Study of the operation features of CHP cooling tower in conditions of forced air supply

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Abstract. In our country, at thermal and nuclear power plants, tower cooling towers built in 1960-1975 are still in operation. At the same time, the construction of new facilities and the modernization of existing installations requires a high-quality mathematical study of technical solutions. As part of the work, it is proposed to simulate the operation of a tower cooling tower, subject to additional forced air supply. Using the equations of heat and material balance for the cooling tower, a mathematical model of the operation of the cooling tower was developed in Microsoft Excel. The modelling of the operation of the cooling tower in the design conditions of the city of Yoshkar-Ola, as well as when installing additional fans of various capacities, has been carried out.

1. Introduction
In our country, cooling towers built in 1960-1975 are still in operation at thermal and nuclear power plants. [1] At the same time, the construction of new facilities and the modernization of existing installations requires a high-quality mathematical study of technical solutions. The modern mathematical apparatus for calculating heat and mass transfer processes in cooling towers is presented in the work of Ponomarenko V.S., Arefiev Yu. I. [2]. In this work, the calculation is based on the compilation of heat and mass balances for the process of cooling water in a cooling tower; the process of heat and mass transfer between water and air in the cooling tower packing is described.

For a long time, the calculation of cooling towers was based on the graphs obtained in the framework of experimental studies on model cooling towers [3]. Empirical graphs gave good results in the design of cooling towers; however, they did not allow improving design solutions, using computer systems. For a long period of time, work was carried out to refine the dependencies for calculating the aerodynamics of cooling towers [4, 5]. Many scientists have been involved in the thermal design of cooling towers since the 30s of the 20th century. It is worth highlighting the method of thermal calculation by L.D. Berman, that was based on the approximate solution of the basic equations of heat balance [7], and the method of B.V. Proskuryakov, based on the approximate integration of the heat balance equation [6].

There are also many works devoted to increasing the energy efficiency of cooling towers [8-10], numerical modelling of heat and mass transfer processes [11-13], assessing the effect of wind on the operation of a cooling tower [14,15].
Within the framework of the study, it is proposed to simulate the operation of cooling towers subject to additional forced air supply.

2. Materials and methods

Within the framework of the study, the features of the operation of a cooling tower of the BG-1200-70 type are investigated. The cooling tower is designed to cool the circulating water at a thermal power plant. The water capacity of the cooling tower is 7000-9000 m$^3$/hour with a temperature difference of 8-10° C. Tower cooling tower BG-1200-70 installed at Yoshkar-Olinskaya CHPP-2

To assess the effect of the installation on the existing cooling tower of additional fans, two fans with different capacities were selected (table 1).

| Fan and impeller name | VG-50M with RK-50M | VG -70M with RK-70M |
|-----------------------|---------------------|----------------------|
| 1. Impeller diameter, mm | 4980 | 6980 |
| 2. Productivity, thousand m$^3$/hour | 580-610 | 1150-1700 |
| 3. Number of blades, pcs. | from 4 to 6 | from 4 to 6 |
| 4. Blade weight, kg | 20 | 30 |
| 5. Hub weight, kg | 70 | 80 |

To simulate the operation modes of the cooling tower, the equation of the balance of heat given off in the cooling tower by water and perceived by air [1] was used:

$$ Q = C_w * (L_w * (t_{w1} - t_{w2}) + G_v * t_{w2}) = G_a * (I_2 - I_1), $$

(1)

where $C_w$ is the specific heat capacity of water, J / kg K; $L_w$ - water consumption, kg / s; $G_v$ - is the amount of evaporated water, kg / s; $t_{w1}$, $t_{w2}$ - temperatures at the inlet and outlet of the cooling tower, °C; $G_a$ - air consumption, kg / s; $I_1$, $I_2$ - specific enthalpy of air at the inlet and outlet of the cooling tower, J / kg.

The material balance of moisture in the volume of the cooling tower was determined by the equation [1]:

$$ G_v = G_a * (x_2 - x_1), $$

(2)

where $x_1$, $x_2$ - moisture content of saturated air at the inlet and outlet of the cooling tower, kg / kg.

Using the equations of heat and material balance for the cooling tower, a mathematical model of the operation of the cooling tower with the possibility of additional air supply was developed in Microsoft Excel. For this, a model of the cooling tower operation in the design conditions of Yoshkar-Olala was previously developed in Microsoft Excel (figure 3.1).

As part of the study, three situations were modelled: operation of a cooling tower under the design conditions of Yoshkar-Olala (Russian Federation), operation of a cooling tower with the installation of an additional VG-50M fan with an RK-50M impeller, and operation of a cooling tower with the installation of an additional VG-70M fan with an impeller RK-70M.

In this case, the main difference between the models is the volumetric air flow passing through the cooling tower:

- for design conditions, the volumetric air flow for the cooling tower was calculated equal to 3,030,000 m$^3$/h;
- for conditions with the installation of an additional VG-50M fan with an RK-50M impeller, the volumetric air flow was calculated equal to 3,640,000 m$^3$/h;
- for conditions with the installation of an additional VG-70M fan with an RK-70M impeller, the volumetric air flow was calculated equal to 4,730,000 m$^3$/h.
3. Results and discussion

Based on the simulation results, the values of undercooling of circulating water in a cooling tower under external conditions were obtained, which exceed the design ones for the city of Yoshkar-Ola (RF), for each simulated situation. The ambient temperature and humidity were taken as external conditions.

Figure 1 shows the simulation results for the operation of a cooling tower under design conditions. The graph shows the dependence of the value of the undercooling of the circulating water, °C, on the relative air humidity, % and the temperature of the outside air, °C. Under the most unfavourable operating conditions of a cooling tower (the maximum possible outdoor temperature (39°C) and relative air humidity (100%)), the undercooling value of the circulating water can reach 9 ° C. If we take into account that the required amount of cooling is 10° C, then under these conditions the cooling tower practically stops working.

![Figure 1](image1.png)

**Figure 1.** Dependence of the amount of circulating water undercooling on the relative humidity and air temperature for design conditions.

To analyze the efficiency of a cooling tower with an additional VG-50M fan with an RK-50M impeller in conditions different from the design ones, its operation was simulated with a change in the relative humidity and air temperature, the results are shown in figure 2. Under the most unfavourable operating conditions of a cooling tower (the maximum possible outdoor temperature and relative air humidity), the undercooling value of the circulating water can still reach a significant value of 9° C. However, it is observed that the onset of perceptible undercooling has shifted to higher temperatures and at the design humidity (53%) is observed at temperatures above 29° C, at the design air temperature (23° C) in the entire range of relative air humidity.
Figure 2. Dependence of the amount of undercooling of circulating water on the relative humidity and air temperature for a cooling tower with an additional fan VG-50M.

To analyze the efficiency of a cooling tower with an additional VG-70M fan with an RK-70M impeller under conditions different from the design ones, its operation was simulated with a change in the relative humidity and air temperature, the results are shown in figure 3. Under the most unfavourable operating conditions of the cooling tower (the maximum possible outdoor temperature and relative air humidity) the undercooling value of the circulating water can still reach a significant value of 8.5° C. However, it is observed that the onset of perceptible undercooling has shifted to the area of very high temperatures and at the design humidity is observed at temperatures above 35° C, at the design air temperature in the entire range of relative air humidity. And thus, the use of an additional fan can significantly reduce the likelihood of the system operating in undercooling mode.

Figure 3. Dependence of the amount of circulating water undercooling on the relative humidity and air temperature for a cooling tower with an additional fan VG-70M.
4. Conclusions
In the framework of the study, the modelling of the cooling tower operation was carried out in the design conditions of the city of Yoshkar-Ola, as well as when installing additional fans of various capacities. During the simulation, it was found that when the most unfavourable operating conditions of the tower cooling tower are reached (the maximum possible outdoor temperature (39°C) and relative air humidity (100%)), the undercooling value becomes practically equal to the required cooling tower cooling value. Moreover, this is typical for all situations that have been simulated. However, installing additional fans can significantly reduce the likelihood of the system operating in undercooling mode. The onset of the undercooling regime shifts to the area of high and very high ambient temperatures and humidity.

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References
[1] Laptev A G and Vedgaev I A 2004 Design and calculation of industrial cooling towers (Kazan: KSEU)
[2] Ponomarenko V S and Arefev U I 1998 Industrial and energy cooling towers (Moscow: Energoatomizdat)
[3] 1971 VSN 14-67. Technical guidelines for the calculation and design of tower counterflow cooling towers for thermal and industrial enterprises USSR Ministry of Energy (Leningrad: Energy)
[4] Sukhov E A 1997 Hydro-aerodynamic studies of cooling towers and their elements Izv. VNIIG named after E.A. Vedeneeva. Part II. Hydraulics 230 10-5
[5] Arefev U I, Ponomarenko V S 2000 Technological calculations of tower cooling towers Water supply and sanitary engineering 7 17-20
[6] Proskurikov B V 1935 Theory of thermal regime of a film cooling tower Izvestiya NIIG 16 112
[7] Berman L D 1960 Evaporative cooling of circulating water (Moscow: Gosenergoizdat)
[8] London A, Mason W and Boelter L 1940 Performance characteristics of a mechanically induced draft counterflow packed cooling towers TRANS ASME 62 41-50
[9] Al-Waked R and Behnia M 2007 Enhancing performance of wet cooling towers Energy Conversion and Management 48(10) 2638-48
[10] Jaber H, and Webb R L 1989 Design of Cooling Towers by the Effectiveness-NTU Method ASME. J. Heat Transfer 111(4) 837-43
[11] Al-Waked R, Behnia M 2006 CFD simulation of wet cooling towers Applied Thermal Engineering 26 (4) 382-95
[12] Kloppers J C, Kröger D G 2005 A critical investigation into the heat and mass transfer analysis of counterflow wet-cooling towers International Journal of Heat and Mass Transfer 48(3-4) 765-77
[13] Hasan A, Sirén K 2002 Theoretical and computational analysis of closed wet cooling towers and its applications in cooling of buildings Energy and Buildings 34(5) 477-86
[14] Armitt J 1980 Wind Loading on Cooling Towers Journal of the Structural Division 106(3) 601-21
[15] Wei Q, Zhang B, Liu K, Du X, Meng X 1995 A study of the unfavorable effects of wind on the cooling efficiency of dry cooling towers Journal of Wind Engineering and Industrial Aerodynamics 54-5 633-43