Study of hydrodynamics in counterflow cooling tower with corrugated contact elements

A.V. Dmitriev[1], I.N. Madyshev[2], A.I. Khafizova[2], A.N. Nikolaev[2]

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

Abstract. Packing for liquid cooling with counter flow of liquid and gas phases had developed by authors of paper. This packing is different from other devices in that it has quite simple design where self distribution of liquid in apparatus working area is organized. In paper an estimating calculations of packing operating mode with maximum efficiency of performed heat and mass transfer processes had conducted. The performed numerical study is showing that at mean gas velocity up to 4 m/s, contact device width equal to 0.1 m and liquid column height on contact stage – 0.02 m the share of liquid that forced through by gas flow is not more then 2 %. Decreasing of holes diameter on inclined contact elements results in increasing of bubbled liquid share.

1. Introduction

Cooling of circulating water during contact with atmosphere on different plants is organized in evaporative mechanical-draft cooling towers in most cases. Such towers are characterized by high liquid cooling efficiency, small dimensions and simplicity in operation [1–3]. At the present time there is huge number of cooling tower sprayer designs, each of which has own advantages and deficiencies [4–12]. However, there is number of problems, whose solving allows significant enhancing of circulating water cooling efficiency. Efficiency largely depends on liquid and gas distribution evenness in the working volume of apparatus where phase interaction occurs [13–15].

Contact devices divided on two main types (plate and packed) are used widely in many industrial plants. In plate contact devices liquid is distributed more evenly, but in packed devices following advantages are highlighted: low hydraulic resistance and high productivity.

The main technological specifications required to contact devices are uniform liquid distribution in working area of apparatus, high heat and mass transfer processes efficiency and low hydraulic resistance also. The most notable are those of Rachig rings, Pall rings, regular packing “Ingechem” and other. Wide study and development of new contact devices are taken place abroad: HY-PAK, CASCADE-RINGS, SULZER, NORTON, GLITSCH and other [16]. Surely, all specified types of packing have advantages, which allow using them in industrial units, but most of them have one following deficiency.

For uniform liquid distribution along packing elements surface distributing and redistributing devices with large number of watering points are set up in apparatus and as a result apparatus dimensions are increasing. So, it is necessary to design such contact devices which possess advantages of packed apparatuses together with ability of liquid self distribution by cross section with minimum number of watering point [17].

2. Description of the device and its operation

Packing for liquid cooling with counter flow of liquid and gas phases had developed by authors of present paper. This packing is different from other devices in that it has quite simple design where self distribution of liquid in apparatus working area is organized. Also, the main difference from analogs is that liquid enters to the device through one liquid inlet point.

During investigation of contact device design the experimental unit for physical experiments in water-air system was developed. Functional scheme of experimental unit is shown at figure 1.

Experimental unit includes packed contact device, which consists of two contact stages with total height 340 mm tightly embedded into glass housing for observation of liquid distributing processes along the cross section at various mass flow rate values. Contact device looks like two inclined corrugated elements positioned at angle 45º to surface of casing wall. Plates are belt-line contact elements with horizontal corrugations of 7.5 mm radius circular profile. Round holes of 5 mm diameter are drilled on side surfaces and upper part of corrugations. Dimensions of studied contact device in casing cross section are 100x100 mm.

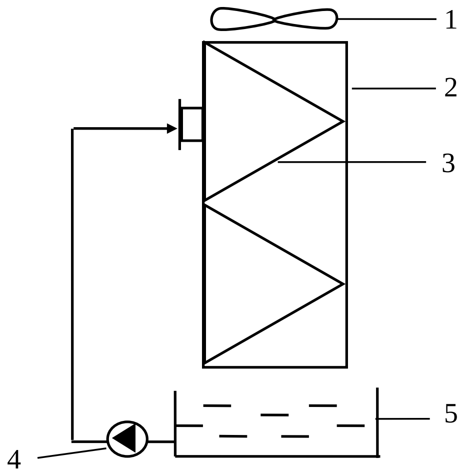

Figure 1. Functional scheme of experimental unit: 1 – fan; 2 – casing; 3 – inclined corrugated contact elements; 4 – pump; 5 – tank.

Water was carried by the feed tube to the central part of contact device upper stage and moved along inclined plate surface in corrugations bottoms as film from upper contact stage to lower. Some part of liquid passed through the holes in corrugation, and appeared herewith droplets fall to surface of liquid, which flowed over the lower plate, created continuously refreshed surface of phase contact.

Packing was blowing off by air flow with countercurrent scheme principle. Herewith, fictitious air flow velocity (on full device cross section) varies in range of 1–4 m/s. In the case if hydrostatic pressure of liquid column is balanced out by pressure produced by air flow water accumulation between inclined plate and casing wall is taken place. Part of liquid or full volume of accumulated liquid was bubbled by gas when air velocity increased. Then gas involved liquid in joint motion and throw it to the side wall and it also facilitated to water cooling efficiency growth.

3. Description of the study and its results

In present paper an estimating calculations of packing operating mode with maximum efficiency of performed heat and mass transfer processes had conducted by considering of corrugated plate as flat (figure 2).

A perforated plate of square cross-section positioned at angle 45° relatively casing wall is presented on figure 2. It is possible dead spaces formation between plate and wall where liquid don’t falling through holes in plate during the device operation, and thereby gas pressure value not enough for passing through liquid layer. Such situation will lead to decrease of packing active volume share where intensive heat and mass transfer is expected.

Thereby, the purposes of numerical researches are determination of dead space formation conditions in inclined corrugated contact elements and selection of most expedient design and technological packing operation modes for dead space share reducing [18].

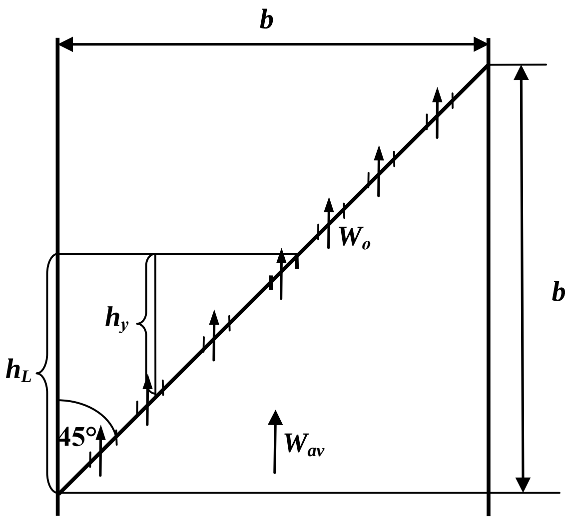

Figure 2. Schematic image of contact stage part: b – contact device width, m; h_L – liquid, filling contact stage, column height, m; h_y – liquid column height in selected point, m; W_{av} – mean gas velocity, m/s; W_o – mean velocity in narrowing, m/s.

Gas pressure drop during passing through single hole can be obtained from equation [19]:

$$\Delta p = \zeta \frac{\rho_G W_o^2}{2} \quad (1)$$

where $\zeta = 0.5$ – local resistance coefficient during passing through the hole; ρ_G – gas density, kg/m^3; W_o – mean velocity in narrowing, m/s.

Mean velocity of gas passing through hole can be obtained from continuity equation:

$$W_o = \frac{G_m}{S_o \rho_G n_o} \quad (2)$$

where G_m – gas mass flow rate, kg/s; $S_o = \pi d_o^2 / 4$ – cross section area of hole on a plate, m^2; n_o – number of holes.

Hydrostatic pressure of the liquid column can be obtained by formula:

$$p = \rho_L g h_y \quad (3)$$

where ρ_L – liquid density, kg/m^3; g – standard acceleration of gravity, m/s^2; h_y – liquid column height in selected point, m.

Gas will bubble through liquid layer only in that case when pressure created by liquid layer height will be less then air rising flow pressure. For this purpose we can equate formulas (1) and (3) and obtain mathematical expression for calculation of minimum liquid column height sufficient for forcing through by gas flow:

$$h_y = \zeta \frac{\rho_G}{\rho_L} \frac{W_0^2}{2g} \quad (4)$$

Liquid volume filling the contact device up to height h_L can be obtained by equation:

$$V_L = \frac{h_L^2 b}{2} \quad (5)$$

where h_L – liquid, filling contact stage, column height, m; b – contact device width, m.

Herewith, liquid volume with column height h_y forcing through by gas flow can be obtained as:

$$V_y = \frac{h_y^2 b}{2} \quad (6)$$

Therefore, let bring in the dimensionless value $\omega = V_y/V_L$ indicated share of contact device active volume where bubbling phenomenon is observed.

Calculations of liquid part forced through contact stage of proposed device are performed on air – water system at temperature 20°C. Mean gas flow velocity varied in range 1–4 m/s. Over the course of research contact device dimensions are changed, in particular width and height – from 0.1 to 0.4 m, column height of liquid kept by gas flow – from 0.02 to 0.08 m. Furthermore, the influence of holes diameter, which varies from 3 to 7 mm, on bubbled liquid share is examined. Total number of holes on single plate was in these cases from 364 to 5989 (at large values of contact device width). The research results showed that share of liquid forced through by gas flow depends on design and operation parameters of contact device work.

Dependence of bubbled liquid share on mean gas velocity is presented on figure 3 at various contact device width values. It is seen, that contact device width reducing at keeping the constant value h_L/b leads to increasing of bubbled liquid share.

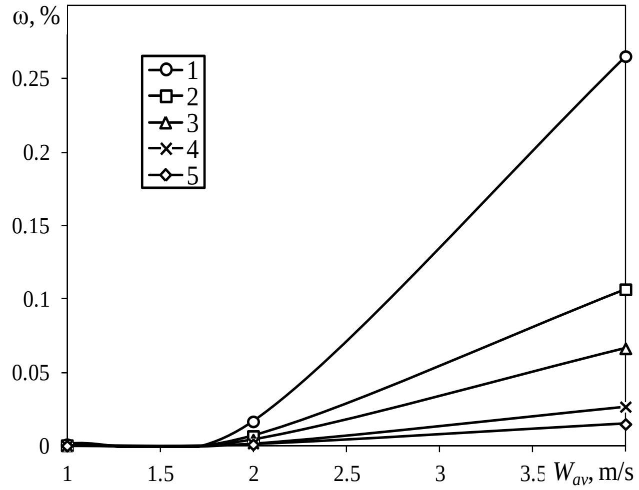

Figure 3. Share of bubbled liquid dependence on mean gas velocity at constant ratio h_L/b = 0.2 and various contact device width b, m: 1 – 0.1; 2 – 0.15; 3 – 0.2; 4 – 0.3; 5 – 0.4.

As will be seen from graph presented on figure 4, the share of bubbled liquid is increased at liquid column height reducing on contact stage with studied device width keeping constant (b = 0.2 m). This is due to the fact that low hydrostatic pressure is created at low liquid column height and gas energy is enough to force through this liquid layer.

Decreasing of holes diameter on inclined contact elements results in increasing of bubbled liquid share (figure 5). It is explained by the fact that narrowing appeared at decreasing of holes diameter leads to growth of mean gas velocity in holes and, as result, to rising of gas pressure loss.

The performed numerical study is showing that at mean gas velocity up to 4 m/s, contact device width equal to 0.1 m and liquid column height on contact stage – 0.02 m the share of liquid that forced through by gas flow is not more then 2 %. It shows that main part of liquid flows down to the underlying contact stage. Consequently, there is a capacity for further mean gas velocity growth at steady operating of contact device without significant increasing of liquid retention in it.

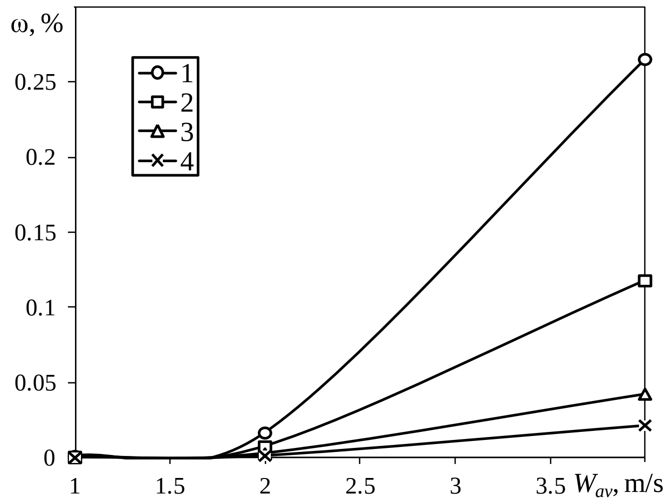

Figure 4. Share of bubbled liquid dependence on mean gas velocity for various level of liquid on contact stage h_L, m: 1 – 0.02; 2 – 0.03; 3 – 0.05; 4 – 0.07; b = 0.2 m.

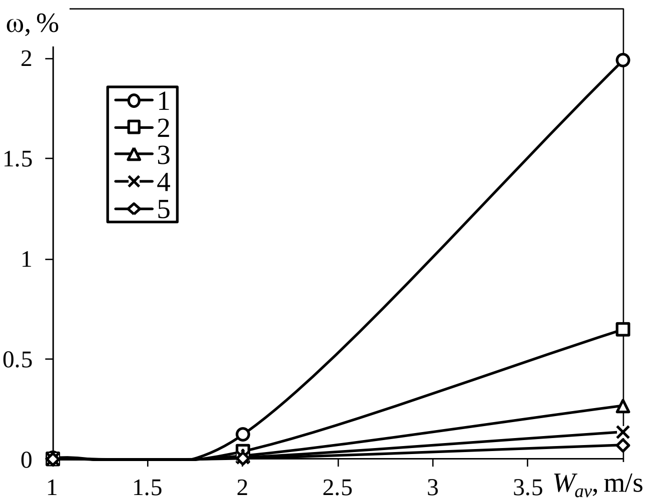

Figure 5. Share of bubbled liquid dependence on mean gas velocity for various values of holes diameters, performed on inclined contact elements, d_o, m: 1 – 0.003; 2 – 0.004; 3 – 0.005; 4 – 0.006; 5 – 0.007; b = 0.1 m, h_L = 0.02 m.

4. Conclusion

1. The contact devise design with self distribution of liquid in working area is presented in paper, experimental unit is developed and created, on which the research of two phase flows is carried out.

2. Minimum liquid column height necessary for forcing through by gas flow and bubbled liquid share in dependence on mean gas velocity at various design performance of contact device was obtained.

3. Influence of holes diameter on share of bubbled liquid in working area of contact device was investigated.

4. Wide range of contact device steady operating was confirmed to both gas and liquid phases without significant increasing of liquid retention in it.

5. Acknowledgments

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6. References

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