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Energy and water conservation at lignite-fired power plants using drying and water recovery technologies

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ABSTRACT

Lignite is considered as a competitive energy raw material with high security of supply viewed from a global angle. However, lignite-fired power plants have many shortcomings, including high investment, low energy efficiency and high water use. To address these issues, the drying and water recovery technologies are integrated within lignite-fired power plants. Both air-cooling and wet-cooling units with three kinds of lignite as feeding fuel were analyzed quantitatively. Results showed that energy conservation and water conservation are obtained simultaneously. The power plant firing high moisture lignite becomes more environmental friendly with higher power generation efficiency and a lower water makeup rate than the one firing low moisture lignite. And further calculation revealed that the air-cooling unit needs no makeup water and even produces some water as it generates power, when the water carrying coefficient is higher than 40 g/MJ.

1. Introduction

As it turns out, water and power are intertwined. Producing power uses water, especially for thermoelectric power. A national level about 41% of all freshwater withdrawals in the United States in 2005 was for thermoelectric power plants [1]. As a result, how to estimate and reduce the water use of power plants has become a hot topic and attracted a lot of attentions [2–4]. Many technologies have been undertaken to conserve water resources through optimizations of design [5] and operation [6]. However, energy conservation, water conservation and pollutant disposal are often in conflict with each other. Dry-cooling systems use air instead of water to cool the exhaust of steam turbines. It is an effective method to decrease the total water use of power plant by more than 90%. The tradeoffs to these water savings are higher costs and lower efficiencies. Similarly, pollutant control systems e.g., the carbon capture and storage (CCS) and flue gas desulfurization (FGD), also increase the water use of power plant [7]. Hence, researches on technologies, which are able to conserve water and energy simultaneously in coal-fired power plants, should be accelerated.

Coal can be classified to lignite (V_{daf} (the volatile content at dry ash-free basis) >37%, M_{ar} (the moisture content at as received basis) = 20–50%), bituminous coal ($V_{daf} > 10\%$, $M_{ar} = 3–18\%$) and anthracite ($V_{daf} \leqslant 10\%$, $M_{ar} = 1–5\%$), etc. [8]. Most of coal is used to generate power in thermoelectric power plants. For example, about 50% coal is consumed in power plants in China [9]. However, coal-fired power plants exhaust a lot of pollutants and consume much water, among which the lignite-fired power plants are the least environmental friendly. Because of the high moisture content, lignite is lower in heating value than the other kinds of coal. As a result, lignite-fired power plants have many shortcomings, including high investment, low energy efficiency and high water use. Lignite is considered as a competitive energy raw material with high security of supply viewed from a global angle [10]. As a result, many researches were carried out to make lignite-fired power plants greener [11,12].

Pre-drying of lignite is a potential way to increase the efficiency of lignite-fired power plants [13]. Lignite could be pre-dried in various types of dryers [14], in which either boiler flue gas or steam extraction is used as the drying heat source. In recent years, some innovative drying methods, including WTA (Wirbelchicht-Trocknung mit integrierter Abwärmenutzung) [15], MTE (Mechanical Thermal Expression) [16], as well as drying dynamics [17], were studied and analyzed. The influence of external dryer on the efficiency of lignite-fired power plants was simulated [18,19] and theoretically analyzed [20,21]. Results showed

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Nomenclature

Abbreviations

CLPP	conventional lignite-fired power plant
FGD	flue gas desulfurization
HHV	higher heating value
LHV	lower heating value
PLPP	pre-dried lignite-fired power plant
PLPPW	Pre-dried Lignite-fired Power Plant with Water recovery
PLPPWA	pre-dried lignite-fired power plant with water cooler and air cooler

Symbols

F	mass flow rate of makeup water, ton/h
P	power output of power plant, kW
$r_{recover}$	water recovery efficiency, i.e., the ratio of the water recovered to the water pre-dried out of 1 kg lignite
r_w	the water makeup rate of power plant, ton/MW h
t	temperature, °C
φ	non-condensable gas ratio of dryer exhaust, i.e., the volume ratio of non-condensable gas to dryer exhaust
η_p	power generation efficiency,%
λ	pre-drying degree, i.e., the moisture mass pre-dried out of 1 kg lignite, kg/kg
ζ	water carrying coefficient of lignite, i.e., the ratio of water mass carried by lignite to LHV of lignite, g/MJ

that pre-drying of lignite is an effective way to increase the power generation efficiency. Waste heat recovery from the dryer exhaust could further increase the power generation efficiency [22]. However, previous studies did not pay enough attention to water conservation. NETL(National Energy Technology Laboratory)'s IEP (the Innovations for Existing Plants) program addressed water conservation strategies for lignite-fired power plants including reducing cooling tower evaporation losses via coal drying and recovery water from combustion flue gas [5]. Because the dryer exhaust has higher moisture content than the flue gas, water recovery from the dryer exhaust will be easier. So the technologies of drying and water recovery may be potential to simultaneously conserve energy and water in lignite-fired power plants.

In the present study, the integration of pre-drying and water recovery technologies within lignite-fired power plants was analyzed with the attention to its influence on the energy and water conservation. The aim of this paper is to draw attention to these technologies, which could make the energy conservation and water conservation simultaneously realizable. The analysis was based on the reference cases of conventional lignite-fired power plants. To make the research results versatile: both the air-cooling and wet-cooling units with three kinds of lignite mined around the world were analyzed; the energy conservation potential was analyzed both based on higher heating value (HHV) and lower heating value (LHV); the water content in lignite and non-condensable content rate in dryer exhaust were analyzed parametrically.

2. Water use in conventional lignite-fired power plants

The model of a conventional lignite-fired power plant (CLPP) is shown in Fig. 1. Water uses of power plants are divided into three parts: the steam cycle water use including blowdown and miscellaneous water losses, the wet-cooling water use, and the wet FGD water use. As a result, the makeup water of power plant mainly includes water makeup of steam cycle, cooling, and FGD:

$$F_{plant} = F_{Cycle} + F_{Cooling} + F_{FGD} \quad (1)$$

where F_{Cycle}, $F_{Cooling}$, F_{FGD} are the makeup water of steam cycle, wet-cooling, and FGD, ton/h, respectively. If the exhaust of steam turbines is cooled by air, the makeup water of cooling is removed.

The makeup water of CLPP could be calculated with the help of IECM (Integrated Environmental Control Model) [7]. IECM was developed by Carnegie Mellon University, which is a computer-modeling program that performs a systematic cost and performance analysis of emission control equipment in coal-fired power plants. IECM is widely used in the water use analysis of power plants [7,23,24]. The water system models, which were introduced in Ref. [7], were omitted here for the sake of conciseness. The water uses of power plants could be calculated based on compositions and heating value of coal, main parameters of steam cycle [25].

The water makeup rate of power plant is reported in terms of the mass of makeup water to electrical power output:

$$r_w = \frac{F_{plant}}{P} \quad (2)$$

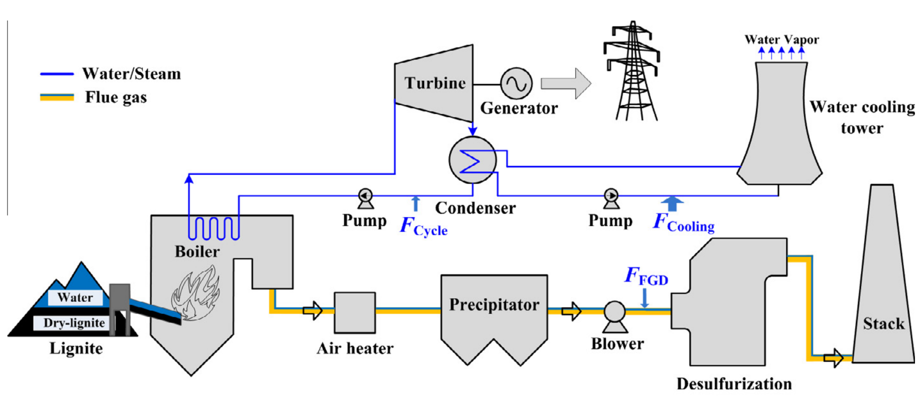

Fig. 1. Model of a conventional lignite-fired power plant.