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ENHANCEMENT OF RELIABILITY AND EFFICIENCY OF COOLING TOWERS OF NUCLEAR POWER PLANTS

Й.С. Мисак, М.Я. Кузнецова, Т.І. Римар, Ф.Д. Матіко. **Підвищення надійності і ефективності роботи баштових градирень АЕС.** Наведено результати випробувань баштових градирень Рівненської АЕС з метою виявлення зміни їх охолоджуючої ефективності під час тривалої експлуатації шляхом порівняння фактичної температури охолодженої в них води з її розрахунковим значенням, яке визначалось за технологічною характеристикою, що була встановлена в попередній досліджуваний період. З метою встановлення можливості підвищення охолоджуючої ефективності градирень досліджено вплив додаткового збільшення площі зрошування градирень на ефективність їх роботи, а також виявлено вплив протизаморожуючого обігріваючого пристрою на охолоджування води в цих градирнях в літній період. Встановлено, що в порівнянні з попереднім дослідним періодом відбулося погіршення охолоджуючої ефективності градирень через порушення рівномірності зрошення градирень охолоджуючою водою. Це викликано засміченням і виходом з ладу недостатньо ефективних та маломіцних типових розбризкуючих сопел. Підвищення охолоджуючої ефективності градирень вдалося досягти внаслідок збільшення їх площі зрошування, а також в результаті зменшення неорганізованого витікання охолоджуючої води, що дозволило забезпечили більш рівномірну подачу охолоджуючої води на зрошуючі пакети і зниження її температури.
Ключові слова: градирня, охолоджуюча ефективність, площа зрошування, розбризкуючі сопла

J.S. Mysak, M.Ya. Kuznetsova, T.E. Rymar, F.D. Matiko. **Enhancement of reliability and efficiency of cooling towers of nuclear power plants.** Present paper contains results of Rivne nuclear power plant cooling towers testing to define their cooling efficiency change during continuous service by means of comparing the actual temperature of cooled water with the calculated value defined based on technological performance determined for previous testing period. In order to determine the possibility of increasing the cooling efficiency of cooling towers, the effect of extra increase of cooling tower wetting surface on the performance of the tower has been investigated. The influence of antifreezing heater on water cooling in the cooling towers in summer has been detected. It was ascertained that cooling efficiency of the cooling towers decreased in comparison with previous testing period due to the deterioration of uniformity of wetting with cooling water by the sprinklers of the towers. This is caused by clogging and breakdown of insufficiently effective and weak sprinkling nozzles. We managed to achieve the increase of cooling efficiency of cooling towers by means of their wetting surface increase, as well as unorganized cooling water leakage reducing. This enabled to ensure more uniform feed of cooling water on the tower packing and to reduce water temperature.
Keywords: cooling tower, cooling efficiency, wetting surface, sprinkling nozzles

Introduction. The most widespread in Ukraine system for providing NPPs with water and cooling of heated circulating water with the use of natural reservoirs has its own limitations.

This is because during their operation it is necessary to take into account the effect of heated water on the functional state of existing water ecosystems, which is determined by the level of temperature rise.

The effects of increasing of water temperature above the design value (overheating) are characterized by the phenomenon of “thermal pollution” of the water environment. The influence of temperature on aquatic ecosystems depends on the temperature of waste water and the sensitivity of different groups of organisms to it. The increase in water temperature to 28...32 °C for most species of aquatic organisms is threshold. In addition, the use of natural water as a source of cooling water, has another significant drawback. Their cooling capacity depends on the season and significantly decreases in the summer months, which does not allow to guarantee the optimal conditions for the operation of power plants throughout the year. In order to refuse the use of water from natural reservoirs as a cooler, various systems have been developed in which cooling is carried out in towers and which do not have the above-mentioned shortcomings, but require some material costs.

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Thus, the problem of servicing, repairing and modernizing the park of existing cooling towers is particularly relevant. Its solution will reduce the negative impact on nature and increase the reliability of cooling of the recycled water in cooling towers.

Analysis of recent research and publications. The efficiency of the work of the evaporating cooling towers, in which the liquid and gas phases move in opposite directions, depends not only on the parameters of the circulating process fluid (flow and temperature) and on the state of the environment. Significant influence on the cooling process by evaporation also has the rate of ascending air flow and especially its distribution in the volume of the cooling tower [1]. Taking into account these circumstances, it is possible to look for ways to improve the efficiency of cooling towers. This will maximize the benefits of circulating water systems both in the technical as well as in the ecological and economic aspect (reducing the specific consumption of fuel, water, electricity, etc.).

The system of technical water supply (STWS) is a natural-technical complex, which is the main technological element of the low-potential part (LPP) of the power plant. The LPP includes STWS with circulating pumps and coolers, steam turbine condensers, lubricating oil and gas coolers and other common-purpose technological heat exchangers. The main function of the LPP is to provide the turbine units with installed capacity with cooling water and maintain the most favorable (economic) vacuum in the condensers, regardless of the change in their operation modes. The effective operation of the LPP depends on the balance of the parameters of the turbine condensers, circulation pumps, coolers in various combinations with the meteorological parameters of the location of the power plant.

Cooling towers of power plants (Fig. 1) is most appropriate in areas with limited water flow rate [2] because the additional fresh water is used only to replenish water loss through evaporation and its removal from the cooling towers.

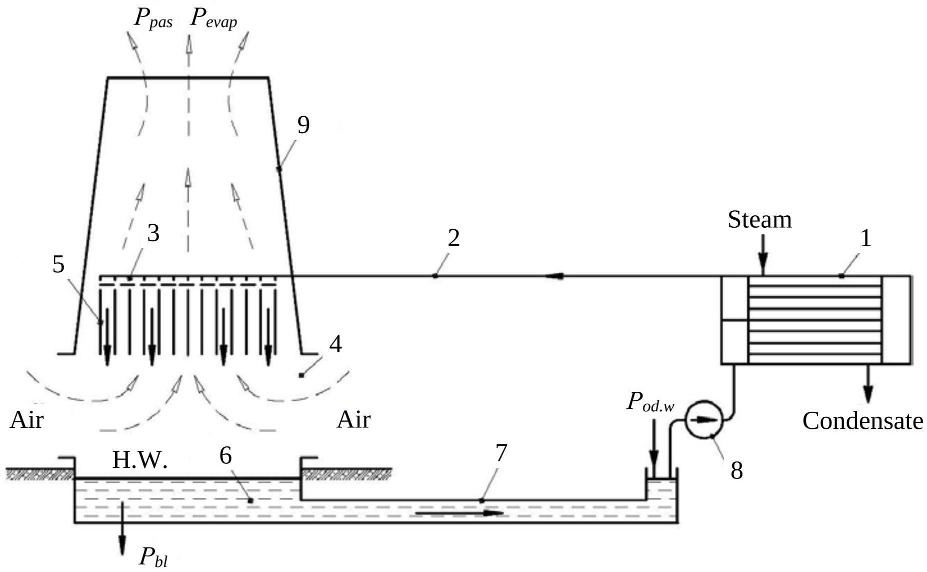

Fig. 1. Circulating water supply system of the power plant with a cooling tower: 1 – turbine condenser; 2 – drainage pipeline; 3 – distribution trough of cooling towers; 4 – air supply; 5 – sprinkling device of cooling tower; 6 – collecting pool of water; 7 – feed channel; 8 – circulation pump; 9 – exhaust tower; HW – the horizon of water; P_{evap} – water loss for evaporation; P_{pas} – loss of water with passing; P_{bl} – blowing of recycled water; $P_{ad.w}$ – additional fresh water

The purpose of the research was to establish the possibility of increasing the cooling efficiency of cooling towers on an example of Rivne NPP.

Presenting main material. The system of technical water supply of the first stage of the Rivne NPP is made of two-lifting reverse with cooling of circulating water in four film cooling towers with an estimated capacity of 100 000 m^3/h each. Cooling towers are included in the scheme in parallel.

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Water supply to the engine room is carried out by a group of pumps installed in two pump stations (BPS-1 and BPS-2), and on the cooling tower – the second group of pumps installed in two separate pump stations (PSG-1 and PSG-2).

To cool the circulating water, high-performance tower coolers are used with wetting surface of 10000 m^2 and exhaust concrete tower of hyperbolic form of 150 m high with the supply of cooling water of pumps of type OPV 10-185 (for cooling towers № 1 and 2) and 170 type DPV-12 / 22EG (on the towers № 3 and 4).

Replenishment of water losses from STVS (take-off, filtration, evaporation, etc.) is carried out from the river, on which the pump station of additional water (SAW) is built.

In order to establish the cooling efficiency of cooling towers and the possibility of raising it, a number of studies were conducted. In accordance with the research methodology, the parameters characterizing the work of cooling towers were fixed, namely: the flow of circulating water, the temperature of the incoming and cooled water, and the meteorological conditions.

Meteorological conditions during the research of cooling towers: the temperature of the outside air for the “dry” thermometer, θ – 10.2...24.5 °C ; relative humidity of air, φ – 50...81 % ; wind speed, W – 0.8...5.6 m/s .

The specific heat load of cooling towers during the test period was 46.3...101.2 Mcal/(m^2 hour).

The placement of measuring devices during the testing of cooling towers: flowmeters, tubular spring manometers and level rails (pressure before nozzles) were installed on the lines of supplying of cooling water to a cooling tower, thermometers for measuring the water temperature were installed at the entrance and exit of the cooling tower.

Cooling towers during the tests worked with the thermal load, which was determined by the dispatch schedule of the electric loading of the nuclear power plant.

Cooling efficiency of cooling towers was evaluated by comparing the actual temperature of the cooled water with its estimated values, which was determined by the investigated technological characteristic. For this purpose, the data obtained during the measurement (water consumption in the cooling tower G, t/hour, air temperature for the “wet” thermometer τ, ° C, relative humidity φ, wind speed W, m/s, water temperature entering in cooling tower t_1, °C, temperature of cooled water t_2, °C) we calculate: the density of sprinkling $q = \frac{G}{F_{spr}} \left(\frac{\text{т}}{\text{m}^2 \cdot \text{hour}} \right)$; water temperature difference $\Delta t = t_1 - t_2$ °C; specific heat load of the cooling tower $q \cdot \Delta t \cdot c$, $\left(\frac{\text{Mk}}{\text{m}^2 \cdot \text{hour}} \right)$. With graphic dependencies, set the temperature of the cooled water t_2' and corrections $\Delta_{q\Delta t}$ °C; $\Delta_{\Delta t}$ °C; Δ_w °C. We calculate $t_2^p = t_2' - \Delta_{q\Delta t} + \Delta_{\Delta t} + \Delta_w$ °C and incomplete cooling $\Delta = t_2 - t_2^p$ °C.

The tests of cooling towers were carried out in two stages. At the first stage, tests of cooling towers № 1–4 were carried out under existing water distribution systems design systems, which are equipped with typical sprinkling nozzles, in which the cup reflector is solid and attached to the nozzle by two holders (racks).

The purpose of the research at this stage was to determine the cooling efficiency of all four cooling towers, to compare the efficiency of the cooling tower №1 with the results of its research in the previous period, to find out the change in the efficiency of the cooling towers № 3 and 4 from the additional installation of asbestos cement sheets as well as the detection of exposure of anti-freezing heating device on cooling water in these cooling towers in the summer.

At the second stage, the research of cooling towers № 2 and 4 was carried out after the equipment of their water distribution systems with new sprinkling nozzles, in which the cup reflector of the nozzle was perforated and attached to the pipe with three holders. The purpose of the research at this stage was to determine the effect of the replacement of sprinkling nozzles on efficiency of water cooling.

Results. Analysis of the obtained results of researches of cooling towers and their comparison with the results of researches of the cooling tower № 1 in the previous study period (the period between the studies is 6 years), showed that in the range of thermal loads 46.3...88.6 Mcal/(m^2·h) and with a temperature cooling zone width of 4.2...8.4 °C, there was a deterioration in the cooling efficiency of cooling towers № 1 and 2, respectively, at 1.1 and 0.7 °C compared with the calculated water temperature for the investigated technological characteristic.

This deterioration of the cooling efficiency was due to the violation of the uniformity of sprinkling cooling towers by cooling water caused by clogging and failure of the inefficient and low-strength typical sprinkling nozzles. Clogging and failure of sprinkling nozzles leads to a reduction of spray torches, which prevents crossings of the bases of sprinkling flares from neighboring nozzles, and as a consequence, there is insufficient sprinkling of the cooling tower (Fig. 2). Such inefficient use of the whole wetting surface reduces the efficiency of the cooling tower in general, especially in the summer.

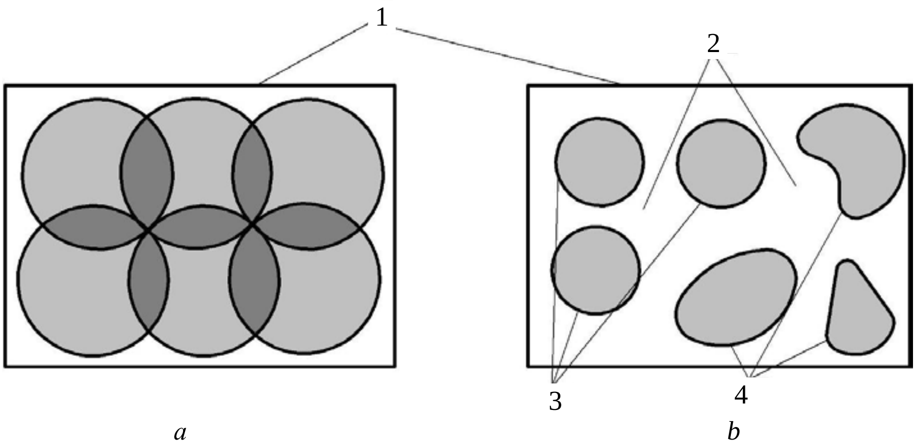

Fig. 2. Normal intersection of the bases of cone of torches on the surface of wetting (a), formation of non-irradiated areas with clogged or malfunction of sprinkling nozzles (b); 1 – total wetting surface; 2 – non-wetting area; 3 – failure of the sprinkling system (reduction of the torch); 4 – sprinkling clogging (deformation of the torch)

On the contrary, the improvement of the cooling effect of cooling towers № 3 and 4 in the range of thermal loads of 50.4...101.2 Mcal/(m^2·h) and with a temperature cooling zone with width of 4.9...9.2 °C on 0.7 and 1.1 °C, respectively, was due to the sealing of the joints of the asbestos-cement pipes of the water distribution system, as well as the installation of additional packages of asbestos-cement sheets in the existing apertures of sprinkling coolers.

Sealing of joints of asbestos-cement pipes eliminated the unorganized leakage of cooling water in the amount of about 5 % of the incoming into the cooling tower. This provided a more even supply of cooling water to irrigating packages and a decrease the temperature by about 0.3 ºC.

The installation of additional sheets of sprinkling allowed to increase the cooling area of each cooling tower by 5.6 % of the design area of cooling, and also ensured the reduction of unorganized leakage of cold air from a cooling tower that did not contact with cooling water. Thus, studies have determined that the installation of additional sprinkling blocks in cooling towers № 3 and 4 provides a decrease in the temperature of cooling water by an average of 0.6 °C.

When working in the winter, for protecting sprinklers from freezing the coolers № 3 and 4 are equipped with a warming device, which is made in the form of “warm water curtain”. During the study of cooling towers, an examination was carried out on the effect of the device on the coolant effect of the cooling tower in the summer operating conditions. For this purpose, on the cooling tower № 4, two rings of the warming device with which the cooling tower worked before the end of the research were included in the work. The inclusion of a warming device on a cooling tower in the summer period contributes to an increase in the temperature of the water cooled therein by about 0.3...0.4 °C. The reason for this is the imperfection of the typical reflective nozzles used in this device,

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which are directed downhole by opening holes and operate at low pressure, and as a result, a poor splitting of the cooling water supplied to these devices.

Conclusions Thus, on the basis of conducted researches and analysis of the obtained results of the work of cooling towers, it has been established that in order to increase the reliability and efficiency of tower cooling towers, it is necessary:

For cooling towers № 1 and 2, fill apertures in sprinklers with additional asbestos cement blocks according to the model installed in towers № 3 and 4. This will ensure a decrease in the temperature of the cooled water in them by about 0.6 ºC. In addition, it is recommended to replace sprinklers, made of asbestos cement sheets, with modern sprinkling systems, made of polymeric materials. The use of polymeric materials (high density polyethylene, polyvinyl chloride, polyester resins, etc.) for the manufacture of sprinkling has a number of advantages: such sprinkling systems are not prone to corrosion, have high strength and have low density, from them it is possible to easily form pipes, lattices and spatial elements of complex configurations. Such sprinklers can be provided with configurations that will combine high cooling capacity and low aerodynamic resistance. For the same parameters of air, the sprinkling systems made of polymeric materials are more efficient and allow lower temperatures of cooling water to be obtained compared to asbestos cement sprinklers [3].

Sprinkling nozzles in the water distribution system of the cooling towers should use reinforced construction with perforated cup reflectors. To prevent clogging of sprinkling nozzles on water separating pipelines of cooling towers, it is necessary to install ringing nozzles with outlet diameter of 40…50 mm.

During the winter period of operation of cooling towers, it is necessary to mount ring-shaped heating devices at all cooling towers and to equip them with sprinkling nozzles with reflectors instead of typical nozzles, which will enable to refuse the necessity of switching off plugs in the summer. Operation of cooling towers № 3 and 4 in the summer with the included warming devices equipped with typical reflecting nozzles is not reasonable.

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