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Mathematical simulation of the flue-gas recovery system for coal-fired boilers based on the direct-contact heat exchanger

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Abstract

In China, coal-fired boilers and coal-fired combined heat and power plants (CHP) are primary heat sources for district heating, and there is severe heat loss due to flue gas flowing out at a high temperature level. This paper introduces an approach to regather the exhausted heat contained in the coal-fired flue gas based on direct-contact heat exchanger and absorption heat pumps (DAHP). This paper has established a mathematical model for the DAHP system and validated the model with experimental data, and the overall performance evaluation of the DAHP system were conducted, including energy consumption, environmental and economic feasibility. The results showed that the thermal efficiency is 104.5% (evaluated by lower caloric value), emissions significantly decrease and large amount of condensed water is regathered.

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Keywords: coal-fired boiler; flue gas heat recovery; direct-contact heat exchanger; absorption heat pump; DAHP

1. Introduction

Here follows further instructions for authors. District heating is an essential part of modern life but consumes a great deal of energy at the same time. At present, the building energy consumption accounts for 20% of total energy consumption (2014) in China, 22% of which is used for winter heating (2014) [1]. In northern China, the main heating systems are coal-fired boilers and coal-fired CHPs. The amount of coal resources exploited for heating is tremendous and still keeps increasing with the urbanization process. However, there is severe heat loss due to flue

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gas flowing out at a high temperature. If the temperature of flue gas could be lowered than its dew point, the containing latent heat and sensible heat could be re-gathered, and the thermal efficiency for boilers could be improved. At present, there are primarily two kinds of flue gas heat recovery systems for coal-fired boilers: ① with return water in thermal network or outdoor air as the cold source, ② with the cold source generated by heat pumps.

The first kind is the most common and traditional manner for heat recovery, i.e. with return water in thermal network or outdoor air as the cold source to exchange heat with flue gas in indirect heat exchangers. There are studies conducted on the influence of various arrangements of these heat exchangers in the coal-fired boiler system. V. D. Stevanovic et al. added a high-pressure economizer parallel with the air preheater [2]. C. Wang et al. examined the effect of low-pressure economizers installed before the desulphurizer [3]. Y. Yang et al. and G. Xu et al. altered the air preheaters and separated the original air preheater into a high-temperature heater, a main heater and the low-temperature heaters [4, 5]. The temperature of flue gas is still around 100˚C. Y. Yuan et al. reduced the temperature of flue gas to 97˚C with heat pipe. Both economizers and air preheaters cool the flue gas to a limited temperature level be-cause of the constraints of the cold source [6]. The temperature of return water in thermal network is generally 50-60˚C, higher than the dew point of flue gas. Though the temperature of outdoor air in winter is as low as 0˚C, the heat capacity of air is small com-pared with flue gas when there is moisture condensed. M. Terhan et al. carried out theoretical research and results showed that the temperature of flue gas could be reduced to 40˚C by 10˚C cold water in horizontal tube type heat exchanger made of stainless steel. Therefore, the temperature of flue gas can further decreases when there is suitable cold source [7]. For that reason, some researchers have proposed the second kind of the heat recovery system for flue gas, which applies the heat pump to generate cold water. Fu Lin et al. first put forward a scheme involving absorption heat pumps and indirect heat exchangers to recover waste heat contained in flue gas [8]. The temperature of flue gas could be lowered to 25˚C and the thermal efficiency was elevated by more than 10%. Q. Ming et al. analyzed and compared the performance of three kinds of absorption heat pump driven by flue gas, natural gas and hot water combined with indirect heat exchangers. This theoretical analysis showed that the flue gas temperature could be lowered to 30˚C [9].

However, when the exhausted heat of flue gas is recovered with its temperature dropping below its dew point, there will be a lot of condensed acid water, which leads to corrosion on the metal surface of indirect-contact heat exchangers. As a result, there are researches on corrosion resistance [10]. Nevertheless, the corrosion treatment increases the heat exchange resistance and cost of exchanger. To tackle this problem, some researchers pro-posed a heat recovery system combining direct-contact heat exchangers and absorption heat pumps (DAHP) [11]. The direct-contact heat exchanger can adopt the spray tower manner without metal heat exchange surface. At the early stage, this system is only ap-plied in natural gas boilers and the temperature of flue gas could be lowered to 30˚C [12]. X. Zhou et al. conducted experimental study on the parameters of direct-contact heat exchanger [13].

In 2015, this system was first utilized in a coal-fired boiler plant in northern China. There are differences between a coal-fired boiler and a natural gas boiler, for example, much less moisture in coal-fired flue gas, lower inlet temperature of coal-fired flue gas due to desulphurization. Few literature is about the DAHP heat recovery system applied in the coal-fired boiler plants. This paper has developed a mathematical model for this system and has it verified by the actual operation data, and conducted the study about the system's thermodynamic characteristics, economic profits and pollutant reduction effect.

2. DAHP heat recovery system

The Fig. 1 demonstrates the overall systematic scheme for the flue-gas heat recovery system, consisting of the coal-fired boiler, the desulphurizer, the absorption heat pump, the direct-contact heat exchanger, flue gas ducts, water ducts and accessory devices. The new adding part is marked by the dashed box and the boiler, the desulphurizer and main flue gas duct are the original facilities.

When the flue gas heat recovery system turns on, the flue damper 1 is closed and the flue damper 2 is open. The flue gas from wet-desulphurizer flows into direct-contact heat exchanger to transfer heat and moisture with cold water generated by the absorption heat pump. After the heat transfer, the flue gas discharges into environment, while the cold water runs back to the heat pump for cooling again. The absorption heat pump is driven by steam. The return water in the thermal network firstly gets heated in the absorber and the condenser in the heat pump and then flows into the boiler to get further heated to the required temperature.