Research of coefficient of aerodynamic resistance of a separation nozzle of industrial coolers

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Abstract. Water resources of Russia are a national wealth and not only the level of economic development of the country, but also health of the population depends on their state. Rational use of water resources at the industrial enterprises is provided with the independent, closed water supply systems equipped with devices of vaporizing cooling of water. 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. Capacity of processing equipment, quality and cost of the product, a specific consumption of raw materials and the electric power depend on quality and overall performance of systems of reverse water supply. One of elements of a system of reverse water supply is the cooler. In this article the design of the water catcher of the cooler Application of the Offered Design is described will allow to reduce considerably moisture content in the steam-gas stream released by the cooler into the atmosphere.

1. Introduction
According to the data of the State accounting of water use by the industry of the Russian Federation, about 40 billion m$^3$ of fresh water is spent per year, which is 50% of the total amount taken for the needs of the national economy from water supply sources. This equates to about 20% of the water demand of industrial enterprises. The missing amount (160 billion m$^3$) is provided by re-use of water by cooling and/or purification. Such water is called return or circulation water [1–4].

The main purpose of water in production is as follows:

- water can be a heat carrier when the product is cooled through the wall or when the structures of the unit are protected from destruction (run-out). In both cases, the water is heated during use and is practically free from contamination;
- water may be a environment which absorbs and transports mechanical or dissolved impurities (when washing, enriching and purifying the raw material or product). During use, this water is contaminated with mechanical and dissolved impurities;
- water can be a solvent of reagents used in the preparation of media for floatation of coal, ore or non-ore minerals, etc. In this sludge, as in the chemical preparation of water to produce steam therefrom, the water is converted into process water or solution. Some water is directed to the effluent along with waste reagents and other impurities;
• water can also be used in a complex way - as a medium absorbing and transporting mechanical and dissolved impurities, and simultaneously serve as a tep-carrier (product cooler), for example, in gas purification and the like [2].

In industrial enterprises, some type of water use is prevalent. For example, at thermal power plants, 85% of the total water flow rate is used to cool air, oil, and condensate spent steam; About 12% for hydraulic ash transport (if coal is used as fuel); 3% - for steam preparation. In plants of ferrous and non-ferrous metallurgy the main amount of water is spent for cooling of structural elements of furnaces, rolling mills and machines, some amount - for hydraulic transportation of scale. In the mining industry, water is a medium that absorbs and transports mechanical impurities (rocks) [5-12].

In general, for all industries 70-75% of the total water consumption is used mainly as a heat carrier.

Requirements for the temperature of recycled water by various industrial enterprises are dictated by the technological process and operational properties of the equipment. When choosing the type of cooling towers to ensure this temperature, the possibility of water contamination by the products of the production in the water circulation cycle should be taken into account.

Enterprises of thermal power industry consume two thirds of fresh water taken for industrial needs from water supply sources, with the greatest consumption of it for cooling of technological equipment (96%). However, the water turnover rate in the industry is lower than the industrial average and is about 60% due to the remaining from previous years in many power plants of direct-flow water supply systems. Thus, out of 144 TPP with installed capacity of 215 GW, 45 and 99 work on direct-flow water supply systems.

Exceeding the temperature of recycled water from the regulated water leads to a decrease in production (often up to 15%) and a deterioration in its quality. At the same time, the temperature of the water returned to the return cycle often exceeds the regulated temperature, and enterprises resort to undesirable reception - "refreshment" of the return water supply system, at which the discharge of warm water from the system is increased to 10% or more while simultaneously increasing the consumption of make-up fresh water from the natural source [3].

Industrial consumption of fresh water can be greatly reduced by switching production to non-waste, anhydrous or low-water technologies. However, many manufacturing processes do not always or do not fully allow the use of such technologies. Then cooling systems of recirculated water supply with cooling tower of various types and structures come to the fore in realization of the task of water saving in industry.

One negative factor in the operation of cooling towers is drip waste of recycled water, which contains various chemical compounds specific to production, for example, heavy metal ions, detergents, pesticides, biogenic eles, toxic chemical compounds, phenols, petroleum products, organochlorine and much more. The value of drip carry-over of cooling towers is regulated by SRaR and is defined as water loss due to wind carry-over (in tower cooling towers) and air flow injection by the fan (in fan cooling towers). The value of the permitted carry-over SRaR depends on the type of cooler and the level of harmful (toxicity) water. For cooling towers with water traps this value is 0.05-0.2%, for tower cooling towers without water collectors 0.5-1% [2]. But often even in chemical enterprises fan cooling towers are not equipped with water collectors at all or poor structures are installed because the majority of cooling towers were designed in the middle of the last century, when environmental issues were simply not taken into account, their main components of devices and devices are morally obsolete and do not meet modern requirements. As a result, drip may be 5-7%, resulting in a significant deterioration of the environmental situation of the industrial and surrounding areas. At the same time the makeup of the water circulation system is increased, i.e. excess intake of fresh water from natural sources.

Principle of operation of practically all water collectors consists in deposition on working surface of drops of cooled liquid flying upwards in steam-air flow, which takes place under action of inertial forces arising in flow due to change of direction of its speed. Variation of flow velocity vector is achieved by different structural features of water collectors. In some cases, these may be radial, plate-like wavy or angled elements [13-20].
The efficiency of the process can be improved by:

- Reducing the distance to the surface of the trap on which the liquid is deposited, that is, reducing the distance between the elements of the water trap, which leads to an increase in the resistance of the trap and an increase in the material consumption of the structure;
- An increase in deposition time, which is most often due to an increase in the height of the trapping device;

Increasing the deposition rate by introducing additional forces such as centrifugal or inertial forces.

2. Results
On the basis of analytical studies, the design of the water trap of cooling towers (figure 1, 2) has been developed.

![Figure 1. General view of cooling tower water trap.](image1)

![Figure 2. Section of water catcher element in section.](image2)

The separation water trap comprises tubes of thermoplastic material and represents a module of tube segments 1, Welded along the end surface between the joint and arranged in the module parallel to each other; The pipes may be arranged in both staggered and rectangular order. Each pipe section comprises swirling element 2 with conical flow splitter 3 and trapping element 4 made in the form of hollow truncated cone.
The water trap operates as follows. The water-air flow comes from below the water trap, where it gets on the swirling element with the conical flow splitter, it acquires rotational motion. Zones with different pressure are formed in water-air flow: low pressure zone is formed in axial area, high pressure zone is formed at wall. Due to centrifugal force, the main part of water is pushed to the wall. Upon reaching the catch element made in the form of a hollow truncated cone, water droplets are increasingly pushed towards the wall and flow down.

Studies of aerodynamic resistance of dry packing devices are carried out at the following experimental installation (figure 3).

The experimental plant is located indoors. Air with temperature of 25 °C is forced from the environment by means of 1 fan with electric drive installed on vibration isolation support into process air pipeline with diameter of 150 mm. The air flow rate is measured by means of a rotary gas counter which allows recording of the gas flow rate. Flow rate control is performed by means of relay valve (2) with manual drive. Further, the air flow from below is supplied to the wind tunnel 3, in which the aerodynamic nozzles of the separation nozzles are examined. Confuser 4 is installed in lower part of unit for stabilization and equalization of high-speed air flow in cross section of wind tunnel, as well as for transition from circular section to rectangular section. Air of plane-parallel flow moves vertically from bottom to top through block of ice-tortured drip trap 5. Since the flow area remains constant, due to the resistance generated by the device, head losses, defined as the difference in aerostatic pressures, occur. Pressure control is carried out using a micromanometer. The exhaust air is released into the atmosphere.

Experimental plant for studying aerodynamic characteristics of separation nozzles is a process system consisting of fan, control and measuring equipment, wind tunnel installed on stand, and air ducts.

Below we will present the main technological characteristics of the equipment making up the technological system of the plant for studying aerodynamic characteristics of separation nozzles.

Calculation of the coefficient of aerodynamic resistance of the separation nozzle was produced according to the Weisbach formula:

\[ \zeta = \frac{2\Delta P}{\rho \omega^2} \]  
(1)
where $\Delta P$ - overpressure, Pa;  
$\omega$ - air flow rate, m/s;  
$\rho_x$ - outside air density, kg/m$^3$.

Calculation of overpressure generated by the nozzle is performed according to the formula:

$$\Delta P = K \cdot \rho_x \cdot g \cdot (h_1 - h_2),$$

(2)

where $\rho_x$ - density of operating fluid of micromanometer, kg/m$^3$;  
$K$ - micromanometer constant;  
$h_1$ - height of liquid column at the specified flow rate, mm;  
$h_2$ - height of liquid column at flow rate equal to zero, mm.

Based on the results of experimental studies of fluid movement, the developed packing device in the ascending air flow obtained the following data and experimental results (figure 4).

![Figure 4](image)

**Figure 4.** Dependence of the coefficient of aerodynamic resistance $\zeta$ on the speed of the ascending air flow $\omega$ at different values of the height of the packing device $H$.

3. **Conclusions**

Based on the studies carried out and based on the analysis of the prior art, the design of a cooling tower water trap is proposed. The main technical characteristics of the design have been investigated.

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