Effect of H₂ and CO contents in syngas during combustion using Micro Gas Turbine

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Abstract. Synthetic gas or syngas is produced from the gasification process. Its main compositions are hydrogen, H₂; carbon monoxide, CO; methane, CH₄; carbon dioxide, CO₂ and nitrogen, N₂. Syngas is a substitute for the depleting natural gas (80-90 % vol. CH₄). Natural gas is combusted in gas turbine in gas-fired power plant to produce electricity. However, combustion of syngas using gas turbine is expected to show different behavior compared to natural gas combustion. This is because of H₂ and CO contents in syngas have higher adiabatic flame temperature than CH₄. In this study, different quality of syngas with different contents of H₂ (0.6-0.8 % vol.) and CO (1-3 % vol.) were combusted using 30kW Micro Gas Turbine (MGT). Performances of different syngas quality were studied using NOₓ, CO, CO₂ emissions and combustion efficiency parameters. NOₓ and CO are the main pollutants from the combustion process. NOₓ emissions were the highest for syngas with H₂ contents of 0.8 % vol. and CO contents of 3 % vol. CO emissions were in the range of 220-310 ppm for all the tested syngas. While, CO₂ emissions were in the range of 0.96-1.06 % for all the tested syngas. Combustion efficiencies were reduced for syngas with CO contents of 1 % vol. and H₂ contents of 0.6-0.8 % vol. This is most probably due to the dilution effect of N₂ in syngas.

1.0 Introduction

The Integrated Gasification Combined Cycle (IGCC) produces electricity from a solid or liquid fuel. The fuel is first converted to syngas which is a mixture of hydrogen (H₂), carbon monoxide (CO) and methane (CH₄). The syngas is then converted to electricity in a combined cycle power block which consists of a gas turbine process and a steam turbine process with heat recovery steam generator (HRSG) (Figure 1).

The move towards the reduction of greenhouse gas emissions with the use of syngas as a fuel for the production of electricity is predicted to grow sharply in the near future as a result of:

- global warming and ocean surface acidification, which imply the need to control and reduce greenhouse gas emission,
- the low estimated reserves of oil, and
- rising cost as well as demand for natural gas and the need to reduce the dependence on fossil fuel imports from unstable areas.

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Syngas has lower heating value than natural gas. When applying low heating value syngas, instead of natural gas, as fuel for an industrial gas turbine engine, some gas turbine performance problems are likely to occur. In this project, syngas is going to be tested using Micro Gas Turbine (MGT), in order to study the combustion performance of the syngas.

2.0 Materials and Method

Simulated syngas with different \( \text{H}_2 \) and \( \text{CO} \) contents and fixed content of \( \text{CH}_4 \) (60\%.vol) were used as syngas sources (Table 1). Nitrogen, \( \text{N}_2 \) is the balance for all the syngas samples. Different types of syngas were combusted using Micro Gas Turbine (MGT) 30kWth at TNB Research Sdn Bhd, as shown in Figure 2 [1]. The highest contents of \( \text{H}_2 \) and \( \text{CO} \) in syngas that can be accepted for this type of MGT are 1 \%.vol and 5 \%.vol. Higher contents of \( \text{H}_2 \) and \( \text{CO} \) in syngas will contribute to longer flame length and is expected to damage the combustor [2]. Bench Top Gas Analyser, Siemen was used for measuring gas emissions (eg. \( \text{NO}_x \), \( \text{CO} \), \( \text{CO}_2 \)) during combustion tests, as shown in Figure 3.

Table 1. Syngas with different \( \text{H}_2 \) and \( \text{CO} \) contents

| \( \text{H}_2 \) (%.vol) (in syngas) | \( \text{CO} \) (%.vol) (in syngas) | \( \text{CO} \) (%.vol) (in syngas) | \( \text{CO} \) (%.vol) (in syngas) |
|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 0.6                           | 1                             | 2                             | 3                             |
| 0.7                           | 1                             | 2                             | 3                             |
| 0.8                           | 1                             | 2                             | 3                             |

Combustion performances of different syngas quality were evaluated using \( \text{NO}_x \), \( \text{CO} \), \( \text{CO}_2 \) emissions and combustion efficiency parameters [3]. Combustion efficiency was calculated using Equation 1, as below,

\[
\eta_c = 100\% - \frac{\text{Total Heat Losses} \times 100}{\text{Fuel Heating Value}} = \frac{\text{Total Heat Produced} \times 100}{\text{Fuel Heating Value}}
\]
3.0 Results and Discussion

Performance parameters of CO, NO\textsubscript{x}, CO\textsubscript{2} and combustion efficiency were studied against different contents of H\textsubscript{2} and CO in syngas. It was found that CO emissions from the combustion of syngas using MGT were slightly increased with the increasing of H\textsubscript{2} and CO contents in syngas (Figure 4). CO emissions were increasing as the adiabatic flame temperature increased due to the increasing of the H\textsubscript{2} and CO contents in syngas. High CO emissions also can be related to the incomplete combustion at lower flame temperature from the dilution effect of N\textsubscript{2} in syngas.

![Figure 2. Micro Gas Turbine, Capstone 30 kWth.](image)

![Figure 3. Bench Top Gas Analyser, Siemen.](image)

Table 2 shows that adiabatic flame temperature for H\textsubscript{2} and CO are higher than CH\textsubscript{4} [4]. This distinction contributes to low emissions from natural gas, which is mostly methane, compared to syngas containing H\textsubscript{2} and CO.

![Table 2. Comparison of adiabatic flame temperatures.](image)

Figure 5 shows that NO\textsubscript{x} emissions were the highest for H\textsubscript{2} contents of 0.8 \%vol. and CO contents of 1-3 \%vol. This data trending had shown that higher contents of H\textsubscript{2} in syngas had prominent contribution for higher NO\textsubscript{x} emissions compared to the increased of CO content in syngas. However, NO\textsubscript{x} emissions were maintained below 50 ppm with the Lean Premix Combustion (LPM) design of MGT [4]. High level of NO\textsubscript{x} emissions is contributing to the unhealthy levels of ozone in the air.
CO$_2$ emissions from the syngas combustion with different contents of H$_2$ and CO in syngas had shown steady increased (Figure 6). Especially for the syngas with CO content of 1% vol. and H$_2$ contents of 0.6-0.8% vol. However, overall CO$_2$ emission is only within the range of 0.9-1.06%.

Combustion efficiency for syngas with CO content of 1% vol were decreasing as H$_2$ contents in syngas were increased from 0.6% vol. to 0.8% vol. The highest combustion efficiency was at CO contents of 1% vol. and H$_2$ contents of 0.6% vol. The combustion efficiencies for other syngas were slightly changed (Figure 7). Again, the incomplete combustion due to the dilution effect of N$_2$ in syngas was expected to reduce the combustion efficiency. This finding is aligned with Sadig et al [5]. Overall, combustion efficiency with the presence of H$_2$ and CO in syngas is higher (>77%) than in 60% CH$_4$ (~65%) from previous study.

**Figure 4.** CO emissions from different contents of H$_2$ and CO in syngas.

**Figure 5.** NOx emissions from different contents of H$_2$ and CO in syngas.

**Figure 6.** CO$_2$ emissions from different contents of H$_2$ and CO in syngas.

**Figure 7.** Combustion efficiency from different contents of H$_2$ and CO in syngas.
4.0 Conclusions

H₂ and CO contents in syngas contributed to higher flame temperature in combustor. It was found that high emissions of CO and NOₓ occurred at higher H₂ and CO contents in syngas. However, combustion efficiency can be increased with the presence of H₂ and CO contents in syngas. Combustion efficiency is the highest at H₂ content of 0.6 % vol. and CO contents of 1 % vol. in syngas.

5.0 References

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