

The Technical and Economic Analysis of the Extending Application of the Device of the Utilization of Waste Heat in the Wet Flue Gas of Natural Gas-Fired Equipment

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Abstract: With the adjustment of energy structure in the world, natural gas-fired equipment is used more and more popularly. However, the temperature of wet flue gas from all natural gas-fired equipment used at present is too high. These cause the consumption of high-quality energy and environmental pollution. The anticorrosive condensing heat exchanger is installed in the natural gas-fired equipment to recover and apply effectively waste heat of flue gas and a great deal of water vapour potential heat, and thus improve the heat efficiency. This paper analysed the feasibility and economy of the central and local boiler house installed the wet flue gas condensing heat exchanger.

Key words: natural gas-fired boiler, wet flue gas, utilization of waste heat, technical and economic analysis.

1. INTRODUCTION

With the operation of the sustainable development strategy in the world, the adjustment of energy structure and the reform of "natural gas replaces coal" in the medium and big cities in China, natural gas-fired equipment, including natural gas-fired boilers, natural gas-fired air-conditions and natural gas-fired dynamotors and so on are used more and more popularly. However, the temperature of wet flue gas from natural gas-fired equipment used at present or in the future is too high. That of natural gas-fired boilers is between 150°C and 250°C, that of natural gas-fired air-conditions is above 170°C, that of household boilers is above 100~120°C. These cause the consumption of high-quality energy and architecture environmental pollution including heat pollution, deleterious gas pollution. The anticorrosive condensing heat exchanger, making the temperature of wet flue gas be lower than the temperature of its dew point, is installed in the natural gas-fired equipments to recover and apply effectively waste heat of flue gas and a great deal of water vapour potential heat, at the same time, condensing water can also absorb deleterious gas in the wet flue gas, for example, CO_x, NO_x, SO_x and so on. However, that doesn't only improve the heat efficiency but also reduce various pollutions.^[1-3]

This paper analysed the feasibility and economy of the central and local natural gas-fired boiler house installed the wet flue gas condensing heat exchanger. It will supply some reference for current reconstructing projects of natural gas-fired boiler houses.

2. THE TYPE OF CONDENSING HEAT EXCHANGERS

According to the different installed position of condensing heat exchanger, the condensing boiler includes two types, the whole and the separate. When the traditional natural gas-fired boiler house is reconstructed into the condensing, an anticorrosive condensing heat exchanger need be installed in the natural gas-fired boiler; this is called the separate condensing boiler. The condensing heat exchanger also includes two types, the direct contact and the indirect contact, in terms of the different heat transfer principles.

The wet flue gas and water exchange directly heat and matter in the direct contact heat exchanger, its outlet temperature of wet flue gas is far lower than the one of the indirect contact heat exchanger. It has high heat efficiency, and is simple, at the same time, can cleanse the wet flue gas, but it can't be used in the system where water quality must be high.^[4]

The wet flue gas and water exchange indirectly heat by the wall in the indirect contact heat exchanger. Because some deleterious gas is dissolved into the condensing water, it is so acidic and corrosive (the value of pH is 4~5) that will corrupt seriously the heat exchanger. Therefore, we must mediate between the anticorrosion and the heat transfer, when the structure must be compact.^[8-9, 10]

The condensing heat transfer material is different from the one of the traditional natural gas equipment, and must be anticorrosive or is plated anticorrosive materials. There is the heat exchanger made of peculiar stainless steel abroad, but at home none of homemade condensing boilers or homemade condensing heat exchangers is still on sale.

3. THE POTENTIAL OF SAVING ENERGY IN THE CONDENSING BOILER

When the natural gas is burning, 80%~85% of the high heat value (HHV) of the fuel transfers to working substance, but the rest transfers to outer atmosphere by expelling wet flue gas and heat loss on the surface. However, the heat of water vapour in the wet flue gas is 55%~75%. Therefore, when the temperature of wet flue gas is above the temperature of dew point, waste heat recovery can improve heat efficiency of the natural gas-fired equipment by more 2%~5%. When the temperature of wet flue gas is below the temperature of dew point, it can also recover water vapour potential heat, which will improve heat efficiency by more 11%~15%.^[4]

Now we compare two situations. When the primary temperature of wet flue gas drops to 90°C and 50°C respectively, what is the heat efficiency of the boiler? the detail calculation is overlooked^[4, 7], but the result is showed in the Table1.

Table1: The heat efficiency of boiler under the different temperature of wet flue gas

the primary temperature of wet flue gas form the boiler (°C)	200	170	120
The percent of improved heat efficiency(d roping into 90°C)	4.4%	3.2%	1.2%
The percent of improved heat efficiency(d roping into 50°C)	10.2%	8.96%	6.96%

The table1 shows that the recovery of potential heat will improve obviously the heat efficiency of boiler, so that the fuel is saved, when the temperature of wet flue gas drops to 50°C.

4. THE RECONSTRUCTING PROJECTION OF THE NATURAL GAS-FIRED HEATING BOILER HOUSE

Natural gas-fired heating boiler is mainly hot water boiler, and it supplies mainly hot water to low temperature hot water heating consumers and living hot water consumers. The paper analyses chiefly the following projects about the heat recovery of wet flue gas.

Presently, the following two projects are popular in Russia.^[4, 5]

Project 1: Figure1, the heat excess of wet flue gas provides heat into return water of boiler, and the water and wet flue gas exchange heat by counter flow. Because the temperature of cold water is lower, it is more advantaged to recover waste heat of flue gas and a great deal of water vapour potential heat, and thus improves the heat efficiency of condensing heat exchanger. Therefore, when the water-supply temperature and living hot water temperature have a few of discrepancy, we can use this project.

Project 2: Figure2, the heat excess of wet flue gas provides directly heat into living hot water, and the water and wet flue gas exchange heat by counter flow. The heat efficiency is same to the one of project 1

basically. At the same time, it installs heat exchanger on the water-supply pipe line in order to ensure the needed water-supply temperature of living hot water. We can apply this project to the same occasion of project 1, but the water quality must be high, or the water has been dealt with in magnetization.

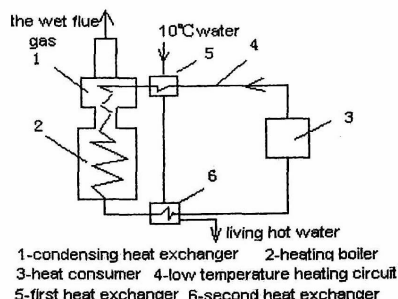


Figure1: project 1

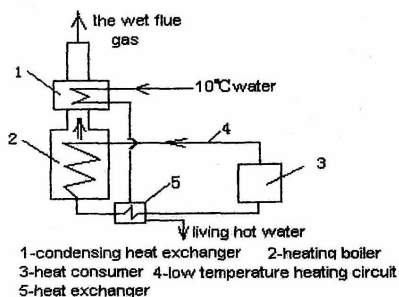


Figure2: project 2

Projects comparison: In the project 2, cold water is heated firstly and the cost increases, but the heating water and living hot water are apart. On the hand, the temperature of cold water entering the condensing heat exchanger is low, which makes a larger difference in temperature so that the condensing heat exchanger operates efficiently, on the other hand, when the condensing heat exchanger stops operating, the heating system isn't affected, and the water system is steady, only installs a common heat exchanger. However, in the project 1, the system installs first and second common heat exchangers; both supply water and return water heat up the living hot water together. Because the load of boiler is unsteady during the heating period, the condensing heat exchanger also operates unsteadily, so that the whole heating circuit operates unsteadily. When the condensing heat exchanger stops operating, we only need stop supplying cold water.

Asking questions and improving projects: In the above two projects, the living hot water is heated up by the heat exchanger installed on water-supply pipe line, which will make the actual water-supply temperature different from the designed one when boiler is working

in full load, so we must take measures to ensure the water-supply temperature being behind heat exchanger. We can improve the project 2 (figure3). Generally, the temperature of wet flue gas is between 150°C and 250°C, and it is still high when boiler is working in part load. We can lay circuit like figure3. The heat exchanger is on standby, and the valves are controlled by servomechanisms, thus solves the above question to some extent.

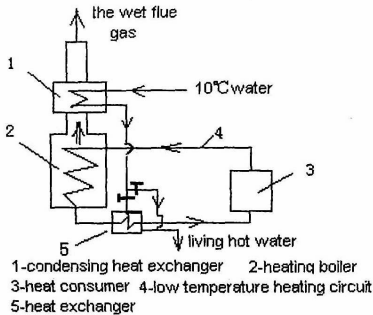


Figure3: improved project 2

Presently, besides the above two projects, there are several projects in our country.

Project 3: figure 4, the heat excess of wet flue gas provides heat into complementary water of boilers, and the water and wet flue gas exchange heat by counter flow. Because the temperature of cold water is lower, it is more advantaged to recover waste heat of flue gas, and the heat efficiency is the highest. The project is often applied to unlocked low temperature radiant floor heating system, and it supplies living hot water to heat consumers.

Project 4: figure 5, the heat excess of wet flue gas provides heat into complementary water of boilers, and the water and wet flue gas exchange heat by counter flow. The heat efficiency is same to the one of project 3. The project is often applied to unlocked low temperature (95/70 °C) heating system. We needn't install a cold and hot water mixing tank in the boiler house, only need supply directly 95 °C hot water to heat consumers, so the consumers adjust the temperature of living hot water by mixing cold and hot water according to their need.

Project 5: figure6, the heat excess of wet flue gas provides heat into complementary water of boilers, and the water and wet flue gas exchange heat by counter flow. Because the temperature of cold water is lower, it is more advantaged to recover waste heat of flue gas and a great deal of water vapour potential heat, the project can be applied to close low temperature radiant floor heating system, and it only supplies heating water Project 5: figure6, the heat excess of wet flue gas provides heat into complementary water of boilers, and the water and wet flue gas exchange heat by counter flow. Because the temperature of cold water is lower, it is more advantaged to recover waste heat of flue gas and a great deal of water vapour potential heat, the

project can be applied to close low temperature radiant floor heating system, and it only supplies heating water to heat consumers. Its efficiency is high comparatively. But when it is applied to 90/70 °C close heating system, the efficiency is lower comparatively than the one of the above projects. In this system, sometimes, condensing heat exchanger doesn't operate in high efficiency area, but it can still recovers a great deal of waste heat. And this project is reconstructed simply, expediently and economically.

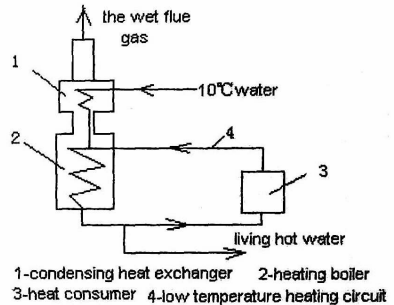


Figure4: project 3

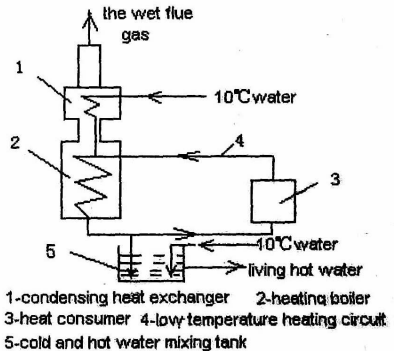


Figure5: project 4

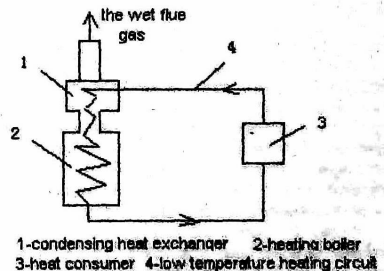
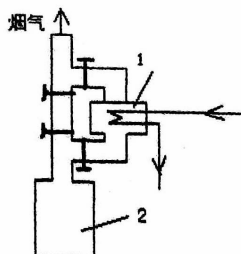


Figure6: project five



1-condensing heat exchanger 2-heating boiler

Figure7: the simple installed position picture

The above five projects have respective merits and defects, and are applied to different occasions. When reconstructing natural gas-fired boiler house, we can choose those projects according to primary systems and economic situations. Meanwhile, when reconstructing natural gas-fired boiler house, we

should pay attention to the installed position of the condensing heat exchanger and build the side-cross flue, so that the boiler can operate normally when the condensing heat exchanger is being fixed. The simple installed position picture is like figure 7.^[5]

5. WATER-SUPPLY AND WATER-RETURN TEMPERATURE IN HEATING CIRCUIT HAS EFFECT ON THE CONDENSING HEAT TRANSFER DURING HEATING AJUSTMENT PERIOD

Analyzing the above projects, we only considerate the designed water-supply and water-return temperature (it is 95/70°C in the low hot water heating system, 60/50 °C in low temperature radiant floor heating system), but the actual water-supply and water-return temperature in the circuit is lower than the designed one mostly when the boiler operates actually and is adjusted by all kinds of modes, like table 2.

Table 2:Water-return temperature (95/70°C) under different outdoor temperatures by different adjustment modes

Outdoor temperature $t_w(^{\circ}\text{C})$			5	4	3	2	1	0	-1
$\bar{G}=1$	$\bar{F}=1$	water-return temperature $t_h(^{\circ}\text{C})$	44.59	46.05	47.49	48.9	50.29	51.65	52.99
$\bar{G}=1.3$	$\bar{F}=1.5$	water-return temperature $t_h(^{\circ}\text{C})$	37.28	38.34	39.38	40.4	41.4	42.38	43.35
Outdoor temperature $t_w(^{\circ}\text{C})$			-2	-3	-4	-5	-6	-7	-8
$\bar{G}=1$	$\bar{F}=1$	water-return temperature $t_h(^{\circ}\text{C})$	54.31	55.61	56.89	58.15	59.4	60.63	61.85
$\bar{G}=1.3$	$\bar{F}=1.5$	water-return temperature $t_h(^{\circ}\text{C})$	44.3	45.24	46.16	47.07	47.97	48.86	49.74
Outdoor temperature $t_w(^{\circ}\text{C})$			-9	-10	-11	-12	-13	-14	-15
$\bar{G}=1$	$\bar{F}=1$	water-return temperature $t_h(^{\circ}\text{C})$	63.05	64.24	65.41	66.58	67.73	68.87	70
$\bar{G}=1.3$	$\bar{F}=1.5$	water-return temperature $t_h(^{\circ}\text{C})$	50.6	51.46	52.31	53.14	53.97	54.79	55.61

This will have two sides effect on the above projects. Firstly, concerning the system installing heat exchanger in the water-supply pipe line ,like project 1 and 2 ,we must ensure the temperature after heat exchanger be same to the primary actual temperature. Secondly, it will have a large effect on the system where the return water in circuit is heated up directly, like project 5. Form this table, we can see that the actual water-return temperature is different in terms of different adjustment modes, and is lower than the designed one generally. Because the temperature of cold water is lower, it is more advantaged to recover waste heat of flue gas and a great deal of water vapour potential heat, and thus improves the heat efficiency of condensing heat exchanger. But the heat recovery of condensing heat exchanger is instable. As heating adjustment ,sometimes, the condensing heat exchanger only recovers waste heat so that its efficiency is low, , but , sometimes ,it recovers waste heat and potential heat so that its efficiency is high.

6. THE ECONOMIC ANALYSIS OF THE BOILER HOUSE RECONSTRUCTION

The economic evaluation is mainly to calculate the extra charge of equipment after installing the condensing heat exchanger, thus evaluates the economic feasibility, when the traditional natural gas-fired boiler house reconstructs the condensing boiler house.

After installing condensing heat exchanger, the efficiency is improved, so the fuel is saved, but it increases the investment, including the material cost of condensing heat exchanger, the charge of valve and pipe line, the installing charge, the extra fixing charge and the extra fan charge because of the increased wet flue gas resistance.^[5] Here we only calculate and compare the cost of condensing heat exchangers made of different materials.

6.1The costing of anticorrosive condensing heat exchanger

We investigated and calculated the current price of different materials of heat exchangers, like table 3.

Table 3: The current price of different materials of heat exchangers

The materials of heat exchanger	price (¥/t)	The price of every unit(heat transfer surface) (¥/m ²)
Carbonizing. steel	4150	30
stainless steel	27000	103
Copper with anticorrosion plating of Ni	43000 (copper)	141

Therein to, the price of anticorrosion plating of Ni is 0.75yuan /m².

From the table 3, we can see the price of copper with anticorrosion plating of Ni is the highest, but its anticorrosion is the best, and its heat transfer is better than other materials^[8, 9, 10].

Generally, there is a common heat exchanger (made of carbonizing. steel) in the traditional boiler. Now installing the condensing heat exchanger, we compare the two anticorrosive materials to the material of the common heat exchanger. The results are like table4.

Table4: The increased multiple of the cost of condensing heat exchangers made of different materials

		Compare with the common heat exchanger carbonizing. steel) in the boiler	Condensing heat exchanger					
			copper with anticorrosion plating of Ni			stainless steel (same volume calculation with copper with anticorrosion plating of Ni heat exchanger)		
The primary temperature of wet flue gas (°C)			200	170	120	200	170	120
The fallen temperature of wet flue gas (°C)	90	Increased multiple of heat transfer surface	1.2	1	—	3.1	2.6	—
		Increased multiple of cost	5.64	4.7	—			
	50	Increased multiple of heat transfer surface	2	1.5	1	5.2	3.9	2.6
		Increased multiple of cost	9.4	7.05	4.7			

The table4 shows that the cost of condensing heat exchanger made of copper with anticorrosion plating of Ni is always higher than the one made stainless steel under the different temperature of wet flue gas, and their costs will increase as the temperature of wet flue gas runs down.

7. CONCLUSION

- 1) Because the wet flue gas of natural gas-fired boiler includes a large of water vapour, a lot of potential heat can be recovered, thus improves the efficiency of boiler.
- 2) Offering and comparing several feasible projects about reconstructing boiler houses, we also offer their applied occasions. Those will supply some references for the current boiler houses reconstruction.
- 3) By costing and economic compare, we can choose proper projects in terms of own economy conditions. The price of copper with anticorrosion plating of Ni condensing heat exchanger is high but heat transfer is better, while that of stainless steel is low but heat transfer is worse than the former
- 4) The device of the utilization of waste heat in the wet flue gas of natural gas-fired equipments will be very popular.

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