Numerical study of the influence of external heat exchanger tube fins on heat transfer in hybrid cooling tower

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Abstract. Hybrid cooling towers with a closed circuit to cool the process water are a progressive type of cooling equipment for industrial water systems. A numerical study is performed to determine the thermal characteristics of the finned outer surface of the tubes of a heat exchanger located inside the developed hybrid cooling tower operating in dry mode. During the simulations, the parameters of the circular fins of the tube are changed: the height of the fin in the range from 2 to 8 mm and the pitch of the fins from 3 to 8 mm. It was found that with an increase in the fin height and fin pitch, i.e., with increasing fin surface transfer area, the average value of heat transfer coefficient decreases, but the overall heat power improves. It was also established that replacing the circular fins of the tubes with spiral fins can increase the heat power by up to 20.2%.

1 Introduction

Cooling tower (CT) is widely used in water recycling systems in many industries due to their ability to provide low temperature heat transfer and high performance. At the same time, research is ongoing and has relevance in solving the problems of process water circulating systems to increase cooling efficiency, resource conservation, intensify heat and mass transfer processes, and improve designs of CT and internal fill units [1]. For example, wet CT has been modified into a hybrid type to reduce the need for make-up water and reduce the droplet entrainment, which is especially important in water-deficient areas. The main feature of the hybrid cooling system is the possibility to use wet and dry parts, in which the water flows in the closed circuit formed by the heat exchanger, both separately and simultaneously. The advantages of operating a dry section in comparison with the classic wet section of CT are the reduced growth of microorganisms in water and corrosion of the design element material due to the lack of contact of hot water with atmospheric oxygen. It is also worth noting that, taking into account seasonal changes in ambient air parameters, to prevent icing of technological elements in winter, the dry section of hybrid CT is used mainly [2].

Therefore, the need to improve the heat transfer performance of the dry section of CT is becoming increasingly urgent. One of the most direct ways to increase thermal performance

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is to increase the interphase area between cooling air and process water. The heat transfer characteristics are also affected by the uniformity of air distribution across the CT cross section and its velocity rate. Typical shapes of the tube heat exchanger in a dry unit of the hybrid CT are round and elliptical tubes, the thermal characteristics of which are compared in works [3]. The relatively low heat transfer coefficients on the air side compared to the coefficients on the process water side can be partially compensated by increasing the heat transfer surface on the air side. Due to the fins, the heat transfer area can be increased 10–20 times compared to smooth tubes [4]. In the works [5,6] the influence of the use of smooth and finned tubes on the cooling capacity of CTs was analyzed. Research results [7] showed that the finning of tubes in the dry part increases the cooling capacity of a CT by 22% and 260% in the wet and dry regimes, respectively. Thus, to intensify the heat transfer process, the heat exchanger tubes are usually finned, allowing the thermal resistance to heat transfer to be equalized [8]. In this regard, the evaluation of the influence of the type of heat exchanger tube surface on the heat transfer rate in hybrid CT is relevant.

2 Operation of the hybrid CT

Consider the operating principle of the dry unit of the developed hybrid CT, in which water circulates through tubes through a closed cooling system. The water heated in the process equipment enters the heat exchanger through an inlet installed in the lower part of the unit (Figure 1). Then it sequentially enters other tubes, moving from the bottom to the top. Cooling of process water occurs because cold atmospheric air flows, which are also supplied to the lower part of the unit perpendicular to the tubes, wash the outer surface of the heated tubes, remove heat, and warm air is discharged into the ambient. It is obvious that with such closed water cooling system, the main resistance is focused on the heat transfer from the air, and the heat transfer coefficients can differ significantly. The advantage of the proposed unit design is the possibility of using CT in both dry (closed) and wet (spray) regimes.

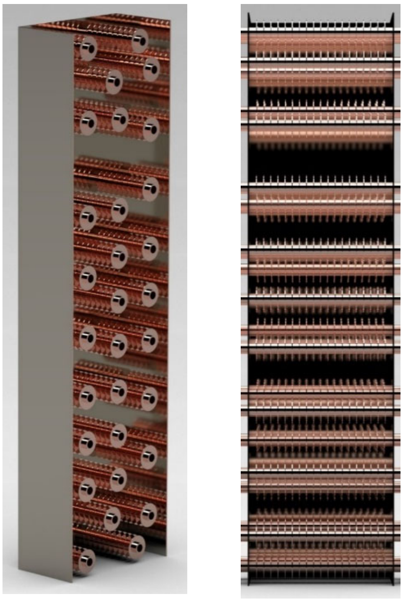
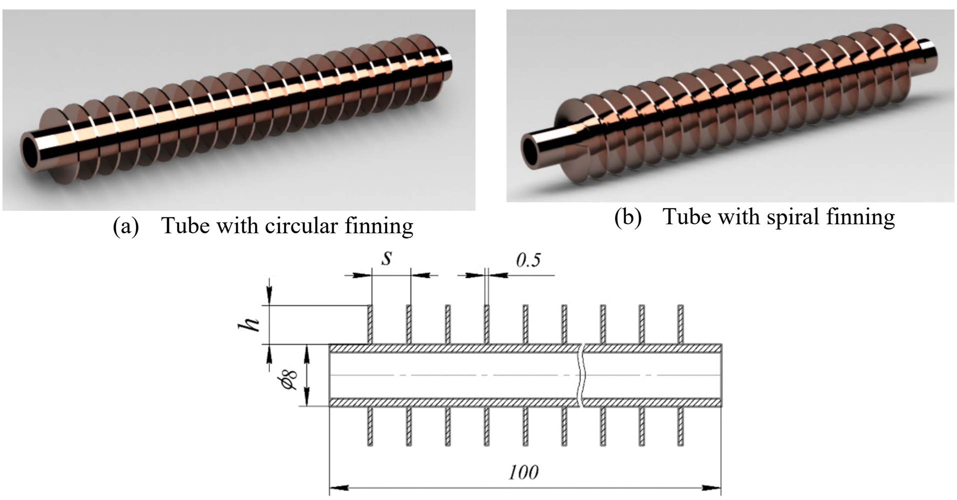


Fig. 1. 3D model of the dry unit of the hybrid CT.

The heat transfer coefficient from the air to the heat exchanger tube wall can be used to evaluate the thermal performance of the hybrid CT [9]. To estimate these heat transfer coefficients with different configurations of the advanced surface, numerical studies of the heat transfer process of the basic design of the hybrid CT with a smooth wall tube were previously carried out. The research aims to determine the convective heat transfer coefficients and the overall heat rate of the heat exchanger tubes of the hybrid CT operating in dry mode with different characteristics of the fins.

3 Methodology

Numerical studies were performed using computational fluid dynamics modeling. A three-dimensional model of the unit with the tube heat exchanger was built, consisting of 30 finned tubes of 100 mm long. The dimensions of the unit are 100 mm (width), 100 mm (length), and 400 mm (height). The inner diameter of the tubes was 6 mm. Finned tubes with circular and spiral configuration under study with basic sizes are shown in Figure 2. During the simulations, the following characteristics were varied: fin height h = 2 to 8 mm, and fin pitch s = 3 to 8 mm. Copper was taken as the material for both tubes and fins. It was assumed that the water temperature at the input of the tubular heat exchanger was 40 °C, and the air temperature at the input of the unit was 20 °C.



(a) Tube with circular finning

(b) Tube with spiral finning

(c) Size of the circular finning tube

Fig. 2. Configuration of the finned tubes under study.

During the study, the average air velocity across the entire cross section of the unit changed from 1.0 to 8.5 m/s, which corresponds to a change in the Reynolds number for air flow from $0.606\cdot10^3$ to $5.287\cdot10^3$. In this case, the Reynolds number Re, related to the outer diameter of the heat exchanger tube, was determined by equation (1), in which the maximum air flow velocity in a narrow section of the tubes $w_{\max}$ can be defined by equation (2).

$$\mathrm{Re} = \frac{w_{\max} d_{out}}{\nu_g} \tag{1}$$

$$w_{\max} = \frac{G_m}{\rho_g f_{\min}} \tag{2}$$

where d_{out} is the outer diameter of the heat exchanger tube, m; v_g is the coefficient of kinematic viscosity of air, m^2/s; G_m is the mass flow of air passing through the unit of the hybrid CT, kg/s; ρ_g is the air density, kg/m^3; f_{min} is the minimum flow area of air in the tubes of the heat exchanger, m^2.

Previously, it was found that a change in the average water velocity in the heat exchanger tube within the range of 1.0–2.5 m/s does not affect the thermal characteristics of the heat transfer process. Therefore, the average values of the heat transfer coefficients from the finned tubes of the heat exchanger of the hybrid CT operating in the dry regime, as well as the value of the overall heat power, were obtained.

4 Results and discussion

The results of numerical studies of the influence of the fin height of the heat exchanger tubes on the thermal characteristics of a hybrid CT show that with increasing fin height, the average value of the heat transfer coefficient decreases (Figure 3a). This is because when the tubes are finned, the heat transfer surface increases. The results obtained agree well with the data presented in the development of a mathematical model of a hybrid CT operating in dry mode, as well as with the results of other studies on the heat transfer of finned tubes [10-12]. The overall heat flow of the finned heat exchanger tubes improves with increasing fin surface area. So, with an increase in fin height from 5 mm to 8 mm, the overall heat power in the hybrid CT increases by 33.1–39.2%, depending on the air Reynolds number (Figure 3b). In all studied cases, it was found that an increase in the Re values for cooling air leads to an increase in both the values of heat transfer coefficient and heat power. It should be noted that the average air velocity in the unit equal to 1 m/s corresponds to the laminar flow pattern ($200 < Re < 10^3$), and in other cases to the transitional flow ($10^3 < Re < 2 \cdot 10^5$).

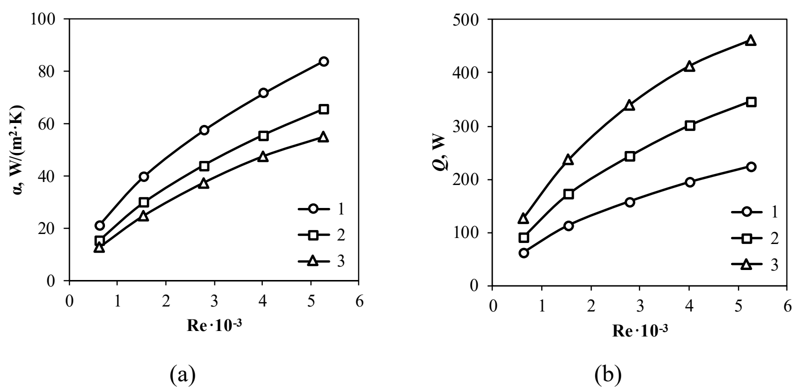
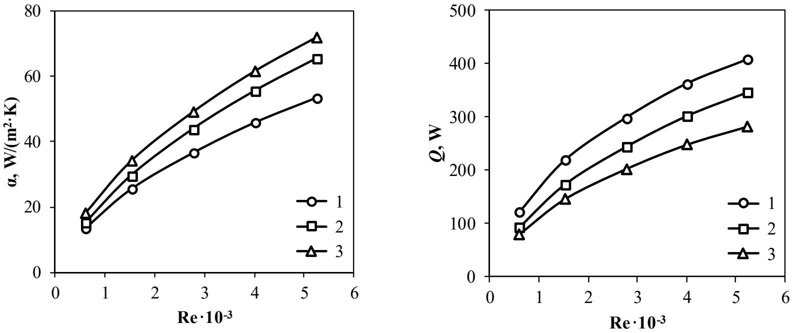


Fig. 3. Dependencies of the heat transfer coefficient α (a) and overall heat power *Q* (b) of the hybrid CT depending on the Reynolds number for the cooling air flow at different heights of the finned tube *h*: (1) 2 mm; (2) 5 mm; (3) 8 mm.

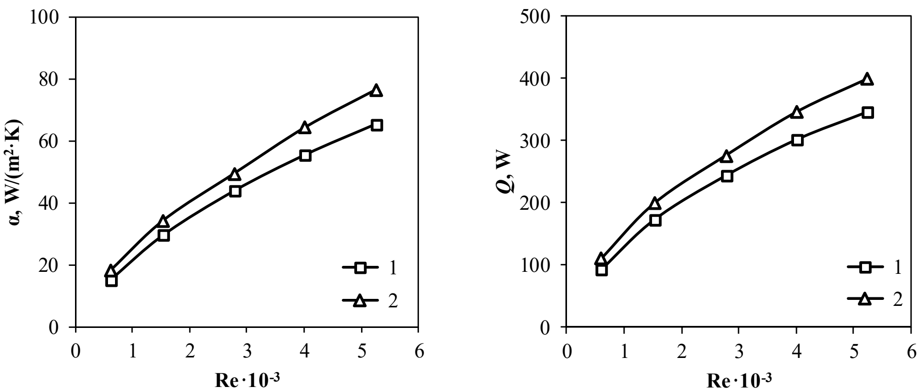
The results of numerical studies of the influence of fin pitch on the thermal characteristics of the hybrid CT show that reducing the fin pitch leads to a decrease in the average heat transfer coefficient. For example, changing the pitch *s* from 5 mm to 3 mm results in reducing α by 9.8–18.4% depending on the Reynolds number (Figure 4a). At the same time, due to an increase in the heat transfer surface, an increase in the *Q* value is observed by 17.7–32.2%, depending on the Reynolds number (Figure 4b).



(a) (b)

Fig. 4. Dependencies of the heat transfer coefficient α (a) and overall heat power *Q* (b) of the hybrid CT depending on the Reynolds number for the cooling air flow at different pitch of the tube fins *s*: (1) 3 mm; (2) 5 mm; (3) 8 mm.

In addition, simulations were carried out using spiral fins of heat exchanger tubes with the following sizes: $h = 5$ mm and $s = 5$ mm (Figure 2c). A comparison of the thermal characteristics of round and spiral fins, other things being equal, shows that the average heat transfer coefficient for spiral finned tubes increases by 12.8–20.1% depending on the Reynolds number for air (Figure 5a). At the same time, it was established that the overall heat power also increases by 13.3–20.2% (Figure 5b).



(a) (b)

Fig. 5. Dependencies of the heat transfer coefficient α (a) and overall heat power *Q* (b) of the hybrid CT depending on the Reynolds number for the cooling air flow for different configurations of the heat exchanger tubes: (1) circular; (2) spiral.

5 Conclusion

Numerical studies of the influence of the geometric dimensions of the fins on the thermal characteristics of a hybrid CT show that with an increase in the fin height and fin pitch, i.e., with increasing finning surface, the average value of heat transfer coefficient decreases. At the same time, the value of the overall heat flow increases, which has a positive effect on the efficiency of heat transfer from the cooling air to process water. Note that, due to the external fins of the heat exchanger tubes of the hybrid CT, the thermal resistance of heat transfer from the limiting stage of the heat transfer process (from air side) is reduced, which is most appropriate.

Analysis of the influence of the finning configuration of heat exchanger tubes shows that with the same geometric size, spiral fins can increase the heat flow by up to 20% compared to circular fins due to the creation of turbulence in the air flow near the surface of the spiral fins. Thus, the results obtained make it possible to determine the average values of the heat transfer coefficients for different geometric sizes of the fins, as well as for their different configurations. In the future, this will make it possible to create a reliable engineering method for calculating the hybrid closed cooling system operating in dry regime in winter.

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