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ASSESSING THE IMPACT OF THERMAL POWER PLANTS IN THE AQUATIC ENVIRONMENT IN RESERVOIR-COOLER

Abstract. This paper presents an assessment of the operation impact of thermal power plants on the environment by mathematical modeling method, which is solved by the Navier-Stokes and temperature equations for an incompressible fluid in a stratified medium, based on the projection method which is approximated by control volume method. A numerical algorithm for solving the Navier-Stokes and the temperature transport equations are as follows: in the first stage it is assumed that the transfer of momentum is carried out only by convection and diffusion. The intermediate velocity field is solved by 5-step Runge-Kutta method. In the second stage, based on the found intermediate velocity field, the pressure field is solved. Poisson equation for the pressure field is solved by Jacobi method. In a third step it is assumed that the transfer is carried out only by the pressure gradient. The fourth step numerically solved temperature transfer equation as the momentum equation by 5-step Runge-Kutta method. The algorithm is parallelized on high-performance systems. The obtained numerical results of three-dimensional stratified turbulent flow reveals qualitatively and quantitatively approximate the basic laws of hydrothermal processes occurring in the aquatic environment.

Keywords: stratified environment, the Navier-Stokes equations, operational capacity, Ekibastuz GRES-2, finite volume method, Runge-Kutta method, Shandaksor lake.

1 Introduction

Interaction between energy enterprises and environment takes place at all stages of fuel production and using, processing and transmission of energy. In composition of pollutants there are suspended solids, petroleum products, chlorides, sulphates, heavy metals, hydrogen sulfide, formaldehyde, etc. The main water consumers on TPP and NPP are the turbine condensers. Water consumption depends on steam parameters and technical water supply system. According to some estimates in the future, in condenser cooling will spend water: on TPP – 120 kg/ (kW.h), on NPP – 220 kg/ (kW.h). The large specific steam consumption on NPP accounts for more specific water consumption. At washing the surfaces of aggregates, dilute solutions of hydrochloric acid, sodium hydroxide, ammonia, ammonium salts, iron and other substances are formed. In addition, the discharges of cooling water of nuclear power plants on NPP do not exclude the radionuclides in the aquatic environment.

Annual electricity consumption in industrialized countries is only increasing every year, which resulted in the growth of capacity power units on NPP and TPP. In order to condensation of steam cooling water is supplied to the capacitor. The costs of technical or cooling circulating water are enormous, which make 95 % of the total water consumption for the needs TPP and 90 % for NPP.

TPP with cooling water dropping 4-7 kJ of heat per 1 kW/h of produced energy. But discharges of warm water on TPP by the sanitary standards should not increase the temperature of the reservoir higher than 3 degrees in the summer and 5 degrees in the winter. Propagation of heat emission from TPP depends on several factors: topography, ambient temperature, wind speed, cloudiness, precipitation, etc.

The reservoirs are required by both thermal and nuclear power plants. For work of these stations is required a large quantity of water for cooling aggregates, an average of 35-40 m.c/sec at 1 million kW installed power. Hence it is evident that it takes 70-160 cubic meters of water every second for the thermal power plant of 2-4 million kW. Therefore, when choosing the construction site of TPP and NPP their water supply is the important aspect. Naturally, the large thermal power stations should be located on the banks of large rivers, reservoirs and lakes or artificial reservoirs.

As an example of the thermal effects by TPP to the aquatic environment is taken Ekibastuz SDPP-2, located in township Solnechnyi, about 40 kilometers north of the city Ekibastuz, Pavlodar region, Kazakhstan. Ekibastuz SDPP-2 generates electricity from high-ash coal by two power units of 500 MW and has an installed capacity of 100 MW. Today two power blocks produce about 12 % of all electricity produced in the country.

Technical water supply is carried out according to the scheme of recycling technical water supply with artificially created self-leveling reservoir-cooler. The reservoir-cooler was created on the basis of bitter-salty, drying up, not having national economic value Shandaksor Lake. Recycled water supply scheme is following: cold water is taken from deep water intake reservoir-cooler and comes to the block pumping station by supply channel, and then to the power plant heat exchangers. Warm water from the heat exchanger on the exhaust channel is discharged into the reservoir-cooler. The maximum dimensions of the cooling reservoir are about 7,2x7,7 km.

2 Mathematical model

For many years in the study of the hydrodynamics of lakes and reservoirs there were two separate areas one of them full-scale analysis of the observational data, and the other is mathematical modeling. Field experiments are observations, although made in a variety of complex conditions, were passive, as were not allowed to actively manage the experiment, wherein not possible to predict hydro-physical processes. One of the most effective methods for studying the hydrodynamics of the lake waters is the method of mathematical modeling. In some cases, this method may be the only way to forecast changes in the hydrological regime and ecosystems of lakes, for example in the study of changes that may occur with territorial redistribution of water, construction of hydraulic structures and other activities related to the use of water objects.

The cooling pond spatial temperature change is small. Therefore, the stratified flow in the cooling pond can be described by equations in the Boussinesq approximation. For the mathematical modeling the system of equations is considered, including the equation of motion, continuity equation and the equation for the temperature. We consider developed spatial turbulent flow in the stratified cooling pond. For the modeling of the temperature in the reservoir three-dimensional mathematical model is used [1-12, 17]:

$$\frac{\partial \overline{u_i}}{\partial t}+\frac{\partial \overline{u_j u_i}}{\partial x_j}=-\frac{\partial \overline{p}}{\partial x_i}+\nu\frac{\partial}{\partial x_j}\left(\frac{\partial \overline{u_i}}{\partial x_j}\right)+\beta g_i(T-T_0)-\frac{\partial \tau_{ij}}{\partial x_j}, \tag{1}$$

$$\frac{\partial \overline{u_j}}{\partial x_j}=0, \quad (i= 1, 2, 3), \tag{2}$$

$$\frac{\partial T}{\partial t}+\frac{\partial u_j T}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\chi\frac{\partial T}{\partial x_j}\right), \tag{3}$$

where $\tau_{ij}=\overline{u_i u_j}-\overline{u_j u_i}$, g_i - acceleration of gravity, β - coefficient of volume expansion, u_i - velocity components, χ - thermal diffusivity, T_0 - the equilibrium temperature, T - the temperature deviation from equilibrium.

To close the system of equations (1) - (3) turbulence model Smagorinsky [13] is used.

For discretization system of equations (1) - (3) using the control volume method. For this we represent the Navier-Stokes equations and equation for temperature in the form of integral conservation laws for an arbitrary fixed volume Ω with boundary dΩ [14, 15]:

$$\int_\Omega \left(\frac{\partial U}{\partial t}+\frac{\partial F_i}{\partial x_i}+\frac{\partial G_i}{\partial x_i}-B_i\right)d\Omega=0, \tag{4}$$

Where

$$U=\begin{pmatrix}0\\ u_j\\ T\end{pmatrix},\ \begin{pmatrix}u_i\\ u_iu_j+p\delta_{ij}-\tau_{ij}\\ v_iT\end{pmatrix}\ G_i=\begin{pmatrix}0\\ v\dfrac{\partial u_i}{\partial x_j}\\ \chi\dfrac{\partial T}{\partial x_j}\end{pmatrix},B=\begin{pmatrix}0\\ Bg_i(T-T_0)\\ 0\end{pmatrix}.$$

equation (4) can be written as follows:

$$\int_\Omega \left(\frac{\partial U}{\partial t}-B\right)d\Omega+\oint_{d\Omega}(F_i+G_i)n_i d\Gamma=0, \tag{5}$$

The equation (5) to a form:

$$\int_\Omega \left(\frac{\partial U}{\partial t}\right)d\Omega+\oint_{\partial\Omega}(F_i+G_i)n_i d\Gamma=\int_\Omega B_i d\Omega, \tag{6}$$

Grid features are defined in the center of the cell and the values of flows across the border in divided cells. The volume of the cell is denoted by grid functions.

Now we perform discretization equation (6) for the control volume (CV) and a reference surface (CS)

$$\sum_{CV}\left(\frac{\Delta U}{\Delta t}\right)\Delta\Omega+\sum_{CS}(F_i+G_i)n_i\Delta\Gamma=\overline{B_i}\Delta\Omega \tag{7}$$

or you can write the equation (7) in the form:

$$\sum_{CV}\Delta U\Delta\Omega+\sum_{CS}\Delta t(F_i+G_i)n_i\Delta\Gamma=\Delta t\overline{B_i}\Delta\Omega \tag{8}$$

3 Numerical algorithm

For the numerical solution of equations (1) - (3) splitting scheme on physical parameters [14-16] is used. For numerical implementation of (1)-(3), discretization of the form (8) is used. In the first step it is assumed that transfer of momentum carried out only by convection and diffusion. The intermediate velocity field is found by 5-step Runge-Kutta method [11, 12, 14, 15]. In the second stage, based on the found intermediate velocity field, is found the pressure field. Poisson equation for the pressure field is solved by Jacobi [14, 15]. In a third step it is assumed that the transfer is carried out only by the pressure gradient. On the fourth step numerically temperature transfer equation as the equation of motion by 5-step Runge-Kutta method is solved. In solving the equation for temperature also the finite volume method and the same calculations for the equations of motion is used [11, 12]. The algorithm of task is parallelized on high-performance systems. The calculations were performed on cluster systems URSA and T-Cluster of BPH Research Institute of Mathematics and Mechanics at Al-Farabi Kazakh National University.

I) $\displaystyle\int_\Omega \frac{\vec{u}^{\,*}-\vec{u}^{\,n}}{\tau}d\Omega=-\oint_{\partial\Omega}\left(\nabla(\vec{u}^{\,n}\vec{u}^{\,*}-\tau_{ij})-v\Delta\vec{u}^{\,*}\right)n_i d\Gamma,$

$$\text{II)}\ \oint_{\partial\Omega}(\Delta p)d\Gamma = \int_{\Omega}\frac{\nabla\vec{u}^{*}}{\tau}d\Omega,$$

$$\text{III)}\ \frac{\vec{u}^{n+1}-\vec{u}^{*}}{\tau} = -\nabla p,$$

$$\text{IV)}\ \int_{\Omega}\frac{T^{*}-T^{n}}{\tau}d\Omega = -\oint_{\partial\Omega}(\nabla\vec{u}^{n}T^{*}-\nu\Delta T^{*})n_{i}d\Gamma.$$

4 Results of numerical simulation

Initial and boundary conditions were set for the numerical solution of problems. The initial conditions for the velocity and temperature are defined as follows: $u_j = 0, (j = 0,1,2,3), T = T_0$. The boundary conditions for the velocity at the bottom and side of the border are defined by adhesion condition and temperature by adiabatic conditions. On the surface, for the velocity and temperature are specified Neumann conditions. And also put additional boundary conditions for the velocity and temperature in the lateral border of spillway according to the operational capacity of the Ekibastuz SDPP-2. In the calculations there was used computational grid, with more than 800,000 computing nodes. Figure 1 shows a computational grid for the Ekibastuz SDPP-2. Figure 2 shows the current contour and isolines of the temperature distribution at different time points after the start of work SDPP-2, on a water surface for the operational capacity of 700 MW. Figure 3 shows the contour and isolines of the temperature distribution at different time points after the start of work SDPP-2, on the surface of water for the operating power of 900 MW. In both Figures 2-3 it is seen that the temperature distribution with distance from the flow close to isothermal condition. The results show that the temperature distribution is distributed over a larger area. As can be seen from Figures 2-3, with an increase the operational capacity of SDPP-2, area of heat exposure becomes directed in one direction, and leads to warm water with one part of the reservoir, which has a negative effect on the performance of SDPP-2. When operating power is 900 MW, the temperature is distributed in the northern part of the reservoir and approximately uses only half of the body of water for cooling hot water by SDPP-2. When the operating power of Ekibastuz SDPP-2 increase, the cooling pond is not working effectively, fueling the northern part of the reservoir, the rest of the pond bottom is not involved at cooling the heated water from the SDPP-2.

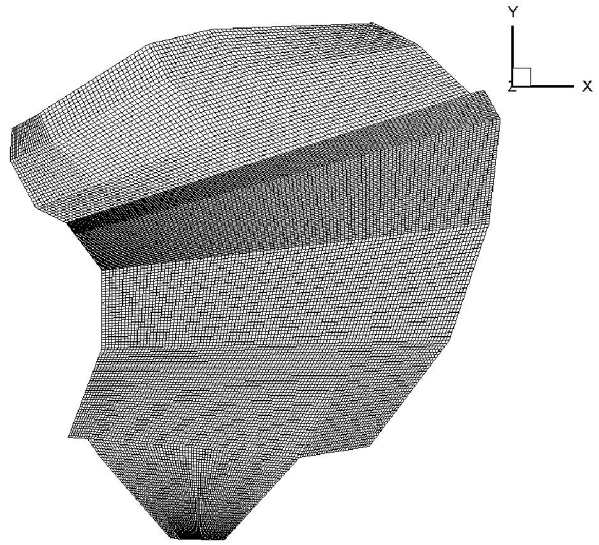


Figure 1 - The computing grid for the Ekibastuz SDPP-2

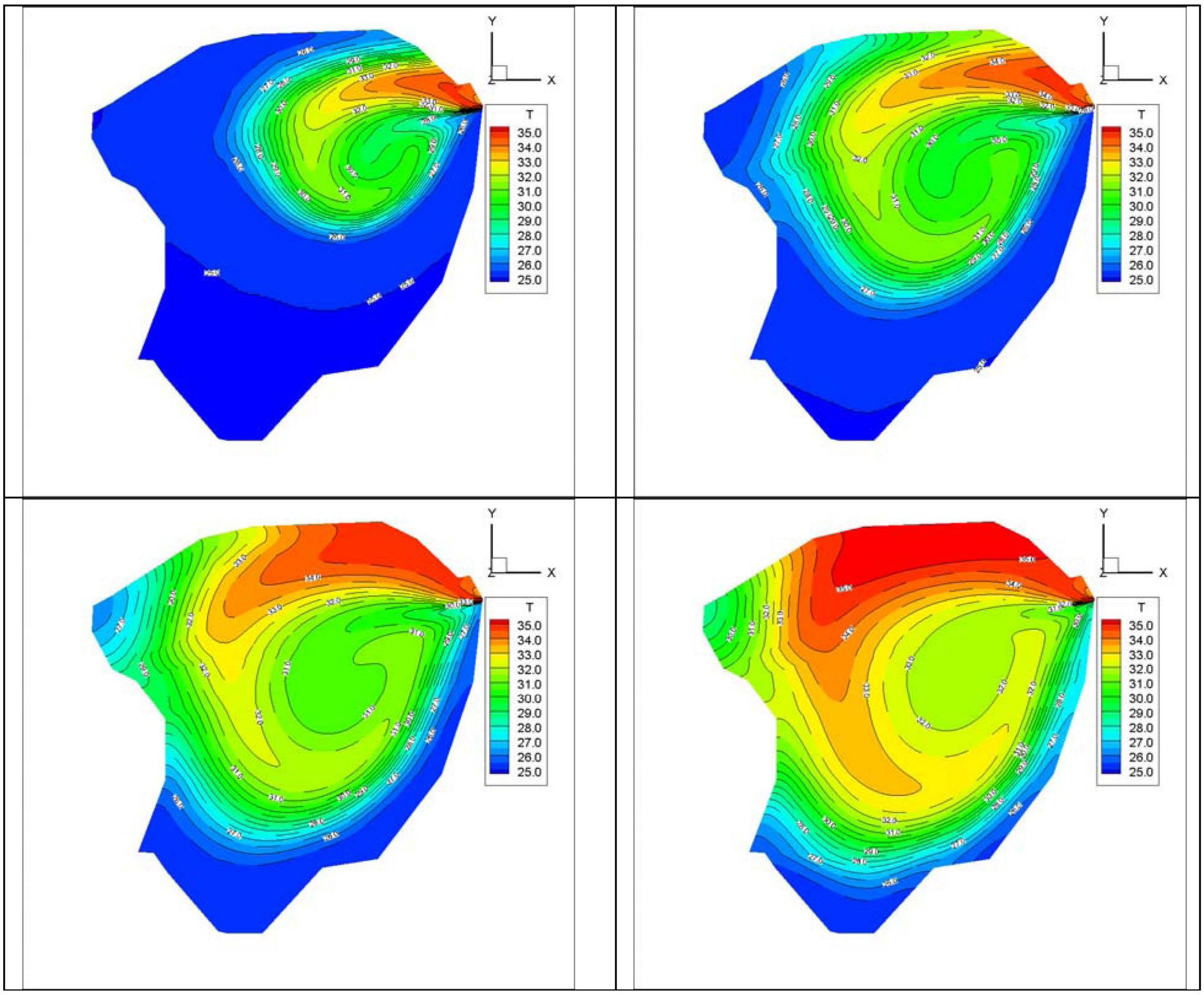
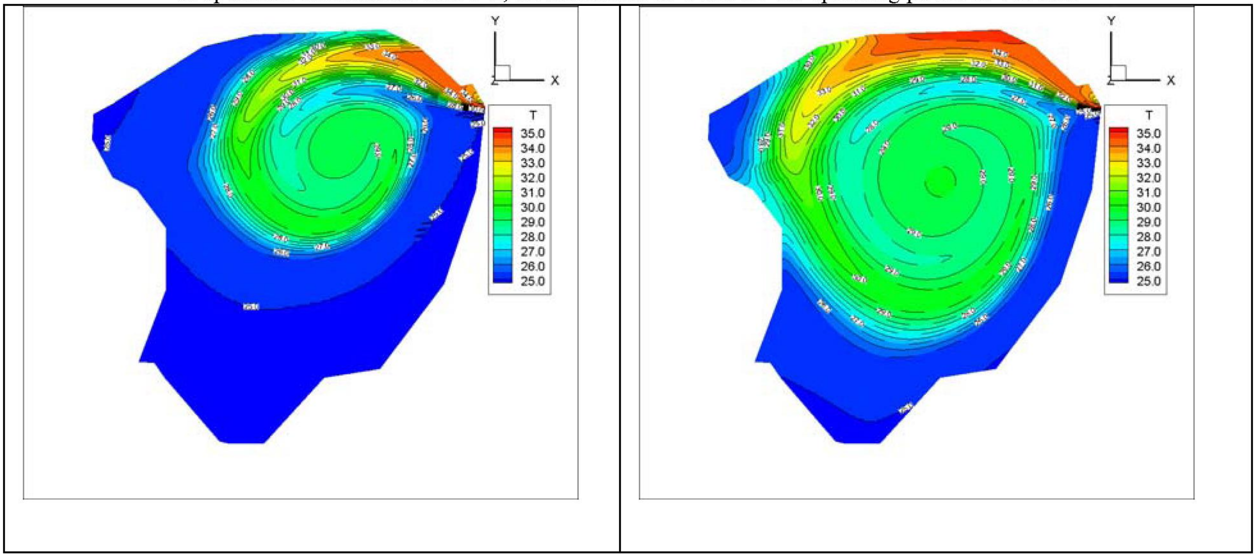


Figure 2 - The outline and contours of the temperature distribution across the 22.5 hr., 50 hr., 72.5 hr. and 90 hr. after the start of operation of Ekibastuz SDPP-2, on the surface of water for the operating power of 700 MW



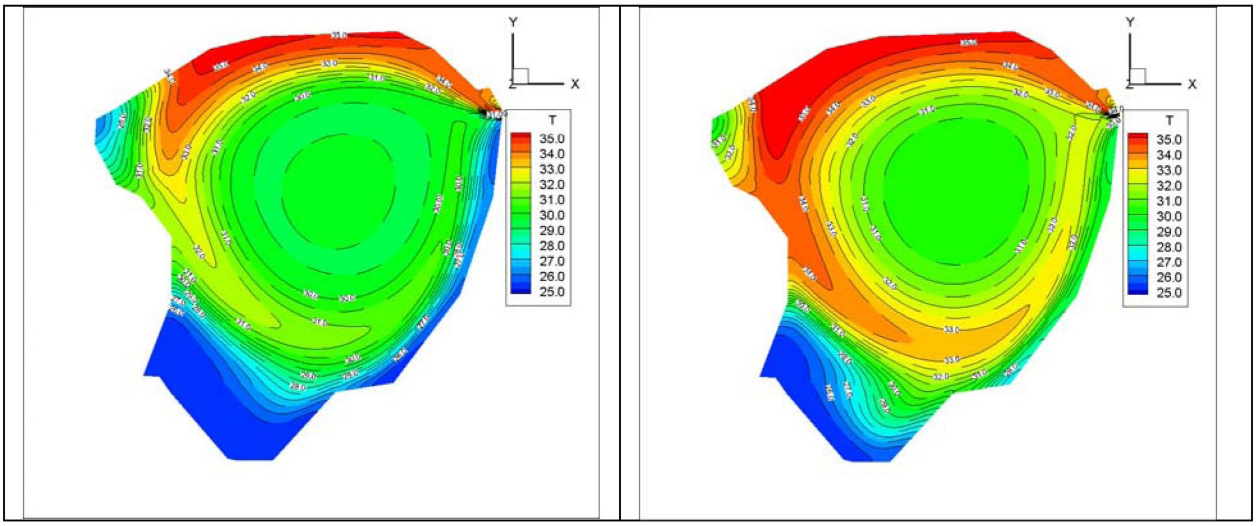


Figure 3 - The outline and contour lines of the temperature distribution over 22.5 hr., 50 hr., 72.5 hr. and 90 after the start of operation of Ekibastuz SDPP-2, on the surface of water for the operating power of 900 MW

5 Conclusion

This work was carried out by predictive modeling to minimize the thermal load to the lake Shandaksor, which is located near the Ekibastuz SDPP-2. The aim of this work is to determine the size and spatial distribution of warm water temperature from the spillway channel for different operating power capacity. Predictive mathematical model developed for this study, showed portions of the thermal plume in which the temperature decreases when moving away from the spillway channel and the flame temperature is close to the values of the reservoir-cooler temperature. Thus, there was developed a three-dimensional model of a stratified turbulent flow that allows identifying qualitatively and approximately quantitatively the basic laws of hydrothermal processes in the pond Shandaksor.

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МАТЕМАТИКАЛЫҚ МОДЕЛЬДЕУ ӘДІСІ АРҚЫЛЫ ҚОРШАҒАН ОРТАҒА ЖЫЛУ ЭЛЕКТР СТАНЦИЯЛАРЫНЫҢ ЖҰМЫСЫНЫҢ ӘСЕРІН БАҒАЛАУ

Аннотация. Жұмыста ақырлы көлем әдісімен аппроксимацияланатын, физикалық параметрлер бойынша ыдырау әдісіне негізделген, стратификацияланған ортадағы сығылмайтын сұйыққа арналған Навье - Стокс және температура теңдеулерімен шешілетін, математикалық модельдеу арқылы қоршаған ортаға жылу электр станцияларының жұмысының әсерін бағалау ұсынылды. Навье-Стокс және температура теңдеулерін шешу үшін арналған сандық алгоритмы осылай болып табылады: бірінші кезеңде қозғалыс санының ауысуы конвекция мен диффузияның есебінен ғана болады деп болжанады. Аралық жылдамдық өрісі 5- қадамды Рунге – Кутта әдісімен табылады. Екінші кезеңде табылған аралық жылдамдық өріс арқылы қысым өрісі табылады. Қысым өрісі үшін Пуассон теңдеуі Якоби әдісімен шығарылады. Үшінші кезеңде алмастыру қысым градиенті арқылы жүзеге асады деп болжаймыз. Төртінші кезеңде температура теңдеуі қозғалыс теңдеуі сияқты 5-қадам Кутта Рунге әдісі арқылы сандық шешіледі. Есептің алгоритмі жоғары өнімді жүйеде параллелденген. Алынған үшөлшемді стратификацияланған турбулентті ағыстың сандық нәтижелері су қоймаларында болып жатқан гидротермиялық процесстердің негізгі заңдылықтарын сапалы және айтарлықтай жуықтап алуға мүмкіндік береді

Тірек сөздер: стратификацияланған орта, Навье-Стокс теңдеуі, операциялық қуаты, Екібастұз ГРЭС-2, ақырлы көлем әдісі, Рунге-Кутта әдісі, Шандаксор көлі.

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ОЦЕНКА ВОЗДЕЙСТВИЯ ФУНКЦИОНИРОВАНИЯ ТЕПЛОВОЙ ЭЛЕКТРОСТАНЦИИ НА ОКРУЖАЮЩУЮ СРЕДУ МЕТОДАМИ МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ

Аннотация. В работе представлена оценка воздействия функционирования тепловой электростанции на окружаю-щую среду методами математического моделирования, которая решается уравнениями Навье - Стокса и температуры для несжимаемой жидкости в стратифицированной среде, основанные на методе расщепления по физическим параметрам, которые аппроксимируются методом контрольного объема. Численный алгоритм для решения уравнений Навье-Стокса и переноса температуры выглядит таким образом: на первом этапе предполагается, что перенос количества движения осуществляется только за счет конвекции и диффузии. Промежуточное поле скорости находится 5-шаговым методом Рунге - Кутта. На втором этапе, по найденному промежуточному полю скорости, находится поле давления. Уравнение Пуассона для поля давления решается методом Якоби. На третьем этапе предполагается, что перенос осуществляется только за счет градиента давления. На четвертом шаге численно решается уравнения переноса температуры также как уравнения движения 5-шаговым методом Рунге-Кутта. Алгоритм задачи распараллелен на высокопроизводительной системе. Полученные численные результаты трехмерного стратифицированного турбулентного течения позволяет выявить качественно и приближенно количественно основные закономерности гидротермических процессов происходящих в водоемах-охладителях.

Ключевые слова: стратифицированная среда, уравнения Навье-Стокса, эксплуатационная мощность, Экибастузский ГРЭС-2, метод конечных объемов, метод Рунге-Кутта, озеро Шандаксор.