by the increased heat loss to the walls, thus causing the temperature to remain nearly the same. Now, the higher temperature for the 400 SLPM case as compared to the 300 SLPM case tends to promote the steam reforming reaction of methane, which is endothermic. Therefore, the methane concentration decreases as flow rate changes from 300 to 400 SLPM. For the 400 and 500 SLPM cases, although the temperatures are almost the same, the residence time decreases. Thus, the effect of residence time dominates, leading to again a higher methane concentration at 500 SLPM.

A detailed insight into species concentrations are obtained using numerical simulations which are presented in the following section. It is worth noting that the NO_x emissions were below 1-ppm in the current work, as expected, since the temperatures are well below those required for NO production.

3. Computational Modeling

The experimental studies were complemented by detailed numerical simulations conducted on a single channel of the monolith. The primary motivation for conducting the numerical simulations was to understand the temperature distribution and species profiles within a single channel. The accurate determination of the temperature inside the reactor is critical to the prevention of local hot spots that can damage the monolith. The axial profiles of temperature and species can help in understanding the effect of the channel length on the heat release and chemical kinetics.

3.1. Numerical model

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A single channel of the catalytic monolith was numerically simulated to understand the combustion phenomena inside the reactor. The computational domain closely approximates the channels near the axis of the monolith. As shown in Figs. 10 and 11, a two-dimensional axisymmetric domain was selected for the numerical simulation, while maintaining the same channel surface area and inlet Reynolds number. The domain was divided into 14 and 350 divisions in the radial and axial direction with necessary biasing near the walls. The porous washcoat and substrate wall were divided into 4 and 6 divisions in the radial direction, respectively. The computational results were verified to be grid-independent. The governing equations of continuity, momentum and energy were discretized and solved using FLUENT. The details of the model for porous washcoat can be found elsewhere [37]. The Laminar Finite Rate model and the surface-to-surface radiation model were used to model the reactions and radiation. Table 3 describes the parameters used for the numerical simulations.

3.2. Chemical kinetics

For heterogeneous chemistry, the mechanism proposed by Deutschmann et al. [38] for the catalytic partial oxidation of C_2H_6 was used. Only the C_1 surface species have been considered in the present study [39]. The scheme was further augmented by an updated H_2/CO heterogeneous scheme reported by Mantzaras et al. [32]. The $HCOO$ pathway included in the scheme has been reported to significantly affect the CO consumption for rich catalytic combustion of H_2/CO mixtures over platinum [32]. The final mechanism consisted of 43 surface reactions with 12 surface species. For gas-phase chemistry, the $C_2/H/O$ mechanism of Warnatz et al. [35] (164 reversible reactions and 34 species) was used. The scheme has been reported to accurately predict the onset of homogeneous ignition in CPO of methane diluted with CO_2 and H_2O [40].

3.3. Results & Discussion

3.3.1. Comparison with experimental results

The comparison of predictions with experimental data is shown in Table 4. The predictions showed reasonable agreement with the experimentally-obtained values of temperature and CO concentration. It must be mentioned that the temperature measured along the axis of the monolith ($r = 0$ mm) was used for comparison. The slight discrepancy in temperature comparison can be attributed to the effect of heat loss in the reactor that was not accounted for in the single channel simulations. This factor also has an effect on the predictions of species composition. The most significant deviation could be observed in the prediction of CH_4 that could have influenced the H_2 and H_2O concentration. The two-dimensional axisymmetric assumption and the kinetic scheme selected could be other possible sources of disagreement between the experimental and computational results. However, the computations can be used to predict the maximum temperature in the reactor as it closely approximates the channels near the axis of the monolith where the highest temperature is observed. This is the key parameter for safe operation of the monolith. The species profiles obtained along the length of the channel also help in optimizing the length of the monolith.

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3.3.2. Temperature variation along the channel length

Figure 12 shows temperature profile along the axis of the channel for equivalence ratios of 4 and 5 at a flow rate of 400 SLPM. The temperature increased rapidly near the inlet and marked the initiation of reactions within the channel. The temperature for $\Phi = 5$ was lower than that of $\Phi = 4$. Peak temperatures of 1150 K and 1050 K were achieved that decreased to 1066 K and 990 K for equivalence ratios of 4 and 5, respectively. The temperature profiles are gradual and no local hot spots characterized by sudden temperature rise can be observed. This further suggests that the present reactor can be operated safely at $\Phi = 4$ and 5.

3.3.3. Variation of species along the channel length

Figure 13 shows species profiles along the channel length averaged over the cross-section. It is observed that H_2 is oxidized at the beginning of the channel leading to a sharp decrease in its mass fraction. The H_2O concentration profile shows a rapid increase reflecting the corresponding decrease in the H_2 concentration profile. The O_2 mass fraction goes to zero within the first 5-10 mm of the channel as it is completely consumed by H_2 . In the absence of O_2 , the subsequent reaction of steam-reforming of methane along the channel length takes place, leading to the gradual production of H_2 and CO and consumption of CH_4 . The methane reforming reaction is endothermic, which explains the observed decrease in the temperature along the channel length.

The initial gradients in the species concentrations can be better observed in Figure 14 that shows the two-dimensional contours for the first 20-mm of the channel. The reactions are predominantly governed by the surface chemistry as gas-phase reaction rates are insignificant at these temperatures. The reactions start near the surface where the initial rise in temperature and oxidation of reactants is observed. After the initial reaction zone, no significant variation along the channel radius can be observed.

From the temperature and species profiles, it can be concluded that the length of the reactor selected (150-mm) is sufficient for the flow rates considered in the present study. This can also be corroborated by the fact that O_2 is consumed within the first 10-mm of the channel. The length of the channel (150-mm) is approximately 15 times greater than the length required for complete O_2 consumption (~ 10 mm). This observation is very significant as it implies that the current reactor can be operated at flow rates much higher than the values used in the present study. However, there may be other limitations in extending the operation to such high flow rates and needs further investigation. Notwithstanding these limitations, it is reasonable to assume that the current reactor can operate at a wider range of turn-down ratios as compared to the turn-down ratio of 1.67 (ratio of maximum to minimum flow rates) that has been investigated in the present study.

4. CONCLUSIONS

The present work describes the development and operation of a catalytic combustion system as a possible hybrid heating source for solar-thermal power generation. Syngas containing 20% CO, 20% H₂, 2% CH₄, 12% CO₂ and 46% N₂ and a calorific value of around 5 MJ/m³ has been used as the fuel. This composition closely represents the fuel obtained from biomass gasification. Detailed experimental studies have been conducted to assess the performance of the system in terms of parameters relevant to solar-thermal applications. Experimental data of temperature and species concentration at the exit of the reactor have been reported for a maximum fuel thermal input of 34 kW and a turn-down ratio of 1.67. The equivalence ratio and the flow rate are the primary parameters that have been varied. From temperature considerations, it was determined that the equivalence ratios of 4 and 5 were suitable for solar-thermal applications. The system also exhibited quick startup that is crucial in accommodating the fluctuations in solar power generation. A light-off time of around 60 seconds and a steady-state time of around 200 seconds were determined from the transient temperature profiles. The heat loss percentage from the reactor decreased with an increase in the flow rate and was found to be of the order of 20-27%.

The experimental results have also been complemented with detailed two-dimensional numerical simulations for an improved understanding of the heat release and chemical kinetics in the catalytic combustor. The simulations confirmed the fact that no hotspots developed within the reactor in spite of the large H₂ content in the fuel. More importantly, the simulations are able to predict the temperature rise across the combustor with reasonable accuracy (within 40-70 K). The species profiles along the monolith length show that the primary reaction zone is limited to within 10-mm from the inlet. This insight from the simulations also suggests that the current combustor can sustain higher flow rates and operate over a much higher turn-down ratio (~15). Stable operation, quick startup, and high turn-down ratio confirm the suitability of the current combustion system to be an important component of a hybrid heating source for solar-thermal power generation.

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Table 1: Specifications of the catalytic monolith.

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Property	Specification
Material	Cordierite
Chemical composition	Al ₂ O ₃ : 35.2±1.5%, SiO ₂ : 50.9±1.5%, MgO:13.9±1.5%
Porosity of washcoat	45%
Catalyst	Platinum
Catalyst loading	10gm/ft ³
Maximum allowable temperature	1200°C for intermittent operation, 800°C for continuous operation
Average pore diameter	7 - 10 µm
Channel hydraulic diameter	1.1 mm
Wall thickness	0.15 mm
Outer dimensions	Diameter = 150mm, length = 150mm
Channel Density	400 channels per square inch
Washcoat Thickness	17 µm

Table 2: Experimental conditions

Φ	mass composition	Total flow (SLPM)	Air (SLPM)	Fuel (SLPM)	Fuel thermal loading (kW)
4	17.13% CO, 16.16% CO ₂ , 1.22% H ₂ , 0.98% CH ₄ , 5.86% O ₂ , 58.65% N ₂	300	66.5	233.5	19.5
		400	88.7	311.3	25.9
		500	109.9	389.1	32.4
5	18.04% CO, 17.01% CO ₂ , 1.29% H ₂ , 1.03% CH ₄ , 4.94% O ₂ , 57.70% N ₂	300	55.7	244.3	20.4
		400	74.3	325.7	27.1
		500	92.8	407.2	33.9

Table 3: Parameters used for the numerical simulations

Channel dimensions	
Diameter	1.4 mm
Length	150 mm
Ceramic substrate	
Material	Cordierite
Thickness	0.037 mm
Thermal conductivity	3 W/m.K
Density	2600 kg/m ³
Specific heat	1464 J/kg.K
Washcoat	
Washcoat thickness	0.017 mm
$F_{cat/geo}$ (washcoat factor)	7
Thermal conductivity	25 W/m.K
Density of the solid	3690 kg/m ³
Specific heat	880 J/kg.K
Other parameters	
Wall emissivity (ϵ)	0.6

Table 4: Comparison between experimental and computational results

		Mass fraction of products (%)											
Cases		CO		CO ₂		CH ₄		H ₂		H ₂ O		ΔT (K)	
Φ	Flow rate	Exp.	CFD	Exp.	CFD	Exp.	CFD	Exp.	CFD	Exp.	CFD	Exp.	CFD
4	300	18.33	18.6	19.32	15.8	0.06	0.09	0.96	0.86	4.78	5.6	498	546
	400	19.18	19.2	20.10	16.42	0.04	0.146	1.07	0.86	4.92	5.68	516	559
	500	18.97	19.17	20.07	16.43	0.08	0.16	1.05	0.854	4.91	5.68	516	592
5	300	19.22	20.11	20.02	16.8	0.23	0.31	1.07	0.96	3.86	4.73	436	483
	400	19.34	19.57	19.54	17	0.22	0.387	1.06	0.89	3.97	4.77	449	490
	500	19.62	19.48	19.36	17	0.26	0.43	1.05	0.88	4.16	4.82	445	495