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Relations among Main Operating Parameters of Gasifier in IGCC

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ABSTRACT

Gasification unit is one of the key subsystems in the IGCC power system; the operating parameters of gasifier directly affect syngas quality and performance of whole IGCC system. The system model of gasification unit with coal water slurry gasifier was simulated and calculated using THERMOFLEX software, and the relations of oxygen coal ratio (R_{oc}), water coal ratio (R_{sc}), gasification pressure, gasification temperature and cold gas efficiency were mostly researched. The results show that R_{oc} and R_{sc} have effect of mutual restriction on gasification temperature, cold gas efficiency and syngas composition. Gasification pressure mainly determines the capacity of the gasifier, little effects on syngas composition.

Keywords: Integrated Gasification Combined Cycle (IGCC); Gasifier; Oxygen Coal Ratio; Water Coal Ratio; Cold Gas Efficiency

1. Introduction

The gasifier is the core of gasification unit and the source of the IGCC system, gasification performance directly affects the chemical energy of syngas and cold gas efficiency, relevant to the economic operation of the whole IGCC system. However, the gasification performance mainly depends on the gasification parameters, such as oxygen coal ratio, water coal ratio, gasification pressure, gasification temperature, which is mutual influence and restrict on each other. How to configure operating parameters reasonably is the key to achieve efficient operation of the gasifier. So the research on gasification effect of operation parameters on gasification performance has important significance.

Domestic and foreign scholars have done a lot of research on gasification mechanism and models, such as JIAO Shujian [1] gave the introduction to the key technology of some IGCC, and the direction of development of IGCC system are analyzed and discussed. Li Zheng [2] established a mathematical model to predict the performance of Texaco coal gasifier, and analyzed in detail the influence of the effect of the main operating parameters on the performance of gasification furnace by the model. Wu Xuecheng [3] has established a flow gasification kinetics model, predicting and studying the influence of various gasification methods on the performance of gas bed. G.S Liu [4] established the entrained-flow gasifier model, researching the influence of coal particle size on syngas from the point of reaction kinetics. NI Qizhi [5] put forward a new simulation method of entrained-flow gasifier, analyzing the effect of O/C ratio, temperature and pressure on the gasification components and cold gas efficiency. Y.C Choi [6] studied the gasification characteristics of entrained-flow gasifier.

On the basis of the above researches, in order to seek the optimal parameters configuration mode, a gasification system model was established, the relations among mainly operating parameters and the effect on gasification performance were analyzed. The result can help to find the optimal operation conditions, to provide references for the design and operation of IGCC power plant.

2. Model and Parameters

2.1. System Model

Gasification unit comprises a gasifier, radiation syngas cooler (RSC), convection syngas cooler (CSC), air separation unit (ASU) and etc, as in **Figure 1**. Gasifier is adopted with slurry gasification and slag-tap mode. Firstly, coal water slurry and oxygen from ASU are fed into gasifier to produce raw syngas, high temperature raw syngas is cooled by RSC and CSC, and then enters syngas purification unit.

The gasifier is the use of pure oxygen gasification of coal water slurry, the composition of coal is shown as in

Table 1. The pressure losses caused by the flow of syngas, steam and water are assumed equal through any equipment in gasification unit. The main operating parameters in designed condition are shown in **Table 2**.

2.2. Operating Parameters

In coal water slurry gasification process, oxygen carbon ratio is a very important index, which usually refers to oxygen carbon molar ratio (ε), and in engineering applications, it can also refer to the ratio of the oxygen consumption and pulverized coal (R_{oc}) in gasifier, as shown in equation 1 and 2.

$$B_o = B_c \times C_{ar} \times 16/12 - B_c \times O_{ar} \quad (1)$$

$$R_{oc} = B_o / B_c = 4/3 \times C_{ar} \times \varepsilon \times O_{ar} \quad (2)$$

where R_{oc} denotes oxygen coal ratio in g/g, B_o and B_c respectively denote consumption of oxygen and pulverized coal, C_{ar} and O_{ar} mean carbon and oxygen elemental mass percentage of coal, ε denotes oxygen and carbon atom ratio.

Water coal ratio (R_{sc}) refers to feed water and pulverized coal mass ratio, which directly affects the flow characteristics, combustion characteristics and calorific value of coal water slurry, as shown in equation 3 and 4.

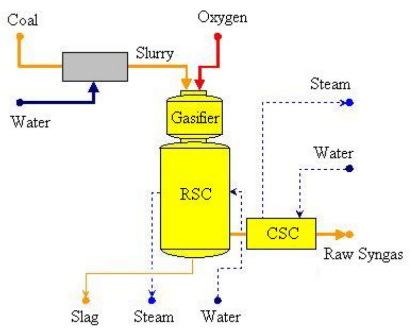

Figure 1. Gasification unit.

Table 1. Proximate and ultimate analysis of coal.

Ultimate analysis of coal /%			Mar(%)	$q_{net,coal}$ (kJ·kg^{-1})
C	H	O		
57.81	3.62	9.29	17.3	21740

Table 2. the main parameters of gansifier.

parameters	data	parameters	data
Gasifier capacity (t/d)	2 000	Oxygen coal ratio (g/g)	0.756
Gasification pressure (MPa)	3.6	Water coal ratio (g/g)	0.386
Gasification temperature(K)	1584	Carbon conversion efficiency(%)	98

$$B_w = B_c \times (1 - M_{ar}) / C_s - B_c - B_a \quad (3)$$

$$R_{sc} = B_w / B_c = (1 - M_{ar}) / C_s - 1 - \phi \quad (4)$$

where R_{sc} denotes water coal ratio in g/g, B_w, B_a respectively denote consumption of water and additive for coal water slurry, C_s denotes the concentration of coal water slurry, M_{ar} is water mass percentage of pulverized coal, Φ denotes the proportion of additive in coal water slurry (0.5%-1.5%).

Cold gas efficiency is another important index to measure the gasifier operating performance, which denotes the ratio of the chemical energy of syngas by gasification to the chemical energy of coal for gasification, as in equation 5.

$$\eta_c = (q_{H_2} + q_{CO} + q_{CH_4}) / q_{net,,coal} \quad (5)$$

The chemical energy of syngas (q_{H_2}, q_{CO} and q_{CH_4}) and coal ($q_{net,\,coal}$)are both corresponding net calorific value. Obviously to improve the cold gas efficiency of gasifier can promote transforming the chemical energy from storage in coal to syngas, improving the whole performance of IGCC.

Pressurized gasification can improve the gasification capacity effectively, and bring obvious economic benefits for transmission, distribution and subsequent chemical processing. But if the pressure is too high, the gas into the combustion engine should be reduced pressure firstly, thus leading to the waste of energy.

3. Results and Discussion

3.1. Oxygen Coal Ratio (Roc)

Figure 2 shows the effect of oxygen carbon ratio on the syngas components. With the increase of R_{oc}, the content of CO first increases and then decreases. When the R_{oc} is 0.75, the maximum mounts to 37.1%. The content of H_2 is similar to CO, the maximum of H_2 amounts to 30.43% when R_{oc} is 0.64. The content of CH_4 decreases sharply from 4.9%, and when R_{oc} is greater than 0.71, it reduces slowly, until close to 0. With the increase of R_{oc}, the content of H_2O increases, and the trend of CO_2 content is opposite to CO. The content of the effective gas composition ($CO+H_2$) firstly increases and then decreases and at R_{oc} of 0.66, the maximum reaches 66.43%.

Figure 3 shows the effect of R_{oc} on gasification temperature and cold gas efficiency. With the increase of R_{oc}, gasification temperature rises, while cold gas efficiency reduces.

Because of oxygen coal ratio increase, the oxygen content increases relatively, it is good for the combustion reaction of C and H to release much heat, which is the main cause of the rise of gasification temperature. Especially in the range of 0.67 to 0.85, R_{oc} is approximately linearly related to the gasification temperature, and gasification temperature increases about 352K when R_{oc} 0.1 per growth. Therefore, we can regulate the gasification temperature accurately and effectively by controlling R_{oc} value in the actual operation.

Based on the chemical kinetics theory, the combustion heat release of CO is basic equal to H_2 under the same pressure and volume, while the heat release of CH_4 is 3 times as much as CO. In the process of the increase of $CO+H_2$ content to maximum value, CO+ H_2 content increases from 59.78% to 66.43%, while CH_4 decreases from 4.9% to 0.77%. Therefore, the chemical energy of syngas is reduced totally, which leads to the decrease of cold gas efficiency.

3.2. Water Coal Ratio (Rsc)

It is two situations to change water coal ratio, one assumes oxygen coal ratio is unchanged and the other assumes gasification temperature is constant. But the second is difficult to be implemented when practically operation. **Figure 4** gives the effect of R_{sc} on the components of syngas under the condition of R_{oc} is 0.75. When R_{sc} increases from 0.27 to 0.57, only the content of CO decreases, while the other main components increase. The content of CO decreases from 45.76% to 34.63%, H_2 increases from 23.97% to 25.49%, CH_4 from 0.0006% to 0.0107%, CO_2 from 9.512% to 13.06% and H_2O from 20.01% to 26.16%. **Figure 5** shows the effect of R_{sc} on gasification and cold gas efficiency. When R_{sc} increases from 0.27 to 0.57, the efficiency of cold gas decreases from 73.9% to 72.98%, , and the gasification temperature decreases from 1518K to 1838K.

The above reasons can be analyzed from the following aspects. With the increase of R_{sc}, the amount of steam also increases, while the amount of pulverized coal and oxygen relatively decreases, leading to weaken combustion reaction in the gasifier. At the same time, a large amount of heat is carried by steam, all these lead to gasification temperature decrease.

It is generally believed that methanogenesis (6) occurred in pressure and temperature lower than 1423K, and that reforming reaction of methane-steam (7) is a reversible and endothermic reaction. Therefore, with the increase of R_{sc}, gasification temperature decreases, leading to the increase of methane content.

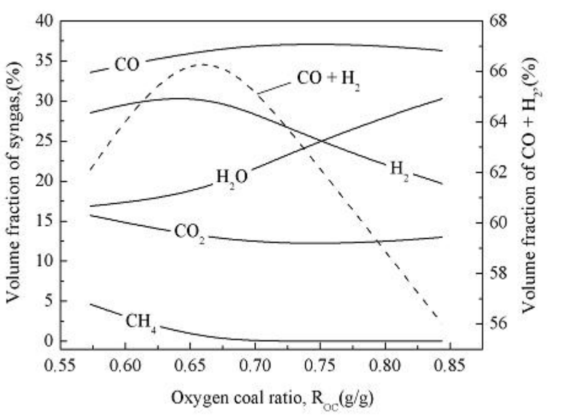

Figure 2. Effect of oxygen coal ratio on syngas components.

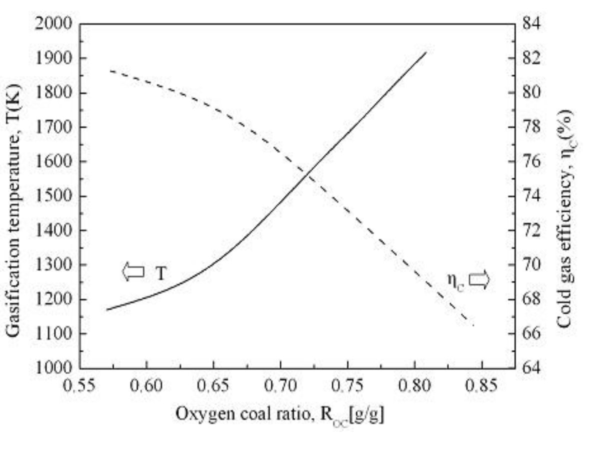

Figure 3. Effect of oxygen coal ratio on gasification temperature and efficiency.

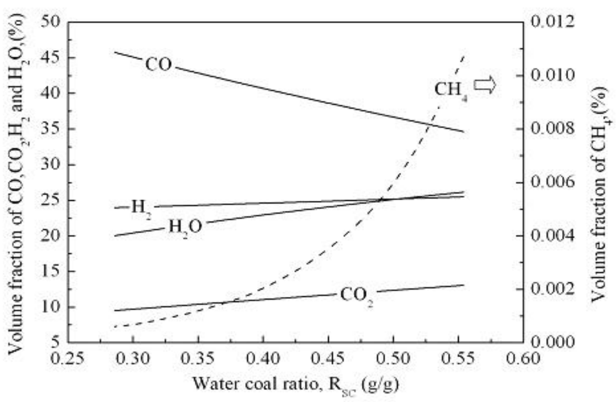

Figure 4. Effect of water coal ratio on syngas components.

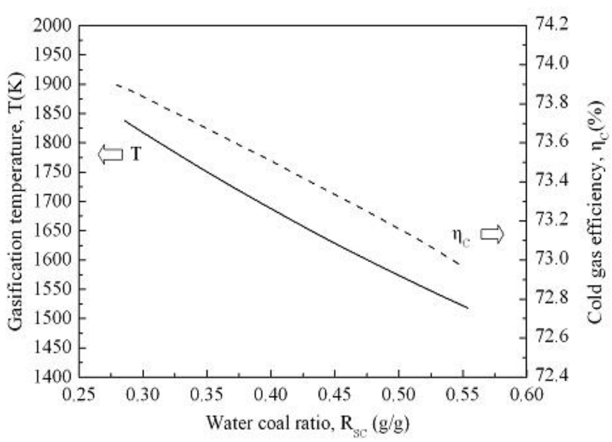

Figure 5. Effect of water coal ratio on gasification temperature and efficiency.

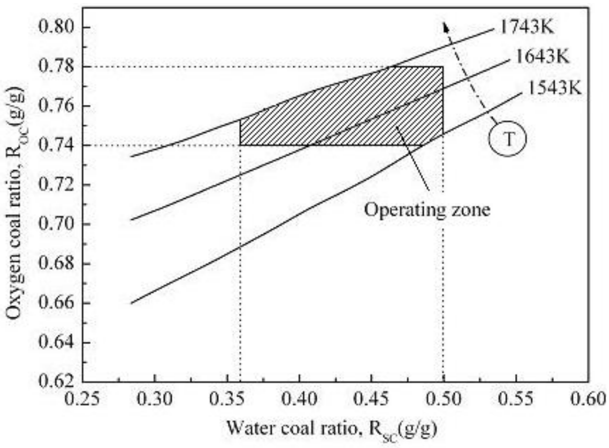

Figure 6. Double effects of water coal ratio and oxygen coal ratio on gasification temperature.

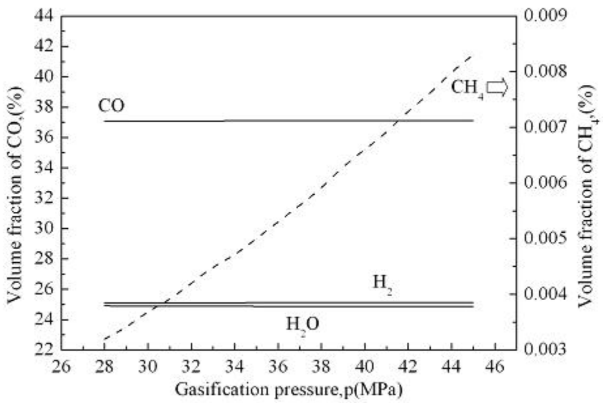

Figure 7. Effect of gasification pressure on syngas components.

$$C+2H_2 \rightarrow CH_4+74.9MJ.(kmol)^{-1} \quad (6)$$

$$CH_4+H_2O \leftrightarrow CO+3H_2-319.3MJ.(kmol)^{-1} \quad (7)$$

The decrease of gasification temperature prevents the reduction reaction (8) of CO_2, at the same time leads to the equilibrium point of CO conversion reaction (9) moves right, eventually lead to the decrease of CO content and the increase of CO_2 content.

$$C+CO_2 \rightarrow 2CO-162.4MJ.(kmol)^{-1} \quad (8)$$

$$CO+H_2O \leftrightarrow CO_2+H_2+41.2MJ.(kmol)^{-1} \quad (9)$$

On one hand, with the decrease of gasification temperature, water-gas reaction (10) weakens, methanogenesis (6) strengthens and the equilibrium point of methane-steam reforming reaction (7) moves left, all these lead to the decrease of H_2 content. On the other hand, as water content increases, water-gas reaction (10) strengthens, the equilibrium point of CO reforming reaction (9) moves right, leading to the increase of H_2 content. The combined effects of the two aspects result in H_2 content increasing slightly.

$$C+H_2O \leftrightarrow CO+H_2-131.5MJ.(kmol)^{-1} \quad (10)$$

Figure 6 shows the matching relationships between R_{oc}, R_{sc} and gasification temperature. We can see that there are double effects of R_{oc} and R_{sc} on gasification temperature. When Increasing the value of R_{oc}, gasification temperature become higher, while increasing the value of R_{sc}, gasification temperature become lower.

Generally, as far as possible to reduce R_{sc} can improve the gasification performance, at the same time, it can also be affected the flow and combustion characteristics of coal water slurry. The selection of gasification temperature depends on the characteristics of coal and the requirements of syngas. Gasification temperature is generally higher than the ash melting point 30~50 K.

According to the specific coal and IGCC system, shadow in **Figure 7** indicates the region of the optimum operating points, which R_{oc} is from 0.74 to 0.78, oxygen carbon molar ratio corresponding is 0.96 to 1.01, R_{sc} is from 0.36 to 0.5, the concentration of coal water slurry corresponding is 60% to 66%, gasification temperature is from 1543K to 1743K.

3.3. Gasification Pressure

Figure 7 shows the effect of gasification pressure on syngas components. We can see that the volume fraction of syngas has little change under different gasification pressures. The content of CO increased slightly from 37.08% to 37.12%, H_2 content increased from 25.10% to 25.14%, H_2O content decreased from 24.91% to 24.86% and CH_4 content increases slightly from 0.003% to 0.008%.

4. Conclusions

Oxygen coal ratio, water coal ratio and gasification pressure are initial operating parameters of coal gasification. With the increase of oxygen coal ratio, gasification temperature increases, while cold coal efficiency decreases. With the increase of water coal ratio, gasification temperature and cold coal efficiency both decrease. Influence of gasification pressure is mainly reflected the overall effect in the gasifier, under the high temperature conditions, pressure has little effect on syngas components. All these can provide the reference for low energy consumption, high performance gasification operation in IGCC system.

REFERENCES

[1] S. J. Jiao, "Development and Prospect of Some Key Technologies of IGCC," *Power engineering*, Vol. 26, No. 2, 2006, pp. 153-165.

[2] Z. Li, T. J. Wang and Z. M. Han, "Study of Mathematical Model for Texaco Gasifier ——Calculation and Analy-

sis," *Power engineering*, Vol. 21, No. 4, 2001, pp. 1316-1319.

[3] X. C. Wu, Q. H. Wang and Z. Y. Luo, "Kinetic Model Prediction for Various Coal Gasification Schemes in a Fluidized Bed II. Model Prediction and Analysis," *Journal of Fuel Chemistry and Technology*, Vol. 32, No. 3, 2004, pp. 292-296.

[4] G. S Liu, H. R Rezaei, J. A Lucas, *et al,* "Modelling of a Pressurized Entrained Flow Coal Gasifier: the Effect of Reaction Kinetics and Char Structure," *Fuel*, Vol. 79, No. 14, 2000, pp. 1767-1779. doi:10.1016/S0016-2361(00)00037-5

[5] N. Qizhi and W. Alan. "Simulation Study on the Performance of an Entrained-flow Coal Gasifier," *Fuel*, Vol. 74, No.1, 1995, pp. 102-110. doi:10.1016/0016-2361(94)P4339-4

[6] Y. C. Choi, X. Y. Li and T. J. Park "Numerical Study on the Coal Gasification Characteristics in an Entrained Flow Coal Gasifier," *Fuel*, Vol. 80, No.15, 2001, pp. 2193-2201. doi:10.1016/S0016-2361(01)00101-6