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Influence of Throttling and Nozzles Switching Sequence on Indicator of Water Distribution Uniformity in Cooling Tower Model

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Abstract

The article analyzes factors leading to non-uniformity of water distribution in cooling towers. These include imperfections in the design of pipelines and nozzles of the water distribution system of cooling towers. Previous studies conducted on a model of the water distribution system of the tower-type cooling system at Rivne Nuclear Power Plant have revealed uneven water distribution on the nozzles. Simulation of the simultaneity of nozzle activation showed that the nozzle that is activated first has the highest flow rate. Therefore, to achieve acceptable uniformity of water distribution, this nozzle was throttled using a throttling orifice plate. It has been shown that such throttling is effective even in the presence of hydrodynamic cavitation at orifice plate diameter ratios of 0.449...0.624. When four model nozzles are activated one after the other, the flow rate of the first nozzle decreases both with and without throttling. At the same time, increase in the number of working nozzles up to four does not significantly affect the flow rate of the first nozzle.

Keywords: cooling tower; water distribution system; nozzle; throttling orifice plate.

1. Definition of the problem to be solved

Due to the strengthening of requirements for environmental protection, the need to save material and fuel, and energy resources, energy enterprises use circulating water supply systems. Such systems include, in particular, cooling towers. With the help of cooling towers, circulating water is cooled with atmospheric air. Unsatisfactory operation of cooling towers leads to overspending on raw materials, under-delivery of products, and sometimes emergency situations [1], [2].

The water distribution device is a technological element of the cooling tower, which in many cases determines its efficiency and reliable operation. It should ensure uniform water distribution with low energy consumption [3]. Modernization of water distribution devices is one of the most effective ways to improve the performance of technical water supply systems for thermal power plants and nuclear power plants, as well as their technical and economic indicators [4].

The indicator of water distribution uniformity for cooling towers is described in [3] by the following equation

$$m = \frac{q_{beg}}{q_{end}}, \tag{1}$$

where q_{beg} and q_{end} is the flow rate through the first (initial) and last (final) nozzle in the direction of water flow. The value of the indicator should be m = 0.90...0.95.

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The non-uniformity of water distribution between nozzles depends on the ratio of head losses through them and along the length of the working pipeline. This non-uniformity can be reduced by increasing the head loss through the nozzles or decreasing the head loss along the length of the pipeline. The head loss through the nozzles can be increased by reducing the number of nozzles or their productivity [3]. However, reducing the productivity of nozzles in the peripheral part of the water distribution device of cooling tower No.2 at Cherkasy Thermal Power Station by decreasing their diameter led to inadequate water cooling in the tower by an average of 0.2°C with an insignificant decrease (up to 3.2%) in their productivity [5]. It is possible to reduce pressure losses along the length of the pipe by increasing its cross-sectional area. If the available pressure is insufficient or an increase in the diameter of the pipes is undesirable, then reducing the unevenness of the distribution can be achieved by changing the distance between the nozzles at a given pressure or reducing the diameter of the pipe due to the movement of water, performing its telescopic form to restore the high-speed pressure [3] (Fig. 1).

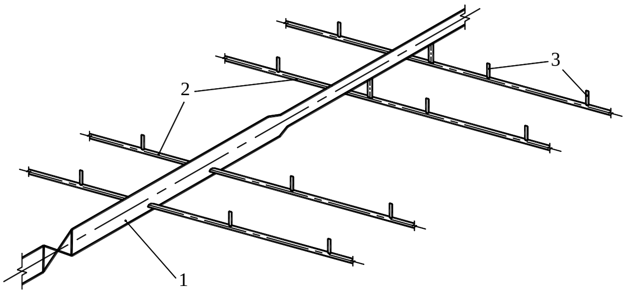

Fig.1. Reduction of the main pipeline diameter by providing a telescopic form:
1 – main pipeline; 2 – working pipeline; 3 – nozzles [6].

During the reconstruction of cooling tower No. 1 of the Gomel Thermal Power Station No.2, the working and main pipelines were replaced to ensure uniform water distribution [7] and a jumper $D = 1600$ mm was installed between the coolers and draining main circulation water pipes to reduce the uneven distribution of water flows [4], [7].

For a more even distribution of water due to the avoidance of siltation of pipelines, the water distribution device is made by a closed connection of main pipelines with working pipelines [8]. For the main pipelines of cooling towers, in which major head losses $h_f > 0.3...0.5$ m, it is economically expedient to use a scheme with the placement of the top of the nozzle risers according to the piezometric pressure line (Fig. 2) [6].

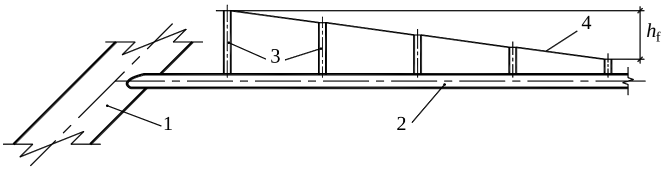

Fig.2. Placement of nozzle tops according to the piezometric pressure line on the working pipeline:
1 – main pipeline; 2 – working pipeline; 3 – nozzle riser; 4 – piezometric pressure line;
h_f – major head losses along the working pipeline.

2. Formulation of the goal of the paper

The goal of this work is to identify patterns of changes in the flow rate of one nozzle model of the water distribution device of the cooling tower with a different number of working nozzles.

3. Analysis of the recent publications and research works on the problem

The model of the pressure water distribution device of the cooling tower of the circulation water supply system of the Rivne Nuclear Power Plant (scale 1:59) [9], for which the main pipeline is sequential in structure, and the working pipeline is bifurcated [10], was studied. It was found [11] that the movement of water between distribution node 6 and node 7 (Fig. 3) is uniform, and the uneven distribution of water occurs on the working pipelines and nozzles. This is consistent with the naturally occurring violation of irrigation uniformity due to nozzle clogging and failure [12].

It was demonstrated [13] that the order of inclusion in the operation of the nozzles plays a role. In addition, water flow rate is always greater through those nozzles that are activated first. Therefore, when regulating the flow rate of water through these nozzles, it is proposed to apply throttling with the help of a throttling orifice plate [14]. The absence of hydrodynamic cavitation, in this case, is observed provided that [14]:

$$\frac{Q_{cav}}{Q_o} \geq 1, \tag{2}$$

where Q_o is the flow rate through the nozzle without flow throttling; Q_{cav} is the flow rate corresponding to the beginning of cavitation.

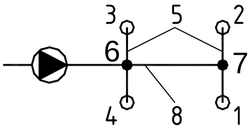

Fig. 3. Schematic diagram of the water distribution model
of the cooling tower circulation water supply system of the Rivne Nuclear Power Plant:
1…4 – nozzle; 5 – working pipeline; 6, 7 – water distribution node; 8 – main pipeline.

The flow rate Q_{cav} for the cavitation curve $Q_{cav}/Q_o = f(\omega/\Omega)$, the calculation of which is given in the Table 1, calculated according to [15]. In this experiment, water flows through nozzle 4 without throttling the flow $Q_o = 0.1613$ l/s. The absence of hydrodynamic cavitation (Fig. 4) corresponds to the area ratio $\omega/\Omega \geq 0.39$, i.e. the relative diameters of the orifice of the throttling orifice plate $d/D \geq 0.624$, where ω is the area of cross-section of the cross-sectional area of the orifice of the throttling orifice plate with a diameter of d; Ω is the area of cross-section of the cross-sectional area of the working pipeline with an internal diameter $D = 17.8$ mm.

During the operation of the water distribution device model of the cooling tower without throttling, there is little uniformity of water distribution. Throttling of nozzle 4 with a throttling orifice plate with a diameter of opening of $d = 8$ mm (Fig. 5) with a different sequence of activation of nozzles 1...4 ensured acceptable uniformity of water distribution even in the presence of hydrodynamic cavitation [16] (Fig. 4). The use of a throttling orifice plate with a diameter of opening of $d = 6$ mm (Table 1) led to mechanical vibration of pipelines and acoustic noise [17]. These disturbances probably occur in the zones of local flow separation near the throttling orifice plate [18].

Table 1. Calculation of water flow rate ratio Q_{cav}/Q_o.

Diameter of throttling orifice plate opening *d*, mm (according to [19])	Area ratio ω/Ω	Flow rate Q_{cav}, l/s	Ratio of flow rates Q_{cav}/Q_o
4.3	0.058	0.023	0.143
5.3	0.089	0.035	0.217
6.4	0.129	0.050	0.310
8.4	0.223	0.088	0.546
10.5	0.348	0.142	0.880
13.0	0.533	0.233	1.445

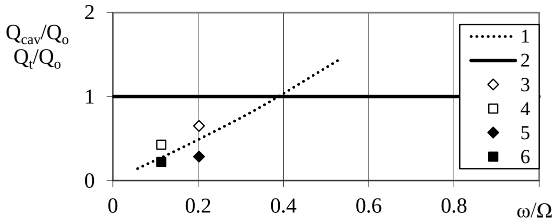

Fig. 4. Application of throttling for nozzle 4:
1 – data of the Table 2; 2 – the line corresponding to the ratio $Q_{cav}/Q_o = 1$; 3...6 – data of Table 1 for a throttling orifice plate with a diameter of opening $d = 8$ mm (3, 5) and $d = 6$ mm (4, 6); unshaded notations match transparent symbols correspond to the operation of one nozzle 4, shaded notations match opaque symbols correspond to the operation of nozzle 4 in the sequence of nozzles 4→2→1.

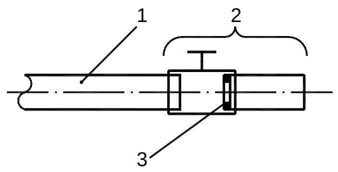

Fig. 5. Installation diagram of the throttling orifice plate in the nozzle model:
1 – model working pipeline; 2 – nozzle model; 3 – throttling orifice plate.

4. Presentation and discussion of the research results

Due to the short length of the model working pipeline (Fig. 5), it was believed that the main unevenness of water distribution is at the nozzles.

Water flow rate through nozzle 4 during throttling was displayed by the dependence $Q_t/Q_o = \mathrm{f}(\omega/\Omega)$, where Q_t is water flow rate through nozzle 4 during throttling when one nozzle 4 is operating and the sequence of nozzles 4→2→1 (Fig. 4) according to the data in the Table 2.

Table 2. Calculation of the ratio of water flow rate Q_t/Q_o for throttling the flow at the nozzle 4.

Diameter, mm		Diameter ratio of throttling orifice plate d/D	Area ratio ω/Ω	Flow rate Q_t, l/s, nozzle 4 during operation		Ratio of flow rates Q_t/Q_o during operation	
D	d			one nozzle 4	in the sequence of nozzles 4→2→1	one nozzle 4	in the sequence of nozzles 4→2→1
17.8	8.0	0.449	0.202	0.1051	0.0462	0.652	0.286
	6.0	0.337	0.114	0.0688	0.0360	0.427	0.223

In order to see the changes in the water flow of one nozzle 4, the obtained data were presented in the form of a dependence $Q_t/Q_o = \mathrm{f}(d/D)$, where Q_t/Q_o is the relative flow rate through nozzle 4; Q_t is the flow rate through nozzle 4 when working with other nozzles (Fig. 6). When increasing the number of nozzles from one nozzle (4) to three (sequence 4→2→1), the flow rate through nozzle 4 decreases both without throttling and with throttling. Increasing the number of nozzles to four (sequence 4→2→1→3) does not significantly reduce the flow rate through nozzle 4.

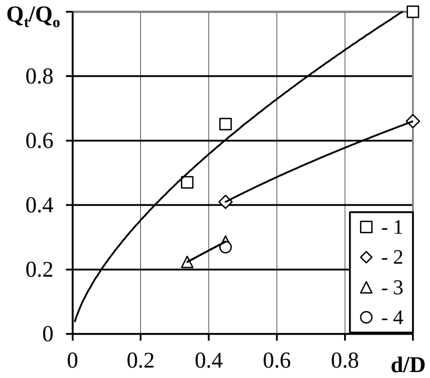

Fig. 6. Dependence $Q_t/Q_o = \mathrm{f}(d/D)$ for nozzle 4 during operation
one nozzle 4 (1); in the sequence of nozzles 4→2 (2); 4→2→1 (3); 4→2→1→3 (4).

The uniformity of the distribution of water by the nozzles by throttling nozzle 4 was controlled by the flow ratio Q_i/Q_4 (Table 3). Here, the subscript "i" corresponds to the nozzles that are triggered sequentially after nozzle 4. With the nozzle activation sequence 4→2→1, the flow rate through nozzle 4 with a throttling orifice plate with $d = 8$ mm remained almost unchanged (Fig. 7), which confirms the conclusions of [16]. At the same time, the indicator of uniformity of water distribution is within the recommended limits. When throttling nozzle 4 with a throttling orifice plate with $d = 6$ mm, the flow rate of the nozzle 4 decreases, which confirms the conclusions of [17] about the impracticality of using a throttling orifice plate with such an opening diameter. In contrast to [20], the reduction of the live cross-sectional area of nozzle 4 by throttling significantly affected water flow rate.

Table 3. Calculation of ratios of water flow rate Q_i/Q_4 and the indicator of uniformity of water distribution for throttling at nozzle 4 and the sequence of activation of nozzles 4→2→1

Flow rate of nozzles Q_i, l/s				Ratio of flow rates Q_i/Q_4	Indicator of uniformity of water distribution m
1	2	3	4		
diameter of opening of throttling orifice plate d = 8 mm					
			0.0462	1.000	0.928
	0.0462			1.000	0.928
0.0498				1.078	1.000
		—		0	—
diameter of opening of throttling orifice plate d = 6 mm					
			0.0360	1.000	0.601
	0.0629			1.747	1.050
0.0599				1.664	1.000
		—		0	—

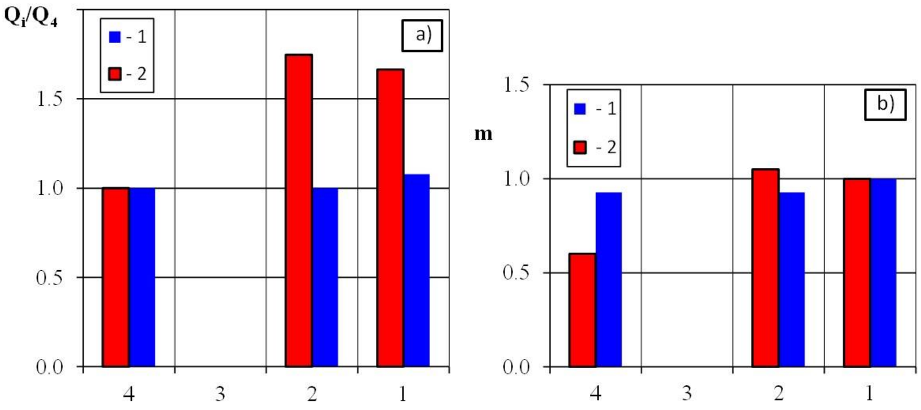

Fig. 7. Relative change in water flow rate through nozzles *(a)* and indicator of uniformity of water distribution *(b)* in the sequence of activation of nozzles 4→2→1 for throttling nozzle 4 with a throttling orifice plate with opening diameter d = 8 mm (1) and d = 6 mm (2).

5. Conclusion

The factors leading to non-uniformity of water distribution in cooling towers have been analyzed. To achieve acceptable uniformity of water distribution, the throttling of flow on nozzles of water distribution system of cooling towers using throttling orifice plate was proposed. When the four model nozzles are activated one after the other, the flow rate through the first one decreases both with and without throttling. At the same time, increase in the number of working nozzles to four does not significantly affect the flow rate through the first one.

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Вплив дроселювання та послідовності спрацьовування сопел на показник рівномірності розподілу води моделі баштової градирні

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Анотація

Проаналізовано фактори, які призводять до нерівномірності розподілу води в градирнях. До них належать недосконалість конструкції трубопроводів і сопел водорозподільного пристрою градирень. Попередні дослідження, виконані на моделі водорозподільного пристрою баштової градирні системи циркуляційного водопостачання Рівненської АЕС, виявили нерівномірність роздавання води на соплах. Моделюванням неодночасності спрацьовування сопел встановлено, що сопло, яке спрацьовує першим, має найбільшу витрату. Тому для досягнення допустимої рівномірності роздавання води проводили дроселювання цього сопла за допомогою дросельної діафрагми. Показано, що таке дроселювання є ефективним навіть за наявності гідродинамічної кавітації за відносних діаметрів діафрагми 0,449…0,624. При спрацьовуванні чотирьох модельних сопел один за одним витрата першого з них зменшується як без дроселювання, так і за дроселювання. При цьому збільшення кількості працюючих сопел до чотирьох істотно не впливає на витрату першого.

Ключові слова: баштова градирня; водорозподільний пристрій; сопло; дросельна діафрагма.