Energy Saving Effect Test and Operational Optimization of Low Pressure Economizer under Multi-variable Factors

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Abstract: The energy saving effect of low-pressure (LP) economizer of a 220MW unit was tested under multi-variable factors. Using the equivalent enthalpy drop method, the energy saving effect of LP economizer at different operational modes and different operating parameters has been calculated. When the higher water flow rate and inlet temperature of LP economizer is necessary, condensate water from NO.6 LP heater outlet should be used priority. Under the condition of 220MW, the optimal flow into LP economizer from NO.6 LP heater outlet is about 250t/h, the thermal efficiency of the unit could be increased 0.645%. If LP economizer inlet temperature is lower, the outlet of LP economizer should be connected to the outlet of NO.6 LP heater. And water temperature at LP economizer outlet should be slightly higher than the temperature of the NO.6 LP heater outlet. Otherwise, the energy saving effect will be decreased. Under the condition of 220MW, the thermal efficiency of unit increases 2.003%. For different LP economizer operation mode, there will be an optimal water returning location and optimal inlet flow rate.

1. Introduction

The problem of high exhaust smoke temperature is prevalent in domestic coal-fired boilers. The high temperature of exhaust smoke not only affects economy of unit, but also affects safety of air preheater. Therefore, it is a great practical significance to reduce exhaust temperature for reducing the energy consumption and improving the safety and reliability of the boiler. For the problem of boiler exhaust temperature being much higher than the design value, it is one of the most effective measures to save energy by adding LP economizer in rear flue of boiler\[1\].

2. Energy saving principle of LP economizer

2.1 Connection mode of LP economizer

The LP economizer is installed in rear flue of boiler with the similar structure of general economizer. The typical thermal system of LP economizer is shown in figure 1.
The LP economizer is arranged paralleling with main condensate system. The inlet water is derived from the LP reheat system of turbine. The inlet water flow and temperature of the LP economizer can be adjusted during the operation. After absorbing heat from boiler exhaust flue, the condensate water pass through LP economizer and returns to the condensate system and mix with the main condensate water. During this kind of connection, the condensate water entering the LP economizer strides several stage heaters, the flow resistance caused from the LP economizer body and connecting pipeline is overcome by the pressure drop during different stage heaters. The operation reliability is improved, and the cascade utilization of waste heat of exhaust smoke is effectively realized without install pumps [2, 3].

2.2 Analysis method of energy saving effect of low pressure economizer

The LP economizer will reduce the steam extraction quantity by inputting heat into the condensate reheat system, increasing cold source loss of the steam turbine, and result in decrease of the thermal cycling efficiency, and reduce the portion of extracted steam, which will increase the exhaust steam flow of LP cylinder and reduce condenser vacuum. But after installing the LP economizer, huge flue gas waste heat is input reheat system of the unit. The turbine unit gets extra heat from the outside. The reduced steam extraction continues to work in LP cylinder, adding a certain amount of working ability. This additional thermal work is much greater than the heat loss caused by reducing condenser vacuum and steam extraction. Therefore, the economy of unit is improved to a certain extent. At present, two main methods for analyzing thermal economy of LP economizer are equivalent enthalpy drop method and thermal performance test of steam turbine.

The equivalent enthalpy drop method takes LP economizer recycling exhaust heat as a pure heat inputting reheat system. But the energy consumption of generating 1kg new steam from boiler is constant. The thermal efficiency of turbine unit increases with all the power that added by heating system from the decreasing steam extraction. The equivalent enthalpy drop method take as premise that the initial, final steam parameters and reheat parameters, new steam flow of turbine unit and fuel heating quantity are fixed. Under the conditions like this, any small changes affecting thermal economy in thermal systems only relates to power change of the unit. It cannot change all levels of extraction steam. The economic effect of the whole thermal system change can be obtained by the quantitative calculation from extraction steam flow and heat of certain stage.

The thermal performance test is directly conducted at operating condition of the unit with or without LP economizer operation. The energy saving effect of the LP economizer is analyzed by the change of heat consumption rate of the unit. The recycled waste heat from the LP economizer is...
regarded as pure heat inputting reheat system, and the energy consumption of the boiler generates 1kg new steam keeps the same. The thermal efficiency increase and heat rate decrease of turbine unit are resulted from the power increase from the decreased steam extraction of reheat system. So the reduced heat consumption rate is the energy saving effect of LP economizer.

From the articles [4-6] we can find, the energy saving effect of LP economizer are tested and calculated by the method of equivalent enthalpy drop and thermal performance test. The energy saving effect of LP economizer in various conditions has not been analyzed and discussed in articles and works. In this paper, multi-variable performance tests are performed on energy saving effect of the LP economizer at very kinds of operating condition. The energy saving effect under typical conditions has been calculated by equivalent enthalpy drop method. The test result has been analyzed. The operational modes and parameters of the LP economizer have been optimized to gain best operational mode and running parameter.

3. Energy saving effect test of LP economizer under multi-variable factors

The energy saving effect test of LP economizer is performed on a 220MW unit. Through the testing of energy saving effect of LP economizer under corresponding conditions with several operational parameters change, the energy saving effects of different working conditions and different LP economizer operational modes have been compared. The affection of operational parameters and modes on energy saving effect is further determined.

3.1 Connection mode and performance parameters of LP economizer

The connection mode of LP economizer belongs to hybrid mode. The condensate water came from NO.6, NO.7 and NO.8 LP heater is mixed and enter into the LP economizer for heating. After heated, the condensate water returns back to the outlet of NO.5 or NO.6 LP heater, entering the deaerator with main condensate water. The schematic diagram of the specific system is shown in figure 2.

![Schematic diagram of LP economizer connection system](image)

**Figure 2.** Schematic diagram of LP economizer connection system

The design parameters of LP economizer are shown in table 1.

| Parameter                     | Unit | Design data | Parameter                     | Unit | Design data |
|-------------------------------|------|-------------|-------------------------------|------|-------------|
| Feed water flow               | t/h  | 267.84      | Average smoke speed           | m/s  | 6.64        |
| Water inlet temperature       | ℃    | 105.5       | Average water speed           | m/s  | 0.41        |
| Water outlet temperature      | ℃    | 146.9       | Smoke flow resistance         | Pa   | 165         |
3.2 Energy saving efficiency test of LP economizer under multi-variable factors

For the LP economizer system above, through changing several operational parameters, experiments with different purposes have been finished. Those are optimal water flow rate test, and the test of optimum returning location from LP economizer outlet to main condensate system.

3.2.1 Optimal water flow rate test for LP economizer. The condensate water entering into the LP economizer comes from the outlet of NO.6 or NO.7 LP heater. After heated by the LP economizer, the condensate water is introduced to outlet of NO.5 LP heater. In order to compare the effect of water flow from NO.6 or NO.7 LP heater export on energy saving effect, test conducted includes the following conditions: (1) under the condition of 180MW, the water flow entering into the LP economizer from NO.6 or NO.7 LP heater is 100t/h, 150t/h, 200t/h, 270t/h respectively. (2) under the condition of 220MW, the water flow entering into the LP economizer from NO.6 or NO.7 LP heater is150t/h, 190t/h, 240 t/h, 300t/h respectively.

3.2.2 Test of optimum returning location from LP economizer outlet to main condensate system. The condensate water entering into the LP economizer comes from the outlet of NO.7 or NO.8 LP heater, then heated by the LP economizer, after that the condensate water is introduced to outlet of NO.5 or NO.6 LP heater. In order to analyze the energy saving effect of different returning positions to main condensate system, test conducted includes the following conditions: (1) under the condition of 220MW, condensate water from LP economizer outlet returns to outlet of NO.5 LP heater. Smoke temperature at LP economizer outlet is 99℃. (2) Under the condition of 220MW, condensate water from LP economizer outlet returns to outlet of NO.6 LP heater. Smoke temperature at LP economizer outlet is 96℃. (3) Under the condition of 110MW, condensate water from LP economizer outlet returns to outlet of NO.6 LP heater. Smoke temperature at LP economizer outlet is 91℃.

4. Energy saving effect of LP economizer under multi-variable factors

4.1 Optimal water flow rate test results of LP economizer

The results of optimal water flow rate test of LP economizer has been calculated by equivalent enthalpy drop method. Test data and calculation results are shown in table 2 and table 3.

Table 2. Test results of change condensate water flow into LP economizer from NO.6 or NO.7 LP heater outlet under the condition of 220MW

| Parameter                                | Unit    | Condition1 | Condition2 | Condition3 | Condition4 | Condition5 | Condition6 | Condition7 | Condition8 |
|-------------------------------------------|---------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Water flow into LP economizer from NO.6 LP heater kg/h | 150762  | 189687     | 238649     | 300507     | 0          | 0          | 0          | 0          | 0          |
| Water flow into LP economizer from NO.7 LP heater kg/h | 0       | 0          | 0          | 0          | 142950     | 192876     | 239328     | 301240     |
| Inlet water temperature of LP economizer °C | 120.74  | 120.30     | 117.92     | 121.34     | 94.35      | 94.45      | 93.67      | 92.67      |
| Outlet water temperature of LP economizer °C | 148.64  | 144.15     | 138.72     | 137.62     | 133.05     | 127.05     | 122.01     | 118.64     |
| Outlet water temperature of NO.5 LP heater °C | 142.47  | 142.24     | 142.05     | 142.28     | 141.48     | 141.45     | 141.38     | 141.42     |
| Heating efficiency %                      | 0.5712  | 0.6049     | 0.6451     | 0.6276     | 0.5873     | 0.5935     | 0.581      | 0.578      |
Table 3. Test results of change condensate water flow into LP economizer from NO.6 or NO.7 LP heater outlet under the condition of 180MW

| Parameter                                    | Unit  | Condition 1 | Condition 2 | Condition 3 | Condition 4 | Condition 5 | Condition 6 | Condition 7 | Condition 8 |
|----------------------------------------------|-------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Water flow into LP economizer from NO.6 LP heater (kg/h) | 105817 | 147636 | 204174 | 270267 | 0 | 0 | 0 | 0 |
| Water flow into LP economizer from NO.7 LP heater (kg/h) | 0 | 0 | 0 | 0 | 105979 | 166533 | 202877 | 269459 |
| Inlet water temperature of LP economizer (℃) | 112.65 | 112.39 | 116.34 | 114.39 | 82.92 | 84.19 | 83.06 | 82.83 |
| Outlet water temperature of LP economizer (℃) | 137.78 | 136.38 | 135.65 | 130.79 | 126.58 | 119.15 | 112.75 | 108.31 |
| Outlet water temperature of NO.5 LP heater (℃) | 132.5 | 133.34 | 135.9 | 135.1 | 133.3 | 136.02 | 135.4 | 141.55 |
| Heating efficiency improved (%)              | 0.4438 | 0.5729 | 0.6118 | 0.6524 | 0.5924 | 0.6458 | 0.6058 | 0.549 |

From table 2 and table 3, we can see that the energy saving effect of condensate water from NO.6 LP heater into LP economizer is better than NO.7, when the water flow into LP economizer is among 200t/h–270t/h under the conditions of 180MW and 220MW. The reason could be the condensate water entering LP economizer from NO.7 LP heater reduces extraction steam flow of NO.6 LP heater. The water outlet temperature from LP economizer is lower than that of NO.5 LP heater outlet, leading to an increase of deaerator extraction steam flow. High quality of extraction steam flow increase, resulting in less work of LP cylinder of the unit. By the reason of economy of the unit is reduced, the operational mode of condensate water from NO.6 LP heater outlet to LP economizer should be suggested to use.

Based on test results of 220MW condition above, the trend chart of influence of condensate water flow from NO.6 LP heater outlet to LP economizer on economic indicators of the unit could be made to determine the optimal water flow rate from NO.6 LP heater outlet.

![Trend chart of the optimal water flow rate under 220MW condition](image)

Figure 3. Trend chart of the optimal water flow rate under 220MW condition

As shown in figure 3, the optimal water flow from NO.6 LP heater outlet to LP economizer is about 250t/h at the condition of 220MW. From the test results of two conditions above, the change of effect of water flow change on unit economy is small when the water flow entering the LP
economizer is huge. Take the case of 220MW condition, when the LP economizer inlet water flow is 240t/h and 270t/h, thermal efficiency improved of the unit is 0.6451% and 0.6355%. Its difference is only 0.01%. According to heat consumption rate of the unit being 8500 kJ/(kW·h), the difference of thermal consumption rate affected is 0.85 kJ/(kW·h), which means that the energy saving effect changes very small among high flow rate.

4.2 Test results of optimum water returning location form LP economizer outlet
The test data of optimal water returning location from LP economizer outlet to main condensate system has been calculated by the equivalent enthalpy drop method. Test data and calculation results are shown in table 4.

| Parameter                                      | Unit         | Condition 1 of water from LP economizer outlet to NO.5 LP heater outlet | Condition 2 of water from LP economizer outlet to NO.6 LP heater outlet | Condition 3 of water from LP economizer outlet to NO.6 LP heater outlet |
|------------------------------------------------|--------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Unit load                                      | MW           | 220                                                                      | 220                                                                      | 110                                                                      |
| Flue gas export temperature                   | °C           | 99                                                                       | 96                                                                       | 91                                                                       |
| Water flow into LP economizer from NO.7       | kg/h         | 44345                                                                   | 50778                                                                   | 42824                                                                   |
| Water temperature into LP economizer from NO.7| °C           | 110.54                                                                  | 111.36                                                                  | 106.12                                                                  |
| Water flow into LP economizer from NO.8       | kg/h         | 259180                                                                  | 319914                                                                  | 177969                                                                  |
| Water temperature into LP economizer from NO.8| °C           | 63.56                                                                   | 64.24                                                                   | 61.05                                                                   |
| Water temperature of desulfurization           | °C           | 111.04                                                                  | 109.34                                                                  | 109.8                                                                   |
| Outlet water temperature of NO.5 LP heater    | °C           | 137.58                                                                  | 131.44                                                                  | 128.31                                                                  |
| Outlet water temperature of NO.6 LP heater    | °C           | 157.7                                                                   | /                                                                       | /                                                                       |
| Thermal efficiency improved                    | %            | 1.3022                                                                  | 2.003                                                                   | 1.2801                                                                  |

From table 4, we can find that increase the inlet flow rate of LP economizer could reduce the exhaust smoke temperature. But at the same time, the temperature of the outlet water came from the LP economizer is also decreased. The outlet of LP economizer is lead to outlet of NO.5 LP heater, when the LP economizer outlet water temperature is lower than that of NO.5 LP heater outlet, the 4th stage extraction steam flow must be increased to make up for heating shortage. Therefore, it will be more economical when outlet water temperature of the LP economizer is slightly higher than that of NO.5 LP heater outlet. Otherwise, the energy saving effect will decrease when the water flow rate of the LP economizer is increased. Under the premise that the pipe resistance meets the operating requirements, if the outlet of LP economizer is lead to outlet of NO.6 LP heater as shown in Table 2, the inlet flow of the LP economizer can be increased. The water temperature and smoke exhaust temperature of the LP economizer outlet can be reduced also. The boiler exhaust heat can be further utilized. The thermal efficiency of the unit could be higher improved. The results of experiment and simulation show that it is better to export the condensate water from the LP economizer to outlet of NO.6 LP heater than to NO.5 LP heater outlet. Compare the condition 2 with the condition 1, condition 2’s thermal efficiency is 0.701% larger, heat consumption rate is 59.6kJ/(kW·h) lower.

5. Energy saving effect analysis and operational optimization of LP economizer
The test results above have analyzed the energy saving effect of a LP economizer in a 220MW unit that with different system operational modes and different variable factors. From the analysis results we can find, the water inlet flow, water inlet temperature and outlet temperature of the LP economizer have the greatest impact on energy saving effect. The adjustment of operating condition of LP
economizer directly affects its energy saving effect. Even test one system at different times, when the flow and temperature of the condensate water into the LP economizer change, the outlet water temperature of the LP economizer and the energy saving effect of the LP economizer will also be different.

The performance of the LP economizer is calculated with the equivalent enthalpy drop method. The results show that under certain conditions of inlet water temperature of the LP economizer, while adjusting the inlet condensate water flow of the LP economizer to reduce smoke temperature at economizer outlet, it is also important to ensure that the outlet water temperature of the LP economizer is higher than that of the LP heater outlet before confluence with main condensate system. Otherwise, increasing the water flow entering the LP economizer, the energy saving effect will be decreased.

During the daily operation, when the LP economizer operates, according to the change of unit load and coal burning, the outlet temperature of the LP economizer is controlled not lower than the design outlet temperature of the LP economizer, in order to determine the inlet flow and temperature of the LP economizer, as well as the water flow rate from LP heater export entering LP economizer. For the LP economizer system above in a 220MW unit, when the condensate water from outlet of LP economizer return back to the main condensate system at outlet of NO.5 LP heater, the condensate water from NO.6 outlet is selected preferentially. At unit of 180MW to 220MW, the inlet flow of the LP economizer is between 200t/h ~ 270t/h. As long as the water outlet temperature of the LP economizer is not lower than that of the NO.5 LP heater outlet, the change of energy saving effect of the LP economizer is not significant. Under this conditions, the inlet flow of the LP economizer do not need to be adjusted frequently, which reduces the workload of adjustment.

When the exhaust smoke temperature of boiler is higher, in order to reduce the temperature, the condensate water entering the LP economizer can be chosen from NO.7 and NO.8 LP heater outlet. Under this working condition, the water outlet of the LP economizer should be introduced to NO.6 LP heater outlet, and the water outlet temperature of the LP economizer is higher than that of NO.6 LP heater outlet, while the LP economizer has the highest energy saving effect. Under the test condition of 220MW, if the smoke temperature is reduced to 96℃, thermal efficiency of the unit increases 2.003%. If the heat consumption rate of the unit is 8500kJ/(kW·h), it can be reduced by 170.3 kJ/(kW·h).

6. Conclusion
On a 220MW unit, the tests of optimum discharge water flow rate and the optimum water returning location to main condensate system are carried out on the LP economizer. The inlet water of LP economizer comes from NO.6 or NO.7 LP heater outlet. When the heated condensate water returns back to the condensate pipeline at NO.5 LP heater outlet, the condensate water from NO.6 export is selected preferentially. The energy saving effect of the condensate coming from outlet of NO.6 LP heater outlet is higher than that of condensate water coming from NO.7 LP heater outlet. The optimal water flow rate from NO.6 LP heater outlet entering LP economizer is about 250t/h at 220MW condition, which could increase the thermal efficiency of the unit by 0.645%. At the condition of 180MW to 220MW, the inlet flow of the LP economizer coming from NO.6 LP heater outlet is between 200t/h ~ 270t/h. As long as the water outlet temperature of the LP economizer is not lower than that of the NO.5 LP heater outlet, the change of energy saving effect of the LP economizer is not significant. Under this working condition, the inlet flow of the LP economizer does not need to be adjusted frequently, which reduces the workload of adjustment.

The condensate water enters the LP economizer which comes from NO.7 and NO.8 LP heater, after heated, it is introduced to outlet of NO.5 or NO.6 LP heater. The test results show that the outlet water of the LP economizer returns to NO.6 LP heater export is better than returns to NO.5 LP heater outlet. The water outlet temperature of the LP economizer should be higher than that of NO.6 LP heater outlet, while the LP economizer has the highest energy saving effect. Under the test condition of 220MW, if the smoke temperature is reduced to 96℃, thermal efficiency of the unit increases 2.003%

The experimental results of LP economizer at multi-variable factors show that under the certain conditions of water inlet temperature of the LP economizer, adjust the inlet condensate water flow of the LP economizer to reduce exhaust smoke temperature of the economizer, It is also important to
ensure that the outlet water temperature of the LP economizer is higher than that of the LP heater outlet before confluence with main condensate system. Otherwise, increase water flow into the LP economizer, which will cause the energy saving effect be reduced. For different LP economizer operational modes, there also have the optimal water returning location and optimal inlet flow.

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