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Performance study and application of new coal-fired boiler flue gas heat recovery system

Maolin Wei [a], Xiling Zhao [b,*], Lin Fu [b,c,*], Shigang Zhang [a]

[a] *Dept. of Energy Planning & Design, Tsinghua Planning & Design Institute, Beijing, China*
[b] *School of Architecture, Tsinghua University, Beijing, China*
[c] *Beijing Key Laboratory of Indoor Air Quality Evaluation and Control, Tsinghua University, Beijing, China*

HIGHLIGHTS

- Application of a new desulfurized flue gas heat recovery system is introduced.
- System performance is fully discussed basing on measured data.
- Boiler thermal efficiency is significantly improved after heat recovery.
- The plant pollutants emission concentrations are significantly reduced.
- The system owns good economic with a short payback period.

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ABSTRACT

The recovery of heat from the flue gas is an effective way to improve the thermal efficiency of a boiler. In a coal-fired boiler with wet-desulphurization, a portion of the flue gas thermal energy is used for the latent heat process, which leads to temperature reduction and humidity increase. Although it still contains significant heat, flue gas without sulfur cannot be further utilized; as such, in conventional systems, it is directly exhausted. This paper proposes a new system that utilizes the remaining heat in sulfur-reduced flue gas, where direct-contact heat transfer and absorption technologies are used to even further reduce the exhausted flue gas temperature. Here, not only is the heat recovered, but waste water is also reused as the make-up water in the flue gas desulphurization (FGD) tower. An engineering application analysis provides a detailed account of the system thermodynamic characteristics, economic profitability, and pollutant emission reduction effects. The results show that the boiler efficiency improves by 3.2 percentage point when the exhaust temperature decreases to 39 °C. Also, the pressure drop in the heat exchanger remains below 400 Pa, which results in low extra electricity consumption. The direct-cooling treatment removes 59% of sulfur dioxide and 8.8% of nitrogen dioxide. The investment is 28.8 million RMB and the annual net revenue is 7.4 million RMB, with a static payback period of 3.8 years; as such, it is commercially viable. In summary, the new system simultaneously saves energy, saves water, and reduces pollutant emissions.

1. Introduction

In a coal-fired boiler, 4–8% of the fuel heat content is ultimately converted into thermal energy that is carried by the flue gas [1]. If the remaining heat can be recovered, it would significantly improve boiler thermal efficiency; as such, numerous waste heat recovery strategies have been investigated and implemented [2–5]. Based on the location of heat recovery equipment, existing systems can generally be divided into two types: pre-FGD and post-FGD towers.

For the pre-FGD tower systems, the heat recovery equipment is located before the FGD tower. In this model, the flue gas is used to heat boiler feed water, network return water, cold air or to pre-dry boiler fuel [6–8]. Here, ORC technology is also applied for waste heat recovery, where flue gas functions as the driving heat source [9]. He et al. [10,11] analyzed the performance of a low-pressure economizer-based (LPE) waste heat recovery system and presented the internal relationships between the correlated parameters. The

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* Corresponding authors at: School of Architecture, Tsinghua University, Beijing, China (L. Fu).

E-mail addresses: zhaoxiling@126.com (X. Zhao), fulin@mail.tsinghua.edu.cn (L. Fu).

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Nomenclature

Q	heat quantity
V	volume flow rate
ρ	density
H	enthalpy
m	mass flow rate
cp	specific heat
t	temperature
COP	coefficient of performance
E	electric power
P	pressure drop
η	efficiency
γ	local resistance factor
d	humidity
M	amount of mass
K	amount of money
k	price per unit
Y	static payback period
n	molar fraction

Subscripts

rel	released
f	flue gas
i	inlet
o	outlet
obt	obtained
w	water
sup	supply
s	steam
b	boiler
fu	fuel
inc	increment
fan	draft fan
de	demister
dy	dynamic
cw	condensed water
inv	investment
rev	revenue
Q	heat
E	power
M	mass

LPE was positioned between the electrostatic precipitator (ESP) and FGD. Flue gas was used to heat a portion of the condensed water via the auxiliary heat transfer surface, which saved part of the extraction steam. A standard coal equivalent of the selected 350 MW power plant was reduced by 3.85 g/(kw h) with an installed LPE, means 1.5% improvement of the plant thermal efficiency. Yang et al. [12] proposed a novel waste heat recovery system that included the installation of a high temperature air preheater (HTAP) and a low temperature air preheater (LTAP); here, the LPE was located between the ESP and the LTAP. Yang et al. [13] evaluated system performance with an exergy method; the results showed a significant reduction in exergy loss as well as substantial economic improvement due to savings from the extraction steam. The plant thermal efficiency was improved by 0.81%. Espetolero [14] investigated a new feed water heat exchanger network configuration in which a high-pressure economizer (HPE) was added before the air preheater. Based on the simulation results, optimal operational conditions were established. As a result, the steam consumption was reduced. The boiler efficiency was improved by 0.9%. In the aforementioned studies, waste heat was partly recovered through the additional heat exchange process. However, in order to avoid acid corrosion and to ensure desulphurization efficiency, the flue gas temperature exiting the heat exchanger was always maintained above the acid dew point, which ranged from 85 to 95 °C (corresponding to the different coal types [15–18]). Here, the boiler thermal efficiency improvement was less than 2%. As such, existing conventional heat recovery systems do not sufficiently utilized thermal energy from the exhaust flue.

In order to obtain better heat recovery results, more attention is given to the outlet flue gas of the FGD. Flue gas temperature decreases and humidity rises after wet-desulphurization. Also, the flue gas enthalpy increases upon addition of the SO_2 reaction heat. To recover both latent and sensible heat from the low-temperature flue gas after desulfurization, sorption technology and heat pump integrated systems have been developed. Riffat et al. [19] investigated the technical feasibility of using absorption or adsorption systems for heat recovery in conventional heating appliances. The results showed that both systems achieved significant thermal efficiency improvements; however, no thermodynamic or experimental analyses were provided. Coper et al. [20] proposed a system that applied liquid desiccant-based dehumidification technology to extract water and heat from wet flue gas after desulphurization. Moisture was absorbed through direct-contact absorption via a strong desiccant solution; it was then released while the solution was regenerated in a flash drum. Water vapor condensed and the latent heat was transferred to the network return water in the condenser; as such, heat and water recovery was simultaneously achieved. A pilot-scale test was conducted and the results showed that water removal from the flue gas ranged from 23 to 63% vol.; however, corrosion caused by the sulfur dioxide dissolution was not addressed. And despite the water removal effects, no more test data about the heat recovery performance was demonstrated. Research has also been conducted into membrane technology. Wang et al. [21] introduced a transport membrane condenser (TMC) for heat and water recovery. Due to the high selectivity trait of the membrane, only water vapor in the flue gas passed through the membrane and condensed upon direct contact with the cold water. Hence, both heat and water were recovered. A pilot test was established and good heat and water recovery performance was achieved. However, the TMC is not suitable for large-scale boilers. The production of a large membrane heat exchanger is not feasible because structure and material strength considerations are complex and cost-prohibitive. Furthermore, the cold water source (used to cool the flue gas) was not expounded in the literature; this is a limiting factor in existing flue gas heat recovery systems. Zhao et al. [22] introduced a conceptual heat recovery system that combined a gas-water heat exchanger and a heat pump with a coal-fired boiler. This system was essentially an extension of the heat recovery strategies widely used for natural gas boilers [23–28]. Due to different physical properties of gas boiler and coal-fired boiler flue gas, it was not feasible to utilize the existing systems without modifications. While some reports noted that evolved system applications have been used in waste-to-energy power plants in Hendeverket (Sweden) and Vestforbranding (Denmark) [29], nevertheless, no related literature about the system description, performance, or optimization could be confirmed.

In order to achieve heat recovery from the flue gas after desulphurization, various systems are proposed and researched.