Problem and Countermeasure Analysis of IGCC Combustion Gas Turbine Fueled with Low Heating Value Syngas

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Abstract. IGCC technology is recognized as one of the cleanest and most efficient power generation technologies. Inferior fuel is gasified into clean syngas by IGCC gasification reaction. Syngas is then sent to combustion gas turbine and combusted to generate power. Problem and countermeasure of IGCC combustion gas turbine fueled with low heating value syngas is analyzed in this paper. Main fuel components and combustion characteristics of syngas are significantly different with that of conventional natural gas. Diffusion combustion mode is adopted to match syngas combustion characteristics. The gas turbine will trip due to unstable combustion if direct burning syngas at low load case. Alternative fuels should be used at low gas turbine load case. There is an appropriate load window for fuel switching. Fuel switching at 50% load within 10 minutes is selected in this paper.

1. Introduction
Integrated Gasification Combined Cycle (IGCC) power generation technology has been recognized as one of the cleanest and most efficient power generation technologies[1,2]. A world-scaled IGCC power plant is currently being developed along with a large refinery in Saudi Arabia, and the primary feedstock to the IGCC power plant is vacuum residue produced by the refinery. The whole plant can be divided into six main process modules, which are Gasifier Unit, Acid Gas Removal Unit, Hydrogen Recovery Unit, Sulphur Recovery Unit, Air Separation Unit and Power Generation Unit.

![Figure 1. Overall process flow diagram of IGCC power plant.](image-url)
Illustrated from the overall process flow diagram, shown in Figure 1, that the vacuum residue is converted into clean syngas, then sent to combustion gas turbine and combusted to generate power. Conventionally, combustion gas turbine is designed to use natural gas as major fuel. However, the main components of syngas are significantly different from those of natural gas. Problem and countermeasure of combustion gas turbine fueled with syngas is analyzed in this paper, and it is expected to provide reference for other related works and projects.

2. Fuel Composition and Characteristic

2.1. Fuel Composition

The main component of natural gas is methane, with a volume fraction of about 96%. It is generally used as fuel for gas turbines. Instead of nature gas, syngas is used for the gas turbine in this IGCC power plant. Composition of syngas is listed in Table 1.

| Description | Units | Value |
|-------------|-------|-------|
| Ar          | Mole %| 0.1   |
| CH₄         | Mole %| 0.32  |
| CO          | Mole %| 52.45 |
| CO₂         | Mole %| 3.34  |
| H₂          | Mole %| 43.36 |
| H₂O         | Mole %| 0.30  |
| N₂          | Mole %| 0.12  |
| Sulfur      | ppmv  | 10    |

As demonstrated in Table 1, the main components of syngas are carbon monoxide and hydrogen, which accounts for 52.45% and 43.36%, respectively, that add up to 95.81% of the total composition of syngas, which is distinctly different from the composition of natural gas (methane accounts for about 96%).

2.2. Fuel Characteristic

Combustion characteristics of carbon monoxide, hydrogen and methane are listed in Table 2[3].

| Gas  | Lower Heating Value (kJ/m³) | Density (kg/m³) | Ignition Temperature (°C) | Explosive concentration (%) |
|------|----------------------------|-----------------|---------------------------|----------------------------|
| CO   | 12630                      | 1.250           | 610~658                   | 12.5~77                    |
| H₂   | 10790                      | 0.0899          | 510~590                   | 4~74                       |
| CH₄  | 35740                      | 0.715           | 530~750                   | 5~16                       |

It is obvious that the Lower Heating Value (LHV) of carbon monoxide and hydrogen are much lower than that of methane. The LHV of methane is about three times of that of carbon monoxide and hydrogen. In addition, explosive concentration range of carbon monoxide and hydrogen are much higher than that of methane.

Even though, the composition of natural gases produced by different gas fields vary in practical application, their main component are all methane, LHV of natural gas is temporarily replaced by that of methane herein. In other words, it is assumed that natural gas is pure methane in this project. LHV of methane per unit mass is 50041 kJ/kg. Compared with the LHV of syngas (shown in Table 1) produced in this IGCC power plant, it can be found that the value of the former is about 3.37 times higher than that of the latter.

The combustion flame propagating velocity of carbon monoxide, hydrogen and methane at different temperatures (at air coefficient 1.05 case) is shown in Figure 2[3]. Under the same combustion conditions, the flame propagation velocity of carbon monoxide and hydrogen is much higher than that of methane.
3. Problem and Countermeasure

The difference of flame propagating velocity will lead to a high risk of flashback when burning syngas. Therefore, the premixed combustion mode of natural gas is not suitable for syngas. Burners of conventional gas turbine need to be modified and the combustion mode is changed to diffusion combustion mode accordingly[4]. Also, as the flame temperature can reach to over 2200°C under diffusion combustion mode, which will result in the generation of a large amount of thermal NOx, injecting inert gas, steam or nitrogen e.g., becomes an effective way to control the combustion temperature[5,6].

The LHV of syngas is only 14853kJ/kg, which is much lower than that of natural gas. The gas turbine will trip due to unstable combustion if direct burning syngas at low load, which means burning syngas is not possible in IGCC power plant at low load. In order to operate at low load condition, other alternative fuels with high LHV, such as natural gas or oil, e.g., should be used. Except for utilizing vacuum residue to generate fuel gas as mentioned above, another product from refinery, Ultra-Low Sulfur Diesel is selected as an alternative for low load operation of IGCC power plant, which is considered as a convenient fuel source provided to IGCC power plant during future operation. The LHV of product diesel is 42613kJ/kg and it is much higher than that of syngas.

There are two stages when gas turbine runs at low load case, one is start-up stage, the other is shutdown stage. Fuel needs to be switched during both two stages. During start-up stage, the gas turbine is ignited using diesel. When the gas turbine is further loaded to certain value, the fuel shall be switched from diesel to syngas. After the fuel transition, the gas turbine load is further loaded to the target level. As for shutdown stage, when the gas turbine is unloaded to certain value, the fuel shall be switched from syngas to diesel. Then the gas turbine load continues to unloaded until the gas turbine is off.

There is an appropriate load window for fuel switching. Gas turbine can maintain stable operation only in the switching window. It means that fuel transition can not proceed if the load is lower than a certain lower limit value or higher than a certain upper limit value. The lower limit should not be lower than the minimum running load when burning syngas. Otherwise, it is easy to cause combustion instability, resulting in combustion oscillation, combustion chamber vibration, excessive humming, tripping and even parts damage in combustion chamber[7,8]. The upper limit should not be higher than the maximum running load of syngas operation. Since the LHV of diesel is much higher than that of syngas, fuel switching with high load of gas turbine will bring large fluctuation of fuel flow into combustion chamber, resulting in overload and overtemperature.

Being analyzed and tested, the appropriate load window for fuel switching is about 31%~52% of gas turbine rated load in this project. With further optimization, fuel switching load is selected at 50% stage, while it is written into gas turbine automatic control system. During the start-up and shutdown stage, the fuel switching is carried out according to the established sequence control program, and the whole switching is completed within 10 minutes. Start-up and shutdown curves of gas turbine is shown in Figure 3 and 4.
4. Conclusion
The main components of IGCC syngas are carbon monoxide and hydrogen, which account for 95.81% of the total composition of syngas. Conventionally, combustion gas turbine is designed to use natural gas as major fuel. The main components of natural gas is methane. The difference in fuel composition results in completely different combustion characteristics between syngas and natural gas. Compared with conventional natural gas, syngas has much faster flame propagation velocity but lower heating value. The gas turbine will trip due to unstable combustion if direct burning syngas at low load case. Alternative fuels with high heating value should be used at low load case. There is an appropriate load window for fuel switching. The selected fuel switching load in this IGCC project is 50% and the fuel switching process should be completed within 10 minutes.

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