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Numerical analysis of factors affecting condensation capacity of air-cooled condenser

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Abstract. The working environment of the air-cooled condenser is very complicated. By analyzing the heat transfer process of the air-cooled condenser, it is found that the temperature of the environment, the lateral wind speed in the environment and the rotational speed of the axial fan all have an influence on the condensation capacity of the air-cooled condenser. Through research, it is found that the condensation capacity of the space-time condenser at -25 °C is about 3.75 times that at 30 °C; compared with no lateral wind speed, when the wind speed increases from 4m/s to 12m/s, the decline of the condensation capacity of the air condenser changes from 1.2% to 12.6%; when the axial fan is at 1.1 times rated speed, its condensation capacity is 1.6 times that of 0.5 times. It can be seen that the rotational speed of the axial flow fan and the ambient temperature are the main influencing factors, and the rotational speed of the axial flow fan is an active adjustment factor. Furthermore, the control scheme of the axial fan speed as a function of ambient temperature can be obtained through analysis.

1. Introduction

There are many studies on air condensers abroad. Ankur Kumar, Jyestharaj B. Joshi [1] and others found that as the fin spacing increases, the heat transfer coefficient increases and the pressure drop decreases. Keep the wind speed constant. Xuelei Zhang and Tingting Wu [2] installed a diffusion orifice plate structure in the lower part of the air-cooled condenser platform to eliminate the adverse effects of ambient wind-to-air condenser heat flow. Alan O'Donovan, Ronan Grimes [3] proposed a new modular air-cooled condenser (MACC). Weifeng He [4] et al. studied the mechanism of the temperature increase of the air inlet of a forced air blower in an air-cooled steam condenser. Kaipo Kekaula et al. [5] conducted a numerical study on the condensation process of inclined tube air condensers, and proposed a coupling model of laminar film condensation and air side convection cooling of inclined air condenser tubes. J.R. Bredell [6] and others used Fluent to simulate the flow field of the airflow of the axial fan of the air-cooled condenser, and obtained a better fan blade design. However, there is not much work on the analysis of the factors affecting the condensation capacity of direct-type air-cooled condensers in domestic. Therefore, this paper takes the air-cooling condenser of a 2×330MW direct air-cooling unit as the research object, and numerically analyzes the main factors affecting its condensation capacity to guide the safe and efficient operation of the air-cooled condenser.
2. Air cooling system and theoretical analysis

2.1. Air cooling system
Air cooling system is a system that uses air as a cooling medium to cool a turbine exhaust, which is also called a dry cooling system. The whole system has the advantages of cyclic sealing and obvious water saving effect. It is an ideal water saving technology[7]. In this paper, a 2×330MW domestic subcritical direct air cooling unit of a power plant is studied. Each 330MW direct air-cooling unit is divided into 6 columns. Each column consists of 5 small air cooling units. Among the five small air cooling units in each column, the middle small air cooling unit is a counter current air cooling unit, and the angle between the tube bundles of the A type is 58°.

The technical parameters of the axial flow fan are shown in Table 1:

| Project            | Parameter               | Project Parameter               |
|--------------------|-------------------------|---------------------------------|
| Model              | 30ZLF7                  | Diameter of impeller: 9.81m     |
| Number of blades   | 5                       | Blade mounting angle: 17.2°     |
| Rated speed        | 84rpm                   | Maximum speed: 92.5rpm          |
| Rated speed air volume | 508m3/s                   | Rated speed static pressure: 77.9Pa |

2.2. Theoretical analysis
By calculating the size of the Reynolds number $Re_a$ in the rectangular flow channel, it can be seen that the flow state of the air in the rectangular flow channel is laminar. For this situation, the Sider-Tate formula is used to calculate the average Nusselt number $Nu$:

$$Nu = 1.86 \left( \frac{Re_a \cdot Pr}{L/l} \right)^{1/3} \left( \frac{\eta_a}{\eta_w} \right)^{0.14}$$

Where:
- $Re_a$ is the Reynolds number of the air in the runner;
- $Pr$ is the Prandtl number of air in the flow channel;
- $L$ is the length of the rectangular flow channel, that is, the length of the base pipe;
- $l$ is the characteristic length of the rectangular wall runner with equal wall temperature;
- $\eta_a$ is dynamic viscosity at average air temperature;
- $\eta_w$ is the dynamic viscosity of air at wall temperature.

According to the information provided by the manufacturer, using MATLAB's curve fitting toolbox, the relationship between the ambient lateral wind speed and the airflow of the axial fan is fitted, and the relationship between the two is as follows:

$$m_f = 517.8 + 0.02912v_e^3 - 1.131v_e^2 + 0.4859v_e$$

Where:
- $m_f$ is axial fan volume;
- $v_e$ is ambient lateral wind speed.

3. Analysis of influencing factors

3.1. Analysis of the effect of the average speed of the fan
The temperature difference in the four seasons is large in the north, so the analysis of the relationship between the axial fan and the condensing capacity should be considered seasonal factors. According to local historical meteorological data, the average temperature of the area in spring (March-May) is 5.8°C, in summer (June-August) is 20°C, in autumn (September-October) is 9.7°C, in winter (November-February) is -11 °C. Set the relative humidity of the air $\phi = 60\%$, ignoring the effects of
solar radiation and ambient wind. According to the technical parameters of the fan, the rated speed of the axial fan is \( n = 84 \text{ rpm} \), and the range of the selected axial fan rotation speed is \( 0.5n-1.1n \), that is, \( 42\text{rpm}-92.5\text{rpm} \). Using the simulation model, the relationship diagram shown in Figure 1 is obtained.

It can be seen from the curve in the figure that the larger the average fan speed, the smaller the influence of the fan speed on the condensation capacity of the air-cooled condenser. And at different temperatures, when the fan is at maximum speed, the condensation capacity of the air-cooled condenser is about 1.6 times that of the minimum speed. Therefore, it is considered that the change of the axial fan rotation speed has a great influence on the condensation capacity of the air-cooled condenser.

![Figure 1. Relationship between condensation capacity of air-cooled condensers and axial fan speed in different seasons.](image)

3.2. Analysis of the effect of environmental temperature

Set the relative humidity of the air \( \phi = 60\% \), ignoring the effects of solar radiation and ambient wind. Then analyze the relationship between the change in ambient temperature and the condensing capacity of the air-cooled condenser at different speeds. According to the gas phase data of the region, the range of ambient temperature change in this area is \(-25 ^\circ\text{C}-30 ^\circ\text{C}\), and the relationship between the condensation capacity of the air-cooled condenser and the ambient temperature at different fan rotation speeds is obtained as shown in Figure 2:

![Figure 2. Relationship between condensation capacity of air-cooled condenser and ambient temperature at different fan rotation speeds.](image)

It can be seen from the figure that the condensation capacity of the air-cooled condenser decreases with the increase of the ambient temperature; meanwhile, it can be seen that as the ambient temperature increases, the effect of the fan speed is weaker. In addition, at different fan rotation speeds, the ratio of the condensation capacity of the air-cooled condenser at \( 30 ^\circ\text{C} \) to the condensation
capacity at -25 °C is approximately equal to 3.75, which indicates that the ambient temperature is an important environmental factor affecting the condensation capacity of the air-cooled condenser.

3.3. Analysis of environmental lateral wind effect
The lateral wind in the environment affects the air volume of the axial fan, which affects the condensation capacity of the air-cooled condenser. Assuming that the axial fan speed is 84 rpm and remains unchanged, the ambient temperature T is taken to be an average temperature of 4.6 °C for the whole year and an air humidity of 60%. Ignore the effects of solar radiation. According to the simulation model, the influence of the ambient lateral wind speed on the condensation capacity of the air-cooled condenser under this working condition is obtained as shown in Figure 3.

It can be seen from the figure that as the lateral wind speed of the environment becomes larger and larger, the condensation capacity of the air-cooled condenser is also reduced accordingly. According to the trend of the curve, the effect is more obvious when the lateral wind is large.

![Figure 3. Effect of lateral wind speed on the condensation capacity of axial fans.](image)

3.4 Operation optimization analysis

![Figure 4. Axial fan speed as a function of ambient temperature control scheme.](image)
According to the analysis, the effect of the axial fan speed and ambient temperature on the condensation capacity of the air condenser is obvious, and the rotation speed of the axial fan is the active adjustment factor. When the ambient temperature changes, the condensation capacity of the air condenser changes accordingly, causing a mismatch between the condensation capacity and the exhaust flow rate. Therefore, when the ambient temperature changes, the fan speed must be adjusted to match the condensation capacity of the air condenser with the steam exhaust flow rate.

According to the operation data of a power plant, it can be seen that the range of steam exhaust flow of the steam turbine is 350t/h-700t/h. Therefore, we select steam turbine exhaust flow rates of 400t/h, 500t/h, 600t/h and 700t/h. According to the local historical gas phase data, the temperature range is selected to be -35-35°C.

According to the analysis, under different exhaust steam flow, the control scheme of the axial fan speed as a function of ambient temperature is shown in Figure 4:

4. Conclusions
In this paper, three factors affecting the condensation capacity of air-cooled condensers are analyzed. Through analysis, it is found that: (1) The effect of the axial fan speed on the condensation capacity of the air-cooled condenser is obvious. The condensation capacity at 1.1 times the rated speed is 1.6 times the condensation capacity at 0.5 times the rated speed; (2) The ambient temperature also has a great influence on the condensation capacity of the air-cooled condenser. The condensation capacity of the air condenser at -25°C is about 3.75 times that of the 30°C; (3) The effect of environmental lateral wind to air-cooled condenser is related to the lateral wind speed. When the lateral wind speed is 4m/s, the condensation capacity of the air condenser is only reduced by 1.2%. When the ambient wind speed reaches 12m/s, the condensation capacity is reduced by up to 12.6%. And through the analysis, the control scheme of the axial fan speed as a function of ambient temperature under different exhaust steam flow is obtained. The air condenser condensing capacity is matched with the exhaust steam flow and get the best economy.

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