Performance Analysis of a Small-Sized Screw Cooling Tower

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Abstract. In this Article describes analysis of efficiency, i.e. analysis of coefficient of thermal- and mass transfer, which carried out thanks to increase of time of phases interaction in developed cooling tower with a spiral air flow. There is given a description of the construction of effective the small-size cooling tower with the spiral type airflow. The main difference of the cooling tower of the existing constructions of that the sprinkler, made of layers of cylindrical polymer cellular pipes, laid on screw line, alignment to the current of the screw type airflow. The small-size cooling tower operates as following: the water, heated at technological process from the closed loop of system is brought to water distribution system. It is distributed evenly on all square of the sprinkler laid on the screw, in which take place a heat and mass transfer of the water and air spiral type flow, which is create by the fan. There is a swirling of the gas phase the tangential feed of the cooling air flow in the bottom of the cylindrical small-size cooling tower, and it can be described by two elements of speed: rotational and translational. Such action allows to intensify a heat and mass transfer processes.

1. Introduction
At using in processes and equipments of chemical technologies of recycled water supply, quality of manufactured products depends on physicochemical properties and temperature of a recycled water. In chemical industry enterprises water is use as a refrigerant, which cools an equipment, for example, to condensate of substances in heat exchangers, where water heats and in some cases fouled by this substances [1-4]. In most cases to cooling of water, heated at process are used cooling towers. Then after cooling and if necessary of clearing, most of water is return to the system.

To date one of the actual method is search of scientific and technical solutions, which allow to change existing systems of industry enterprises to local systems of recycled water cooling (mini cooling towers), which are more mobile, service a specific technologic facilities and devices, less power-consuming, are effectives and ecologically safe.

In result of made analysis of the exist constructions of small-size cooling towers, it can be name the following common disadvantages: difficult of make; low efficiency due to short-term contact of interacting flows; high level of noise; a high index of drop entrainment; a high coefficient aerodynamic resistance of a sprinkler device and cooling tower.
2. Materials and methods

It is offer a construction of small-size cooling tower with a spiral flow of cooling air to increase contact time, which allows to increase an efficiency of heat-mass exchange process thanks to that the airflow is "twisted" [5-8]. At a tangential supply of cooling airflow in the bottom part of cylindrical small-size cooling tower, will form a spiral motion of gas phase. As move of airflow up on the cooling tower, a rotational speed will decrease, and a vertical speed- will increase (Figure 1).

![Figure 1. Distribution of air flow speeds.](image)

In top part of the cooling tower, a rotation of airflow is absence almost, and it moves progressively vertically up. Such move of airflow allows to decrease a vertical speed, and it result to increase of time of interacting phases contact.

3. The study

To estimate of changing of rotational and translational elements of the speed by height of cooling tower, we will use the continuity equation at the cylindrical coordinate system, axes z, which is coincides with the axis of symmetry of the cylindrical cooling tower:

$$\frac{1}{r} \frac{\partial}{\partial \theta} \mathcal{G}_\theta + \frac{\partial}{\partial z} \mathcal{G}_z = 0, \tag{1}$$

where $r$– is a distance from axis of rotation, m;

$\mathcal{G}_\theta$– rotational element of the speed, m/s;

$\mathcal{G}_z$– vertical element of the speed, m/s.

A speed of rotation motion will determine by the ratio:

$$\mathcal{G}_\theta = \omega \cdot r, \tag{2}$$

where $\omega$ - a radial speed of rotation of the airflow, rad/s.
Considering that the element of air speed at inlet of the cooling tower is 0, and by increase of height it will increase, we will search a decision of the equation (1) as:

\[ g_z = \frac{4G_v}{\pi D^2} \left( \frac{z}{H} \right)^n, \]  

(3)

where \( G_v \) - air volumetric flow, \( m^3/s \);
\( D \) – cooling tower diameter, \( m \);
\( H \) – cooling tower height, \( m \);
\( n \) – exponent.

Substituting the expressions (2) and (3) to the continuity equation, will get:

\[ \frac{\partial \omega}{\partial t} + \frac{4G_v}{\pi D^2} \frac{z}{H^n} \omega = 0. \]  

(4)

Entering the symbol \( K=\frac{4G_v}{\pi D^2} \) and considering that \( \frac{\partial \theta}{\partial t} = \omega \frac{\partial t}{\partial t} \) \( (t \) – time of airflow motion in cooling tower), the equation (4) will as follow:

\[ \frac{1}{\omega} \frac{\partial \omega}{\partial t} + \frac{Kn}{H^n} z^{-1} = 0. \]  

(5)

Solving the equation (4) we can determine a change radial speed of airflow on height of the cooling tower and also time of stay in air flow in it:

\[ \omega = \omega_0 e^{Kn \frac{z}{H^n}}, \]  

(6)

where \( \omega_0 \) will determine by the constructive parameters of cooling tower:

\[ \omega_0 = \frac{4G_v}{\pi d^2 R}. \]  

(7)

where \( d \) - diameter of inlet pipe, \( m \);
\( R \) - cooling tower radius, \( m \).

As we can see from the last ratio, as move up on the cooling tower, an angular velocity will decrease in accordance with a exponential rule. Considering that at \( z = H \), will determine a characteristic staying time of airflow in the cooling tower \( \omega \rightarrow 0 \)

Similarly with a determination of time of transients we will get:

\[ \omega(z = H) = \frac{\omega_0}{e} \rightarrow 0. \]  

(8)

At the same time, a characteristic staying time of airflow in the cooling tower will determine by follow formula:

\[ t = \frac{5H}{Kn}. \]  

(9)
Knowing time of air flow staying in the cooling tower, we can determine an average longitudinal speed of move on height:

$$\langle \theta_t \rangle = \frac{H}{t} = \frac{Kn}{5}. \quad (10)$$

An average speed on height also can be calculated by the formula:

$$\langle \theta_t \rangle = \frac{1}{H} \int_0^n 9(z) dz = \frac{1}{H} \int_0^n K \left( \frac{z}{H} \right) dz = \frac{K}{n+1}. \quad (11)$$

Comparing the expression (10) and (11), we will get a ratio to determine of exponent index n:

$$\frac{n}{5} = \frac{1}{n+1}, \quad (12)$$

from which follow, that \( n = 1.79 \).

Thus, in a cooling tower with a tangential input of the cooling air is realise "twisted" move of air flow, wherein a radial speed of rotation is decreased on height of the cooling tower in accordance with the exponential rule (6) and a linear speed is increase with increasing of z-coordinate in accordance with power law:

$$\theta_z = \frac{4G_z}{\pi D^2} \left( \frac{z}{H} \right)^{1.79} \quad (13)$$

Considering, that a time of a flow in cooling tower is related with the coordinate z by formula \( t = z/\langle \theta \rangle \), it can be convert ratio (6) to determine of angular rotation speed:

$$\omega = \omega_0 e^{-\left( \frac{z}{H} \right)^{n}}. \quad (14)$$

To estimate of work efficiency there was developed and made the experimental facility of spiral type small-size cooling tower with twisted airflow (Figure 2).

4. Conclusion

On base of got data were calculated coefficients of mass transfer and heat transfer, which for studied spiral type mini cooling tower are more than the coefficients of mini cooling tower counter of flow type of the same size in 20%.

At distribution of speeds of airflow in small-sized cooling tower with tangential supply of air, as move up of air, a rotational speed will decrease in accordance with the exponential rule (6), but a vertical speed is increase in accordance with the power law (13). It result to increase of time. It result to increase of contact time of heat exchanging phases and as follow from made experiments, that such move increase coefficients heat- and mass exchange processes compared with a cooling tower of counter flow type.
Figure 2. Small-size cooling tower with twisted airflow.
1 - framework, 2-fan, 3-tangential branch pipe, 4-feeder, 5-water catchment tank, 6-output branch pipe for water, 7-water-irrigate system, 8-water trap, 9-output branch pipe for air.

Experimental data were compared with got data on the facility with counter-current movement of air and water flows.

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