COMBUSTION CHARACTERISTICS OF DISTILLED SPIRIT LEES ON A DUAL FB SYSTEM AND A CFB SYSTEM

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Abstract − To treat the high-water (30-60 wt. %) industrial biomass residue effectively and environmentally friendly, such as distilled spirit lees (DSL), a novel decoupling combustion process adopting dual fluidized bed (DFB) reactor has been proposed. On the basis of previous fundamentals, an industrial demonstration plant with a treatment capacity of 50 000 t/y has been designed and built, which can operate under the DFB and CFB modes. Compared to the direct combustion of DSL in CFB combustion, the operating mode of first pyrolysis or partial gasification of fuel and then combustion of fuel gas can bring a stable combustion easily, and effectively inhibit the produced NOx, reaching the level of 50 ppm, far below the Chinese gas emission standard. Up to now, this system has run over 1000 hours, fully demonstrating the technology feasibility and property.

1. INTRODUCTION

As the world's largest producer and consumer of distilled spirits, China has a production capacity of about 12.5 million tons per year, leading to around 30 million tons of distilled spirits lees (DSL) each year. Being the main solid residue in the fermentation process, distilled spirits lees have high moisture content above 70% and many nutrient components, making them easy to decay and thus cause serious environmental problems, such as groundwater pollution and smelly gas release [1]. On the other hand, due to the property of ready collection and abundance in cellulose, hemicellulose and lignin, DSL can be employed as a kind of renewable energy source. So, how to reuse and recycle this kind of biomass resource on the industrial scale effectively and environmentally friendly is a very urgent significant, yet difficult topic.

Considering the large amount of steam needed in spirit production, the technical route of combust DSL to produce steam seems very promising and convenient, which will utilize DSL in large-scale, replace the utilization of coal-fired boiler and thus avoid the greenhouse gas emission. However, the existing direct combustion by grate boiler and CFB boiler is very difficult for the feedstock with high moisture above 25% [2-3]. Moreover, even for the low moisture DSL, the existing direct combustion process still face the problems of low combustion efficiency and high NOx emission in flue gas.

On this basis, a novel dual fluidized bed decoupling combustion technology has been proposed by Institute of Process Engineering (IPE), Chinese Academy of Sciences (CAS). As shown in Fig.1, this process decoupled the complexed combustion process into feedstock pyrolysis and combustion of pyrolysis product by a FB pyrolyzer and transport FB (TFB) combustor, respectively. DSL is firstly heated by the high-temperature heating carrier particles (HTHCPs) and then pyrolyzed or partial oxidation in the FB pyrolyzer. The produced char from pyrolyzer mixed with the low-temperature heat carrier particles (LTHCPs) and then is forwarded to the bottom of the TFB combustor to generate heat, while the pyrolysis gas with tar is sent to the middle of TFB combustor to co-combustion with char. Depending on the reduction effects of both char and reducing species in fuel gas from pyrolyzer [4], the released NOx in combustor will be decreased strongly.

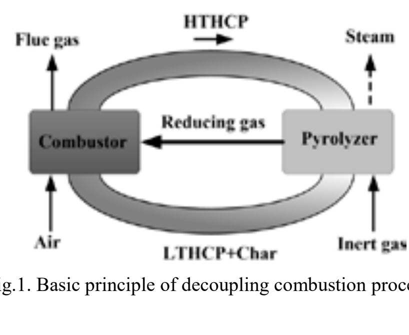


Fig.1. Basic principle of decoupling combustion process.

In this paper, an industrial demonstration plant adopting the newly developed combustion process will be introduced, and the decoupling combustion characteristics of DSL on this plant will be examined systematically. Finally, to display the technical features of decoupling combustion, the results from direct combustion and decoupling combustion were compared further.

2. EXPERIMENTAL SECTION

2.1. FUEL AND BED MATERIAL

The DSL residue adopted in this study was from a distilled spirits company located in Sichuan Province of China, whose proximate analysis, ultimate analysis and heating value were listed in Table 1. From it, one can see clearly that the contents of volatile and nitrogen were very high. To make the operation easy, coal ash was adopted as heat carriers by adding a certain amount coal in combustor. The particle size of the employed coal particles was in the range of 0-5 mm.

2.2. INDUSTRIAL DEMONSTRATION PLANT

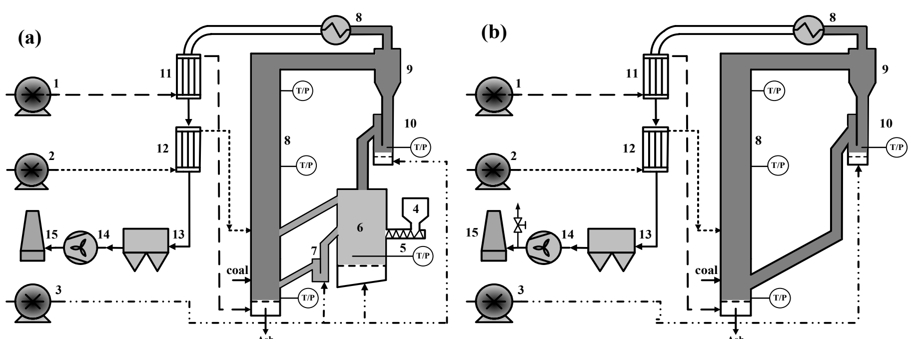
An industrial demonstration plant adopting the DFB decoupling combustion process was designed and built in Sichuan province of China, which has a treating capacity of 50000 t/a and operates under the mode of DFB and CFB, as illustrated in Fig.2 (a) and Fig.2 (b), respectively.

Table 1. The proximate analysis and elemental analysis of DSL and coal.

Sample	Proximate analysis (wt.%)				Elemental analysis (wt.%)					LHV (MJ/kg)
	M_{ad}	V_{ad}	FC_{ad}	A_{ad}	C_{daf}	O_{daf}*	H_{daf}	N_{daf}	S_{daf}	
DSL	29.98	43.40	12.95	13.67	54.24	39.14	3.07	3.27	0.28	15.62
Coal	3.92	16.61	44.53	34.94	58.85	36.66	2.76	0.88	0.85	17.37

ad: air-dry basis; daf: dry ash free; * by difference

In the DFB system, a bubbling fluidized bed pyrolyzer with a height of 4.5 m and TFB combustor with a height of 24.5 m were adopted. DSL and coal were added into pyrolyzer and combustor respectively by different screw feeders. The heat carriers were circulated in the pyrolyzer and gasifier via cyclone separator and two loop seals. When DSL was fed into the pyrolyzer, it was quickly heated by HTHCP and reached a steady fluidization state in pyrolyzer. The residual char was carried out by bed material and forwarded to the bottom of the combustor through the regulation of loop seal. The generated fuel gas flowed into the middle of combustor to co-firing with char. In the bottom of combustor, coal was fed to stabilize the bed temperature, and the produced coal ash can be used as the bed material. Compared to the DFB system, the CFB system did not have the bubbling fluidized bed pyrolyzer, and the DSL and coal were fed into the bottom of riser combustor. In terms of heat exchanging and flue gas purification system, it shared with DFB system. A flue gas sampling point was located in chimney for analyzing the gas composition. For both of the DFB system and CFB system, in operation, the start-up of the plant was firstly heated by burning coal in TFB combustor to raise their temperatures to a required value, which usually lasted about 20 hours.



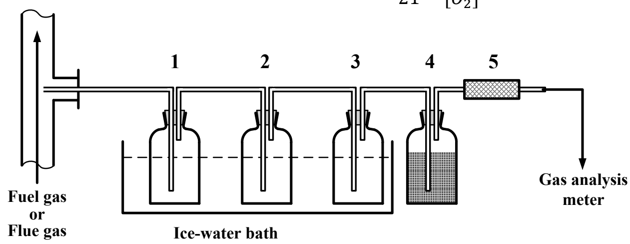
1-primary air fan, 2-secondary air fan, 3-air fan for pyrolyzer, 4-feedstock hopper, 5-screw feeder, 6-FB pyrolyzer, 7-downstream loop seal, 8-TFB combustor, 9-cyclone, 10-upstream loop seal, 11- primary air heat exchanger, 12-secondary air heat exchanger, 13-bag-type dust collector, 14-induced fan, 15-chimney

Fig. 2. Schematic of dual fluidized bed (a) and circulating fluidized bed (b) system.

2.3. FUEL GAS AND FLUE GAS ANALYSIS

The components and heating value of fuel gas from pyrolyzer was analyzed by an infrared gas analyzer (Gasboard-3100P), while the components of flue gas produced in combustor was measured by a handy flue gas analyzer (Testo 350 M/XL). As shown in Fig.3, before analysis, the fuel gas was preheated by removing dust and water by silica gel and filter. The emission of NO_x was calculated on the basis of 6% oxygen content using the following equation, respectively, (mg/Nm^3). Where [NO], [NO_2] and [SO_2] were the contents of NO, NO_2 and SO_2 in ppm; [O_2] was the oxygen content of flue gas in vol.%.

$$NO_X\ emissions = 2.05 \times ([NO] + [NO_2]) \times \frac{21 - 6}{21 - [O_2]} \qquad (1)$$



1/2/3 Ice-water bath, 4-silica gel drying bottle,5-filter

Fig. 3. Schematic of gas cleaning for fuel gas and flue gas analysis.

3. RESULTS AND DISCUSSION

During tests of DFB system and CFB system, the feeding rate of DSL with moisture about 30 % was maintained at 3 t/h more or less, while that of coal was kept at about 0.9 t/h. Air was used as carrier gas and oxidation agent in pyrolyzer and combustor.

Figure 4 shows the temperature variation of different points in DFB and CFB systems. From Fig.4 (a) for DFB system, it can be seen that, generally, the temperature of combustor began to stabilize in about 20 hours after operation, while that of gasifier reached a steady state in about 40 hours. In the normal operation mode, the temperatures in the bottom of gasifier and combustor were about 610 °C and 850 °C, respectively. The smooth curves in stable stage indicated a continuous and steady run of this industrial demonstration plant.

For the CFB system, it firstly operated in normal operating mode for only coal combustion. Then the DSL was fed into the bottom of combustor, and the feeding rate of coal and DSL were regulated into the required values. From Fig.4 (b), one can see that after DSL was fed into combustor, the temperature of the combustor and loop seal fluctuated strongly. After 90 min, the temperature in bottom of combustor decreased to 600 °C rapidly, while the temperature in loop seal and middle and top of the combustor raised up to 1000 °C. Both of these indicated that perhaps it mainly conducted the drying or pyrolysis process of DSL in the bottom of combustor, while the combustion reaction mainly happens in the middle and top of the combustor. Obviously, the combustion area would move upward.

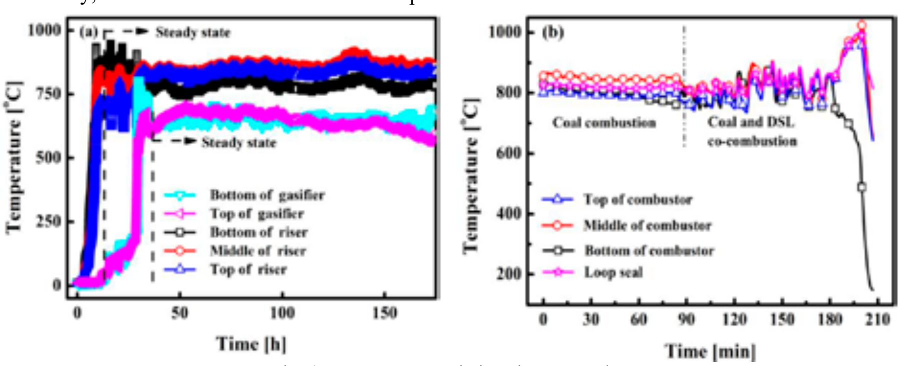


Fig. 4. Temperature variations in DFB and CFB system.

Figure 5 displays the variation of pressure drop at different points in DFB and CFB systems. For the DFB system, the pressure drop increased quickly and then reached a steady value from the starting-up stage to steady stage. In the normal operating mode, the pressure drops at the distributing plant in gasifier and combustor were kept at about 1.5 kPa and 5.5 kPa, respectively. The smaller fluctuations during the steady state also shows the good operating state of DFB system for the DSL. While for the CFB system, it can be seen that after feeding DSL, the pressure drop at the bottom and middle of combustor began to increase and fluctuate remarkably, indicating the absence of partial fluidization and dead bed. After that about 90min, the previous steady mode of coal combustion was destroyed, and the CFB system had to stop.

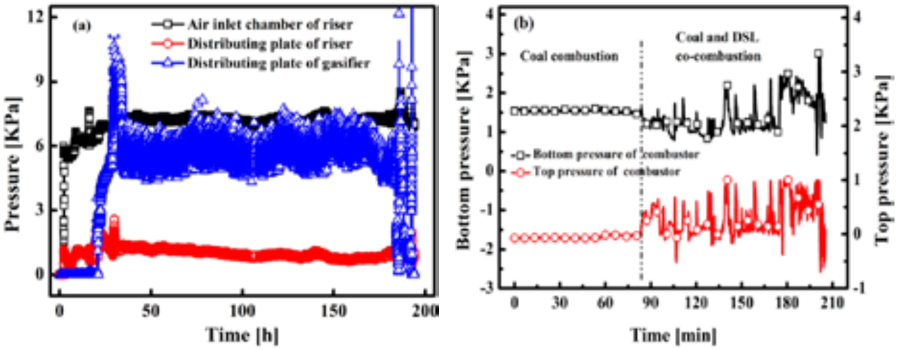


Fig. 5. Pressure drop variations in DFB and CFB system.

For the CFB system, during the maintenance and clean work, obvious slagging phenomenon can be seen in combustor and loop seal connected to cyclone. Figure 5 shows the picture of slags for the CFB system. The slag in combustor was much related to the high combustion temperature in the bottom and top of combustor, while the slag in loop seal was mainly due to the high temperature and carbon content in fly ash, indicating the lower combustion efficiency in direct combustion. The slag would block the circulation of bed material seriously during running, which might be one of the major reasons for bottom temperature of riser combustor decreasing sharply. From Figure 5(b), it is clearly that high temperature melted the ash of coal and DSL, resulting in the slag formation.

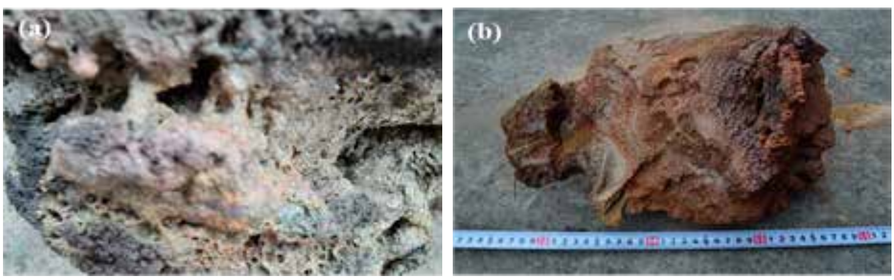


Fig. 5. Picture of slag in the combustor (a) and loop seal (b) for the CFB system

In the steady stage of DFB system, the average gas components of fuel gas from pyrolyzer, including O_2, CO_2, CO, H_2, CH_4, N_2, were about 1.92 %, 17.44 %, 7.74 %, 7.10 %, 4.14 %, 61.66 %, respectively. As air was selected as gasification agent, the content of N_2 was dominant, leading to lower LHV of fuel gas. The reductive gas will further affect the combustion characteristics of DSL in DFB system [5].

Figure 6 illustrates the compositions of flue gas from DFB and CFB system. In the steady state of DFB system, the components of flue gas (O_2, CO_2, CO and NO_x) showed narrower fluctuation of each composition concentration indicated the operation stability of combustor. Obviously, the content of CO was no more than 3000 ppm, indicating complete combustion. And the content of NO_x was only about 45 ppm (98 mg/m^3), far below the national emission standard of flue gas for coal-fired boiler (400 mg/m^3, GB 13271-2014). For the CFB system, the NOx emission in flue gas was higher and fluctuated fiercely, which was very close to emission standard of 400 mg/m^3. Compared to the DFB system, decoupling combustion technology obviously decreased the NOx emission. Perhaps this is mainly because the generated reduction gas components, including CO, H_2, CmHn, NH_3 and HCN, could reduce NOx into N_2.

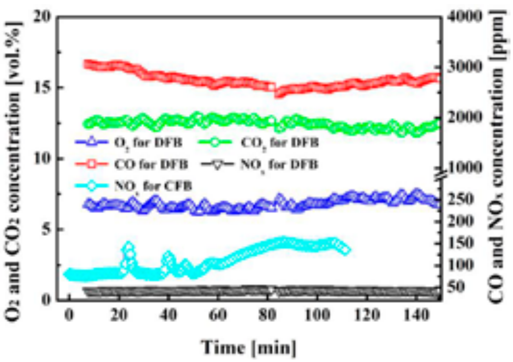


Fig. 6. Comparison of gas components in flue gas for DFB and CFB system

4. CONCLUSIONS

To utilize the high water- and high N-containing DSL, a new DFB decoupling process was proposed, and an industrial demonstration plant has been designed and built. Under the temperatures of pyrolyzer and combustor at about 610 °C and 850 °C, the decoupling combustion system can operate steadily and continuously. Compared to direct combustion in CFB system, the decoupling combustion in DFB system had higher combustion efficiency for the high water DSL and lower NOx emission in flue gas.

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