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**Research Article**

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# The experimental investigation of thermal flow field of direct air-cooled system for a large power plant

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## ABSTRACT

*The thermal buoyancy effect was introduced into model tests on a direct air-cooled condenser (ACC) for a large power plant in wind tunnel simulation. In order to get thermal flow field of air-cooled tower, PIV experiments are performed and recirculation ratio of each condition is calculated. Results show that the thermal flow field of the cooling tower has great influence on the recirculation under the cooling tower. Ameliorating the thermal flow field of the cooling tower can reduce the recirculation under the cooling tower and improve the efficiency of direct air-cooled system also.*

**Key words:** Direct air-cooled system; Thermal flow field; Recirculation ratio; PIV experiment; power plant

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## INTRODUCTION

Recently years many large direct air-cooled condenser (ACC) has been constructed in power plants where cooling water is unavailable or costly in nearby areas. Recirculation was usually formed under the cooling tower in the effect of ambient wind. When recirculation occurred; the efficiency of air-cooled condenser dropped dramatically, which sometimes even made the system break off[1-3]. ZhifuGu[4,5]carried out the wind-tunnel simulation on the direct-air-cooled system for one power plant in China, using the traced gas, which is different from the surrounding air in density, to simulate hot air flow exhausted from ACC. Recirculation was weighed by measuring the concentration of traced gas. Although use of the traced gas could act as hot exhausted air from finned tubes with the thermal buoyancy effect, the heat exchange between the hot finned tube and the cold air cannot be simulated realistically; yet backpressure of the steam turbine is extremely sensitive to ambient temperature. Therefore this model of the traced gas investigation on the ACC may not be sufficiently accurate.C.A. Salta and D.G Kroger[6] carried out an experimental study on a scale model of a forced draft air-cooled heat exchange (ACHE). The results showed significant change in air flow rate caused by varying the platform height. It was found that lowering the platform height resulted in a decrease of air flow rate across the fans, and badly decreases in boundary fans of the platform Furthermore, the influence of the width of a walkway along the boundary of the platform on the air flow rate through an ACHE was also considered. Tests shown that flow rate of the ACHE can be improved by increasing the width of walkway or extending the height of the platform. P.VanStaden[7], Martin P.VanStaden and Pretorius[8] numerically simulated the effect of ambient conditions nearby the Matimba power station. The effect of the recirculation on the fan performance and the steam-turbine backpressure based were predicted, and the effects of the wind speed and the wind direction on the cooling efficiency of the ACC were discussed. They found that the cooling efficiency and the turbine backpressure were very sensitive to the wind speed and wind direction. But the mechanisms that caused hot recirculation and the measures that minimized recirculation were not mentioned. C.Ziller, D.Schwarzkopf, and R.Balzereit[9], studied the influence of wind speed and direction on the efficiency of mechanically driven cooling devices, which include multi-cell the cooling towers and air-cooled condensers, by means of wind tunnel simulation. Their results show that the negative influence affects the cooling devices. Besides, plant structures like gas turbines which can suck hot exhaust air as fresh air can lead to a dramatical decrease of its efficiency. Peiqing Liu,et al[10] carried out the numerical simulation of direct air-cooled system of Datong NO.2 power plant in China, and got the recirculation under the cooling tower.

As we all know the thermal flow field around ACC directly influences the hot air dispersing from ACC to the cold air. It is very important to obtain thermal flow field around ACC, especially in certain direction angles. However, most current investigations have not concerned on thermal flow field. Some researches on recirculation were in cold condition, and engineering measures to reduce recirculation are very few. The present paper introduces the buoyancy effects to experimental investigation on direct air-cooled system for a power plant. PIV experiment is conducted in wind tunnel to get thermal flow field around ACC. At last, some measures are taken to reduce the recirculation ratio.

## EXPERIMENTAL SECTION

### 2.1 Definition of Recirculation Ratio

In the practice, recirculation may be formed under the action of environment wind. In order to explain the recirculation in quantification, Zhao Wanli[1-2]gives evaluation criteria of recirculation ratio:

$$R=\frac{T_{in}-T_a}{T_{ou}-T_a} \tag{1}$$

The average recirculation rate is

$$\overline{R}=\frac{\sum R}{N} \tag{2}$$

Where $T_a$ indicates temperature of ambient air; $T_{in}$ indicates average temperature of air at the inlet of fans; $T_{ou}$ refers to average temperature of finned tubes. So we can calculate the recirculation ratio of each measuring point by equation 1 through measuring the temperature at the inlet of fans and outlet of finned tubes. We can also get average recirculation rate by equation 2 under different conditions.

### 2.2 The Model Apparatus

The experiment is carried out in FL-8 wind tunnel of Chinese Aviation Industry and Aerodynamic Research Institute. The wind tunnel is a circulative tunnel. The section of test segment is flat eight-square and the area of section is 7.685 square meter. The length of experimental section is 5.5 meters, and maximum velocity is 70m/s. Scaling model is similar to Datong No.2 direct air-cooled system[2] the model scaling ratio is 1:120.The boundary layer of atmosphere of B type is simulated in wind tunnel, and section plane exponent of time-average velocity are expressed by $\alpha = 0.16$ . The turbulence rate close to the ground is greater than 5%. The device of measuring temperature is multi-channel temperature patrol system produced by Keithley Corporation of USA. The sensor is thermocouple of T type. There are 92 measuring points altogether placed at inlet of fans and outlet of finned tubes. In model test, the two supplies produced by LongWei electronic Ltd. HongKong provide direct current and steady voltage to 112 model fans, and voltage can change continuously.

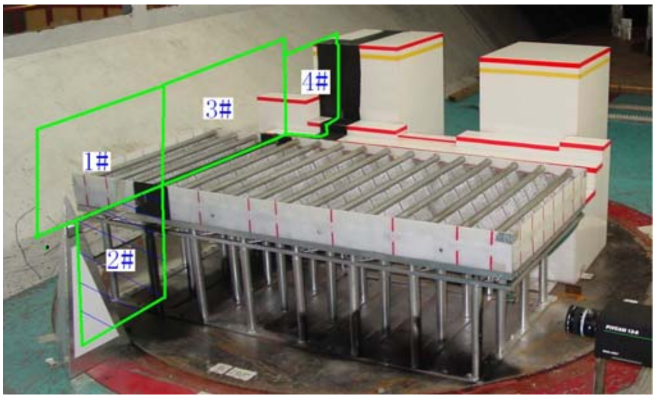


**Figure1. Sketch map of measuring area and camera layout**

### 2.3 PIV and Particle Casting Equipment

In this experiment, double compositive Nd: YAG laser is used as a lamp-house, single fluctuating energy is 200mJ, the lamp-house produces green light, and wave length is 532nm. CCD camera is PIVCAM 13-8, resolving power of gray degree is 4096, resolving power of image is 1280x1024, and image gathering velocity is 8 frames per second. Frame grabber reads number image of CCD camera to memory, and INSIGHT software is used to deal with, and TECPLOT is used to display.

**2.4 Layout of PIV Experiment**
Because of the whole area of measuring spatial is too large (the width of measuring region is about 1500mm), so the whole area is divided into four little areas to measure respectively, and then connect four images to form an integrated image. Figure1 displays the sketch map of measuring area and camera layout.

**2.5 Parameter Choice of Experiment**
The choice of experiment parameter according to idiographic instance experiences a process of gradual optimization. The parameters mainly include: wind velocity, measuring area, size of question area, interval time of fluctuating time $\Delta t$ , arithmetic choice et al.

(1) Velocity: V=6m/s
(2) Size of question area: the pixel is 32×32
(3) Interval time of fluctuating time $\Delta t$ : displacement of particle in $\Delta t$ should less than 1/4 of question area, so interval time of fluctuating time can be calculated by: $\Delta t = (\Delta x \times \frac{1}{4}) / U_{\max}$
In which, $\Delta x$ is size of question area, $U_{\max}$ is maximum velocity in question area. If $\Delta x = 8mm$ , $U_{\max} = 8mm$ then $\Delta t < 200\mu s$ .
(4) Arithmetic choice: INSIGHT software provides two arithmetic, there are, FFT arithmetic and Hart arithmetic, in this study; FFT arithmetic is used.

## RESULTS AND DISCUSSION

In order to change the thermal flow field of the cooling tower, three methods are used in the experiment: adding the height of wind wall, adding the width of the platform, and adding the length of the platform. Meanwhile the recirculation under the cooling tower of three methods is measured.

**3.1 Add the Height of the Wind Wall**
From the results of the measuring recirculation, adding the height of the wind wall can reduce the recirculation under the cooling tower[3]. Figure2 and Figure3 gives the streamline picture of mid-section of unit under different height of wind wall,when wind velocity is 6m/s, and wind direction angle is $\beta = 0^0$ (west wind). So the relationship between the thermal flow field of the cooling tower and recirculation ratio under the cooling tower is investigated.

From the Figure3 we can find in the case that height of wind wall $H_w$=150mm, the large eddy at the lee back of the boiler is uplifted, and has a trend of throwing away to the backward position. But only a little hot air discharged from ACC closed to turbine house was brought into eddy and then pumped by outer fans of platform.The streamline on the top of platform was ascending, and the eddy at backward position was raised. Eddy core flowed away from wind wall, and threw away to the backward position. From velocity profile of mid-section of the unit in wind direction angle $\beta = 0^0$ , compared to designed height of wind wall, when height of wind wall increased, velocity profile above the platform became slim, and magnitude of velocity closed to the platform diminished. That is, the horizontal inertial force was reducing, when buoyancy kept constant, which was helpful for hot air to discharge. The results show good agreement with recirculation results of experiment [3].

When wind velocity ratio increases, the average recirculation under the cooling tower increases as well. That is because air separated at the top of boiler house and boundary of windwall far from the turbine house.At the back of boiler house and backward position of windwall, two eddies came into being. At the boundary of vortex, strong turbulent entrainment, and mixing up, which caused more and more plumes roll into the vortex[11].

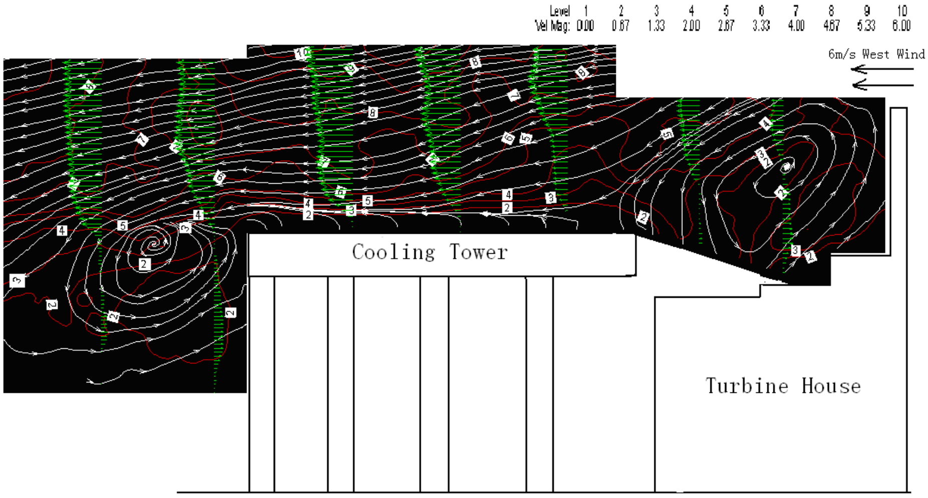


**Figure2 The streamline picture of mid-section for unit under the height of wind wall $H_w$=108.3mm , wind direction angle $\beta = 0^0$**

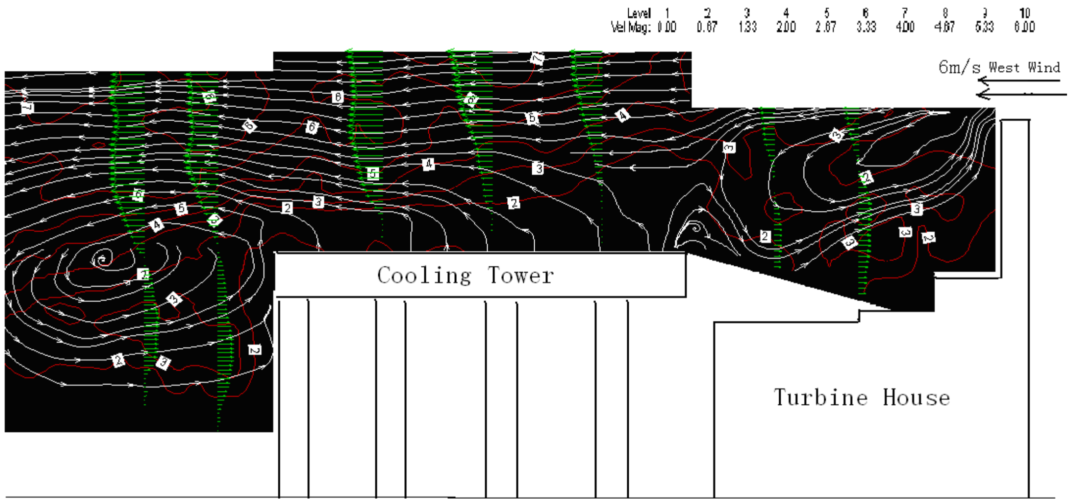


**Figure3. The streamline picture of mid-section for unit under the height of wind wall $H_w$=150mm, wind direction angle $\beta = 0^0$**

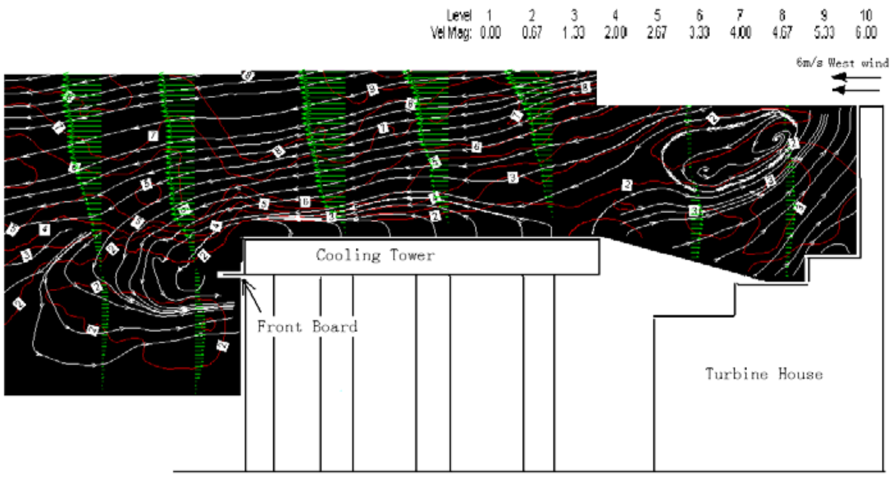


**Figure4. The streamline picture of height of wind wall $H_w$=108.3mm, and width of front board $H_b$=50mm**

### 3.2 Add the Length or Width of the Platform

Figure 4 gives the streamline picture of height of wind wall is 108.3mm, and width of front board $H_b$=50mm. By comparing Figure 2 and figure4, we can see that adding the width of the platform, vortex configuration at the back of boiler increased remarkable, and "adverse flow" close to turbine house was weaken obviously. Because of the supporting of the width board, the eddy configuration downward position of the cooling tower is destroyed, so when incoming flow conditions keep constant, turbulent entrainment and mixing-up intensity of eddy downward position weaken evidently. Then the hot air discharged from ACC returned to the bottom of the cooling tower becomes less. Besides, from the velocity figure we can find that velocity figure above the platform becomes very slim and velocity closed to the bottom of platform becomes less because of front-board supporting function, which could help the hot air to discharge[3]. Therefore, adding the length or width of the platform can both change the thermal flow flied configuration around the cooling tower, and the recirculation under the cooling tower is decreased.

## CONCLUSION

The principal conclusions derived from investigations in present paper can be summarized as follows:

The thermal flow field has great influence on the average recirculation under the cooling tower, recirculation under the cooling tower increases as wind velocity ratio increases.Increasing height of wind wall can ameliorate the thermal flow field of the cooling tower, which can help decrease the average recirculation ratio under the cooling tower.Adding the length or width of the platform can also improve the thermal flow field of the cooling tower; the average recirculation under the cooling tower can be reduced by this way.

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