Analysis of Energy Saving and Consumption Reduction Effect of Ejector confluence on Heating Unit

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Abstract. Achieving the utilization of thermal energy according to its quality is the main means for power generation enterprises to improve the efficiency of primary energy utilization. This paper introduces the application of ejection confluence technology in 330 MW unit of a factory, and calculates and analyses the energy saving effect under the ejection confluence mode based on the method of thermal performance test. The results show that when the unit load is above 210 MW, the average energy saving of ejector-confluence heating mode is 2.18 g/ (kW·h) relative to reheat heating mode.

Key words: heat supply, energy saving and emission reduction, ejection confluence

1. Introduction
With the continuous changes of the times and the progress of society, the environment we live in is becoming happier and happier. As the industry develops, the industrial 4.0 era has come, and people's demand for energy is increasing. The environment we live in depends on energy, such as primary energy, coal, oil, natural gas, secondary energy, electricity, gas, oil, etc. However, their storage are gradually decreasing. Reform and opening-up has accelerated China's industrialization process, and the demand for energy has increased sharply, thus leading to China's energy relying more on external "blood transfusion". The total consumption of coal is 68.8% and that of oil and gas is 23.1%. Generally speaking, it is still in the coal age. Electricity, as an indispensable part of life, is a secondary energy source transformed from primary energy for human direct application. Power plants, as conversion plants, consume large amounts of coal resources every day. Although China has abundant fossil energy dominated by coal, it is not inexhaustible. Uncontrolled exploitation and use will only lead to energy exhaustion. The contradiction between supply and demand of energy is becoming more and more prominent.

Energy is an important material basis for human survival and development. Energy conservation and emission reduction is the only way for sustainable energy development. In recent years, new technologies, steam seal modification, boiler combustion adjustment, unit operation optimization, low and low temperature economizer modification have been adopted by power generation enterprises to achieve energy saving and consumption reduction of units. With the rapid development of industry, the demand for industrial steam is increasing, which leads to the transformation of pure condensation units in thermal power plants. Energy consumption according to quality and step-by-step use are the basic principles of energy-saving work. As energy conversion plants, while consuming a large amount of coal
resources, power plants produce a variety of steam of different qualities in the production process. Correctly recognizing the differences of various qualities and using them according to needs in production can not only improve the efficiency of energy utilization, but also improve the economic efficiency of enterprises and realize the placement of energy utilization and step-by-step use.

2. Heating Reform
Two 330MW sub-critical, primary reheating, single cylinder, three cylinders, double exhaust and condensing steam turbines in a factory provide industrial steam extraction and residential heating steam to the surrounding industrial parks. The designed heating extraction steam is extracted from the middle exhaust, the rated extraction pressure is 0.45 MPa (adjusting range: 0.35-0.6 MPa) and the rated extraction volume is 300 t/h. The extraction steam is supplied through a DN800 pipeline with two DN1200 outlets at the lower part of the middle exhaust cylinder. After the unit is put into operation, industrial steam is mainly supplied. Its industrial steam parameters require pressure of 1.0 MPa and temperature of 230°C. In order to meet the needs of industrial users, the heat supply transformation was carried out. After the transformation, the industrial steam was extracted from the reheat section of the outlet of the boiler reheater and heated externally after temperature and pressure reduction; the cooling water was supplied by the booster pump, and the heating and supplementary water was supplied directly to the condenser. This way of external heating, which adopts high-parameter reheated steam after temperature and pressure reduction, contributing to the formation of low-quality steam for external heating, enables high-quality steam to supply outside heat without work, resulting in a large amount of energy waste and reduction of the benefits of the unit.

In order to improve the economy of the unit and find a more reasonable way of external heating, the ejector-confluence device is used; the high exhaust steam is used as the driving steam source by using Laval gas injection principle, and the five-stage steam extraction is ejected. After mixing two different quality steams, a new steam is formed for industrial users. In order to meet the requirements of heating users for steam parameters, pressure matchers are also equipped. The diagram of the reformed heating system is shown in Fig. 1.

3. Steam Distribution Principle
The valve distribution of pressure matcher is composed of driving steam, inhaling steam, mixing steam and cooling water. The total steam quantity at the outlet of mixing steam is equal to the steam quantity at the driving inlet + the steam quantity at the inhaling inlet + the cooling water quantity. The ratio of the steam flow rate at the driving inlet to the steam flow rate at the suction inlet (called ejection coefficient), the pressure difference between the steam pressure at the mixing outlet and the steam pressure at the suction inlet (called compression ratio), the pressure difference between the steam
pressure at the driving inlet and the steam pressure at the suction inlet (called expansion ratio) are related. Therefore, the steam flow rate at the suction inlet is determined by many factors. In the process of designing gas distribution, the pressure difference between driving inlet steam and inhalation steam should be increased as much as possible, and the pressure difference between inhalation inlet steam and mixed outlet steam should be reduced as much as possible, that is to say, the steam quantity at the suction inlet of pressure matcher should be increased, and the utilization rate of low pressure steam should be increased, so as to improve the economic benefit of the system. In the actual steam distribution work of pressure matcher, the actual parameters have been determined, as long as the steam distribution is in accordance with the predetermined parameters. In actual operation, the closer the pressure matcher approaches the rated parameter, the higher the efficiency.

4. Analysis of Energy Conservation and Consumption Reduction

In order to effectively analyze the energy-saving and consumption-reducing effect of the ejector-confluence technology, the steam turbine thermal performance test method is used to conduct on-site thermal performance tests under reheat section heating mode and after retrofitting using ejector-confluence heating mode to obtain relevant calculation data. Due to the influence of heating flow rate by heating users and other factors, there are certain errors under different test conditions. The unit load should be adjusted, and isolation measures should be taken to meet the requirements of the test outline, so that the thermodynamic system should operate strictly in accordance with the thermodynamic cycle stipulated in the design heat balance diagram and keep stable, and each test condition should be maintained for two hours. The main formulas for calculating the experimental heat consumption rate are as follows:

\[ H_t = \frac{(g_{ms} - g_{h}) \times (h_{ms} - h_{ffw}) + G_{sht} \times (h_{ms} - h_{sht}) + G_{crh} \times (h_{hrh} - h_{crh}) + G_{gr} \times (h_{grh} - h_{gr}) - G_{fr} \times h_{fr}}{G_{ms} \times h_{ms}} \]

where \( H_t \) is the experimental heat consumption rate, \( G_{ms} \) is the main steam flow rate, \( h_{ms} \) is main steam flow rate, \( h_{ffw} \) is feed water enthalpy, \( G_{sht} \) is superheater desuperheating water flow rate, \( h_{sht} \) is superheater desuperheating water enthalpy, \( G_{crh} \) is cold and re-steam flow rate, \( h_{hrh} \) is reheat steam enthalpy, \( h_{crh} \) is refrigeration enthalpy, \( G_{grh} \) is reheat desuperheating water flow rate, \( h_{grh} \) is reheat desuperheating water enthalpy, \( G_{gr} \) is heating flow, \( h_{gr} \) is heating enthalpy.

Among them, cold reheat steam flow rate

\[ G_{crh} = G_{ms} - G_{vlhp} - G_{glhp} - G_{ex1} - G_{ex2} \]

\( G_{vlhp} \) is the total amount of steam leakage from high-pressure valve stem, \( G_{glhp} \) is the total amount of steam leakage from high-pressure cylinder front seal to medium-pressure cylinder and from high-pressure cylinder rear seal, \( G_{ex1} \) is #1 high added steam flow and \( G_{ex2} \) is #2 high added steam flow. The main data and calculation results obtained by the experiment are shown in Tables 1 and 2.

| Name                                  | Unit  | 320MW | 300MW | 270MW | 250MW | 230MW | 210MW |
|---------------------------------------|-------|-------|-------|-------|-------|-------|-------|
| Generator power                       | MW    | 316.79| 303.79| 270.59| 251.09| 229.85| 210.65|
| Steam extraction flow rate            | t/h   | 52.03 | 64.62 | 57.19 | 64.65 | 61.42 | 57.68 |
| in reheat cold section                | MPa   | 4.22  | 3.97  | 3.49  | 3.09  | 2.80  | 2.55  |
| Steam extraction pressure             |       |       |       |       |       |       |       |
| in reheat cold section                | °C    | 337.29| 335.33| 322.69| 315.18| 309.25| 312.02|
| Steam extraction temperature          |       |       |       |       |       |       |       |
| in reheat cold section                | t/h   | 28.68 | 26.94 | 19.97 | 18.44 | 11.37 | 9.15  |
| Five-stage steam extraction flow      | t/h   | 0.95  | 0.90  | 0.82  | 0.74  | 0.70  | 0.64  |
| Five-stage extraction pressure        | MPa   | 346.56| 350.33| 346.37| 349.10| 340.82| 344.80|
| Five-stage extraction temperature     | °C    | 0.98  | 1.02  | 1.00  | 0.97  | 0.97  | 0.90  |
| Back pressure of pressure matcher     | t/h   | 80.70 | 91.56 | 77.16 | 83.08 | 72.79 | 66.82 |
| Total Drainage Flow of Unit           | %     | 7.04  | 7.17  | 7.43  | 7.82  | 7.70  | 7.81  |
| Utility Rate of Power Plant           | %     | 93.34 | 92.96 | 92.70 | 92.54 | 92.87 | 92.76 |
| Boiler efficiency                     | g/(kW·h) | 7804.9 | 7762.5 | 7798.9 | 7702.4 | 7715.8 | 7744.5 |
| Coal consumption in power supply      |       | 310.02| 310.02| 313.24| 311.22| 310.24| 312.14|
Table 2. Main data and calculation results under reheat section heating mode

| Name                           | Unit   | 320MW | 300M W | 270M W | 250M W | 230M W | 210M W |
|--------------------------------|--------|-------|--------|--------|--------|--------|--------|
| Generator power                | MW     | 311.99| 296.87 | 270.92 | 251.23 | 230.81 | 211.04 |
| Steam extraction flow rate in reheat section | t/h    | 75.34 | 84.76  | 71.84  | 68.77  | 69.70  | 74.39  |
| Steam extraction pressure in reheat section | MPa    | 3.79  | 3.54   | 3.21   | 2.88   | 2.63   | 2.39   |
| Steam extraction temperature in reheat section | ℃      | 537.06| 537.68 | 537.88 | 536.00 | 535.44 | 535.20 |
| External heating pressure      | MPa    | 1.00  | 1.01   | 1.01   | 1.01   | 1.01   | 1.00   |
| Total Drainage Flow of Unit    | t/h    | 75.34 | 84.76  | 71.84  | 68.77  | 69.70  | 74.39  |
| Utility Rate of Power Plant    | %      | 7.04  | 7.41   | 7.72   | 7.88   | 7.87   | 7.82   |
| Boiler efficiency              | %      | 93.22 | 92.86  | 92.65  | 92.38  | 92.62  | 92.61  |
| Unit heat consumption rate     | kJ/(kW·h) | 7855.1| 7805.8 | 7830.2 | 7752.9 | 7727.2 | 7750.8 |
| Coal consumption in power supply | g/(kW·h) | 312.40| 312.91 | 315.64 | 314.01 | 312.10 | 312.92 |

From the comparison of the above two heating modes, when the boiler burns steadily and the heating parameters meet the needs of heat users, the unit load is between 250 MW and 320 MW, and the external heat supply is basically equal, the energy saving of the ejector-confluence heating mode is more than 2 g/(kW * h) than that of the reheat section heating mode, and the energy saving effect is remarkable. In the interval, the decrease of heat consumption rate is more obvious, while the maximum hourly load of energy saving occurs at 300MW, reaching 2.89g/(kW h). In order to more intuitively see the effect of energy saving and consumption reduction brought by the ejection confluence, a comparison chart of coal consumption for heating under two heating modes is drawn as shown in Fig. 2.

Figure 2. Comparison of coal consumption for heating under two heating modes

When the unit load drops to 230MW, the energy saving of the ejector-confluence heating mode is still 1.86 g/(kW h). As can be seen from Figure 2, when the unit load continues to drop by 210 MW, the energy saving decreases sharply, only 0.78 g/(kW h). Under low load, the flow rate of ejector five pumps decreases, and the effect of energy saving and consumption reduction is not significant compared with that under high load. The test results show that when the unit load is above 210 MW, the energy saving of ejector-confluence heating mode is 2.18 g/(kW h) on average compared with reheat heating mode.
5. Conclusion
(1) The ejection confluence technology changes the heating mode of the unit, uses high quality steam to eject low quality steam, and forms new quality steam for external heating after mixing. Optimize the use of different quality steam produced in the production process, so as to avoid the phenomenon of "high energy and low consumption" caused by external heating without high quality steam work, and realize energy saving and consumption reduction of units.

(2) At low load, due to the reduction of the ejected flow, the external heating is mainly undertaken by the ejected flow, and the effect of energy saving and consumption reduction is not obvious; in order to ensure the effect of energy saving and consumption reduction, it is necessary to maintain a certain ejection ratio.

(3) The ejection confluence technology can not only rationally utilize the steam of different quality produced in the production process, but also recover the waste heat generated, so as to realize the utilization of waste heat and achieve the effect of energy saving and consumption reduction.

6. References
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