EPJ Web of Conferences **110**, 01042 (2016)
DOI: 10.1051/epjconf/201611001042

ANALYSIS OF INFLUENCE OF HEAT INSULATION ON THE THERMAL REGIME OF STORAGE TANKS WITH LIQUEFIED NATURAL GAS

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Abstract. Is numerically investigated the process of convective heat transfer in the reservoirs of liquefied natural gas (LNG). The regimes of natural convection in a closed rectangular region with different intensity of heat exchange at the external borders are investigated. Is solved the time-dependent system of energy and Navier-Stokes equations in the dimensionless variables “vorticity – the stream function”. Are obtained distributions of the hydrodynamic parameters and temperatures, that characterize basic regularities of the processes. The special features of the formation of circulation flows are isolated and the analysis of the temperature distribution in the solution region is carried out. Is shown the influence of geometric characteristics and intensity of heat exchange on the outer boundaries of reservoir on the temperature field in the LNG storage.

1 Introduction

Natural gas is the important component of the guarantee of global energy needs in view of a number of advantages over other forms of the mineral of fuel. Frequently the transport of liquefied natural gas occurs more preferably in comparison with other methods of its delivery [1,2]. Demand on LNG grows, but the logistics processes of production and storage of LNG in the modern environment - not an easy task. For the low-temperature storage LNG are used the constructions with different geometric and insulating characteristics [3,4]. The analysis of the influence of such characteristics on the formation of the convective flows of liquefied natural gas in the storage tanks is one of important for their design and operation [4-7]. Accordingly, it is of interest for numerical study of unsteady convective heat transfer in a rectangular LNG storage and analysis of the impact as the geometric dimensions and the influx of heat from the outer limits of the reservoir. Is respectively of interest conducting numerical studies of nonstationary convective heat transfer in a rectangular LNG storage and the analysis of influence both the geometric dimensions and inflows of heat from the outer boundaries of reservoir.

2 Statement of the problem and the method of solution

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Article available at http://www.epj-conferences.org or http://dx.doi.org/10.1051/epjconf/201611001042

Are examined several versions storage LNG in the reservoir of rectangular form with the varied conditions for heat insulation (Fig. 1). The process of heat transfer in the solution field (Fig.1) was described by the system of the nonstationary two-dimensional convection equations in the Boussinesq approximation 2.

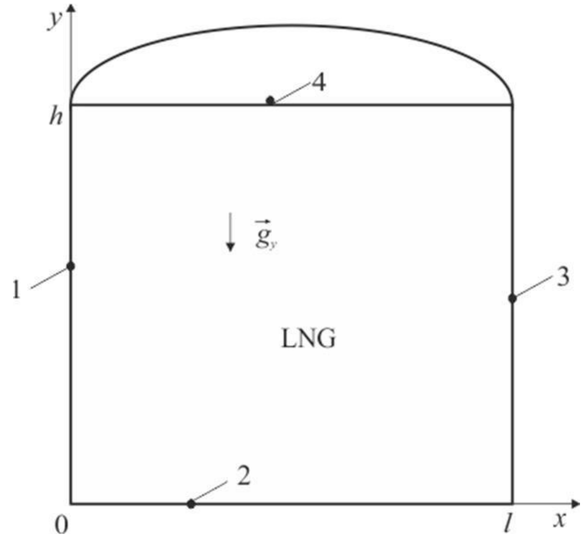


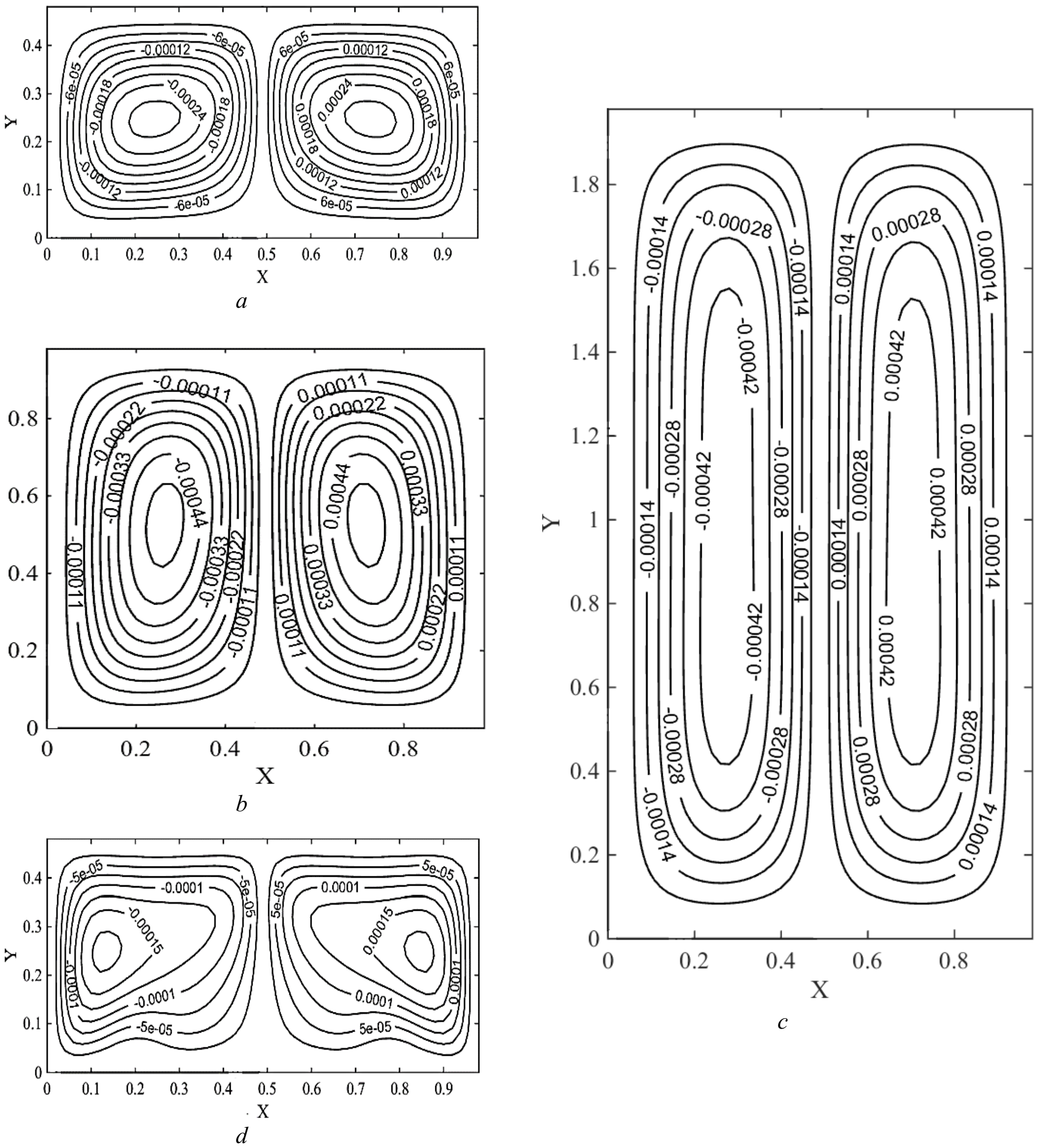
Figure 1. Solution area to the problem: 1 – the solution region: 1, 2, 3 – boundary “LNG – wall”, 4 – the free surface.

On the upper free boundary was assigned the free surface condition, on the rest – the second kind. Numerical studies are carried out for the regimes of natural convection, which correspond to the Grashof numbers to 10^7 (laminar regime). Numerical solution of the problem is carried out by the method of finite differences using the algorithm was tested in group decision problems [8-12] of conjugate heat transfer in areas with local energy sources.

3 Results and discussion

Numerical analysis is carried out on four fairly typical examples of the size of areas: 1) $l = 10$ m, $h = 5$ m; 2) $l = 10$ m, $h = 10$ m; 3) $l = 10$ m, $h = 20$; 4) $l = 20$ m, $h = 10$ m. Heat-flux density on three outer boundaries of region (Fig. 1) it was assigned by the equal: $q = 0.05$ W/m^2. The value l is selected as the dimensionless scale.

Figure 2 shows the temperature field, which is formed with different relationships of the reservoir dimensions on the x coordinates and y. In all cases, is clearly see stable stationary during the formation of two vortices. Depending on the sizes of the sides of the solution region the vortices take the form, which corresponds to the direction of gravitational forces. With an increase in the size of reservoir along the height grows the gradient of temperatures (Fig. 3,4), which leads to the stratification of liquid in the reservoir. When a temperature difference of altitude of more than 0.1 degrees high probability of spontaneous revolution of different density layers, caused by temperature difference (the phenomenon of “rollover” [4-7]).



a

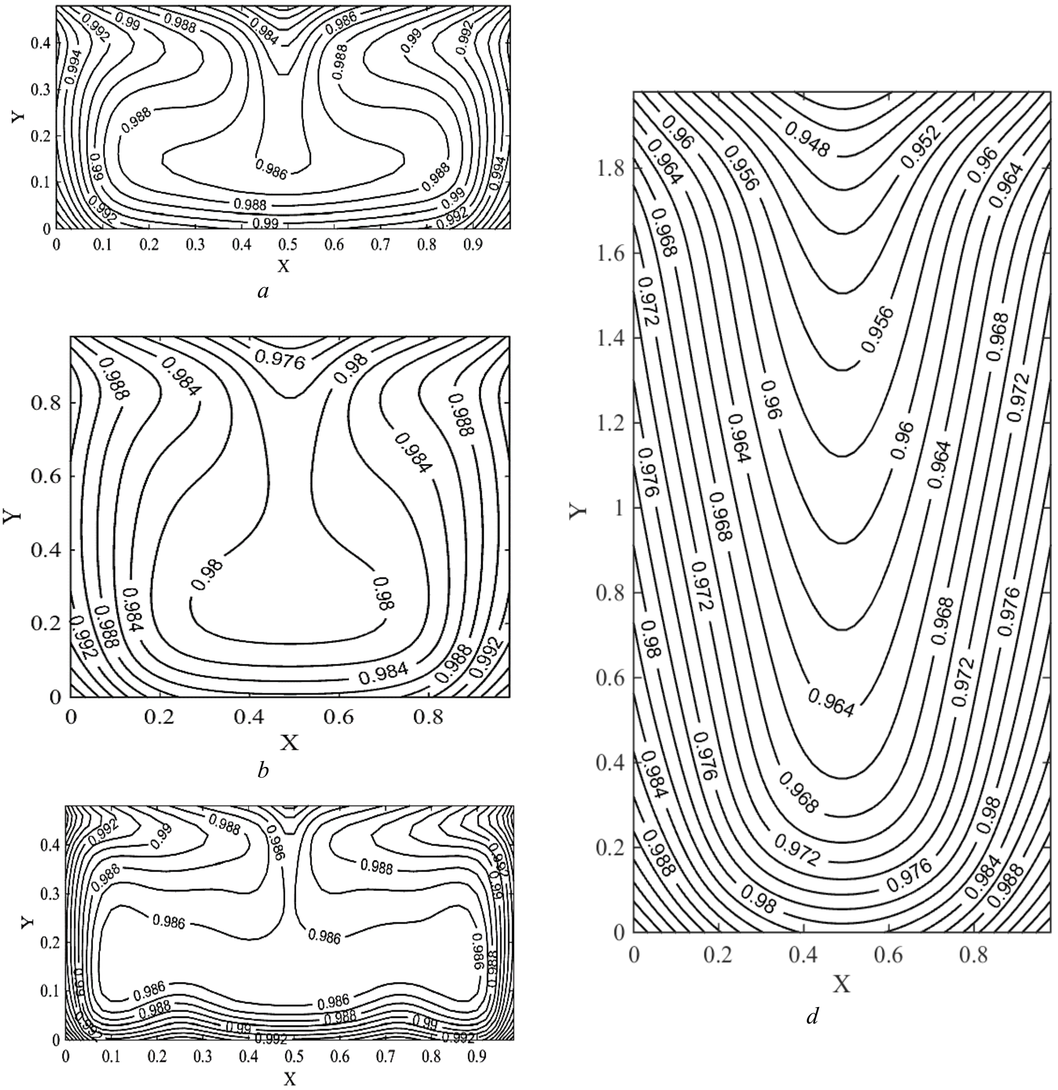
b

c

d

Figure 2. Contours of stream function in the storage tanks LNG with different geometric dimensions: *a*) l = 10 m, h = 5 m; *b*) l = 10 m, h = 10 m; *c*) l = 10 m, h = 20; *d*) l = 20 m, h = 10 m. The numerical values of coordinates and temperatures are given in a dimensionless form.

The results of numerical studies suggest a significant influence of the geometric dimensions of LNG storage on non-stationary temperature fields and stream lines.



a

b

c

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Figure 3. Fields temperature in the storage tanks LNG with different geometric dimensions: *a*) l = 10 m, h = 5 m; *b*) l = 10 m, h = 10 m; *c*) l = 10 m, h = 20; *d*) l = 20 m, h = 10 m. The numerical values of coordinates and contour line of the function of current s are given in a dimensionless form.

The most intensive circulation flows in the liquefied natural gas appear in the wide low reservoirs. The use of tanks with this relationship of sides excludes stratification LNG in them and, correspondingly, the appearance of the phenomenon “of rollover”.

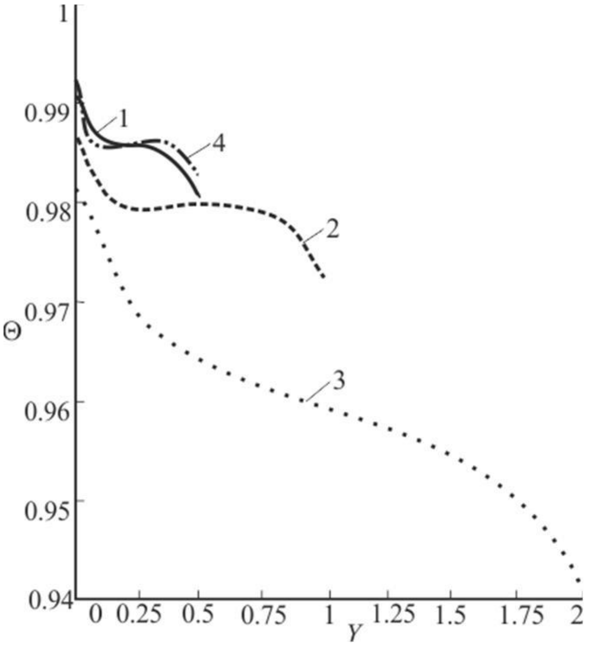
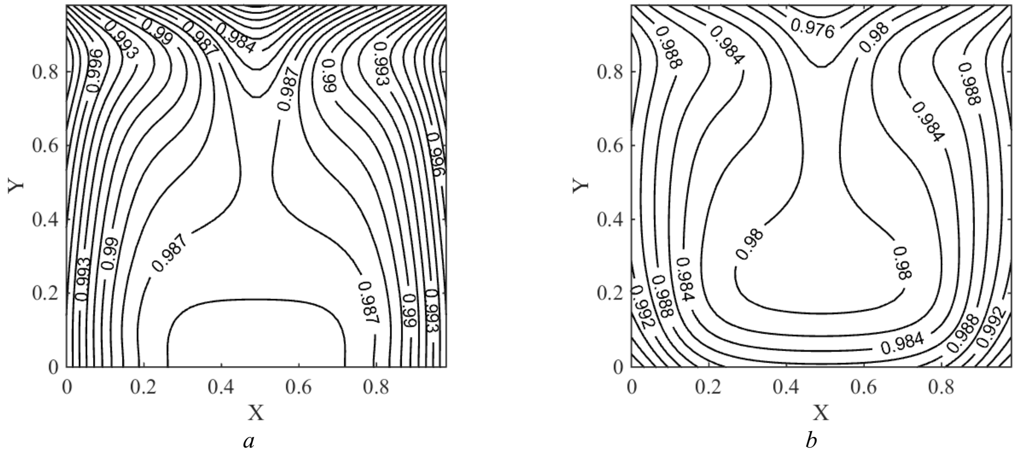


Figure 4. Temperature profile on the height ($X = 0.5$, $0 \leq Y \leq 1$) with different geometric dimensions of LNG reservoir: *a*) $l = 10$ m, $h = 5$ m; *b*) $l = 10$ m, $h = 10$ m; *c*) $l = 10$ m, $h = 20$; *d*) $l = 20$ m, $h = 10$ m.



a *b*

Figure 5. Fields temperature in the LNG storage tank: *a*) with the heat insulation on lower boundary ($q = 0$), *b*) with the heat flow on lower boundary ($q = 0.05$ W/m^2).

A change in heat exchange conditions on lower boundary does not exert a substantial influence on the structure of circulation flows and the temperature field in the reservoir (fig.5, 6). The decrease of the value of heat flux on lower boundary leads to reduction in the gradient of temperatures in the reservoir on the height (fig.6) and to the smoothing of temperature profile in the central section of region ($X = 0.5, 0 \leq Y \leq 1$) (fig.7).

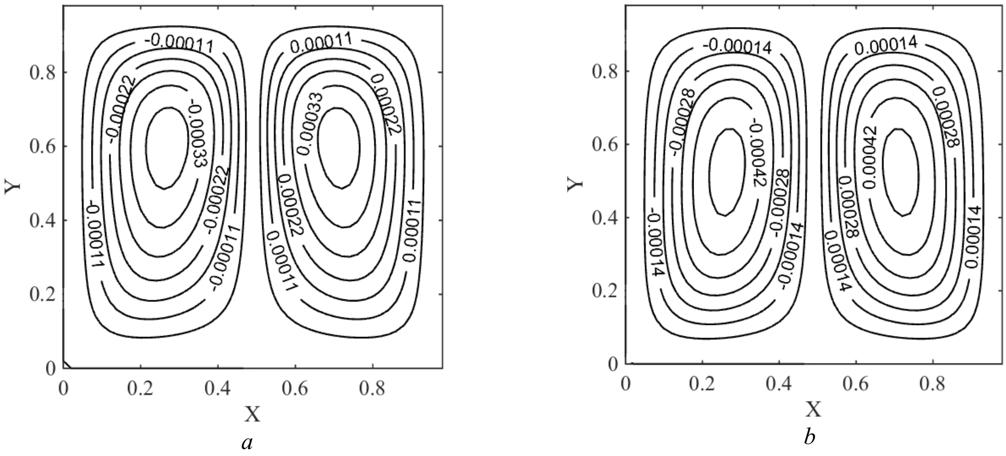


Figure 6. Contours of stream function in the LNG storage tank: *a*) with the heat insulation on lower boundary ($q = 0$), *b*) with the heat flow on lower boundary ($q = 0.05$ W/m^2).

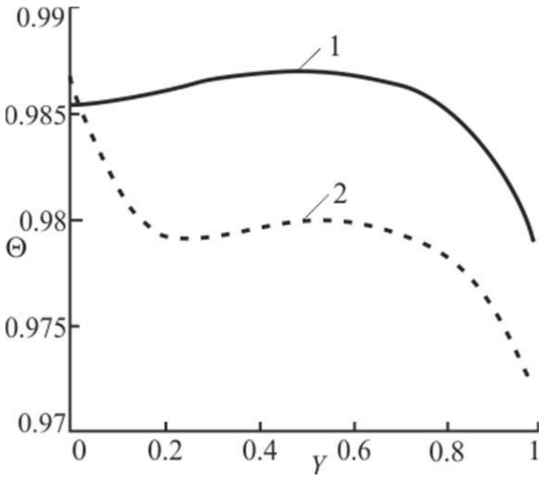
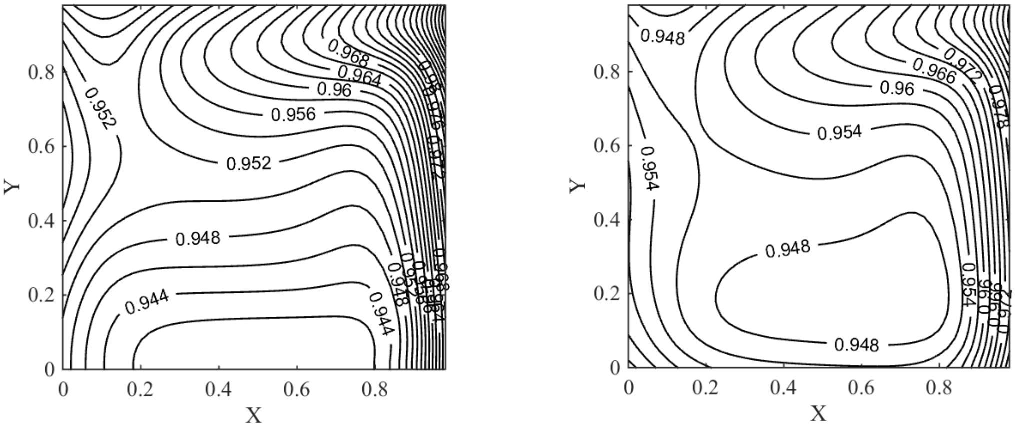


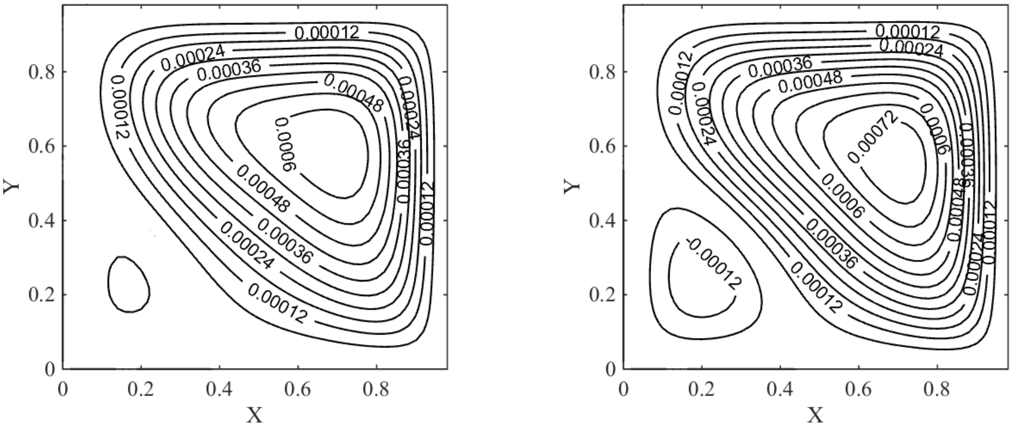
Figure 7. Temperature profile in the section $X = 0.5$, $0 \leq Y \leq 1$: 1) with the heat insulation on lower boundary ($q = 0$), 2) with the heat flow on lower boundary ($q = 0.05$ W/m^2).

The fields of temperature and flow line with the different values of heat flux on all three boundaries of the solution region are shown on figures 8,9.



a *b*

Figure 8. Fields of temperature with different heat flows on the left (q = 0.05 W/m^2) and right (q = 0.05 W/m^2) boundary: *a*) heat insulation on lower boundary (q = 0), *b*) with the heat flow on lower boundary (q = 0.05 W/m^2).



a *b*

Figure 9. Contours of stream function with different heat flows on the left (q = 0.05 W/m^2) and right (q = 0.05 W/m^2) to boundary with: *a*) heat insulation on lower boundary (q = 0), *b*) with the heat flow on lower boundary (q = 0.05 W/m^2).

The basic heating of liquid is achieved from the side of boundary with the large heat flow (fig.8). The prevailing vortex, which intensifies the mixing process of liquid in the region (fig. 9). It is established that, a change in the intensity of heat flow on one of the vertical boundaries leads to scale changes in the flow pattern and temperature field in the entire region of the solution.

4 Conclusion

Conducted numerical investigations of convective heat transfer in the low-temperature storage of liquefied natural gas with different geometric and thermal conditions give the new information, which not only characterizes regime of convective flow in such reservoirs, but also it can be used for the improvement of the procedures of their design and improvement in the operating conditions.

Presented in this paper results may be used in the analysis of fluid flow and convective heat transfer of liquefied natural gas in other technological equipment with its production, transport and storage.

The work was realized within the research state assignment "Science" №13.1339.2014/K (Code of Federal Target Scientific and Technical Program 2.1410.2014).

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