The analysis of the process in the cooling tower with the low efficiency

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Abstract. We put quite a difficult task maintaining a temperature drop to 11-12 degrees at thermal power plants to ensure the required depth of cooling of vacuum in the condenser, cooling towers. This requirement is achieved with the reducing of the hydraulic load with the low efficiency of the apparatus. The task analysis process in this unit and identify the causes of his poor performance was put in the work. One of the possible reasons may be the heterogeneity of the process in the volume of the apparatus. Therefore, it was decided to investigate experimentally the distribution of the irrigation water and the air flow in the cross section of industrial cooling towers. As a result, we found a significant uneven distribution of flows of water and air in the volume of the apparatus. We have shown theoretically that the uneven distribution of irrigation leads to a significant decrease in the efficiency of evaporation in the cooling tower. The velocity distribution of the air as the tower sections, and inside sections are interesting. The obtained experimental data allowed to establish the internal communication: the effects of the distributions of the density of irrigation in sections of the apparatus for the distribution of changes of the temperature and the air velocity. The obtained results allowed to formulate a methodology for determining process problems and to develop actions on increase of the efficiency of the cooling tower.

The maintaining at a predetermined level of the vacuum condenser of the steam turbine is ensured by the cooling capacity of cooling towers. In the conditions of the low efficiency of the apparatus, you can resort to the reduction of the water consumption to achieve the required cooling temperature. Presumably the reason may be in the uneven flow distributions in the cooling tower. The occurrence of irregularities are usually due with various factors – from errors in the design to violations of constructions during the operation of the apparatus. Thus, the reduction of the contact of liquid and gas phases can lead to a significant reduction of the thermal efficiency of the cooling tower [1]. Therefore, the aim of this work is the experimental study and the analysis of uneven distributions of irrigation water and air flow at the sections of the cooling tower in the cooling efficiency of the apparatus. In summer, when the ambient temperature is 25 – 31 degrees, measurements of the density of irrigation water were operated on the cooling tower with the irrigation area of 2600 square meters and its hydraulic load 8840 TPH. The positions of each section of the apparatus, a measuring vessel is fixed in the end with the help of the telescopic pipe, were obtained with the time of the filling this tank with water. According to the obtained results, the density of irrigation was calculated. In each half of section 7 positions were chosen (in the Figure №1 the 2-d section and positions of measurements is showed). As you can see from the Figure №1, the positions of the measurements belong to the most part of the cross-sectional area of the section that allows to judge about the representative data.
Three parallel experiments were carried out to obtain reliable and reproducible results. The obtained experimental values are normalized to average values and are represented as histograms of the distributions for each section (Figure №2) and the radius of the apparatus (Figure №3 shows the distribution of neighbor sections). These data were combined into a histogram (Figure №4), according to which the average density of irrigation of the cooling tower was equal to 3.4 m/h, the unevenness of the density of irrigation was 30%. The mean square error was calculated to assess the accuracy of measurement, which was equal to 0.0335 m/h or 1.015% of the average. Data on the density distribution of irrigation subject to the normal law of distribution, which is confirmed by a test of hypothesis for goodness of fit Pearson. It should be assumed that a obtained significant degree of irregularity should affect the operation of the cooling tower.

Figure 1. The position measurements of the density of the irrigation

Figure 2. The sectional density of the distribution irrigation $q$

Figure 3. The radial distribution of the density of irrigation $q$ in 2 sections
Figure 4. The static density of the distribution of the density of irrigation $q$ of the cooling tower

In the next stage of research was decided to find out how this irregularity affects the primary process – water evaporation in the apparatus. The unevenness of the static function $f(u)$ was proposed to account mathematically by adopting the average irrigation density $U$ of a continuous random variable, where the density of irrigation was varied from 0 to $w$ [2]:

$$U = \int_{0}^{w} uf(u)du.$$  

(1)

In addition, if the intensity of the evaporation in the cooling tower is characterized by an average mass transfer coefficient $H$, it can be expressed as a formula based on the average density of irrigation:

$$H = BU^m.$$  

(2)

where $B$ is a constant value, $m$ is the indicator of the degree of non-uniformity of the average density of irrigation.

The index $m$ is a measure of the efficiency of the mass transfer in the cooling tower and proof of the relationship between the intensity of the mass transfer and the density of the distribution of irrigation:

$$m = \frac{\ln \int u^n f(u)du}{\ln \int uf(u)du}.$$  

(3)

So it is established that, for example, the index $m$ is decreased under the normal law of distribution of density of irrigation, with increasing dispersion of the distribution, and it means that the speed of evaporation falls.

The experimental study and analysis of the causes of the uneven density of the distribution of irrigation water has allowed to establish:

1) the presence of significant uneven density of the distribution of irrigation water;

2) about the significant influence of non-uniformity of irrigation on the evaporative capacity of the cooling tower;

3) about a malfunction of the water distribution system.

Further, a study and an analysis of the distribution of air flow were conducted. For this, we investigated the non-uniformity of air distribution over the cross section of the apparatus. Under equal conditions as in the experimental study of the distribution of irrigation water, measurements of air
velocities in the cooling tower were made. So, the speed of the incoming air is locked in the positions of each section of the apparatus using the telescopic tube with a digital anemometer AM-4206, in the cross section of the irrigation space. Four positions of the measurements were chosen in each half of the section (Figure №5). The positions of measurements of air speed were chosen such that they were in the position measurements of the density of irrigation. Therefore, the experimental data can also be attributed to a number of the representative data.

Three parallel experiments were made for reliable accuracy. The air flow distribution was shown with the help of histograms of the sectional and the radial distribution of air velocity (Figure №6 and Figure №7).

According to this it can be argued that the device has a significant sectional and the radial nonuniform distribution of the air flow. The experimental data showed that the average air velocity is equal to 1.27 m/s, and its unevenness is equal to 32% and 24% of the sectional and radial distribution. The root mean square error of the measurements was 0.0489 m/h or a 3.85% average. Further, the analysis was researched of the causes of the established irregularity:

1) the effect of non-uniformity of the density of irrigation water;
2) the effect of wind;
3) the impact of malfunction of sprinkler units of the cooling tower.

We will analyze the influence of non-uniformity of the irrigation on the uneven distribution of air. Polygons of the distribution frequency is constructed for the clarity in the histogram of the sectional and the radial density distribution of irrigation water and the air flow (Figure №2, Figure №3 and Figure №6, Figure №7), according to which one can detect the connection between the irrigation water and the air flow. For example, from section №1 to section №3, there is an increase in the density of the irrigation, while the air flow in these sections is the nature of the reduction. A similar relationship of the distribution of phases is observed in other sections of the apparatus.

Based on the results of the uneven distribution of liquid and gas phases, the regression model of dependence of the air flow $W$ from the density of irrigation $q$ was obtained (Figure №8).

![Figure 8](image)

**Figure 8.** The dependence of the air flow $W$ from the density of irrigation $q$ of the tower

The dependence is described with the regression equation of the parabolic type:

$$W = 0.334q^2 - 2.99q + 7.584.$$  \hspace{1cm} (4)

The correlation coefficient of regression was 0.47, which indicates about a weak power connection of the air flow rate and the density of irrigation. However, it does not exclude the established connection. Laboratory studies were conducted in order to verify this dependence. Measurements of the density of irrigation $q_{wci}$ and air speed $W_{wci}$ were conducted in the laboratory of Kazan State Power Engineering University, in a pilot plant cooling tower WCI – 0.3. The experimental procedure was the following: a setting bowl was filled with water for the performance of the circulation system. Speed with different water flow rates were chosen on the circulation pump circulating system, which were calculated the corresponding values of the density of the irrigation. At the same time, the intake air flow rate measured at the inlet of the air duct windows. Four repeated experiments were conducted with the aim of reliability of precision. Data were averaged for which the dependence of the speed of the air flow $W_{wci}$ of the density of irrigation $q$ (Figure №9).
Figure 9. The dependence of the air flow $W_{wci}$ from the density of irrigation $q_{wci}$ of the laboratory setup

The regression equation of parabolic type with a correlation coefficient of 0.44 is obtained as a result of processing of the experiment:

$$W_{wci} = 0.012q_{wci}^2 - 0.195q_{wci} + 2.36.$$  \hspace{1cm} (5)

Thus, the proof of the dependence of the air flow $W$ from the density of irrigation $q$ of cooling towers at the laboratory unit is obtained. A weak correlation coefficient also says that in addition to the distribution of the density of irrigation on the distribution of the air flow is influenced with the wind speed and malfunction of sprinkler units. Also, preliminary studies of the effect of wind velocity on air distribution in sections of the cooling tower were carried out.

Therefore, the distribution of the air flow allows you to:

1) to calculate the total air flow;
2) to establish the malfunction of sprinkler units;
3) to determine the effect of the wind.

Along with measurements of the density of irrigation, at the same time the temperature of the water at the level of the nozzles in the water distribution system and at the level of the cooling tower basin was removed. The instantaneous temperature of cooling water was recorded using digital thermometer with a remote sensor, lowered into the measuring vessel. The regression model of dependence is built on the basis of experimental data on the density of irrigation $q$ and the temperature drop of water $\Delta T$ (Figure №10).
The dependence is described with the regression equation of the parabolic type:

$$\Delta T = 0.279q^2 - 4.46q + 23.3.$$  \hspace{1cm} (6)

The correlation coefficient of regression is 0.87, which confirms the high degree of correlation of the temperature difference and the density of irrigation. The regression model of dependence allows to obtain the dependence of the cooling capacity of the cooling tower sections, which are «weak» and «strong» sections are determined. Thus, the established relationship and the results obtained can be used to establish problems and malfunctions of cooling towers poor performance, and when carrying out engineering calculations. On the basis of it, technical solution to reduce the uneven density distribution of irrigation and air flow is advanced. The problem of optimization of flow distribution in the cross section and increase the cooling capacity of the cooling tower based on the uniformity of flow along the radius of the device is supplied. The elimination of unevenness of distribution of liquid and gas phases will increase the cooling capacity of cooling tower and therefore, the efficiency of the plant.

References

[1] Berman L D 1949 *Evaporative cooling of circulating water* (Moscow: State energy publishing house) p 440
[2] Gmurman V E 2003 *Theory of Probability and Mathematical Statistics* (Moscow: High School) p 2003

Figure 10. The operational characteristics of the cooling tower