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POLYMERIC DROP-FILM SPRINKLERS FOR COOLING TOWERS

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Designs of drop-film sprinklers based on cellular polymeric shells formed by a layer of intersecting cylindrical (or other shape) polymeric fibers are described. The dependence of the evaporation number on the relative flow rate of air is investigated for the designs presented. An empirical relationship is derived for calculation of the pressure drop in the cooling-tower sprinkler, which permits most accurate determination of the load on the fan and the optimal operating conditions of the cooling tower.

The temperature regime of any production process is ensured by the use of circulating water-supply systems normally equipped with mechanical-draft and chimney-type cooling towers.

Closed autonomous water-supply systems [1], which provide for delivery of water to a production process with the required volumes and appropriate quality, function for the purpose of rational utilization of water resources at industrial establishments, since water cooling is currently most economically expedient for basic and auxiliary equipment.

Industrial water-supply systems consist of a set of interrelated structures – water intakes, pumping plants, and installations to clean and improve the quality of the water, which regulate both the reserve tanks, water coolers, and distributing network of pipelines. Some of the enumerated structures cannot be used in the water-supply systems, depending on the purpose and local conditions [2].

The circulating water that passes through the production cycle is cooled to the required temperature in chimney-type or mechanical-draft cooling towers. The requirements set forth for the temperature of the circulating water by various industrial establishments depend on the production process and operating properties of the equipment. A temperature in excess of that regulated for the circulating water will lead to reduction in output of production and degradation of its quality.

The effectiveness of the water-cooling process in cooling towers is determined by structural characteristics of the packings (sprinklers), which ensure the required surface area of phase contact with minimal aero- and hydrodynamic resistances.

Despite a wide variety of sprinkler designs for cooling towers, the need currently arises for the development of new highly effective designs adapted to manufacture, which are formed from polymeric materials, since a trend toward an increase in output of articles formed from these materials with different dimensions and cross-sectional shapes is observed in industry.

The sprinklers may be film or drop-film, depending on the character of the dominant cooling surface. Different types of sprinklers may also have extremely different designs of individual components and dimensions.

Results of analysis of familiar structures are used in developing new sprinkler designs for cooling towers. Let us examine the operating principles of the sprinklers and their structural characteristics. In each specific case, the sprinklers should correspond to technical requirements established by government standards with respect to their cooling capacity, and the cost of the cooling tower in which they will be used.

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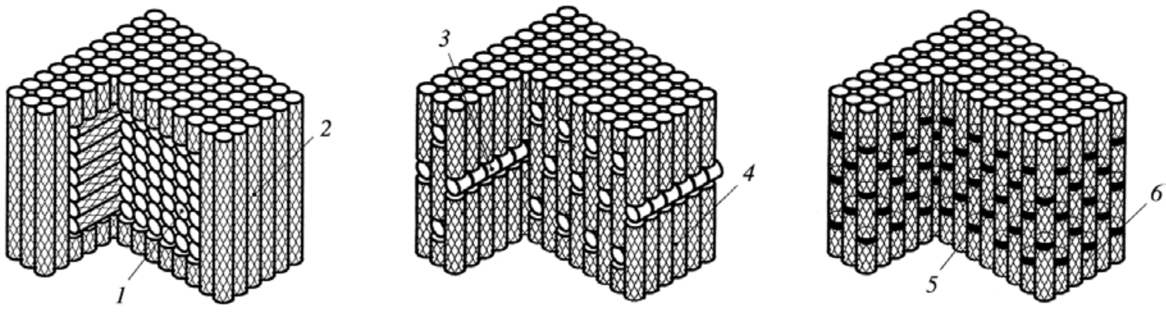

Fig. 1. OGBB-45 (*a*), OGGT-45 (*b*), and OGLZ-45 (*c*) sprinklers for cooling towers: *1*) small module; *2*, *4*, *6*) cellular shells; *3*) corrugated tube; *5*) bladed vortex generator.

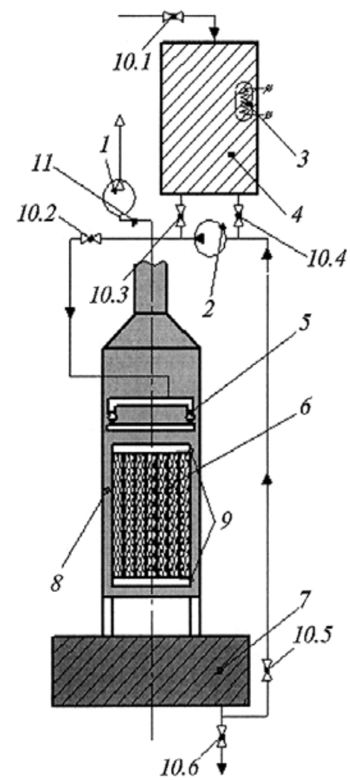

Fig. 2. Schematic diagram of experimental sprinkler: *1*) fan; *2*) pump; *3*) heating units; *4*, *7*) tanks containing hot and cooled water; *5*) water-distribution system; *6*) cooling-tower sprinkler under investigation; *8*) vertical shaft (sprinkler housing); *9*) measuring devices; *10.1–10.6*) shut-off fitting; *11*) anemometer.

Head losses in a sprinkler during the movement of air are important indicators of its operation, which characterizes the operating expenditures for the cooling tower. A number of other sprinkler indicators (longevity, wearability of the material, strength, and weight), as well as the weight of the installation, accessibility for repair and inspection, and content of suspended substances, and impurities of aggressive fluids in the water being cooled must also be considered.

Figure 1 shows sprinklers designed for cooling towers [3–5]. The OGBB-45 sprinkler (see Fig. 1*a*) for a cooling tower is a module formed from cellular cylindrical polymeric shells *2*, which are arranged in all vertical layers parallel one to the other, and which are welded one to the other at points of contact along the ends of the modules. Moreover, the module in question additionally contains small module *1* consisting of similar cellular shells placed in all layers parallel one to the other and directed perpendicular to the shells of the basic module. The small module is rigidly affixed in the basic module by soldering or other means of attachment.

Horizontal corrugated tubes can be established as a component part of each row of vertically situated cellular shells in a 1:2:1 ratio for each of the subsequent rows of vertically placed cellular shells (see Fig. 1*b*). The cellular shell of the cooling-tower sprinkler (see Fig. 1*c*) may additionally contain bladed vortex generators, which are polymeric cylinders, on the inside of which blades are arranged.

The sprinklers for the cooling towers function in the following manner. The circulating water to be cooled is delivered into the sprinkler and travels through it under mass forces as a thin stream along the polymeric cellular tubes. The small module, bladed vortex generator, and corrugated tubes prevent free passage of drop flow in the tube space of the sprinkler, additionally rendering the ascending air flow turbulent and intensifying the heat- and mass-exchange processes; this promotes an increase in the time of contact between the water drops and air flow.

Hydroaerothermal tests of the sprinklers were conducted to determine the volume coefficients of heat- and mass efficiency based on the data set obtained – parameters of the water passing through the sprinkler (flow rate, temperature of the hot and cooled water), and the entering air (flow rate, temperature, and relative humidity at the inlet, and barometric pressure).

The experimental heater consisted of the following basic components (Fig. 2): vertical shaft; water-conducting, water-distributing, water-collecting, water-heating, and air-discharging systems.

The 4.5-m-high **vertical shaft** is assembled from various configurations of metalwork, and serves as a seat for all component parts of the sprinkler, and models the counterflow circuit for the cooling water in the tower. The lateral walls of the shaft are fashioned from sheet polystyrene, and the front face from acrylic plastic; this permits visual observation and monitoring of the water-distribution (redistribution) process in components of the sprinklers.

The shaft consists of an upper section in which the water-distribution system is placed; an effective section for installation of the sprinkler components being tested with a height of up to 1.5 m, width of 0.5, and depth of 0.5 m (sprinkling area of 0.25 m^2); and, a lower section for collection of cooled water and delivery of the air flow. The effective section and section containing the water-distributing devices have appropriate production "doors," which permit unhindered assembly and preventive work. The "doors" are tightly closed during the testing. When necessary, a special assembly platform can be connected to the effective section of the shaft.

A confusor, which ensures equalization of the velocity of the air flow across the section of the shaft serves as a transition from the rectangular upper section to the air duct.

The **water-conducting system** of the sprinkler serves to organize the water-circulation cycle, and also for the installation of primary flow-rate transducers and temperature sensors. A tank containing the hot water, circulation pump, heating devices, pressure conduits, shut-off fitting, surplus-water cock, and tank containing the cooled water are component parts of the system. A frequency power transducer, which permits regulation of the rotational speed of the electric motor and centrifugal pump, and, consequently, smooth variation in the flow rate of water delivered to the cooling-tower sprinkler under investigation, is established in the water line.

The pressure type of **water-distribution system** of the sprinkler serves to distribute the water uniformly over the spray area of the effective section, which is carried out through a tube to the water-distribution grate consisting of four arterial pipelines possessing a row of water-discharge openings.

The **water-collection system** of the sprinkler is designed to collect water cooled in the effective section and discharge it into the tank containing the hot water.

The **water-heating system** serves to heat the circulating water and maintain its temperature at the required level. It consists of three 4-kW water heaters, which are located in the tank containing the hot water. The system makes it possible to establish and maintain the required heating level of the water, and control heating of the water both manually and automatically.

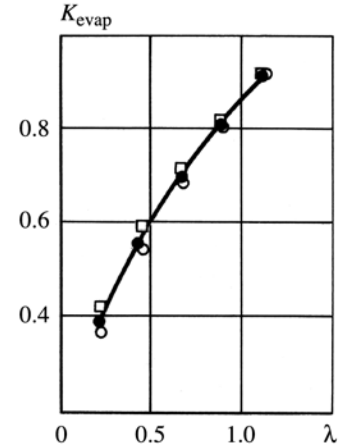

Fig. 3. Dependence of evaporation number K_{evap} on relative flow rate λ of air for sprinklers: ●) OGBB-45; □) OGGT-45; ○) OGLZ-45.

The **air-discharge system** of the sprinkler serves to create an ascending air flow directed into the effective section. A diaphragm is mounted in the discharge air conduit to measure the flow rate of air. Smooth variation in the flow rate of air is ensured by a butterfly-gate valve mounted in the air line.

The experimental sprinkler functions in the following manner. Water is delivered by circulation pump to the tank containing the hot water, heated to the required temperature, and then enters the water-distribution system of the shaft through the pressure line, passing an electroacoustic flow-rate transducer. This system distributes the water flow relatively uniformly across the spray area of the effective section of the shaft in which a segment of the sprinkler being tested is installed.

The air flow encountered in the shaft of the sprinkler is created by a centrifugal fan and system of air lines. Air is sucked through intake ports situated along the sides of the shaft, passes through the effective section with the sprinkler and the water-distribution system, and is carried- off into the atmosphere via air lines. The height of the air-intake ports is limited by the lower portion of the effective section of the shaft and the upper portion of the water-collecting tank.

The most vigorous heat- and mass-exchange process between the flowing hot water and cold air moving toward the flow occurs in the sprinkler. The water cooled in the sprinkler flows into the water-collecting tank established in the lower section of the shaft. From the tank, the water is again delivered via pump into the pressure pipeline and tank containing the hot water. The water-circulating cycle of the hydroaerothermal tests is closed.

In practice, it is accepted to represent the final results of determination of the coefficients of heat- and mass efficiency in the form of a relationship (Fig. 3), linking the two dimensionless sets – evaporation number K_{evap} and the relative flow rate of air λ [6].

This relationship is most precisely approximated in exponential form: $K_{evap} = A_p\lambda^m$, where A_p is an empirical coefficient characterizing the structural characteristics of the sprinkler, $\lambda = G_a/G_l$ is the ratio of the specific mass flow rate of air to the specific mass flow rate of liquid, and m is an exponent reflecting the effect of the mass flow rate of air on cooling of the liquid in the sprinkler design in question.

Empirical relationships for determination of basic production characteristics

$$\Delta p = [K_1 + K_2 q]\frac{\rho_a w^2}{2g\rho_l}$$

were derived on the basis of the investigations conducted for the characteristics of sprinklers fashioned from polymeric cellular shells, where Δp is the total-pressure loss in the sprinkler in m H_2O; K_1 and K_2 are functions of the velocity of the air flow, which depend on the diameters of the cellular shells (presented in Table 1); w is the velocity of the air flow in m/sec;

TABLE 1

Cooling-tower sprinkler	Coefficient K_1	Coefficient K_2
OGBB-45	$K_1 = 0.91w^2 - 4.86w + 20.14$	$K_2 = -0.05w^2 + 0.11w + 0.53$
OGGT-45	$K_1 = 0.97w^2 - 5.31w + 21.42$	$K_2 = -0.04w^2 + 0.2w + 0.47$
OGLZ-45	$K_1 = 0.88w^2 - 4.75w + 19.38$	$K_2 = -0.01w^2 + 0.03w + 0.52$

q is the density of the spray in $m^3/(m^2 \cdot sec)$; g is the acceleration of free fall in m/sec^2; and ρ_a and ρ_l are the densities of the air and liquid in kg/m^3.

The rather complex configuration of the polymeric fibers forming the cellular shell gives rise to the need for development of methods for calculating its basic parameters. Thus, the equation

$$m_{\text{lin}} = \pi^3 S_s \rho \frac{Da}{L^2} \frac{\left(3 + \dfrac{L^2}{\pi^2 a^2}\right)}{\left(1 + \dfrac{4\pi^2 a}{L^2}\right)^{1/2}}$$

is derived to determine the mass m_{lin} of one linear unit of cellular shell as a function of the diameter of the polymeric fibers and their spatial arrangement, where S_s is the sectional area of a polymeric fiber, ρ is the density of the polymeric material, a is the amplitude of the sinusoid of a polymeric fiber, L is the spatial period of the sinusoid, $D = 2na/\pi$ is a parameter dependent on the number of polymeric fibers in the shell, and n is the number of polymeric fibers in the shell.

The mass of the sprinkler units in a cooling tower is calculated as a function of their clearance dimensions, and the number and length of the cellular shells.

A series of designs for drop-film sprinklers based on polymeric cellular shells, which are formed by a layer of intersecting cylindrical (or other shapes) polymeric fibers is proposed on the basis of results of the investigations conducted, and analysis of familiar designs of cooling-tower sprinklers.

The dependence of evaporation number on the relative flow rate of air is investigated for the sprinkler designs presented, and an empirical relationship derived for calculation of the pressure drop in the sprinkler, which makes it possible to determine most precisely the load on the fan and the optimal operating regimes of the cooling tower.

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