Peculiarities of the Thermal Regime of the Magnitogorsk Reservoir in the Zone of Water Use by PJSC “Magnitogorsk Iron and Steel Works”

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Abstract. The solution of a wide range of tasks of protection and rational use of water bodies requires, first of all, an assessment of the levels of impact of industrial complexes. The solution of such problems for extreme technological and hydrometeorological conditions is carried out on the basis of appropriate computational experiments. However, verification of the underlying mathematical models can be performed only on the basis of correct input data. The paper presents materials of field studies of the temperature distribution of water both in the water area and in the depth of the Magnitogorsk reservoir, in the zone of influence of thermal effluents of PJSC "Magnitogorsk Iron and Steel Works" (PJSC MMK). It is shown that in the warmest limiting period, a significant vertical temperature inhomogeneity is formed.

1. Introduction
Magnitogorsk reservoir on the Ural River (cooling pond) was commissioned in 1939 according to the design of the Vodokanalproekt Institute, Moscow. The reservoir is of the channel type, the type of regulation is seasonal [1]. The area of the mirror is 21.1 km², the volume at NPU is 148 million m³, the average depth is ~ 7 m.
In 1971-1972, separating and diverting dams were built on the Magnitogorsk reservoir (cooling pond), which formed the circulating part of the Magnitogorsk reservoir. Industrial water supply of the main industrial site of PJSC "MMK" is carried out according to the circulating scheme through the circulating part of the Magnitogorsk reservoir and local revolving cycles, with repeated use of water. The total length of the waterway from the discharge to the common industrial septic tanks to the water intake facilities is 15–16 km (Figure 1).
The recharges of the circulating water supply system through the circulating part of the Magnitogorsk reservoir are:
- wastewater entering the circulating part of the Magnitogorsk reservoir, after using the intaken water from the Magnitogorsk reservoir by pumping stations of the first rise No. 16, 16a (wastewater after cooling the process equipment of the oxygen department (oxygen station No. 4) and TTP (northern discharge in the summer period);
- river water entering the circulating part of the Magnitogorsk reservoir through the northern regulating water meter during the flood period (during the low-flow period the tray is closed).
Recharge is used to cover irretrievable losses at the industrial site: losses in production, feeding of local circulating cycles (evaporation from the surface of sewage treatment plants, dripping and venting, from cooling towers).
2. The main factors of formation of the thermal regime of the reservoir

The thermal regime of reservoirs is formed under the influence of various factors that can be divided into two main groups. The first group includes various types of income and heat loss by water. This includes the heat exchange of water mass with the environment (atmosphere and bottom soil), as well as heat from internal sources (heat generation and ice melting, internal friction, biological processes, etc.) [2].

The second group includes factors due to which the incoming heat is redistributed within the water mass: turbulent, wind and dynamic mixing and free convective mixing. These processes occur simultaneously and are in interaction. The morphometric characteristics of the reservoir and, first of all, the depth of the reservoir and the area of the water surface have a great influence on the thermal regime. Obviously, at the same specific heat input to the water surface, the temperature value and its variability in the vertical direction depend on the water depth. As for the size of the water surface, they largely determine the intensity of wind action on thermal regime.

It should be taken into account that each individual reservoir may have its own individual "features" and peculiarities in the formation of the thermal regime. They can influence both at a sufficiently local level, by changing the temperature in certain areas, and play dominating role in the formation of temperature fields. In modern conditions of operation of reservoirs, such influence is often associated with technogenic impact.

For most part of the Magnitogorsk Reservoir, the general conditions and principles of the formation of the temperature regime in different seasons of the year are the common. For the assessment of technogenic impacts and the development of measures to minimize them, the analysis of thermal fields generated by diverting heated effluents from PJSC MMK is fundamentally important. If in work [3], the processes of formation of zones of thermal effects of the energy complex with a direct-flow cooling system were studied, in the present work the features of the formation of zones with a re-sequential cooling system are considered. Field studies were conducted in May 2015 and 2017, as well as in July 2013, in compliance with the requirements of the governing documents [4] and the use of modern equipment.

3. Features of technological and meteorological conditions during studies

At all stages of the investigations, the operation of PJSC “MMK” and the water use system was carried out in a regular mode. Water balance, thermal and hydrochemical regimes in the central part of the site under consideration, is mainly formed under the influence of inflow of the Ural river, as well as wastewater of the outlet number 1.

During studies performed on July 11, 2013 the flow rate in the Ural river (Magnitogorsk Reservoir) in the area of the "Southern passage" was ~ 5 m³ / s, the surface water temperature was 25.2 °C. The discharge flow rate by discharge No. 1 is 11.6 m³ / s with a temperature of 29.1 °C. When mixing of 2 streams of different densities occurs in the water area between passages, a water temperature distribution is formed, characterized by the presence of a jump layer, which is located at a depth of 2-4 m. The difference between surface and bottom temperatures reaches 5-7 °C (Figure 1). Characteristics of meteorological conditions are given in Table 1.

During surveys of May 24 in 2015 and 2017, due to the passage of different phases of the flood during this period, the flow rate in the Ural river was, respectively, ~ 110 and 12 m³ / s. The surface water temperature was 13 and 13.3 °C, respectively. The discharge flow rate of issue No. 1 was about 8.5 m³ / s with temperatures of 23.1 and 21.4 °C, respectively. The difference between surface and bottom temperatures did not exceed 3 °C (Figure 1).

The most detailed study of water temperature fields was performed on May 24, 2017. The measurement results are presented in Figure 2 and Figure 3.
Table 1. Meteorological conditions during field studies (www.rp5.ru)

| Date       | Time  | Temperature, °C | Direction of the wind | Wind Speed, m/s | Cloudiness, % |
|------------|-------|-----------------|-----------------------|-----------------|---------------|
| 11.07.2013 | 02:00 | 17.3            | Northeast             | 3               | 60            |
|            | 08:00 | 20.0            | Northeast             | 2               | 20–30         |
|            | 14:00 | 28.5            | South-South-West      | 3               | 70–80         |
|            | 20:00 | 26.1            | South                 | 3               | 60            |
| 24.05.2015 | 02:00 | 14.5            | Southeast             | 1               | 70–80         |
|            | 08:00 | 19.4            | West-North-West       | 3               | 40            |
|            | 14:00 | 27.0            | West-North-West       | 6               | 70–80         |
|            | 20:00 | 20.4            | Northwest             | 3               | 90            |
| 24.05.2017 | 02:00 | 3.8             | Calm                  | 0               | 100           |
|            | 08:00 | 7.7             | Western               | 3               | 20–30         |
|            | 14:00 | 12.4            | Western               | 4               | 60            |
|            | 20:00 | 13.3            | Western               | 3               | No clouds     |

4. Main results of temperature surveys

Attention is drawn to the fact that the water temperature distribution curves in depth are close to each other in the measurements of 2015 and 2017, with a significant difference in the flow rates of water in the Ural river, as well as air temperature. These results quite well confirm the statement that the flow rate in the Ural river is not the governing factor in the formation of the thermal regime of the central part of the Magnitogorsk reservoir. The role of daily air temperatures, due to the very high heat capacity of the water, is also small. Thus, in particular, according to Table 1, the average daily air temperature on May 24, 2015 was by 11 °C higher than on May 24, 2017, while temperature distributions, as follows from Figure 1, are very close.

The presented materials make it possible to get a fairly "solid" idea about the formation of temperature fields in the central part of the Magnitogorsk reservoir at the time of the studies, to provide input data for verifying hydrodynamic models for calculating the heat affected zones of large energy complexes for both 2D and 3D approaches. The water temperature distribution was characterized by substantial inhomogeneity both in the water area and in the depth of the water body, and also by the presence of a fairly stable jump layer, especially during the warmest period (July-August). The presence of a significant difference in water temperature on the surface and in the near-bottom horizons allows us to work out possible variants for selective water intake in order to increase the sustainability of the enterprise’s water supply system in fairly short-term periods with extremely high air temperatures.

5. Conclusions

Field studies of thermal fields in the Magnitogorsk reservoir, formed in the active impact zone of PJSC MMK, showed their stability and inertia with respect to both hydrological and meteorological factors. In the warmest limiting period, a substantial vertical temperature inhomogeneity is formed. The obtained data are a necessary and obligatory component for verification and binding of hydrodynamic models for the conditions of the Magnitogorsk reservoir.
Figure 1 Water temperature distribution in depth at different verticals in the central part of the Magnitogorsk reservoir (area of activity of PJSC "MMK")
Figure 2 Water temperature distribution as measured by May 24, 2017, at the surface
Figure 3 Water temperature distribution as measured by May 24, 2017, at a depth of 2 m

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References
[1] Technical and economic substantiation of water supply in Sverdlovsk 1983 M: Soyuzgiprovodkhoz, (in Russian).
[2] Gottlieb J.L. Thermal regime of hydroelectric reservoirs 1976 Leningrad: Gidrometeoizdat (in Russian).
[3] Lyubimova T, Lepikhin A, Parshakova Ya, Lyakhin Yu, Tiunov A 2018 International Journal of Heat and Mass Transfer 126 342
[4] RD 52.10.842-17 Manual of hydrometeorological stations and posts 2017 9 Hydrometeorological observations at sea stations and posts. Part 1. Hydrological observations at coastal stations and posts M.: Publishing house ITRK, (in Russian).