Analysis of Influence of 1000MW Unit Boiler Side Wind, Side Wind and Solar Radiation on Direct Air Cooling System

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Abstract. In the operation of direct air-cooled units, there are many factors that affect the safety and economy of the unit. The "hot air recirculation" and "backfill" phenomena caused by lateral wind, the influence of high ambient wind on the heat transfer performance of the air cooling unit near the windshield wall, and the "hot air recirculation" phenomenon caused by the back wind of the furnace, these may affect the direct air cooling unit. Safe and economical operation. Through carrying out on-site test research, collecting the actual operating conditions of the unit operation, the organic combination of laboratory simulation data and actual data is provided to provide a strong basis for the development of corresponding technologies.

Keywords: Unit Boiler, Side Wind, Direct Air Cooling System, Anti-side Molding Test System, Solar Radiation Heat Effect.

1. Introduction

Direct air-cooled units are currently the most common choice for thermal power generating units in the water-scarce areas in the north, and the construction of large-capacity, high-parameter, low-pollution direct air-cooled units is the best choice. A series of researches on the direction of energy consumption improvement, unit safety, and economic operation of large-capacity direct air-cooled units are urgently needed.

During the operation of the direct air-cooled unit, there are many factors that affect the safety and economy of the unit, which will eventually be reflected in the heat exchange performance of the air condenser [1-4], and the heat exchange performance of the air condenser is affected by the horizontal. The effects of “hot air recirculation” and “backfilling” caused by wind, and “hot air recirculation” caused by wind behind the furnace [5-8], especially the influence of the wind and side wind during the high temperature in summer can cause the moment of unit vacuum It is close to the protection value, resulting in related derivative problems such as non-stop of the unit. It is very necessary to study the back wind, side wind and solar radiation of 1000MW unit. In this paper, the design and construction of the anti-crosswind modeling test system and the CFD simulation system for the influence of the wind behind the air-cooled island furnace, and the actual measurement system of solar radiation on site. Under the different working conditions of the unit, it can realize the combination of simulation and actual data, propose solutions to related problems, and provide first-hand test data for the design, operation, optimization and later transformation of the direct air-cooled unit.
2. Test System and Test Method

In the research of the back air, side wind and solar radiation of the air cooling system, relying on a 1000MW direct air cooling unit of a power plant, a typical unit of a unit is selected, and related performance measurement points and performance test systems are arranged, including: unit finned tube windward surface Wall temperature, oncoming wind speed and air side wind temperature measurement system; unit fin tube leeward wall temperature and air side temperature measurement system; unit leeward fin tube outlet cooling air velocity distribution measurement system; unit internal cooling fan outlet velocity distribution measurement system; condensate flow measurement system; solar radiation measurement system.

2.1. Anti-side Molding Test System of Direct Air Cooling System

Drawing on the design parameters of a 1000MW class direct air cooling system of a power plant, a 1:20 ratio was selected according to similar theory to design and build a side wind modeling test system. It includes: axial flow fan, air duct and internal diversion and damping device to simulate ambient wind, axial flow fan to simulate air cooling unit cooling fan, Venturi tube for flow measurement, and instrument control system.

![Figure 1. Design drawing of anti-crosswind test bench](image)

On the basis of numerical simulation analysis and research, the design parameters of the 1000MW direct air cooling unit were selected for reference, and a direct air cooling system anti-crosswind modeling test system was developed and built to simulate the heat transfer performance of the direct air cooling system to the air cooling unit under actual wind conditions. The impact of the direct air cooling system to prevent cross-wind impact modeling test research work. The experiment obtains the quantified characteristics of the air output of the air cooling unit cooling fan affected by the environmental wind speed, verifies the accuracy and reliability of small experimental results such as numerical simulation, and lays the foundation for the industrial side verification test to be carried out later.

Experiment procedure:
(1) Fan frequency matching optimization test, obtain the best matching value of cooling air volume corresponding to different environmental wind speeds, and determine the maximum value of the cooling fan output air volume affected by the environmental wind;
(2) Structure optimization test of adjustable angle diversion cascade to obtain the best structural design parameters of diversion device;
(3) Modeling test of the influence of environmental crosswind on heat transfer performance, and obtaining the test data of the heat transfer performance improvement of the air cooling unit modeling system after the installation of the flow guide device.

2.2. Simulation Analysis of the Influence of the Wind on the Boiler

The subsequent wind of the boiler is one of the hidden dangers of the safe operation of the direct air cooling system. Especially in summer, the wind of the boiler with a higher wind speed will cause a serious accident of the shutdown of the direct air cooling turbine. In the numerical simulation, a 1000MW direct air-cooling unit of a certain plant was selected as the research object, the physical model
was established according to the design parameters, the effect of the back-furnace air on the heat transfer performance of the direct air-cooled island was analyzed, and the back-furnace air with a high wind speed affected the heat transfer performance of the direct air condenser. And the measures to prevent the effect of the wind behind the furnace on the heat exchange effect of the direct air condenser.

![Figure 2. Simulation analysis and calculation of flow field area and streamline diagram](image)

2.3. *Anti-crosswind Modeling Test*

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2.4. *Analysis of Solar Radiation Heat Effect*

The effects of solar radiation on the air cooling system mainly include direct radiation effects and indirect radiation effects. The former refers to the effect of direct sunlight on the direct air condenser on the performance of the air cooling system. The latter refers to the solar radiation on a certain environmental area around the direct air cooling unit. Due to the different irradiated objects, different factors such as different absorption, storage, scattering, reflection of solar radiant heat, and different atmospheric heat dissipation conditions, etc., cause the air condenser area to accumulate a certain amount of heat in a certain sunshine time, resulting in local ambient temperature rises, causing indirect radiation effects. As the temperature rises, the increase of the direct solar radiation on the back pressure also increases, and the increase in general conditions is 1.5 to 3 kPa. According to the analysis of the measured data, due to the difference in topography and topography in some areas, the short-term local ambient temperature rise caused by the effect of indirect solar radiation has reached more than 3 °C, and the increase in back pressure caused by indirect radiation may reach 4-8 kPa, which is greater than the direct radiation influences.

Direct air-cooled unit solar radiation effect on heat transfer performance test, choose to purchase and install solar radiation instrument, measure the radiant heat value of the sun on the inclined surface of the air-cooled island, and calculate the solar radiation heat effect on a row of air-cooled units after data compilation. The specific value of the back pressure change to the air cooling unit.

The specific steps of the test are as follows:

1. Select an open area under the air-cooled island in the factory area and build an observation platform.

   The base plate of the total radiometer is fixed on the observation platform and adjusted according to
the instructions. After the adjustment is completed, connect the output line of the total radiometer to the recorder, at the same time collect and automatically display and record.

(2) Select a point on the air-cooled island to build an observation platform. The direct radiometer and the total radiometer are fixedly installed on the observation platform, and adjusted according to the instructions. After the adjustment is completed, connect the output lines of the direct radiometer and the total radiometer to the recorder, and at the same time collect and automatically display and record.

(3) The data collection cycle can be set to: 5 minutes, 10 minutes, and 15 minutes.

(4) Simultaneously test the solar radiation on the inclined surface of the air-cooled island and the solar radiation below the air-cooled island.

(5) Calculate the solar heat value on the inclined surface.

3. Calculation Method

3.1. Atmospheric Pressure Correction Calculation Formula
The measurement result of atmospheric pressure needs to be converted into the atmospheric pressure at the installation height of the empty condenser by Boltzmann atmospheric pressure equation. Boltzmann's atmospheric pressure equation is as follows:

\[ P_W = P_M \times \left( \frac{(288 - 0.0065 \times H_w)}{(288 - 0.0065 \times H_M)} \right)^{5.255} \]

Formula: \( P_W \) — atmospheric pressure at the height where the empty condenser is installed; 
\( P_M \) — atmospheric pressure at the actual measuring point; 
\( H_W \) — the distance from the height of the air condenser to the ground, unit: m; 
\( H_M \) — the distance from the ground at the actual measuring point, unit: meter.

\[ Z_2 - Z_1 = 18400 \left(1 + \frac{t_a}{273}\right) \log \frac{P_1}{P_2} \]

Formula: \( P_1 \) and \( P_2 \) are the air pressure values of the heights \( Z_2 \) and \( Z_1 \) respectively, and \( t \) is the Celsius scale.

3.2. Air Density Correction
Direct air condensers are generally installed above 30–47 m, and the air density at the installation height is obtained by the following formula:

\[ \rho_a = 1.205 \times \frac{P_a}{1.01 \times 10^5} \times \frac{293.13}{T_a} \]

Formula: the atmospheric pressure \( P_a \) is calculated according to the formula of pressure and altitude Log Average Temperature Difference Calculation

\[ \Delta t_m = \frac{(t_{a2} - t_{a1})}{\ln(t_{a2} - t_{a1}) / \ln(t_n - t_{a1}} = \frac{\Delta t_a}{\ln[\text{ITD}/(\text{ITD} - \Delta t_a)]} \]

Formula: Q - air condenser heat exchange capacity, W; 
K - Total heat transfer coefficient of air condenser, W/(m²·K); 
S - The total heat transfer area (finned tube heat dissipation area) of the empty condenser, m²; 
\( \Delta t_m \) - logarithmic average temperature difference of air condenser, ℃; 
\( t_n \) - fin wall temperature, ℃; 
\( t_{a1} \) - air inlet temperature, ℃; 
\( t_{a2} \) - Air outlet temperature, ℃;
\[ \Delta t_a - \text{air temperature difference between inlet and outlet of air condenser, } ^\circ\text{C}; \]
\[ \text{ITD} - \text{Initial temperature difference of empty condenser, } ^\circ\text{C}. \]

3.3. Calculation of Heat Absorption of Air outside the Tube

\[ Q_a = G_a c_p (t_{a2} - t_{a1}) = S_{F} n_{F} P_{a} c_p (t_{a2} - t_{a1}) \]

(5)

Formula: \( Q_a \) - heat absorption of air outside the tube, kW; 
\( t_{a1}, t_{a2} \) - air cooling unit inlet and outlet air temperature, \(^\circ\)C; 
\( c_p \) - specific heat of constant pressure of dry air, kJ/(kg·\(^\circ\)C); 
\( G_a \) - air flow rate, kg/s; 
\( S_{F} \) - heat exchanger upwind area, m\(^2\); 
\( V_{NF} \) - frontal wind speed, m/s; 
\( \rho_a \) - air density, kg/m\(^3\).

3.4. Solar Radiation Energy Calculation

\[ Q_T = \alpha \cdot A_T \cdot I_T \times 10^{-6} \cdot 3600 \]

(6)

Formula: \( \alpha \) - the average value of solar absorption rate on the surface of empty condenser, \( \alpha = 0.5 \) 
\( A_T \) - The surface area of the unit air-cooled condenser that can receive scattered radiation and direct radiation is half of the air-cooled island's windward area \( A_F \), \( A_T = A_F/2 \).

3.5. Calculation of Steam Condensation Heat Transfer and Condensation Water Side Heat Transfer

\[ Q_t = D_t (h_s - h_w) \]

(7)

Formula: \( D_t \) - is the steam flow at the inlet of the air-cooled island (deducting the steam flow for small machine)/condensate flow, t/h; 
\( h_s, h_w \) - the enthalpy of exhaust steam and enthalpy of condensed water at the exhaust temperature, kJ/kg.

4. Experimental Results and Analysis

4.1. Boiler Later Wind Simulation Analysis

\[ \text{Figure 3. The temperature field of the air inlet of the air-cooled island directly after the wind speed of different boilers (K)} \]
Figure 4. The boiler's later air speed is 10m/s and 14m/s unit air intake

The results of numerical simulation calculation analysis show that: when the boiler's subsequent wind speed is less than 4m/s, the increase in hot air recirculation rate and the decrease in the air intake of the air-cooled island are two important factors that lead to the deterioration of the heat exchange effect of the air-cooled island; when the boiler's subsequent wind speed is greater than 8m/s when the hot air recirculation rate remains basically the same, the air intake of the air-cooled island decreases and the heat exchange of the air condenser further deteriorates; at a wind speed of 10m/s, the air intake of the air-cooled unit fan generally decreases, especially in the air near the turbine room side Condenser unit, the air intake of the outermost unit is below 100kg/s flow rate, which is far less than 600kg/s in a windless environment; when the wind speed reaches 14m/s, the air intake of all unit fans is further reduced, close to the turbine More units in the house are experiencing serious "backflushing".

4.2. Mathematical Analysis and Modeling Test Research on the Influence of Air Cooling System against Crosswind

4.2.1. Numerical simulation results

Figure 5. Curves of influence of different environmental wind speeds on air intake of air-cooled fan
Table 1. Simulation result of improving air intake of air cooling unit by installing diversion net

| Measures | Unit1(Kg/S) | Unit2(Kg/S) | Unit3(Kg/S) | Unit4(Kg/S) |
|----------|-------------|-------------|-------------|-------------|
| 0        | 9.42        | 363.27      | 546.8       | 553.9       |
| 1        | 402.21      | 231.21      | 324.87      | 365.75      |
| 2        | 348.28      | 371.04      | 408.49      | 463.12      |
| 3        | 333.59      | 374.93      | 414.95      | 467.84      |
| 4        | 313.16      | 383.56      | 427.03      | 477.87      |
| 5        | 437.22      | 451.18      | 495.71      | 536.49      |
| 6        | 427.15      | 457.32      | 510         | 542.75      |
| 7        | 414.9       | 458.02      | 514.87      | 546.8       |
| 8        | 519.83      | 524.75      | 551.02      | 580.21      |
| 9        | 516.56      | 531.22      | 559.14      | 585.82      |
| 10       | 490.97      | 532.44      | 556.49      | 589.22      |

Explanation:
No measures: no diversion measures are taken;
Measure 1: 4 layers of non-porous deflectors are arranged downward from the lower edge of the windshield;
Measure 2: 4 layers of 24 mesh diversion nets are arranged downward from the lower edge of the windshield;
Measure 3: lay 4 layers of 36 mesh diversion nets from the lower edge of the windshield;
Measure 4: lay 4 layers of 48 mesh diversion nets from the lower edge of the windshield;
Measure 5: lay 8 layers of 24 mesh diversion nets from the lower edge of the windshield;
Measure 6: lay 8 layers of 36 mesh diversion nets from the lower edge of the windshield;
Measure 7: 8 layers of 48 mesh diversion nets are arranged downward from the lower edge of the windshield;
Measure 8: From the lower edge of the windshield, 16 layers of 24 mesh diversion nets are arranged down to the ground—24 mesh full size diversion nets.
Measure 9: From the lower edge of the windshield, lay 16 layers of 36 mesh diversion net to the ground—36 mesh full size diversion net.
Measure ten: From the lower edge of the windshield, lay 16 layers of 48 mesh diversion net to the ground—48 mesh full size diversion net.

4.2.2. Analysis of simulation results. Compared with no measures, the air intake of the first unit has been greatly increased after the installation of the deflector at the lower edge of the air-cooled island. The air intake of the first and second units increased significantly, and the increase of the cooling air intake of the unit was 303.74 kg/s~510.41 kg/s.

4.2.3. Modeling test research

![Figure 6. Fan 1-1, 1-2 outflow speed corresponding to different speed change curve](image)
The test results show that: the axial fan frequency of the simulated ambient wind is more than 20Hz, and the cooling fan frequency is adjusted to the range of 6-50Hz. The air output of the fan is significantly affected by the side wind. With the increase of the fan frequency, the cooling fan outlet wind speed and air volume are significantly reduced, and the wind speed the relative reduction rate is 12.35%-29%, and the change trend is consistent with the simulation analysis results. A deflector was installed in front of the simulation test stand. When the angle was adjusted to 45°, the influence of the side wind on the output of the cooling fan was greatly improved. Among them, the frequency of the ambient air fan is 50Hz, and the frequency of the cooling air fan is in the range of 6-12Hz. The air output of the cooling fan is significantly improved, and the increase rate of the air output can reach 29.1%-164.6%.

4.3. Solar Radiation Test Results

4.3.1. Test results. Test start and end time: 2013-12-1, start at 12:45, end at 13:00. Ambient temperature: -1.4°C.

Table 3. Solar radiation test data sheet

| Serial number | Direct radiation (W) | Total radiation (W) | Calculated value of solar radiation energy (MJ) |
|---------------|----------------------|---------------------|-----------------------------------------------|
| 1             | 322                  | 409                 |                                               |
| 2             | 361                  | 375                 |                                               |
| Mean          | 341.5                | 392                 | 95.5                                          |

4.3.2. Test conclusion. The measured total radiant energy of solar radiation to the east of the unit finned tube leeward under winter environmental conditions is 95.5MJ. The calculation results show that the influence of winter solar radiant heat on the heat exchange performance of the unit is manifested by the
increase of the unit back pressure by 0.47kPa.

5. Conclusion
In this paper, the following conclusions can be obtained by simulating and actual testing the subsequent wind, crosswind and solar radiation of the boiler of the unit:

Later simulation analysis of the boiler showed that when the ambient wind speed reached 10m/s, the air intake of the outer units such as the first to third units near the turbine room side of the air-cooled island was reduced by about 67%; when the wind speed reached 14m/s, the air turbine was close to the turbine Units 1-3 of the room appear to have "reverse irrigation" phenomenon, and further cause the unit to shut down;

The anti-crosswind modeling test results show that after installing an adjustable angle cascade vertically down the air-cooled island windshield, the air-cooled fan's air volume increase rate can reach 29.1%-164.6%;

The influence of solar radiant heat on the heat exchange performance of the unit. Under -1.4°C in winter, the solar radiant energy is 95.5MJ, which translates to an influence of +0.47kPa on the back pressure of the unit. When the ambient temperature in summer is 42°C, the influence of solar radiation on the back pressure of the unit is about +2.1kPa. It can be seen from the above that the solar radiation has little effect on the heat exchange performance of the unit, which can be compensated from the design margin of the air cooling system.

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