# Numerical simulation of hydrodynamics and heat transfer in the technological reservoir with the heat pump

*N*.V. Demyanovich[1], *V*.I. Maksimov[1,*], *T*.A. Nagornova[1]

[1]National Research Tomsk Polytechnic University, 634050 Tomsk, Russia

**Abstract.** The mathematical modeling of mixed convection of viscous incompressible fluid in a rectangular reservoir with the sources of input and output of mass has been carried out. Is studied the influence of heat sink as a result of the work of heat pump and its position on the formation of convective flows and a change in the temperature conditions. Are revealed basic laws governing the heat transfer in the small environment of heat pump. The analysis of the influence of Reynolds numbers on the intensity of the heat exchange is carried out.

## 1 Introduction

The contemporary tendencies of the production of thermal and electrical energy by eco-friendly and cost-effective methods caused development and application in power engineering of heat-pumping systems and installations [1,2]. But to use them effectively requires an analysis of thermal conditions water reservoirs [3,4]. The solution to this problem can be carried out within the framework of natural convection models for an incompressible fluid in a closed area with a local energy sources (eg, as in [5,6]). But the results of experimental studies show that in same cases of liquid flow in the reservoirs with a heat pumps more greatly correspond to the regime of mixed convection. Therefore with the estimation of effectiveness in the work of heat pumps it is expedient to consider the special features of flow of liquid near this energy converter in the regime of the mixed convection. The results of the numerical simulation of the combined convective-conductive heat transfer in the rectangular gas region with source of heat emission, are known [7-8]. But the simulation of convective flows in the reservoir under the conditions of complex heat exchange with the environment, and also inflows and the heat of sink, so far not been carried out.

Therefore, it is appropriate numerical study of mixed convection of a viscous incompressible liquid in a rectangular area with a local heat sink and sources of input and output mass.

* Corresponding author: elf@tpu.ru

## 2 Problem statement and the method for the solution

Viewed rectangular cavity with a local heat sink (heat exchanger-evaporator heat pump) having input and output portions and a liquid free surface (Fig. 1).

Thermal properties of the liquid and the wall material is not temperature dependent. Liquid was considered heat-conducting, viscous, newtonian, that satisfies the Boussinesq approximation. Flow conditions – laminar, the boundaries of cavity (with exception of the sections of input and output of water) – are not penetrated. The draining of mass due to the evaporation from the free surface was not considered. It was assumed that the temperature of the entire region in question is constant and identical at the initial moment of time.

These assumptions are not introduced into the formulation of the problem of significant limitations, but they make it possible to simplify its solution. The temperature of heat exchanger- vaporizer was received as constant during entire process.

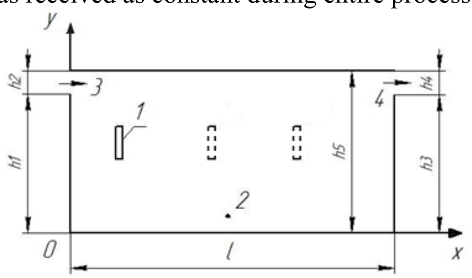


**Fig. 1.** The area of solving the problem: 1- heat exchanger-evaporator; 2 – fluid; 3, 4 - areas of fluid input and output.

In the section of the mass input (figure 1) speed in the direction $X$ is received as constant and the conditions of symmetry are accepted at the output from the cavity. Are analyzed three versions of the position of heat exchanger- vaporizer (Fig. 1).

In the real reservoirs the realization of the three-dimensional distributions of temperatures and components of speeds is possible, but under the conditions in question the velocity component in the direction $Z$ there will be much less than other two components, which correspond to the reference plane ($X$,$Y$) of the movement of the water introduced into the reservoir. Therefore it is possible to consider assumption about the two-dimensional formulation of the problem as that substantiated.

Process of heat transfer in the liquid (Fig. 1) described by the system of nonstationary two-dimensional Navier-Stokes equations in the Boussinesq approximation with the nonlinear boundary conditions [8]. The problem was solved in dimensionless formulation similar to [9].

The solution of equations (1–3) with initial and boundary conditions is carried out by the finite-difference method on the uniform grid. Used algorithm [5,6] developed for the numerical solution of problems of natural convection in a closed rectangular areas with local energy sources.

## 3 Results and discussion

Numerical studies are carried out with the following values of the dimensionless quantities, which correspond to the regime of the mixed convection: Re = 500 ÷ 1000, Gr = $10^5 \div 10^6$. Temperatures: $T_0$ = 278 K, $T_{in}$ = 293 ÷ 313 K, $T_i$ = 274 K, $T_e$ = 258 ÷ 278 K.

Figure 2 shows the current lines and temperature field, the characterizing regime of mixed convection of a viscous incompressible fluid in the rectangular region for different variants of the position of the heat pump vaporizer in the reservoir. It is seen, that the heat overflow occurs mainly in the direction of movement of the main stream. In the first position of the heat pump evaporator can selected two circulation flows: before and after heat exchanger (Fig. 2 b).

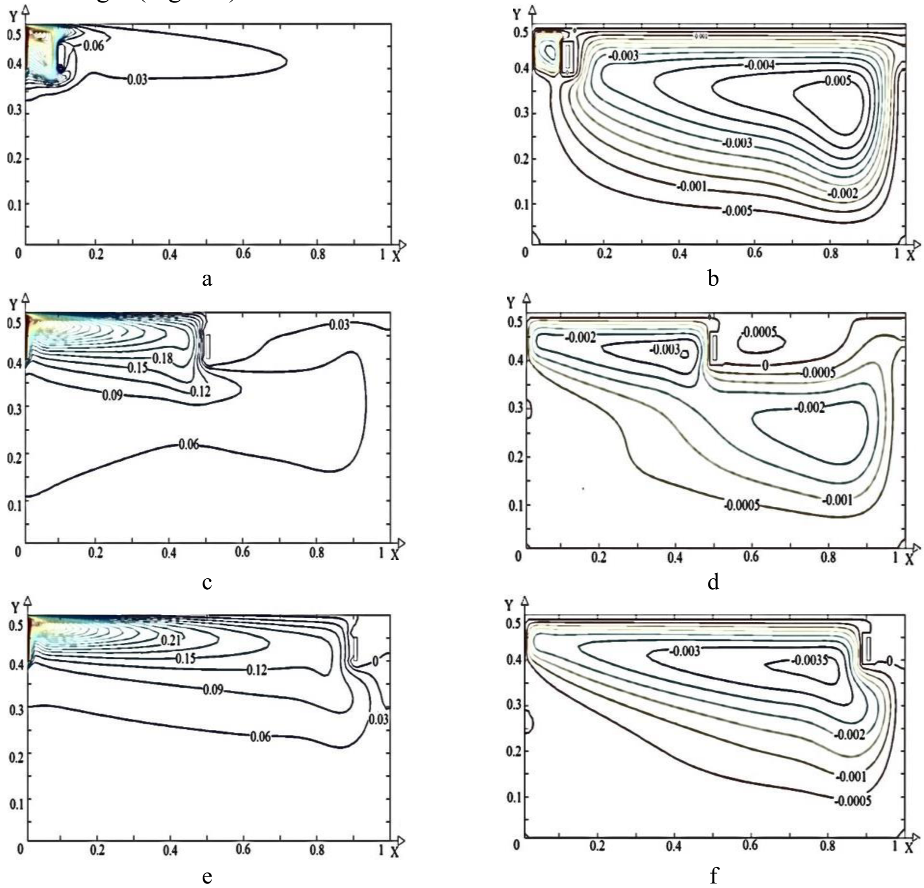


**Fig. 2.** Field of temperature (*a*, *c*, *e*) and current lines (*b*, *d*, *e*) for various positions of the heat pump.

As a result, immediately after the section of the input of liquid is formed the zone, which prevents the intensive mixing of liquid in the reservoir, which leads to the decrease of the intensity of the heat exchange of vaporizer with the surrounding liquid. In other variants of the position of heat exchanger is formed a main extensive circulation area. This circulation flow appears as a result of the flow around heat exchanger and contributes to the intensive mixing of liquid. In all three versions of the vaporizer location the cold water, which is located in the left lower region angle, does not get mixed with the main flow of liquid.

Displacement of vaporizer to the right wall (Fig. 2 *d*, *e*) lead to the deformation of extensive stagnant low-temperature zones and intensify heat exchange between liquid and vaporizer. The temperature distribution in this case is sufficiently even throughout entire volume of reservoir (Fig. 3).

Figure 3 shows the temperature profiles in the vertical section passing through the middle of the reservoir at $X = l/2$, at different positions of the heat pump heat exchanger-evaporator. In all cases, besides the arrangement of vaporizer in the position 2 (Fig. 2 *c*, *d*), with which the heat exchanger falls in the section, the maximum temperature is observed in the upper part of the cavity.

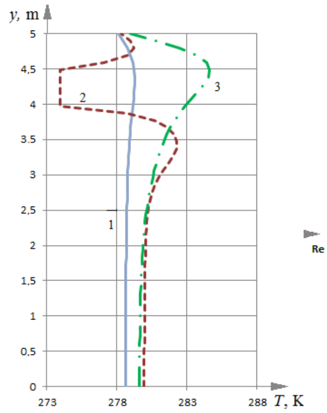


**Fig. 3.** Temperature distribution in the section, which passes on to center cavities with $X = l/2$, during different arrangements of the heat exchanger of the heat pump vaporizer.

The analysis of the influence of Reynolds number on the values of average Nusselt number [6-8] on three boundaries of reservoir and free surface of a liquid is carried out. It can be seen (Fig. 4), that with increasing number Re at the boundaries $X = 0$ and $X = 1$ (Fig. 4, *b*) a decreases the dimensionless heat transfer coefficient values for all variants of placement of the evaporator heat exchanger. The position of heat pump in the left and middle part of the reservoir prevents to the developed circulation flow in the center zone.

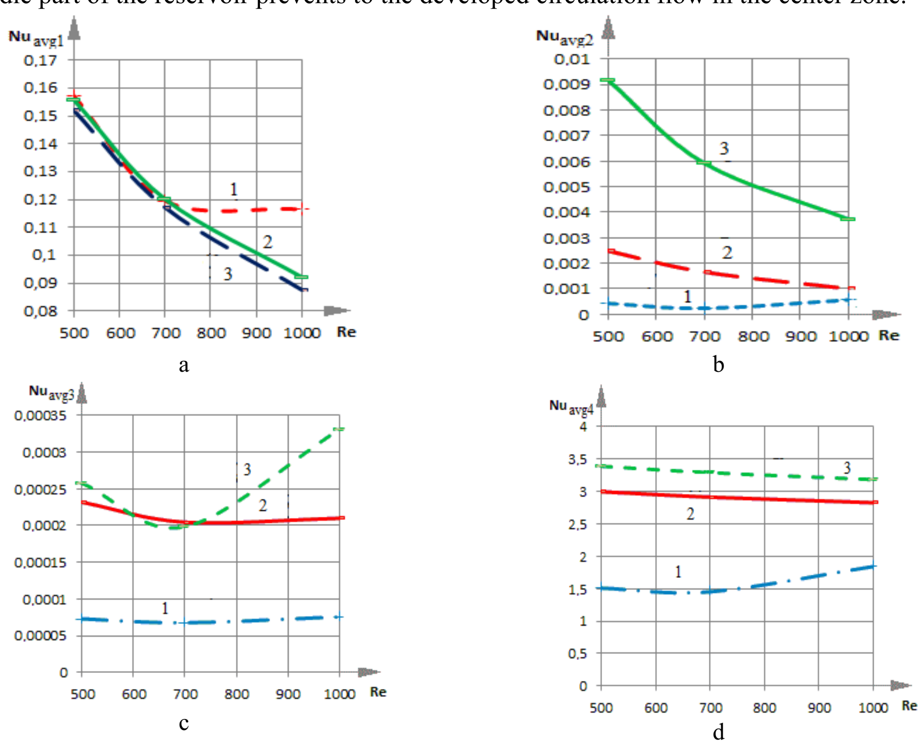


**Fig. 4.** Dependence of average Nusselt number on Reynolds number with different position of the heat exchanger- heat pump vaporizer.

At the same time, depending $Nu_{avg} = f$ (Re) for the boundaries $Y = 0$ and $Y = 1$ of extreme left and right placement of the heat exchanger are different. Are separated well corner points (Fig. 4 *c*, *d*). This position of the heatsink with the low speeds of the water entry prevents the advance of fluid flow with the temperature $\Theta = 1$ to the outlying zones (in the angles) of the considered region and contact with the adjacent walls. But with increasing circulation rates are achieved sufficient conditions for the overflow of the part of fluid energy behind of evaporator located to the left (Fig. 2 *a*, *b*). Position of heat exchanger to the right (Fig. 2 *e*, *f*) prevent the moving fluid flow to reach the lower part of the boundary $X = 1$. This factor has an effect on the average coefficient of heat exchange (Fig. 4 *a*, *d*).

With numerical studies it is established that Nusselt number on the free surface of reservoir ($Nu_{avg}$) (Fig. 4 *d*) is relatively high. On the solid boundaries $Nu_{avg}$ does not exceed 0.16, on a free same - the average Nusselt number reaches 3.4. On the liquid border $Y = 1$ is achieved the intensive heat outflow, but with an increase of Reynolds number the range of a change in the values of average on this boundary of Nusselt number is insignificant.

## 4 Conclusion

It was found that the dependences $Nu_{avg} = f\,(Re)$ change with different schemes of placing the evaporator heat exchanger, which allows to make a conclusion about changing temperature regimes due to displacement of heat sink in the reservoir.

The formulated model of the mixed convection of liquid in the reservoir, used as the low-potential energy source for the heat pump vaporizer, with the local input and output sections of the mass can be used to improve the methodology for calculating the thermal conditions of the reservoirs – low potential energy source.

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