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Reasearch on the main factors for changes in pressure based on turbulent circulating fluidized bed coal gasification technology

Duan Feng*,,†, Jin Bao-Sheng*,†, Huang Ya-Ji*, Li Bin*, Sun Yu*, Wu Yiming*, and Zhang Ming-Yao***

*Thermoenergy Engineering Research Institute, Southeast University, Nanjing 210096, Jiangsu Province, China
**School of Metallurgy and Resource, Anhui University of Technology, Maanshan 243002, Anhui Province, China
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Abstract−High temperature preheated air and steam as gasifying agent and coal gasification was performed in a pressurized turbulent circulating fluidized bed (CFB) gasification pilot plant to investigate the pressurized gasification process and estimate its potential. Within the scope of this paper this test facility as well as its operation behavior was described. Furthermore, the parameter pressure has been investigated regarding its influence on the syngas composition and was presented and discussed in the following. The results show that the gasification quality is improved at higher pressure because of the better fluidization in the reactor. Coal gasification at a higher pressure shows advantages in lower heat value and carbon conversion. With the gasifier pressure increased from 0.1 MPa to 0.3 MPa, the gas heating value is increased by 15%. Increasing the gasifier pressure would increase the carbon conversion from 57.52% to 76.76%. Also, the dry gas yield and efficiency of cold gas increase little with the increase of the gasifier pressure. The operating parameter of pressure exists at optimum operating range for this specific CFB coal gasification process.

Key words: Circulating Fluidized Bed, Gasification, Pressurized, Bituminous

INTRODUCTION

Pressurized CFB gasification is a new technology applying pressurized gasification to circulating fluidized beds and, in industrial applications, has the advantages of large unit capacity, long particle detention time, easy scale expansion, etc. In gasification, it has high coal type adaptability, high gasification intensity and high carbon conversion and can not only solve the pollution problem in direct combustion to a considerable degree but also yield high-value products. Therefore, it is quite significant to carry out studies on application of pressurized CFB gasification technology.

Up to now, the CFB gasification has been in the pilot plant stage. Studies on CFB gasification in Korea [1], China [2,3] and Lurgi GmbH in the US [4,5] are mainly conducted under normal pressure. In most studies of the influence of pressure on the gasification, spouted beds [6,7] and fluidized beds [8,9] are used. However, until now, no study has been reported on pressurized CFB coal gasification.

Possibly due to small designed bench coal feed, great upper heat loss of the furnace and low furnace height, problems such as short coal powder residence time in the furnace, low LHV of coal gas and high carbon content of fly ash are present in all current studies on CFB gasification. So for the first time pressurized CFB gasification was proposed in this study. The reactor riser was wide at the bottom but narrow on the top; turbulent fluidization was adopted in the dense phase zone of the riser for thorough mixing and heat and mass transfer of coal, limestone, the gasifying agent and the returning material. Fast core-annulus flowing on the top of the reactor was realized by adding wide-range bed materials.

The objectives of the present work were to demonstrate the feasibility validation of pressurized turbulent CFB gasification using bituminous coal, and study the effect of gasifying pressure on gas quality, carbon conversion, carbon content of fly ash, gas yield, cold gas efficiency and lower heating value.

FLOW CHARACTERISTIC

Most of the industrial fluidized reactors operate in bubbling fluidization and turbulent fluidization [10,11]. A turbulent fluidized bed has the advantages of strengthened gas-solid contact and lessened gas short-circuit and so on. It is generally believed that a turbulent fluidized bed is more suitable for gas-solid fluidized reactor compared with bubbling fluidized bed. As a result, turbulent fluidization is adopted in the dense zone of this reactor.

But today the discrimination of turbulent fluidization is still a matter of controversy. The empirical formula of Cai [12] is used here to analyze flow pattern transition. To maintain sufficient residence time in the riser of the targeted reactor, the superficial velocity in the dense zone is $2.25\ m\cdot s^{-1}$, higher than the critical velocity for bubbling fluidization to transform into turbulent fluidization $2\ m\cdot s^{-1}$. In the upper part of the riser, a cylinder having a smaller diameter than the dense phase zone was adopted, further increasing the superficial velocity in this part. The superficial velocity in the upper zone of the reactor is $3.0\ m\cdot s^{-1}$, also higher than the minimum transition velocity of fast fluidization, U_{tr}, which is also calculated with the empirical formula of Bai [13]. By now, dense phase turbulent fluidization in the dense zone and fast fluidization in the upper zone of the reactor are basically established in the test.

The bed materials used in the tests are pre-treated with sieve in order to form two groups of bed inert materials with different size distribution, and the mean diameters of them are 0.8 mm and 0.27

†To whom correspondence should be addressed.
E-mail: ddffeng@126.com

mm, respectively. The big bed materials are mainly used in the dense zone and turbulent fluidization is adopted in this zone. The big bed materials can transfer the heat to the coal rapidly. This accelerates the volatile precipitation and promotes its combustion reaction to provide the heat which gasification needs. The small bed materials are put into the standpipe at the beginning of the tests. The purpose of the small bed materials is to ensure large solid circulation rates after circulation; most of the small bed materials are carried to the upper part of the riser because of its small size. The participation in circulation by lots of small bed materials helps to promote the circulation of the unreacted char and limestone and increase the carbon conversion and the sulfur removal efficiency of pollutants.

EXPERIMENTAL SECTION

1. Materials

Huaibei bituminous coal was used for the test. This coal is one of the main coal types for power generation plants in China. The coal is a high ash, low sulfur bituminous coal with a high ash melt point. The mean diameter was 0.5 mm and the particle density was 1,400 kg/m^3. Proximate analysis and element analysis are shown as Table 1, while particle size distributions of coal and bed material are shown as Table 2. The inert bed material used in the gasification tests was silica sand (99.5% SiO_2) with a particle density of 2,600 kg/m^3, and a bulk density of 1,500 kg/m^3. Approximately, 3.5 kg of big silica sand and 6 kg of small silica sand were used as inert material during each gasification test.

2. Test Facility

The CFB gasifier test facility is a pressurized air-blown facility that mainly consists of four parts: (1) feeding system of coal and inert material; (2) supply and preheated system of air and steam; (3) gasifier vessel equipped with a cyclone and a particle recirculating system; and (4) gas analysis equipment and data acquisition. A schematic diagram of this pilot plant is shown in Fig. 1.

2-1. Feeding System of Coal and Inert Material

The test rig is equipped with two feedstock hoppers suitable for pressurized environment. During tests, only one feeding hopper is used. Coal and big inert material are conveyed to the bottom of the gasifier via a rotary impeller and a screw feeder. A variable speed rotating motor of rotary impeller on the basis of the calibration curve controls the feedstock feed rate. And a screw feeder runs at a high rotating rate for rapid transfer towards the hot zone of the riser. The feeding point is at 0.5 m above the distribution plate. Small inert material is put into the standpipe through the gas outlet of the first cyclone at the beginning of the test.

2-2. Supply and Preheated System of Air and Steam

This system consists of air-steam supply unit and preheat unit. Air-steam supply unit consists of a compressor, a steam boiler, two flow meters, and two main valves to control the air and steam flow rate. Preheat unit consists of a low-temperature air heater, an overheater and a high-temperature mixing heater.

Saturated steam generated by a steam boiler was introduced into an overheater and heated to 200 °C, and then mixed with compressed air preheated to 350 °C by a low-temperature air heater. Air and steam were mixed in a high-temperature mixing heater and heated again to 700 °C and then they enter into the body of the gasifying furnace via a windbox. Two groups of material-returning wind for the loop seal were supplied by nitrogen cylinders.

2-3. Gasifier

The gasifier is a refractory-lined reactor with an inside diameter of 70 mm and a height of 1.2 m in the dense bed, and shrinks to an inside diameter of 60 mm and a height of 5.4 m in the freeboard. The total height of the gasifier is 6.8 m including a height of 0.2 m in the tapered part of the riser. Both the feeding spot and the return spot are arranged in the dense bed. The air distribution plate has a flat structure with an opening rate of 1.4%, into which eight directed air nozzles are embedded at equal intervals. Solid recirculation part consists of a cyclone, a standpipe, an expansion joint and a loop seal. The outsides of both the reactor tube and the standpipe are provided with an electric heating system to minimize heat losses. The pressure vessel is made of 5 mm thickness, 159 mm in diameter steel cylinder. A thickness of 25 mm of mullite refractory and a thickness of 20 mm of thermal insulation material are arranged between the pressure vessel and the reactor. The section plane of the riser is shown in Fig. 2.

The syngas generated by the gasifying reactor passes through a

Table 1. Proximate and ultimate analysis of coal

Ultimate analysis/%					Proximate analysis/%				LHV/kJ/kg
C_{ad}	H_{ad}	O_{ad}	N_{ad}	S_{ad}	M_{ad}	V_{ad}	FC_{ad}	A_{ad}	**Q**
54.8	3.54	7.47	0.88	1.00	3.01	27.53	40.16	29.3	21451.5

Table 2. Distribution of coal particle size of Huaibei bituminous and bed material

Particle size (mm)	Huaibei coal (wt%)	Particle size (mm)	Big bed material (wt%)	Particle size (mm)	Small bed material (wt%)
0-0.1	6.59	0-0.2	6.49	0-0.1	19.9
0.1-0.3	22.1	0.2-0.4	13.9	0.1-0.2	17.8
0.3-0.5	27.7	0.4-0.6	23.6	0.2-0.4	17.8
0.5-0.7	19.5	0.6-0.8	26.1V	0.4-0.6	31.6
0.7-0.9	12.5	0.8-1.0	21.6	0.6-0.8	11.1
>0.9	11.6	>1.0	8.30	>0.8	1.8
Mean diameter (mm)	0.5	Mean diameter (mm)	0.8	Mean diameter (mm)	0.27

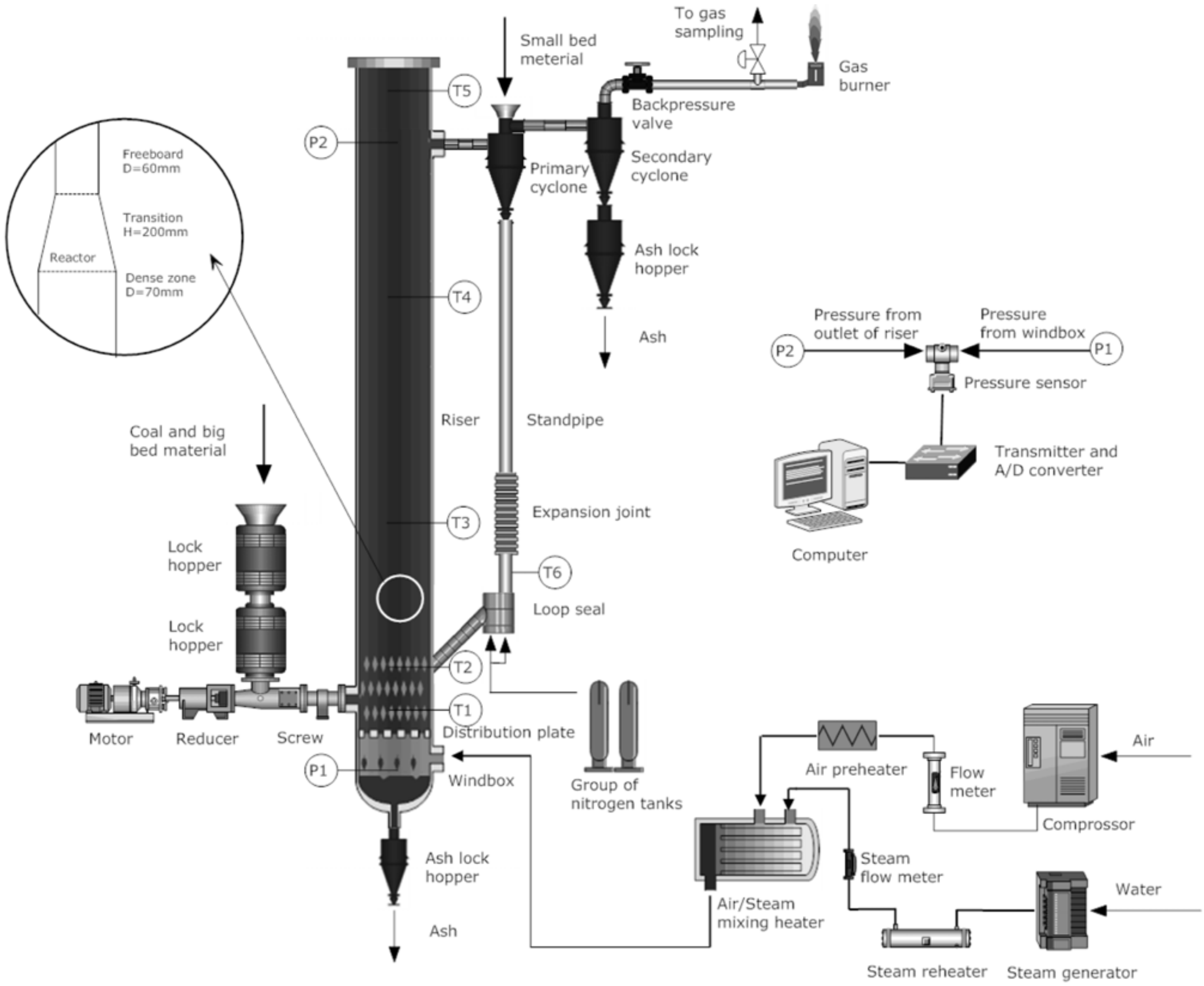

Fig. 1. Schematic diagram of pilot plant.

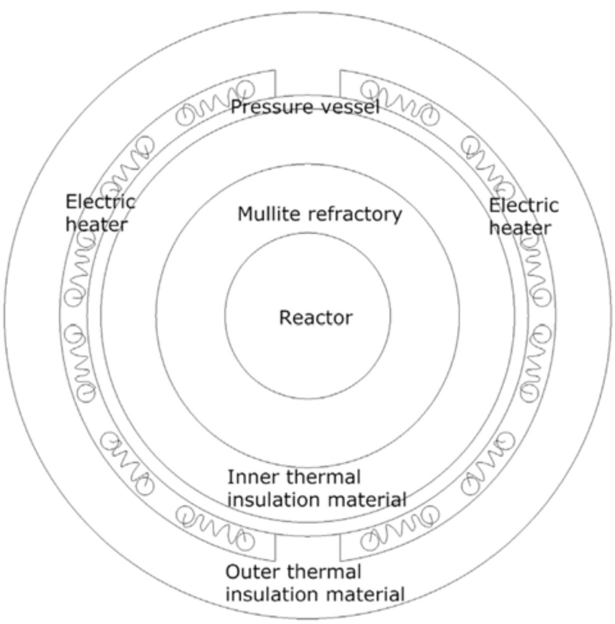

Fig. 2. The section plane of the riser.

primary cyclone and a secondary cyclone to remove most of the entrained, unreacted char, and ash particles and is burnt out in the combustor; the exhaust is then emitted into the atmosphere. The fly ash removed form the secondary cyclone is discharged via the lock hoppers. The mean diameter of the fly ash is 0.055 mm.

2-4. Gas Analysis Equipment and Data Acquisition

Gas sampling point is located downstream of the secondary cyclone. The fuel gas is taken out by a stainless pipe with a filter to remove particles. The sampling line is electrically heated (200-300 °C) to avoid condensation of organic compounds. Emerson gas component analyzer is used for determination of gas components. Mainly determined are O_2, N_2, CO, CO_2, H_2 and CH_4. The bottom ash and fly ash are sampled on line in their individual hopper. During each test, 2-3 gas samplings are carried out at about 30 min intervals and the ash sampling is carried out at about 1 hour interval. All measurements start during the phase of steady operation in order to ensure representative data.

Five thermocouple probes (K-type) are positioned at 0.1 m, 0.3 m, 1 m, 3.2 m and 6.6 m, respectively, above the air distribution plate of the riser. The position of the thermocouple probes can also be seen in Fig. 1. The probes T_1 and T_2 monitor the temperature of the dense phase zone. The probe T_3 monitors the temperature of tapered part. The probe T_4 monitors the temperature of middle-upper part, and the probe T_5 monitors the outlet temperature. Whether the material return is normal can be judged by the temperature change of the standpipe. The probe T_6 is placed at the bottom of the standpipe to monitor the temperature of standpipe separately. Two pressure taps are mounted at the bottom and exit of the riser to monitor the fluidization state in the reactor. The pressure sensors are connected to a computer based data acquisition and control system.

3. Test Procedure

Experiments carried out at the test facility described in this work can be divided into four main phases: empty furnace temperature rise, circulation-free combustion, circulation combustion and pressurized circulating gasification. At the very beginning of each test run, 6 kg of small bed material is put into the standpipe from the outlet of the primary cyclone; the reactor of the riser is heated with an electric heater. After a few hours, the temperature of the dense zone exceeds 600 ºC, then 3.5 kg big material bed is pneumatically conveyed to the reactor and the bed temperature drops quickly. After a few hours of reheating, the bed temperature exceeds 450 ºC again, and then bituminous coal is fed into the reactor under a carefully controlled feed rate that ensures the complete combustion of coal. In such a combustion atmosphere, coal is combusted and the reactor is rapidly heated to about 900 ºC. Then the circulation is started and the temperature of other monitoring points rises gradually. When the circulation combustion reaches to a phase of steady operation, the pressure of the reactor is controlled by the backpressure valve. The transition from combustion to gasification is done by increasing feeding of coal, decreasing the air flow rate, and introducing steam to the gasifier. When operation of the gasifier is stable, i.e. the temperature profile is steady, gas and ash samplings are taken for analysis.

RESULTS AND DISCUSSION

Working conditions are shown in Table 3. No secondary air was used in these tests. The gasification temperature, defined as the average of the temperatures of the thermocouples T_1 and T_2, was maintained at 897-936 ºC in all tests. Air preheating temperature probe is located in the outlet of the air/steam mixer heating.

During the increasing of bed pressure, static bed height, the preheated temperature of the gasify agent, the equivalence ratio and the steam/coal ratio are basically unchanged. Gasifying temperature and the outlet temperature are changed a little. The air/coal ratio is expressed as equivalence ratio (ER). ER and steam/coal ratio are the most important operational variables in the gasification process. Another study was carried out in this pressurized CFB bed to find the optimal operation conditions range for gasification of the bituminous used in the pilot plant tests [14]. On the basis of this study, when the ER is about 0.33 and steam/coal ratio is 0.38 $kg\cdot kg^{-1}$, these parameters have an optimum operating performance.

The bituminous CFB gasification tests were operated in the pressure of the reactor range of 0.1-0.5 MPa to study its effect on the gas quality, with respect to lower heating value (LHV) and raw gas yield, and on the gasification process.

LHV of syngas on dry basis was calculated from the fuel gas composition analyzed by Emerson. The hydrogen balance and the nitrogen balance were used to calculate water vapor content of gas and gas yield, respectively. The fly ash discharged from the secondary cyclone was analyzed to determine carbon content of fly ash. Carbon conversion to dry gas is calculated on carbon evolution (mass flow rate of carbon in fuel gas used divided by the mass flow rate in coal). Cold gas efficiency is calculated based on the total heating value of fuel gas divided by the coal heating value [15].

1. Temperature Profile

The gasifier temperature profiles during the start-up and partly test procedure are shown in Fig. 3. From this figure, it can be seen that before the circulation began, temperature of the dense phase zone, T_1 and T_2, could soon reach about 920 ºC after bed material and coal were fed, then a reaction zone very stable can be observed regarding the temperature. Because the surface temperature in flanged connections and the radiating heat loss are high, and heat absorption of refractory in the reactor, so temperatures T_4 and T_5 rose slowly. After the circulation began, particles including small bed material

Table 3. Working conditions

		0.1 MPa	0.2 MPa	0.3 MPa	0.4 MPa	0.5 MPa
Operation condition						
Coal feed rate	kg/h	2.7	5.2	7.5	8.8	9.5
Air flow rate	Nm^3/h	5.4	10.6	15.6	17.2	18.7
Equivalence ratio (ER)		0.34	0.34	0.34	0.33	0.33
Steam feed rate	kg/h	1	1.9	2.8	3.2	3.6
Steam/coal ratio	kg/kg	0.38	0.38	0.38	0.38	0.38
Operation temperature (mean value)						
Agent preheated temperature	ºC	700	700	700	700	700
Gasifying temperature	ºC	929	905	917	918	920
Outlet temperature	ºC	817	814	822	822	824
Gasification parameter						
Dry gas yield	Nm^3/kg	2.56	2.64	2.72	2.77	2.82
Cold gas efficiency	%	38.69	44.84	50.63	53.07	54.69
Carbon conversion	%	57.79	67.57	76.13	78.49	80.48
Carbon content of fly ash	%	35.22	30.46	27.31	23.75	22.97

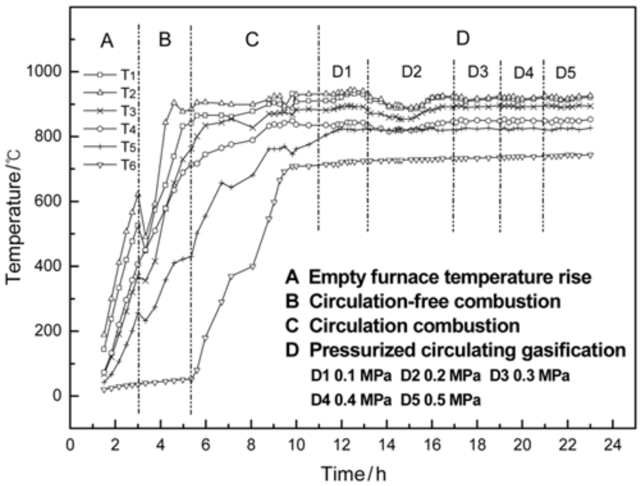

Fig. 3. Gasifier temperature profiles.

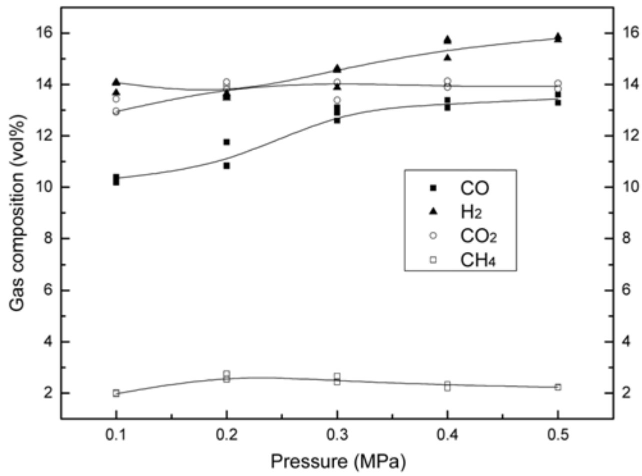

Fig. 4. Effect of pressure on gas composition.

and residence carbons in the standpipe, for their small diameters, were brought into the upper part of the riser, which can promote the residence carbons' participation in combustion. Thus the temperature of the upper part of the reactor, T_4, rose quickly, and the temperature difference between the top and the bottom gradually shrank.

From the figure, it also can be seen that the temperature of T_1-T_3 is uniform and the maximum deviation is only 40 ºC after the gasification process is steady, which indicates perfect gas/solid mixing. The main temperature drop is concentrated between T_2 and T_3 in the lower part of the dense bed. Because of the satisfactory mixing in turbulent beds, a separate reaction zone is not obvious as fixed beds and bubbling beds that result in a uniform temperature distribution in the dense bed on the whole. Temperature of the lowest part of the standpipe, T_6, increased quickly from 70 ºC after the circulation began and stayed 725-745 ºC. The average of the temperatures of the thermocouples T_1 and T_2 was maintained at 897-936 ºC, and the temperature probe T_5 located in the exit of the gasifier was 817-852 ºC, about 70 ºC lower than T_1 due to the heat loss and gasification reaction in the freeboard.

2. Effect of Gasifier Pressure

As the pressure increased, the bed temperature, gasifying agent temperature, static bed height, and steam-to-coal ratio were fixed. Since gasification temperature or bed temperature is one of the most important operating variables [16] the ER was adjusted slightly to maintain a constant bed temperature.

2-1. Gas Composition

Effect of pressure on gas composition is shown in Fig. 4. The results show that the pressure significantly affects the gas composition. As can be seen from the figure, when pressure increased from 0.1 MPa to 0.5 MPa, CO and H_2 concentrations exhibited a most substantial increase, from 10.17% and 13.68% to 13.6% and 15.86%, respectively. However, CH_4 and CO_2 concentrations changed slightly with varying pressure. CH_4 concentration increased first and then decreased, ranging from 1.96% to 2.74%; CO_2 concentration slightly decreased.

If only from the reaction equilibrium point of view, the pressure on gasification reaction is negative. But in the actual operation of the fluidized bed gasifier, it cannot reach the equilibrium state, and results indicated that pressurization improved the fuel gas quality. The reasons for it are as follows: on one hand, this result, possibly due to that the gasification kinetics, was enhanced directly by pressure. Pressurization increases the reaction rate and promotes the following three important reactions in coal gasification, increasing the contents of combustible components, CO, H_2 and CH_4, in the coal gas.

$$C+CO_2 \rightleftarrows 2CO \qquad \Delta H=159.7\ kJ/mol \tag{1}$$

$$C+H_2O \rightleftarrows CO+H_2 \qquad \Delta H=118.9\ kJ/mol \tag{2}$$

$$CO+H_2 \rightleftarrows CO_2+H_2 \qquad \Delta H=-40.9\ kJ/mol \tag{3}$$

Combustible components increase with increasing pressure and then level off at a pressure higher than 0.3 MPa. It is thus clear that pressurization influences the coal gasification rate greatly under low pressures but has hardly any effect under high pressures. In this test, the effect was quite marked in the pressure range of as low as 0-0.3 MPa.

On the other hand, fluidization in the reactor becomes better at higher pressure. In gasification, ideally, all coal powder can thoroughly contact and react with the gasifying agent. However, in practice, this ideal state cannot be realized, and coal powder and the gasifying agent are always in non-uniform distribution. Varadi and Grace investigated homogeneous fluidization using air with a density increased by 20 times to fluidize 260 μm sand under 1.5-2.2 MPa [17]. Therefore, pressurization cannot realize homogeneous fluidization but increases, to a certain extent, the density of the gasifying agent and approximates the fluidization form to ideal state. Pressurized turbulent fluidization in the lower part of the reactor causes fast aggregation and ruptures of numerous bubbles, while pressurization reduces the bubble size, increasing the volume of the dense phase area for uniform gas-solid contact and prolongs the residence time of the gasifying agent in the dense bed, which favor the gasification reactions in the gasifier [18].

In hydrogenation reactions for producing methane, linearity between the reaction rate and the hydrogen partial pressure is manifested at comparatively large scope. On one hand, methane is generated from the cracking of coal. On the other hand, H_2/CO is produced

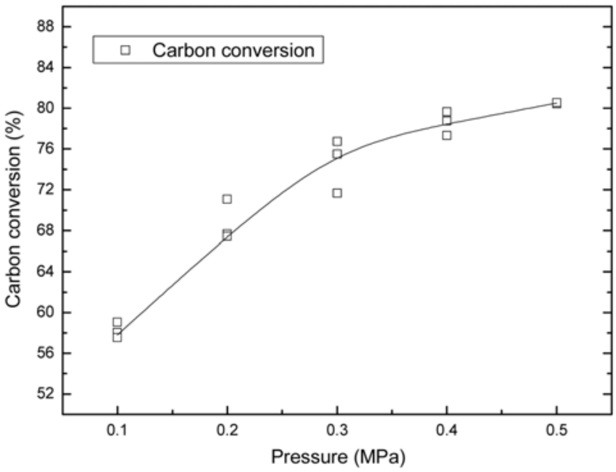

Fig. 5. Influence of pressure on carbon conversion.

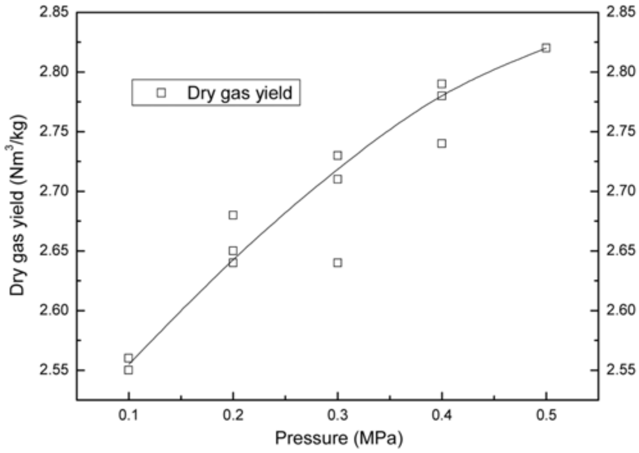

Fig. 7. Effect of pressure on yield of the syngas.

by methane continuous conversion reaction at the same time. Methane concentration is related to gasifier temperature and pressure. After the system pressure begins to rise, methane concentration gradually increases. However, the pressure of the tests is not very high, and the majority of the methane originates from volatile components of the coal, which could be inhibited by pressurization; increasing the temperature of the reactor decreased the generation of the methane concentration. So the methane concentration changes very little due to contradiction of the two effects.

2-2. Carbon Conversion

Fig. 5 shows the influence of pressure on carbon conversion. The carbon loss is unreacted carbon contained in the bottom ash and fly ash discharged from the gasifier. At the pressure range studied from 0.1 MPa to 0.3 MPa, the carbon conversion varied from 57.52% to 76.76%. Afterwards, continual pressurization had little influence on the carbon conversion, which maintained at 80.55% under 0.4-0.5 MPa. That is, the carbon conversion increase was notable during the initial stage of pressurization, which agrees with the studies published by other authors [19,20].

2-3. Carbon Content of Fly Ash

The effect of pressure on carbon content of fly ash is presented in Fig. 6. The results show that the pressure significantly affects the carbon content of fly ash. Increasing the pressure decreased the carbon content of fly ash form 35.22% of 0.1 MPa to 22.97% of 0.5 MPa. The explanation for these results is that possibly the actual velocity of fuel gas decreases with increasing the pressure. So the coal powders brought out of the reactor were small and the total amount of fly ash brought out decreased correspondingly. Zhang et al. [3] studied the coal gasification process in normal pressure CFB. In their studies, the content of carbon in the fly ash was, in general, 40%-50%, which leads to lower carbon conversion.

2-4. Gas Yield

Effect of pressure on yield of the syngas is shown in Fig. 7. Increase in pressure generally also leads to an increase in gas yield. From these experimental tests, the gas yield varies from 2.56 Nm^3/kg at a pressure of 0.1 MPa to 2.82 Nm^3/kg at a pressure of 0.5 MPa. A higher gasification pressure will produce more fuel gas due to more carbon converted to gas.

2-5. Cold Gas Efficiency

The effect of pressure on cold gas efficiency is shown in Fig. 8. As can be seen, cold gas efficiency increases sharply with pressure up to 0.3 MPa and then increases slowly at pressure higher than 0.3 MPa. The results are mainly due to the gasification rate that varies

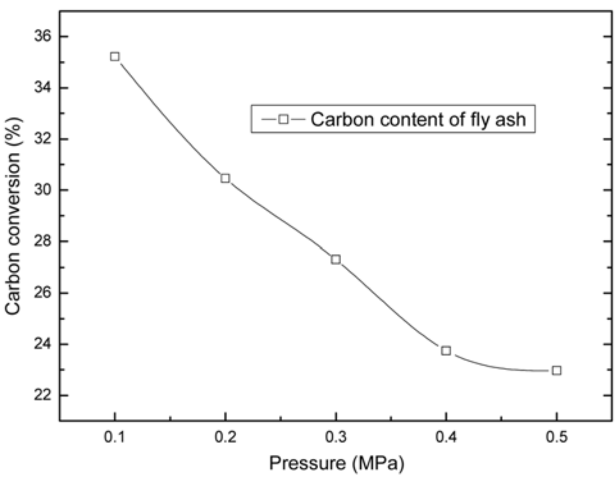

Fig. 6. Effect of pressure on carbon content of fly ash.

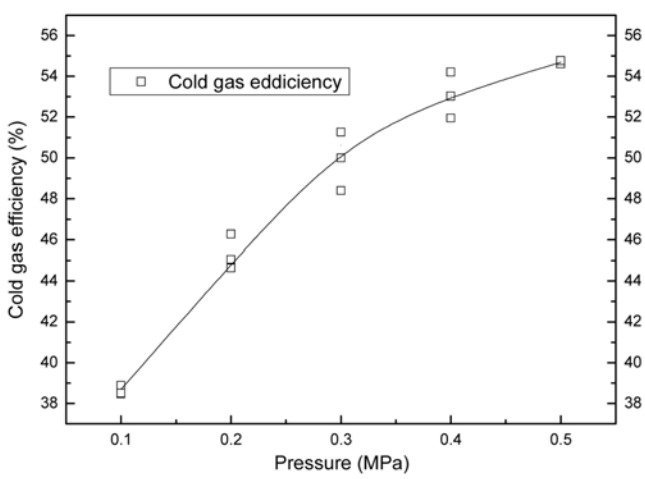

Fig. 8. Effect of pressure on cold gas efficiency.

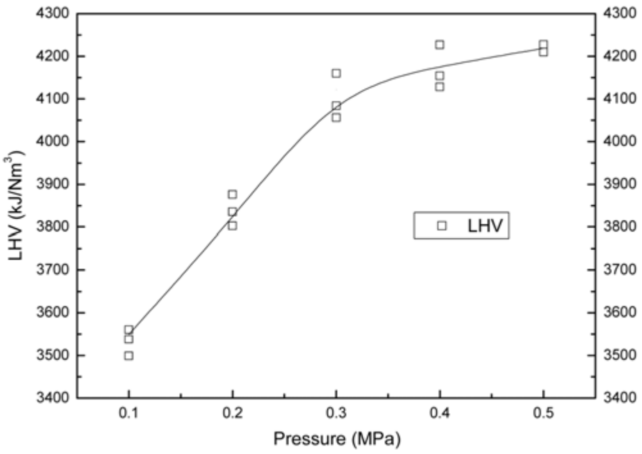

Fig. 9. Effect of pressure on LHV.

with the increase of the operation pressure.

As defined previously, the cold gas efficiency depends on dry gas yield, lower heating value of syngas, and calorific value of bituminous. While the calorific value of bituminous is a fixed value, dry gas yield increases with the increasing pressure; LHV of syngas increases with increasing pressure and then levels off at pressure higher than 0.3 MPa. So the cold gas efficiency also expresses a similar tendency with dry gas yield.

2-6. Lower Heating Value of Syngas

Fig. 9 presents the gas LHV at different reaction pressure. Compared with experimental results obtained by other authors [1-5], gas LHV shows a significant increase from 3,550 to 4,083 kJ/Nm^3 due to an improvement of fluidization when the pressure is increased to 0.3 MPa. The results are mainly due to the combustion components increase with increasing pressure. The influence of pressurization on reaction rate was weak when the pressure was above 0.3 MPa. The reaction rates of (1) and (2) are independent of partial pressure when the pressure increases to a certain level [21].

In addition, the reaction equilibrium shifts towards the reverse direction with the pressure increase for reaction (1), reducing the content of CO of syngas. Therefore, in terms of chemical equilibrium, high pressurization is unfavorable to increase of LHV of coal gas. Under high pressures, the significant increase of pressure influence on LHV begins to slow. However, the major effects of continuously elevated pressure on coal gasification are manifested as improving the gasification intensity, increasing the production capacity, compacting the equipment, etc.

3. Material Balance Data

Material balance data are shown in Table 4. Because all tests are carried out continually, bottom ash is calculated based on ash balance. From this table, it can be seen that the material taken into the gasifier is nearly equal to the material out of the gasifier.

CONCLUSIONS

The pressurized turbulent circulating fluidized bed gasification realized at Southeast University is able to perform, due to the electrical heating of the reactor, allothermically as well as autothermically. Therefore, it opens the possibility to investigate the gasification process at different pressures, which are so far sparsely published. At this stage of the project, the influences of the gasification stability and the operating pressure have been investigated.

Due to the successful running of long-term experiments, results presented in this work show that continuous operation of the turbulent CFB gasification under different operating conditions is feasible. Pressurization significantly improved the component of the coal gas. When the gasifying pressure increased from 0.1 MPa to 0.5 MPa, CO concentration exhibited a most substantial increase, from 10.17% to 13.6%; H_2 concentration increased also from 13.68% to 15.86%; CH_4 concentration increased first and then decreased, overall ranging from 1.96% to 2.74%; CO_2 concentration slightly decreased. Additionally, the reaction improved the LHV of coal gas by 15% when the pressure was changed from 0.1 MPa to 0.3 MPa. The turbulent fluidization at the bottom of the furnace ensured volume increase of the dense phase zone for homogeneous gas-solid contact, improving the coal gas composition and gradually increasing the carbon conversion. The effect was especially marked when the pressure was below 0.3 MPa; an increase from 57.52% to 76.76% was generated. Following the pressure increase, gas yield and cold gas efficiency also increased with the pressure, while the carbon con-

Table 4. Material balance data

		0.1 MPa	0.2 MPa	0.3 MPa	0.4 MPa	0.5 MPa
Material in (kg/h)						
1	Coal	2.7	5.2	7.5	8.8	9.5
2	Steam	1	1.9	2.8	3.2	3.6
3	Air	7.24	13.7	20.1	23	24.2
	Oxygen	1.65	3.15	4.62	5.29	5.57
	Nitrogen	5.67	10.55	15.48	17.71	18.63
4	Total	10.94	20.8	30.4	35	37.2
Material out (kg/h)						
1	Dry gas	8.8	17.78	26.21	30.24	32.49
2	Steam of syngas	0.33	0.62	0.91	1.1	1.2
3	Fly ash	0.38	0.36	0.32	0.27	0.25
4	Bottom ash	0.8	1.68	2.43	2.85	3.1
5	Total	10.31	20.44	29.87	34.46	37.04

tent of fly ash decreased from 35.22% under 0.1 MPa to 22.97% under 0.5 MPa.

Within the scope of this project further experimental research with a focus on the effect of circulating flux on gasification will be carried out, especially the influence of the operating pressure on the syngas composition, including ammonium content as well as H_2S content will be investigated.

From the constructed test facility exact data have been obtained and validated and a simulation model is about to be generated. Therefore, existing gasification models have already been extended with the parameter of pressure. The lessons learned of the pressurized gasification unit should give fundamentals for the development of bigger pilot plants and provide a basis for scale up to demonstration plants.

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