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Slag Cooler Waste Heat Supply System and Energy Saving Analysis

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Abstract. In view of the drawbacks of the traditional scheme of recovering residual heat from slag cooler to condensate water system, this paper proposes a new scheme for the utilization of residual heat from slag cooler of circulating fluidized bed heating units. During heating period, a return water from heat network is drawn from the main return water pipeline of heat network as the cooling water source of slag cooler. The residual heat of slag cooler is directly used for heating, and the residual heat of slag cooler will be recovered to condensate water system in non-heating period, in order to realize the free switching between the two schemes, valves are installed in the pipeline. The energy-saving effects of the two schemes are analyzed, and the results show that the new scheme is more energy-saving.

1. Introduction

Due to the wide fuel adaptability, high efficiency desulfurization in furnace and low emission of NO_x [1], CFB Units have developed rapidly in recent years [2-3]. CFB Units usually use fuel with high ash content and low calorific value so that the slag discharge temperature is often above 850 C and the heat loss of slag discharge accounts for 1%~2% [4] of the heat input into the furnace. If this part of heat can be recovered and utilized, the energy-saving of the units will be greatly improved.

As an important auxiliary machine of CFB Units, the main purpose of slag cooler is to reduce the temperature of bottom slag and facilitate transportation. In recent years, with the improvement of requirements for energy saving and consumption reduction, the utilization of residual heat of slag cooler has become a new research hotspot. At present, there are two main types of slag coolers at home and abroad: fluidized bed slag cooler [7-9] and drum slag cooler [10-12]. Fluidized bed slag cooler has strict requirements on the size of bottom slag. The fluidization quality of bottom slag particles greatly affects the reliability of the slag cooler. In our country, the main fuel for CFB Units is inferior coal which contains a certain amount of coarse particles in the bottom slag and the fluidization quality is not good. The drum slag cooler is relatively reliable because it does not require the size of the bottom slag [13], so at present domestic CFB Units more use drum slag cooler.

The cooling mode of drum slag cooler is water cooling. At present, the utilizing way of waste heat utilization is to recover the heat from slag discharging to condensate system. The specific method is to set up a slag cooler at the slag discharging port, lead condensate water into the slag cooler from a low-pressure inlet, absorb the heat from the bottom slag to the condensate water system. By reducing the cycle heat absorption of the system, the energy-saving of the unit is improved. Many domestic scholars



have carried out a lot of research on this way of waste heat utilization. According to the different location and mode of cooling water of slag cooler connecting to condensate water system, various schemes have been put forward, and the energy-saving analysis and comparison of various schemes have been made by using the method of equivalent heat drop, so as to determine the optimal scheme suitable for unit [14-20].

However, the energy-saving effect of this waste heat utilization method is not very good., if the return water level of the slag cooler is improperly set and the return water temperature is lower than the main condensate temperature at the entrance point, the effect of waste heat utilization will be further reduced.

Most of the thermal power units in northern China are heat supply units. For CFB Units, if the slag heat is directly used for heating during heating period, from the point of view of energy efficiency, this method is more energy-efficient than the slag heat recovery to condensate water system.

Therefore, a new scheme of waste heat utilization for slag cooler of CFB Units is put forward in this paper, that is, to recover slag heat to condensate water system during non-heating period, and to directly use slag heat to heat supply during heating period.

2. Unit survey

The equipment of a 150MW CFB Units is summarized as follows: Boiler is an ultra-high pressure intermediate reheating, single drum natural circulation, circulating fluidized bed boiler produced by Shanghai Boiler Works Co., Ltd, which model is SG-480/13.7-M569. Turbine is an ultra-high pressure, primary reheat, double cylinder, double exhaust, single shaft and condensing steam turbine produced by Shanghai Steam Turbine Works, which model is N150-13.24/535/535.

In the later stage of the unit, the heat supply was reformed. The steam extraction capacity was designed to be 200 t/h by drilling holes in the connecting pipes of the middle and low-pressure steam turbines, and a first heating station was built. The backwater from the heating network at 50°C entered the circulating water pump through the decontaminator and the heat exchanger after pressurization. The circulating water of the heating network was heated to 95°C high by using 0.9 MPa superheated steam from the steam engine room and 352°C superheated steam through the steam-water heat exchanger and water heat exchanger. Hot water is sent from the hot water pipe network to the secondary heat exchanger stations in each urban area.

The slag discharge capacity of each boiler is 9.2 t/h under the designed coal type and 17.2 t/h under the checked coal type. There are two slag discharge ports with inner diameter of $\Phi 500$ mm on both sides of the furnace. The slag discharge with temperature of 1000°C is discharged through a conical valve through a slag discharge pipeline. Two water-cooled drum-type slag coolers are installed at each slag discharge port to ensure that the slag discharge temperature is less than 100°C and can operate safely and reliably for a long time under the full load condition of the boiler, no matter periodically or continuously. The cooling water quantity of the slag cooler is less than 60t/h, the inlet water temperature is 34.6-51.1 C, the source of water is condensate water of the power plant, the inlet water pressure is about 2.45 MPa, the outlet water temperature is less than 90°C, and the water resistance of the slag cooler is 0.05 MPa.

3. Two schemes for waste heat utilization of slag cooler

The existing scheme of waste heat utilization of slag cooler of the 150 MW CFB heat supply units is to recover the waste heat of the slag cooler to the condensate water system (scheme 1). As shown in Fig. 1, the slag cooler is parallel to the No. 1 low-pressure heater. Part of the condensate water is drawn from the inlet of the No. 1 low-pressure heater, and is pressurized by the slag water pump into the slag cooler. After absorbing the heat of slag discharge, it returns to the outlet of No.1 low-pressure heater with an electric adjusting door on the intake pipe to adjust the cooling water flow according to the discharge amount of slag.

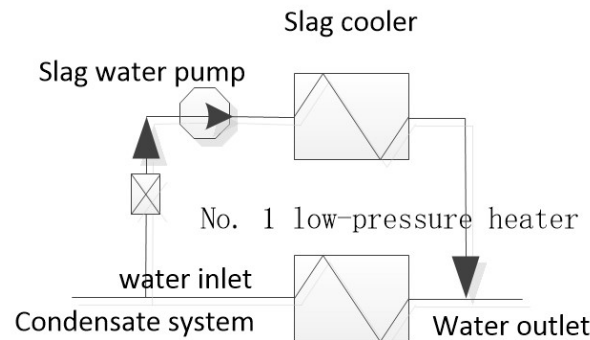


Figure 1. Slag waste heat recovery to the condensate system

This scheme is not the most energy-saving. In this paper, a new scheme of waste heat recovery is proposed, that is, to recover the heat of slag discharged into condensate water system in non-heating period, and to directly use the heat of slag discharged in heating period (scheme 2).

The specific implementation method is shown in Fig. 2. Compared with the scheme of waste heat recovery in Fig. 1, the new scheme adds a cooling water source from the backwater pipe of the heating network and installs an electric gate in the cooling water inlet pipeline to adjust the water quantity according to the amount of slag discharged by the unit. The backwater of the heating network enters the bottom slag of the slag cooler after pressurization by the slag pump, and adjusts the cooling water flow through the gate, so that the slag discharging temperature drops to 100°C and the backwater temperature of the heating network rises to 95°C , and enters the main hot water pipe network for heating. In addition, the new scheme installs electric gate valves on the original condensate water inlet and outlet slag cooler pipeline and pipeline of backwater slag cooler of the heating network respectively to realize the switching of cooling water source during heating and non-heating periods. The new scheme maximizes the use of the original system and its equipment. Adding only one cooling pipe to the periphery makes the system simple and less investment.

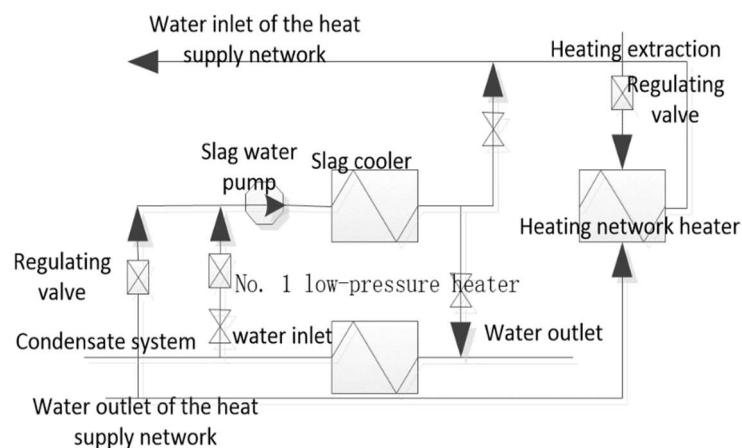


Figure 2. Slag heat recovery waste heat recovery to the heat net system

4. Energy saving analysis of two schemes

Compared with the existing scheme of using condensate water to recover the heat of slag cooler in the heating period, the scheme proposed in this paper directly provides heat to the outside after the heat is absorbed from the slag cooler, and the steam extraction capacity of heating with higher energy efficiency

level is squeezed out, which is more energy efficient than the existing scheme of using condensate water to recover the heat of slag cooler in the heating period.

In order to more accurately compare the energy-saving effect of the two schemes, this paper adopts the method of equivalent heat drop [21] to analyze the energy-saving effect of the two schemes. Because only the heating period can recover the residual heat of the slag cooler by using the backwater of the heating network, the energy saving effect of the two schemes during the heating period is compared. The thermal data of the unit under the heating condition are shown in Fig. 3.

For scheme 1, according to the theory of equivalent heat drop, the residual heat recovery from slag cooler to condensate water system belongs to the internal hot water heat inlet system, so the calculation formula of unit work increment caused by scheme 1 is as follows:

$$\Delta H_1 = \alpha_{cn} \left[(\bar{t}_{cn} - \bar{t}_1) \eta_2 + \tau_1 \eta_1 \right] \quad (1)$$

Where: ΔH_1 —Scheme 1 unit work increment, kJ/kg; α_f —Pumping share of slag cooler, $\alpha_f = D_f/D_0$; D_f —Cool water quantity of the slag cooler, t/h; D_0 —Main stream flow rate, t/h; h_l —Outlet water enthalpy of the slag cooler, kJ/kg; \bar{t}_1 —No. 1 low-pressure heater enthalpy, kJ/kg; τ_1 —Enthalpy rise of No.1 low-pressure heater condensate water, kJ/kg; η_1 —Extraction efficiency of No.1 low-pressure heater; η_2 —Extraction efficiency of No.2 low-pressure heater.

Regarding scheme 2, the residual heat of slag cooler is recovered by the return water of the heating network for heating. On the premise of the constant heat supply of the unit, the steam extraction capacity of the unit for heating can be reduced. According to the equivalent heat drop, the unit's external heating and steam extraction will cause insufficient work, resulting in the unit's power loss, while the unit's working capacity will increase if the heat supply and steam extraction capacity are reduced.

The unit's external heat supply and steam extraction system is equivalent to the working medium carrying heat out system. According to the theory of equivalent heat drop, the calculation formula of unit work reduction is as follows:

$$\Pi_{cn} 0 = \alpha_{cn} (h_{cn} - h_n) \quad (2)$$

Where: $\Pi_{cn} 0$ —Reduction of unit work, kJ/kg; α_{cn} —Share of heat supply and extraction steam, $\alpha_{cn} = D_{cn}/D_0$; D_{cn} —Amount of heat supply and extraction steam, t/h; h_{cn} —Extraction enthalpy, kJ/kg; h_n —Exhaust enthalpy of steam turbine, kJ/kg.

The unit heat supply and steam extraction releases heat and condensates in the heater of the heating network, and all the condensate water returns to the #1 low-pressure heater outlet. According to the equivalent heat drop theory, the calculation formulas of the recovery work obtained by the unit are as follows:

$$\Delta H_{cn} = \alpha_{cn} \left[(\bar{t}_{cn} - \bar{t}_1) \eta_2 + \tau_1 \eta_1 \right] \quad (3)$$

Where: ΔH_{cn} —Recovery power brought by condensate water returning to heat supply system, kJ/kg; \bar{t}_{cn} —Enthalpy of condensate in heat supply and extraction steam, kJ/kg.

The actual work loss caused by heat supply and steam extraction is equal to the work loss caused by steam extraction and heat supply minus the work recovered from the return water of heat supply to the heat system. The calculation formula is as follows.

$$\Pi_{cn} = \Pi_{cn} 0 - \Delta H_{cn} = \alpha_{cn} \left\{ h_{cn} - h_n - \left[(\bar{t}_{cn} - \bar{t}_1) \eta_2 + \tau_1 \eta_1 \right] \right\} \quad (4)$$

Where: Π_{cn} —Actual work loss caused by heat supply and steam extraction of the unit, kJ/kg.

For scheme 2, remaining heat of slag cooler used for heat supply causes reduction of heat supply and steam extraction capacity of unit. The calculation formulas are as follows:

$$\Delta D_{cn} = c_{dz} D_{dz} (t_{dz(in)} - t_{dz(out)}) / (h_{cn} - h_{cs}) \quad (5)$$

Where: ΔD_{cn} —Reduction of heat supply and steam extraction of unit by direct heating with residual heat of slag cooler, t/h; D_{dz} —Quality of bottom slag, t/h; c_{dz} —Specific heat of bottom slag, kJ/kg. °C; $t_{dz(in)}$ —Temperature of bottom slag at the entrance of slag cooler, °C; $t_{dz(out)}$ —Temperature of bottom slag at the outlet of slag cooler, °C; h_{cs} —Enthalpy of Condensate from Extraction Steam, kJ/kg.

The formulas for calculating the increment of unit work in scheme 2 are as follows:

$$\Pi_{cn} = \Delta \alpha_{cn} \left\{ (h_{cn} - h_n) - \left[(\bar{t}_{cn} - \bar{t}_1) \eta_2 + \tau_1 \eta_1 \right] \right\} \quad (6)$$

Where: $\Delta \alpha_{cn}$ —Reduction of steam extraction from unit heating caused by residual heat heating of slag cooler accounts for the share of main steam volume, $\Delta \alpha_{cn} = \Delta D_{cn} / D_0$

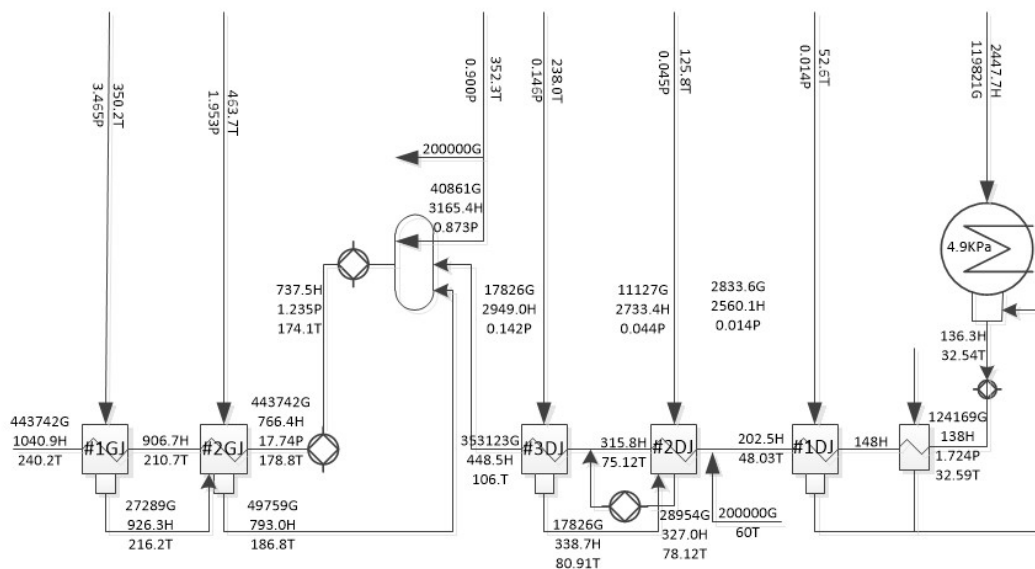


Figure 3. A 150MW circulating fluidized bed unit heating conditions map

5. Comparison of energy conservation benefits of two schemes

According to the energy-saving analysis of the two schemes of waste heat utilization of slag coolers, combined with the design data of slag coolers and the thermal data of units under heating conditions, the energy-saving benefits of the two schemes can be calculated.

In order to compare the energy-saving effect of the two schemes more comprehensively, this paper calculates the work increment caused by the two schemes of waste heat utilization adopted by the unit under the designed and checked coal types, and converts them into coal consumption for power generation. According to the annual utilization hours of the equipment, 5000 hours can be converted into the coal consumption saved by the unit during the four-month heating period. The calculation results are shown in Table 1.

The following results can be obtained from table 1:

(1) Under the designed coal type, the energy-saving benefits of scheme 1 and scheme 2 are 76.93 tons of standard coal and 216.33 tons of standard coal respectively; under the checked coal type, the energy-saving benefits of scheme 1 and scheme 2 are 163.21 tons of standard coal and 402.56 tons of standard coal respectively; under the two kinds of coal, the energy-saving benefits of scheme 2 are greater than that of scheme 1.

(2) Under the designed coal type, the unit adopts scheme 2 to save 139.4 tons more standard coal than scheme 1; under the checked coal type, the unit adopts scheme 2 to save 239.35 tons more standard coal than scheme 1, and the energy-saving income increases; the larger the slag discharge, the greater the energy-saving income of scheme 2.

Table 1. Calculation results of energy-saving benefits of two schemes

Number	Name	working condition of the designed coal	working condition of the checked coal
1	Main steam flow/(kg/h)	443739	443739
2	Generator power/MW	102.724	102.724
3	Net equivalent heat drop of new steam/(kJ/kg)	846.0784	846.0784
4	Coal consumption for power generation /(kJ/kg)	235.37	235.37
5	Bottom slag temperature at the inlet of slag cooler /°C	1000	1000
6	Bottom slag temperature at the exit of slag cooler /°C	100	100
7	Bottom slag specific heat /(kJ/kg. °C)	1.0048	1.0048
8	Slag discharge /(t/h)	9.20	17.20
9	Heat release from bottom slag /(kJ/h)	8320008.96	15554799.36
10	Exhaust enthalpy of low pressure cylinder /(kJ/kg)	2447.7	2447.7
11	# 1. Low entrainment enthalpy /(kJ/kg)	148.0	148.0
12	# 1. Low added water enthalpy /(kJ/kg)	202.5	202.5
13	# 1. Low enthalpy rise /(kJ/kg)	54.5	54.5
14	# 1. Cooling water flow from low-pressure inlet to slag cooler /(kg/h)	60000	60000
15	Cooling water temperature rise /°C	33.09	61.87
16	Inlet temperature of slag cooler /°C	35.35	35.35
17	Backwater temperature of slag cooler /°C	68.44	97.22
18	Enthalpy of water at the outlet of slag cooler /(kJ/kg)	286.56	407.05
19	# 1. Low Addition and Extraction Efficiency /%	4.7051	4.7051
20	Steam extraction temperature for heating /°C	352.30	352.30
21	Steam extraction pressure for heating /MPa	0.90	0.90
22	Extraction enthalpy of heat supply /(kJ/kg)	3165.02	3165.02

Number	Name	working condition of the designed coal	working condition of the checked coal
23	Reduction of heat supply and steam extraction /(kg/h)	2855.37	5338.30
24	Condensate Temperature of Steam Extraction in Heating Supply /°C	60.00	60.00
25	Enthalpy of Condensate in Heat Supply and Extraction Steam /(kJ/kg)	251.21	251.21
26	Backwater temperature of heating network /°C	50.00	50.00
27	Enthalpy of Backwater in Heat Network /kJ/kg	209.34	209.34
28	# 2. Low Addition and Extraction Efficiency /%	11.1872	11.1872
29	Annual Utilization Hours of Generators /h	5000	5000
30	Heating period /m	4	4
32	Increase in Unit Work Caused by Scheme 1 /(kJ/kg)	1.6183	3.4409
33	Relative Increased Thermal Efficiency of Units Caused by Scheme 1 /%	0.1909	0.4050
34	Reduction value of coal consumption in converted power generation /(g/kWh)	0.4493	0.9533
35	Coal Saving Quantity of Scheme 1 /t	76.93	163.21
37	Increase in Unit Work Caused by Scheme 2 /(kJ/kg)	4.5667	8.5377
38	Relative Increased Thermal Efficiency of Units Caused by Scheme 2 /%	0.5368	0.9990
39	Reduction value of coal consumption in converted power generation /(g/kWh)	1.2636	2.3513
40	Coal Saving Quantity of Scheme 2 /t	216.33	402.56

6. Conclusion

The conventional scheme of waste heat utilization of slag cooler in CFB unit is to recover the waste heat of slag cooler to condensate water system, and energy-saving effect is not optimal. A new scheme of waste heat utilization is put forward in this paper, that is, during the heating period, the heat of discharged slag is directly used for heating the backwater of heat supply network, and in non heating period, the heat of discharged slag is still reclaimed to the condensate system. The unit does not need major renovation, only one cooling water source is added to the original slag cooler cooling system, and the return water from the heat network is used as the cooling water of the slag cooler. Three electric gate valves are added to the main cooling water pipeline to realize the switch between the cooling water source of the slag cooler in heating and non-heating periods. The calculation results show that the new scheme has better energy-saving effect.

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