Sprinklers of cooling towers

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Abstract. The systems of reverse water supply are one of the most important elements of a technological complex of the enterprises of many industries: chemical, oil processing, petrochemical, machine building, metallurgical, etc. Productivity of processing equipment, quality and prime cost of a product, a specific consumption of raw materials and the electric power depend on quality and overall performance of systems of reverse water supply. Temperature conditions of any production are observed by means of recirculated water supply systems, which are most often equipped with fan and tower cooling towers. This article describes the design of drip-film sprinklers, which are one of the main components of the cooling tower.

1. Introduction

Process water is used in industrial enterprises for condensation and cooling of gaseous and liquid products, for condensation of spent steam after its expansion in steam engines, heat removal 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) [1-7].

With a view to the rational use of water resources in industrial enterprises, there are autonomous, closed-circuit water supply systems designed to ensure the supply of water to production in the required quantities and in the corresponding quantity, since the water cooling of the main and auxiliary equipment is most economically feasible on the next day. Industrial water supply systems consist of a complex of interconnected structures - water intake devices, pumping stations, plants for water quality purification and improvement, regulating and spare tanks, water coolers and distribution network of pipelines. Depending on the purpose and local conditions, some of the listed structures may not exist in the system. In turn, recycled water that has passed the process cycle is cooled to the necessary temperatures in tower or fan the heat exchanger.

Requirements for the temperature of recycled water by various industrial enterprises are dictated by the technological process and operating properties of the equipment, as the excess of the temperature of recycled water from the regulated one leads to the reduction of production and deterioration of its quality. Degree of cooling of water in cooling towers is determined by structural features of packing devices (sprinklers) providing necessary contact surface of phases with minimum aerodynamic resistances. A wide variety of cooling towers sprinkler designs are now known, but since the industry tends to replace traditional materials (wood, asbestos cement) with polymer products with different sizes and cross-sectional shapes, the demand for which is increasing in both the domestic and global markets, there is a need to create new highly efficient and technologically logical structures of cooling tower sprinklers from polymer materials.
Depending on the nature of the prevailing cooling surface, the sprinklers may be: film; drop and film. Each type of irrigation device may have a very diverse combination of individual elements and dimensions. In the process of creating new structures of sprinklers of cooling towers, it is necessary to be analyzed on the basis of analysis of known structures, for which purpose we will consider the principle of their operation, technical features and we will summarize the main information on this problem available in the modern scientific, technical and patent literature. At the same time, irrigation facilities in each specific case must meet the technical requirements of the State standards with regard to the cooling capacity and cost of the cooling tower in which they will be used.

The value of head losses during air movement in the sprinkler is also an acceptable indicator of its operation, as it characterizes the operating costs of the cooling tower. A number of other indicators should be taken into account - durability, wear and tear of the material, strength and weight of the sprinkler, ease of installation, availability of repairs and inspections, as well as content of suspended substances and aggressive impurities in the cooled water [8-20].

2. Results

Thus, the branch of the Ufa State Petroleum Technological University in Sterlitamak developed a series of structures of polymer drop-film irrigation-bodies of cooling towers. The cooling tower sprinkler (figure 1) is a construction 1 of layers of mesh cylindrical elements that are placed parallel to each other and connected at the points of contact. In addition, this design contains in its volume a small block 2 consisting of similar mesh elements.

![Figure 1](image1.png)

Figure 1. Cooling tower sprinkler "unit in unit" (CTSUU-45): 1 - is a construction of polymer mesh sheath layers; 2 - small construction from similar set shells.

Corrugated sheets can also be installed as part of each row of horizontally arranged mesh shells (figure 2, 3).

![Figure 2](image2.png)

Figure 2. Cooling tower sprinkler with corrugated sheets (CTSCS1-45): 1 - is a mesh shell; 2 - corrugated pipe.

![Figure 3](image3.png)

Figure 3. Cooling tower sprinkler with corrugated sheets (CTSCS2-45): 1 - is a mesh shell; 2 - vane swirler.
Hydroaerothermal tests of irrigation devices were carried out to determine volumetric coefficients of heat and mass recovery on the basis of a set of obtained data, which includes parameters of water passing through the plant (flow rate, temperature of hot and cooled water) and air (flow rate, temperature and relative humidity at the inlet, barometric pressure). The experimental plant (figure 4) operates as follows:

![Figure 4](image_url)

**Figure 4.** Experimental installation: 1 - fan; 2 - pump; 3 - heating devices; 4 - hot water tank; 5 - water distribution system; 6 - test sprinkler of cooling tower; 7 - container with cooled water; 8 - vertical shaft (unit housing); 9 - measuring instruments; 10.1-10.6 - isolation valves; 11 anemometer.

The experimental plant consists of the following main elements:

1. Vertical shaft with total height of 4.5 m is assembled from metal structures of different profile and serves for installation of all layout elements in the cooling tower. Side walls of shaft are made of sheet polystyrene. The front side of the shaft is made of organic glass, which makes it possible to carry out visual observation and control the process of distribution (re-limit) of water in the elements of irrigation devices. The shaft consists of an upper section where the water distribution system is located; Working section for installation of elements of tested irrigation devices up to 1.5 m high, 0.5 m wide and 0.5 m deep (irrigation area 0.25 m2); Lower section for collection of cooled water and supply of air flow. Working section and section of water distribution devices arrangement have corresponding technological "doors," which allow to freely carry out installation and preventive works. "Doors" close tightly during testing. If necessary, a special mounting platform is connected to the working section of the shaft. For transition from rectangular section of upper section to air duct confuser is used, which provides equalization of air flow speed along section of shaft.

2. The water supply system of the plant is used for organization of water-circulation CRC, installation of primary flow transducers and temperature sensors. It consists of hot water tank, circulation pump, heating devices, pressure pipelines, shut-off valves, additional water valve and cooled water tank. On the water bringing pipeline the frequency converter of energy allowing to regulate rotation frequency is installed. the engine and the centrifugal pump given by it, thereby smoothly to change a consumption of the water pumped on the studied cooler sprinkler.
3. Water distribution system of the unit - pressure type. It serves for initial-number distribution of water over irrigation area of working section. Water is supplied through pipe to water distribution grid consisting of four main pipe-pipes having a number of water outlet holes.

4. The water collection system of the plant is designed for collection of water cooled in the steam-side section, discharge into the hot water tank.

5. The water heating system is designed to heat the recirculated water and supply its temperature at the required level. The water heating system consists of three 4 kW water heaters in the hot water tank. It allows to set and maintain the necessary level of water heating, to carry out manual and automatic control of water heating process.

6. The air discharge system is used to create a directed ascending who-shower flow in the working section of the plant. To measure air flow rate in the outlet air duct, a diaphragm is installed, and smooth change of air flow rate is performed by means of a gate valve installed in the air duct.

In practice, the final results of determining the coefficients of heat and mass production are assumed to be represented as a dependence linking two dimensionless complexes - evaporation number $K_e$ and relative air flow rate $\lambda$.

Based on the conducted research, the following empirical dependencies were obtained to determine their main technological characteristics:

$$K_e = A_p \lambda^m,$$

where $A_p$ - empirical coefficient characterizing design features of the sprinkler; $\lambda$ - relation of mass flow of air to a water consumption; $m$ - coefficient reflecting the effect of the mass flow rate of air on the cooling of water in a given structure of the sprinkler.

$$\lambda = \frac{G_a}{G_w},$$

where $G_a$ and $G_w$ - specific mass flow rate of air and liquid, kg/(m$^2$s).

**Figure 5.** Dependence of evaporation number on relative air flow rate.

Based on the study of the characteristics of the presented cooling tower sprinklers, the following empirical dependencies were obtained to determine their main technological characteristics:
\[ \Delta P = [K_1 + K_2 \cdot q]^2 \cdot \frac{P_a \cdot w^2}{2g \cdot \rho_w}, \]

where \( \Delta P \) - losses of total pressure in the sprinkler, m of water column; \( K_1, K_2 \) - are airflow velocity functions depending on the diameter of the mesh shells; \( w \) - air flow rate, m/s; \( q \) - sprinkling density, \( m^3/(m^2 s) \); \( g \) - acceleration of gravity, m/c\(^2\); \( \rho_a \) - density of air, kg/m\(^3\); \( \rho_w \) - density of water, kg/m\(^3\).

| COOLER SPRINKLER | Coefficient \( K_1 \) | Coefficient \( K_2 \) |
|------------------|------------------------|------------------------|
| CTSUU-45         | \( K_1 = 0.91\omega^2 - 4.86\omega + 20.14 \) | \( K_2 = -0.05\omega^2 + 0.18\omega + 0.59 \) |
| CTSCS1-45        | \( K_1 = 0.94\omega^2 - 5.45\omega + 20.47 \) | \( K_2 = -0.04\omega^2 + 0.23\omega + 0.41 \) |
| CTSCS2-45        | \( K_1 = 0.82\omega^2 - 4.85\omega + 19.64 \) | \( K_2 = -0.01\omega^2 + 0.03\omega + 0.47 \) |

The rather complex configuration of the polymer fibers forming the mesh shell leads to the need for methods of calculating its basic parameters. So, for determination of running mass of a mesh cover depending on diameter of polymeric fibers and their spatial arrangement the equation is received:

\[ m_n = \pi^3 S_c \rho \frac{Da}{L^2} \left( \frac{3 + \frac{L^2}{\pi^2 a^2}}{1 + \frac{4\pi^2 a}{L^2}} \right)^{1/2}, \]

where \( S_c \) - is the cross-sectional area of the polymer fiber; \( \rho \) - density of polymer material; \( a \) – sinusoid amplitude of the polymer fiber; \( L \) - spatial period of a sinusoid; \( D \) – parameter depending on the amount of polymer fibres in the shell \( (D = 2na/\pi, \text{where } n \text{ – amount of polymer fibres in the shell}) \).

Cooling tower sprinkler blocks weight is calculated depending on their overall dimensions, number and length of mesh shells.

3. Conclusions

Based on the conducted research and based on the analysis of known structures, a series of designs for drip - film cooling tower sprinklers based on polymer mesh elements formed by a layer of intersecting polymer fibers of cylindrical shape is proposed. The main technological characteristics of structures are investigated.

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