Development of an experimental facility for cooling circulated water of industrial plants

Nzomjon Usmonov[1*], *Yusufbek* Abdullabekov[1], and *Saodat* Axmatova[1]

[1] Department of Thermodynamics, Tashkent State Technical University, 100097 Tashkent, Uzbekistan

Abstract. The article discusses the installation and the hydrodynamic results analysis of three-phase fluidized bed experimental studies. An energy coefficient linear dependence of the circulating water evaporative cooler of the considered type on the irrigation coefficient has been experimentally established. The dependence of the fraction of circulating water evaporated moisture in an evaporative cooler of the type under consideration on the cooled water temperature at the inlet to the cooler and the irrigation coefficient has been established. The analysis of hydrodynamic and thermal processes occurring in a three-phase fluidized bed is carried out, and the main technological parameters for the optimal operation of installations with the specified bed are obtained in relation to solving the problem of cooling the circulating water. The dependence of the expansion of a three-phase fluidized bed on air velocity and irrigation density has been investigated. On the basis of the performed experimental studies, empirical formulas for calculations are derived.

1 Introduction

In the Republic of Uzbekistan, one of the main areas of the economy is currently receiving a lot of attention: the development of technological equipment for the energy industry that meets modern standards, such as the modernization of cooling systems for circulating water and air conditioning [1, 2]. The 2017–2021 Strategy of Actions for the Further Development of the Republic of Uzbekistan emphasized the necessity of reducing the economy's energy and resource intensity through widespread use of energy-saving technologies [3-6]. To some extent, this research aids in the completion of the regulations' tasks.

The use of a three-phase fluidized bed is one of the most advanced heat and mass transfer techniques available [7-9]. The introduction of such forms into the industry has the potential to greatly improve heat and mass transfer intensity, but it is challenging due to a lack of accurate methods for calculating the equipment.

On the basis of field studies, determining the degree of thermal engineering perfection of evaporative circulating water coolers, especially those with a fluidized bed, takes a long time and a lot of money. A numerical method that takes into account any changes in the parameters of the cooled water, the environment, design, thermal engineering, and operational characteristics of individual elements and units of the cooler is another

* Corresponding author: nizomiddin1981@mail.ru

advanced method for handling this problem [10]. This method allows for more reliable initial data to be obtained and substantiated for the development of appropriate engineering solutions to ensure the efficient operation of coolers of this type in various branches of the energy, processing, petrochemical, and food industries at the current stage of computer technology development.
The following tasks are set: to describe the structure of the layer at different operating modes of the apparatus, to determine the rates of the beginning of fluidization W' and the rate of carryover W'' depending on the irrigation density L [11].
The intensification of air conditioning and cooling systems operation is one of the urgent problems in the practice of evaporative cooling of water [1, 2]. Many developers have proposed a number of solutions for intensifying the cooling process based on this method. For example, making a part of the body in the form of a diffuser, organizing a higher degree of water dispersion, installing centrifugal nozzles, changing the design of sprinklers. All these measures give an additional increase of water cooling by another $1\ ℃$ [11].

2 Methods

Analysis works for intensifying water-cooling process shows that conventional process intensification methods in the air-evaporator apparatus (intensive operation modes, compact bundles counter flow cooling system etc.) are almost exhausted. At the same time, the problem of cleaning the heat exchange surface from contamination in air-evaporative heat exchangers has practically not been overcome. From the results of the analysis it follows that in order to increase the efficiency of the process of cooling the circulating water; the following problems must be solved:

- to intensify heat exchange during the evaporation of cooling water, applying new technology;
- to ensure cleaning of the surface of the apparatus from contamination;
- intensification of heat exchange and surface cleaning from contamination should be provided at relatively low costs and equipment dimensions.

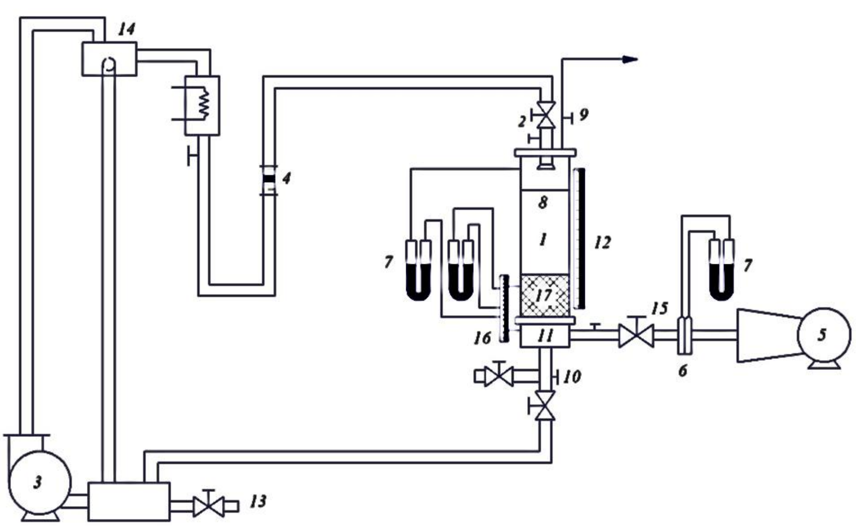

Fig. 1. Diagram of the experimental setup, the main element of the setup is the working area

To solve these problems, it seems appropriate to use a three-phase fluidized bed. The results of experimental research [11-13] and the heat and mass transfer efficiency of the process cooling water on experimental setups have shown that heat and mass transfer intensification in the device with a three-phase fluidized bed is higher than in the hollow unit or the machine with a fixed nozzle. The best conditions for its stable terms and engineering parameters of field development of the water-cooling process in a three-phase layer have been found, and a prototype installation for researching the hydrodynamics of a three-phase fluidized bed has been produced and implemented.

Fig. 1 depicts a carefully built experimental setup. A column (1), a feeding system and fluid discharge, an air supply system, and measuring equipment make up the experimental apparatus. The working area is composed of glass so that the fluidization process can be observed visually. The working surface is 104 mm in diameter and 950 mm in height. A support grid (11) with a free cross-section of 40% is put in the lower part of the working section. The slotted aperture width of the lattice is 5 mm. A layer of inert packing (17) - hollow balls - is placed on the lattice. During the experiment, the diameter of the balls was modified (26 mm and 14 mm). A separating device - a disk with apertures with a free cross-section of 70% - is inserted in the upper half of the working region to prevent entrainment. Ambient air was used as a fluidizing gas. Under the support grid, a high-pressure fan provides air to the lowest half of the working area. A standard diaphragm (6) is mounted on the air supply line; the differential pressure gauge is a supplementary device to the diaphragm. An earlier experiment was used to validate the accuracy of the calibration. The air flow was controlled by the number of rotations of a DC-powered fan. In order to control the flow rate, a butterfly gate (15) was installed in the air supply line. A metering ruler was put up along the height of the working area to measure the height of the static H 0 and dynamic layer H d of the nozzle (12). In the upper part of the active area, a spray device has been set up. From a pressure tank, water (with a consistent liquid level) is supplied to the working area (14). The liquid flow rate is measured by a rotameter on the water supply flow pipe. The drain tank was flooded with water from the active area (13). A pump provided the water to the pressure tank (3). At the working area, differential pressure gauges (8, 9) were installed to measure the hydraulic resistance of the support grid, the packing layer at rest and in the fluidized condition, as well as the total hydraulic resistance of the apparatus.

The experiment went as follows: the fan was turned on, a specific air speed was set, and the hydraulic resistance of the dry distribution grid was measured, then the speed was modified and the corresponding hydraulic resistance was fixed again. Introduction to hydrodynamic resistance studies dry lattice in the range $F_{dg} = 2.0 \div 6.5$ % over a wide range of variation of the flow rate showed that the supporting-distributing grating with a free cross-section of 30 % or more the resistance varies slightly, and can calculate the resistance (with error 5 %) according to the Darcy formula [11].

$$\Delta P = \xi_p \cdot \frac{\rho_g \cdot W_g^2}{2 \cdot g} \tag{1}$$

After that, balls of a specific diameter and layer height H 0 were placed on the lattice, a fan was turned on, and the hydraulic resistance of the dry packing was measured, first in a quiet state, and then as the speed increased, the hydraulic resistance of the two-phase fluidized bed was recorded, as well as a fluidization curve and a graph of the entrainment rate's dependence on the air flotation rate.

Irrigated packing fluidizes at lower gas velocities than non-irrigated packing. At the same time, with an increase in the irrigation density, the rate of the beginning of fluidization decreases. For a three-phase irrigated layer, the dependences obtained by the authors [4–6] are in poor agreement with each other.

The results of experiments carried out by us in an experimental column with a diameter of 100 mm with a spherical polyethylene packing $d_1 = 26\, mm$ and $d_2 = 14\, mm$, are shown in Fig. 3, 4. The experiments were carried out with the following parameters: air velocity varied from 0.5 to 4 $\frac{m}{s}$,, irrigation density from 10 to 50 $\frac{m^3}{m^2 * h}$, the height of the static layer of the packing H_0 was equal to 100 and 200 mm. Fig. 2 shows the curves of fluidization of a three-phase layer.

3 Results and Discussions

As seen in Fig. 2, the bed begins to expand at a little larger pressure drop than the Darcy formula predicted resistance of a two-phase fluidized bed of dry packing [11].

During the experiments, the height of the fluidized bed H_d was fixed, fluctuations in the height of the dynamic bed were observed. Fig. 2 shows the results of determining the dependence of the hydraulic resistance of the dry distribution grid on the air velocity in the apparatus.

The graph shows the data of Novikov, as well as the data calculated by the formula of Blyakher. The analysis showed good agreement of our data with the data of other authors and developers [11].

After evaluating the experimental error, the main experiment with a 3-phase layer was started.

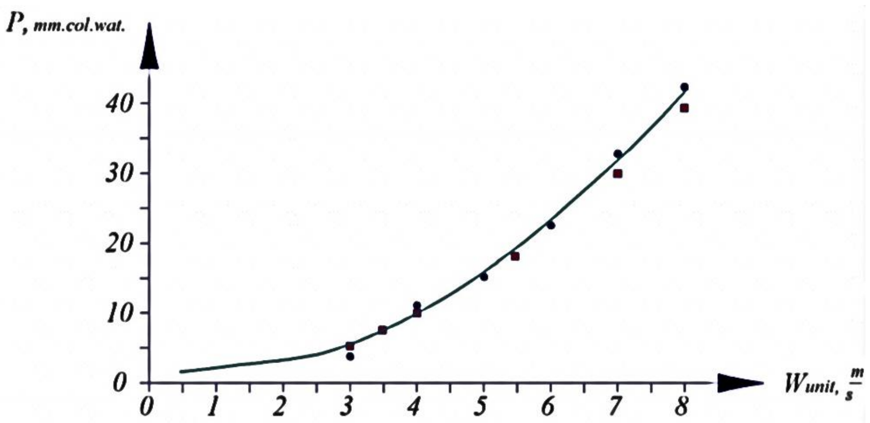

Fig. 2. The effect of air velocity in the apparatus on the hydraulic resistance of a dry grid without a nozzle

The irrigation of the packing was switched on, and at a constant irrigation density, the specifications of the three-phase fluidized bed were set down: hydraulic resistance of the bed, the rate of onset of fluidization, the rate of entrainment, the height of the dynamic bed H_d, and liquid retention in the bed.

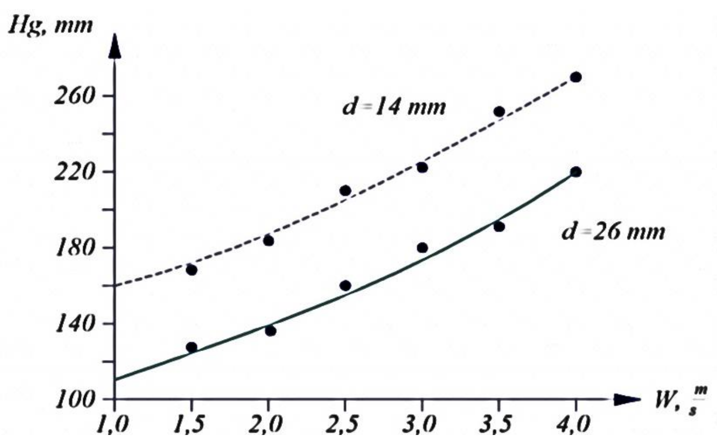

Fig. 3. The effect of air speed and irrigation density on the dynamic height $H_d = 100\ mm$ of a three-phase fluidized bed

The dynamic height of the three-phase layer is shown in Fig. 3 as a function of irrigation density and air velocity when the static layer height is H_0 = 100 mm, and in Fig. 4 as a function of irrigation density and air velocity when the static packing layer height is H_0 = 200 mm.
The speed in the apparatus modified between 1 and 4 $^m/_S$, the irrigation density was $10 \div 30\ \frac{m^3}{m^2 h}$. From the obtained experimental data, it follows that the degree of expansion of the fluidized bed is capable of reaching the value R = 5 with an increase in the rate and density of irrigation [11].

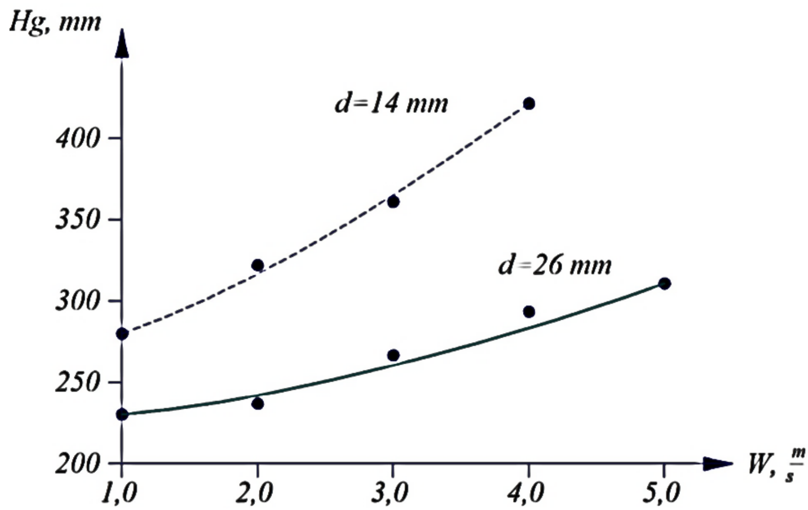

Fig. 4. The effect of air speed and irrigation density on the dynamic height $H_d = 200\ mm$ of a three-phase fluidized bed

The results obtained are compared with the data calculated by the formula of Krainev [11].

$$H_d = 0{,}13 \cdot H_0^{0.9} \cdot L^{0.35} \cdot W^2 \quad (2)$$

The maximum disarrangement was 14 %, which is within the experimental inaccuracy. The elaboration of experimental data to identify the dependence of the height of the three-phase fluidized bed on the air velocity revealed that $H_d \sim W^{0,6}$ and is stated by the equation

$$H_d = 0{,}1 \cdot W^{0.6} \quad (3)$$

The maximum discrepancy between the experimental and calculated data is 7.4 %.
An equation was obtained for the dependence of the dynamic layer height on the rate and density of irrigation, which has the following form:

$$H_d = 0{,}22 \cdot W^{0.6} \cdot L^{0.14} \quad (4)$$

4 Conclusions

To tackle the problem of flowing cooling water at industrial businesses, the major technological indications of optimal evaporative cooler operation have been determined. The experimental results corroborated the study data that had been calculated. According to the analysis, the difference between estimated and experimental data is less than 6.7 percent.

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