Heat and Technology
Vol. 32, n. 1-2, 2014

PERFORMANCE STUDY OF COAL-WATER GASIFICATION PROCESS IN A TEXACO GASIFIER

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ABSTRACT

In this paper, numerical models of coal-water gasification process are formulated and used to describe coal gasification within Texaco gasifier which is normally used in modern coal power plants. To identify operation performance of Texaco gasifier, Aspen plus software is employed to process the numerical simulation and a typical Chinese coal--Beisu coal—was selected to be dealed with by the gasifier. Important parameters affecting gasifier's gasification performance including coal-water slurry concentration, oxygen-coal ratio and oxygen concentration are analyzed Numerical results show that improving the coal-water slurry concentration will significantly increase the contents of active ingredients in raw gas; hydrogen and carbon monoxide, and increasing oxygen-coal ratio and the concentration of oxygen will decrease their contents.

1. INTRODUCTION

Polygeneration system based on the coal gasification is one of the new technologies of modern coal clean utilizations, it burns coal, residual oil or petroleum coke as raw material and uses synthesis gas gasified to realize cogeneration of chemistry, electricity and heat. Department of Energy of USA emphasizes integration of many kinds of advanced technology and gives great impetus to coal polygeneration system technology in 2000 within the famous Vision 21 scheme. Coal polygeneration system will use flexible coal gasification generator, efficient gas equipment in removing impurity and purification, advanced fuel cell and gas turbine system, convenient chemical products production and fuel synthesis craft, and combine existing thermal generation plants and chemical engineering industries to reduce cost and to reduce emmission [4-8].

There are many kinds of methods of coal gasification in which gasifier are essential components. According to motion state of coal and gasification components in the gasifier, gasifiers can be divided into spouting bed gasifier, fluidized bed gasifier and fixed bed gasifier. Texaco coal-water slurry gasifier belongs to a kind of spouting bed gasifier, it employes coal-water slurry and pure oxygen as raw material and gasification agent respectively. Texaco coal-water slurry gasifier is one of the most advanced coal gasification technologies, and also a kind of most used gasification craft in each thermal power plant' power generation demonstration project in the world[9]. High temperature and high pressure working conditions of Texaco gasifier help to achieve gasification reaction, eventually generates synthesis gas with H_2 and CO as the main element. Based on Aspen plus software, Texaco coal gasification model is established and system performances are numerically analyzed in this paper.

2. GASIFIER MODEL

The flow chart of Texaco gasifier is shown in Figure 1. Because coal is a complex mixture, so in the flow chart, the coal is firstly broken down into single element in DECOMP module, then it conducts fully reaction with oxygen and water in the GASIFIER module, finally it produces RAWGAS and SOLID, which the solid is excluded in the bottom of the SEPARATE module and raw gas is produced on the top of the SEPARATE module.

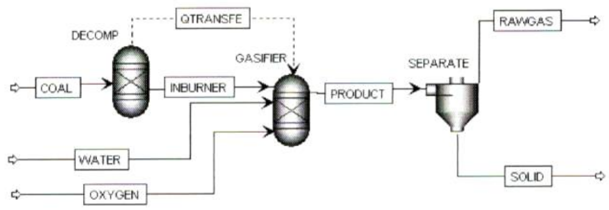

Figure 1. flow chart of Texaco coal water slurry gasifier

A typical Chinese coal, the Beisu coal, is selected as the design coal. Characteristics of coal-water slurry concentration using in Texaco gasifier is relevant to coal. Usually, the mass fraction of solid coal using in the Texaco gasifier is 60%-70%, therefore the coal-water slurry concentration of Beisu coal used in this section is set to 65%. When complete combustion happens in the gasifier, the amount of oxygen supply is about 1 kg O_2/(1kg dry coal) and the ratio of oxygen consumption in the gasification process with carbon consumption in the coal, i.e. the ratio of oxygen with carbon ranges 0.9 -0.95. The mass flow rate of dry coal is 20000 kg/hr and the mass flow rate of oxygen is 18900 kg/hr. Components of raw gas produced in the gasification are different. As well, the pressure of in the gasifier is also different. In order to improve the content of active ingredients CO and H_2 in the raw gas, the operation pressure is set to 4 MPa in the gasifier. Table 1 gives the industry and elemental analysis of Beisu coal. Table 2 gives the operation parameters of the gasifier.

Table 1. Constituent of Beisu coal

Industry analysis					
W/%	A/%	C/%	V/%	Net calorific value kJ/kg	
3.44	6.90	59.09	30.57	31059	
Constituent analysis					
C/%	H/%	O/%	N/%	S/%	A/%
69.27	4.56	8.08	1.28	3.6	13.21

Table 2. Operation Parameters of the Gasifier

Coal slurry concentration	Oxygen purity	Oxygen coal ratio	Coal slurry flow rate	Oxygen flow rate	Operation pressure
%	%	kg/kg	kg/hr	kg/hr	MPa
65	0.95	0.90	30750	18900	4.0

If uses C_mH_nO as the molecular formula of coal, the chemical reactions in the gasification process [10] can be described by equations (1)-(18).

Under complete oxidation conditions

$$C_mH_nO+\left(\frac{m-1}{2}+\frac{n}{4}\right)O_2=mCO_2+\frac{n}{2}H_2O \tag{1}$$

While under partial oxidation conditions

$$C_mH_nO+\left(\frac{m-1}{2}\right)O_2=mCO_2+\frac{n}{2}H_2 \tag{2}$$

Further reactions after oxidation includes (3)-(18).

$$CH_4+2O_2=2H_2O+CO_2 \tag{3}$$

$$2CO+O_2=2CO_2 \tag{4}$$

$$2H_2+O_2=2CO_2 \tag{5}$$

$$C+O_2=CO_2 \tag{6}$$

$$2C+O_2=2CO \tag{7}$$

$$C+H_2O=CO+H_2 \tag{8}$$

$$C+H_2O=CO+H_2 \tag{9}$$

$$C+2H_2O=CO_2+2H_2 \tag{10}$$

$$C+CO_2=2CO \tag{11}$$

$$C+2H_2=CH_4 \tag{12}$$

$$\frac{1}{2}S_2+H_2=H_2S \tag{13}$$

$$\frac{1}{2}S_2+CO=COS \tag{14}$$

$$CO+3H_2=CH_4+H_2O \tag{15}$$

$$CO_2+4H_2=CH_4+2H_2O \tag{16}$$

$$2CO+2H_2=CH_4+CO_2 \tag{17}$$

$$CO+H_2S=COS+H_2 \tag{18}$$

Chemical reactions (1)-(5) may be the chemical reactions when the coal particles burn. Reaction formulas (6)-(9) are the chemical reactions in high temperature and high pressure condition, coal particles or fixed carbon in the semi-coke has chemical reactions with gasifying agent (oxygen, water vapor) and among them, reaction formulas (8) and (9) are the main reaction of manufacturing coal-water gas, both of them are the heat absorption reactions. Reaction formulas (10)-(13) are the reactions between high temperature semi-coke particles and gases generated by reactions, and the reaction between sulfur content in coal and reducibility gas under high temperature. Since the concentration of generated gas is very big, reaction formulas (14)-(18) are reversible reactions existed in generated gases under high temperature.

Following assumptions are employed: (1) the gasifier is in a stable operation state, all the parameters is unchanged with time; (2) agent and coal slurry is completely mixed in gasification furnace in moment; (3) H, O, N, S in the coal are all changed into gas phase, and C is not completely transformed with the change of the conditions; (4) the pressure inside the gasifier is the same and with no pressure drop; (5) the ash content in coal are inert materials, and do not participate in react in the gasification process ; (6) all the speeds of the gas phase reactions are very fast, and the gas phase reactions can achieve thermodynamic balance.

3. GASIFICATION RESULTS AND ANALYSIS

Table 3 gives the simulation results and compares them with literature [11]. One can see they are in good consistent.

Table 3. results comparison with literature[8]

	gas component /(vol, %)					
	H_2	CO	CO_2	N_2	H_2O	H_2S
Literature[8]	29.6	40.8	10.2	0.7	17	
Simulation Results	7.91	41.27	10.36	0.62	18.66	0.1
Relative Error /%	-5.7	1.15	1.567	-11.43	9.76	

3.1 Coal Water Slurry Concentration

Coal-water slurry concentration is an important parameter affecting the component of raw gas. When the concentration changes to 71% from 63%, main compositions of raw gas generated by gasification and initial temperature calculation results are shown in Table 4. Keep the same oxygen and coallow rate, change the flow rate of water to achieve the change of coal-water slurry concentration.

Table 4. results of gasification under different coal-water slurry concentration

coal-water slurry concentration	gas initial temperature K	gas component (vol, %)					
		H_2	CO	CO_2	N_2	H_2O	H_2S
63%	1474.19	28.19	39.35	11.09	0.61	19.63	0.1
65%	1520.11	27.91	41.27	10.36	0.62	18.66	0.1
67%	1564.12	27.67	43.07	9.71	0.64	17.75	0.1
69%	1608.88	27.44	44.85	9.07	0.65	16.81	0.1
71%	1653.56	27.22	46.59	8.45	0.66	15.87	0.11

Figure 2 shows the relationship between raw gas composition and gas initial temperature under different coal-water slurry concentration. From this figure, along with the increase of coal-water slurry concentration, effective gas composition($CO+H_2$) are also increasing when concentration changes to 71% from 63%, the gasifier outlet gas temperature changes larger, from 1474.19 K to 1653.56 K. Therefore, in the actual operation process, it should try to ensure that gasification temperature is not too large and to get as much effective gas composition as possible. The increased coal-water slurry concentration leads to water reduction and gasifier temperature increase, this results in a higher raw gas temperature.

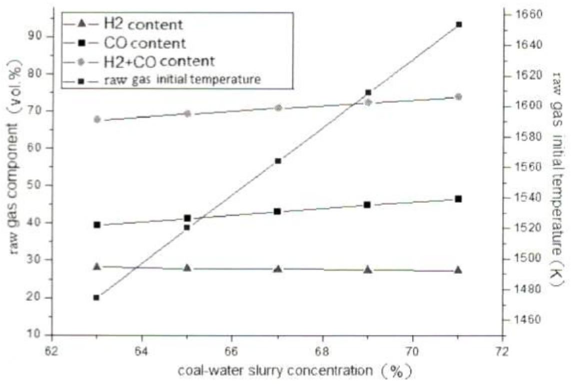

Figure 2. raw gas component under different coal-water slurry concentration

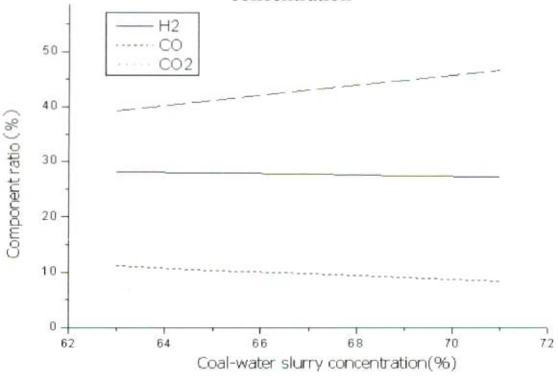

Figure 3. relationship of coal-water slurry concentration and gas composition

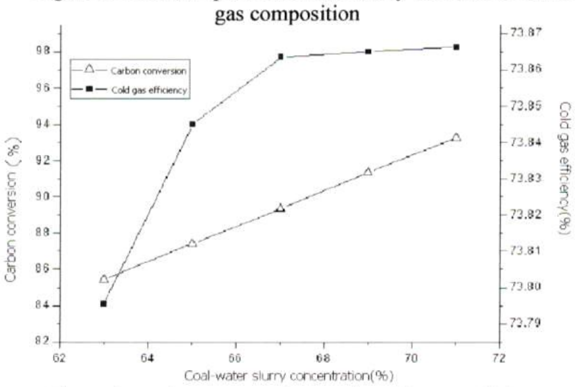

Figure 4. carbon conversion and cold gas efficiency under different coal-water slurry concentration

Figure 3 shows the relationship between the dry concentration and coal-water slurry concentration. To increase the coal-water slurry concentration does good to the increase of CO+H_2 and the content change of CO+H_2 has nothing to do with concentration, and the value is approximate 66% due to water evaporation in coal-water slurry and the increased CO has transformed into CO_2.

Figure 4 shows the relationship between the carbon conversion and cold gas efficiency under different coal-water slurry concentration. Along with the increase of coal-water slurry concentration, carbon conversion rate is increasing gradually, and cold gas (CO+H_2) efficiency declines when coal-water slurry concentration achieves at 69%.

3.2 Oxygen Coal Ratio

Oxygen-coal ratio is an important parameter to affect gasification process. Keep other operating parameters unchanged, let oxygen-coal ratio change to 92% from 88%, main content of raw gas generated from gasification process and initial temperature calculation values are shown in Fig.5. Keep flow rate of coal-water slurry unchanged and let oxygen flow rate change to change the oxygen-coal ratio.

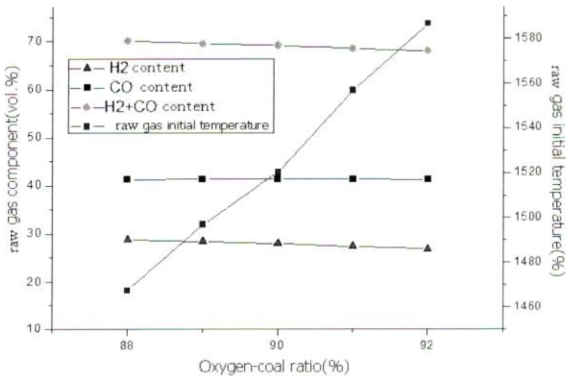

Figure 5. gas component under different oxygen-coal ratios

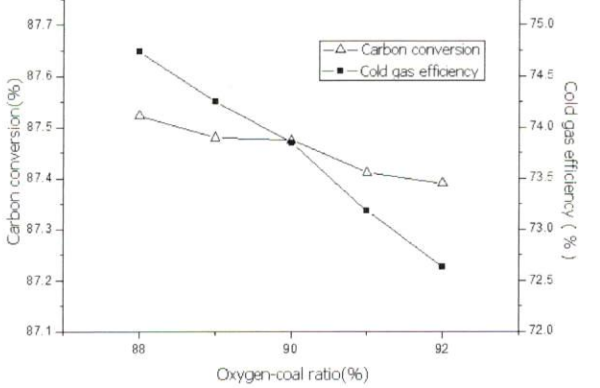

Figure 6. carbon conversion and cold gas efficiency under different oxygen-coal ratios

Table 5. gasification results under different coal-water slurry concentration

Oxygen coal ratio,%	gas initial temperature K	gas component (%)					
		H_2	CO	CO_2	N_2	H_2O	H_2S
88	1467.47	28.82	41.26	10.40	0.62	17.74	0.1
89	1496.91	28.32	41.27	10.37	0.62	18.26	0.1
90	1520.11	27.91	41.27	10.36	0.62	18.66	0.1
91	1556.76	27.29	41.27	10.36	0.63	19.30	0.1
92	1586.61	26.78	41.25	10.38	0.63	19.81	0.1

Figure 5 shows the content of raw gas under different oxygen-coal ratio and Figure 6 shows the relationship between carbon conversion rate and cold gas efficiency under different oxygen-coal ratio. With the increase of oxygen-coal ratio, the flow rate of oxygen increases in the gasifier and the combustion reaction is intensified so that the temperature in gasifier increases.

However, with the increase of oxygen flow rate, more CO and H_2 are burned but the absolute amount of CO and H_2 increase, thereby to increase the calorific value of raw gas and carbon conversion rate. With the amount of CO_2 converted from C and CO increases, water vapor amount increases so that the relative amount of H_2 and CO decrease and the relative amount of CO_2 and H_2O increase. Thus, the increased gasification temperature and the intensified gasification reaction lead to the decreased effective gas composition and eventually lead to the decreased cold gas efficiency.

3.3 Oxygen Concentration

Oxygen concentration is another important parameter to affect the content of raw gas. Table.6. shows the change of raw gas composition and initial temperature when the oxygen concentration changes to 98% from 93%. Fig.7. shows the raw gas composition under different oxygen concentrations. With the unchanged oxygen-coal ratio, the increase of oxygen concentration means the decrease of the gasification agent flow and the decrease of N_2 so that the gasification reaction is intensified and the initial temperature increases. Different from aforementioned, the supply of water vapor is unchanged so that the reaction of coal-water gas is strengthened and the reduction reaction of CO_2 is intensified and the production and concentration of CO shows an upward trend. The volume fraction of CO_2 increases only due to the decrease of total raw gas and in fact the absolute quality of CO_2 is declining.

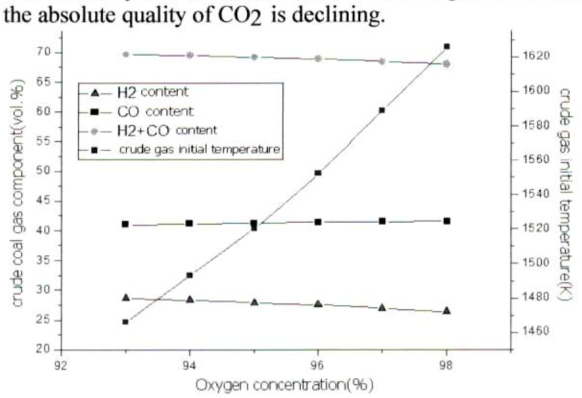

Figure 7. raw gas composition under different oxygen concentrations

Table 6. gasification results under different oxygen purities

oxygen concentration /%	gas initial temperature /K	gas component (vol, %)					
		H_2	CO	CO_2	N_2	H_2O	H_2S
93	1466.05	28.65	41.01	10.38	1.12	17.67	0.1
94	1492.93	28.29	41.15	10.37	0.87	18.17	0.1
95	1520.11	27.91	41.27	10.36	0.62	18.66	0.1
96	1552.08	27.46	41.4	10.38	0.5	19.25	0.1
97	1588.91	26.93	41.5	10.41	0.5	19.91	0.1
98	1625.92	26.39	41.58	10.46	0.5	20.57	0.1

4. CONCLUSIONS

Texaco gasifier model is established based on Aspen plus and the simulation results are consistent with other literatures.

Influences of oxygen-coal ratio, coal-water slurry concentration and oxygen concentration on the gasification process are analyzed. The results show that the increase of coal-water slurry concentration, oxygen-coal ratio and oxygen concentration will increase the gasifier outlet temperature and the increase of coal-water slurry concentration will significantly increase the content of effective gas composition ($CO+H_2$) and the increase of oxygen-coal ratio and oxygen concentration will decrease the content of effective gas composition ($CO+H_2$).

REFERENCES

1. XU Xin, LUO Fangtao, LU Xuehong. The Status and Progress of Coal Gasification Co-production System. *Guangdong Chemical Industry*, 2010, 37(7): 85-86.
2. WANG Yanming, LI Guoxiang, YU Gewen. Coal Polygeneration is an Important Direction for the Development of Clean Coal Industry. *Inner Mongolia Petrochemical*, 2010, (9):45-46.
3. NI Weidou, CHEN Zhen. Clean and Efficient Use of Coal is the Key to the Low Carbon Economy of China. *Journal of Taiyuan University of Technology*, 2010, 41(5):456-458.
4. Christoph Stiller, Bjørn Thorud, Olav Bolland, Rambabu Kandepu, Lars Imsland. Control Strategy for a Solid Oxide Fuel Cell and Gas Turbine Hybrid System. *Journal of Power Sources,* 2006 (158):303-315
5. NI Weidou, LI Zheng, JIANG Hua. Analysis of Coal-based Generation System. *Coal Conversion*, 2003, 26(4):1-4.
6. YANG Dong, MA Zheshu. Conceptual design and performance analysis of waste heat recovery system for intelligent marine diesel engines. Part 1: Impractical analysis of traditional WHR systems. *International Journal of Heat and Technology*, 2012, 30(2): 85-91.
7. MA Zheshu, YANG Dong. Conceptual design and performance analysis of waste heat recovery system for intelligent marine diesel engines. part 2: Integrating power turbine into WHR systems. *International Journal of Heat and Technology*, 2012, 30(1): 119-125.
8. MA Zheshu, WU Jieer. Numerical simulation of heat transfer phenomenon in a two- phase closed thermosyphon, *International Journal of Heat and Technology*, 2009, 27(1) : 75-79.
9. LENG Xuefeng, PAN Weiguo, WANG Wenhuan, SHEN Minqiang, GU Xianqing, ZHANG Ling, HU Shenya. Development Status of Gasification and its Co-production System. *Journal of Shanghai University of Electric Power*, 2009, 25(2):117-121.
10. FU Changliang, HANG Aimin. *Chemical Production Technology of Modern Coal.* Beijing: Chemical Industry Press, 2009, 43-90.
11. MENG Hui, DUAN Liqiang, YANG Yongping. The Performance Research of the Texaco gasifier Based on Aspen Plus. *Modern Electricity*, 2008, 5(4):53-58.