Aerodynamic and hydroaerothermic tests of cooling tower sprinkler

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Abstract. Industrial water supply systems are designed to supply water to production in the required quantities and of the appropriate quality. They consist of a complex of interconnected structures - water intake devices, pumping stations, installations for cleaning and improving water quality, control and spare tanks, water coolers and a distribution network of pipelines. Depending on the purpose and local conditions, some of the listed structures may not be available in the system. The temperature regime of any production is carried out using recycled water systems, most often equipped with fan and tower cooling towers. The main element of all types of cooling towers, affecting the efficiency of the interaction of the droplet liquid with the ascending air flow and, accordingly, the efficiency of the cooling towers, is the sprinkler. This article describes the design of the polymer drip-film sprinkler of cooling towers, and also presents the results of aerodynamic and hydroaerothermic studies of this nozzle design.

1. Introduction

Water in industry and energy is used to condense and cool gaseous and liquid products of chemical and petrochemical industries, to condense exhaust steam after expanding it in steam engines, to remove heat from oil coolers and equipment in order to protect it from rapid destruction under the influence of high temperatures (for example, compressor cylinders, masonry production furnaces) [1-5].

The consumption of fresh water in industry can be significantly reduced due to the transfer of production to wasteless, anhydrous or low-water technologies. However, many production processes do not always fully allow the use of such technologies. Then, cooling water recycling systems with cooling towers of various types and designs come to the fore in the implementation of the task of saving water in industry [6-11].

Devices for cooling water with its direct contact with air (cooling towers) are currently widely used in all industries where there is a need for cooling circulating water. The use of cooling towers is enormous.

They are used:

- in the energy sector (cooling towers of thermal and nuclear power plants with a cross-sectional area - irrigation up to 9400 m²).
- in metallurgy (cooling of ingots).
- in the gas, petrochemical industry, in mechanical engineering (equipment cooling with circulating water).
• in the food industry (for condensation of refrigerants in refrigeration units) [12].

The creation of recycled water supply systems using cooling towers allows reducing the costs of enterprises for the consumption and discharge of industrial water, increasing the efficiency of using equipment, so that the costs of acquiring, transporting and installing the cooling tower pay off within a few months. At the same time, such systems allow solving current environmental problems.

The cooling effect in the tower is achieved by evaporating -1% of the water circulating through the tower, which is sprayed by nozzles and flows into the tank in the form of a film through a complex system of irrigation channels to meet the flow of cooling air pumped by fans.

Basically, the efficiency of the process of cooling the circulating water on the cooling towers is determined by nozzle devices (sprinklers) designed to provide the necessary phase contact surface with minimal aerodynamic and hydrodynamic drags.

Currently, a wide variety of designs of cooling tower sprinklers is known, however, due to the fact that in industry there is a tendency to replace products from traditional materials (wood, asbestos cement) with polymer products with various sizes and cross-sections, the demand for which increases as in the domestic and in the global market, there is a need to create new highly efficient and technologically advanced constructions of cooling tower irrigators made of polymer materials. At the same time, irrigation devices in each particular case must comply with the technical requirements of state and industry standards in relation to cooling capacity at minimal cost [13-20].

The value of the pressure loss during the movement of air in the sprinkler is also an integral indicator of its operation, since it characterizes the operating costs of the tower. It is necessary to take into account a number of other indicators - durability, material wear, strength and weight of the sprinkler, ease of installation, the availability of repairs and inspections, as well as the presence of suspended solids and aggressive impurities in the cooled water.

2. Results
At the Department of Equipment for Petrochemical Plants, a branch of the Ufa State Petroleum Technical University in Sterlitamak, the design of a tower sprinkler has been developed (figure 1, 2), which is a module of layers of polymer mesh shells 1 made of cylindrical shells placed in all vertical layers parallel to each other and welded along the ends of the module between each other in places of contact, and horizontally lying corrugations are installed in each row of vertically placed mesh shells pipe 2 in a ratio of 1 to 2 to 1 for each subsequent row.

![Figure 1. Sprinkler cooling tower with a diameter of the mesh shell and corrugated pipe 45 mm (OGGT-45): 1 - mesh shell; 2 - corrugated pipe.](image)

To study the main technological characteristics of the developed design of the tower sprinkler, aerodynamic tests were carried out to determine the aerodynamic drag coefficient of irrigation devices...
in the self-similar region, its dependence on the flow rate (irrigation density) of water and air flow rate (air flow rate).

Hydroaerothermal tests of irrigation devices were carried out with the aim of determining volumetric heat and mass transfer coefficients based on a set of obtained data, which includes parameters of water passing through the installation (flow rate, temperature of hot and chilled water) and air (flow rate, temperature and relative humidity at the inlet, barometric pressure).

Aerodynamic and hydroaerothermic tests of irrigators were carried out independently from each other with the corresponding preparation of the experimental stand shaft, equipment and measuring equipment.

![Figure 2. Sprinkler cooling tower with a diameter of the mesh shell and corrugated pipe 65 mm (OGGT-65): 1 - mesh shell; 2 - corrugated pipe.](image)

The experimental setup (figure 3) worked as follows:

![Figure 3. An experimental setup for the study of hydroaerothermic and aerodynamic characteristics of cooling tower irrigators: 1 - fan; 2 - pump; 3 - heating devices; 4 - a container with hot water; 5 - water distribution system; 6 - test sprinkler of the cooling tower; 7 - container with chilled water; 8 - vertical shaft (installation casing); 9 - measuring instruments; 10.1-10.6 - shutoff valves.](image)

Using a circulation pump 2, water was supplied to the hot water tank 4. Water was heated to the required temperature and supplied through the pressure pipe, bypassing the electro-acoustic flow transducers into the water distribution system 5 of the mine of the experimental unit 8. The water distribution system uniformly distributed the water flow over the irrigation area of the mine working section, where the test fragment of the irrigation device 6 was installed. The oncoming air flow in the installation shaft was created by a centrifugal fan 1 and a duct system. The air passed through the air
inlets located on all sides of the shaft, then through the working section with an irrigator, a water distribution system and through the air ducts it was vented to the atmosphere. The height of the air inlet windows was limited by the lower part of the working section of the shaft and the upper part of the drainage tank 7. In the volume of the tested irrigation device, the most intense processes of heat and mass transfer between the flowing hot water and the upward flow of cold air took place. Cooled water in the sprinkler flowed into the catchment tank installed in the lower section of the experimental plant shaft, from where it was again pumped into the pressure head supply pipe and hot water tank.

The elements of the tested irrigation device create resistance to the ascending air flow, measurements of the corresponding pressure drop were carried out using piezometric tubes and a manometer.

The initial water temperature $t_1$ was measured directly above the sprinkler; chilled water temperature $t_2$, air flow rate $\omega$ - under the cooling tower sprinkler. Irrigation density $q_w$, barometric pressure $\rho_w$ and air temperature were also measured using a wet thermometer $\tau$.

In practice, the final results of determining the heat and mass transfer coefficients are usually presented in the form of a relationship connecting two dimensionless complexes - the evaporation number $K_e$, the relative air flow $\lambda$.

The relative air flow was determined by the dependence:

$$\lambda = \frac{\sigma_a}{\sigma_w},$$

(1)

The dependence of the evaporation number on the relative air flow was most accurately approximated in a power-law form:

$$K_e = A_p \lambda^m$$

(2)

This dependence is sufficient to calculate the mass transfer and heat transfer coefficients.

The aerodynamic drag coefficient of the sprinkler $\zeta_{sp}$ was calculated using the Weisbach formula:

$$\zeta_{sp} = \frac{2g\Delta \rho \rho_w}{\omega^2 \rho_a}$$

(3)

Figure 4. Dependence of the number of evaporation $K_e$ on the relative air flow $\lambda$.
Based on experimental studies of the aero-hydrodynamic characteristics of irrigation blocks from polymer mesh shells, the following empirical dependencies were obtained to determine their main technological characteristics:

\[
\Delta P = \left[ K_1 + K_2 \cdot q \right] \frac{p_a \cdot \omega^2}{\epsilon_{gw}} ,
\]

(4)

Table 1. The values of the coefficients \( K_1, K_2 \).

| Cooling Tower Sprinkler | Coefficient \( K_1 \) | Coefficient \( K_2 \) |
|--------------------------|------------------------|------------------------|
| OGGT-45                 | \( K_1 = 0.97\omega^2 - 5.31\omega + 21.42 \) | \( K_2 = -0.04\omega^2 + 0.2\omega + 0.47 \) |
| OGGT-65                 | \( K_1 = 0.85\omega^2 - 4.17\omega + 17.34 \) | \( K_2 = -0.04\omega^2 + 0.17\omega + 0.13 \) |
To determine the hydroaerothermic characteristics and the cooling ability of the sprinkler, the following were measured:

- air velocity in the free section of the tower above the sprinkler \( \omega \), m/s.
- irrigation density \( q_w \), m\(^3\)/m\(^2\)h.
- temperature of hot water at the entrance to the tower \( t_1 \), °C.
- temperature of chilled water at the outlet of the tower \( t_2 \), °C.
- barometric pressure \( P_b \), mm Hg.
- air temperature by dry thermometer \( \theta_d \), °C.
- air temperature using a wet thermometer \( \theta_w \), °C.

In addition, 2 more quantities are measured: the area of the sprinkler in terms of \( F \), m\(^2\) and the height of the sprinkler \( h \), m.

Processing of measurement results was carried out according to the formula:

\[
Me = \frac{\Delta t \cdot c_w}{K \cdot \Delta i_{av}},
\]

where

\[
\Delta t = t_1 - t_2;
\]

value \( K \) was calculated as a function of \( t_2 \):

\[
K = 1 - 0.00173 \cdot t_2.
\]

The calculation of the average difference in the heat content of air \( \Delta i_{av} \), according to the method of L.D. Berman was carried out using the formula:

\[
\Delta i_{av} = \frac{(i_1 - i_2)(i_2 - i_3)}{m_1(i_1 - i_1) - m_2(i_1 - i_2) - m_3(i_1 - i_2) - \delta_1 i_1 - \delta_2 i_2 - \delta_3 i_3}.
\]

**Table 2.** Hydroaerothermic characteristics of the irrigators of cooling towers from polymer mesh shells and corrugated pipes.

| Type of sprinkler | \( H_{SP} \), m | Parameters | Conversion factor | RMS errors | \( \sigma_{dry.sp.} \) * |
|-------------------|-----------------|------------|------------------|------------|------------------|
| OGGT-45           | 1.5             | 0.871      | 0.581            | 0.96       | 0.012/0.25       | 15.7 |
| OGGT-65           | 1.5             | 0.739      | 0.493            | 0.94       | 0.011/0.24       | 14.0 |

*) – at air speed \( \omega = 1 \) m/s.

A rather complicated configuration of polymer fibers forming the reticular sheath leads to the need to create methods for calculating its main parameters. So, to determine the linear mass of the retina depending on the diameter of the polymer fibers and their spatial location, the equation is obtained:

\[
m_n = \pi^3 S c \rho \frac{Da}{L^2} \left( \frac{3 + \frac{L^2}{\pi^2 a^2}}{1 + \frac{4\pi^2 a}{L^2}} \right)^{\frac{1}{2}},
\]
The mass of cooling tower sprinkler blocks is calculated depending on their overall dimensions, number and length of mesh shells.

From a practical point of view, the proposed design of the cooling tower sprinkler has the following advantages:

- the design of the mesh shell promotes uniform film-droplet distribution of the liquid over the surface of the irrigator, as well as the self-cleaning process (provided that the inclusions in the circulating water have little adhesion to polymer products);
- effective cooling of the recycled water of industrial enterprises, due to the high contact surface of the phases, will prevent the discharge of process water into natural sources and minimize the recharge of the water circulation system, which will significantly improve the environmental situation of industrial and surrounding areas;
- the sprinkler unit is able to withstand large static loads, due to the high damping ability of the mesh shell;
- in comparison with wood and asbestos-cement sprinklers, the developed designs have a longer service life, which is determined by the properties of the polymeric material used to make the mesh shell;
- due to the low mass of the sprinkler, the supporting structures of the support frame under the sprinkler can be significantly facilitated.
- the design of these irrigators due to the installed inserts additionally turbulent the air flow in their volume, and, therefore, increase the intensity of the heat and mass transfer process.
- reducing the energy intensity of the heat and mass transfer process, namely, reducing the power consumption of the fan is due to the relatively low coefficient of aerodynamic drag of the sprinkler based on polymer honeycomb pipes;
- durability.

3. Conclusions

Analyzing the results obtained, it can be stated with confidence that the use of the presented designs of polymer drip-film sprinklers of cooling towers in the gas and petrochemical industries for the purpose of cooling circulating water with the help of cooling towers seems very promising.

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