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Thermal and environmental performance of IGCC system with wood dust as feed

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ABSTRACT

increasingenvironmental problem have raised interest in energy saving and renewable energy development.As the most potential renewable energy resource, biomass energy is not only rich and abundant, but also available and clean. Biomass gasification technology is good at the adaptability of raw material and quiet mature in China, which is applied for the power generation industry. This paper investigates the operation of IGCC plants with wood dust as feed. The investigated plant designs gas - steam combined cycle with biomass gasification technology, leading to different energy vectors(power, heat etc). Gasification of wood coupled with gas - steam combined cycle will pave the way towards zero emissions power plants. The energy conversions investigated in the paper were simulated using Aspen Plus in order to produce rigorous material and energy balances nessary for the proposed evaluation. As illustrative cases, the thermal and environment performance under different gasification parameter, were presented. The case studies investigated in the paper produce a up to the total energy efficiency of 75% and CO_2 emissions of 0.68Kg/KW • h. Special emphasis were given to optimalization of gasification process, to select the parameter for gasification reactor, analysis the thermal performance of the energy conversion process and etc.

Key words: wood dust,integrated gasification combined cycle,energy efficiency

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INTRODUCTION

The IGCC (Integrated Gasification Combined Cycle) system with wood dust as feed is an advanced power system developed by combining gasification technology and gas-steam combined cycle. IGCC has the advantages of high efficiency, low pollution, and the ability to integrate with other chemical processes. As a result, great attention has been paid to IGCC in recent years [1-2]. Many domestic and overseas scholars have done much exploratory research on the thermal performance and environmental benefits of the coal-based IGCC system. For example, ZhiqiangDuan et al. [3] studied on the comprehensive evaluation standards for the performance of the IGCC system and came up with an evaluation method based on the comprehensive pollution index of energy efficiency. Zachary Hoffman et al. [4-5] researched on the thermal-economic benefits and return on investment of the IGCC system. Meanwhile, in order to reduce greenhouse gas emissions, various technologies of the IGCC system for CO_2 capture and storage were presented successively, so as to explore new approaches and methods for the IGCC system to realize zero release of CO_2[6-7]. However, fundamental research on the IGCC system of biomass fuels is still insufficient. Biomass is a clean renewable energy source with the characteristics of large resource quantity, wide distribution, low price, and ease of material drawing. The "China's National Climate Change Program" enacted by the National Development and Reform Commission in 2007 confirmed that greenhouse gas emissions would reduce by 30 million tons of CO_2 equivalence annually through developing biomass fuels after 2010 [8]. Moreover, the chemical molecular constitution and energy utilization pattern of biomass fuels are quite similar to those of fossil fuels. Therefore, biomass fuels could replace regular fuels without significantly improving existing industrial technologies. In this case, this paper analyzed the gasification process and its characteristics in all operating states of the IGCC system with wood dust as feed by using Aspen Plus, and illustrated the relationship between the gasification process of wood dust and the overall performance of the IGCC system. The research achievements are of important practical significance for the energy industrial restructuring in China.

IGCC SYSTEM MODEL

PHYSICAL MODEL

The IGCC (Integrated Gasification Combined Cycle) system with wood dust as feed mainly consisted of gasification unit, treatment and condition unit, combined cycle unit, and heat recovery stream generator(HRSG), as shown in Figure 1. The main process was that proportional biomass was added from the top of the gasification furnace, gasifying agent (air) was added through the oxidation layer in the middle of the gasification furnace, then the biomass went through the top-down gasification process, including moisture removing, thermal decomposition of volatiles, incomplete combustion of volatiles and carbon, and secondary decomposition of macromolecule volatiles; the high-temperature combustion gas generated from biomass gasification exchanged heat with the air pre-heater and low pressure reheaterof the combustion gas turbine and HRSG, in order to lower the temperature and remove the dust. The acid gas from cooling syngas went through NH_3 removal, desulfurization, and other decontamination devices, mixed with the outside air pressurized by compressors, then entered the combustion gas turbine together for combustion. Outside air needed to go through three extraction processes before entering the combustor, and the extracted air was used for cooling the gas turbine. Afterwards, the exhaust gas emitted from the combined cycle unit exchanged heat with condensate water in the HRSE, so as to recover the waste heat from exhaust gas. After heat exchange condensate water with high, medium, and low pressure evaporated through the economizer, evaporator, and superheater, and finally entered the steam turbine for electricity generation.

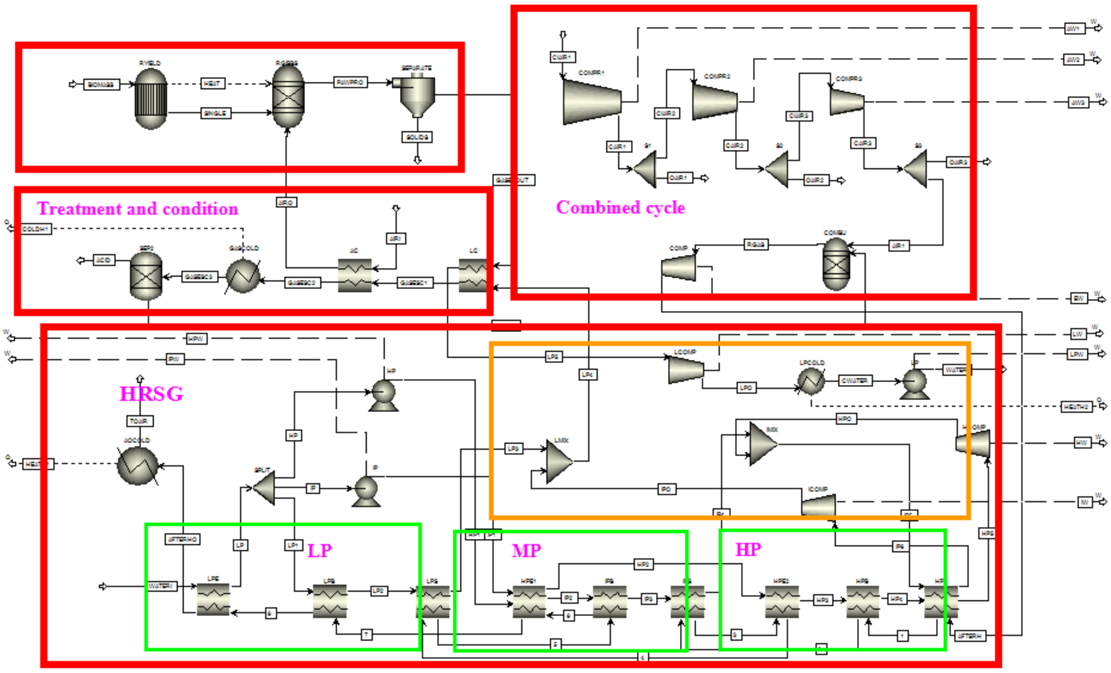


Fig. 1 a schematic of the IGCC system

The IGCC system with wood dust as feed used the GE9FA combustion gas turbine as the prime mover. The design parameters of the turbine in combined cycle were listed in Table 1 [9].

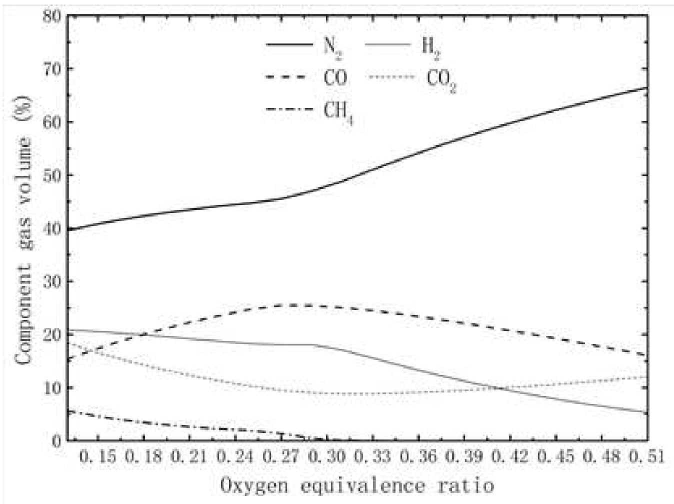
Table 1 operation parameters for gas turbine

Inlet temperature for combustion chamber(□)	340
Air flow for combustion chamber（kg/s）	602
Inlet temperature for turbine(□)	1175
Pressure ratio for turbine	14.285
Exhaust gas temperature(□)	557
Pressure ratio for compressor 1	9.7
Pressure ratio for compressor 2	1.46
Pressure ratio for compressor 1	1.06
Exhaust volume of aspirator1（kg/s）	25.63
Exhaust volume of aspirator2（kg/s）	19.69
Exhaust volume of aspirator3（kg/s）	17.12
Exhaust temperature of aspirator 1（℃）	307
Exhaust temperature of aspirator 2（℃）	379
Exhaust temperature of aspirator 3（℃）	382

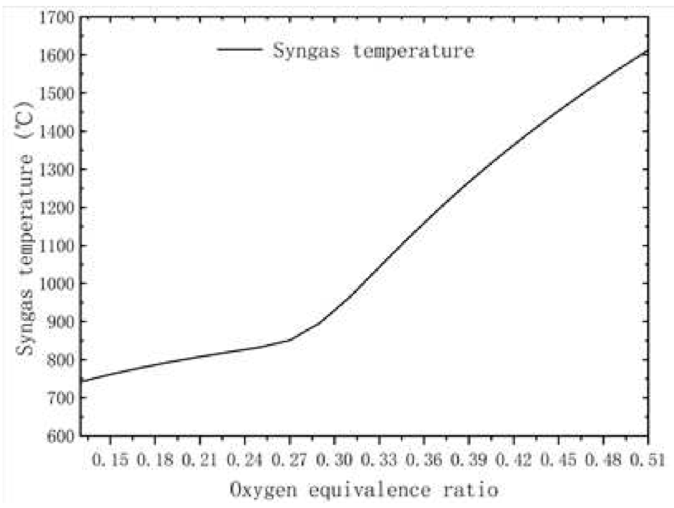
RESULTS AND DISCUSSION

Compared with regular IGCC systems, the IGCC system with wood dust as feed combined the gasification of biomass. As a result, the gasification unit was the core equipment of the system, influencing on the load and output of the combined cycle and followed HRSG. In terms of a certain gasification process, four indicators, namely gas yield, heat value, gasification efficiency, and carbon conversion ratio, were normally considered [10-12].

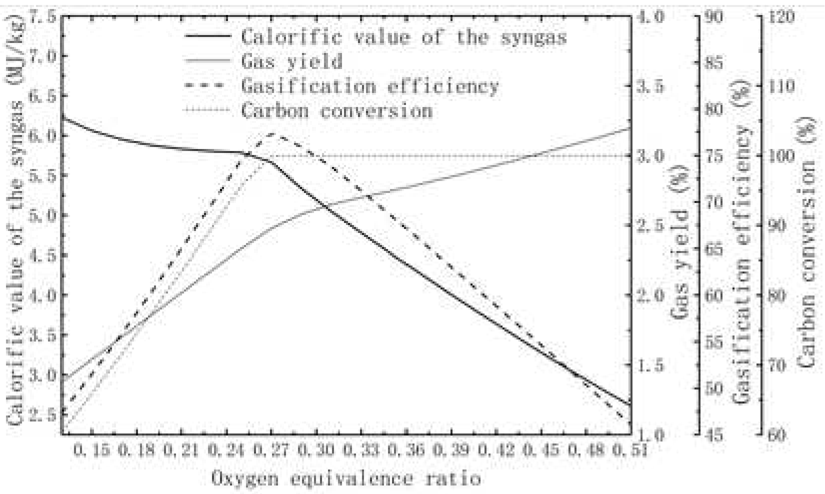
THE THERMAL PERFORMANCE OF GASIFICATION PROCESS



(a)componentgas fraction



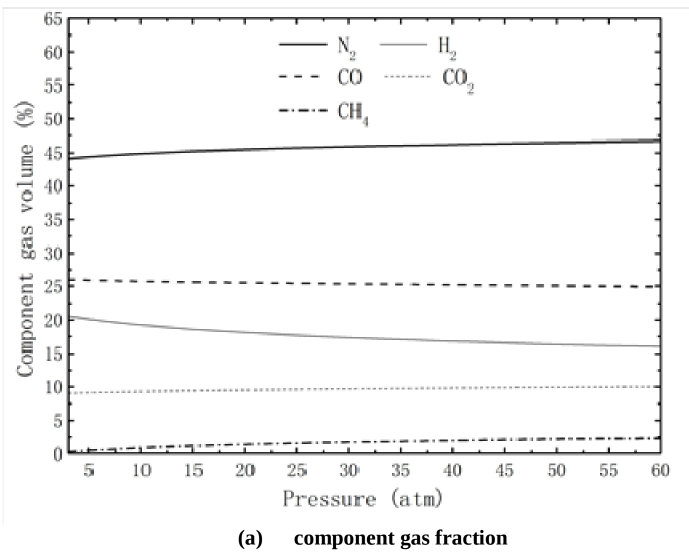
(b)the syngas temperature



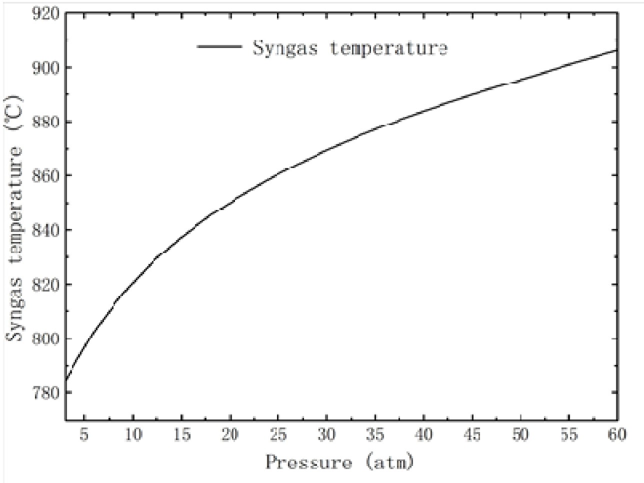
(c)gasification efficiency

Fig. 2 the relationship between oxygen equivalent ratio and the gasification process

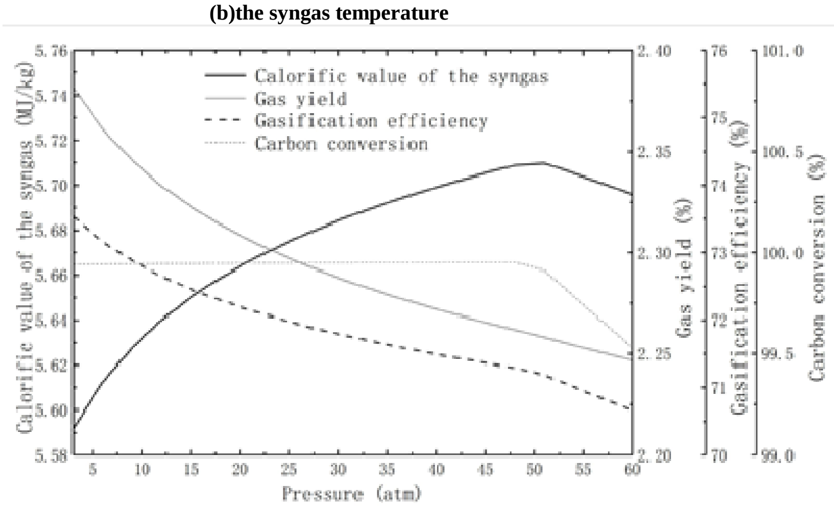
Material properties and operating conditions are the main factors affecting the biomass gasification process. Operating conditions including the reaction temperature, reaction pressure and oxygen equivalent ratio.Figure2 showed the relationshipbetweengasification processand oxygen equivalent ratio. In figure 2 (a), with the increasing oxygen equivalent ratio, the volume percentage of CO_2 decreased first and then increased. When the oxygen equivalent ratio was at 0.35, the volume percentage of CO_2 reached the minimum value, which was 9.27%. In contrast, the oxygen equivalent ratio was at 0.29, the volume percentage of CO reached the maximum value, which was 25.23%. The volume percentage of CH_4 gradually decreased, when the oxygen equivalent ratio was at 0.13, the volume percentage of CH_4 was only 3.02%. In figure 2(c), the gas yield and carbon conversion ratio showed a tendency of increasing while oxygen equivalent ratio is between 0.15-0.51. When the oxygen equivalent ratio was at 0.27, the gasification efficiency of wood dust reached its maximum value, which was 77.45%. At the same time, the heat value of syngas would reduce sharply with the increasing oxygen equivalent ratio, especially when the oxygen equivalent ratio was above 0.27. The temperature of the reactors was restricted to about 900 ℃due tolimitation ondurability and the added cost of higher temperature materials.It could be concluded thatthe oxygen equivalent ratio should be 0.15~0.31from Figure 2 (b). Lv PM's and Lu Pengmei's experiment provides H_2、CO、CO_2、CH_4 yield that used pine as its feed[13-14]. The volume percentage of H_2 in the referring mentioned aboveis28.93%，whilethe simulation result on modeling the gasification of biomass is 32.26%. It must be highlights the error of CO、CO_2、CH_4 volume percentage is more litter. Therefore, the simulation result is credit.



(a) component gas fraction



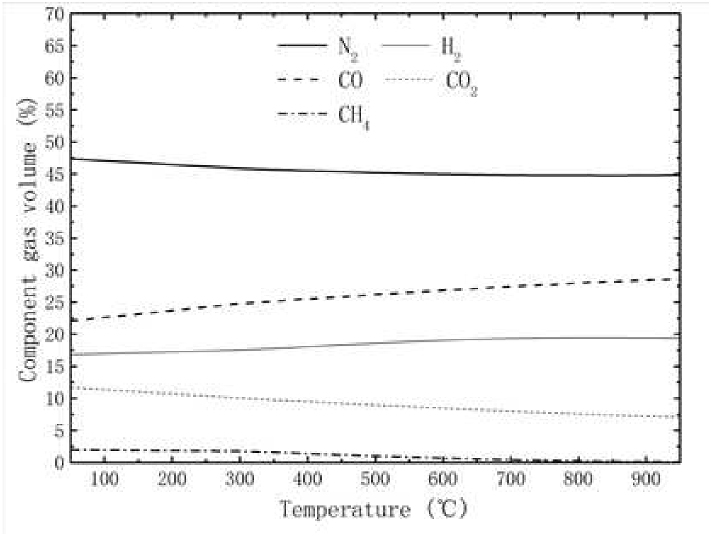
(b)the syngas temperature



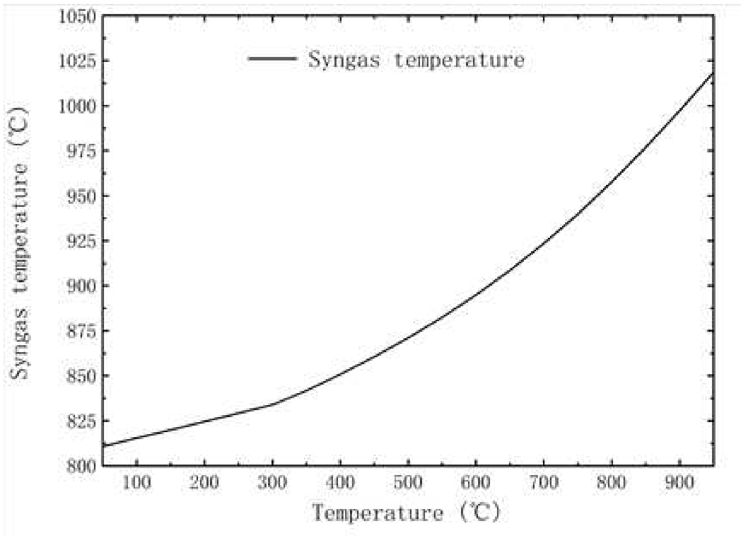
(c)gasification efficiency

Fig. 3 the relationship betweenreaction pressureand the gasification process

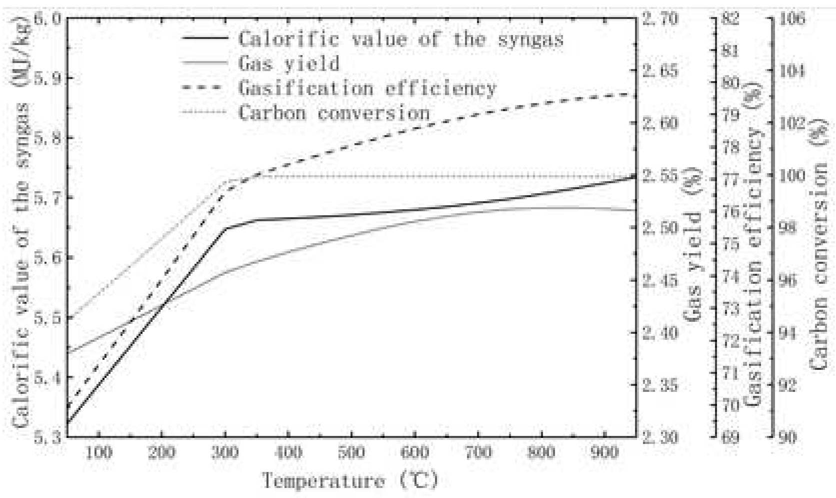
Figure 3 showed that the relationshipbetweengasification processand reaction pressure. The volume percentage of N_2 increased from 44.44% to 46.76%, the volume percentage of CO_2 increased from 9.02% to 10.02%, and the volume percentage of CH_4 increased from 0.25% to 2.13%. However, the volume percentage of H_2 and CO decreased. In figure 3 (b), when reaction pressure changed within 3~60 atm ,the syngas temperature went up from 784.53□ to 906.19□. It could be concluded that the effect of pressure on the gasification process was relatively small. In figure 3 (c), with the increasing reaction pressure, gas yield, gasification efficiency, and carbon conversion ratio all decreased, while the heat value of gases increased first and then decreased. The main reason was that increasing pressure led the reactions $C+CO_2 \rightarrow 2CO$ and $C+H_2O \rightarrow CO+H_2$ to react towards the direction in which the volume of H_2 and CO decreased.



(a)componentgas fraction



(b)the syngas temperature



(c)gasification efficiency

Fig. 4 Fig. 3 the relationship betweenreaction temperatureand the gasification process

Figure 4 showed the relationship betweenreaction temperatureand the gasification process. In fig. 4(a) the volume percentage of CO continuously increased with the increasing temperature, from 22.08% at 50□ equably up to 28.65% at 950□. However, the volume percentage of CO_2 and CH_4 linearly decreased. The volume percentage of CO_2 decreased from 11.67% to 7.06% and that of CH_4 decreased from 2.00% to 0.07%. It was because that the endothermic reactions $C+CO_2 \rightarrow 2CO$ and $C+H_2O \rightarrow CO+H_2$ move forward intensely, while exothermic reaction $C+2H_2 \rightarrow CH_4$ react in the reverse direction intensely, which benefited the production of CO and H_2 and thus led to a more obvious tendency of decreasing CO_2 and CH_4. The temperature was not the higher the better and should be decided according to fig.4(b) and fig.4(c). In terms of wood dust, the best reaction temperature could be controlled as420□. The JinhuiAn’s thesis provides a reaction temperature range of 300-500□, which was used as one of the operation parameter for the gasifier of Hull, sawdust, straw[5].

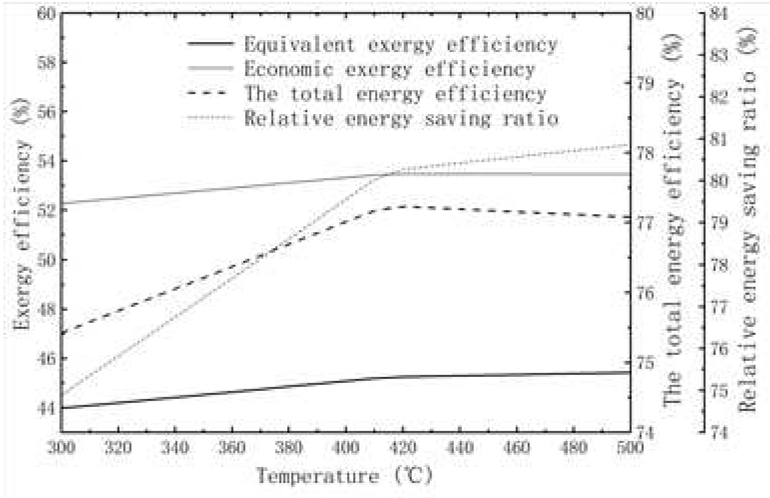
THE ENVIRONMENTAL PERFORMANCE AND EFFECIENCY OF IGCC SYSTEM

The overall performance of the IGCC system has also be simulated on the Aspen Plus platform.AndThe condensate water flow in the HRSE maintained at 330 t/h, the wood dustamount of 170 t/h. In this condition, the environment performance and efficiency of the IGCC system were discussed.the overall performance of the IGCC system included:the total energy effeciency, equivalent exergyefficiency, andeconomic exergyefficiency[16-17]. Generally speaking, the higher the exhaust temperature of combustor, the higher the efficiency of power generation would be. But due to the limitation of technological level, the temperature of inlet in the turbine could not be above 1600□. Within this scope, for an increase of 1□ in temperature of the inlet gas, the exhaust temperature of combustor and turbine increased by 0.169□ and 0.106□ respectively. In order to maintain the steady operation of the turbine , the gasification efficiency of gasification units must be kept within a relatively stable range. In the model used in this paper, the syngas flow of the combined cycle should be maintained at about 100kg/s. According to the results of gasification analogue simulation, the reaction pressure should be set at 1atm, the temperature should be set at 420□, and the oxygen equivalent ratio should be set at 0.27. The performance of the IGCC system under the supposed condition were shown in Table 2.

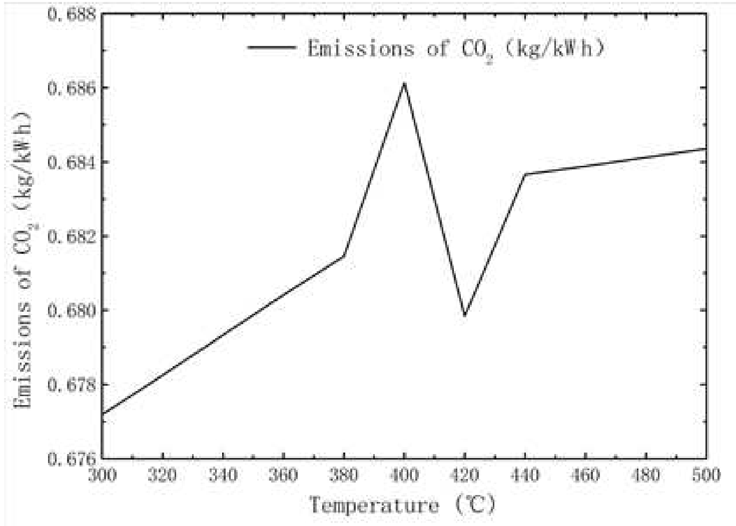
Table 2 parameters performance for IGCC system

Inlet temperature of combustion chamber(□)	389
Inlet pressure of combustion chamber(MPa)	1.5081
Inlet temperature of turbine(□)	1189
outlet temperature of turbine (□)	571.5
outlet pressure of turbine (MPa)	0.1106
outlet temperature of HRSG(□)	104.1
Power produced by gas turbine（MW）	228.357
Power produced by stream turbine（MW）	123.930
power（MW）	246.130
the total energy effeciency（%）	77.228
equivalent exergy efficiency（%）	45.249
economic exergy efficiency（%）	53.469

The rated temperature of inlet in the combustor was 340□, and the simulation result was 389□in table 2. The rated inlet temperature of theturbine was 1175□, and the simulation result was 1189□in table 2.The rated outlet temperature of the turbine was 557□ and the simulation result was 571.5□in table 2. Therefore, this IGCC system was able to make sure the operation of the combined cycleunder the supposed condition. The emissions of sulfide and nitride from the IGCC system could meet the strictest requirements of environmental protection. Therefore, tts environmental performance focused on CO_2 emissions. the thermal and environmental performance of the IGCC system were shown in Fig. 5-6.

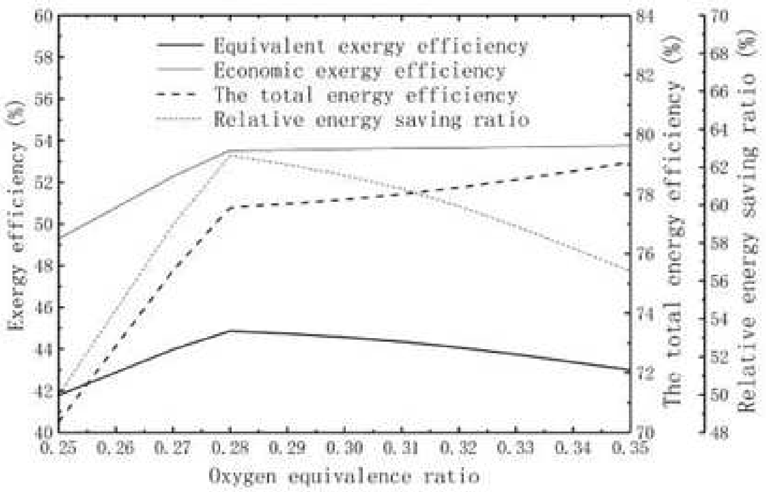


（a）efficiency

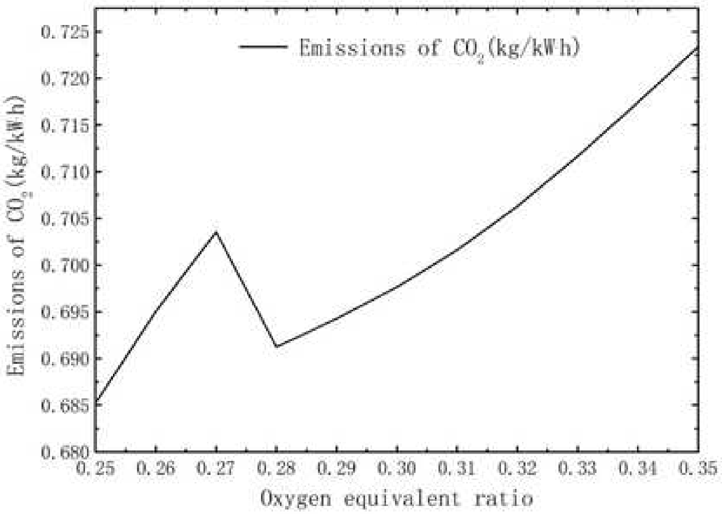


（b）CO_2emission

Fig. 5 the relationship betweenreaction temperature and performance of IGCC



（a）efficiency



(b) CO_2emission
Fig. 6 the relationship between oxygen equivalent ratio and performance of IGCC

The increasing tendency of energy efficiency became moderate at around 420℃, as shown in Figure 5. The effects of the temperature on CO_2 emissions were relatively complex. When the temperature of gasifying reaction was 420℃, CO_2 emissions were about 0.68kg/kW·h. Figure 6 showed that energy efficiency of the IGCC system increased first and then decreased with the increasing oxygen equivalent ratio. Meanwhile, CO_2 emissions showed an increasing tendency with the increase of oxygen equivalent ratio.

CONCLUSION

When the reaction pressure was at 1 atm, the temperature was at 420℃, and the oxygen equivalent ratio was at 0.27, the IGCC system with wood dust as feed was able to meet the requirements of stable operation. At this time, CO_2 emissions were about 0.68 kg/kW·h and the total energy utilization ratio of the system was 75%. Therefore, the system was better at environmental protection and energy conservation compared with coal-fired power plants.

when the reaction temperature was below 400℃, increase in heat value, yield, and temperature of syngas was obvious. Increasing temperature and heat valueof syngas would lead to increase in outlet temperature of the turbine and HRSG. However, overlarge variation in the outlet temperature of the turbine would cause excessive evaporation of the vapor in HRSG, which did not follow the given temperature curve. And it was required by the national standards that the gas yield in the gasification process must be above 70%. In a summary, the reaction temperature of gasifier could be between 300-500℃.At the same reason, the oxygen equivalent ratio could be 0.25-0.31.

Effects of the reaction pressure on the gasification process were relatively small. When the oxygen equivalent ratio was above 0.27, the heat suppliedby the combined units decreased quickly and electricity gradually decreased as the gas yield declined, which led the relative energy conservation ratio to increase first and then decrease. However, the total energy utilization ratio of the system would not decrease with the increasing oxygen equivalent ratio. It was because that the oxidation process was more complete with the increasing oxygen equivalent ratio, thus receiving more thermal energy. Decrease in the relative energy conservation ratio only indicated that directly burning biomass fuels would cause great energy losses from another perspective.

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