Study on optimal distribution of heating load based on the first law of thermodynamics

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Abstract. The principle of external heat supply for cogeneration units is to meet the maximum heat load demand of the heating network, and the heat load of the heating network will vary significantly with the climate and solar light intensity. The heat supply system of extraction steam unit with high back pressure heating unit is taken as the research object to study the influence of heat load peak and valley change on the economy of cogeneration units. The energy consumption and operation economy of the cogeneration unit are analyzed by the heat consumption theory and the standard coal consumption of generating and heating income standard. The results show that the heat consumption of cogeneration units is reduced by 411.62 kJ/(kWꞏh)¹ during the peak heat load in the extreme cold period than the low heat load in the end of the heat supply. The standard coal consumption per yuan income of the generation and heating is increased by 15 g.RMB⁻¹. The daily gross income of generating and heating is reduced by about 47196 RMB per day for 12 hours of heat load. The cogeneration unit should use the return network temperature of the heat network as the basis for the change of the peak and valley of the heat network load when adjusting the external heating parameters and the operation mode of the unit.

1. Introduction

The high back pressure waste heat and heat supply series extraction and heating transformation technology have the advantages of simple thermal system, mature technology, investment time cost and capital cost. Low, strong adaptability and so on, is widely used[1-2]. At present, there are three main aspects of heat supply optimization for cogeneration unit. One is whether the output and heat consumption of the heating unit meet the requirements of the design value when the heating unit is satisfied with the demand of the maximum heat load. The second is the change of the heat transfer station performance parameters to the heat transfer unit and the one or two network of heat network. The third is the influence of the operation parameters of the heat supply network on the economy of the heating unit. At present, the change of heat load peak and valley in heating network has hardly touched on the economic change of heating units and the change of overall operating profit of cogeneration enterprises[3-5].

This paper studies the heating system of a series of steam extraction and heating units of a high back pressure heating unit in a factory. In this paper, operation index and profit is tested and calculated when thermal network thermal load peaks and valleys caused by climate changes in a heating season and 24 hours of light changes in a day. It can provide basis for energy saving optimization of heating units.
2. Research objects and analytical methods

2.1. Research objects
A heating system with a high back pressure heating unit in series with two pumping units is used as the research object. The exhaust steam after the work of the low pressure cylinder of the high back pressure heating unit is directly discharged into the condenser, heating the circulating water of the first network of the heat network, and the high temperature and high pressure steam pumped out of the middle pressure cylinder from the exhaust pipe of the middle pressure cylinder. Through the primary heat exchanger, the circulating water of the primary heating network is reheated to ensure that the heat supply of the primary heating network meets the demand of the heat load of the heating network. The high temperature circulating water in the first network of the heat network is heated by the two stage heat exchanger in different regions of the city to heat the circulating water of the two network of the heat network, and the two network circulating water is circulated to the heat network users, and the heat net circulating water after the cooling is returned to the condensers of the high back pressure heating unit.

2.2. Theory analysis method
When the heat consumption is used to evaluate the performance of the high back pressure heating unit and the pumping unit, the conventional method is the benefit of the power return. The cold source loss of the high back pressure unit and the external heating amount of the extraction unit are all considered as the heat outside the power generation. The method can not be considered when calculating and analyzing. This method can reflect the heating unit in heating. The energy consumption of power generation in the state can not reflect the transformation effect of the flow part and the work ability of the turbine, and it can not reflect the weighted energy consumption of the generating and heating of the unit, and is not suitable for the comprehensive evaluation of the power generation and the weighted benefit of the heating unit. Therefore, in comparison with the economy of the weighted heat consumption of the whole plant, the traditional analysis method (formula 1) is adopted for the total heat absorption of the boiler, not the benefit of heating [6-8].

\[
HR = \frac{(G_m - \dot{G}_m) \cdot h_m - h_{p}}{\dot{G}_m} + (\dot{G}_m - \dot{G}_m) \cdot \frac{h_m - h_{p}}{\dot{G}_m} + \frac{G_m \cdot (h_m - h_{p})}{\dot{G}_m} \]

Where, \(HR\) is the test heat consumption rate, kJ/(kWꞏh); \(h\) is the enthalpy corresponding to each flow, kJ/kg; \(\dot{G}_m\) is the steam flow, t/h; \(\dot{G}_m\) is the cold reheat steam flow, t/h.

For the coal-fired unit of cogeneration, the index of directly judging the generating and heating economic benefits of the unit is the income and cost. The income is the income of power generation and heating, and the cost is the amount of coal consumption of the boiler. In this paper, the operation and operation economy of the cogeneration unit is calculated and analyzed by generating the standard coal consumption of generating electricity per yuan of generating electricity. The standard coal consumption formula of heat generating units for heating units is as follows.

\[
b = \frac{B \times 10000}{(W + Q) \times 29310} \times \eta_h \times \eta_p \]

Where, \(b\) for per yuan income coal consumption rate, g/RMB; \(B\) for coal consumption, kg/RMB; \(W\) for power generation income, RMB; \(Q\) for heating income, RMB; \(\eta_h\) for boiler efficiency, take 0.9; \(\eta_p\) for pipeline efficiency, take 0.99.
3. Economic analysis of heat supply unit with 2 heat load peak and valley change of heat supply network

3.1. Economic analysis of heating units during heating season

The heat load of the heat supply network is larger during the extremely cold period than the initial and final stage of heating because of different environmental temperatures. The heat load of the heat network is obvious peak and valley change in the whole heating season. The heat consumption theory is used to calculate and analyze the heating unit of the heat and cold period and the end of the heat supply. It also calculates the standard coal consumption and the heat for sale in two stages, and analyzes the operation benefit of the cogeneration unit.

3.1.1. The peak and valley variation rule of heat load in a heating season.

The most obvious change of the primary heating network is the backwater temperature of the heating network when the heat load of the heating network changes. The higher the temperature of the primary network in the heat network, the higher the heat of the heat supply, the higher the heat of the backwater after heating, that is, the heat absorption of the two network in the heat network is reduced, and the heat absorption of the two network from the heat network is reduced, which leads to the thermoelectric enterprise. The amount of external heat is reduced. Fig. 1 shows the variation of backwater temperature of the primary network of a heating system during the heating season.

![Fig.1. The trend of return water temperature of the heating network 24 hours a day.](image)

As shown in Fig.2, the temperature of the return water of the heating network is rising month by month, especially at the end of the heating season. The return water of the heating south line and the North heat supply line in February is up to 53.02°C and 52.25°C, up to 1.73°C and 3.81°C centigrade than in the early heating season in November, indicating the heat exchange of the user and the heat network in two network and the two network of the heat network and one of the heat network. The heat transfer of the secondary network is reduced month by month.

In winter heating, as a livelihood project, the whole society pays attention to the whole society at the beginning of heating, which generally adopts the way of excessive heating, and the temperature of the return water of heat network is relatively low; with the gradual increase of the temperature of the environment, the heat load of the heat network decreases gradually at the end of the heat supply, and when the heat network is low, if the cogeneration unit still uses the heating initial stage and the heat supply, the heating network is still used in the heating period and heating. The medium term heating mode will cause high return water temperature of the heating network and decrease the external heating capacity.

3.1.2. Economic analysis of different heat load in extreme cold period and end of heating period.

In table 1 and table 2, it can be seen that the weighted heat consumption of the heating extreme cold period is 411.62 kJ(kW·h)^{-1} lower than the end of the heat supply. In the extreme cold period of
heating, the heat consumption of the unit is better. The energy consumption of the heating unit is 15 g RMB⁻¹ higher than that at the end of the heat supply in the end of the heat supply. At the end of the heating season, the business profits of cogeneration enterprises are higher.

Table 1. Main indexes of heating units when flow rate of heating 11000 t/h⁻¹.

| Item                                      | Flow rate of heating 11000 t/h⁻¹ |
|-------------------------------------------|----------------------------------|
| Unit                                      | Unit 2                      | Unit 3          | Unit 4          |
| Load (MW)                                 | 125.15                       | 299.51          | 307.61          |
| Vacuum (kPa)                              | 26.874                       | 5.532           | 5.355           |
| Sale of heat (GJ·h⁻¹)                     |                               |                 |
| Heat consumption (kJ·(kW·h)⁻¹)            | 10109.72                     | 8898.54         | 8808.17         |
| Electricity output per ton of standard coal (kW·h) | 2583.18             | 2934.77         | 2964.88         |
| Unit thermal efficiency (%)               | 35.61                         | 40.46           | 40.87           |
| Heat rate of the three units (kJ·(kW·h)⁻¹) |                               |                 |
| Electricity heating income standard coal consumption (g RMB⁻¹) | 814                             |

Table 2. Main indexes of heating units when flow rate of heating 10000 t/h⁻¹.

| Item                                      | Flow rate of heating 10000 t/h⁻¹ |
|-------------------------------------------|----------------------------------|
| Unit                                      | Unit 2                      | Unit 3          | Unit 4          |
| Load (MW)                                 | 120.56                       | 175.53          | 176.58          |
| Vacuum (kPa)                              | 31.190                       | 6.201           | 5.351           |
| Sale of heat (GJ·h⁻¹)                     |                               |                 |
| Heat consumption (kJ·(kW·h)⁻¹)            | 10333.82                     | 9286.51         | 9087.30         |
| Electricity output per ton of standard coal (kW·h) | 2527.16             | 2812.17         | 2873.81         |
| Unit thermal efficiency (%)               | 34.84                         | 38.77           | 39.62           |
| Heat rate of the three units (kJ·(kW·h)⁻¹) |                               |                 |
| Electricity heating income standard coal consumption (g RMB⁻¹) | 799                             |

At the end of the heat supply, although the profitability of the cogeneration unit became stronger, the external heat in the end of the heat supply was 182.55 GJ·h⁻¹ lower than that in the extreme cold period, indicating that the backwater temperature of the heat network at the end of the heat supply was higher than that in the extreme cold period. At this time, the back pressure of the high back pressure heating unit increased and the high back pressure heating unit did not lose the cold source, and it did not affect the unit. Heat consumption, but the back pressure increases the power performance of the steam turbine, while the temperature of the return water will lead to the relative decrease of external heat, indicating that the end of the heating, the profitability of cogeneration units still have a substantial increase in space.

3.2 Economic analysis of heating units when sunlight changes

3.2.1 Peak and valley change rule of heat load in 24 hours a day: The running mode of the heat source side of the first grade heat transfer station is that the circulating water flow and the outlet temperature of the first stage heat exchanger are basically stable. Only when the temperature of the heat source and the heating extremely cold period is greatly changed, the other most time heat source side heat supply is used in the way of the fixed flow and the fixed temperature. The two network heat supply network is adjusted according to the change of the temperature of the environment and the return water of each
two grade heat exchange station. The temperature of the return water of the first network of the heat network has a obvious regular change trend, such as the following chart.

![Fig.2. Change trend of return water temperature in 24 hours a day.](image)

As shown in Fig.2, the temperature of the return water of the south line is higher than the north line back water temperature of about 1 °C, the temperature of the return temperature of the south line and the north line of the heat network is basically the same, the temperature from 0 o'clock to 8 o'clock is basically stable, the temperature of the return water from 8 o'clock to 12 o'clock down, the temperature of the return water from 17 o'clock to 20 o'clock rises, and the temperature of the return water is stable from 20 o'clock to 0 o'clock. The higher the backwater temperature of the primary network is, the lower the heat load of the two network.

The peak of daily heat load is at noon, lasting about 5 hours, and the minimum of daily heat load is from 20 o'clock to 8 o'clock the next day, lasting about 12 hours.

3.2.2 Analysis of economic benefits of thermoelectric enterprises in 24 hours heat load peak and valley change. The water supply temperature and the flow rate of the first network of the heat network are determined by the maximum heat load of the heat network. The principle is to ensure the user's demand in the peak period of the heat load in the heat network of the two network. If the heat net heat load is low in the low period of the two network, the heat network will continue to run according to the heating flow and heating temperature in the peak period, and the temperature of the return water of the first network of the heat network is on the net. It will increase, and during the heat load period, the heat generated by cogeneration units will be greatly reduced. The heat consumption of the 24 hours heat load peak valley period is shown below.

![Fig.3. Change trend of total heat consumption 24 hours a day.](image)

As shown in Fig.3, the heat supply is about 1800 GJ h\(^{-1}\) at the peak of heat load and about 1700 GJ h\(^{-1}\) when the low valley is sold, according to the heat price of 39.33 RMB GJ\(^{-1}\), 12 hours of low
valley period, and the external sale heat cost is about 47196 RMB per day. At the same time, the return temperature of the primary heat network is about 12 hours a day at the high temperature section, which leads to the rise of the back pressure of the high back pressure heating unit, the efficiency and power of the steam turbine will decrease, and it will also affect the overall economy of the heating unit.

4. Conclusion
In this paper, the heating system of a high back pressure heating unit in series is studied. Through the calculation and comparison of the heat consumption rate and the standard coal consumption rate of the generating heating income standard, the changes of the economic index and the operating income of the thermal power generation unit are analyzed, and the following conclusions are obtained.

When the cogeneration unit is heating to the outside world, the heat load of the heating network will change obviously with the climate and sunlight. The heat load of the heat network is high, the heat load of the heat supply unit is 182.55 GJ.h\(^{-1}\) higher than the end of the heat supply, the back pressure of the heating unit is reduced, and the heat consumption rate of the unit is 411.62 kJ/(kWꞏh\(^{-1}\)) lower than that of the end of the heat supply. During the extremely cold period of heating, the operation index of the heating unit is better. At the end of the heat supply, the temperature of the environment is higher, the heat load of the heat network is low, the extraction steam of the steam pump unit is reduced, the high quality steam work of the steam turbine is more work, and the standard coal consumption of the generation heating ten thousand yuan is higher than 15 g RMB\(^{-1}\). At the end of heating, the profit of cogeneration enterprises is higher.

References

[1] Ge, Z.H., Sun, S.M., Wan, Y., Zhao, S.F., He, J.R. (2017) Applicability Analysis of High Back-pressure Heating Retrofit for Large-scale Steam Turbine Unit. J. Proceedings of the C. S. E. E., 37: 3216–3222.

[2] Wan, Y., Sun, S.M., Ge, Z.H., He, J.R. (2016) Thermo-Economic Analysis of High Back Pressure Heating Retrofit for Large-Scale Cogeneration Unit under Full Condition. J. Electr.Pow.Constr., 37: 131–137.

[3] Wang, F.L. (2016) The Key Technology and Economic Research for High-back Pressure Heat-supply Transformation. J. Turb. Technol., 58: 133-135.

[4] Wang, X.D., Zheng, W., Song, A. (2014) Analysis and Evaluating on Performance Characteristics of Heating Supply Unit with High Back-pressure. J. Pow. Sys. Eng. Technol. 30: 49–53.

[5] Wang, X.D., Cheng, X.W., Zheng, W. (2013) Test and Analysis on Performance of Condenser after High Back Pressure Reconstruction for Heat Supply. J. Turb. Technol. Eng. 55: 135–138.

[6] Zhao, J.F., Lu, Q., Chu, S.L., Li Y. (2016) Dynamic Characteristics Analysis Heater for Heating Network of Return Water Temperature Change. J. Turb. Technol. 58: 136–142.

[7] Yang, J.W. (2016) Discussion on Heating Mode of 300MW High Back Pressure Heating Unit. J. SD. Indust. Technol. 57: 72–72.

[8] Li, W.T., Yuan, W.X., Fu, L., Sun, J. (2015) Energy Consumption Analysis of High Back Pressure Heating Mode of Steam Turbine. J. Reg. Heat. 4: 10–17.