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Experimental study on heat power of wet and pipe sections of wet/dry cooling tower with extended surface pipe exchanger

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Experimental study on heat power of wet and pipe sections of wet/dry cooling tower with extended surface pipe exchanger

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Abstract. A hybrid system for recirculated water cooling of industrial enterprises is proposed. The major feature of the cooling system is a wet/dry cooling tower with an inner pipe exchanger. To enhance the heat transfer process, the outer surface of the heat exchanger pipe has fins. Design and function of the experimental setup are described. The goal of this work is to evaluate experimentally the heat power of the wet and pipe sections of the cooling tower. Results were presented as dependencies of the heat power in the wet/dry cooling tower on the mean gas velocity (from 0.89 to 3.20 m/s) and the ratio of the weight flow rates of the gas/liquid phases at various irrigation rates (13.7–35.6 $m^3/(m^2 \cdot h)$).

1. Introduction

Modern enterprises in many industries use circulating water supply systems, in which the main equipment is the cooling towers (CTs). The problem of efficient cooling of recirculated water in the CTs in today's conditions requires a complex approach that combines technical, economic, and environmental aspects. The fact is that warm water and the presence of air are a favorable environment for the growth of aerobic microorganisms, fouling layers appear on the heat exchange surface, which sharply reduces the cooling efficiency of thermal equipment [1,2]. There are several methods of biofouling control technology: the use of chemicals, bio-filtration and frequent maintenance, which leads to increased economic costs for enterprises [3–5]. Therefore, the best option is to create conditions under which the growth of microorganisms will be particularly heavy.

The task of reducing biofouling in CTs can be solved using the wet/dry (hybrid) cooling system. The pipe exchanger is installed inside the fill zone of the cooling tower to eliminate mixing of the main liquid stream with ambient air. So, the growth of microorganisms in an aqueous environment without O_2 becomes impracticable. Industries using this cooling system can significantly reduce chemicals consumption, or completely abandon them. To enhance the cooling efficiency of dry-type CTs, as a rule, an irrigation of the exchanger with additional flow of liquid is applied. So, the combination of operating principles of dry and wet CTs makes it possible to reduce the vapor plume and save high heat power [6,7]. In addition, to improve the heat power of the wet/dry cooling tower, a finning of the outer surface of the exchanger pipes was implemented, which increases the heat exchange surface [8,9]. Furthermore, finned exchanger pipes allow the heat-transfer resistance to be equalized without significant increases in pressure drop [10,11].

The goal of the paper is an experimental investigation of the heat power of the developed wet/dry cooling tower with a finned pipe heat exchanger.

2. Methodology

The proposed wet/dry cooling system for recirculated water is shown in Figure 1. The working concept of the system is as follows: the water heated in the process equipment is divided into two streams before being supplied to the CT: the first one is cooled (main liquid stream), and the second stream of recirculated water will be conditionally considered as a coolant. The first stream is directed into the pipe exchanger to avoid interaction with ambient air. The second water stream is supplied to the top part of the cooling tower fill zone, contacts with an air and partially evaporates, and it discharged into the collecting reservoir. Cooling process of the main liquid streams occurs as a result of heat removal through the exchanger wall to the atmospheric air, as well as irrigating liquid, consisting of a cooled second water stream and fresh makeup liquid. This liquid is then pumped back to the CT top. Thus, the irrigating liquid stream acts as a coolant, thereby forming a closed coolant circuit.

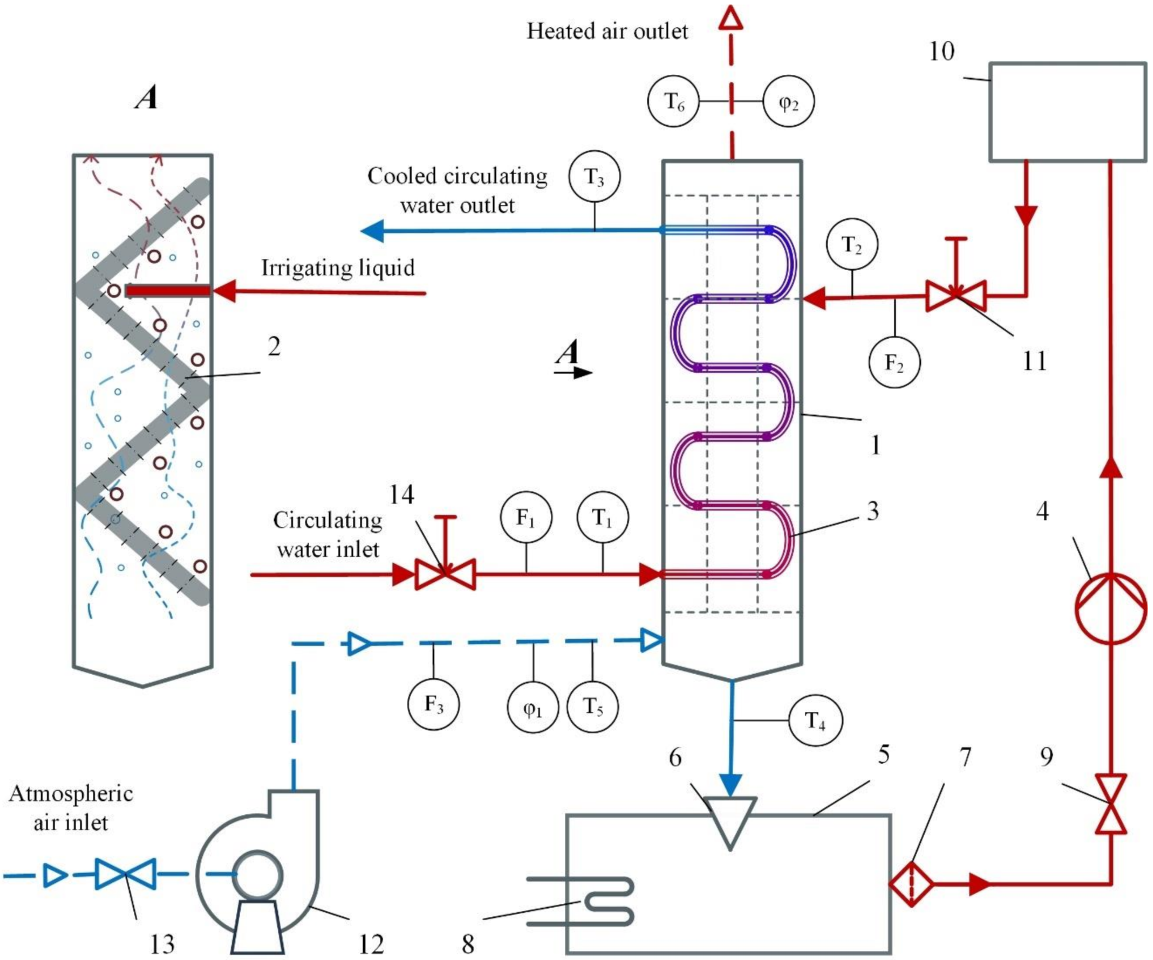


Figure 1. Test setup: (1) wet/dry CT; (2) fill zone; (3) pipe exchanger; (4) pump; (5), (10) reservoirs; (6) funnel; (7) filter; (8) heating element; (9), (11), (13), (14) valves; (12) fan.

The cooling efficiency of the recirculated water in the pipe exchanger largely reliant on the cooling rate of the water in the volume of the fill zone, which is influenced by its type. The fill zone consists of units mounted vertically in rows and consisting of inclined and corrugated contact elements [12]. The liquid enters the irrigation unit through a distributor located on the side surface of the tower wall. The unit is a square column with metal plates placed inside it. The plates are mounted to each other at an angle 90°. The curve surface provides turbulence of the flowing liquid film. The liquid in the volume of the irrigation unit is distributed as follows: water flows down, irrigates the surface of the pipes, removing heat, and flows down in the form of a film over the plates. Part of the water falls through the holes in the plates and is sprayed into drops that, hitting the surface of the liquid film of the lower plate and pipes, break up again to form new drops. The gas is forced by the fan from the bottom up and passes through the plate holes, pushing the water drops into directions, spraying water throughout the irrigation unit and along the outside of the pipes.

The heat transfer of water moving in the pipe exchanger of the wet/dry cooling tower in the general form can be expressed in two steps:

1. Heat and mass transfer between direct interaction of the air and water, that can be described by the classic heat balance of evaporative CTs.
2. Heat transfer through the exchanger wall from precooled water and air that flows around the heat exchange pipes.

Let's consider the conjugated variant of the wet (irrigation) and pipe sections of the wet/dry cooling tower. The amount of heat removed to the recirculated water through the exchanger pipe walls can be determined by the following equation:

$$Q_1 = L_{m1} c_L \left(t_{L1} - t_{L2} \right), \tag{1}$$

where L_{m1} is the weight flow rate of the recirculated water in the pipe exchanger, kg/s; c_L is the specific weight heat capacity of the water, J/(kg·K); t_{L1} is the water temperature at the inlet of the pipe exchanger, K; t_{L2} is the water temperature at the outlet of the exchanger, K.

The heat removed by irrigating (cooling) liquid in direct interaction of the air and liquid with sufficient accuracy (excluding convection, condensation, and thermal conductivity) can be found by the equation:

$$Q_2 = L_{m2} c_L \left(t_{L3} - t_{L4} \right), \tag{2}$$

where L_{m2} is the weight flow rate of the irrigation (cooling) liquid, kg/s; t_{L3} is irrigating liquid temperature at the inlet to the irrigation unit, K; t_{L4} is irrigating liquid temperature at the exit of the irrigation unit, K.

The total amount of heat removed by air in the wet/dry CT (excluding heat loss) is defined as the sum of heat flows in the irrigation and pipe parts of the cooling tower, i.e. $Q = Q_1 + Q_2$.

The finning of the exchanger pipes is made by fixing to each pipe 19 metal rings with a thickness δ_{fin} = 0.5 mm at an increment of s_{fin} = 5 mm. The external diameter of the pipe with circular finning is D_{fin} = 15 mm (Fig. 2).

(a) real image (b) 3D model

Figure 2. A finned pipe exchanger.

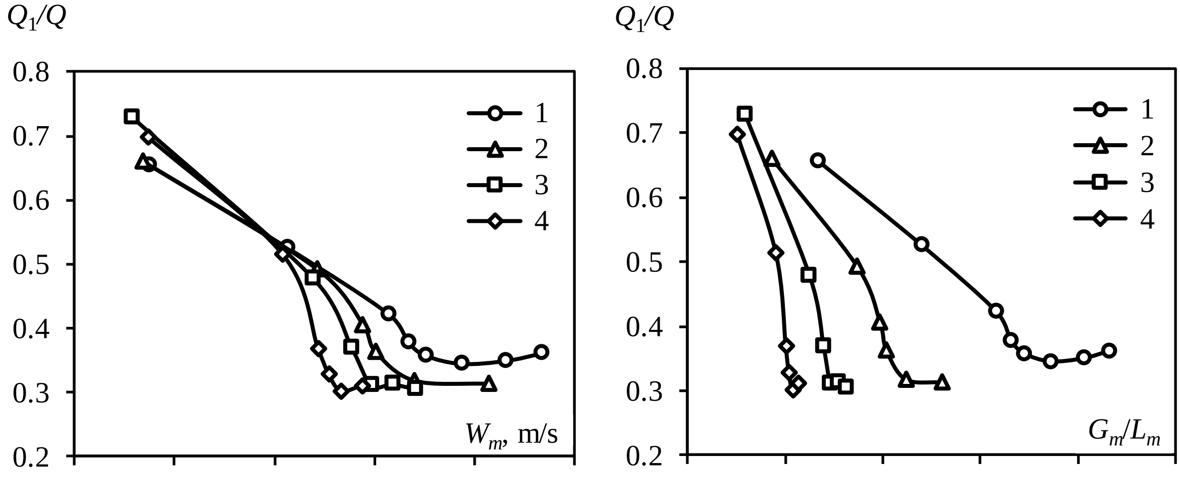
Table 1. Parameters.

Parameter	Instrument	Operating interval
Mean air velocity in the supply pipe	Hot-wire anemometer TESTO 405i	0.89–3.20 m/s
Air temperature	Thermohygrometer TESTO 605i	24.7–25.7°C
Air humidity		35.0–41.9%
Water temperature supplied for irrigation	Meter-regulator OWEN 2TRM1	33.3–34.9°C
Irrigation rate	Rotameter LZB-VA10-15F	13.7–35.6 $m^3/(m^2{\cdot}h)$
Flow rate of the water inside finned pipe exchanger	Flow meter Betar SGV-15	0.0135–0.0236 kg/s

3. Results and discussion

Test studies show that the heat power transferred to the recirculated water through the wall of the finned exchanger from the irrigating liquid is affected by the mean air velocity and irrigation rate. Therefore, at a mean air velocity of 1.45 m/s, the Q_1/Q ratio = 0.55, regardless of the irrigation rate of the cooling liquid (Fig. 3a). The decrease in the heat removed by the wall of the finned pipe exchanger with an increase in the mean air velocity is caused that the amount of heat transferred by the irrigating water during the direct contact of the air and water in the wet section of the wet/dry CT increases considerably. The total heat power also increases (Fig. 4).

Note that as the irrigation rate increases, the operating range of the flow rates of the air/water decreases. Therefore, with the irrigation rate q equal to 13.7 $m^3/(m^2{\cdot}h)$, the ratio G_m/L_m changes from 0.27 to 0.87, and with $q = 35.6$ $m^3/(m^2{\cdot}h)$ – G_m/L_m varies only in the range of 0.1–0.23 (Fig. 3b).



(a) (b)

Figure 3. The heat ratio depending on the mean air velocity (a) and the ratio of the air/water weight flow rates (b) at different irrigation rates q, $m^3/(m^2{\cdot}h)$: (1) 13.7; (2) 20.5; (3) 28.3; (4) 35.6. The mean flow rate of the recirculated water in the pipe exchanger $13.5{\cdot}10^{-3}$ kg/s.

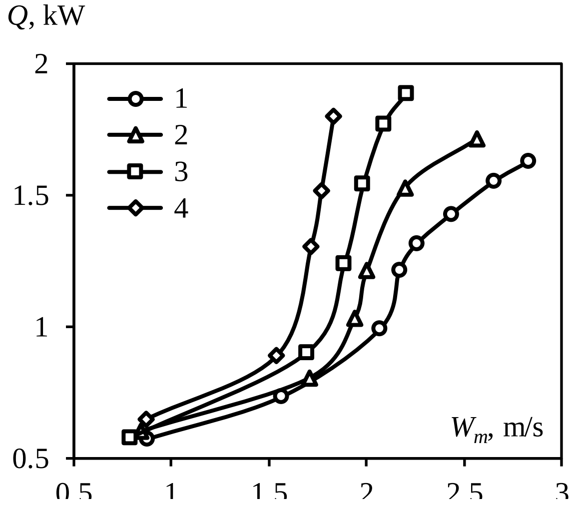
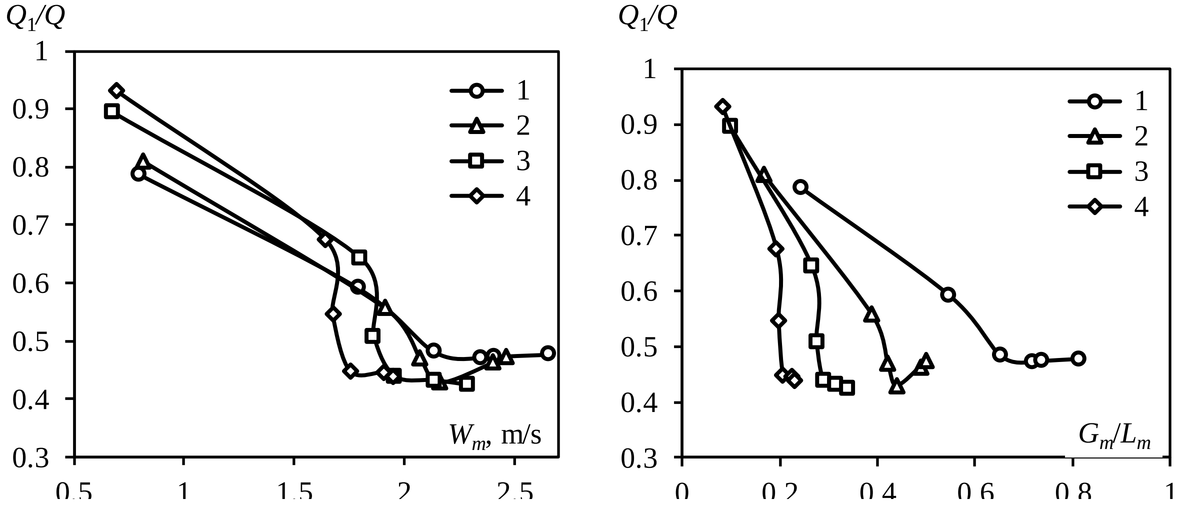


Figure 4. Change in the total heat power in the wet/dry cooling tower against the mean air velocity at various irrigation rates *q*, $m^3/(m^2 \cdot h)$: (1) 13.7; (2) 20.5; (3) 28.3; (4) 35.6. The mean flow rate of recirculated water in the pipe exchanger $13.5 \cdot 10^{-3}$ kg/s.

If the mean weight flow rate of recirculated water in the pipe exchanger is $23.6 \cdot 10^{-3}$ kg/s, then the dependence of the heat power removed through the exchanger wall on the total heat power in the wet/dry cooling tower remains the same (Fig. 5a, b). At the mean gas velocity of 1.5 m/s, a change in the mode of interaction between liquid and gas in the wet part of the wet/dry CT is observed (transition from film mode to suspending mode). An increase in the weight flow rate of water in the pipe exchanger leads to a growth in the heat removed by the wall of the exchanger (in the flow rate range studied by 16.0–36.3%).



(a) (b)

Figure 5. The heat ratio versus the mean air velocity (a) and the ratio of the air/water weight flow rates (b) at different irrigation rates *q*, $m^3/(m^2 \cdot h)$: (1) 13.7; (2) 20.5; (3) 28.3; (4) 35.6. The mean flow rate of the recirculated water in the pipe exchanger $23.6 \cdot 10^{-3}$ kg/s.

The total heat power of the wet/dry cooling tower with transverse finning of the exchanger pipes reaches almost 2 kW with the mean flow rate of the recirculated water in the pipe exchanger equal to $23.6 \cdot 10^{-3}$ kg/s (Fig. 6).

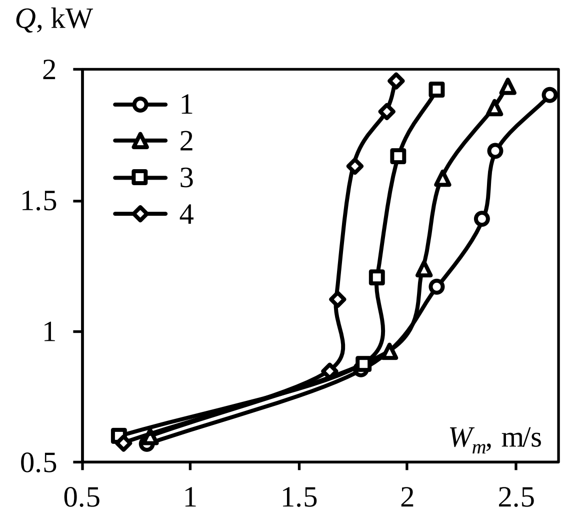


Figure 6. Change in the total heat power in the wet/dry CT against the mean air velocity at various irrigation rates q, m^3/(m^2·h): (1) 13.7; (2) 20.5; (3) 28.3; (4) 35.6. The mean flow rate of recirculated water in the pipe exchanger 23.6·10^{-3} kg/s.

The results show that the share of heat power removed by the wall of the finned pipe exchanger to the total heat power in the wet/dry cooling tower can reach 0.93 (at low mean air velocities and weight flow rate of the recirculated water in the pipe exchanger equal to 23.6·10^{-3} kg/s). An increase in the mean air velocity leads to a growth in the heat power transferred to the irrigating liquid by direct air/water interaction in the wet section of the wet/dry CT, with the Q_l /Q ratio decreasing. High values of heat power occur due to the efficient operation of the wet part of the wet/dry cooling tower, where there is a uniform distribution of the liquid phase in the fill unit during film mode operation. The suspending mode is observed, as a rule, at mean air velocities of 1.5–1.95 m/s (according to the irrigation rate of the cooling liquid). It is worth noting that the mean gas velocity without significant liquid entrainment from the wet part of the wet/dry cooling tower reaches 2.2 m/s at irrigation rate up to 30 m^3/(m^2·h).

4. Conclusions

Thus, the use of a wet/dry cooling system for cooling recirculated water with a finned pipe exchanger provides an enhanced heat rate without significantly increasing pressure drop.

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