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Mechanism of the air temperature rise at the forced draught fan inlets in an air-cooled steam condenser

Weifeng He [a,*], Dong Han [a], Chen Yue [a], Wenhao Pu [a], Yiping Dai [b]

[a] Nanjing University of Aeronautics and Astronautics, Jiangsu Province Key Laboratory of Aerospace Power Systems, Nanjing, Jiangsu 210016, China
[b] Institute of Turbomachinery, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

HIGHLIGHTS

- Air temperature distribution at the fan inlets is investigated.
- Mechanisms resulting in air temperature rise are discovered.
- Generalized recirculation rate is defined to scale the extent of the temperature rise.
- Temperature rise at different wind angles are analyzed.

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ABSTRACT

Air temperature rise at the forced draught fan inlets always results in a performance reduction of the air-cooled steam condenser (ACSC), and It is significant to investigate the principles of the temperature rise to improve the condenser performance. In the paper, a 2×600 MW air-cooled power plant is modeled to investigate the mechanism of the adverse air temperature rise at different wind conditions. In addition to the previous proposed recirculation, It is found that the phenomenon of diffusion effect as well as reverse irrigation is also significant to raise the air temperature at the fan inlets. The average temperature rise as well as the generalized recirculation rate at the inlets of the axial fans grows with the increase of the wind angle at the wind speed of $v_m = 2$ m s^{-1}, while the corresponding peak value arises at the wind angle of $\beta = 135°$ for other wind speed conditions.

1. Introduction

Power plants with air-cooled steam condenser have been extensively applied to reject the waste heat from the turbine exhaust in places which are rich of coal but lack of water. Different from the water-cooled units, turbine exhaust condenses in the finned tube exchangers while the cold ambient air flows outside. Due to the difference of the properties between air and water in the condenser, forced draught axial fans must be used to drive enough air to flow through the exchangers, and then the turbine exhaust is cooled. Obviously, the performance of the air-cooled steam condenser is sensitive to the wind conditions due to its exposure in the ambient.

As a result of the sensitivity to the wind conditions, the performance of the direct air-cooled power plants will deviate the design values during the running period at adverse wind conditions, and frequent adjustment should be necessary for a higher efficiency of the system because of the unpredictability of the meteorological conditions. Computational fluid dynamics (CFD) has been applied to investigate the relationship between the wind conditions and the power plant performance. As early as 1995, M.P. Van Staden [1] numerically modeled the effects of ambient conditions on large power station air-cooled steam condensers. Performance difference resulting from types of air-cooled heat exchangers as well as the arrangement of the power plants was evaluated. The research provided a very fine prediction results, which verified the superiority of the numerical approach compared to other methods. J.A. Van Rooyen [2] found that the flow distortions and corresponding low-pressure area under the upstream edge fans cause the performance reduction of the air-cooled steam condenser as the wind speed increases, while a positive influence on the performance of several fans was also found. X.F. Gao [3]

* Corresponding author. Nanjing University of Aeronautics and Astronautics, Jiangsu Province Key Laboratory of Aerospace Power Systems, No. 29 Yudao Street, Qinhuai District, Nanjing 210016, China. Tel./fax: +86 02584892201.
E-mail addresses: heweifeng_turbine@163.com, wfhe@nuaa.edu.cn (W. He).

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Nomenclature

Roman symbols

C_1, C_2, C_μ	constants in turbulence equations
c_p	specific heat (J kg^{-1} K^{-1})
H	height (m)
k	turbulent kinetic energy (m^2 s^{-2})
p	pressure (Pa)
P_r	Prandtl number
R	generalized recirculation rate (%)
S	source term (N m^{-3})
t	time (s)
T	temperature (K)
v	velocity (m s^{-1})
x, y, z	coordinates (m), steam quality

Greek letters

β	thermal expansion coefficient (K^{-1})
ρ	density (kg m^{-3})
μ	dynamic viscosity (kg m^{-1} s^{-1})
ε	turbulent kinetic energy dissipation rate (m^2 s^{-3}), heat transfer effectiveness
σ	Prandtl number for k, ε and T
Φ	general variable
Γ	diffusion coefficient

Subscripts

f	fan
m	measure
out	outlet
s	steam
t	turbulence
w	wind

simulated the effect from the wind speed, direction and height of the air-cooled steam condenser on the relevant condenser performance. It was assumed that the simplified model with a cubic fluid zone was regarded as the condenser cell. Based on the assumption, it was found that the condenser performance decreases with the increase of wind speed and increases as the platform height is elevated. Furthermore, the performance increased rapidly with the increase of the wind angle up to a critical value, and then leveled off. Based on a representative 2 × 600 MW direct dry cooling power plant, the physical and mathematical models of the air-side fluid and heat flow in the air-cooled condensers at various wind conditions were set up, and the radiator type was introduced to model the fin-tube bundles [4]. The volumetric flow rate as well as the inlet air temperature and heat rejection for different air-cooled steam condensers as a whole, condenser cells and fin-tube bundles were obtained by using CFD simulation. M.T.F. Owen [5] also investigated the performance of an air-cooled steam condenser without other buildings at wind conditions. It was found that reduced fan performance due to distorted flow at the inlet of the upstream fans is the primary contributor to the reduction in condenser performance associated with increased wind speed, and the developed model has the potential to allow for the evaluation of large air-cooled steam condenser installations. User defined function based on steam properties was utilized to simulate the condensation of the turbine exhaust in the finned tube heat exchangers [6,7], and the numerical model closed to the true status was established. The reliability of the new method was also approved through the comparison between the predicted back pressures and the values at design cases.

Recirculation is always a problem to reduce the performance of the air-cooled power plants. C. Ziller [8] initially revealed the adverse influence from the wind conditions on the forced draught devices including the air-cooled steam condenser by wind tunnel experiments. It was suggested that the corresponding influence should be considered during the design period. Based on the similarity theory, an equivalent model of the wind tunnel for an air-cooled power plant was built by Z.F., Gu [9]. The phenomenon of recirculation under the effect of wind conditions were studied, and the corresponding criteria and measuring method were proposed. It was found that the influence from the wind conditions and the height of the condenser platform is significant for the recirculation, and the distance between the new air-cooled steam condensers and the original ones have a very small influence on the recirculation rate on the new condensers. P.Q., Liu [10] numerically proved the influence of the wind condition on the hot air recirculation, and appropriate measures were recommended to reduce the recirculation such as enhancing the wind wall height and increasing the fan rotational speed. But the internal flow-fields of the air-cooled steam condensers were not simulated. As a result, the fluid zone inside the A-frame was ignored, and the fans and condenser outlets were just considered to be boundaries with measured parameters. Q.W. Wang [11] also simulated the hot air recirculation phenomenon and proposed some constructive suggestions to avoid the adverse effect.

Air temperature rise through the fans, which was always attributed to the recirculation in the previous investigations, is harmful to the air-cooled steam condenser performance due to the heated air flowing into the forced draught fans, and the decreasing temperature difference between the air and the turbine exhaust weakens the corresponding heat transfer capacity. However, there are several reasons to raise the air temperature at the fans, and it has great significance to investigate such mechanisms to prevent the adverse effect. The numerical model used in the current paper is detailedly illustrated in the reference [6], and the function based on the steam property is also utilized to simulate the condensation

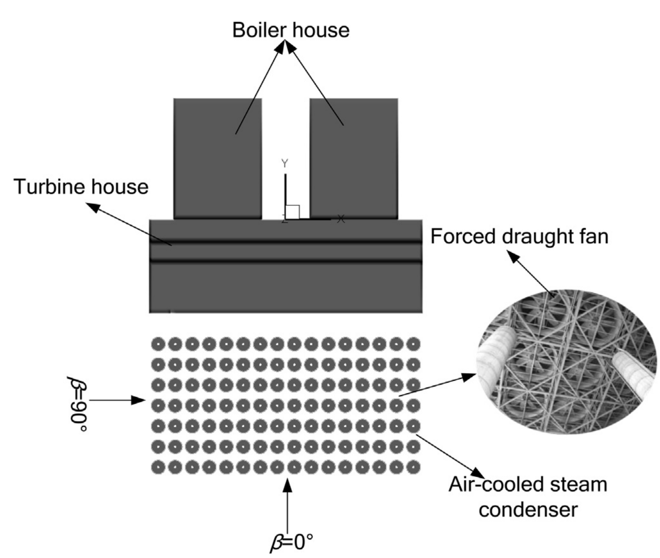

Fig. 1. Schematic diagram of the 2 × 600 MW air-cooled power plant.