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RECOVERING WASTE HEAT FROM FLUE GAS OF COMBINED HEAT AND POWER PLANTS FOR DISTRICT HEATING IN CHINA

Haichao Wang[1,2,*], Xiaozhou Wu[1], Lin Duanmu[1], Rämä Miika[3]

[1]Dalian University of Technology, Dalian, China
[2]Aalto University, Espoo, Finland
[3]VTT, Technical research centre, Finland
[*]*Corresponding email: haichao.wang@aalto.fi*

SUMMARY

Currently, the flue gas heat recovery rate is very low in China. But flue gas can contain a large amount of waste heat according to the heat balance of the boiler. In the meantime, flue gas heat loss also dominates different kinds of heat losses for a boiler. Therefore, it is necessary to reduce the flue gas temperature and recover sensible and latent heat for district heating purpose. This paper discusses the application mode of a flue gas scrubber for a combined heat and power (CHP) plant, calculate the flue gas recovery rate using absorption heat pumps and analyse the feasibility for a real case study in China. The results show that the maximum heat recovery rate is about 8% if the flue gas can be cooled down to 30°C, and the payback time for the flue gas scrubber is around 5 years.

Keywords: waste heat, heat recovery, scrubber, combined heat and power (CHP), district heating

1 INTRODUCTION

In a CHP plant, flue gas heat loss usually account for 5%~8% of the boiler effect depending on the coal types, moisture contents and excess air rates. This amount of heat loss can be over 70% with respect to all heat losses of a coal-fired boiler. Therefore it is necessary to recover as much as possible the waste heat from the flue gas and use it as the heat source for the space heating, ventilation and hot water preparation in the buildings nearby. It thus increases the energy efficiency and reduces the pollutant emissions from the CHP plant.

It is possible to combine the flue gas heat recovery with the district heating (DH) network. The DH return temperature is usually 40~50°C depending on the load profile of the DH system and the outdoor temperature. The dew point of the flue gas is usually about 57°C for gas-fired boilers and power plants, this means that the temperature difference could be not big enough for deep recovery through condensing heat exchanger or would lead to a very low energy saving efficiency. Therefore, the heat pump technology can be used for enhancing the heat transfer efficiency between the flue gas and DH return water. This is also supported by the 'large temperature difference, small flow rate' operating strategy that usually employed with heat pumps. Fu et al. (2003) proposed to use absorption heat pump to reduce the DH return water and use it to recover waste heat from flue gas for district heating. This study give one solution to the above problem caused by the high DH return water temperature and they reported that it can increase the energy saving efficiency by 5% compared to the traditional condensing heat recovery without absorption heat pumps. Sun et al. (2016) also implemented an energy efficiency analysis for a real case which adopts the absorption heat exchangers for flue gas heat recovery of a gas-fired boiler, and they reported that this can increase the heat capacity by 47% to the primary network and thus suitable for those DH system with insufficient heat sources.

However, as far as we know, there are few studies or reports on the flue gas heat recovery from coal-fired boilers or CHP plants. In this study, we propose to use a direct contact scrubber to recover the waste heat from coal combustion flue gas, and connect it with a plate heat exchanger to transfer the recovered heat to DH return water. In this paper, we build a model for the proposed heat recovery system with HP, and implement the thermodynamic analysis based on the models. We also investigate the factors that affect the heat recovery rate, and how they influence it. Then, we check the technology and economy feasibility in a case study in Dalian, China. In addition, the environmental gains are also evaluated for the case.

2 METHODS

2.1 Flue gas heat recovery rate and influencing factors

It is widely acknowledged that latent heat is the big part in the flue gas the heat recovery, and sensible heat only accounts for a small share. Figure 1 shows the relationship between flue gas heat recovery rate for wood fuel and flue gas temperature, fuel moisture and flue gas oxygen concentration. Oxygen level is 4.5% and fixed; different curves correspond to different fuel moisture. It can be concluded that more hydrogen element (H) that one fuel contains, the higher moisture in the flue gas and thus lead to a higher heat recovery rate. But this does not mean that the higher moisture in the fuel would be better for the boiler effect. The fact is that, if one kind of fuel was born with high moisture e.g. wood and other biomasses, and it is difficult or uneconomical to dry it before combustion, then we have to burn it as it is and try to recover the heat accompanied with the high moisture.

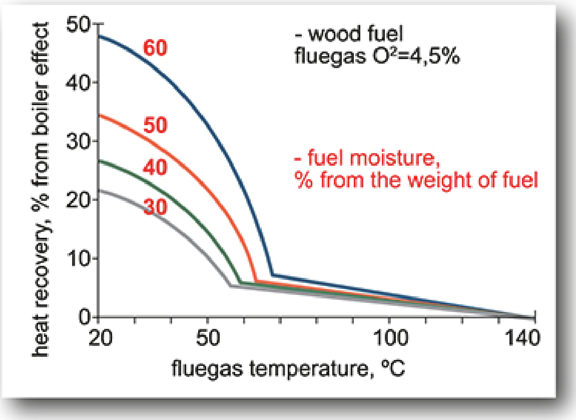

Figure 1. The relationship between flue gas heat recovery rate for wood fuel and flue gas temperature, fuel moisture and flue gas oxygen level. (Condens 2017)

Different oxygen levels will affect the heat recovery rate as well. In fact, the oxygen in the flue gas mainly comes from the excess combustion air, and if more air are blowed in the combustion chamber, then the oxygen level in the flue gas will be higher. In some European countries e.g. Finland, the oxygen level in flue gas is about 4%~6%, but in China this could be 8%~10% or even more. This is because of the high excess combustion air rate and relatively low operating level. High oxygen content in the flue gas is more or less like the dilution of flue gas by fresh air. Technically, because the moisture in the fresh air is usually much lower than the flue gas, so that the flue gas with high oxygen level will have lower partial pressure of water vapour, which will reduce the dew point. Further, the low dew point affects directly the possible highest water temperature after the direct contact heat and mass transfer in the scrubber. This temperature is very important, because if it is higher than the DH return water, then it can be used directly by a water-water heat exchanger, otherwise, a heat pump is used to reduce the return water and create large enough water temperature difference.

2.2 Basic flue gas heat recovery mode using a scrubber

The basic flue gas heat recovery mode using a scrubber is shown in Figure 2. This mode is technically viable only when the water temperature in the bottom of the scrubber is higher than the DH return temperature, and the temperature difference is large enough for the water-water plate heat exchanger.

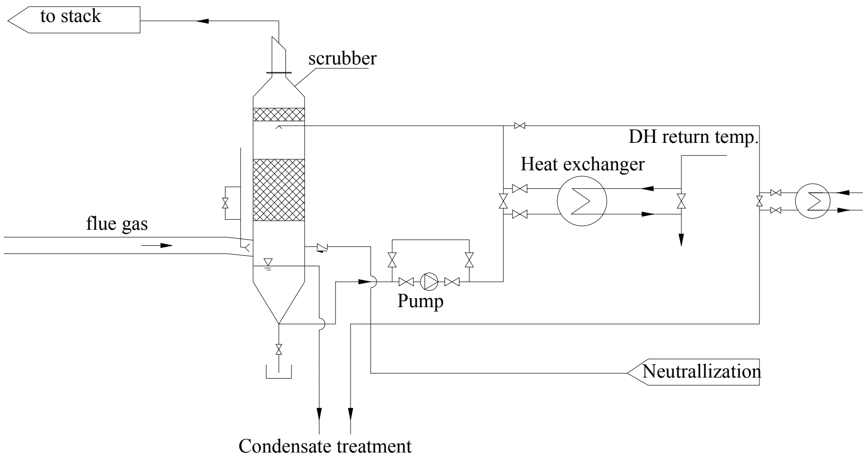

Figure 2. The basic flue gas heat recovery mode using a scrubber.

The hot flue gas enters the bottom of the scrubber, and the cooled circulating water is sprayed on the top of the scrubber. In this way, a high-efficient direct-contact heat and mass transfer process happens between the flue gas and the circulating water. During this process, the flue gas will be cooled down to a temperature under its dew point, in fact dew point is the maximum possible temperature that it can reach, provided the scrubber is high enough and the contact time is long enough. Therefore the latent heat of condensing water is transferred into the cold circulating water. This also makes it possible that the total energy efficiency of the boiler exceed 100%. Neutralization is also necessary before the warm circulating water flows into the plate heat exchanger because of the acids gases dissolved in the water and condensate treatment is also required.

2.3 Flue gas heat recovery mode enhanced by absorption heat pump

For most situations in China, the dew point of coal combustion flue gas is lower than 57°C, which is the dew point of gas combustion flue gas, and could be much lower because of less moisture. So that we propose to use the absorption heat pump driven by steam or hot water to enhance the heat recovery.

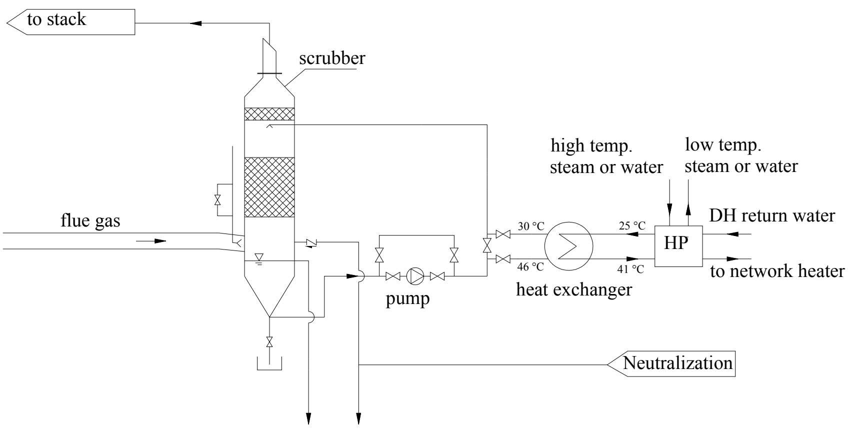

Figure 3. The flue gas heat recovery mode enhanced by an absorption heat pump.

As can be seen from Figure 3, the DH return water will be heated up by the heat pump, and in most cases the water flow will go to the network heater for further heating according to the DH need. And the heat pump can cool down the scrubber circulating water to 30°C for enhancing the heat and mass transfer in the scrubber.

3 RESULTS AND DISCUSSION

3.1 Combined heat and power plant for case study

One CHP plant in Dalian, China is planning to use the scrubber for flue gas heat recovery, because the current heat supply is insufficient due to the decommissioning of small coal-fired boilers and also because of the more rigid emission standard (Ministry of Environmental Protection of China 2017). The CHP has four high pressure coal-fired coal boiler (220t/h) and three steam turbine generators, including two back pressure steam turbine (25MW) and one extraction steam turbine (50MW). There are also two peak shaving gas-fired boilers; each has 35t/h capacity. The heating area is about 7569,000 m2. The CHP has already equipped the dust remover, so that the scrubber will be installed after the dust remover. The design indoor and outdoor temperatures are 18°C and -9.5°C, respectively. District heating season is about 5 months.

3.2 Design of the flue gas scrubber and heat pump

Taking one of the four identical coal-fired boilers (220t/h) as an example, we can calculate that the maximum recovered heat energy can be 12.3MW provided the flue gas temperature can be cooled down to 30°C. The flue gas heat recovery rate is 8%. In order to reach this, the inlet temperature in low temperature side should be 25°C and the flow rate is 200kg/s. the flow rate in the high temperature side of the heat exchanger is 150kg/s.

In order to recover 12.3MW heat, the capacity of the absorption heat pump can be calculated by,

$$Q_{HP} = COP/(COP\text{-}1)Q_{Recover} \quad (1)$$

where COP is the coefficient of performance, and COP = 1.8 in this study; Qrecover is the heat that recovered from flue gas, MW. It can be calculated that the capacity of heat pump is about 27.6MW, which means that the driven heat source should provide at least 15.3MW high grade heat (steam or water).

3.3 Preliminary feasibility analysis

The feasibility analysis mainly takes into account the added investment, operating cost and revenue from selling the heat released to the DH network.

- ***Added investment***

There are mainly two equipments, scrubber and heat pump. For a 220t/h coal-fired boiler the flue gas scrubber investment is about 2 million Euros according to Condens Heat Recovery Company. This investment already includes the pipes, pumps, heat exchangers, and condensate treatment facility, but not including construction and tax. We consider the import tax rate (5%) and the value added tax (17%) to the scrubber cost in this study. In addition, the construction cost is taken into account based on the local price level. In all, the investment for the flue gas scrubber system is around 20.29 million Chinese Yuan (CNY).The absorption heat pumps will be bought from China manufactures. The investment calculation can be found in Table 1. We can see that the total added investment is 20.29 + 6.9 = 27.19 million CNY.

Table 1. Investment and required parameters of the absorption heat pump.

Heat pump	Absorption heat pump, LiBr/H_2O
Main parameters	Inlet water temperature in the heat exchanger side is 27~46° C; out let water temperature in the heat exchanger side is less than 25° C. COP = 1.8.
Energy input	Steam, 15.3MW
Energy output	27.6MW
Price level	200,000~300,000 CNY/MW
Investment	6.9 million CNY, including the commissioning

- ***Operating cost***

The operating cost for recovering the flue gas heat is mainly referred to the energy input for the heat pump. For the coal-fired CHP plant, steam will be extracted and used for driving the absorption heat pump. This part of steam will not be used for power generation as it would be, therefore, the electricity generated by the plant will be reduced to some extent. This is actually the cost for running the heat pump. The pumping cost for circulating the water in the scrubber and the heat exchanger is another operating cost, which is proved to be very small compared to the heat pump operating cost, so that we did not consider this part. However, the neutralization cost is considered in this analysis. The calculation of the operating cost can be found in Table 2.

Table 2. Calculation of operating cost for flue gas heat recovery using a scrubber and an absorption heat pump.

Heat pump capacity	27.6MW
Maximum heat recovery	12.3MW
Total heat recovery during the whole heating season [1]	103615GJ (28782MWh)
Total heat released to the DH network [2]	232502GJ (64584MWh)
Operating cost of heat pump during a heating season [3]	Steam consumption: 128887GJ (35801944kWh) Reduced electricity generation: 12888700kWh Reduced revenue from selling electricity: 5.53 million CNY
Neutralization system operating cost [4]	400,000CNY for a whole heating season

1. The heating season is five months, and the average DH load ratio is 65%, so that we assume the total average heat recovery rate is 65% of the maximum;
2. Total heat released to the DH network includes the recovered heat from flue gas and the energy input for driving the absorption heat pump. 103615GJ + 128887GJ = 232502GJ.
3. The boiler efficiency is 90%, and the average electricity efficiency for coal-fired power plants in Dalian area is 36% (which is calculated by the average coal consumption rate for power generation: 341g/kWh), the electricity uploading price is 0.4293CNY/kWh.
4. Because the CHP has desulphurization tower, so the neutralization is used at minimum working load, and the estimated operating cost is based on a neutralization liquid consumption rate of 1ton/day.

- ***Revenue from selling the heat and payback time***

The profit from selling the heat released to the DH network is the main revenue of this flue gas heat recovery system. As can be seen from Table 2, the total useful heat is 232502GJ, and the local heat price level is 50CNY/GJ, so that the total revenue from selling heat would be: 11.63 million CNY. We did not consider the revenue from the emission reduction, CO2 saving, water saving et al. The calculation of the revenue and estimation of the payback time is shown in Table 3.

Table 3. Calculation of the revenue and the payback time for the flue gas heat recovery system.

Total investment	27.19 million CNY	
Operating cost	Heat pump: 5.53 million CNY Neutralization: 400,000 CNY	5.93 million CNY
Revenue from selling heat	11.63 million CNY	
Payback time	4.77 years	

To conclude, the payback time will be 5 years, and this result shows that the flue gas heat recovery technology is viable in China, but the economic feasibility is affected by many other factors, e.g. the heat recovery rate, DH return water temperature and time of DH season. The payback time of the system varies case by case, it can be shorter when the DH return water temperature is lower, heat recovery rate is higher and DH period is longer and vice versa.

Besides, this flue gas heat recovery system will also be able to reduce the particulate matter and SO2 emissions, it also can save water. If these benefits are also considered and considering the local subsidies to the environmental protection project, then the payback time would be shorter.

4 CONCLUSIONS

Nowadays, most countries all over the world have to face the problem of the sustainable and reliable energy supply in the future and the CO_2 emission control. In China, a huge amount of the hot flue gas is emitted directly to the atmosphere, leading to the waste of energy stored in the flue gas and causing the air pollution. However, the flue gas heat recovery rate is very low in China, especially for the coal-fired boilers and power plants. Therefore, we propose to use a scrubber in combination of the absorption heat pump to recover the sensible and latent heat stored in the flue gas and used for district heating purpose. Firstly, we introduced the basic principles for recovering the heat from flue gas, and also analysed the influencing factors of the heat recovery rate. Secondly, we described the basic flue gas heat recovery mode that uses only the scrubber and a water-water plate heat exchanger. But this mode is technically viable only when the water temperature in the bottom of the scrubber is higher than the DH return temperature, and the temperature difference is large enough for the water-water plate heat exchanger. However this prerequisite is difficult to satisfy in China since the dew point is usually lower than 50° C for the coal combustion flue gas. That is why we propose to use a scrubber in combination with an absorption heat pump to enhance the heat recovery process. For the enhanced heat recovery mode, we implemented the preliminary design and feasibility study for a coal-fired CHP plant in Dalian, China. The results show that the maximum heat recovery rate is about 8% provided the flue gas can be cooled down to 30° C, and the payback time for the flue gas scrubber is around 5 years. Besides, this flue gas heat recovery system will also be able to reduce the particulate matter and SO_2 emissions, it also can save water.

Next step, we will continue our work in two directions, the first one is to develop a detailed mathematical model for the flue gas heat recovery system, and to analyse the effects of influencing factors on the heat recovery rate. Second one is try to determine the dew point of the flue gas in a more rational way, because the dew point is a very important parameter for the flue gas heat recovery.

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REFERENCES

Condens heat recovery company. (2017). Available at: http://www.condens.fi/eng/heatrecovery.htm.

Fu L., Tian G.S., Sui J., Jiang Y. (2003). Combining absorption heat pump with gas boiler for exhaust condensing heat recovery in district heating system. Acta Energiae Solaris Sinica, 2003,(5): 620-624.

Ministry of Environmental Protection of China. (2017). Technical specifications for flue gas ultra-low emission engineering of coal-fired power plant. Available at: http://www.zhb.gov.cn/gkml/hbb/bgth/201706/t20170623_416594.htm.

Wang S.L., Liu G.C. (2013). An integrated equipment for flue gas heat recovery and dust removal. Patent, CN, 102407070 B.

Wang S.L., Pan S.Y., Mu L.B., Shi Y.Z., Ge H.X., Qin B., Liu M.K., Zhang X.J., Fei Y.M. (2011). Measurement and analysis of an energy saving retrofitting project of flue gas heat recovery from gas-fired boiler. Journal of HV&AC, 2011, (7): 22-24.

Sun F.T., Zhao J.Z., Fu L., Zhao X.L., Zhang S.G. (2016). Energy Efficiency Analysis of the Waste Heat Recovery of Flue Gas from Natural Gas Boiler based on the Absorption Heat Exchange. Building Science, 2016, (10): 59-64.