PRESSURIZED FLASH DRYING CHARATERISTICS USING SUB-BITUMINOUS COALS FOR CIRCULATING FLUIDIZED BED GASIFIER

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Abstract – Low rank coals are abundant, easily accessible and mineable with low costs. However thermal efficiency of low rank coal is relatively low and it can increase fire risks and transportation costs because of high moisture content. Therefore drying or dewatering prior to thermo-chemical conversion processes, such as combustion, gasification and so on, should be inevitably used for the economical usage of low rank coal. Especially gasification offers one of the most versatile and clean ways to convert fossil fuel or biomass resources into electricity, hydrogen, and other valuable products. Among various gasifiers, circulating fluidized bed (CFB) gasifiers might be the most suitable option to gasify low rank coal and biomass resources because of advantages of CFB gasifiers. Even if CFB gasifier is used, moisture in low rank coals should be reduced to improve gasification efficiency. To study flash drying characteristics a pressurized flash drying system was designed and experimented. The effects of pressure (up to 40 bar), drying temperature (up to 600 °C), particle size (212-300 μm, 300-355 μm) on drying ratios were investigated. As a result, the drying ratio increases with temperature and length of drier. However, an increase of pressure was not always good solution.

INTRODUCTION

The rapid development of developing countries' economy, such as China, India and so on, resulted in the increase of energy need and energy price fluctuation. Many countries insufficient for energy resources have paid attention to more abundant, cheap energy resources. Especially Korea which is 9th biggest coal consumer and 3rd biggest coal importer has made efforts to gain enough energy resources economically. However, prices of oil and gas have severely fluctuated and it is difficult to secure enough bituminous coal due to the decrease of high quality coal export. Therefore, many countries such as Korea could try to increase the consumption of low rank coals because low rank coals are abundant, easily accessible and mineable with low costs[1-4].

Lignite has been considered as a potential primary energy resource due to huge reserves, significant amount of volatile matters, low amount of pollution-generating impurities and low content of heavy metals. In spite of these advantages, the high moisture content of lignite might be one of major problem which has prevented to be used in energy industries. The high moisture content brought various issues, such as: (1) The origin of lignite is economically underdeveloped, the using of local is limited, the long distance transportation increase the costs; (2) High volatile lignite, high reactivity is not conducive to long-term storage, as a result of lignite mainly used for electricity generation of pithead, if directly into the boiler combustion, part of the heat for evaporation, low energy efficiency, and increases CO_2 greenhouse gas emissions[5,6].

To increase or expand the usage of lignite in industry fields, drying or dewatering lignite should be essentially needed prior to thermochemical conversion processes, such as pyrolysis, combustion, gasification and liquefaction. Until now, various drying processes for lignite such as rotary tube drier, fluidized bed drier, mechanical thermal dewatering, hydrothermal dewatering, solvent dewatering, flash drying have been developed in the world[7,8]. Each drying methods had its own advantages and disadvantages[8]. For example, the most common drying way was rotary drying; however, large-scale subjected to rotary diameter. Hydrothermal drying technology received the high temperature and high pressure restrictions and high cost. Among various drying technologies, drying with hot air or flue gas has been widely used in commercial plant compared to mechanical dewatering, solvent dewatering and microwave radiation[7,8].

Recently flash drying with hot gas might be good option due to short residence time and its high heat rate[7] and flash drying step might be easily integrated with combustor or gasifier for lignite. However, the pressure condition of combustor or gasifier would be raised to increase conversion efficiency. Therefore, database or design criteria should be provided in high pressure conditions to construct flash drying processes because flash drying in high pressure conditions has been less studied. In this study, the flash drying characteristics of low rank coals has been investigated in high pressure conditions. Also, the effect of drying temperature, residence time and length of tube on drying ratios are determined. Finally, the possibilities of flash drying at high pressure conditions are evaluated.

EXPERIMENTAL

The flash drying experiments of low grade coals at high pressure conditions were conducted in a pressurized flash dryer as shown in Fig. 1. The pressurized flash dryer system consisted of high pressure mass flow controllers(MFCs), a sus-tube(1/4inch I.D. and 4 m length), a pressurized container, a feed hopper, a disk feeder, an external electric heater, a cyclone, a back pressure regulator, controllers and auxiliary accessories. Drying system was a rolled sus-tube placed in an external electric heater. Flash drying temperatures were changed and controlled by using the external electric heater and pressure conditions were controlled by back pressure regulator. Flow rate was adjusted for obtaining the same inlet volume flow rate for same pressure conditions.

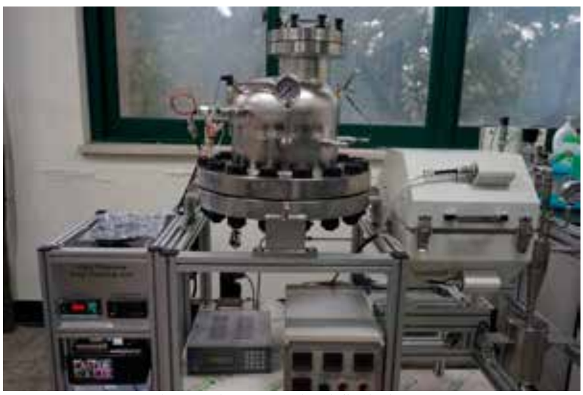

Fig. 1. The pressurized flash dryer

A flash drying process with high temperature might be integrated with combustor or gasifier. To increase drying efficiency, raising operation temperature might be good option. However higher operation temperature could result in volatizing volatile matter in coals. To prevent the devolatilization of coal samples, operation temperature should be carefully controlled. In this study, the external electric heater was used and controlled. As can be seen, gas temperatures reached around 300 ºC at which devolatilization of coal could rarely start. Therefore, temperature range in this study was selected up to 600 ºC.

The coal was fed to sus-tube from a feed hopper with a disk feeder in a pressurized container having some aeration. When experimental pressure and temperature reached planned conditions by using the heater, high pressure nitrogen gas, MFCs and back pressure regulator, sample coal was injected at mass flow rate of 1-10 g/min. The flash drying temperature varied from 200 ºC to 600 ºC and pressure was changed between 1 bar and 40 bar. To investigate the effect of residence time at same condition on flash drying were used in this study. All experimental conditions are shown in Table 1. In this study, sub-bituminous coal was chosen. The raw coals were crashed and sieved to the size similar to average particle size in commercial circulating fluidized bed boilers as shown in Table 1. The proximate analysis of the coal sample is shown in Table 2. The proximate analysis was conducted with TGA-DSC1 thermogravimeter (LECO) and the ultimate analysis was done with

TruSpec Elemental Analyzer (LECO). Those analyses showed high oxygen contents even with a dry ash-free basis which result in a low heating value of the sample. As shown in Table 2, average moisture content was 21.5wt%. But moisture contents of each coal were different, so moisture contents of samples were analyzed at each experiment.

Table.1: Experimental conditions.

Particle size of coal (μm)	212-300, 300-355
Pressure (bar)	1, 10, 20, 30, 40
Operation Temperature (°C)	200, 300, 400, 500, 600
Length of tube (m)	4

Table.2: Proximate analysis of coal.

Coal	Proximate analysis			
	Moisture	Volatile Matter	Fixed Carbon	Ash
Coal A	21.5	35.3	31.3	11.9

The coal samples and dried coals which was separated from gas and moisture by a cyclone and was finally sent to a hopper for storage and sampling were used to calculate flash drying ratios. Weight of each sample is measured by using a scale (Ohaus AVG213C). The moisture content can be expressed through following equation.

$$M_c = \frac{m_d - m_o}{m_o} \quad (1)$$

where M_c is the moisture content of each sample, m_o is the original weight of sample and m_d is the weight of moisture free sample by using oven drier in which each sample was dried at 106 °C condition during 3hours. Also, TGA was used to analyze moisture content of each sample and to compare results from oven drier with results from TGA. Drying ratio of each sample was calculated by following equation.

$$\text{Drying ratio} = (1 - \frac{M_d}{M_o}) \times 100 \quad (2)$$

where M_o is moisture content in original coal sample and M_d is moisture content in dried coal.

RESULTS AND DISCUSSION

Effect of drying ratio on operation temperature is shown in Fig. 2. In this experiment, coal A was used and its particle sized distribution was 212-300 μm in tube length 4 m. As can be seen, drying ration increased with increasing temperature. The drying ratios of coal A increased from around 20% to around 98%. Nikolopoulos et al.[9] said coal grains are heated and dried during pneumatically transportation and the most intensive drying occurred during the first 2-3 m of the dryer. In the experiments of flash dryer[2], moisture removal increased with increasing gas temperature between 400 °C and 600 °C. When operation temperature increases, the heat transfer into coal particle and the evaporation rate of moisture inside the particle are enhanced, resulting in an increase of drying ratio.

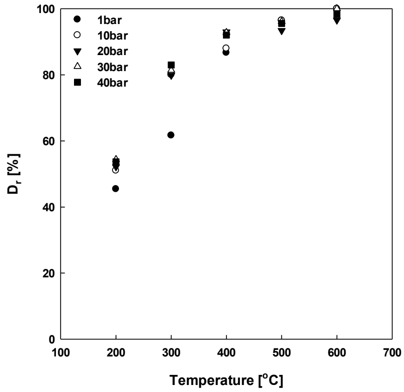

Fig. 2. Effect of drying ratio on operation temperature

Effect of drying ratio on operation pressure is shown in Fig. 3. As can be seen, drying ratio increased with increasing operation pressure. In this study, flow rate had been fixed. Therefore, mass flow rate should increase with increasing pressure. Increasing mass flow of nitrogen gas might result in an increase of drying ratio. However, drying ratio at 200 ºC had maximum value and decreased over 20 bar. As pressure in the dryer had increased, boiling temperature of water increased from 100 ºC (1 bar) to 250 ºC (40 bar) as shown in Table 3. Therefore, the operation temperature of 200 ºC was not enough to boil water in coal particles over 20 bar. This resulted in maintaining or decreasing the drying ratios of coal at 200 ºC experiments.

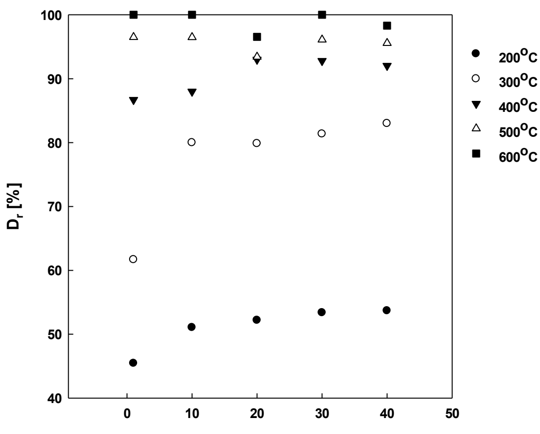

Fig. 3. Effect of drying ratio on operation pressure

Table.3: Boiling temperatures of water with an increase of pressures

Pressure (bar)	Boiling temperature of water (ºC)
1	99.61
10	179.88
20	212.38
30	233.85
40	250.35

The effects of operation conditions on drying of coal are shown in Fig. 4. As can be seen, the results showed that the drying ratio increased with increasing temperature and pressure. Compared with the effect of pressures and temperatures, temperature might be more influential than operation pressure.

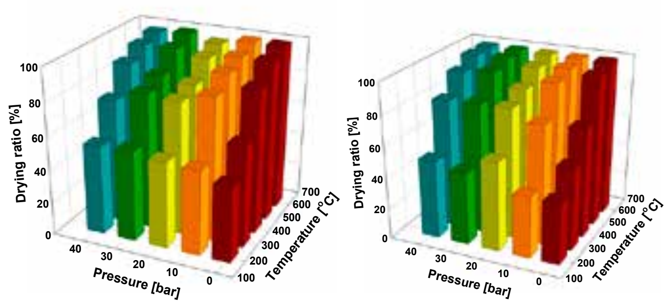

Fig. 4. Effect of drying ratio on operation temperature and pressure

(a) : particle size : 212-300 μm

(b) : particle size : 300-355 μm

Fig. 5 shows drying ratios of different particle size samples. As particle sizes of coal increased, moisture removal decreased in flash dryer, because smaller coal particles have a larger external surface area and facilitates heat transfer from the drying medium to the center of particles and moisture evaporation from the inside of the coal particle to the surface[10]. In the experiments of Kim et al. with 100-2000 μm, water contents of dried coals decreased with decreasing particle sizes[2].

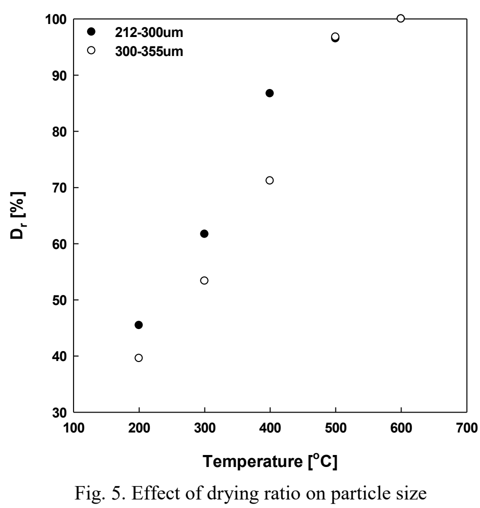

Fig. 5. Effect of drying ratio on particle size

CONCLUSION

A pressurized flash drying characteristics of high moisture coals was investigated in the present study. The flash drying experiments were carried out under the temperature of 200 ºC-600 ºC, the pressure of 1 bar-40 bar. The moisture in coal samples removed up to around 98%. As the temperature of the external electric heater increased, drying ratios increased similar to previous results. As pressure in the flash dryer increased, boiling point of water increased and finally affected drying behaviors. Also, drying ratio decreased in flash dryer as particle sizes of coal increased.

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