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PREDICTION ON CO_2 AND NO_X REDUCTION ON MICRO GAS TURBINE FED BY DIFFERENT SYNGAS QUALITY

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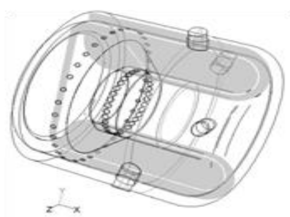
Graphical abstract



Abstract

The stringent requirement of power plant environmental emissions and the need to improve efficiency have led to significant rise of research in clean energy in this decade. Gas turbines are favourable in the power generating industries since it has environmental advantages besides capable to utilize variety of fuels like natural gas, fuel oils and synthetic gas. In recent years, the use of synthetic gas or syngas has been increasing due to its advantages such as CO_2 and NO_x emission reduction. Although many studies have been carried out in the area of syngas combustion, the study on the combustion characteristics and pollutant emission remains a challenge due to its complexity and limitless variety of fuel compositions involved. This paper presents the investigation of CO_2 and NO_x reduction on micro gas turbine combusting syngas with different methane compositions using computational fluid dynamics (CFD). The combustion trend of syngas is found to be similar to combustion with natural gas in general. However, the average temperature distribution is found to be very much dependent on the methane composition of the mixture. Higher methane composition is fuel results in higher average temperature distribution. The reduction of CO_2 and NO_x is predicted to be significant in combustion with syngas compared to conventional natural gas.

Keywords: Syngas, micro gas turbine, NOx, computational fluid dynamics

1.0 INTRODUCTION

With the ultimate aim of reducing pollutant emissions, many alternatives have been developed for low-carbon energy in the recent decade. As a result, intermediary products such as syngas are becoming increasingly attractive for the power industries. Syngas which is rich in hydrogen and carbon monoxide is primarily produced through coal or biomass gasification. It can be directly burned or further process for other gaseous or liquid products. It is noted that, the heating values of syngas are lower compared to natural gas [1]. Syngas is primarily used in gas turbine due to its ability to burn fuel with lower heating values [2-4]. Combustion with syngas produces better flame stability compared to natural gas [2]. Combustion flame for syngas is shorter, able to stabilize closer to the inlet jet, and no acoustic oscillation observed [5-7]. Besides combustion behaviour and performance, much attention must be given to the effect of fuel mixture on the production of greenhouse effect and pollutant emission. Based on the researches done by [8-15], NOx emission measured is clearly lower than for natural gas. Nevertheless, NOx emission is highly influenced by the hydrogen concentration as reported by [13]. This paper aims to investigate the reduction in NOx and CO_2 in micro gas turbine fed using syngas fuel. Three cases of syngas with different methane composition and fixed $CO-H_2$ ratio were simulated through computational fluid dynamics (CFD). Comparison is then made with similar combustion simulation using conventional natural gas.

2.0 METHODOLOGY

The three-dimensional model of the micro gas turbine under investigation is illustrated in Figure 1. The 30 kW micro gas turbine model is developed based on the actual micro gas turbine combustor used for the experiment. Due to the limited availability of the actual dimensions and complexity of the gas turbine, minor approximation is made on tiny components to simplify the model geometry without altering. The general effect of these micro components to the numerical solution for important parameters such as temperature and species distribution was found to be insignificance and thus could be ignored. The micro gas turbine is divided into four major sections; air inlet, fuel inlet, main combustion zone and an outlet as illustrated in Figure 1. Air enters through the air inlet in a circumferential area upstream of the combustor. Downstream of the air inlet, fuel is injected through four fuel inlets arranged circumferentially into the combustion chamber. Mixing of fuel and air occurs prior to the entrance to main combustion zone which is located slightly downstream of the fuel inlets. The exhaust gas will then be channeled through the centre core. Figure 2 illustrates the cut-out view of the 3D model of the gas turbine. For the purpose of this study, two iso-surfaces were created on the z-axis and x-axis as shown in Figure 3. These iso-surfaces were created to clearly illustrate the properties of combustion gas at the critical regions; combustion region (z-plane) and outlet (x-plane).

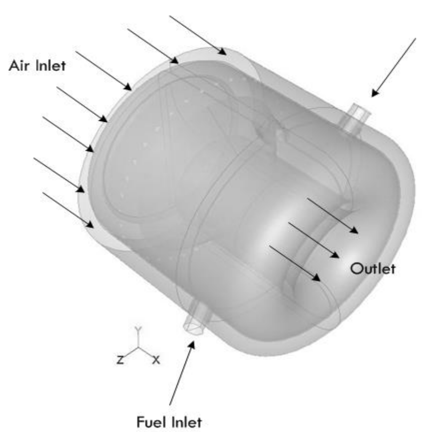


Figure 1 Three-dimensional view of the micro gas turbine model

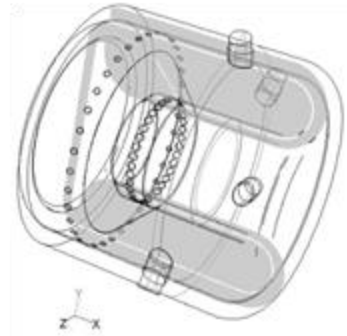


Figure 2 Cut-out section of the micro gas turbine model

2.1 Meshing

In CFD, quality of mesh plays important role for the calculation of flow properties. The governing equations of flow and combustion will be discretized according the mesh scheme generated for the flow domain. In this work, unstructured mesh is employed throughout the flow domain with appropriate size functions where flow is critical. The model employs approximately 1,285,574 cells which are sufficient to resolve the flow field with reasonable accuracy. Grid dependency test was carried out and it was found that the current mesh adopted in to the model is sufficient to resolve the flow field. The overall mesh of the micro gas turbine model is illustrated in Figure 4.

2.2 Model Assumptions

The combustion model was based on eddy dissipation model which compute the rate of reaction under the assumption that the chemical kinetics are fast compared to the rate at which the reactant are mixed by turbulent fluctuations. The individual component concentrations for the species of interest are derived from the predicted mixture fraction distribution using the probability density function (PDF). The flow is assumed to follow ideal gas behavior (Pv=mRT) and the specific heat values are assume to obey the mixing law.

2.3 Boundary Conditions

In this analysis, only the major compositions of fuel are included as the main source of fuel. Three different cases were established namely Case 1, Case 2 and Case 3. In addition to the three cases, a base case (Case 0) simulation is first established where 100% natural gas is assumed for the fuel. The three cases differ in the sense that the mass fraction of natural gas (methane) varies in all cases and at the same time, other species were made fixed. The summary of the syngas fuel composition is listed in Table 1. The mass flow rate for fuel and air is set to be 0.003 kg/s and 0.516 kg/s respectively for all four cases. The internal emissivity, turbulence kinetic energy (m^2/s^2) and dissipation rate (m^2/s^2) are maintained at 1 for all cases. Boundary condition for wall is set as non-slip stationary wall with no heat flux while the outlet is set as pressure outlet.

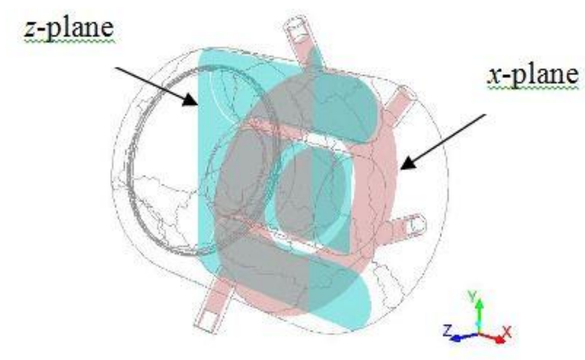


Figure 3 Iso-surfaces created inside the micro gas turbine

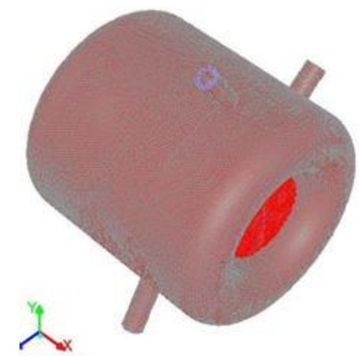


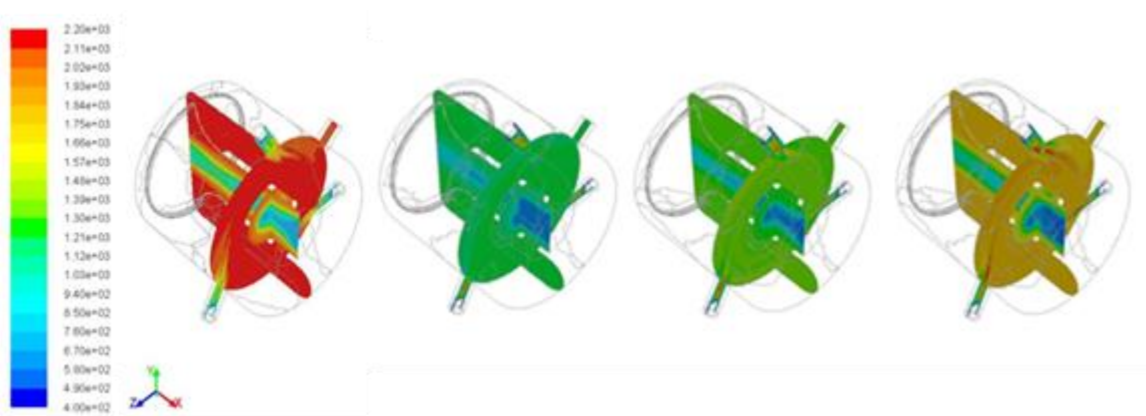
Figure 4 Three-dimensional mesh scheme generated on the model

Table 1 Species distributions for different syngas cases

	LHV [MJ/kg]	Hydrogen [ppm]	Carbon Monoxide [ppm]	Methane [ppm]	Nitrogen [ppm]
Case 1	15	50	50	500	1000
Case 2	20	50	50	1000	1000
Case 3	25	50	50	2000	1000

3.0 RESULTS AND DISCUSSION

Figure 5 shows the temperature distribution for all four cases. Temperature distribution for combustion with syngas shows similar pattern as combustion with methane. It is noted that higher methane concentration results higher overall temperature distribution as seen in Figure 5 where Case 1 produces the lowest temperature distribution followed by Case 2 and Case 3. Another important aspect in this study is to investigate the distribution of species particularly CO_2 and NO_x. It is anticipated that the mass fraction of CO_2 is the highest compared to other species since it is the main fuel composition. It is also predicted that highest NO_x distribution is found at the highest temperature distribution.



(a) (b) (c) (d)

Figure 5 Temperature distribution inside the micro gas turbine in Kelvin (K)(a)Case 0 (b)Case 1 (c)Case 2 (d)Case 3

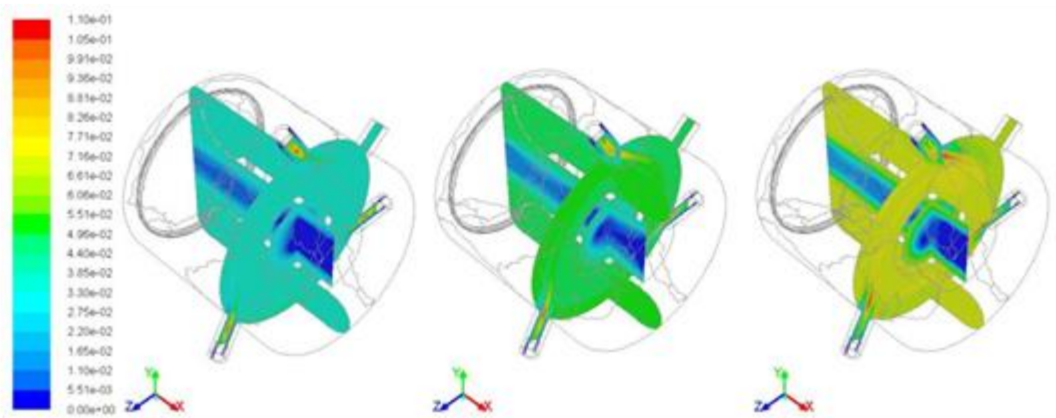
3.1 Carbon Dioxide (CO_2) Distribution

In methane combustion, most of the carbon in hydrocarbon molecules is converted to CO_2 and therefore it is anticipated that the mass fraction of CO_2 is the highest as compared to other species. Figure 6 illustrates the CO_2 concentration distribution for all cases, methane and syngas. The highest CO_2 concentration is located in the main reaction zone and reduces as the combustion gas flows towards the turbine exit. Similar trend is observed for combustion with syngas. Concentration of CO_2

depends on the concentration of methane in fuel. Higher methane concentration in fuel results higher CO_2 in the exhaust. In this case, Case 3 gives the highest CO_2 concentration followed by Case 2 and Case 1. Comparing with the base case, reduction of CO_2 is significant in syngas combustion due to the drastic reduction in carbon molecule in the supply fuel.

3.2 Nitrous Oxide (NOx) Distribution

Besides reduction in CO_2, one of the most important motivations in adopting syngas combustion in micro gas turbine is to reduce NO_x. This could be made possible by reducing the average temperature inside the turbine through the help of recuperator. Compared with the combustion with natural gas, combustion with syngas produces slightly lower average temperature. Hence, it is predicted that combustion with syngas produces lower NO_x distribution. From the temperature distribution from Case 1, 2 and 3, it could be expected that the NO_x produced in Case 3 will be the highest due to its highest average temperature. Calculation of NO_x in each case shows reasonably good agreement compared with the trend on the temperature. Figure 7 shows the NO_x distribution at turbine exit normalized to Case 1. It is clear that Case 1 produces the lowest NO_x, followed by Case 2 and Case 3 respectively. The trend agrees very well with the magnitude of average temperature in the turbine channel.



(a) (b) (c)

Figure 6 CO_2 mass fraction distribution inside the micro gas turbine (a) Case 1 (b) Case 2 (c) Case 3

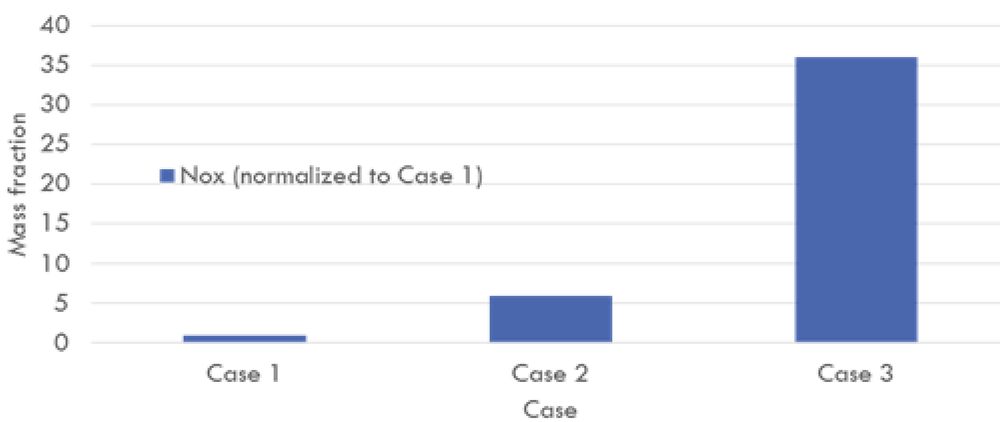


Figure 7 NO_x distribution at turbine exit (Normalized to Case 1)

4.0 CONCLUSION

Study on the prediction of CO_2 and NO_x emissions when syngas combustion is applied in micro gas turbine have been conducted with reference to the conventional natural gas combustion. Three cases of fixed CO-H_2 ratio and variable methane composition were analysed. The fuel properties and simulation parameters were based on the actual operating conditions. Simulation with syngas shows similar flow and temperature distribution as natural gas. The average temperature distribution is dependent on the concentration of methane in the syngas gas. CO_2 reduction is very significant for syngas combustion as compared to natural gas combustion in micro gas turbine. Comparing all cases of syngas, highest CO_2 produced by syngas with the highest concentration of natural gas. Moreover, the reduction in NO_x is also significant as a result of reduction in average temperature in the turbine. In this study, CO_2 and NO_x reduction is predicted in combustion with comparison to natural gas in micro gas turbine.

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