

SUPER-HEATED STEAM DRYING: AN INNOVATION OF CLEAN COAL TECHNOLOGY FOR LIGNITE

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ABSTRACT

A comprehensive overview of the status of lignite pre-drying technology is given in this study. The practical problems of high energy consumption, high investment and poor safety exist in the lignite drying using the traditional thermal drying, for the reason that the super-heated steam drying technology for lignite is put forward. The mechanism experiment research and pilot-scale test research of the super-heated steam drying technology for lignite were carried out, and the results show that the drying efficiency of the super-heated steam is better than the hot air at given conditions, the lignite drying can be accomplished stably and continuously and the drying product can meet the requirement of the industrial application of the lignite fired power plant. A more innovative approach as a new lignite Super-heated steam low-rank Coal Upgrading (SCU) is proposed by Energy Conservation Research Center of Shandong Academy of Sciences. The technical advancement in terms of energy-

saving and safety among the applied technologies are compared and analyzed, and the results show this technology has the advantages of low energy consumption, high safety and energy saving. To sum up, the exploitation of the super-heated steam drying technology for lignite fired power plant can promote the development of the energy and power industry, and the technology has wide application prospect.

INTRODUCTION

Lignite is a low rank coal which has the disadvantages of high volatile, high moisture content, high ash content, low ash fusion temperature, serious pollution and low utilization ratio. Lignite resources in China are relatively abundant. If raw lignite is burned directly, the serious environment pollution will generate and the construction and running costs of the electric power plant will increase. The capacity usage ratio of lignite will be enhanced and the environment pollution will be reduced if lignite is dried before using.

A lot of research works on lignite drying technology have been done [Ho et al., 2009; Iwaia et al., 2002]. Lots of drying technology such as hot gas, hot water and hot oil were used, but they have some disadvantages, for example, high investment and high operating cost. Now there is a widespread concern on the super-heated steam drying technology. The super-heated steam drying involves the use of super-heated steam in a direct (convective) dryer in place of hot air or flue gases as the drying medium to supply heat for drying and to carry off the evaporated moisture [Mujumdar, 2006]. The advantages of the super-heated steam drying are energy-saving, higher drying rate, better quality product and no fire or explosion hazards, so the super-heated steam drying can be used for lignite drying. The CRC for New Technologies for Power Generation from Low-Rank Coal in Australia investigated the mechanism of lignite drying using super-heated steam [Bongers, et al., 1998; Bongers, et al., 2000]. The RWE Co. from Germany built 3 super-heated steam fluidized bed dryer systems and the maximal water separation capability reached 110t/h.

Coal continues to be the most important energy source in China. The lignite-fired power plants increased very fast, so popularizing the super-heated steam drying technology is very important. The super-heated steam drying for lignite will be investigated and a Super-heated steam Fluid bed low-rank Coal Upgrading (SFCU) technology will be put forward in this paper.

MECHANISM EXPERIMENT

Experimental

In order to investigate the drying kinetics of lignite, a special experimental apparatus was designed and built, showing in Fig. 1. Pure water in a tank (6) was dosed by a pump (7) to an electric heater (9) to generate steam, further heated to a desired temperature by another electric heater (12). In order to take the consideration of air influences to the drying features, an air stream was introduced to the experimental system. The air flow was heated to a desired temperature by an electric heater (4), then mixes with the steam in a mixing chamber (11). The lignite sample was put in the testing chamber (14) by a sample tray (15), which connects to an electronic balance (13, METTLER TOLEDO, PL3002, 0.01g) to measure the mass changes during drying. The flow rate of the steam was controlled by the dosing pump (7), measured by a flow meter (8). The flow rate of the air was controlled by an adjusting valve (2) assembled downstream the air compressor (1). A serial of thermocouples was employed to measure temperatures of the steam and air.

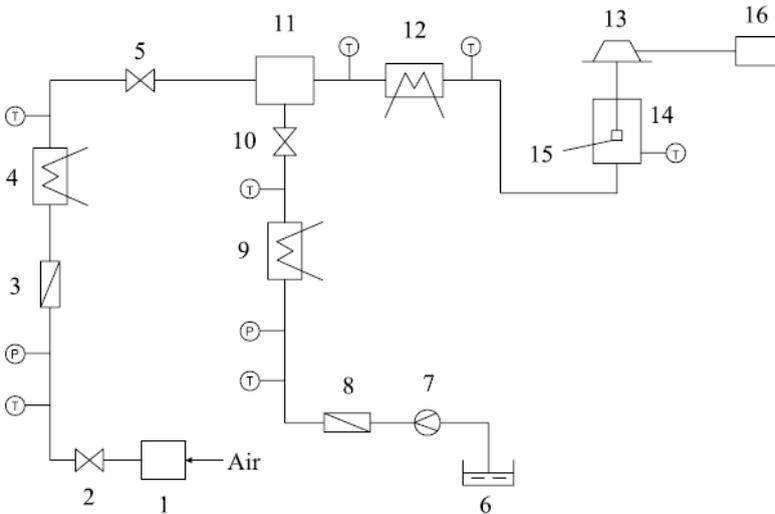


Figure 1. Schematic diagram of the superheated steam processing system, 1-air compressor, 2-valve, 3-flow meter, 4-electric heater, 5-valve, 6-tank, 7-dosing pump, 8-flow meter, 9- electric heater, 10-valve, 11-gas mixing chamber, 12-elctric heater, 13- electric balance, 14- testing chamber, 15- sample tray, 17-computer, T- thermocouple, P-pressure gauge.

The drying gases used in experiments were super-heated steam, hot air and their mixed gas. The components of the drying gases were shown in Table 1. The drying gases in the drying installation chamber were at

atmospheric pressure (0.1 MPa), temperature of 150°C and steam velocity of 0.5 m/s.

Table 1. Components of the drying gases.

No.	Air Mass Flow (kg/h)	Super-heated steam Mass Flow (kg/h)
1#	6	0
2#	4	2
3#	2	4
4#	0	6

The initial moisture content of the lignite sample was determined to be 39.31% dry mass basis (db), and the particle size was 1~2mm. Each lignite sample prepared for the drying experiments was weighed approximately 5.0 g. The thickness of each lignite sample in the sample tray was approximately 15 mm.

Results and discussion

The drying curves of lignite sample at various conditions are shown in Fig. 2. The moisture contents in the figure were dry mass basis (db).

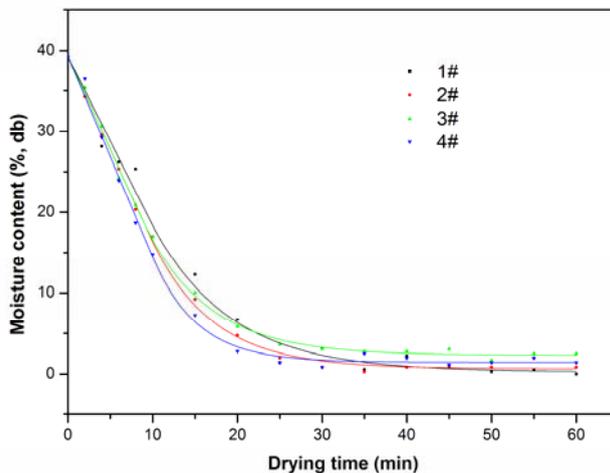


Figure 2. Drying curves of lignite sample at different experimental conditions.

It is obvious that there are inflection points in the drying curves. According to the drying mechanism, the drying process is best depicted by two stages, as a constant drying rate stage followed by a falling drying rate stage.

In the constant drying rate stage, the material surface can keep moistening from beginning to end. The water by evaporation was mostly unbound water, and it comprised of the absorbed water and pore water. The vapor pressure of the unbound water was equal to the vapor pressure of the pure water at the same temperature, so it was removed easily. The drying rate in the constant drying rate stage was depended on the vaporization rate on the material surface. It was described as surface vaporization controlled.

In the falling drying rate stage, the evaporation water was mostly bound water. It consisted of the cell-water and capillary water. The vapor pressure of the unbound water was lower than the vapor pressure of the pure water and this reduced the mass transfer force in the drying process, so it was removed with difficulty. In this stage, the change law of the drying rate was related to the material properties and internal structure. It was described as internal divergence controlled.

If the moisture content was higher than the critical moisture content, the drying curves were straight. If the moisture content was lower than the critical moisture content, the drying curves were exponential. The drying curves can be described as follows [Ranz and Marshall, 1952]:

$$X = X_0 - (X_0 - X_{cr}) \times t / t_{cr} \quad X > X_{cr} \quad (1)$$

$$X = X_{eq} + (X_{cr} - X_{eq}) \times \exp\left(-\frac{X_0 - X_{cr}}{t_{cr}} \times \frac{t - t_{cr}}{X_{cr} - X_{eq}}\right) \quad X < X_{cr} \quad (2)$$

Where X is the moisture content; X_0 is the initial moisture content; X_{cr} is the critical moisture content; X_{eq} is the equilibrium moisture content; t is the drying time; t_{cr} is the drying time when the critical moisture content is reached.

The results are shown in Fig. 2, and the solid line is the predictions from Eq. (2) and Eq. (3). From the figure, we can see that high accuracy of the predictions of material moisture content was obtained.

The drying rate curves of the lignite sample at different experimental conditions are shown in Fig. 3, and they represent the changes of drying rate with moisture content.

It was apparent that the drying rate in super-heated steam was larger than in hot air. There are two reasons. At first, the mass transfer resistance that the evaporation from the material surface can be ignored because only one gas composition existed in the super-heated steam. Secondly, the specific heat of super-heated steam was bigger than the hot air, so the transferred heat by super-heated steam was higher than hot air at the same mass flow. In summary, the heat transfer coefficient of super-heated steam was bigger than hot air. The temperature of 150°C exceeded the inversion temperature.

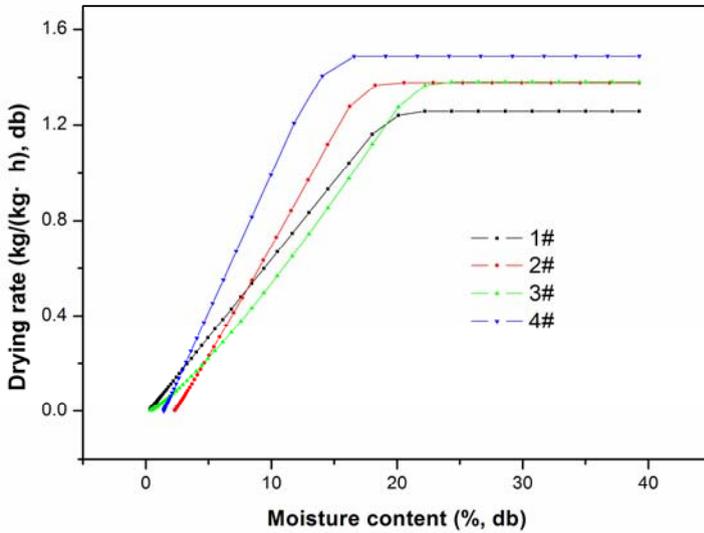


Figure 3. Drying rate curves of the lignite sample at different experimental conditions.

Through analyzing some conclusions can be found as follows: (1) The drying rate decreased as the mass flow of hot air increased. (2) The critical moisture contents increased slightly as the mass flow of hot air increased. (3) The equilibrium moisture contents were lower than 5%, so the drying technology can meet the needs of the industrial lignite drying.

PILOT-SCALE TEST

Test

The super-heated steam high bed-layer fluidized-bed drying system with in-bed heat exchanger was adopted to research the pilot-scale lignite super-heated steam fluidized-bed drying technology. The saturated steam whose average granularity was less than 6.3mm was used to dry the lignite. The main clients were lignite-fired power plants and coal mines which using steam as heat resource. The detailed process is shown in Fig. 4. The saturated steam form the air extracting system of steam turbine was delivered into the special designed heating pipe in dryer. After the heat exchanger between saturated steam and high moisture lignite, the condensate water was discharged and returned to boiler system.

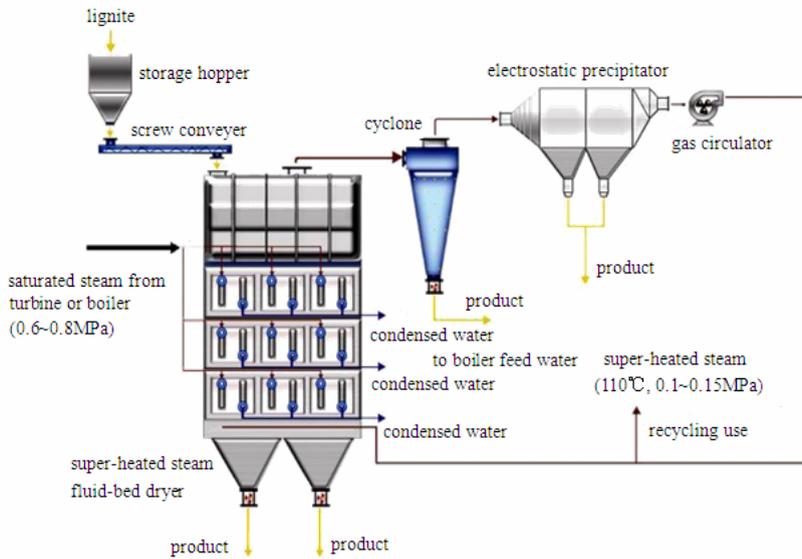


Figure 4. Flow chart of lignite drying.

High moisture lignite was sent into the dryer by feeding valve and feeder, and exchanged heat with saturated steam through in-bed heat exchange pipe. The dried lignite was discharged from the discharging valve, and then delivered to coal conveying system.

The super-heated steam which was formed by the evaporated water was transferred into the second stage dust collecting system. After dust collecting, part of the super-heated steam was sent back to the dryer for the next drying cycle through a circulating fan. The other part was delivered to the waste heat recovery system of the power plant.

The picture of the real pilot-scale testing system of lignite drying is shown in Fig. 5.

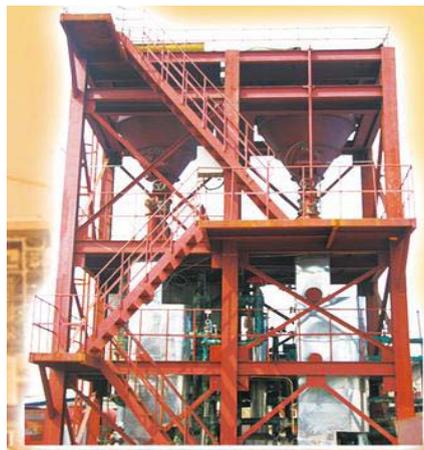


Figure 5. Pilot-scale testing system of lignite drying.

The characteristics of the high bed-layer fluidized-bed dryer with in-bed heat exchanger are as follows: the penetrating bed operated steadily and flexibly; the air distributor designed special and ensured uniformly air distributing; the high bed-layer improved drying capacity, and the heat exchanging devices can be disassembled and assembled separately; the reliable explosion-protected devices were adopted to guarantee the security construction of the super-heated steam system.

The characteristics of dust collecting system are as follows: the two-stage dust collecting system was used to ensure high efficiency; the screw tangential structure was adopted in the first-stage dust collector to reduce power consumption and improve working efficiency; the electrostatic dust collector or bag-type dust collector was applied in the second-stage dust collector to guarantee the system steady operation and acceptable dust content in outlet super-heated steam.

The characteristics of circulating fan are as follows: the single-suction, double base and multiple impeller structure was used to ensure technical parameter; the precise mechanical sealing and medium supplied by lubricating station was adopted to guarantee no air leakage and steady operation.

Result and analysis

The pilot-scale test shows that the super-heated steam drying system can dry lignite steadily and continuously. The moisture content can be reduced from 30% to about 10% which meets the requirement of industrial application. The lignite samples before and after drying are shown in Fig. 6.



Figure 6. Lignite samples before and after drying.

The super-heated steam high bed-layer fluidized-bed with in-bed heat exchanger drying system can achieve seamless connection with power plants. It can be realized in raw coal field or before coal grinder.

The brief process flow of the drying system which was designed before coal grinder can be described as follows: the raw coal was delivered to the drying system after transportation, crushing and screening, and then the qualified dried lignite was transferred to the feeding equipment.

SFCU TECHNOLOGY

Industry Energy-saving Center of Shandong Academy of Sciences developed Super-heated steam Fluid bed low-rank Coal Upgrading (SFCU) technology. Comparison of several kinds of typical drying process is shown in Table 2.

Table 2. Comparison of several kinds of typical drying process.

Drying technology	Energy consumption per ton	Cost per ton	Quantity	Investment (Yuan)
SFCU (Shandong)	0.2t steam, 5.1kW·h	23.06 Yuan	1 set	32 million
SFCU (RWE)	0.2t steam, 9.2kW·h	25.52 Yuan	1 set	90 million
SDCU(Shandong)	0.2t steam, 6.4kW·h	23.84 Yuan	2 set	30 million
tubular drying	0.55 steam, 1.82kW·h	56.09 Yuan	4 set	32 million
Flue gas rotary drying	139kg Coal, 34kW·h	37.08 Yuan	2 set	40 million

Note: Take a project of 300 MW Lignite Pre-Drying Package for example, if per tonnage of steam costs 100 Yuan RMB and electricity charges 0.6 Yuan RMB per degree, per tonnage of lignite drying cost 120 Yuan RMB.

From Table 2, we can get some findings as follows:

(1) The SFCU technology had a lot of evident advantages in terms of the economy and technique comparing with the flue gas rotary dryer method.

(2) The tubular dryer had the same investment as the SFCU dryer, but had some disadvantages such as high energy-consuming, high operational cost, environment-unfriendly, and requiring more area and accessories.

(3) On the other hand, the SFCU technology provided more safe and efficient operation, less cost and less investment. Besides, it brought zero exhaust emission and benefited environment a lot.

(4) Moreover, Shandong Academy of Sciences actively promoted SDCU technology in small, medium-scaled lignite-based chemical and power industry.

CONCLUSIONS

The super-heated steam drying technology was investigated in this study, and the main conclusions are as follows:

(1) The pre-drying of the high moisture lignite and reduction of the moisture content of lignite was an effective technical scheme for enhancing the operating efficiency of the traditional lignite-fired power plant. It will be a development trend for the efficient utilization of lignite.

(2) The super-heated steam drying technology can fulfill the request of the dewatering process of the lignite-fired power plant. Its drying rate was higher than the traditional hot air drying technology.

(3) The lignite drying can process stably and continuously using the pilot-scale test system of the super-heated steam drying. The final products can meet the requirement of the industrial application.

(4) The SFCU technology has a lot of obvious advantages such as safety, energy-saving, consumption reduction and water conservation.

All in all, active promotion and application of the SFCU technology is an important and practical approach to promoting the upgrade and innovation of Chinese energy and power industry, which meet the demand of the enduring development and energy-saving and emission-reduction in China.

REFERENCES

- Bongers, G. D., Jackson, W. R. and Woskoboenko, F. (1998), Pressurised steam drying of Australian low-rank coals Part 1. Equilibrium moisture contents, *Fuel Processing Technology*, Vol. 57(1), pp. 41-54.
- Bongers, G. D., Jackson, W. R. and Woskoboenko, F. (2000), Pressurised steam drying of Australian low-rank coals Part 2. Shrinkage and physical properties of steam dried coals, preparation of dried coals with very high porosity, *Fuel Processing Technology*, Vol. 64(1-3), pp. 13-23.
- Ho, M. T., G. Allinson, W. and Wiley, D. E. (2009), Factors affecting the cost of capture for Australian lignite coal fired power plants, *Energy Procedia*, Vol. 1(1), pp. 763-770.
- Iwaia, Y., Koujina, Y., Arai, Y., Watanabe, I., Mochida, I. and Sakanishi, K. (2002), Low temperature drying of low rank coal by supercritical carbon dioxide with methanol as entrainer, *Journal of Supercritical Fluids*, Vol. 23(3), pp. 251-255.
- Mujumdar, A. S. (2006), *Handbook of Industrial Drying*, Third Edition, CRC Press, Boca Raton.
- Ranz, W. E. and Marshall, W. R. (1952), Evaporation from drops, Part I. *Chemical Engineering Progress*, Vol. 48(3), pp. 141-146.