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Mathematical modeling of influence of the thermal power plant with considering the meteorological condition at the reservoir-cooler[1]

This paper presents the mathematical model of the thermal power plant in cooling reservoir under different meteorological conditions, which is solved by Navier - Stokes equations and temperature equation for an incompressible fluid in a stratified medium. Numerical method based on projection method which is approximated by finite-difference method.

Keywords: thermal power plant, large eddy simulation, stratified medium, Navier-Stokes equation.

А. Исахов

Жылу электр станциясының әр түрлі метеорологиялық жағдайдағы су қоймасының салқындатудағы әсерінің математикалық моделі

Бұл жұмыста жылу электр станциясының әр түрлі метеорологиялық жағдайдағы су қоймасының салқындатудағы әсерінің математикалық моделі қарастылды, ол старификациялық ортадағы сығылмайтың сұйық үшін Навье - Стокс теңдеулері және температураға байланысты теңдеуі қарастылды. Сандық тәсілі ақырлы айырымдар әдісі арқылы жуықталып физикалық параметрға байланысты бөлшектеу әдісімен шешілген.

А. Исахов

Математическое моделирование влияния тепловой электростанции с учетом метеорологических условий на водоем-охладитель

В данной работе представлена математическая модель влияния тепловой электростанции на водоем-охладитель при различных метеорологических условиях, которая решается уравнениями Навье - Стокса и уравнением температуры для несжимаемой жидкости в стратифицированной среде. Численный метод основан на методе расщепления по физическим параметрам, которые аппроксимируются конечно-разностным методом.

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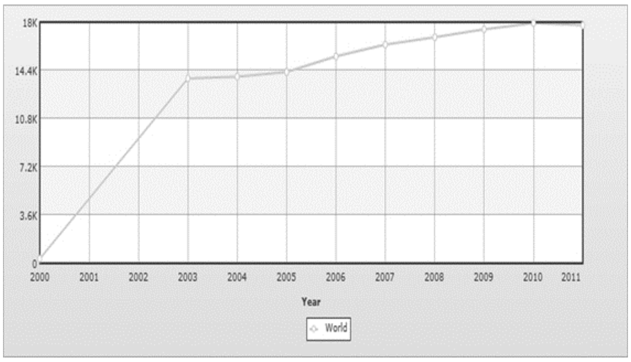

Рис. 1: Energy consumption in the world (in billion kWh)

Environment - the basis of human life, as mineral resources and energy are produced from them. Moreover they are the basis of modern civilization. However, the current generation of energy cause appreciable harm to the environment, worsening living conditions. The basis of the same energy - are the various types of power plants. But power generation in thermal power plants (TPP), hydro power plant (HPP) and nuclear power plants (NPP) is associated with adverse effects on the environment. The problem of the interaction of energy and the environment has taken on new features, extending the influence of the vast territory, most of the rivers and lakes, the huge volumes of the atmosphere and hydrosphere. Previously, the impact on the environment TPP was not in first priority, as before to get electricity and heat had a higher priority. Technology of production of electrical energy from power plant is connected with a lot of waste heat released into the environment. Today the problem of influence of the nature by power is particularly acute because the pollution of the atmosphere and hydrosphere increases each year. Figure 1 shows that the energy consumption scale is increasing year by year, as a result the negative impact of energy on the environment increases too. In the terms of energy primarily guided feasibility in terms of economic were costs, but now more in the construction and operation of energy the most important issue is their impact on the environment. Another problem, of TPP is thermal pollution of reservoirs or lakes. Dropping hot water - is a push chain reaction that begins reservoir overgrown with algae, it violates the oxygen balance, which in turn is a threat to the life of all its inhabitants. Thermal power plants with cooling water shed 4 - 7 kJ of heat for 1 kW / h electricity generation. Meanwhile, the Health Standards discharges of warm water with TPP should not raise the temperature higher than in the summer and in winter of the reservoir initial temperature. Spread of harmful emissions from TPP depends on several factors: the terrain, environmental temperature, wind speed, cloud cover, precipitation intensity. Speed deployment and increases the thermal pollution area - are meteorology conditions. As seen in figure 2, large proportion of electricity (81.3%) in the world is produced by thermal power plants. Therefore, emissions of this type of power plants to the atmosphere and hydrosphere, provide the greatest amount of anthropogenic contaminants in it.

Thermal pollution of reservoirs or lakes water that cause multiple violations of their state is a one representation of environment danger. Thermal power plants generate energy through turbines, driven by hot steam and exhaust steam is cooled by water. Therefore, from

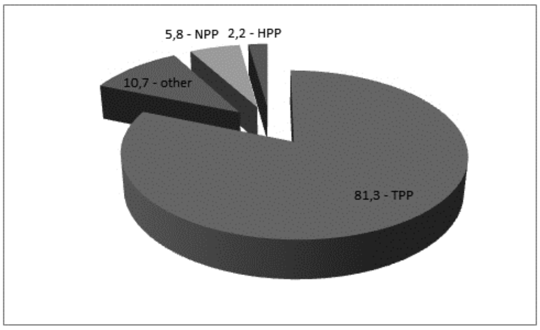

Рис. 2: Electricity production in the world by type of power plant (2010), %

the power plants in the reservoirs or lakes is continuously transferred from the water flow temperature at 8-12 ^{o} C above the temperature of the water in the reservoir. Large TPP shed till 90m ^{3}/s of heated water. For example, according to estimates of German and Swiss scientists, the possibility of rivers of Switzerland and the upper flows of the Rhine on the heating heat relief stations have been exhausted. Hot water at any place of the river should not exceed more than 3 ^{o} C maximum temperature of the river water, which is assumed to be 28 ^{o} C. Following these conditions, the power station of Germany, constructed on the Rhine, Inna, Weser and Elbe, is limited by 35 000 MW.

Thermal pollution can lead to tragic consequences. Scientists predict changes in the characteristics of the environment in the next 100 - 200 years can cause large changes in the environment. Figure 3 shows the effect of TPP on environment.

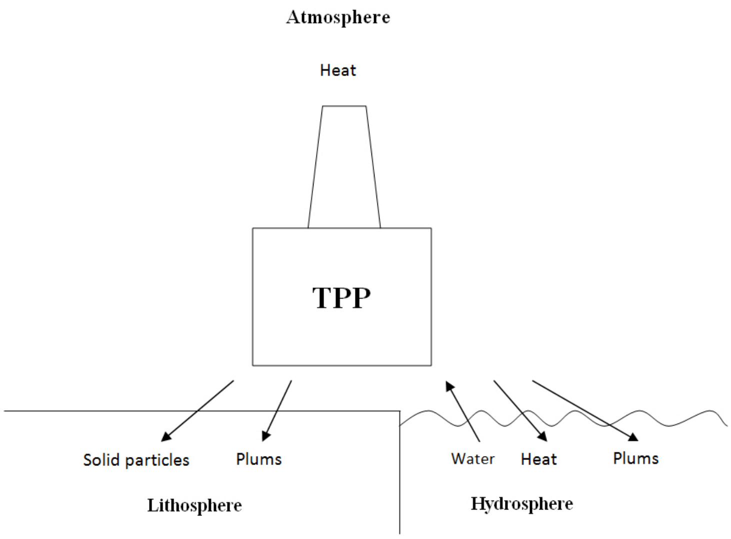

Рис. 3: TPP impact on the environment

Let us consider hydrosphere pollution. Heat from TPP mainly is given to the environment from the water-cooled condenser steam turbines. The value of heat to the environment depends on the capacity of thermal power plants. Number of diverted energy to the environment is for condensing power plants from 40 to 70 % of the thermal energy released by the combustion of fuel. Thermal effects with through cooling water in and direct-flow-back scheme inflow and outflow water is limited by the local allowable increase in water temperature in the source water: river, lake and reservoir. Water supply system has a number of features of TPP. Almost all of the water to 95 % of total cost is applied to cool the condenser coils and auxiliary steam turbines. With up to 5 % of the total value of the water supply to the thermal power plant equipment is generally irreversible consumption. As a rule, the main building of the condensing power plant is located directly at the shore line of the river, lake or reservoir-cooler. Water is supplied to the main unit of heat removal to the environment pumping stations. After heating it in condensers and heat exchangers, water is discharged to the surface water body. However, this amount of water is subject only to heating. Depending on the type of scheme water quantity of heat transfer in the once-through cooling water circuit for TPP will be minimal and some increase in the use of systems apply cooling towers. Figure 4 shows a graphical scheme of the cooling condensers of TPP with the cooling reservoir.

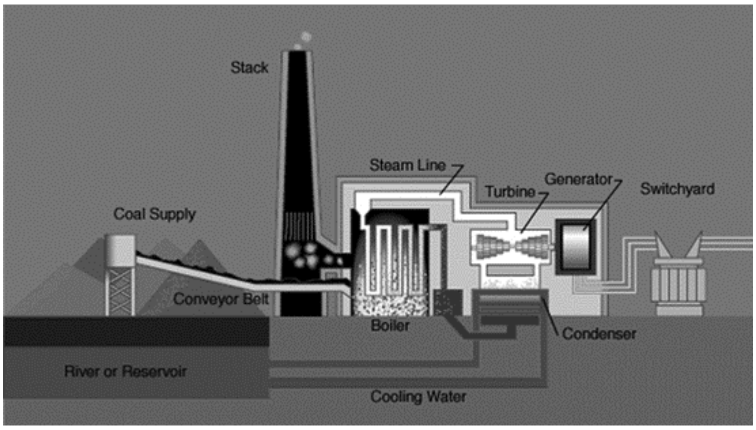

Рис. 4: Graphical scheme of cooling condensers of TPP

Ekibastuz SDPP-1, located in the Pavlodar region, 17 km. to the north-east of the town of Ekibastuz is taken as an example of such an impact of TPP on the cooling reservoir.

1. Mathematical models.

In the cooling - reservoirs spatial temperature change is small. Therefore, stratified flow in the reservoirs - cooler can be described by equations in the Boussinesq approximation. For the mathematical modeling of the system of equations are considered the equations of motion, the continuity equation and the equation for the temperature. Considers the development of spatial turbulent stratified reservoir - cooler [1,2,4,7]. Tree dimensionally model is used for distribution of temperature modelling in a reservoir [12,13,14]

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

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

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

where

$$\tau_{ij} = \overline{u_i u_j} - \overline{u}_i \overline{u}_j \tag{4}$$

g_i−is the gravity acceleration, β−the coefficient of volume expansion, u_i – velocity components, χ−thermal diffusivity coefficient, T_0− the equilibrium temperature, T− deviation of temperature from the balance.

We start with regular LES corresponding to a "bar-filter" of Δx width, an operator associating the function $\overline{f}(\overline{x}, t)$. Then we define a second "test filter" tilde of large $2\Delta x$ width associating $\tilde{f}(\overline{x}, t)$. Let us first apply this filter product to the Navier-Stokes equation. The subgrid-scale tensor of the field $\tilde{\overline{u_i}}$ is obtained from equation (4) with the replacement of the filter bar by the double filter and tilde filter:

$$\tau_{ij} = \tilde{\overline{u}}_i \tilde{\overline{u}}_j - \overline{u_i \tilde{u}_j} \tag{5}$$

$$l_{ij} = \tilde{\overline{u}}_i \tilde{\overline{u}}_j - \overline{u}_i \tilde{\overline{u}}_j \tag{6}$$

Now we apply the tilde filter to equation (4), which leads to

$$\tilde{\tau}_{ij} = \tilde{\overline{u}}_i \tilde{\overline{u}}_j - \overline{u_i \tilde{u}_j} \tag{7}$$

Adding equations (6) and (7) and using equation (5), we obtain $l_{ij} = \tau_{ij} - \tilde{\tau}_{ij}$

We use Smagorinsky model expression for the subgrid stresses related to the bar filter and tilde-filter it to get

$$\tilde{\tau}_{ij} - \frac{1}{3}\delta_{ij}\tilde{\tau}_{ij} = -2C\tilde{A}_{ij} \tag{8}$$

where $A_{ij} = (\Delta x)^2 \left|\overline{S}\right| \overline{S}_{ij}$

Further on we have to determine τ_{ij}, the stress resulting from the filter product. This is again obtained using the Smagorinsky model, which yields to

$$\tau_{ij} - \frac{1}{3}\delta_{ij}\tau_{kk} = -2CB_{ij} \tag{9}$$

where $B_{ij} = (2\Delta x)^2 \left|\tilde{\overline{S}}\right| \tilde{\overline{S}}_{ij}$

Subtraction of (8) from (9) with the aid of Germano's identity yields to $l_{ij} - \frac{1}{3}\delta_{ij}l_{kk} = 2CB_{ij} - 2C\tilde{A}_{ij}$, $l_{ij} - \frac{1}{3}\delta_{ij}l_{kk} = 2CM_{ij}$

where

$$M_{ij} = B_{ij} - \tilde{A}_{ij} \tag{10}$$

All the terms of equation (10) may now be determined with the aid of $\overline{u}$. Unfortunately, there are five independent equations for only one variable C, and thus the problem is over determined. A first solution proposed by Germano is to multiply (10) tensorially by $\overline{S}_{ij}$ to get $C = \frac{1}{2}\frac{l_{ij}\overline{S}_{ij}}{M_{ij}\overline{S}_{ij}}$. This provides finally dynamical evaluation of C, which can be used in the LES of the bar field $\overline{u}$ [4]. Initial and boundary conditions are defined for the non-stationary 3D equations of motion, continuity and temperature, satisfying the equations.

2. Numerical algorithm.

Numerical solution of (1) - (3) is carried out on the staggered grid using the scheme against a stream of the second type and compact approximation for convective terms [3,5,9,10]. Projection method is used to solve the problem in view of the above with the proposed model of turbulence. It is anticipated that at the first stage the transfer of momentum occurs only through convection and diffusion. Intermediate field of speed is handled by using method of fractional steps through the tridiagonal method (Thomas algorithm). The second phase is for pressure which is found by the help of intermediate field of speed. Poisson equation for pressure is solved by Fourier method in combination with the tridiagonal method (Thomas algorithm) that is applied to determine the Fourier coefficients [11,12,13]. At the third stage, it is supposed that the transfer is carried out only by the pressure gradient. The algorithm was parallelized on the high-performance system [9].

I) $\frac{\vec{u}^{*}-\vec{u}^{n}}{\tau} = -\left(\nabla\vec{u}^{n}\,\vec{u}^{*} - \nu\Delta\vec{u}^{*}\right)$

II) $\Delta p = \frac{\nabla\vec{u}^{*}}{\tau}$

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

3. Results of numerical modeling.

Initial and boundary conditions were posed to meet the challenges. In the calculation we used the mesh of 100x100x100 size.

Figures 5 and 6 show the solved spatial outline and contour of the temperature distribution at different times after the launch of the SDPP-1, on the surface, from different angles. Figures 7 and 8 show the solved spatial contour, contour of temperature and velocity vectors at different times in the north-west wind after the launch of the SDPP-1, on the surface, from different angles. All the figures show that the temperature distribution with distance from the flow approaches the isothermal distribution. The results show that the temperature distribution is distributed over a larger area of the reservoir - cooler.

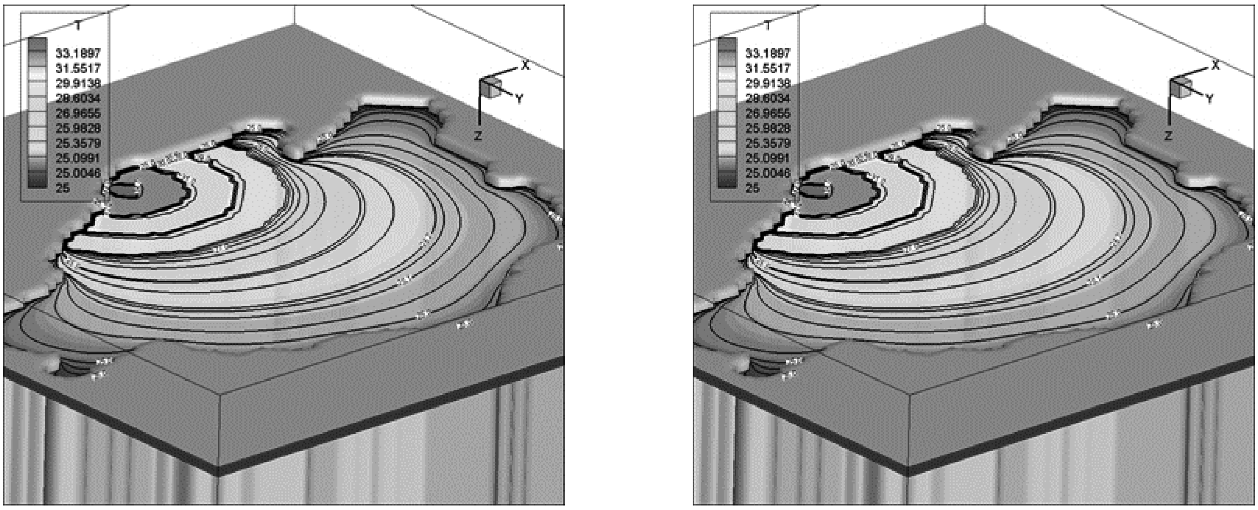

Рис. 5: Outline and contours of temperature at 15 and 24 h after launch of the SDPP-1, on the surface, the side view

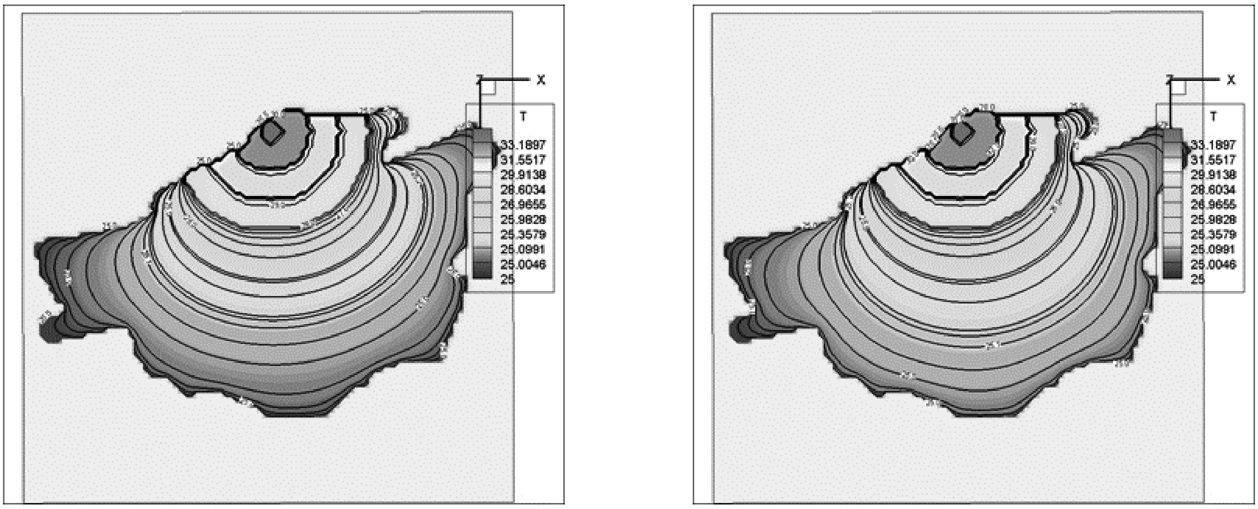

Рис. 6: Outline and contours of temperature at 15 and 24 h after launch of the SDPP-1, on the surface, top view

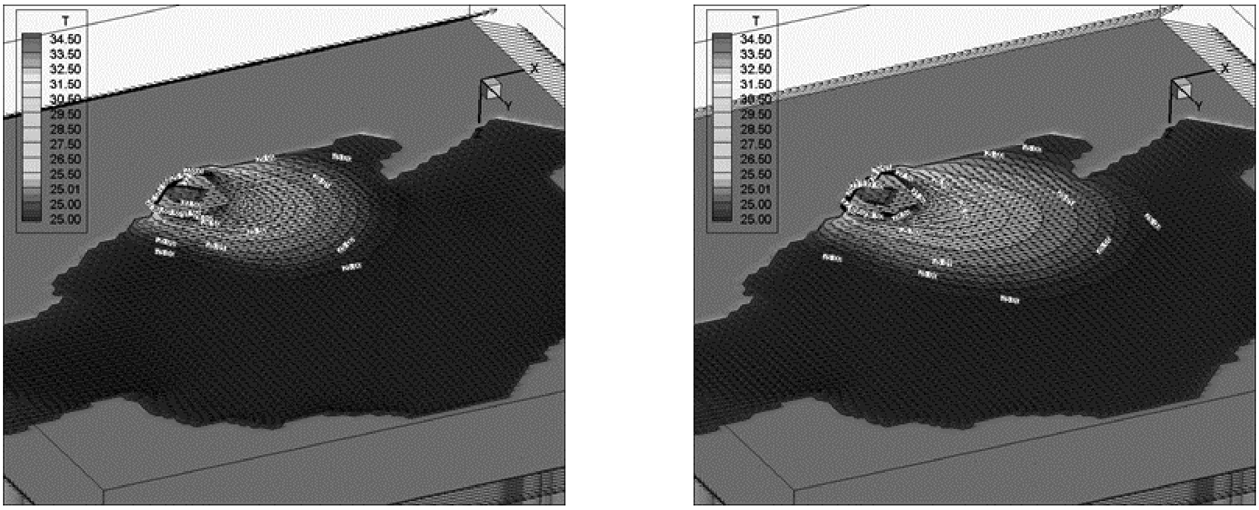

Рис. 7: Outline and contours of temperature at 15 and 24 h at the north-west wind after the launch of the SDPP-1, on the surface, the side view

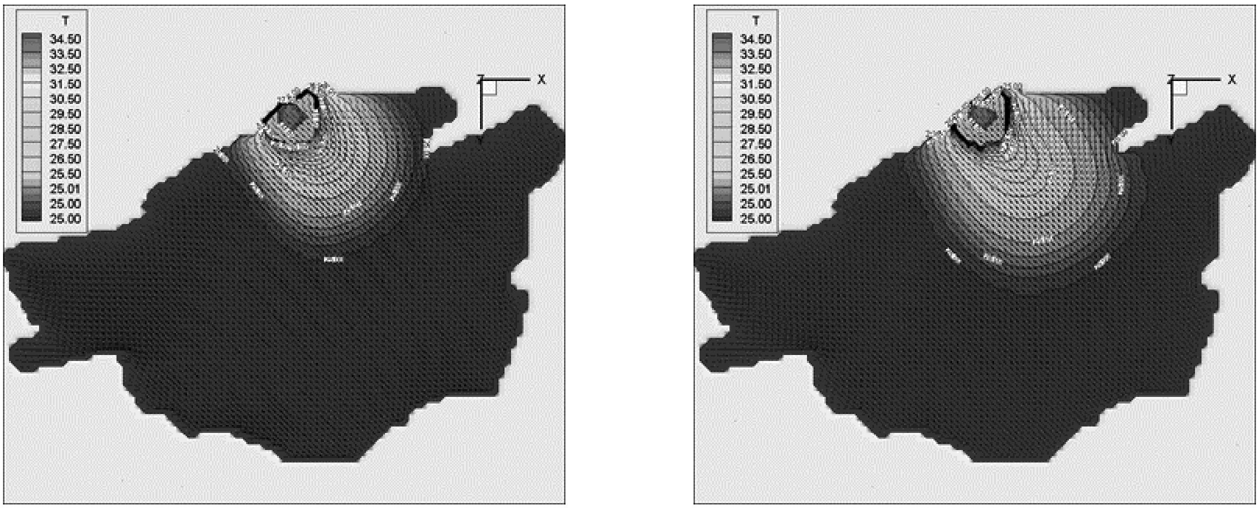

Рис. 8: Outline and contours of temperature at 15 and 24 h at the north-west wind after the launch of the SDPP-1 on the surface of the water, the top view

Thus, using a mathematical model of three-dimensional stratified turbulent flow can be determined qualitatively and quantitatively approximate the basic laws of the hydrothermal processes occurring in the reservoirs.

Список литературы

[1] *Fletcher C.A* Computational Techniques for Fluid Dynamics. Vol 2: Special Techniques for Differential Flow Categories. -Berlin: Springer-Verlag. 1988. -493 p.

[2] *Roache P.J.* Computational Fluid Dynamics. -Albuquerque NM: Hermosa Publications. 1972. -446 p.

[3] *Tolstykh A.I.* Compact difference scheme and their applications to fluid dynamics problems. -M.: Nauka. 1990. -230 p.

[4] *Peyret R., Taylor D. Th.* Computational Methods for Fluid Flow. -New York: Berlin: Springer-Verlag. 1983. -358 p.

[5] *Yanenko N.N.* The Method of Fractional Steps. -New York: Springer-Verlag. In J.B.Bunch and D.J. Rose (eds.), Space Matrix Computations, New York: Academics Press. 1979. -168 p.

[6] *Lesieur M., Metais O., Comte P.* Large eddy simulation of turbulence. -New York, Cambridge University Press. 2005. -219 p.

[7] *Tannehill J.C., Anderson D.A., Pletcher R.H.* Computational Fluid Mechanics and Heat Transfer. 2nd ed., -New York: McGraw-Hill. 1997. -816 p.

[8] *Tennekes H., Lumley J.L.* A first course in turbulence. -The MIT Press. 1972. -390 p.

[9] *Issakhov A.* Large eddy simulation of turbulent mixing by using 3D decomposition method // J. Phys. -2011. -Issue 4, Conf. Ser. 318 042051.

[10] *Zhumagulov B., Issakhov A.* Parallel implementation of numerical methods for solving turbulent flows // Вестник НИА РК. - 2012. - № 1(43). -С.12-24.

[11] *Issakhov A.* Parallel algorithm for numerical solution of three-dimensional Poisson equation // Proceedings of world academy of science, engineering and technologyю - 2012. -Issue 64 P. 692-694.

[12] *Исахов А.* Математическое моделирование влияние ТЭС на водную среду при охлаждении конденсаторов // Вестник КазНУ -2011. - № 4(71). - С. 86-91

[13] *Issakhov A.* Mathematical modeling of the influence of hydrothermal processes in the water reservoir // Proceedings of world academy of science, engineering and technology. -2012. -Issue 69 P. 632-635.

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