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Study on an environmental-friendly and high-efficient fuel cell energy conversion system

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Abstract: The kinds and the distribution of the coal in China are investigated. The results indicated that the 80% coal in China is used by the method of the coal gasification. The possibility of utilization and development of the fuel cell power plant in China is analyzed. A combined cycle generation system is designed. Its net electrical efficiency is about 55% (LHV), which is higher than that of the fire power plant. So it is environmental-friendly and high-efficient generation mode.

Keywords: energy conservation; pollution control; fuel cell; power plant; coal gasification

Introduction

For environment protection and high efficiency, development of new concept power plant has been required in China. The fuel cell is expected that to be used in a power plant as a centralized power station or distributed power plant (Joon, 1998; Eichenberger, 1998). The molten carbonate fuel cell (MCFC) power plant has several attractive features, i.e. high efficiency and lower emission of NOx and SOx.

The MCFC is an electrochemical energy conversion device that converts the chemical energy in a hydrocarbon fuel (CO, H_2 and CH_4 etc.) directly to electric power and not limited by Carnot cycle efficiency (Yu, 2001). This is higher than every type of energy conversion devices commonly used today. The coal in solid state can not be directly used. All the combined cycle generation system composed of the coal as fuel and the fuel cell demands at first to realize the gasification of coal. The catalog of coal has many kinds in China also. At first the coal source and its distribution in China will be concisely described in this paper. Then it was studied to the possibility of utilization and development of the combined cycle generation system composed of the coal, that is used as fuel and greatly abundant in China, and the molten carbonate fuel cell with high temperature.

The coal gasification plants in China are applied in many departments, that mainly are for heating and life. The coal gasification plant and technology has several types at present, such as mobile bed gasification, fluidized bed gasification with scrap coal, gasified bed gasification, underground gasification and so on. In this paper the main type of the gasification technology and plant, that is intended to be composed to a combined cycle generation with MCFC, is selected to give more detailed description. Illustrate the makeup of the generation system, and calculate the heat balance.

1 Kinds and distribution of coal suitable for gasification in China

In the consumption of energy, coal stands in the first place so far in the primary energy in China. The proved amount in place according to the definition by the world energy commission has about 770 billion tons. The stored amount that can be exploited is 114.5 billion tons. Among those stored coal, bituminous coal is 75%, anthracite 12%, lignite 13%. The coal source suitable for gasification is about 80% of whole coal source.

1.1 Anthracite

The sequence of the amount of the anthracite reserve in China is as following: Shanxi, Guizhou, Henan, Hebei, Sichuan, Beijing, Fujian, Guangdong, Yunnan, Jiangsu, Zhejiang, Qinghai, Ningxia

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etc. provinces and cities. The richest anthracite mine area in China is located in Guizhou and Shanxi.

The anthracite reserve in Shanxi Province is about 49.5 billion tons. It is distributed in the southeast side of Jinnan Qinshui, including Yangquan mining area and Jincheng mining area. The anthracite reserve in Guizhou Province is about 31.6 billion tons. About the half of that store amount is distributed in the Zhijin and Nayong coalfield. The characteristic of this anthracite has many properties such as low ash, low sulphur, high melting point of ash, high heat value and easy selectivity etc., which is excellent coal used for gasification. The index of coal quality in main anthracite coal mines is shown in Table 1.

Table 1 The index of coal quality in main anthracite coal mines

Index / Coal mine area	A^r, %	V^r, %	S_Q^g, %	Q_{DW}^y, J/g	ST, ℃	Mechanical strength > 25 mm, %
Yangquan	10—20	7.0—9.0	0.5 ~ 1.6	27220—31400	> 1350	60—80
Jincheng	10—15	4.5—5.5	0.3—3.5	29310	> 1450	85—90
Jingxi	10—30	3—7	0.2—0.5	20940—28470	> 1350 — < 1200	60—90
Jiaozuo	12—28	4.5—6.5	0.3—4.5	27220—30150	> 1350	65—85
Ruqigou	3—10	6.5—9.5	0.2—0.3	30570—34750	< 1250	70—90
Furong	22—35	7—9	2.5—6.5	22190—25960	1150—1250	70—90
Longyan	5—20	2—4	0.6—1.2	25120—30980	> 1400	67—91

Notes: r, y——received; g——dry; DW——low heat

1.2 Lean coal

The lean coal source in China is mainly distributed in Shanxi, Guizhou, Henan, Shaanxi, Sichuan, and Yunnan etc., the total reserve being about 36.1 billion tons. Main production mine areas are Zibo in Shandong Province, Xishan in Shanxi Province, Peigou in Henan Province and Tongchuan in Shaanxi Province etc. The index of coal quality in main lean coal production mine areas is shown in Table 2.

1.3 Lignite

The lignite source in China is abundant, its reserve being about 100 billion tons. It is mainly distributed in Inner Mongolia, Jilin and Yunnan etc. The reserve of lignite in Inner Mongolia is 70.8 billion tons, and 11.7 billion tons in Yunnan. The index of coal quality in main lignite mine zones is shown in Table 3.

In the coal produced annually in China, the proportion of that used for electric utility is the largest one that is 31.3% and 3.3% for gasification, 10.8% for metallurgical coke and 10.2% for civilian application at present. The proportion of the civilian gas consumption will increase with the development of the middle and small cities. Thus, various technology and devices of gasification will be developed, especially the combined cycle generation system composed of the fuel cell.

Table 2 The index of coal quality in main lean coal mines

Mine area	A^g, %	V^r, %	S_Q^g, %	Q_{DW}^y, J/g	ST, ℃
Zibo	11—30	12—18	1.5—4.0	23030—25540	1300
Xishan	8—23	11—18	0.6—2.2	25960—28470	1335
Peigou	17.71	14.41	0.37	27110	> 1500
Tongchuan	26.42	16.24	4.73	24820	1330

Notes: r, y, g, DW are the same as Table 1

Table 3 The index of coal quality in main lignite mine zones in China

Mine zone	A^g, %	V^r, %	S_Q^g, %	Q_{DW}^y, J/g	ST, ℃
Zalai Nuo'er	5—17	41—46	0.3—0.8	10470—15070	1130—1400
Pinzhuang	10—22	40—45	0.5—2.4	12560—16330	1240
Shulan	23—42	50—56	0.2—0.5	11300—14240	1410—1500
Yima	10—25	40—43	0.8—3.1	14650—21770	1190—1240

Notes: r, y, g, DW are the same as Table 1

2 Coal gasification system

If coal is provided fuel cell to generate electricity, the coal gasification plant must be needed to produce the gas containing hydrogen supplied to fuel cell. The different kind of fuel cell requires different kind of gas.

Technology for making circulating bed water gas has been exploited by Jiangsu Polytechnic University who has independent knowledge property right, the heat value of gas being 10870 in the range of middle heat value gas, in operation the content of CO can be controlled below 20%. The feature of this method is that gas can be produced by various kind of coal with 0—14 mm granularity, such as bituminous coal, anthracite, coke powder, lignite and lean coal etc., and its load can be adjusted between 50%—150%. There is no tar and phenol in the gas produced. Its purification is simple and three waste treatments are also easy. Fig.1 is a sketch of the system technology flow chart(Wang, 1999).

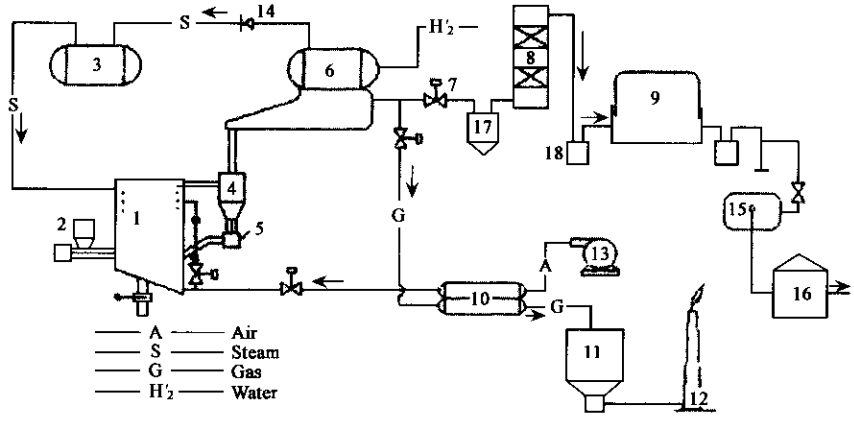

Fig.1 Coal gasification system

1. fluidized bed water gas furnace; 2. screw coal feeder; 3. cushion steam tank; 4. hot cyclone; 5. return feeder; 6. heat recovery steam generator; 7. hydraulic gate valve; 8. scrubber valve; 9. balancing gas tank; 10. air preheated; 11. dust trap; 12. stack; 13. fan; 14. check valve; 15. gas booster; 16. tower of sulphur removal; 17. scrubber tank; 18. water seal

This gasification system produces gas by means of fluidized bed. In parameters, the normal output of gasifier is 1800. Semi anthracite from Henan Baofeng is taken, for example, the product of gasifier is shown in Table 4.

Table 4 Performance indexes of gasification

CO_2, %	CO, %	H_2, %	CH_4, %	O_2, %	N_2, %	H_2S, mg/m^3	Q^G_{net}, Nm^3/kg coal	Gas production rate, %	Gasification rate, %
9.4	19.4	58.81	6.92	0.14	5.63	120	11227	1.19	58.0

3 Making and calculating of coal gasification and MCFC generation system

3.1 Composition of 2MW IG-MCFC generation system

The fuel can not be used totally in the fuel cell because the running cost will be more expensive the utilization rate of fuel is higher. Faculty the utilization rate of fuel is usually 75%, the other 25% fuel being fueled in the steam boiler. Gasification fuel cell combined generation system is shown in Fig.2. The generation system consists of internal reforming molten carbonate fuel cell, steam turbine, steam boiler, heat exchanger and power conversion etc., total generation power output being 2800 kW. The temperature at each point in figure is got by means of calculating of heat balance.

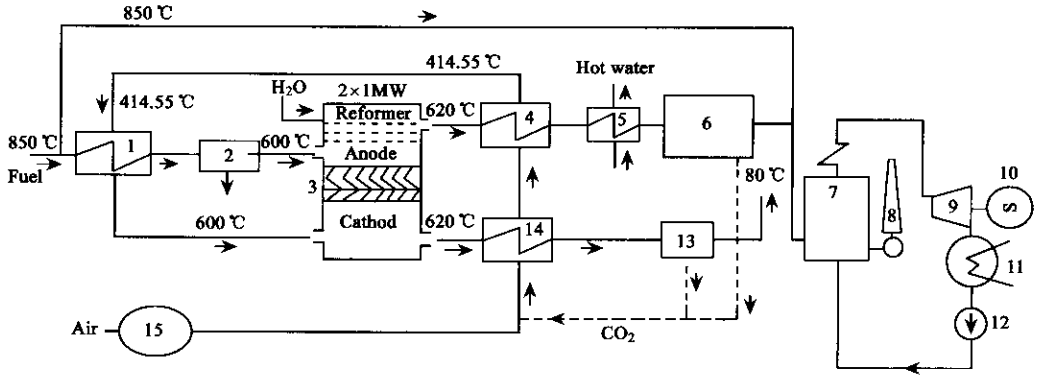

Fig.2 2000 + 800kW IG-MCFC combined generation system

1. heat exchanger; 2. device of sulphur removal; 3. fuel cell; 4. heat exchanger; 5. heat exchanger; 6. water removal CO_2 removal; 7. steam boiler; 8. stack and induced-draught fan; 9. steam turbine; 10. generator; 11. condenser; 12. condensation water pump; 13. CO_2 removal; 14. heat exchanger; 15. compressor

3.2 Calculation of material balance

Assuming the utilization rate of fuel is 75%, the reforming efficiency of methane being 95%. The results of material balance calculation in the reformer and the fuel cell are listed in Table 5 and 6. It is shown that SOx emissions are very low and NOx emissions are almost zero. CO_2 emission is directly related to the efficiency and the primary fuel used.

Table 5 The material balance in the reformer

Fuel	Composition, %	Mole	Chemical reaction	Utilization rate, %	Product	Mole
CO_2	9.3711	0.094		0	CO_2	0.094
O_2	0.1396	0.0014		0	O_2	0.0014
N_2	5.6127	0.056		0	N_2	0.056
CO	19.3405	0.1934	$CO + H_2O \rightarrow CO_2 + H_2$	100	CO_2	0.1934
					H_2	0.1934
CH_4	6.8988	0.0690	$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$	95	CO_2	0.0655
					H_2	0.2621
					CH_4	0.0034
H_2S	0.0078	0.0078		Sulphur removal	H_2S	0.0078
H_2	58.6295	0.5863		0	H_2	0.5863

Table 6 The material balance of fuel cell

Fuel	Composition, %	Mole	Chemical reaction	Utilization rate, %	Product	Mole
CO_2	24.25	0.3529		0	CO_2	0.3529
O_2	0.10	0.0014		0	O_2	0.0014
N_2	3.85	0.0560		0	N_2	0.056
CH_4	0.23	0.0034		0	CH_4	0.0034
H_2	71.58	1.0418	$H_2 \rightarrow 2H^+ + 2e$	75	H_2	0.26045
			$CO_2 + 1/2O_2 + 2e \rightarrow CO_3^{2-}$		H_2O	0.78135
			$2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$		CO_2	Circulating

3.3 Calculation of heat balance

Assuming the operation voltage of fuel cell $U = 0.8V$, the efficiency of heat exchanger being 99% and the conversion efficiency of direct to alternate current being 99%. Steam generated from the steam boiler can be used to drive a set of small steam turbine to generate, and assuming total efficiency 25%. The content of the fuel is 1377.82 and 1800 Nm^3/h respectively. The results are listed in Table 7. When the proportion of the MCFC power output is about 80%, the net electrical efficiency of the power plant is near 58%. Then the net electrical efficiency of the power plant decreases also with the proportion of the MCFC power output decreasing. So the power output of MCFC in the power plant should be about 80%.

Table 7 The results of the calculation

Output of the coal gasification boiler, Nm^3/h	Generation power of the fuel cell, kW	Generation power of the turbine, kW	The heat power, kW	Total efficiency η, %(LHV)
1377.82	2000	480.46		57.60
1377.82	2000	480.46	768	75.47
1800.0	2000	841.40		50.50
1800.0	2000	841.40	768	64.20

4 Conclusion

Through the investigation of the kinds and the distribution of the coal it is shown that about 80% coal in China is suitable to coal gasification.

The fuel cell combined cycle system, which is composed of the fuel cell and the steam turbine, is designed. In this system the coal is used as fuel, the net efficiency is over 55% and the generation proportion of the steam turbine is about 20%.

The material balance of the system is calculated. The characteristic index of the material emissions is given. The CO_2 emissions are lower about 15% than in fire power plant. SOx emissions are very low also and NOx emissions are almost zero.

The new method of the coal source utilization is proposed. With the fuel cell technology developing, the combined cycle generation system with MCFC and steam turbine will be high efficiency and low pollution generation method. So the coal gasification technology become more important in order to produce the gas fuel for the cell.

Symbols description:

N——power of generation, kW; η—— Efficiency of fuel cell, %; LHV—— low heat value of fuel, kJ/mol; Q—— combust heat of fuel gas, kJ/mol; A——ash, %; V——volatile, %; S——sulfur, %; ST——softening temperature, ℃

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