The possibility of increasing the efficiency of condensers at the CHP

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Abstract. In traditional condensers of combined heat and power (CHP) plants, water is used, which is discharged into the environment and creates environmental stress. It is proposed to cool the steam by air or freon. The basic schemes of CHP condensers operating on compressed air and freon are given. A comparative calculation of the condenser operating on water, air and freon was carried out. Analysis of the results shows the effectiveness of air, and freon compared to water. The advantage of freon is that it circulates in the heat exchanger, forming a closed system. At decreasing the temperature difference at the inlet and outlet to the condenser, the heat transfer coefficient of freon is higher than that of air.

1. Introduction

At combined heat and power plants (CHP), as well as at thermal power plants (TPP), the main source of waste low-grade heat is steam turbine condensers. In condensers, the latent heat of vaporization is removed by means of cooling water.

For example, at the Tyumen CHP-1 there is a lake of water, with the help of which the condenser is cooled. It is known that a 1000 MW power station requires a lake with an area of 810 hectares and a depth of about 8.7 m. The condenser cooling water is warmer than the initial one, therefore the environment is simultaneously heated, which adversely affects the ecological situation. Consequently, there is the problem of choosing the method of cooling steam at CHP.

In this regard, studies are being conducted and new condenser cooling systems are being developed. It is proposed to use air, and low-boiling liquids, in particular freon. [1-8].

The purpose of this work is to create a condenser circuit and evaluate the possibility of using air and freon as a working fluid for a condenser. The obtained data should be compared with the work of traditional water condensers. The conclusions on the possibility of using air and freon for cooling the condenser of the CHP plant should be drawn up.

2. Methods

In traditional water condensers, the most commonly used in CHP plants, horizontal shell-and-tube heat exchangers are used. In the proposed scheme, it was suggested to install a vertical shell-and-tube heat exchanger instead of a horizontal one as a condenser. A diagram of the condenser is shown in Figure 1. Air is taken as the cooling medium.
Figure 1. Schematic diagram of the condenser unit:
1 - Condenser; 2 - Compressor; 3 - Condensate collector; 4 - Condenser pump; 5 - Air pump (injector); A - Supply of the working fluid (steam or water); B - Steam from the turbine into the regeneration system.

The condensation process is carried out by taking away the heat of condensation from the steam at the constant pressure. To remove heat released during the steam condensation (heat of phase transition), the compressor 2 is continuously pumping the air from the environment through the condenser pipes, which form the cooling surface. After this, the condenser air is removed to the environment. The authors suggest that heated air may adversely affect the environment.

When using freon, the schematic diagram of the condensing unit will change as after the steam is cooled down, freon comes to the compressor inlet. Thus, a closed condensation system is formed, without discharging the heated working fluid into the environment. The schematic diagram of the installation is shown in Figure 2.

Figure 2. Schematic diagram of the condenser unit:
1 - Condenser; 2 - Compressor; 3 - Condensate collector; 4 - Condenser pump; 5 - Air pump (injector); 6 - Freon condenser; 7 - Throttle; A - Supply of the working fluid (steam or water); B - Steam from the turbine into the regeneration system.

It should be noted that the use of a closed condensation system is environmentally friendly. In addition, it is proposed to use R404a freon. This brand was chosen as it is characterized by the following thermodynamic conditions: 1) the critical temperature of a low-boiling working fluid (LWF) must be in the range from 303.15 K to 323.15 K to ensure its heating in the steam turbine condenser to a supercritical temperature; 2) the critical pressure of the LWF should be in the range of 3 MPa to 5 MPa in order to ensure acceptable pressures of the circulation circuit and the cost of its compression; 3) the temperature of the triple point of LWF should be below 223.15 K in order to exclude freezing over the entire range of operating temperatures in winter; 4) the pressure of the triple point of LWF should be at least 0.1 MPa to eliminate the problems of vacuum creating and ensure the strength and tightness of pipelines and valves. [9-11]

To assess the effectiveness of the use of the considered coolers, two parameters were chosen: the average heat transfer coefficient and the amount of underheating of the coolant. [12-15]

To calculate the heat transfer coefficient in the condenser, the methodology of the All-Russian Thermal Engineering Institute at $t_{av}>35$ °C was chosen. This methodology is based on the integral operating characteristics of the condenser and does not require data on the device tube bundle configuration.
\[ K = 4070 \cdot a \left( \frac{1.1 \cdot w_w}{d_{in}^{0.25}} \right)^{0.12a(1+0.15t_{1w})} \cdot \left( 1 - \frac{(0.52-0.0072 \cdot d_c)\sqrt{d}}{1000} \cdot (35 - t_{1w})^2 \right) \times \left( 1 + \frac{z-2}{10} \left( 1 - \frac{t_{1w}}{35} \right) \right) \cdot \Phi \]  

where \( a=(0.65-0.85) \) is the coefficient of condition of the condenser heat exchange surface; \( w_w \) is the coolant rate in pipes, m/s; \( d_{in} \) is the internal diameter of pipes, mm; \( t_{1w} \) is the temperature of the cooling water at the input to the condenser, \(^\circ\)C; \( z \) is the amount of water paces in the condenser; \( d_c \) is the specific steam load of the condenser, kg/(m\(^2\)h); \( \Phi \) is the coefficient which takes into account the influence of the steam load of the condenser (\( d_c \)).

The underheating in a surface condenser is determined using the formula:

\[ \delta t = \frac{t_{2w} - t_{1w}}{\exp\left( \frac{t_{2w} - t_{1w}}{K \cdot G_w \cdot c_{pw}} \right) - 1} \]  

where \( t_{1w}, t_{2w} \) are the water temperatures at the inlet and the outlet of the unit, respectively, \(^\circ\)C; \( G_w \) is the water consumption, kg/s; \( c_{pw} \) is water heat capacity, kJ/(kg\( \cdot \)K); \( K \) is the heat transfer coefficient in the unit, W/(m\(^2\)\( \cdot \)K); \( F \) is the heat exchange surface, m\(^2\).

3. Results and discussion

The following parameters were taken in our calculations: cooling surface area \( F = 9000 \) m\(^2\), the amount of pipes is 11940, mass flow rate of steam in the condenser is \( D_{c\text{nom}} = 400,000 \) kg/h, pipe material is brass L68.

The average heat transfer coefficient, the coolant temperature at the outlet, the underheating and the vapor pressure in the condenser were determined during the calculation by changing the inlet temperature with a step of 10 \(^\circ\)C. The calculation method was applied to air, water and freon in order to compare the obtained results.

The results of calculations are presented in Figure 3.

From the presented graphs it follows that the most effective coolant-cooler is air. Freon is more effective than water, but it is worse than air. This is due to the fixed values of the temperature difference in the capacitor inlet and outlet.

Analysis of the obtained results shows that with a decrease in the temperature difference, freon is more effective than both water and air. This effect was recorded at the laboratory installation of the department during the study of cooling of heated water by circulating freon in porous heat exchangers. During the unit operation, the temperature difference between the freon at the inlet and outlet of the heat exchanger is practically unchanged. Then we should expect that when freon is working in a CHP...
condenser, the heat transfer coefficient will be higher than that of air. The result of this calculation is shown in Figure 3, highlighted by a dotted line and indicated by freon-2 [16].

The value of underheating characterizes the efficiency of using the heat coming from the heating steam, i.e. thermodynamic perfection of the unit. The results of calculations are shown in Figure 4.

The value of underheating decreases with increasing heat transfer intensification. Analysis of the calculations shows that our conclusions are correct.

4. Conclusions
Thus, it is established that:
1) With a fixed temperature difference at the inlet and outlet to the condenser of the CHP, air is more efficient than freon and water.
2) If one reduces the temperature difference at the inlet and outlet to the condenser of the CHP, then freon is the most effective.
3) The advantage of freon is that it circulates in a closed circuit and does not create an environmental burden on the environment.
4) Therefore, air and freon can be used for cooling steam in CHP condensers.

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