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Improving The Efficiency Of Evaporative Cooling Water

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Abstract— In recent years, the manufacturing enterprises of mining and metallurgical industry, chemical industry and hydrometallurgy of Uzbekistan have been leading an active work on the organization of continuous monitoring after the increase in the efficiency of evaporative cooling water. The main reason for the priority of all made efforts is to improve the quality of industrial products produced thereby, saving operating costs, especially those that are related to improving the efficiency of evaporative cooling and saving production and technical water resources. This article provides an overview of the analysis of theoretical and experimental studies, the principle of the proposed technical installation; methods of conducting experiments, as well as data that we believe are of practical value for solving production problems in the considered field.

Index Terms— contacting installation, gas phase, hydraulic resistance, chilled water, evaporation, evaporative cooling, liquid phase, vortex heat exchanger

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1 Introduction

The effectiveness of any enterprise of mining and metallurgical and chemical industry in Uzbekistan depends on the effective operation of the equipment utilized. So, the factors which are essential to improve the quality of the final product, it is of a practical interest to eliminate the disadvantages of processes and improvement of the structural elements of the existing equipment.

An analysis of data of scientific and technical literature shows that in metallurgy and chemical industries we often encounter processes where liquid and gas phases comes in contact. In these cases there are physical and chemical actions associated with cooling water, heating, absorption, distillation, etc. These actions are observed in production equipment, the so-called membranous, poppet and packed, which are little effective. There is a lack of modern equipment and low investment from outside forces to seek for opportunities to improve existing equipment, expanding their capabilities, so that an improvement in the quality of their work and the efficiency of production processes can be achieved. In this case, experts and scholars require to use packed ones instead of contact equipment, which allow to carry out qualitative process of contacting the gas and liquid phases. However, the specific characteristics of indicators of used raw materials complicate the process related to the complexity of the cycle, economically justifying the using contact equipment, which lead to an increase in operating costs. [1].

In recent years, in some countries and in particular in Uzbektan the usage of contact equipment has been started, which is based on the action of the hydraulic centrifugal force. In these equipments liquid or gas phases due to the rotational motion create an artificial vortex. It has a complex composition and can simultaneously create a current which can be created by helical and spiral flow together. As a result, the relative currents movements cause the formation of a turbulent flow, which speed up the expected process creating the rotational flow. In practice, there are two options of creating rotational flow. These are, by directing the gas tangentially into the machine and the other option is by method of putting into an interior of the installation of the devices facilitate the development of rotational movement. However, both methods have disadvantages such as a chaotic gas flow inside the unit which results in irregular rotational movements and additional technical cost due to changes in the design of the equipment. In the industry, this technical equipment provides water cooling in a small (10-12 ° C) range. For the high hot climate in Uzbekistan this figure is considered (especially in summer) insufficient. So, an improvement of the existing design and creation of more efficient and versatile equipment that allows an uninterrupted production of cold water is a priority. In general, considering the drawbacks of existing contact equipment of gas and liquid phases [2] here is proposed normally usable in both phases method that allows forming a rotational flow of gas due to the centrifugal force creating at the same time a fluidized bed of solid particles, which can have a positive effect.

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2 Statement of a Problem

The reported have been achieved through the equipment, which was created by scientists of Navoi State Mining Institute and have been applied for a patent of the Republic of Uzbekistan. This equipment has been called «Centrifugal vortical apparatus» as shown in Fig.1 below and operates in various phase systems, part of which is shown in the kinematic diagram - Fig. 2 with symbols.

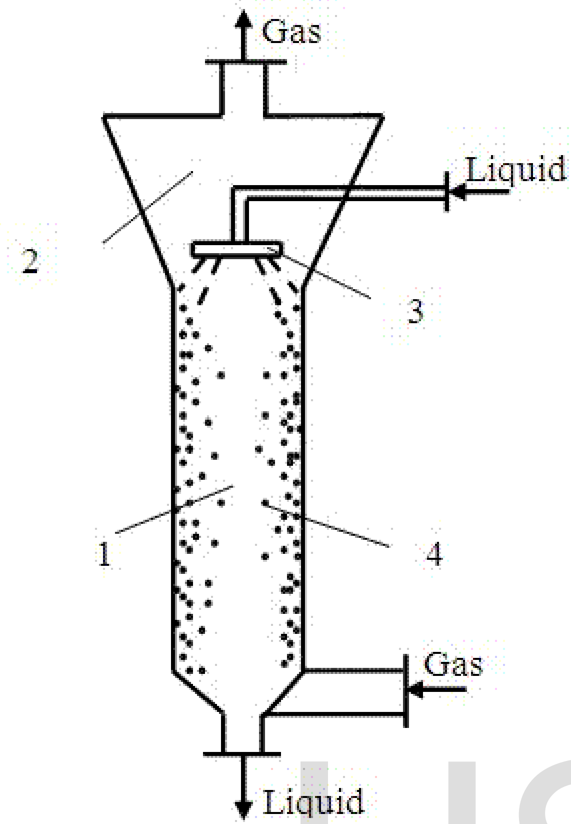

Fig. 1. Centrifugal vortical apparatus
1 Working area; 2 Separation zone; 3 Water sprinkler; 4 Particles;

3 THE CONCEPT OF THE PROBLEM DECISION

The advantage of the offered device is that it can ensure the simultaneous implementation of heat treatment and matter exchange, i.e. providing water circulation, its evaporation - creating steam and cooling, thereby preparing the cooled water for cooling an equipment, which leads to an increase in the efficiency of the technological process at the lowest cost. Essence of the offered method is as follows. Here is proposed a design of a vortical apparatus that consists of two parts: 1st part is a working part; 2nd is a conical separation part. Overall dimensions of the conical part of the separation apparatus is larger by 1.2-1.5 times than the first part. The device is designed so that a tangential gas flow can be able to get inside (inside the machine) through the bottom. To enhance the rotational movement of the gas flow in the apparatus there are mounted rotating lattice paddles under which grain solid material is dropped. In turn, the liquid is supplied to the inside of the machine from the top due to the centrifugal rotational movement of the sprinkler that supports the rotational movement of the dripping water. Movement of the gas flow provided from the bottom of the device forms spiral movement and due to a high speed lifts solids. The result is that a movement of the gas and liquid around the internal space of the apparatus takes place. Centrifugal force pushes gas with a solid particles in the liquid where an increase in the flow turbulence is reached. As a result, clinging water droplets on the inside surface of the device create an envelope. However, the chaotic motion of the solid particles developed by centrifugal forces disturbs a comfort of the envelope and promotes dispersion's rise which takes place around the machine. The result would be a seamless interaction, i.e., contact of the solid and liquid phase, flow and the matter exchange, as well as a collection of fluid under the device. The gas which passes from the working part into the separation may carry liquid or solid particles. The inner diameter of the separation unit contributes to the decline of the flow of the gas apparatus making it difficult to transport the solid particles. The formed solute which contains liquid and solids adherent on the wall gradually move in the working space of the machine. As a result, the clean gas, which got separated from the droplets and particulates are released to the outside through the top of the unit. Depending on the process requirements, you can select beforehand the geometric parameters and the density of the solid particles.

4 REALIZATION OF THE CONCEPT

Bottom unit consists of: 1 main operating unit, 2 fan, 3 electric water heater and instrumentation (fig.2). To measure the waste of water a PC device is used, for air consumption - PM-4Г У3. For humidity measurement an aspirating psychrometer is used. Provided by the highway water is heated and then through the rotametres which is the working part, where subsequently using water distributor receives a rotary motion and moving down, the water gets sprayed around the internal space of the apparatus. Atmospheric air enters the interior of the device through the lower tangential motion, which in consequence of their movement is enhanced by a gas distributer. As a result, solid, piece materials climb up using spiral and random air movement. Then in the process there takes place mixing of the gas with the water (water becomes cooler) and an exchange of matters (water evaporation) will occur. Here evaporation on the surface in most solids will occur except for dispersion of fluid flow and turbulence. This happens due to the contact of the gas and the liquid phase on the surface of the solid particles. At the time of the experiment, air and water temperature was measured by КСП-4 potentiometer and Chromel-Copel of thermocouples and was constantly monitored by exemplary laboratory thermometer, with the scale division of 0,1 ° C. As it has been noted above, the priority of advancement of heating and exchanging the substances is mainly linked to multiphase boiling and using centrifugal forces. To determine the effectiveness of these processes carrying out multi-stage experiments is required. At the initial stage of the experiment the process of reaction of gas and liquid and the degree of cooling water have been studied, where have not been operated rotary movement of flows. In addition, by the mains of this process calibration parameters have been set and verified.

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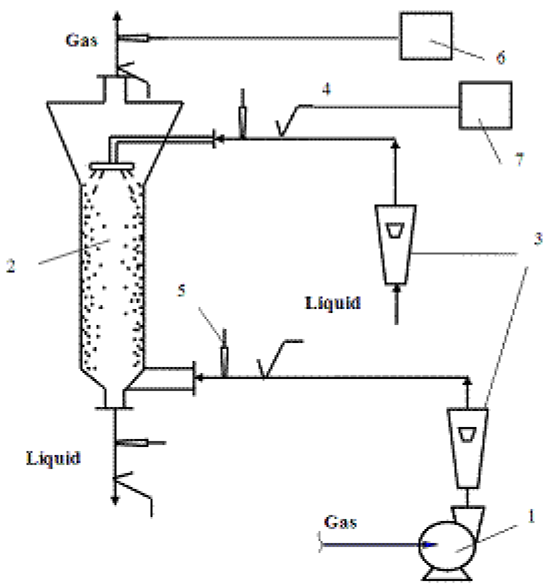

Fig. 2. Experimental installition:
1 Ventilator 2 Vortex apparatus 3 Rotameter 4 Thermocouple; 5 Sensor of the psychrometer; 6 Psychrometeher; 7 Potentiometer.

*to carry out the experiment there was used drinking water from the main pipes of the city.

In the second stage of experimental studies gas was introduced into the apparatus through the tangential movement. There had been ensured a normal rotational movement of the two phases and also the impact of the acceleration of centrifugal force on the process was studied.

As you know there from data about heat transfer and exchange of solid matter in single or multiphase processes, for their acceleration the method of latent boil is used. So, in the third stage of the experiment a cooling degree of water was studied and the influence of centrifugal forces on the acceleration of rotational motion. This object is argued with the fact that the heat transfer coefficients and the exchange of substances were not determined in our case. [3]. For the analytical determination of exchange of the substances rate the following equation is offered: When the difference of the moisture content is a driving force for the exchange of substances

$$\beta_x = M/[\Phi\cdot(x_{\text{surface}} - x_{\text{kernel}})] \qquad (1)$$

When the difference of the partial pressure of the air is the driving force

$$\text{or} \quad \beta_p = M/[\Phi\cdot(p_{\text{surface}} - p_{\text{kernel}})] \qquad (1\text{ a})$$

Here, M- the content of the evaporated water, kg / s; F - the area of cooler becoming surface, m²; x_{surface} и x_{kernel}– equal, the content of moisture on the surface of the liquid and air to the core of the flow, kg / kg; p_{surface} ва p_{kernel} - equal, partial pressure on the surface of the evaporated liquid air and smooth flow, Pa.

It is proposed to determine the amount of evaporated water using the equation (2):

$$M = \Gamma_{\text{кх}}(x_{\text{ох}} - x_{\text{б}}) = [\Gamma_{\text{б}}/(1+x_{\text{б}})](x_{\text{ох}} - x_{\text{б}}) \qquad (2)$$

It is proposed to retain moisture air, the mixture of water vapor from the air the following formula:

$$x = 0{,}622(\phi\cdot P_{nv})/(\Pi - \phi\cdot P_{nv}) \qquad (3)$$

Here ϕ - comparative humidity; $P_{\text{нв}}$ – pressure of the saturated air on the thermometer; barometric pressure, Pa. Relative humidity taking into account the air velocity [4]:

$$\phi = [PP_{\text{nv.humidity}} - B(T - T_{\text{humidity}})\cdot\Pi]/P_{nv} \qquad (4)$$

If the ratio is dependent on the air speed and if w> 0,5 m / s then is determined: $B=0{,}00001[65+(6{,}75/w)]$

The partial pressure of water vapor depends on the content of air moisture [5]:

$$p = 1{,}61\Pi\cdot x\cdot(1 - 1{,}61x) \qquad (5)$$

Equipment where water is supplied by a sprinkler an active volume is determined by relating to volume of heat in the cooler and the coefficients of exchange of mater:

$$\beta_{x\text{в}} = M/[B\cdot(x_{\text{surface}} - x_{\text{kernel}})]$$
$$\text{or} \quad \beta_{p\text{в}} = M/[B\cdot(p_{\text{surface}} - p_{\text{kernel}})] \qquad (6)$$

Coefficients of surface and bulk density are interconnected as follows (3):

$$\beta_{x\text{в}} = \beta_x\Phi/B \quad \text{or} \quad \beta_{p\text{в}} = \beta_p\Phi/B \qquad (7)$$

The ratio of exchange of mater is determined (8):

$$\beta_x = K/(\Phi\cdot\Delta И_{\text{сп}}) \qquad (8)$$

It is proposed to determine the amount of heat as follows:

$$K = \Gamma_{\text{кх}}(И_{\text{ох}} - И_{\text{б}}) \qquad (9)$$

The average difference in gas enthalpy is (10):

$$\Delta И_{\text{сп}} = (\Delta И_{\text{кт}} - \Delta И_{\text{кч}})/\ln(\Delta И_{\text{кт}}/\Delta И_{\text{кч}}) \qquad (10)$$

In these equations: $\Delta И_{kt} = И_{ch.b} - И_{ox}$ and $\Delta И_{rch} = И_{ch.ox} - И_{b}$– differences in the gas enthalpy at the bottom and the top of the equipment; $И_{ch.b}$ – enthalpy of phase boundary of initial air and water temperature; $И_{ox}$ - enthalpy of air core of gas phase at an air outlet of the device; $И_{ch.ox}$ – enthalpy of phase boundary of temperature and water at the outlet of the apparatus; $И_b$ – enthalpy of the core of gas of the temperature phase at the entrance to the apparatus; p - specific heat buildup of steam.

Here is proposed the following formula for determining enthalpy of 1 kg of dry mixture of gas and steam:

$$И=(c_{qx}+c_{steam}x)\cdot т+px \qquad (11)$$

Massive water waste at the entrance and the exit from the machine:

$$Л_{s.b}=В_{s.b}\cdot\rho \quad Л_{s.ox}=Л_{s.b}-М \qquad (12)$$

Enthalpy of water at the entrance and the exit from the machine:

$$И_{с.б}=Ц_{.б}\cdot c_{с.б};\ И_{с.б}=Ц_{.б}\cdot c_{с.б} \qquad (13)$$

Here, Ц and c_c- are temperature and specific heat. A formula for determining the coefficient of α Lewis (14) is proposed as:

$$\alpha_в/\beta_в=c_г \qquad (14)$$

Here $c_г$ - heat capacity of the air. If we consider the humid air and relating to 1 kg of inner dry air:

$$c_{нх}=c_{кх}+c_б x_х \quad (15)$$

Here, $c_{кх}$ - the heat capacity of the dry air; $c_б$ - heat capacity of water vapor; $x_х$ - saving air moisture, 1 kg water vapor / kg dry air.

For a practical application of the offered method further additional parameters should be defined:

Reynolds test for the equipment that does not have a piece material:

$$Ре=wД\rho/\mu \qquad (16)$$

moist air density;

$$\rho_х=\rho_{к.х}+\rho_{буг}=3{,}48\cdot10^{-3}(П-0{,}378\cdot\varphi\cdot P_{тб})/т \quad (17)$$

Reynolds test for the equipment that does have a piece material:

$$Ре=wд_е\rho/\mu \qquad (18)$$

Archimedes criterion for the equipment that has a piece of material

$$Ар=д_е^3\cdot\rho_к\cdot\rho_х\cdot г/\mu_х \qquad (19)$$

Nusselt`s criterion for the equipment with or without the piece material:

$$Ну_\alpha=\alpha Д/\lambda;\ Ну_\beta=\beta Д/к_д;\ Ну_\alpha=\alpha д_е/\lambda;$$
$$Ну_\beta=\beta д_е/к_д \qquad (20)$$

Changes and damping of rotational motion

$$\Delta C=C_б/C_{ох} \qquad (21)$$

Increase in the rotational motion

$$тг\beta=C/(2\pi\cdot P_{ср}) \qquad (22)$$

In these equations: $w_х$ - direct speed of air in straight current; Д - diameter of the device; $\rho_х$and $\mu_х$- air density and dynamic viscosity; α - coefficients of heat and the matter exchange; $д_э$- equivalent diameters of solid particles; $\rho_к$ - density of solids; $\lambda_х$- coefficients of thermal conductivity of the air; $к_д$ – coefficient of diffusion; C - step of rotational flow; $P_{sterniy}$ - average radius of rotational flow.

For piece goods that form rotational movement "г" indicated in the equation (19) serves as a parameter of centrifugal forces of instead of the indicator of gravitational acceleration [7]

On the basis of experimental studies the dependence graph of volume density ratio from the air speed, which is shown in Fig. 3 has been drawn.

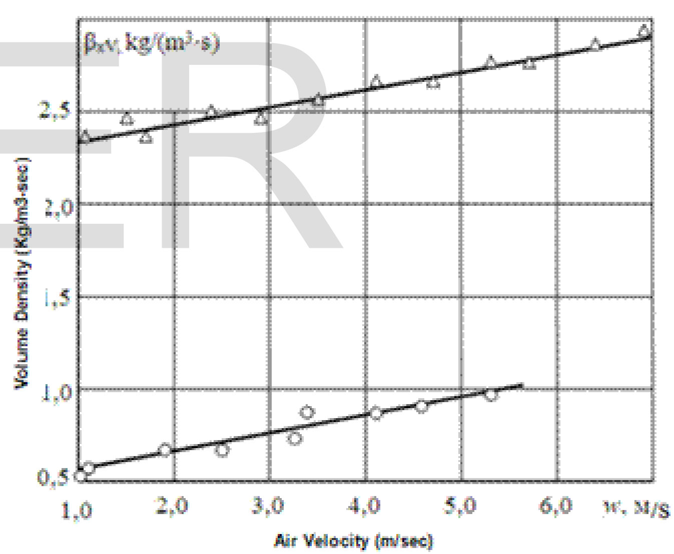

Fig. 3.The dependence of the volume density from the ratio of the air velocity:

1- Two-phased direct current;

2- Two-phase circular current.

The curves show that in certain terms of speed using the centrifugal forces of hydrodynamic effects allows accelerating the matter exchange by 3-4 times. In both cases, increasing velocity provided by air causes gradual and uniform increase in heat and mass transfer coefficients. This phenomenon takes place due to turbulence addition.

The same results were seen in the relation of diffusion criteria of Nusselt and Reynolds, as shown in Figure 4. With the gradual increase of liquid flow at the time of heat and mass transfer it resulted in an improvement in transferring coefficient. It is established that this is due to an increase in flow rate and a decrease in the relative phase velocity. It was revealed that in the heat and mass transfer a huge influence has relative velocities of the phases and their parameters. While monitoring the process slowing of rotational speed on top of the unit was seen.

The following formula for calculating the coefficient of useful action of heat for the liquid phase of the unit is proposed [4]:

$$э=(Ц_{.б}-Ц_{.ох})\cdot 100/(Ц_{.б}-т_{нт.б}$$

Where $Ц_{.б}$ and $Ц_{.ох}$ - the temperature of incoming and leaving water in the unit; $т_{нт.б}$- the temperature of the wet thermometer set at the entrance to the unit.

According to the results of the experiment a correlation coefficient of useful action of liquid and air velocity was revealed basing on which a graph of relation of the criteria of Nusselt and Reynolds was drawn. The graph is presented in Figure 4. This chart makes it possible to analyze the relationship of the efficiency of the air velocity and rotational flow motion.

It was found that the application of the proposed method in practice in the given installation allows you to increase the efficiency for 55-60%. This increase in the efficiency at the straight flowing installation was 25-30%.

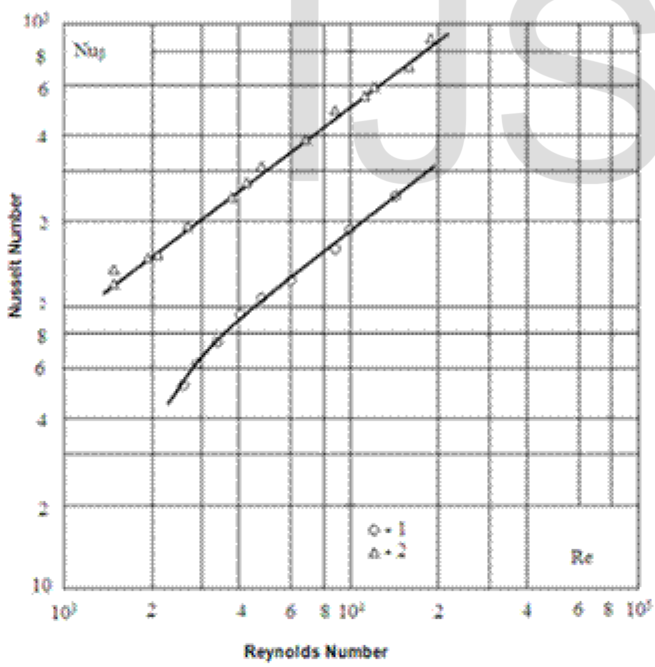

Fig. 4. The dependence of criterion Reynolds's to the Nusselt criterion:
1-Two phase straight flow, 2-Two phase circle flow.

Thus, it is proved that in both cases of increasing the air flow in the device causes a significant increase in efficiency. However, it is observed that with an increase in flow rate the efficiency of the first indicator starts falling. It was found that these facts are related to high operating costs, with the increase in water and heat consumption.

Other research has been focused on studying the process of water steam cooling, which is the product of a mixture of gas and water, which is in the three-phase environment. Where, solids in the form of small spherical pellets of polyethylene are used. According to the research the graph is built, which is represented in Figure 5 and shows the relationship between and the Nusselt and Reynolds criteria.

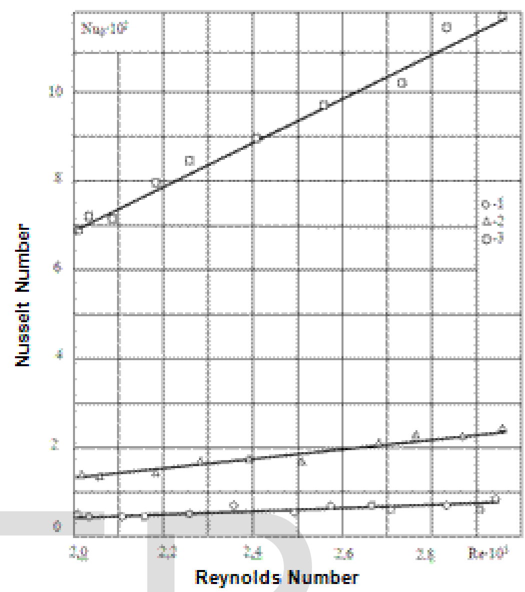

Fig. 5. The relationship of criterion indicators of Nusselt and Reynolds:
1- Two-phase direct current; 2- Two-phase rotatingflow;
3-Three-phase rotating current.

The analysis of figures found that:
-with an increase in criterion indicators of Reynolds elevates and Nusselt also elevated;
-with proper provision of heat and mass exchange in the proposed unit heat transfer in three-phase rotating flow will be 15%, which means it is for 5% more than in the two-phase.

5 Conclusion

It has been revealed that in straight flowing environments where centrifugal forces based on hy

drodynamic effect is used, the heat and mass transfer process is accelerated by 3-4 times. In such cases, an increase in the efficiency of the rotation flow by two times relating to the direct current is observed. It has been established that in the simplified model and the core center of the rotating gas flow, its weakened kinematic and dynamic parameters should be considered as a separate rotating flow. Here has been proposed an advanced design of the device, which provides in condition of proper heat and mass exchange in the offered unit, the three-phase heat transfer rotating flow, as well as the use of a solid piece of pellets which was for 15% higher, which meant that it was 5% more than in the two-phase. The use of polyethylene granules in the water-cooling process in the mining and metallurgical, hydrometallurgical and chemical industries, where a special place is given to preparation of cold water has allowed: i) an increase in the size of the contact surfaces for organizing liquid evaporation process; ii) provide the difference in the gas and pellets velocity which has led to an increase in turbulence; iii) ensure a normal rotational motion of the fluid and its dispersion, which led to an increase in the efficiency of heat and solid matter exchange; Hence it is suggested to implement the same method to similar industrial and laboratory applications.

REFERENCES

[1] Zaminjan A.A., Ramm V.M. Absorbers with fluidized cartridges. –Moscow: Publishing House "Chemistry", 1980. -184 p.

[2] Laptev A.G., Nikolaev N.A., Basharov M.M. Intensification and modelling methods heat and mass exchange apparatus. - M.: Heat techniques, 2011. -335 p.

[3] Берман L.D. Evaporative cooling of circulating water. - M.: Energy edition, 1949. -447 p.

[4] Laptev A.G., Vedgaeva I.A. The device and calculation industrial cooling stack. - M.: Kazan university, 2004. -180 p.

[5] Ponomarenko V. S, Arefyev J.I. cooling stacks of The industrial and power enterprises. - M.: energy atom edition, 1998. -264 p.

[6] Gladkov V. A, Arefev J.I., Ponomarenko V. S. Ventilatory cooling stacks. -M: building edition. 1976. - 186 p.

[7] Todes O. M, Tsitovich O.B. apparatus with boiling granular layer. –L: Publishing House "Chemistry", 1980. -184 p.