# Efficiency of cooling the water droplets within Jet-Film unit of cooling tower filler

*Ilnur* N. Madyshev[1,*], *Oksana* S. Dmitrieva[2], and *Andrey* V. Dmitriev[2]

[1]Kazan National Research Technological University, 420015, Kazan, Karl Marx str., 68, Russia
[2]Kazan State Power Engineering University, 420066, Kazan, Krasnoselskaya str., 51, Russia

**Abstract.** Researches of blocks of sprinklers of cooling towers with jet-film devices are presented. The conducted numerical studies allow us to estimate the influence of the design and operating parameters of the proposed contact device on the efficiency of the process of cooling the recycled water. The increase in the average gas velocity leads to a more intense flow of water drops and more efficient cooling. To achieve high performance, it is necessary to create zones of drip interaction of phases with droplet sizes up to 100 μm at relatively low speeds of two-phase gas-liquid flow. Under such conditions, the drop can be cooled by more than 10°C within one contact stage. The proposed sprinkler units with jet-film contact devices will be able to achieve a lower level of cooling water temperatures in the cooling towers of industrial enterprises at relatively low operating costs.

## 1 Introduction

The needs of national economy of various industries for water resources do not make it possible to use fresh feed water makeup, thus, there are autonomous, closed systems of return water supply [1, 2] at industrial enterprises for the purpose of rational use of natural resources. The main elements of such systems are the cooling towers, where the unit of cooling tower filler, in the form of a nozzle layer serves for effective cooling the water by atmospheric air under conditions of counter flow contact of phases.

An important service factor for the cooling tower is a high intensity of heat-mass transfer processes at the highest capacity for the cooling water and minimum energy costs per the working volume unit of the cooling tower filler unit. Moreover, nozzles shall have a high separation capacity due to the possible droplet moisture entrainment. Droplet entrainment within 5-7% can lead to a significant environmental deterioration around industrial enterprises, especially chemical ones [3].

Currently, there is a large variety of nozzle designs for industrial cooling towers [4-7]. However, interest of researchers in development of new high-performance designs for contact devices, providing a high degree of heat-mass transfer with low pressure losses and high ratio of cooling water rate to air flow rate, is not diminished up to the present day. When designing the apparatuses of large diameters, a "large-scale effect" is often observed,

* Corresponding author: ilnyr_91@mail.ru

which involves reducing the efficiency of heat-mass transfer processes due to the growth of transverse irregularity in the distribution of gas and liquid flows along the section of apparatus.

## 2 Description of the device and its operation

In order to eliminate this disadvantage and to create apparatuses with possible self-distribution of liquid along the cross-section of them, the authors developed the units of cooling tower filler with jet-film devices. The proposed contact devices [8] consist of parallel square drain cups *1* with vertical walls, required for maintaining the liquid level inside of them. Vertical perforated baffles *2* are the supports for drain cups *1* and have slotted holes for the installation of appropriate drain cups *1*. The drain cups *1* are open from the top end, but recurved leaves *3* in the form of circular segments are executed in the bottom of cups. These segments are required for the liquid distribution over the surface of vertical perforated baffles *2* (Fig. 1).

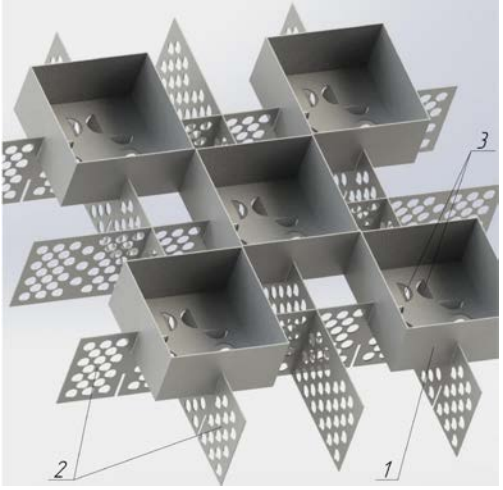


**Fig. 1.** One stage of the jet-film contact device: *1* – drain cup; *2* – perforated flow baffle plates; *3* – recurved leaves.

The jet-film contact device, developed by the authors of this article, operates as follows. The liquid, through the plurality of recurved leaves *3*, executed in the bottom of drain cups *1*, is dispersed in the form of jets to the below located vertical perforated baffles *2*. Thus, the liquid level in these drain cups *1*, is maintained by means of vertical walls of drain cups. The drain cups *1* are arranged horizontally chequer wise, forming a tray. The below tray has an offset of drain cups, forming vertical chequerwise arrangement of them. For this reason, gas, coming to underneath the tray, acquires a zig-zag nature of movement.

When liquid jets move along the surface of vertical baffles *2*, the liquid is distributed with formation of a stable film flow. Thus, the coming down liquid film interacts with an ascending gas flow. After that the formed film, colliding with liquid surface inside of drain cups *1*, collapses. Thus, there is a developed, continuously renewing surface of contact of phases, which is determined by the presence of relatively small gas bubbles in the liquid layer and droplets, departing from the surface. The presence of holes in vertical baffles *2* leads to alignment of the profile of concentrations in the cross-section of apparatus as well as to reduction of metal consumption for the proposed design. When distances between the drain cups, arranged at the same level, are equal to width of a drain cup, it provides stable, uniform gas flow, which leads to decrease in hydraulic resistance of the proposed jet-film contact device. Thus, organization of original interaction between gas and liquid allows stimulating the heat-mass transfer processes both in liquid and in gas phases at relatively simple design of apparatus.

There are several areas of interaction between gas-liquid flows within the proposed contact devices: film liquid flow along the vertical corrugated and perforated baffle; efflux of jets through the holes in the walls and bottom of drain cup; collapse of jets with formation of relatively large droplets and their subsequent fragmentation under the influence of carrying gas flow, as well as deposition of these droplets on a flowing liquid film, resulting in a significant intensification of heat-mass transfer processes within the liquid phase.

## 3 Description of the study and its results

The aim of the numerical studies is to determine the efficiency of cooling the water droplets, flowing through the hole in the bottom of the proposed jet-film contact device. The studies were carried out by means of the software complex ANSYS Fluent, in which the interaction of liquid droplets and gas was simulated as exemplified by air-water system on contact elements with width of the drain cup equal to 100 mm and height of the walls equal to 50 mm. The liquid level in the drain cup was taken as maximum. The diameter of holes, serving for the water droplets formation was taken equal to 4 mm. The initial relative air humidity was 80% at the temperature of 15°C. Water temperature at the inlet of contact stage was taken equal to 50°C.

In the course of numerical studies, the diameters of spherical water droplets were changed from 0.1 up to 2 mm, as well as the average gas consumption rate was changed from 1 up to 3 m/sec. Modification of the two-parameter turbulence model k-ω SST-model, showing satisfactory agreement with experimental data, obtained during earlier studies [9, 10], is chosen as the main model. Boundary conditions: it was assumed that all surfaces of contact elements meet the condition of adhesion.

The results of studies have shown that the contact period of water droplets with the air flow within the proposed devices significantly depends upon the size of droplets formed and the average gas consumption rate. The Fig. 2 shows that droplets with small diameter have the shortest contact period of phases. This is due to the fact that droplets, having a small mass, reach the surfaces of contact elements faster than droplets of relatively large size.

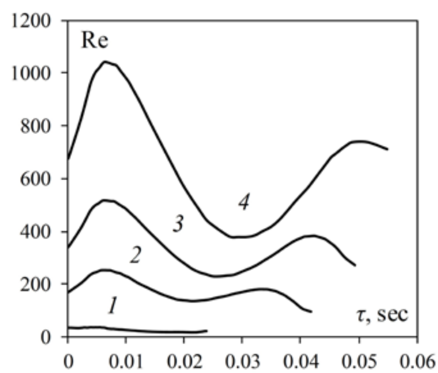


**Fig. 2.** Changing the Reynolds number depending on the time of contact of water droplets with the cooling air flow at different diameters of the droplet *a*, mm: *1* – 0.1; *2* – 0.5; *3* – 1; *4* – 2; average gas velocity $W_{av}$ = 2 m/sec.

However, despite this, the cooling efficiency of such droplets is the highest, while the temperature difference can reach 11.2°C (Fig. 3). It's worth noting that droplets with a diameter of more than 1 mm make a minimum contribution to the overall efficiency of heat-mass transfer processes.

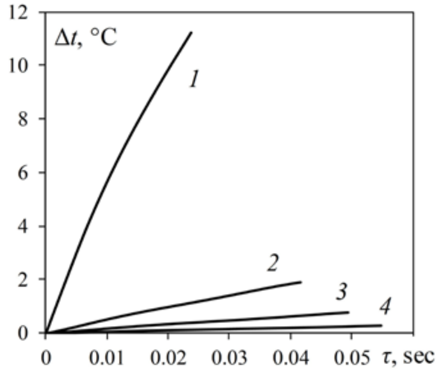


**Fig. 3.** Changing the temperature difference of the droplet depending on the time of its contact with the cooling air flow at different diameters of the droplet *a*, mm: *1* – 0.1; *2* – 0.5; *3* – 1; *4* – 2; average gas velocity $W_{av}$ = 2 m/sec.

An increase in the average air consumption rate leads to an increase in the Reynolds number values (Fig. 4). At the same time, there is a slight decrease in the contact period of phases, for example, with an increase in the average gas consumption rate from 2 to 3 m/sec, the contact period decreases by 13.8%. Local maximum and minimum values of Reynolds number are explained by the formation of vortex structures of gas flow within separate areas of the contact stage.

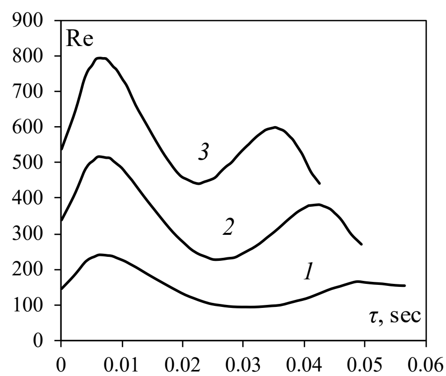


**Fig. 4.** Changing the Reynolds number depending on the time of contact of water droplets with the cooling air flow at its different average speeds $W_{av}$, m/sec: *1* – 1; *2* – 2; *3* – 3; diameter of the drops *a* = 1 mm.

An increase in the average gas consumption rate leads to a more intense flow over the water droplets, and, therefore, to the most efficient cooling (Fig. 5). Thus, when the average air consumption rate is increased from 1 to 3 m/sec, the temperature difference of the cooled droplet may increase up to 39%.

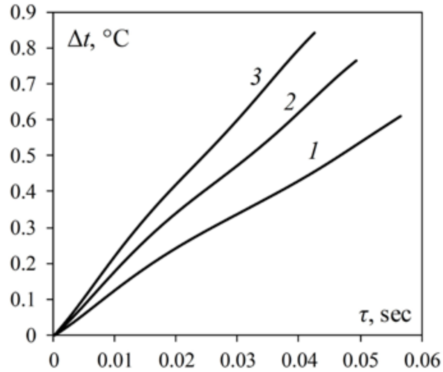


**Fig. 5.** Changing the drop temperature difference depending on the time of its contact with the cooling air flow at its different average speeds $W_{av}$, m/sec: *1* – 1; *2* – 2; *3* – 3; diameter of the drops $a$ = 1 mm.

## 4 Conclusion

The carried out numerical studies allow us to estimate the influence of design and operating parameters of the proposed contact device on efficiency of the process of cooling the return water. Thus, in order to achieve high operational factors, it is necessary to create areas of drip interaction of phases with droplet sizes of up to 100 μm at relatively low velocity of two-phase gas-liquid flow. Under such conditions, the droplet can be cooled by more than 10°C within one contact stage.

Thus, the proposed units of cooling tower filler with jet-film contact devices will be able to achieve a lower level of cooling water temperatures in the cooling towers of industrial enterprises at relatively low operating costs.

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