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Fundamentals of coal topping gasification: Characterization of pyrolysis topping in a fluidized bed reactor

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ABSTRACT

Coal topping gasification refers to a process that extracts the volatiles contained in coal into gas and tar rich in chemical structures in advance of gasification. The technology can be implemented in a reactor system coupling a fluidized bed pyrolyzer and a transport bed gasifier in which coal is first pyrolyzed in the fluidized bed before being forwarded into the transport bed for gasification. The present article is devoted to investigating the pyrolysis of lignite and bituminite in a fluidized bed reactor. The results showed that the highest tar yield appeared at 823 to 923 K for both coals. When coal ash from CFB boiler was used as the bed material, obvious decreases in the yields of tar and pyrolysis gas were observed. Pyrolysis in a reaction atmosphere simulating the pyrolysis gas composition of coal resulted in a higher production of tar. Under the conditions of using CFB boiler ash as the bed material and the simulated pyrolysis gas as the reaction atmosphere, the tar yields for pyrolytic topping in a fluidized bed reactor was about 11.4 wt.% for bituminite and 6.5 wt.% for lignite in dry ash-free coal base.

1. Introduction

Coal is the oldest fossil fuel used by human being, and would still be the major energy resource in the future for China. Coal is generally burned to produce heat and power by completely converting the fuel C into CO_2, the major green house gas. Coal gasification, a process to convert coal into fuel gas or syngas, has the potential to allow efficient and clear utilization of coal. The feedstock for coal gasification is generally rich in volatiles, such as lignite, sub-bituminite and bituminite that are abundant in high-value chemical structures like aromatic rings. In face to the serious shortage of petroleum resources, the use of chemical structures containing in volatile-type coals has become already the strategic choice of many countries in terms of safely supplying aromatic chemicals from resources other than petroleum. Therefore, how to extract the valuably structured chemicals from the coals consumed in combustion and gasification is a fantastic topic to many scholars.

The idea of extracting volatiles of coal in prior to its combustion or gasification can be implemented by coupling the coal pyrolysis into an existing coal combustion or gasification process. The so-called topping gasification was born with this idea and refers to a process that co-produces fuel gas (or syngas) and the aromatics-containing tar from coal. Fig. 1 illustrates the principle of the topping gasification process. The system of the process is based on a bed combination of a fluidized bed for pyrolysis and a transport bed for gasification. Coal is fed into the fluidized bed pyrolyzer to incur there its pyrolysis (including drying) by its interaction with the circulated hot particles (i.e. ash) to produce tar and pyrolysis gas. The resulting char is in turn forwarded to the transport bed to undergo its gasification through the interaction of char with the reagent like O_2, steam and CO_2.

In this coal cascade conversion process, the coal pyrolysis is critically important to the overall performance of the system. On the other hand, the pyrolysis in his process depends closely on the interaction between coal and hot coal ash particles, making it much different from the other traditional coal pyrolysis processes. Principally, the riser combustor of a CFB boiler can be integrated with a pyrolyzer of the bed type as a downer, a moving bed or a fluidized bed. Wang et al. [1] investigated the coal pyrolysis in a downer reactor integrated into a riser combustor, finding that the maximal tar yield was amounted to 14.5 wt.% of dry coal basis for Huolinhe lignite below 280 μm at 933 K. This is a tar yield much higher than the achievable values in the reactors of other types, such as moving bed referred to herein. The investigation of Liang et al. [2,3] in a moving-bed pyrolyzer run by blending coal and hot heat carrier particles (HCPs) demonstrated that increasing the temperature of the HCPs and the HCPs-to-coal blending ratio improved significantly the yield of

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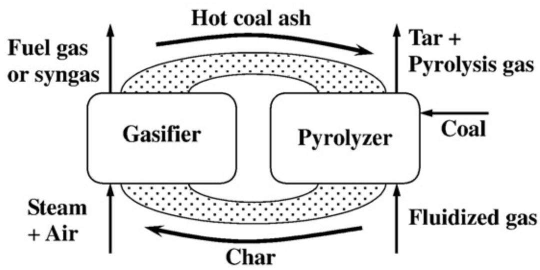

Fig. 1. Principle illustration of the topping gasification process.

pyrolysis gas. Their realized maximal tar yield was up to 11 wt.% in dry coal basis for Shenmu bituminite using quartz sand of 1123 K as the HCPs and about 7 wt.% for Fugu coal using coal ash of 1093 K as HCPs. Regarding coal pyrolysis in fluidized bed, there were actually very few reports under the conditions simulating the coal topping gasification process illustrated in Fig. 1.

From engineering aspect it is really challenging to achieve good mixing of coal and HCPs in large scale moving bed. Regarding the pyrolysis in downer reactor, its suitable feedstock should be coal powders in tens of micrometers because the reaction time is limited to a few seconds [1]. This has to require coal pulverization and for CFB boilers it represents an issue worthwhile to be deeply considered when referring to technology commercialization. Fluidized bed is characterized with its high-efficiency heat exchange and good particle contact/interaction that enables good blending of coal and HCPs. Furthermore, the coal used for CFB boilers in sizes below 10 mm can be treated directly in the fluidized bed pyrolyzer, while the fluidized bed pyrolyzer is also relatively easy to be scaled up. Hence, the use of a fluidized bed pyrolyser to implement the coal topping in CFB-type boilers or gasifiers is seeing good promise, requiring thus the fundamentals of coal fluidized bed pyrolysis, especially in terms of tar production.

There exist some literature studies on coal pyrolysis in reactors of fluidized bed type but under conditions different, at least to a certain degree, from the topping requirement. Tyler [4] carried out experiments of coal flash pyrolysis in a sand-fluidized bed reactor with continuous feedstock and realized their maximal tar yield of 23 wt.% at 853 K for Long Yang lignite below 200 μm. In the same experimental setup, Calkins and Bonifaz [5] examined coal flash pyrolysis at temperatures above 973 K in CH_4 atmosphere, resulting in production of much more ethylene and other hydrocarbons comparing to in N_2. The research in CSIRO of Australia reported that for maximizing the tar yield the suitable pyrolysis temperature for Long Yang lignite is around 853 K in a fluidized bed with a continuous feedstock of 20 kg/h [6]. Li et al. [7–9] studied the effect of temperature on pyrolysis under an intention of developing a pyrolysis model, finding that increasing the fluidized bed reactor temperature varied the gas product composition and the maximal tar yield could appear at 873~923 K.

The present work is devoted to demonstrating the feasibility of using a fluidized bed pyrolyzer to implement the coal topping in the CFB-type gasification (or combustion) process. The pyrolysis of coal, peculiarly the tar production, was tested in a quartz-glass fluidized bed reactor under varied conditions simulating the operation situations of the preceding coal topping. The examined major variables are temperature, coal type and reaction atmosphere. For the first time the article studied the influence on coal pyrolysis of the coal ash from a commercial CFB boiler.

2. Experimental

2.1. Materials

The two types of high volatile coals tested were a lignite from Xiaolongtan (XLT) and a bituminite from Shanxi (SX), and all tested samples had the size of 4–6 mm. Table 1 summarizes the data of proximate and ultimate analyses for the coals dried in an atmospheric oven of 383 K for 3 h. Quartz sand in sizes of 212–380 μm was usually used as the bed material of the fluidized bed reactor. When testing the effect of coal ash, a kind of coal ash from a commercial CFB boiler was used instead of the quartz sand. Table 2 shows the XRF analysis result for the coal ash.

Table 1
Proximate and ultimate analyses for the tested coals dried in advance.

Coal	Proximate analysis [wt.%]			Ultimate analysis [wt.%]				
	M_{ad}	V_{ad}	A_{ad}	C_{ad}	H_{ad}	S_{ad}	N_{ad}	O_{ad}
XLT	4.44	48.96	13.40	56.38	3.57	1.56	1.30	19.35
SX	1.71	31.21	18.20	64.58	4.08	0.62	1.10	9.71

Table 2
XRF analyses of the employed coal ash from a CFB boiler.

Compounds	SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_3
Concentration (wt.%)	41.17	20.70	18.15	7.23	6.51

2.2. Apparatus and method

Fig. 2 shows a schematic diagram of the employed experimental apparatus. The reactor, with an inner diameter of 60 mm and a height of 700 mm, was made of quartz glass and had a porous plate as its gas distributor. The static bed height of the bed material was about 350 mm usually. A K-type thermocouple was placed below 10 mm of the particle-bed surface to measure the bed temperature.

The fluidizing gas, providing reaction atmosphere as well, was formed by mixing the needed component gases (H_2, CH_4, CO, CO_2, N_2) from their cylinders under controls of mass flow meters. The superficial gas velocity at operating temperature was fixed at 0.068 m/s. When the reactor had the desired temperature and reaction atmosphere, 10 g of coal sample was fed quickly into the reactor via a two-stage valve. The discharged gas from the pyrolyzer was quickly cooled down in a pipe condenser and in turn passed through five acetone-washing bottles immersed in an ice-water bath

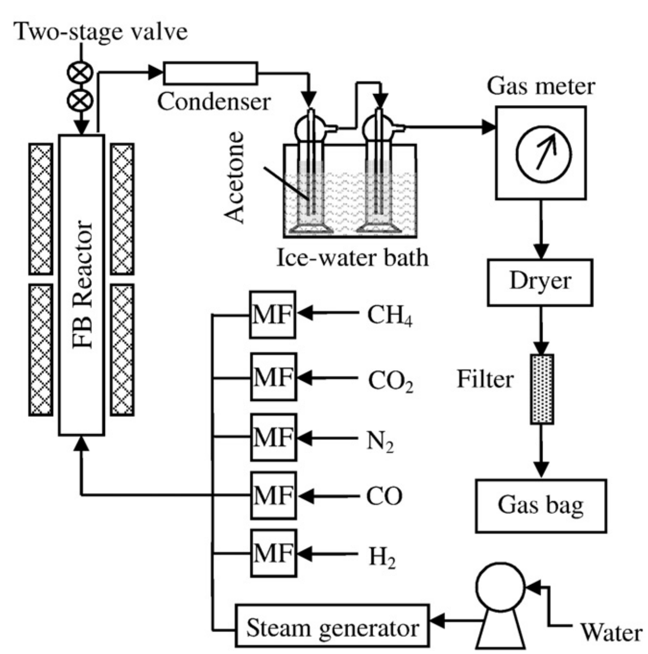

Fig. 2. Schematic of experimental apparatus.