

Experimental assessment of heat and mass transfer of modular nozzles of cooling towers

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Abstract. Data of experimental study of hydrodynamics, heat and mass transfer of modular nozzles of cooling towers and some comparative characteristics of the packed device with nozzles, which have wide industrial application, are given in the article.

1. Introduction

Packed heat and mass transfer devices with different configurations get application in a very wide range of technological processes in many branches of industry. So, for example, those processes in the chemical industry are the processes of absorption and rectification which are realized in packed column mass transfer apparatus. Evaporative cooling of water in cooling towers, sprinklers are processes in the heat-power engineering. In ecological processes it is purification of gas emissions in absorbers and scrubbers.

Named technological equipment has the distinction and the specifics of the processes which occur there. However, the general purpose of the contact devices of the equipment is arrangement of conditions of interaction of the gas and liquid phases when it provides the greatest efficiency of that equipment processes with the least expenditure of energy. There is a wide variety of factors, chemical and thermal physical properties of the contacting flows, but the effectiveness of contact devices is mainly determined by internal geometry and embodiment of nozzles that form the hydrodynamic conditions in two-phase gas-liquid flow, as evidenced by the industrial experience and experimental studies.

Development of new perspective ways of intensification of heat-mass transfer processes in packed devices is currently an actual problem. The main purpose of this paper is to get experimental data in the field of hydrodynamics of a new modular heat and mass exchange nozzle with the function of water disinfection in electric field and comparing of its characteristics with the same characteristics of nozzles which have wide industrial application. That nozzle can get wide application for cooling of circulating water in local water supply systems for industrial enterprises.

This work is focused on experimental investigation of hydrodynamics, heat and mass transfer in new modular heat-mass exchange nozzles for cooling towers of the local water recycling systems [1]. Heat-mass exchange nozzle is made as a module for disinfection of water in electric field. That property in addition to traditional assignments, can suppress the activity of microorganisms and prevent biofilm formation on the surface of the nozzle and on the outer surfaces of the heat exchange process equipment, washed by the circulating water. Diagram of a modular heat-mass exchange in the nozzle is presented in figure 1.



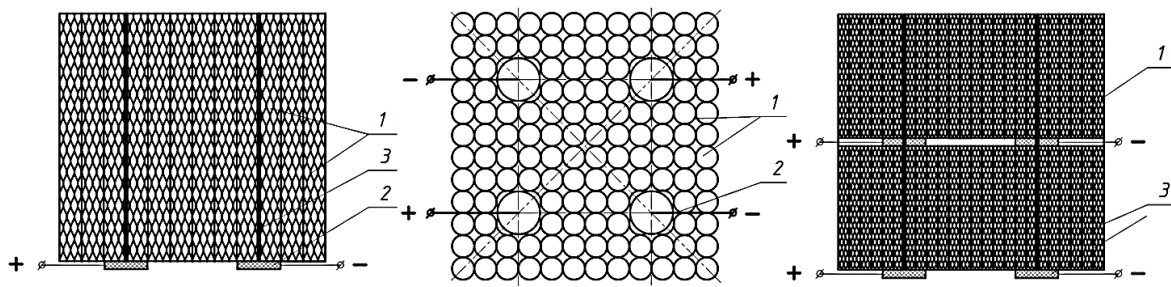


Figure 1. Modular heat-mass exchange nozzle for cooling tower [1].

Heat and mass exchange nozzle of cooling tower is made as a module which consists of layers of polymeric grid casings 1. They have cylindrical shape; they are arranged in parallel to each other in all vertical layers. Dissociating cylindrical insert 2 have the form of swirlers; they installed on the bottom surface of each module uniformly over the cross section. Each dissociating insert is made of electrically conductive material, such as sheet metal or carbon and it provided with the vertical electrode 3 with a height equal to the height of the module. Adjacent inserts 2 are attached to opposite poles of a DC source. The cooled water is intensely mixed because dissociating insert are made as swirlers. It results in the equalization of the residence time of water in the cooling tower and its disinfection by electric current. This effect suppresses bacteria and prevents biofilm formation on the surface of the polymeric grid casings 1 and intensifies heat-mass exchange processes between cooling water and air in cooling tower [1].

It should be noted that nozzle devices for evaporative cooling of water in cooling towers in accordance to their specificity, should provide a high retention capacity for fluids and have a low value of hydraulic resistance. That is, they should not maintain resistance to the upward air flow, smoothly flowing it, providing ventilation and maintaining the driving force of the process. Along with assigned tasks, the comparative characterization of the elaborated nozzles with devices that have wide industrial application is the main purpose of the research.

2. Experimental part

Experimental setup that allows to study the hydrodynamics of packed devices and heat-mass exchange in conditions of counter flow movement of air-water flow was elaborated for a wide range of experimental studies.

The setup is available for visual observation and for development of hydrodynamic and aerodynamic flow regimes of water and air through the nozzle. It allows to determine the holding capacity of hydraulic resistance of dry and irrigated nozzles and to assess the intensity of heat and mass exchange processes in packed devices [2]. Diagram and pictures which explain the construction and principle of the device for the experimentation are shown in figure 2 [2].

The device consists of a frame 1 which contains the nozzle 3. The nozzle is irrigated by water using the dispenser 4. The nozzle is blown by countercurrent air flow which arrives from a centrifugal fan 5. The frame walls are planar and transparent, it allows to observe and record the nozzle in different hydrodynamic regimes by high-speed video cameras without distortion. Cartridge system of replacement nozzles is implemented in the device; that allows to change the nozzles quickly and to ensure the reproducibility of the measured parameters in repeated experiments [2].

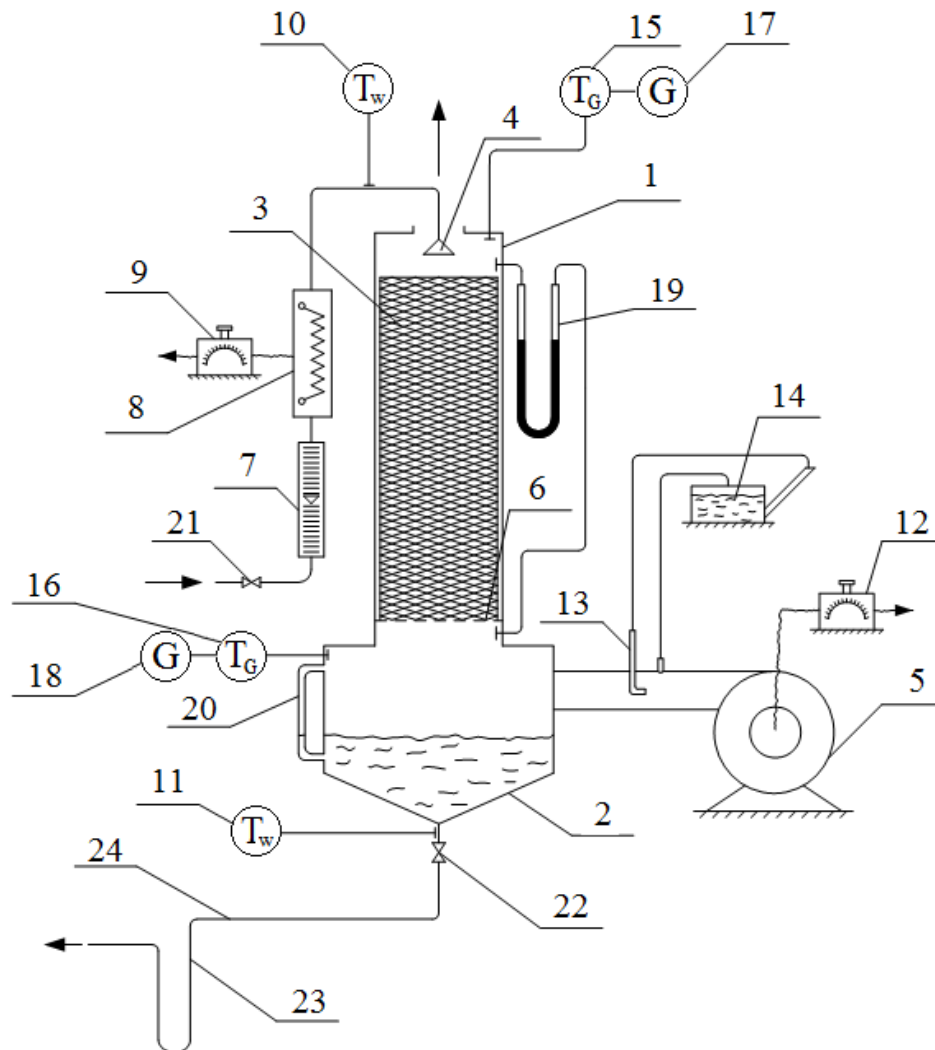


Figure 2. Diagram of the experimental setup for the study of hydrodynamics and heat and mass exchange processes in packed devices.

1 – frame; 2 – water collecting capacity; 3 – nozzle; 4 – dispenser; 5 – centrifugal fan;
 6 – supporting grid; 7 – rotameter; 8 – water heater; 9 – potentiometer; 12 – frequency converter;
 10, 11, 15, 18 – temperature sensor; 13 – Pitot-Prandtl tube; 14 – manometer; 16, 17 – hygrometer;
 19 – differential manometer; 20 – liquid level gage; 21, 22 – valve; 23 – pipe bend;
 24 – pipe for water drain to drainage

The hydraulic resistance of the nozzle without irrigation, regardless of the nature of the process, is one of the most important indicators of its work. It provides the benchmark on the possible range of processes of its industrial applications. The hydraulic resistance of the dry nozzles, in addition to industrial orientation of packing unit, is a kind of "passport" of packed devices, and the reflection of the energy cost in the realization of technological processes.



Figure 3. Photo of the experimental setup for the study of hydrodynamics and heat and mass exchange processes in packed devices.

However, the hydraulic resistance of the dry nozzles gives a not a full picture of the efficiency of the packed devices. The fact is heat and mass exchange nozzles can have completely different geometric configurations and, accordingly, they can implement fairly difficult hydraulic modes of operation. Therefore, it is necessary to explore hydraulic regimes and to conduct comparative characteristics of hydraulic resistance of irrigated nozzles.

3. Results and Discussion

The results of assessment of hydraulic resistance of dry and irrigated modular heat-mass exchange nozzle are presented in figure 4.

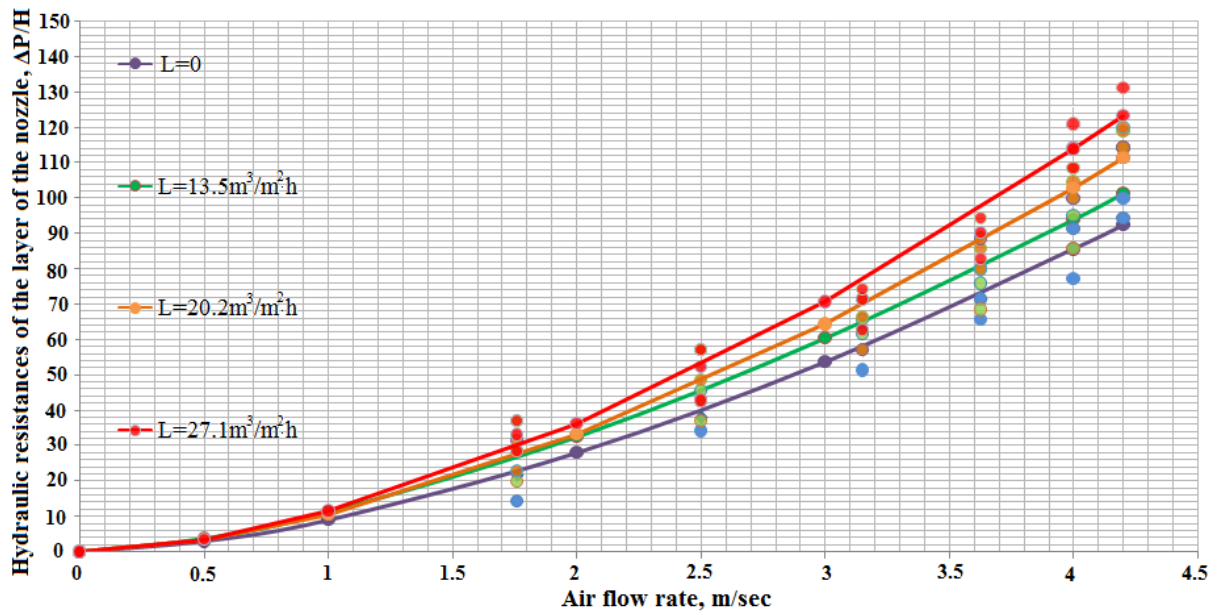


Figure 4. Diagram of dependence of hydraulic resistances of dry and irrigated modular heat-mass exchange nozzle on the air flow rate

We used criteria equation of dependence $\lambda = \frac{2}{Re_m} + 2$ [3,4] to generalize the experimental data and to provide the comparative performance of the test devices and nozzles which have wide industrial application. We can compare the energy efficiency and provide the benchmark to industrial applications of absolutely different packed devices of the most difficult configurations by that criteria equation.

Linear dimensions l_1 and l_2 , the values of α and β which are coefficients, respectively, of viscous and inertial components of the equation Dupuis – Forchheimer, as well as modified criteria of Reynolds Re and the corresponding coefficient of hydraulic resistance λ , were determined on the basis of experimental filtration curves for the proposed modular heat and mass exchange nozzle [1]. The data are presented in table 1 [3,4].

Table 1. The results of mathematical data processing of heat and mass exchange modular nozzle

α, m^{-2}	β, m^{-1}	Re	λ	l_{x1}, m	l_{x2}, m^2
$2.5 \cdot 10^5$	3.6429	0.5667	5.53	0.27451	$1.46 \cdot 10^{-5}$
		1.1333	3.76		
		2.2667	2.88		
		3.4	2.59		
		4.5	2.44		
		4.76	2.42		

The results of the comparative characteristics of the packing devices are shown in figure 5.

We can conclude on the basis of comparative characteristics of kinds of nozzles, with using the generalized criterial equation of dependence of the resistance coefficient on the modified Reynolds number that a modular heat and mass exchange nozzle is in the range of very small hydraulic resistance as compared to industrial nozzles. Therefore, the proposed nozzle can be oriented to the process of

evaporative cooling of water in cooling towers, as well as a to the variety of energy-efficient industrial processes [3,4].

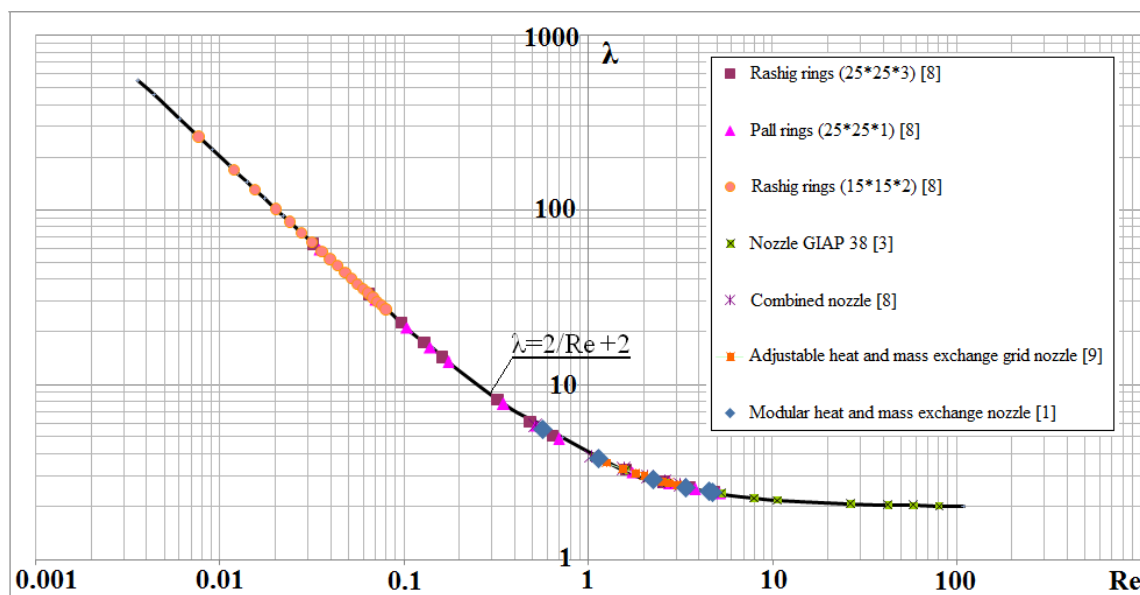


Figure 5. Diagram of dependence $\lambda = f(Re)$ for nozzles with different structure

Holding capacity is one of the main hydraulic characteristics of nozzle devices, which, to our opinion, has not enough attention. We consider it as a base for calculation methods [5,6,7] both with the coefficients of heat and mass exchange. It is the ability of the nozzle to accumulate a certain amount of liquid depending on the operation mode. That ability is a reflection of the total holding time of the liquid and the surface of the mass transfer for a range of nozzles.

The results of the research of holding capacity are demonstrated in Figure 6.

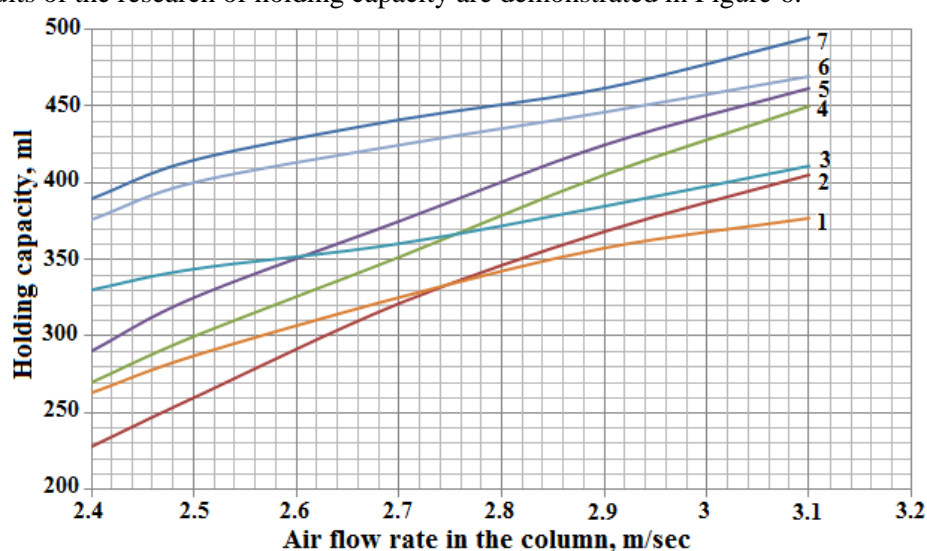


Figure 6. Diagram of dependence of holding capacity of the irrigated packing on the gas flow rate in the column:

1 – sheet nozzle; 2 – Pall rings; 3 – adjustable heat and mass exchange grid nozzle [9]; 4 – Rashig rings; 5 – nozzle with resonant effect [10]; 6 – modular heat and mass exchange nozzle for cooling towers [1]; 7 – regular block grid nozzle with an elastic liquid dispenser.

The modular heat and mass exchange nozzle is shown to have a relatively high holding capacity as compared to a number of industrial and developed nozzles which were analyzed in the experiment.

4. Conclusions

We can conclude that the modular nozzle device for evaporative cooling of circulating water in cooling towers and for devices of inertial scrubbing of gases is promising for industrial applications. That idea is based on described data of the energy-efficiency, hydraulic resistances of dry and irrigated nozzles and their high holding capacity for liquid.

Special attention, in our opinion, should be paid to the prospects of application of modular nozzle device for disinfection of industrial circulating water. That property of the nozzle could help to maintain the constancy of the surface properties of the packed devices, and partly to prevent biofouling of external surfaces of a heat transfer equipment, washed by the circulating water, by microorganisms.

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