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The Condenser Performance Test and Thermal Performance Analysis of Variable Conditions in TQNPC

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ABSTRACT

Condenser is one of the important auxiliary equipments in nuclear power plants. The thermal efficiency of the entire unit was depended on the condenser performance. Cleanliness factor and condenser corrected pressure are the two most important evaluation indexes. The definition and derivation of these two evaluation indexes were elaborated and clarified in this paper. And the condenser performance at variable conditions was analyzed. The seawater temperature, pipe plugging rate and seawater volume rate effect on unit output was calculated. The calculation method was simple, which can provide reference guidance for similar power plant.

Keywords: Condenser; Performance Test; Variable Condition; TQNPC

1. Introduction

Condenser is one of the important auxiliary equipments in nuclear power plants. The thermal efficiency of the entire unit was mostly depended on the condenser performance.

The main factors affect the operation of the condenser performance in the following areas, through the analysis and comparison of the condenser performance impact factors. For example: cooling water inlet temperature, cooling water flow rate, condenser thermal load, cooling tubes fouling, the amount of air leaking into the condenser, condenser cooling area. The cooling water inlet temperature and the condenser heat transfer area were depended entirely on the natural conditions and design value. In general, condenser cooling area had sufficient margin. The cooling water flow rate could meet the need of the heat transfer in VWO condition, unless the circulating pump and circulating water system failure. For the operating condenser, the condenser thermal load, the cooling tubes fouling and the amount of air leaking into the condenser were the key factors to influence performance of condenser.

Cleanliness factor and condenser corrected pressure are the two most important evaluation indexes. But the definitions and calculation methods had some different meaning, in this paper, the performance test data of TQNPC was used to evaluate the condenser performance, and to elaborate and clear these two definitions.

2. The Formulas

The thermal balance equation of condenser was:

$$Q = Wc_p(t_{w2} - t_{w1}) = Wc_p\Delta t = KA\Delta t_m = KA\ln(1+\delta t/\Delta t) \tag{1}$$

and

$$\Delta t = t_{w2} - t_{w1} \tag{2}$$

$$\Delta t_m = \frac{t_{w2} - t_{w1}}{\ln\frac{t_s - t_{w1}}{t_s - t_{w2}}} \tag{3}$$

$$\delta t = t_s - t_{w2} \tag{4}$$

The condenser overall heat transfer coefficient K was important parameter to description condenser performance, which combined a variety of factors effected condenser performance. In this paper, the international Heat Transfer Society (HEI) formula was used, as follows

$$K_{HEI} = K_0\beta_c\beta_{t1}\beta_m \tag{5}$$

3. Condenser Cleanliness Coefficients

The condenser cleanliness coefficients was one of the parameters to characterize the tube dirt degree, which indicated that the ratio of heat transfer coefficient about the old and the new tubes at the same flow rates and steam temperature. The condenser cleanliness coefficient was the average of all the cooling pipe cleanliness coefficients [1].

Assuming the same operating conditions, the heat transfer coefficient of the new cooling pipes was Kc, the old cooling pipes of the heat transfer coefficient was Kf, so cleanliness coefficient as follows[2]:

$$C_f = K_f / K_c \quad (6)$$

Hu Honghua [3] proposed another algorithm of Cf, as follows.

$$Cf = \frac{K_T}{K_{HEI}} C_{fD} \quad (7)$$

CfD was the selected cleanliness coefficient during the calculation of KHEI according the HEI standard [4].

In addition, the reference [5] proposed the following cleaning coefficient calculation method.

$$\beta_c = \frac{K}{K_0 \beta_t \beta_m} \quad (8)$$

β_C was cleanliness coefficient, K_0 was heat transfer coefficient, β_t was the cooling water inlet temperature correction factor, β_m was Pipe material and tube wall thickness correction factor.

These cooling pipe cleaning coefficient formulas seemed contradict, their relationship was as follows.

K_f and K_c in formula 6 was heat transfer coefficients of fouling pipes and new pipes, respectively. But they were measured by the fouling resistance test. In formula 7, the author proposed that the cleanliness coefficient was the ratio of test transfer coefficient and K_{HEI}, and was corrected with C_{fD}. In formula 8, the expression of cleanliness coefficient was different with formula 7, it was deduced by formula 6, and corrected C_{fD} was eliminated. So formulas 7 and 8, actually were a calculation method. The formula 6 and 7 and 8, although the same physical meaning, but has a completely different calculation and methods of expression.

Reference [4] lists various components test data which impacted the heat transfer coefficient. These experimental data had proven to be more accurately. In China we also refer to these data in national standard. Therefore, these test data was used to judge the condenser cleanliness coefficient.

The following equations were obtained by fitting these test data in HEI standard.

$$K_0 = 1260.7 + 1609.63V - 162.88V^2 \quad (9)$$

$$\beta_{t1} = 0.6383 + 0.02298t_1 - 0.00029t_1^2 \quad (10)$$

$$\beta_m = 1.05573 - 0.2265h + 0.03104h^2 \quad (11)$$

The equation 12 was obtained by the differentiation of equation 4.

$$\begin{aligned} \Delta K = {} & \beta_c \beta_{t1} \beta_h (1609.63 - 2 \times 162.88V) \times \Delta V + \\ & K_0 \beta_c \beta_{t1} (-0.2265 + 2 \times 0.03104h) \times \Delta h \\ & K_0 \beta_c \beta_h (0.02298 - 2 \times 0.00029t_1) \times \Delta t_1 \\ & K_0 \beta_{t1} \beta_h \Delta \beta_c \end{aligned} \quad (12)$$

Then we calculated the condenser performance of TQNPC using the equation 12 and test data. The results were shown in **Table 1**.

We can get the values of the pipes cleanliness using the above equations, and we can also get the amount of influence of factors on heat transfer coefficient. The condenser cleanliness coefficient was 0.82 in PT-01, which reduced the rate of 3.12% compared with the design value. In PT-02 the condenser cleanliness coefficient was dropped to 0.77, which reduced the rate of 10.23% compared with the design value.

4. The Condenser Correction Pressure

We can get the following conclusions according to the condenser heat transfer equation in HEI standard [4]. The higher the cooling temperature, the higher the heat transfer coefficient; larger the cycle water volume flow, the higher the heat transfer coefficient. In the same, the cleaner the cooling water pipes, the higher the heat transfer coefficient, and vice versa.

The cooling water temperature was not likely to be exactly the design value (eg. 20℃) when the condenser performance test carried on. Neither was the cooling water volume flow.

The heat transfer coefficient correction equation was as follows:

$$K_c = K_t F_v F_t F_c \quad (13)$$

$$F_v = \sqrt{\frac{V_D}{V_T}} \quad (14)$$

Table 1. The calculation of condenser cleanliness coefficient.

Parameters	Unit	Design value	PT-01	PT-02
Pipe diameter	mm	25.4	25.4	25.4
Wall thickness	mm	0.65	0.65	0.65
seawater flow rate	m/s	1.97	2.02	1.98
Inlet Water temperature	℃	18.8	18.8	14.9
Outlet Water temperature	℃	27.8	27.5	23.8
Cleanliness coefficient		0.85	0.82	0.77
Heat transfer coefficient	kW/(m^2·℃)	2880	2825	2483
Total changes of heat transfer coefficient	kW/(m^2·℃)		-54.7	-396.6
Influence of flow rate	kW/(m^2·℃)		34.7	8.2
Influence of wall thickness	kW/(m^2·℃)		0	0
Influence of water temperature	kW/(m^2·℃)		-1.2	-150.8
Influence of fouling	kW/(m^2·℃)		-89.5	-252.9
The ratio of test cleanliness coefficient and design value	%		3.1	10.2

$$F_t = \frac{\beta_{tD}}{\beta_{1T}} \quad (15)$$

$$F_c = \frac{\beta_{cD}}{\beta_{cT}} = \frac{C_{fD}}{C_{fT}} \quad (16)$$

In the above equations, K_c was the corrected heat transfer coefficient, F_c was flow rate corrected factor, F_t was water temperature corrected factor, and F_c was corrected factor of cleanliness coefficient.

The corrected condenser pressure of TQNPC was calculated though the above equations. The results were shown in **Table 2**. It can be seen that the corrected pressure was 4.91kPa, which was larger than the design value 4.90 kPa. It indicated than the condenser performance was worse than the design value.

5. Condenser Thermal Performance Analyses of Variable Conditions

The steam condensation temperature t_s were decided by equation 17 in operating condition. The saturation pressure corresponding to the steam condensation temperature was condenser pressure.

$$t_s = t_1 + \Delta t + \delta t \quad (17)$$

The condenser pressure curve under different sea water temperature can be obtained using the above equation 1,2,3,4, 17 and through iterative calculation, as shown in **Figure 1.**

It can be seen than at the same condenser heat transfer area, structure form, heat load, cooling water volume flow, vacuum tightness and cooling pipe cleanliness coefficient, the cooling water inlet temperature rise, then the condenser pressure increases. As the temperature increases continually, the condenser pressure increases faster and faster.

According to the operating parameters of seawater temperature, seawater volume flow and condenser design data, we can also get the relation curve of condenser pressure and unit output with the cooling pipes plugging rate using the above equations. The results were shown in **Figures 2 and 3**.

Table 2. The results of condenser corrected pressure.

Parameter	Unit	Design value	PT-01	PT-02
Condenser heat load	kW	1328146	1340349.9	1338410.7
Condenser pressure	kPa	4.90	4.89	4.20
Inlet water temperature	℃	18.8	18.8	14.9
Outlet water temperature	℃	27.8	27.5	23.8
Sea water volume flow	m^3/s	36.13	37.48	36.80
Cleanliness coefficient		0.85	0.82	0.77
Corrected saturated water temperature	℃		32.58	32.56
Corrected condenser pressure	kPa		4.91	4.91

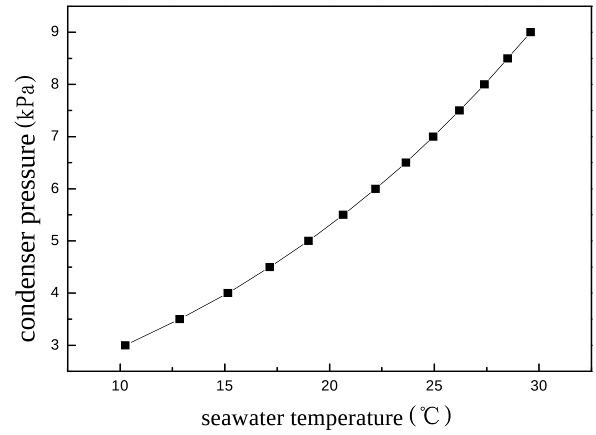

Figure 1. Condenser pressure curve under different seawater temperature.

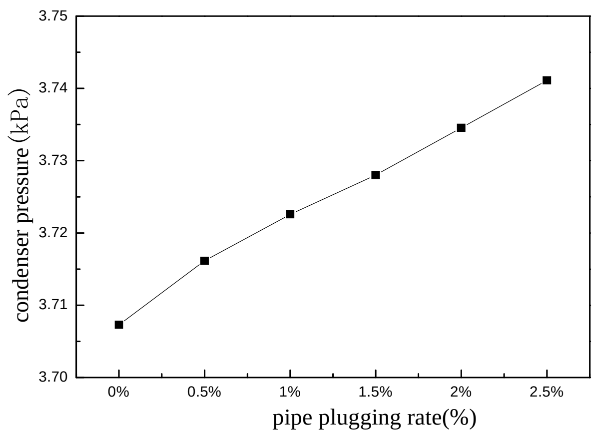

Figure 2. The condenser pressure under different pipe plugging rate.

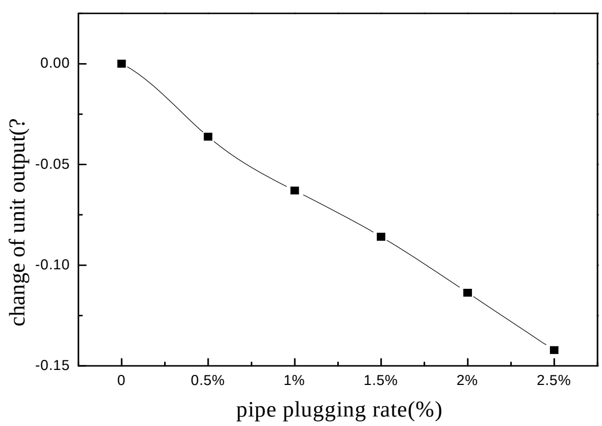

Figure 3. The unit output under different pipe plugging rate.

From the **Figures 2** and **3**, it can be seen that the corrected condenser pressure was 4.93 kPa when the pipe plugging rate was 2%. It can be concluded that there was no obvious impact on the unit output when the pipe plugging rate was low.

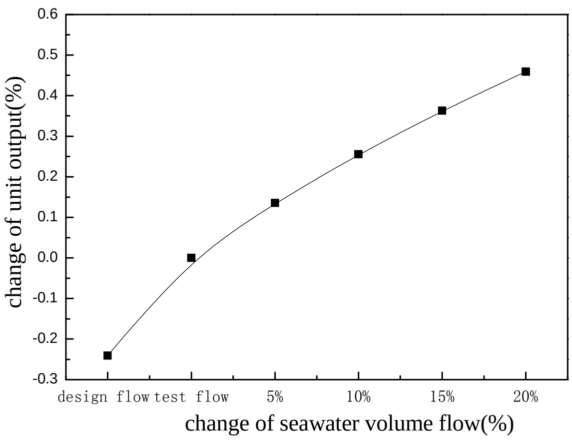

Figure 4. The unit output under different seawater volume flow.

The seawater volume flow at test conditions was larger than design values. So the impact of seawater volume flow on unit power was also analyzed. The calculation results were shown in **Figure 4**.

The seawater mass flow was 39441.2 kg/s, which was 6.5% larger than the design value 36833.5 kg/s. Ac cording to the slight increase of output method [6,7], if the seawater mass flow decrease to design value, the unit output decrease 1.7 MW. If the seawater flow increase 10%, and the unit output can improved 1.9 MW.

Based on the seawater pump curve and the pump power, it calculated that the pump power could save 380.7 kW, but the unit output decrease 1.7 MW, so the unit economic efficiency at test condition was better than the design volume flow.

6. Conclusions

Condenser is one of the important auxiliary equipments in nuclear power plants. The thermal efficiency of the entire unit was mostly depended on the condenser performance. Cleanliness factor and condenser corrected pressure are the two most important evaluation indexes. The definition and derivation of these two evaluation indexes were elaborated and clarified in this paper. And the condenser performance at variable conditions was analyzed. The seawater temperature, pipe plugging rate and seawater volume rate effect on unit output were calculated. The calculation method was simple, which could provide reference guidance for similar power plant.

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