Optimization of the Drain Mode for No. 0 High Pressure Heater

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Abstract. The addition of No. 0 high-pressure heater is a new technology with energy saving and emission reduction benefits, the economic analysis of No. 0 high-pressure heater under different loads and drain modes is provided on a 680 MW unit based on the Equivalent enthalpy drop method principle and the comprehensive economic drain mode for No. 0 high-pressure heater is recommended.

1. Introduction
According to the national coal-fired energy-saving emission reduction upgrade and reconstruction action plan, by 2020, the average coal consumption of the active thermal power unit after reconstruction is less than 310g/kWh, of which the average coal consumption of the existing 600MW and above units (except the air-cooled unit) is lower than the average 300g/kWh[1]. In order to implement the national coal-fired power plant energy-saving emission reduction upgrade and reconstruction action plan, the mature, advanced and applicable energy-saving emission reduction technologies should be applied for coal-fired units, the system energy-saving and new consumption technology scheme allowing for environmental integration (denitration, desulfurization and expansion, Wet dust removal, etc.) and the synchronization and mutual adaptation of the energy saving reconstruction should be adopted.

The combined system technology of No. 0 high-pressure heater and low-temperature economizer not only increases the number of stages of the unit's regenerative system, but also increases the thermal efficiency of the cycle and reduces the heat consumption rate. At the same time, due to the increase of the feed water temperature, the heat exchange capacity of the economizer is reduced, resulting in the economizer exiting smoke temperature rise. thereby ensuring the efficiency of SCR denitration at partial load. Therefore, the No. 0 high-pressure heater and the low-temperature economizer combined system is one of the effective measures to improve the unit’s the economic and environmental indicators at partial load.

2. No. 0 high pressure heater and its drain modes
In the reheat system, a high pressure heater is added to heat the feed water between the No.1 high pressure heater and the boiler economizer. The steam source of the high pressure heater comes from a stage of high pressure cylinder before 1-stage extraction. The steam trap of the high pressure heater flows by itself to the No.1 high pressure heater or deaerator step by step. The high pressure heater that meets the above conditions is called No.0 high pressure heater.
In the following part, the application status of No.0 high pressure heater is analyzed from two aspects of steam source selection and drain mode taking the ultra-supercritical units for examples.

2.1. No.0 high pressure heater steam source selection
It is very important to select high pressure steam source of No.0 high pressure heater with suitable parameters without affecting the safety of the unit. No.0 high pressure heater is fed with the help of the steam turbine existing steam valve, under low load. The steam supplementary valve and No.0 high pressure heater shares the same steam inlet switched by the fast valve, as shown in figure 1.

![Figure 1. Schematic diagram of steam source selection for No. 0 high pressure heater in the unit](image)

For the kind of units without the supplementary steam valve, there is a problem of how to optimize the steam source of 0-stage extraction. Relevant studies of domestic turbine manufacturers[2], indicate that the best steam source should be selected after the dynamic blade of the high-pressure cylinder of stage 7 according to the principle of maximum reduction of weighted average heat consumption under various load conditions. After the 9 of the high-pressure cylinder finally serves as the steam source of stage 0 extraction through optimization calculation. This scheme is still in the stage of theoretical research because of high investment and complex processing. Therefore, no power generation enterprise adopts this scheme.

2.2. No.0 high pressure heater drain modes
No.0 high-pressure heater drain systems are mainly divided into 4 modes: drain to No.1 high-pressure heater, drain to No.2 high-pressure heater, drain to No.3 high-pressure heater, drain to deaerator, and drain to condenser. The mode of drain to condenser is often considered as accidental drainage due to low efficiency. As to the other four modes, the efficiency is gradually reduced, the investment cost is gradually reduced, and the adjustment operation is simplified due to the reduction of the reconstruction of heaters, shown as figure 2.

![Figure 2. Four drain modes of No. 0 high pressure heater schematic diagram](image)
3. Economic Analysis of No. 0 High Pressure Heater

3.1. Equivalent enthalpy drop method calculation model

The equivalent enthalpy drop method is a method used to study the efficiency of thermal conversion and energy utilization [3] based on the thermodynamic conversion principle of thermodynamics, taking the equipment quality, the structure of the thermal system and the parameters of the parameters into account.

The equivalent enthalpy drop method is simple, convenient and accurate, and can replace the complex calculation of the entire thermal system with local operations, simplifying the entire calculation process.

In this paper, the equivalent enthalpy drop method is used to quantitatively analyze the different drain modes of No. 0 high-pressure heater, and the influence of the change of drainage on the economics of the unit is calculated.

![Figure 3. Schematic diagram of the drain mode of a 680 MW unit](image)

As shown in Figure 3, the No. 0 high-pressure heater of the unit is normally drained to No. 2 high-pressure heater, this drain mode is taken as the original system, the unit heat rates and coal consumptions are calculated based on the equivalent enthalpy drop method in 3 different drain modes such as the high-pressure heater drain to No. 1 high-pressure heater, No. 3 high-pressure heater and deaerator under the same load. Since the extraction flow rate and steam parameters of No. 0 high-pressure heater under the same load are constant, the drain parameters of No. 0 high-pressure heater remain unchanged.

\( \Delta H \) is the difference between the work done by the new system and the work of the original system under different drain modes. Expressed by equations (1)–(3):

\[
\begin{align*}
\Delta H_{1,2} &= \alpha_f \left( \bar{t}_{x_0} - \bar{t}_{s_1} \right) (\eta_1 - \eta_2) \\
\Delta H_{3,2} &= \alpha_f \left( \bar{t}_{x_0} - \bar{t}_{s_2} \right) (\eta_3 - \eta_2) \\
\Delta H_{c,2} &= \alpha_f \left[ \left( \bar{t}_{x_0} - t_{x_0} \right) \eta_c - \left( \bar{t}_{s,0} - \bar{t}_{s,1} \right) \eta_2 - \left( \bar{t}_{s,2} - \bar{t}_{s,3} \right) \eta_1 \right]
\end{align*}
\]

In the formula: \( \Delta H_{1,2} \) is the relative change in work done by the drain mode of No.0 high-pressure heater drain to No.1 and No.0 drain to the No.2;  
\( \Delta H_{3,2} \) is the relative change in work done by the drain mode of No.0 high-pressure heater drain to No.3 and No.0 drain to the No.2; 
\( \Delta H_{c,2} \) is the relative change in work done by the drain mode of No.0 high-pressure heater drain to the deaerator and No.0 drain to the No.2;  
\( \alpha_f \) is the ratio of the extraction steam flow of no. 0 high pressure heater to the main steam flow;


\( t_{00}, t_{11}, t_{12}, t_{13} \) is the drain enthalpy of No. 0, 1, 2 and 3 high pressure heaters respectively;

\( \eta_1, \eta_2, \eta_3, \eta_4 \) are the extraction efficiency of stage 1, 2, 3 and 4 respectively;

Is the difference of cycle heat absorption, including the change of the heat absorption of the reheater and the change of the heat absorption of the boiler. In this paper, the evaporation heat absorption of the boiler superheater is constant, the cyclic heat absorption variation is the difference between the change of the heat absorption of the reheater and the change of the heat absorption of the original system reheater in different drain modes. Expressed by equations (4)-(5):

\[
\Delta Q = a \sigma \left[ \frac{t_{10} - t_{12}}{q_1} \left( 1 - \frac{t_{12} - t_{1}^s}{t_{12} - t_{1}} \right) + \frac{t_{1}^s - t_{10}}{q_2} \right]
\]

\[
\Delta Q_{3-2} = \Delta Q_{c-2} = -a \sigma \left( \frac{t_{10} - t_{12}}{q_2} \right)
\]

In the formula:

\( \Delta Q_{c-2} \) is the relative cycle heat absorption difference between the No.0 high-pressure heater drain to No.1 and No.0 to No.2;

\( \Delta Q_{3-2} \) is the relative cycle heat absorption difference between the No.0 high-pressure heater drain to No.3 and No.0 to No.2;

\( \Delta Q_{2-3} \) is the relative cycle heat absorption difference between the No.0 high-pressure heater drain to the deaerator and No.0 to No.2;

\( \sigma \) is the heat absorbed by 1 kg of steam in the reheater;

\( q_1, q_2 \) is the extraction steam enthalpy of high pressure heater of No.1 and No.2.

The cyclic thermal efficiency of the unit under different drain modes of the No.0 high-pressure heater is shown by equation (6):

\[
\delta \eta = \frac{\Delta H - \Delta Q \eta}{H + \Delta H} \times 100\%
\]

In the formula:

\( \Delta H \) is the difference between the work done by the new system and the work of the original system under different drain modes, the same as \( \Delta H_{1-2}, \Delta H_{2-3}, \Delta H_{2-3} \); \n
\( \Delta Q \) is the difference of cycle heat absorption the same as \( \Delta Q_{c-2}, \Delta Q_{c-2}, \Delta Q_{c-2} \);

\( \delta \eta \) is the relative difference of the cyclic thermal efficiency of the unit;

\( \eta \) is the cyclic thermal efficiency of the unit;

\( H \) is the cyclic thermal efficiency of new steam.

When the work is increased, \( \Delta H \) is positive, and When the work is decreased, \( \Delta H \) is negative; when the cycle heat absorption increases, \( \Delta Q \) is a positive value, and vice versa is a negative value.

3.2 Calculation results

The equivalent enthalpy drop Calculation is provided as follows according to the parameters of the unit's different loads given by the unit thermal calculation book. The extraction efficiency and key parameters of the unit under different loads are shown in Table 1.
The unit must also undertake the task of peak regulating. The domestic large capacity units mostly adopt sliding pressure operation in peak regulating mode, the annual operating hours and annual utilization.

### Table 1. Extraction efficiency and key parameters of unit under different loads

| Parameter                        | unit | 75%THA | 50%THA | 40%THA | 30%THA |
|----------------------------------|------|--------|--------|--------|--------|
| Main steam flow                  | t/h  | 1297.37| 845.01 | 675.78 | 518.36 |
| No. 0 high pressure heater inlet flow | t/h  | 52.61  | 71.05  | 51.32  | 35.07  |
| No. 0 high pressure heater drain enthalpy | kJ/kg | 1201.2 | 1068.6 | 1014.7 | 953.6  |
| No. 1 high pressure heater inlet enthalpy | kJ/kg | 3197.6 | 3234.0 | 3248.9 | 3251.9 |
| No. 1 high pressure heater drain enthalpy | kJ/kg | 1108.8 | 989.3  | 939.8  | 884.0  |
| No. 2 high pressure heater inlet enthalpy | kJ/kg | 3129.8 | 3165.1 | 3179.2 | 3182.5 |
| No. 2 high pressure heater drain enthalpy | kJ/kg | 902.9  | 812.0  | 773.1  | 728.8  |
| Stage 1 extraction efficiency (%) |       | 0.5306 | 0.4958 | 0.4775 | 0.4501 |
| Stage 2 extraction efficiency (%) |       | 0.5149 | 0.4799 | 0.4612 | 0.4335 |
| Stage 3 extraction efficiency (%) |       | 0.3616 | 0.3420 | 0.3297 | 0.3005 |
| Stage 4 extraction efficiency (%) |       | 0.3009 | 0.2836 | 0.2716 | 0.2486 |

The effects of different drain modes on the efficiency of the unit under different loads of 75%THA,50%THA,40%THA,30%THA are shown in Table 2.

1. The efficiency is best under any load of the unit in the mode of No. 0 high-pressure heater drain to No.1;
2. The drain mode of No. 0 high-pressure heater has a great influence on the economics of the unit under around 50% THA.
3. The difference of the heat consumption rates is very little between the original system and the mode of No.0 high-pressure heater drain to No.1; however, the economic difference is large when draining to No.3 or deaerator;.
4. The original system with No.0 high-pressure heater drain to No. 2 high pressure heater has the best comprehensive economy, the high-pressure heaters after No.2 need to be reconstrutioned,which can reduce investment and shorten the renovation period.

### Table 2. The influence of different drain modes on the economics of the original unit

| operating condition | drain mode | difference of Work $\Delta H$ (kJ/kg) | difference of cycle heat absorption $\Delta Q$ (kJ/kg) | relative difference of the cyclic thermal efficiency $\delta \eta$ (%) | Reduced heat rate $\delta q$ (kJ/(kW.h)) | Standard coal consumption reduction $\Delta c$ (g/(kW.h)) |
|---------------------|------------|---------------------------------------|--------------------------------------------------|-------------------------------------------------|--------------------------------------|---------------------------------|
| 75% THA             | To No.1HPH* | 0.06                                  | -0.06                                             | 0.0065                                          | 0.08                                | 0.02                            |
|                     | To No.3HPH  | -1.85                                 | -2.12                                             | -0.0669                                         | -0.88                               | -0.19                           |
|                     | To deaerator| -2.95                                 | -2.12                                             | -0.1504                                         | -1.97                               | -0.43                           |
| 50% THA             | To No.1HPH  | 0.11                                  | -0.08                                             | 0.0110                                          | 0.14                                | 0.03                            |
|                     | To No.3HPH  | -2.98                                 | -3.57                                             | -0.1112                                         | -1.44                               | -0.33                           |
|                     | To deaerator| -4.88                                 | -3.57                                             | -0.2590                                         | -3.35                               | -0.76                           |
| 40% THA             | To No.1HPH  | 0.09                                  | -0.07                                             | 0.0093                                          | 0.12                                | 0.03                            |
|                     | To No.3HPH  | -2.41                                 | -2.96                                             | -0.0901                                         | -1.17                               | -0.27                           |
|                     | To deaerator| -4.04                                 | -2.96                                             | -0.2159                                         | -2.79                               | -0.65                           |
| 30% THA             | To No.1HPH  | 0.08                                  | -0.05                                             | 0.0079                                          | 0.10                                | 0.03                            |
|                     | To No.3HPH  | -2.02                                 | -2.45                                             | -0.0760                                         | -0.97                               | -0.24                           |
|                     | To deaerator| -3.23                                 | -2.45                                             | -0.1716                                         | -2.18                               | -0.54                           |

*HPH: high-pressure heater.

3.3. Comparison of economic benefits of different drain modes for No.0 high pressure heater

With the development of our nation’s economy,growth of power grid size,and the changing of electricity structure, the peak-to-valley difference has become more and more large. In addition to the basic load, the unit must also undertake the task of peak regulating. The domestic large capacity units mostly adopt sliding pressure operation In peak regulating mode, the annual operating hours and annual utilization
hours of the unit have obvious influence on the economic comparison results. Refer to the actual operation of the same type of units in Shandong Power Grid, take 5000 hours according to the utilization hours in 2017, and the peak regulating mode of the unit is temporarily considered in Table 3.

Table 3. Run time combination under different loads in peak regulating mode

| Load        | Annual operating hours (h) | Annual utilization hours (h) |
|-------------|----------------------------|------------------------------|
| 100%THA     | 800                        | 800                          |
| 75%THA      | 2800                       | 2100                         |
| 50%THA      | 3800                       | 1900                         |
| 40%THA      | 500                        | 200                          |
| Total time  | 7900                       | 5000                         |

Since the minimum peak load of Shandong renewable energy unit in 2017 is allowed to 40% THA, the running time of the unit's 30% THA load is zero.

In the 40%-100% THA load, the annual utilization hours of the unit are calculated according to the data in Table 3, and the standard coal is 800 yuan/ton. The calculation results are shown in Table 4.

Table 4. Comparison of economic benefits for the unit in different drain modes

| drain mode             | Annual savings of standard coal (t) | Economic benefit (ten thousand yuan) |
|------------------------|-------------------------------------|--------------------------------------|
| No. 0 high-pressure heater | 71.4                                | 5.7                                  |
| No. 3 high-pressure heater | -734.4                               | -58.8                                |
| Deaerator              | -1684.36                             | -134.7                               |

The unit with No.0 high-pressure heater drain to No.1 could produce economic benefits of 57,000 yuan annually compared with the original system in peak regulating mode; The unit with No.0 high-pressure heater drain to No.3, deaerator could reduce the economic benefit by 588,000 yuan and 1.347 million yuan respectively. The original system which has the similar economic benefits with the mode of No.0 high-pressure heater drain to No.1 leaving out No.1 high-pressure heater reconstruction cost and difficult adjustment operation is optimal.

4. Conclusion

According to the performance parameters of No. 0 high-pressure heater under the rated load of 75%, 50%, 40% and 30% of the unit, the thermodynamic calculation of steam turbine and regenerative system for different drain modes of No. 0 high-pressure heater is carried out based on equivalent enthalpy drop method, The cycle thermal efficiency of the steam turbine generator set is provided, and the energy-saving benefit are evaluated. The results show that the unit with No.0 high-pressure heater drain to No.2 is optimal.

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