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Optimization of a lignite-fired open pulverizing system boiler process based on variations in the drying agent composition

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ABSTRACT

This paper evaluates three lignite-fired OPSB (open pulverizing system boiler) processes, named OPSB-A, OPSB-B and OPSB-C, corresponding to three options of drying agents used for the pulverizing systems. OPSB-B is similar to our previous work [18] on drying agent composition. Performances of the three OPSBs were calculated and compared with a 600 MW lignite-fired boiler as the reference. The results showed that the coal savings of OPSB-A and OPSB-C were 5.41% and 4.06% in comparison with the reference boiler, whereas for OPSB-B, the savings was 2.57%. Accordingly, emissions of each OPSB could be reduced in proportion to the coal savings. Among the three OPSBs, OPSB-C showed the best performance of water recovery from mill-exhausts because it had the highest mill-exhaust water dew point of 73.2 °C, whereas the exhaust dew points of OPSB-A and OPSB-B were 63.9 °C and 70.9 °C, respectively. Both OPSB-C and OPSB-B are beneficial for achieving a high mill-exhaust humidity ratio, which facilitates water recovery from the mill-exhaust, and a low oxygen content in mill-exhaust, which improves the operating safety of the pulverizing systems, whereas OPSB-A is relatively inferior in these respects. The OPSB-C process is recommended for engineering applications because of its favorable overall performances.

1. Introduction

Coal is generally expected to continue to play a key role in the future energy supply because it is the most abundant and cheapest fossil fuel source. One type of coal, lignite (otherwise known as brown coal), is important because it accounts for approximately 40% of the total coal reserves worldwide. Generally, lignite's features are a low heating value, high water content (25–65%), high amounts of volatiles and high reactivity. Currently, lignite is mostly used as a utility boiler's fuel for power generation, wherein almost all lignite-fired boilers are equipped with direct-fired pulverizing systems. However, compared with a boiler firing hard coal with the same boiler capacity and steam conditions, a lignite-fired boiler often show a lower thermal efficiency and larger volume, as an overall result of its features of a larger flue gas flow, higher boiler exhaust temperature and being inclined to slag or foul in the furnace. Therefore, lignite-fired boilers or power plants often show a higher emissions and a higher price.

In recent years, heat recovery from utility boilers' exhaust has received significant attention with the purpose of increasing the efficiency of thermal power plants. A popular approach is the placement of a LPE (low-pressure or low-temperature economizer), which recovers the exhaust heat into the steam turbine's regenerative system by using the low-temperature condensate as the coolant, after the dust collector of the boiler, thereby elevating the efficiency of the power plant. In Germany, LPE systems had been applied at several 900 MW lignite-fired power plants, from which an increase in plant efficiency by approximately 0.5%, as the boilers' exhausts were cooled from 170 °C to 130 °C, was reported [1]. In China, a LPE system had been installed in a 1000 MW unit, from which an increase of plant efficiency by approximately 0.7%, as the boiler's exhaust was cooled from 125 °C to 85 °C, was reported [2]. In addition to increased plant efficiency, water consumption of the wet FGD (flue gas desulfurization) system could be reduced with the cooling of the boiler's exhaust, especially for the case when the gas–gas heater (known as GGH) is not used because the low temperature exhaust could decrease the amount of spray water needed in the cooling tower. According to Wang et al. [3], as a result of using a LPE system, approximately 30 t/h of spray water could be

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saved for a 600 MW unit with a wet FGD system when the boiler's exhaust was cooled from 123 °C to temperatures below 100 °C, while the standard coal consumption rate of this unit was reduced by approximately 3.0 g/(kW.h). Recently, Wang et al. [4] and Xu et al. [5] presented analyses of LPE systems to compare the effect of location selection for an LPE embedded in the condensate flow.

Another way to increase efficiency with exhaust heat utilization in a steam power plant is transferring the heat from about one third of the flue gas in tail flue that bypasses the regenerative air-heater to low- and high-pressure feed water preheaters by using flue gas/water heat exchangers [6], referred to as the FGB (Flue Gas Bypassing) system. According to the descriptions in Ref. [1] and Ref. [6], a FGB system had been installed in a lignite-fired 1000 MW unit in Germany. Generally, the use of a FGB system can increase the efficiency of a hard-coal-fired power plant by approximately 0.6%; for lignite-fired power plants, the plant efficiency could be increased by approximately 1.6% given that the boiler exhaust temperature is at approximately 170 °C [6]. Recently, Espatolero et al. [7] conducted an ASPEN Plus simulation study of a FGB system by using a conventional 600 MW unit as a reference and concluded that the efficiency increases of the power plant were in a range of 0.59%–1.07% as the boiler exhaust temperature was decreased from 125 °C to 90 °C by using the FGB systems with different degrees of complexity. In addition, Xu et al. [8] presented a modified LPE system wherein the air-heater was divided into two parts and the LPE was placed in between the air-heater's two parts. They claimed that this system is able to obtain greater thermal economy than the common LPE system. Actually, the system by Xu et al. [8] is very similar to the FGB system in the way the flue gas heat is utilized.

In addition to focusing on exhaust heat utilization, assembling a coal pre-drying system prior to coal being sent to the coal pulverizer and boiler is another strategy for increasing the efficiency of a lignite-fired power plant because the lignite's high water content. Of this, many lignite pre-drying methods, such as steam drying (known as the WTA system) by a rotary steam-heated tubular dryer [9] or by a fluidized bed dryer with steam-heated immersed tubes [10], warm air drying by a fluidized bed [11], hot water drying [12] and mechanical thermal expression systems [13], have been presented and studied. Many papers on this topic have been published since the 1990s. These lignite pre-drying methods mainly differed in the drying medium used and the particular ways waste heat was utilized. Typically, if taking the most popular WTA system as an instance, integrating a lignite pre-drying system into the power generation process can increase the plant efficiency by approximately 2–4% points [14,15], mostly depending on the water content contained in the raw lignite. However, up to now, all lignite pre-drying systems are still facing some technical barriers in achieving commercial-scale applications, such as the low heat transfer rate between the coal particles and the drying medium, which results in large capital and operating costs of the lignite pre-drying system. Additionally, the pre-drying system is at a high risk of fire or explosion because the dried lignite's inherent spontaneous combustibility, which makes it difficult to store and transport dried lignite safely.

On the other hand, because thermal power plants consume much water to maintain their operations, the conflict between running the power station and sustainability of local environment has become increasingly prominent. Typically, the exhaust of a 600 MW boiler fueled by bituminous coal and lignite contains approximately 90 t/h and 270 t/h of water vapor and have exhaust water dew points of approximately 40 °C and 55 °C, respectively. As shown, it is difficult to cool the exhaust to a temperature lower than the low water dew point to attain water recovery even though a lot of water is contained in the exhaust of a coal-fired utility boiler. There were a laboratory experiment [16] and a small pilot-scale experiment [17] on the recovery of water from the utility boilers' exhaust by using surface type condensing heat exchangers. However, the capital cost and spatial volume of such a condensing heat exchanger for utility boilers are too large to be considered a practical solution. To the best knowledge of the authors, until now there has been no practical commercial condensing heat exchanger available for recovering water from the exhaust of large-scale utility boilers.

Recently, we advanced a novel lignite-fired power generation process based on an OPSB (Open Pulverizing System Boiler) and the recovery of water from the mill-exhaust (i.e., the exhaust of the pulverizing system) [18]. In that study, we have demonstrated that applying the OPSB process not only yields an increase in boiler efficiency but also provides an advantage in water recovery from the flue gas. This paper is a continuation of that study [18], with the purpose of further optimizing the OPSB process to achieve better performance. In this paper, three options of the drying agent are conceived for use in the pulverizing system of OPSBs; in addition, an air-preheater heated by the mill-exhaust is integrated into the OPSB process as a counter-measure to the air-heater's low temperature acid corrosion. Accordingly, the difference between the three OPSBs is the proposed drying agents. Then, based on an introduction of the working principle and thermal calculation methods of the three OPSBs, their performances are calculated and compared using an in-service 600 MW lignite-fired supercritical boiler in China as the reference.

2. Principle and novelty of the OPSBs with three drying agent options

2.1. Working principle

The main principle of an OPSB has been discussed in the literature [18] and is not repeated here. However, it's necessary to discuss the pulverizing system for lignite briefly here because the OPSB processes analyzed in this paper are closely associated with the drying agent for the pulverizing system. In a conventional lignite-fired CPSB (Closed Pulverizing System Boiler), the use of a direct-fired pulverizing system with fan mills is preferred when the water content in the raw lignite is higher than 30%. Usually, a three-component gas (hot flue gas, hot air and cold flue gas) or a two-component gas (hot flue gas and hot air) is used as the drying agent for a fan milling system for high moisture lignite. To acquire enough drying capacity of the drying agent, hot flue gas, which is generally extracted from the furnace outlet and has a temperature of approximately 1000 °C, is a major component of the drying agent. However, in a fan milling system used for lignite, the initial drying agent temperature at the drying tube inlet (t_1) is often in the range of 600 ~ 800 °C out of the combined need for the mill's ventilation rate and the drying agent's drying capacity. Therefore, a low-temperature gas (otherwise known as the temperature adjusting medium) is also a necessary component of the drying agent for fan milling systems.

As shown in Fig. 1, this paper presents three options of two-component drying agents (called option A, B and C drying agents) as the possible drying agent selections for the OPSBs. A portion of the hot air from the air-heater outlet, a portion of the mill-exhaust from the pulverized-coal collector outlet, and the hot mill-exhaust from the air-heater outlet are used as the low-temperature component for option A, B and C, respectively. A portion of the hot flue gas that is extracted from the furnace outlet is identical used as the high-temperature component for each option. Accordingly, the three OPSB processes with the different drying agents are illustrated in Fig. 1. They are OPSB-A, OPSB-B and OPSB-C in this paper.