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Evaluating the Effect of Syngas Composition on Micro gas turbine Performance

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Abstract. Syngas in nature can be derived from many sources for instance biomass, natural gas and any hydrocarbon feedstock. Therefore it can replace our reliance on the fossil fuel in future, as they are finite. This research covers the analysis on the combustion efficiency on eight syngas composition that have various hydrogen and carbon moxide (H_2/CO) ratio and the comparisons on the nitric oxide (NO_x) and carbon monoxide (CO) emissions. Each syngas was tested from 0kW load to 3kW load and all the data was taken upon the micro gas turbine (MGT) reaching stable and steady state conditions. It was found that high amount of hydrogen content in syngas lead to an increase in the combustion efficiency and emits more NO_x emissions. CO emissions were released when the combustion efficiency is low and increase with the CO content in the syngas.

1. Introduction

Syngas is a mixture of carbon monoxide and hydrogen in various compositions and can be derived from a number of sources such as coal, biomass gasification or from natural gas during steam reforming. It is used in IGCC because it is a potential clean fuel containing carbon dioxide (CO_2), water (H_2O), ammonia (NH3) and hydrogen sulphide (H_2S) constituents. However, these variations in compositions of syngas potentially affect the IGCC performance and efficiency [1].

Syngas in integrated gasification combined cycle (IGCC) applications should be free of particulates and trace metals that could damage the gas turbine. Catalytic gasification is one of the gasification technologies that produced gas containing high hydrocarbon content which is similar to natural gas. Hence, it is ideal for utilization in the combustion turbines. This is because the design of the gas turbine in IGCC was developed based on the natural gas combustion turbines. However, there are some differences between syngas and natural gas that will affect the design of combustion turbines [2]. Syngas gasification process varies in calorific value, composition, flammability characteristics and contaminants compared to natural gas. Syngas typically consists of carbon and hydrogen, whereas natural gas mainly consists of methane. As the syngas has more hydrogen content, these results in a higher flame speed and wider flammability limits. Thus, this factor make syngas produced a stable flame at leaner conditions. Besides that, it has higher combustion speed than natural gas [3].

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2. Research Methodology

The micro gas turbine (MGT) used is Capstone 30kW while a standard bench top gas analyser was used to run the experiment using eight different syngas with various H_2/CO ratio. Each syngas was tested from 0-30 kW load and the data of heat losses, output power, NO_x and CO emissions were recorded by the gas analyzer. The combustion efficiencies for the syngas were calculated using Equation (1) and (2). In order to calculate the combustion efficiency, the LHV values for each syngas were calculated first.

$$LHVgas = [30CO + 25.7H_2 + 85.4CH_4 + 151.3C_2H_x]\ 0.0042\ MJ/Nm^3 \quad (1)$$

$$\text{Combustion efficiency} = 100\% - ([\text{Heat Losses}/\ \text{Fuel Heating Value}] \times 100) \quad (2)$$

2.1 Experiment setup

The experiments were carried out at TNB Research IGCC Pilot Plant using Capstone 30 kW MGT. The experiment begins by connecting the syngas to the MGT and the pressure of the gas container is ensured to be between 8 to 10 psi. Thereafter, the main power of the MGT at the control panel is switched on together with the gas analyzer before running the Capstone Software to start up the MGT operation. Throughout the experiment, the flow of the gas is monitored by checking the flow meter to ensure no drop in pressure and no freezing occurs. The freezing will block the syngas from entering the MGT causing shut down which will interrupt the experiment processes. The syngas were tested for 10 minutes for each load starting from 0kW to 3kW.These steps were repeated for each syngas compositions with different H_2/CO ratio. The schematic diagram of the experiment system is shown in figure 1.

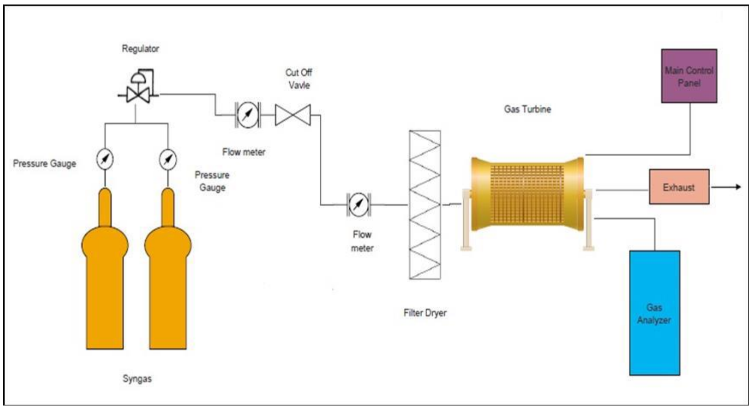

Figure 1. Schematic diagram of the experiment setup.

2.2 Syngas Composition

In this experiment, the ratio of hydrogen (H_2) and carbon monoxide (CO) in the syngas compositions was varied. The combustion efficiency and output power for each syngas were then calculated from the data collected throughout the experiments. NO_x and CO emissions were also compared between each syngas. The ratio of H_2 and CO composition variation is shown in table 1.

Table 1. Syngas compositions tested during the experiment.

Syngas	H_2 (%vol)	CO (%vol)	CH_4 (%vol)	N_2 (%vol)
1	0.6	1	60	38.4
2	0.6	2	60	37.4
3	0.6	3	60	36.4
4	0.7	1	60	38.3
5	0.7	2	60	37.3
6	0.7	3	60	36.3
7	0.8	1	60	38.2
8	0.8	2	60	37.2

3. Results and Discussion

During the experiment, the parameters recorded include the temperature profiles, the heat losses and the output power. The experiments were carried out from 0kW to 3kW for each syngas H_2/CO with 10 minutes duration for each load respectively. The collected data were used to calculate the combustion efficiency. The MGT is connected to the gas analyzer and the gas emissions such as CO (%) and the No_x (ppm) were recorded every 5 seconds.

Figure 2 shows the output power against H_2/CO ratio at load of 3 kW. The 0.6 H_2/CO has the highest output power when connected to 3kW load whereas, 0.7 H_2/CO has the lowest output power. One of the factors contributing to the higher output power is the smaller fuel heating value as it causes an increase in turbine flow [4]. Gas turbine output power is also affected by the ambient temperature. As the ambient temperature increases, less output power will be produced. The experiments 0.7 H_2/CO syngas was carried out at noon, which has a high ambient temperature as compared to other syngas ratio, which were mostly conducted in the morning. This explains the lower output power was produced by 0.7H_2/CO.

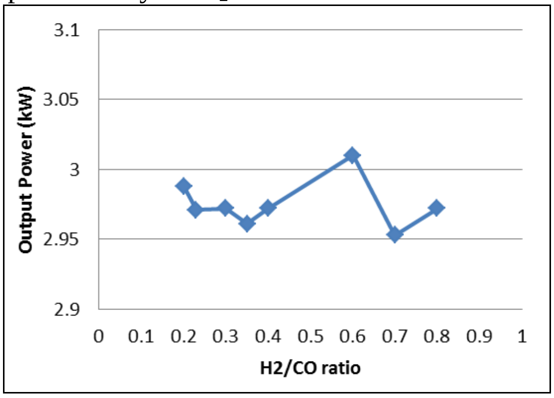

Figure 2. Output power versus H_2/CO ratio at 3 kW load for various syngas compositions.

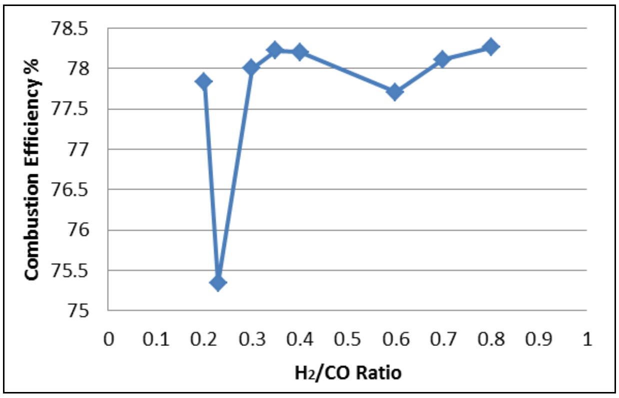

Figure 3. Combustion efficiency versus H_2/CO ratio at 3 kW load for various syngas compositions.

Combustion efficiency indicates the effectiveness of the useful energy conversion from the fuel, which is to rotate the turbine blades. From figure 3, the combustion efficiency increases as the H_2/CO ratio increases. However, there were some points particulary at 0.23 H_2/CO ratio and at 0.6 H_2/CO ratio, it decreases. In this experiment, the 0.80 H_2/CO ratio has the highest combustion efficiency of 78.30%. This H_2/CO ratio has the highest H_2 percentage volume of 0.8 (% volume) with 1 (% volume) of CO. The combustion efficiency was aided by the higher hydrogen content in this syngas H_2/CO ratio since hydrogen has very clean burning characteristics, a high flame propagation speed and wide flammability limits. As it has higher laminar combustion, it reduced the combustion duration, thus increase the combustion efficiency [5]. The syngas with higher hydrogen content elongated the flame because of the presence of more H radical. This H radical promotes the chain branching and chain propagation in which increase the reaction zone length. From the results, it shows that combustion efficiency increases as the hydrogen content increases. It is known that, hydrogen has higher moisture content that might affect the turbine component if the moisture content has reached the moisture limitations [6]. There is a drop in the graph indicating the lowest combustion efficiency of 75.34% at 0.23 H_2/CO ratio. Most of the combustion efficiency range from 78.30% to 77.71%. There was around 2.37% difference in combustion efficiency, compared to the other H_2/CO ratio. This lower combustion efficiency resulted from the higher CO content in this H_2/CO ratio, which has 0.7 H_2 (% volume) and 3 CO (% volume). However, external factors [7] such as the remaining syngas inside the turbine from the preceding experiments and ambient temperature may affect the accuracy of this result as reflected in the 2.37% difference.

Figure 4 shows the emission of NO_x (ppm) emissions for each H_2/CO ratio. The graph shows that at 0.8 H_2/CO emitted the highest NO_x and 0.2 H_2/CO has the lowest NO_x emissions. A best-fit line shows that emissions of NO_x generally increase with H_2/CO ratio. From the data recorded, it shows that NO_x emissions have a direct relationship with the hydrogen content. NO_x emissions are from the nitrogen and oxygen thermal fixation in the inlet combustion air and form the chemically-bound nitrogen conversion in the fuel.Typically, the fuel that has higher combustion efficiency will emit the highest NO_x emissions as it has the highest flame temperature. As in this experiment, 0.8 H_2/CO which records the highest efficiency also emitted the highest NO_x emissions. This is because of higher hydrogen content which relates to higher equivalent ratio. Thus, increase in the flame temperature results in higher NO_x emissions. From literature, NO_x emissions are directly proportional to the H_2 content. As the H_2 content increases,the NO_x emissions become higher [8].

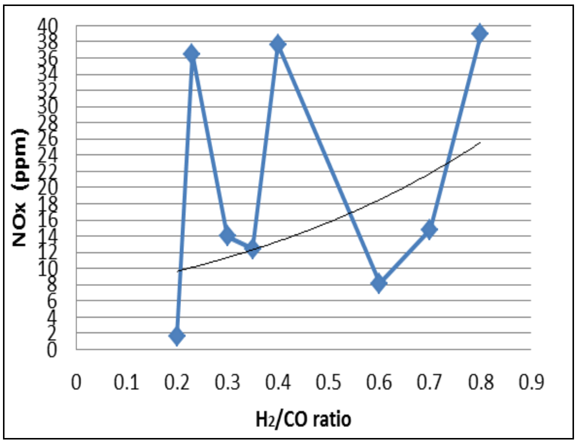

Figure 4. NO_x emissions versus H_2/CO ratio at 3 kW load for various syngas compositions.

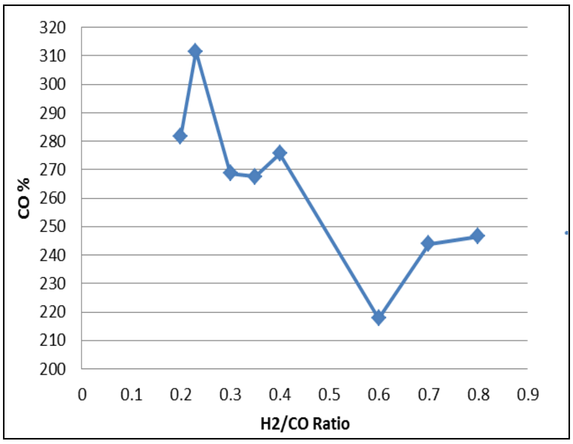

Figure 5. CO emissions versus H_2/CO ratio at 3 kW load for various syngas compositions.

Meanwhile, figure 5 shows the emissions of CO against the H_2/CO ratio. The graph shows at 0.23 H_2/CO ratio, emitted the highest CO, and at 0.6 H_2/CO emitted the lowest CO. Generally,the trend of the graph is inversely to the H_2/CO ratio. There is large dropped in CO emissions at 0.4 H_2/CO to 0.6 H_2/CO ratio. Then, the CO emissions increased at 0.7 H_2/CO onwards. CO emissions result from the incomplete hydrocarbon combustion or no combustion of CO in the fuel gas. Previous studies have proven that more CO is emitted with lower combustion efficiency and fuel with high CO content [9]. The results of this experiment also show that as the H_2/CO ratio decreases, the CO emissions increase. The smaller H_2/CO ratio indicates higher CO content. Previous studies by other researchers [10,11] also found that CO emissions result from a lower efficiency. This explains the result of this experiment at 0.23 H_2/CO, where it emitted the highest CO emissions of 311.58 ppm with the lowest combustion efficiency of 75.34 %.

4. Conclusion

In conclusion, among the eight syngas with different H_2/CO ratio, the syngas with higher hydrogen content gives out the highest combustion efficiency because it aided the combustion processes that resulted in higher laminar combustion. The syngas with higher hydrogen content also emitted more NO_x when released with high flame temperature. It is found that the NO_x emissions are maintained less than 50 ppm by using the MGT in IGCC pilot plant. These emissions are relatively low as compared to the conventional power plant gas turbine. Meanwhile, the syngas that has the lowest combustion efficiency emitted high CO emissions. CO emissions also have a direct relationship with the CO content in the syngas.

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