Proceedings of the 5th International Conference of Fluid Flow, Heat and Mass Transfer (FFHMT'18)
Niagara Falls, Canada – June 7 – 9, 2018
Paper No. 121
DOI: 10.11159/ffhmt18.121

Numerical Analysis of Turbulent Natural Convection in LNG Storage Tank

Djeghdjegh Amel[1], Belmedani Mohamed[1], Salhi Yacine[2]
[1]Laboratory of Transfer Phenomena, Faculty of Mechanical and Process Engineering, USTHB University
BP 23, El Alia, Algiers, Algeria
ameldjegh@yahoo.fr; m_belmedani@yahoo.fr
[2] Faculty of physics, USTHB University
BP 23, El Alia, Algiers, Algeria

Abstract – Nowadays, the heat infiltration through the walls of the liquefied naturel gas (LNG) storage tanks is considered a principal source of security problems throughout the supply and distribution chain. In effect, these infiltrations cause evaporation of LNG coupled with stratification phenomenon, which begat a substantial loss in the quantity and quality of the product and may affect the safe storage. the recent work has been published on the effect of heat infiltration on the storage of cryogenic liquids, with used a parietal heat flux of 50 W/m^2, and the case when them while used up to 330 W/m^2. In our case, our objective is to make a study of the natural convection turbulent in a LNG storage, description of temperature and velocity profiles particularly at the boundary layer and generates contours by a movement of fluid in the tank. The software used to observe the evolution different parameters. We took into account two types of storage tank 37 000 m^3 and 160 000m^3 with the number of Ra varies between 10^7 and 10^{15}, with two turbulence model Kω SST for the boundary layer away to walls and model kε for tank to study significant variations with a minimum constant heat flux of 50 W/m^2 and we increase up to 500 W/m^2.

Keywords**:** LNG, Tank Storage, Naturel Convection.

1. Introduction

The natural gas is considered a not renewable resource the reserves of which are unevenly distributed in the world, the reassurance of the conditions of supplies, transport and thus the storage represent an absolute priority.

In Algeria, after the Skikda accident on 19 January 2004 and the total shutdown of the first LNG " La Camel" complex on 24 April 2010 after 64 years of operation, Algeria has put in place a plan Development of its infrastructure of natural gas liquefaction industry by carrying out two mega liquefaction train

- A new mega- GNL3Z liquefaction train was built for which the production start-up was in June 2014 with a production capacity of 10 586 million m^3 for its storage part, it was equipped with two membrane storage tanks with a unit capacity of 160 000 m^3.
- A mega-train in Skikda with a production capacity of 4.5 MTA of LNG [1].

Indeed, the main sources of the problems during the period of storage of the GNL is the infiltration of the heat through the walls of reservoirs, these cause the phenomenon of evaporation, what engenders a sensitive loss of the quantity and the quality of the product and can have an incidence on the safety of the storage.

The flow of natural convection originates along the vertical walls and that is created at the end of the flows of entering heat. Very little work on natural convection coupled with evaporation in reservoirs with lateral heating of cryogenic liquids while at rest, this lack of studies is clearly due to the complexity of the phenomenon [2][3].

2. Mathematical Formulations

Heat leaking into the tank results in a density change in LNG at different level in the tank leads to stratification and rollover. Thus, a 2D LNG storage tank model is developed based on the following assumptions and simplifications, the governing system of equations can be written as follows:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \quad (1)$$

$$U \frac{\partial \theta}{\partial X} + V \frac{\partial \theta}{\partial Y} = \frac{1}{Gr^{1/2}\ \mathrm{Pr}} \frac{\partial^2 \theta}{\partial X^2} \quad (2)$$

$$U \frac{\partial V}{\partial X} + V \frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + P_r \left\{ \frac{\partial}{\partial X}\left(\frac{\partial V}{\partial X}\right) + \frac{\partial}{\partial Y}\left(\frac{\partial V}{\partial Y}\right) \right\} + Ra\ .\mathrm{Pr}\ .\theta\ .A \quad (3)$$

H : Height of the tank;
D : Diameter of the tank
A = D/H: The aspect ratio of the tank;
Pr : nombre de Prandtl
Ra : Nombre de Rayleigh
Gr : Nombre de Grashof

3. The Initial Conditions

The properties of the LNG product stored at the level of the Arzew complex are mentioned in the following table:

Table 1: Physical property parameters of LNG Arzew complex.

Name	Density (kg/m^3)	Temperature of LNG (K)	Coefficient of thermal expansion (10^{-3} K^{-1})	Specific Heat	Thermal conductivity (W / mK) Cp	µ 10^{-6} (kg m-1 K-1)
Value	470	110	3.12	0.25	3370	157

At time t = 0, the physical quantities are thus taken as follows:

Table 2: Initial conditions of LNG storage tanks.

Parameters	The longitudinal velocity	The transverse velocity,	The temperature	The acceleration of gravity
Value	u = 0	v = 0	$T = T_0 = 111$ K	$g = 9.8$ gms^{-2}

All of the fluid properties except density are taken to be constant.

4. Model Description

Thermal stratification in an axis-symmetric tank is caused due to complex two-dimensional boundary layer phenomenon, occurring close to tank wall.

Our model is developed using FLEUNT solver to simulate thermal turbulent naturel convection in a typical LNG tank, having different diameters: 80 m and 46 m, and liquid level filled up to 88% of the total height.

The present work simplifies this phenomenal into two-dimensional model to predict the fluid temperature and velocity evolution during the occurrence of various thermodynamic transients in the tank.

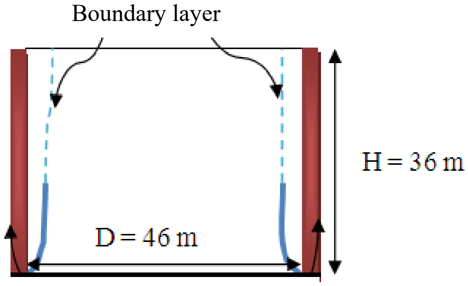

Fig. 1: Schematic of physical model for tank 37 000 m^3.

The Grashof numbers can be calculated and the flow state of rollover can be characterized to be turbulent flow as it showed in Table 3.

Table 3: The different parameters of LNG storage tanks and flow discrimination.

Parameters	D (m)	H(m)	Grashof number	Flow state
Tank 160 000m^3	80	32	10^7-10^{13}	Turbulent flow
Tank 37 000m^3	46	36	10^7-10^{15}	Turbulent Flow

The heat flux absorbed from the ambient is assumed to be constant and uniform along the side and bottom walls. We various the heat flux from 50 W/m^2 up to 500 W/m^2. In the litterature based on [4], used a parietal heat flux of 50 W/m^2, and on [5]used up to 330 W/m^2.

5. Numerical Methods

In this paper, rollover in two type of LNG storage tanks with different capacity are researched. the rollover evolution in a 160 000 m^3 tank with a diameter of 80 m is simulated using FLUENT software.

The governing equations mentioned above with the boundary conditions are numerically solved using the finite volume method.

The creation of the geometry was done under Gambit2.4.6 with a mesh non-uniform rafined at sidewalls as is show in figure 2, after process test of the different meshes it was found that the profiles of velocity axial does not change of ways significant from total number of grid cells is 80.10^4 for 160 000m^3 tank and 10^5 for 37000 m^3 tank.

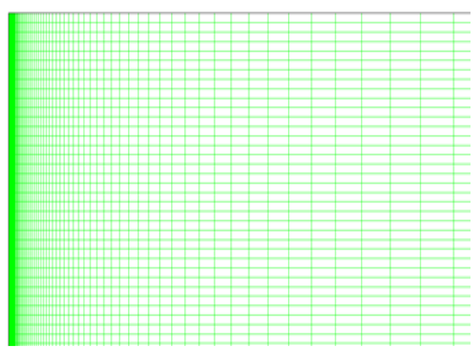

Fig. 2: Expansion of the mesh pre of vertical wall for 37000 m^3.

We used two turbulence models for the study Kω SST significant variations in the boundary layer turbulent and kε for tank, away to walls with a minimum constant heat flux of 50 W/m^2 and we increase up to 500 W/m^2.

6. Analysis on the Simulation Results

The liquid in the upper layer is given at 470 kg/m^3, which is 1 kg/m^3 greater than the liquid in the lower layer.

The contours observed in the figure 2 are shown as the left half of the physical model because rollover occurs symmetrically in the tank for 160 000m^3 with 50 W/ m^3.

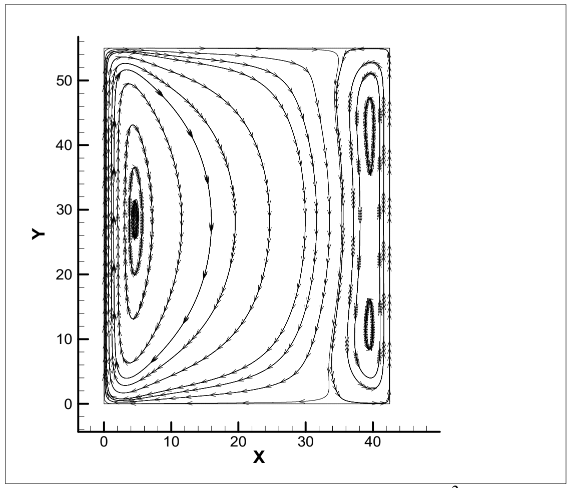

Fig. 3: Contours for velocity in the 160 000m^3 for 50 W/m^2.

Thermal infiltrations that originate from the environment at the LNG storage tank generate a fluid movement from the natural convection phenomenon, causing temperature and velocity gradients. These thermal and dynamic instabilities are limited to the level of the boundary layer, where the notable variations of the flow are recorded.

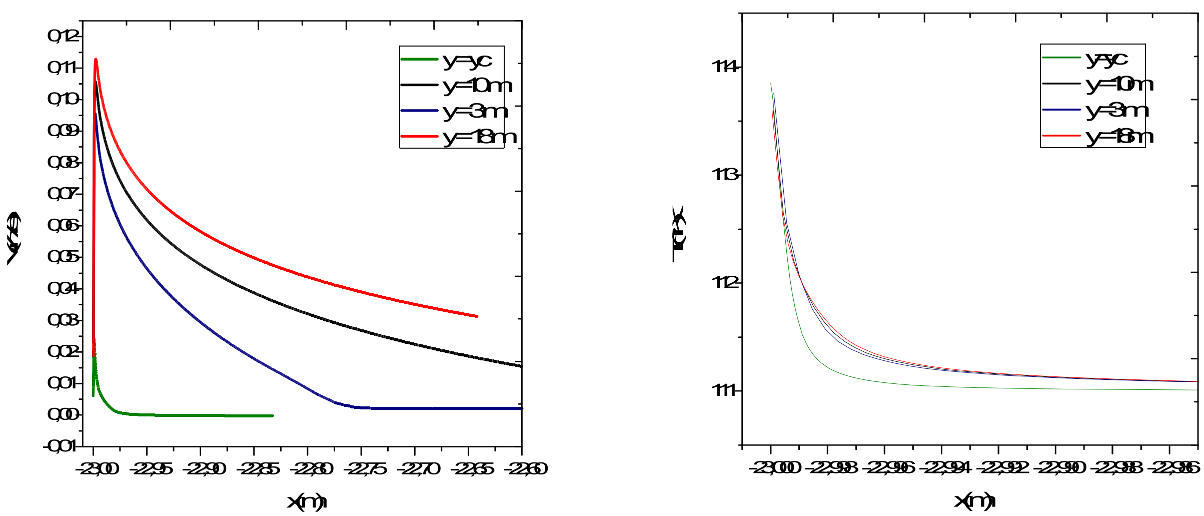

Fig. 4: Velocity and temperature profiles in the turbulent parietal boundary layer of the heat flux 300 W/m^2.

In our work, we setting a flow on the side wall, the nature of the flow depends only the vertical position (Y), as is show variation of velocity and temperature in the profiles (figure 4) with heat flux 300W/m^2.

7. Conclusion

Our work consisted in carrying out a numerical study on natural convection in an LNG storage tank, subjected to a constant heat flux at the walls in a turbulent regime.This study contributed mainly to the analysis of the thermal and dynamic fields, measured in the vicinity of the hot side walls as well as the case of thermal infiltration at the bottom of the storage tank. The results illustrated by the various fields show the intensity of the convective movements in the liquid, which is related to the height of this liquid in the reservoir and to the formation of several rolling zones at the bottom of the tank.

The increase of these convective currents feeds the heat energy provided by the progressive heat flow by causing turbulence, so the more the heat flow imposed on the wall is the more intense and agitated the convective currents and the more the transfers near The wall finishes quickly. These results allowed us to plot the variation of the Nusselt number as a function of the Rayleigh number as well as the evolution of the Grashof number as a function of the increase of the heat flux in order to better distinguish the two laminar flow regimes and Turbulent flow.

Reference

[1] *Sonatrach report*, 2015.

[2] S. Irene, S. Varela, A. Vernet, "Characterization of the reacting laminar flow in a cylindrical cavity with a rotating end wall using numerical simulations and a combined PIV/PLIF technique," *International Journal of Heat and Mass Transfer,* vol. 93, pp. 002-0040-035, 2016.

[3] M. S. Gandhia, J. B. Joshia, A. K. Nayakc, P. K. Vijayan "Reduction in thermal stratification in two phase natural convection in rectangular tanks: CFD simulations and PIV measurement," *Chemical Engineering Science* 100-300–325, 2013.

[4] S. Roha, G. Sona, G. Song b, J. Bae, "Numerical study of transient natural convection in a pressurized LNG storage tank," *Applied Thermal Engineering,* vol. 52, pp. 209-220, 2013.

[5] J. Joseph, G. Agrawal, D. Kumar Agarwal, J. C. Pisharady, S. Sunil Kumar, "Effect of insulation thickness on pressure evolution and thermal stratification in a cryogenic tank," *Journal of Applied Thermal Engineering*, 2016.