ABSTRACT

Heat transfer by natural convection in storage tanks for LNG is extremely related to heat gains through the walls with thermal insulation is not perfectly efficient. In this paper we present the study of natural convection in unsteady regime for natural gas in aware phase using the fluent software. The gas is just on the surface of the liquid phase. The CFD numerical method used to solve the system of equations is based on the finite volume method. This numerical simulation allowed us to determine the temperature profiles, the stream function, the velocity vectors and the variation of the heat flux density in the vapor phase in the LNG storage tank volume. The results obtained for a general configuration, by numerical simulation were compared to those found in the literature.

Keywords: Numerical Simulation, Natural Convection, Heat Gains, Storage Tank, Liquefied Natural Gas.

1. INTRODUCTION

During the period storage of liquefied natural gas, stability is necessarily affected by natural convection along the walls of the tank with thermal insulation is not perfectly efficient. Several studies have been devoted to the understanding of this physical phenomenon by numerical simulation or an experimental works. Among these works we can also mentioned that Evans et al [1] conducted a study in a cylindrical cavity partially filled with a liquid. Belssiotis [2] studied numerically the unsteady natural convection in a cylindrical cavity containing water for a turbulent high Rayleigh number. Barzegar et al [3] presented a numerical study in a storage tank filled with two types of LNG, to treat the heat transfer. Pham et al [4] have carried the study of natural convection double diffusion in a square cavity containing LNG initially stratified. The objective of this study is to know the influence of aspect ratio and boundary conditions on the thermal and dynamic behavior of LNG vapor stored in tank.

2. MATHEMATICAL FORMULATION

The study domain considered is shown in Figure1, the aspect ratio $AL = H / D$. The lateral wall and the roof exchange heat by convection and by radiation with the environment. For cons, the bottom of the tank is considered at the temperature of the liquid LNG. The cavity containing the LNG vapor whose physical properties are constant, the fluid is assumed Newtonian viscous dissipation is negligible, and the flow is incompressible boussinesq approximation is counted. Given the axial symmetry, the problem is two-dimensional and heat transfer along the vertical walls is made by natural convection.

![Figure 1 Domain of Study](image)

The Navies-Stokes equations governing the problem are studied:

\[
\nabla \cdot \mathbf{U} = 0
\]

(1) Continuity Equation

\[
\frac{\partial \mathbf{U}}{\partial t} + \mathbf{U} \cdot \nabla \mathbf{U} = -\frac{1}{\rho_0} \nabla P + \nu \nabla^2 \mathbf{U} + \mathbf{f} \nabla \mathbf{T} g
\]

(2) Equation of movement
\[ \rho c_p (\frac{\partial T}{\partial t} + U \cdot \nabla T) = \nabla \cdot (\lambda \nabla T) \]  \hspace{1cm} (3) \hspace{1cm} \text{Energy Equation}

And the boussinesq approximation is:
\[ \rho = \rho_0 (1 - \beta(T - T_0)) \]  \hspace{1cm} (4)

\[ u_r = \frac{1}{r} \frac{\partial \psi}{\partial z} \hspace{1cm} u_z = -\frac{1}{r} \frac{\partial \psi}{\partial r} \hspace{1cm} \text{Velocity along } r \text{ and } z \]

The associated initial and boundary conditions are respectively:

At \hspace{1mm} t=0 \hspace{1mm} u_r = u_z = \psi = 0 \hspace{1cm} T(0, r, z) = T_0

Where \hspace{1mm} T_0 \hspace{1mm} : \hspace{1mm} The \hspace{1mm} temperature \hspace{1mm} of \hspace{1mm} GNL \hspace{1mm} equal \hspace{1mm} 111K:

\[ r=0, \hspace{1cm} z=0 \hspace{1cm} u_r = u_z = \psi = \frac{\partial \psi}{\partial r} = \frac{\partial \psi}{\partial z} = 0 \]

\[ r=R \hspace{1cm} \psi = \frac{\partial \psi}{\partial r} = \frac{\partial \psi}{\partial z} = 0 \hspace{1cm} z=H \hspace{1cm} \psi = \frac{\partial \psi}{\partial r} = \frac{\partial \psi}{\partial z} = 0 \]

\[ r=0 \hspace{1cm} \left. \frac{\partial T}{\partial r} \right|_{r=0} = 0 \hspace{1cm} z=0 \hspace{1cm} T(0, r, 0) = T_0 \]

\[ r = R \hspace{1mm} \left. -\lambda \frac{\partial T}{\partial r} \right|_{r=R} = h_c(T_{r=R} - T_a) \hspace{1mm} z = H \hspace{1mm} \left. -\lambda \frac{\partial T}{\partial z} \right|_{z=H} = h_c(T_{z=H} - T_a) \]

3. RESULTS AND DISCUSSION

The system of equations is solved numerically by CFD method based on the finite volume method. LNG vapor phase consists essentially of methane. The figure A shows the temperature profiles calculated for the form factors of the cavity \( AL = 1/2, 1/4 \) and 1, which correspond to the different heights of vapor for Rayleigh numbers ranging to \( Ra = 1.10^{07} \) and \( Ra = 1.10^{09} \). We note that the temperature values are higher for the aspect ratio of \( AL = 1 \).

![Figure A. Profiles of Temperature](image1)

![Figure B. Stream function](image2)

![Figure C. Velocity Vectors](image3)
Concerning stream functions shown in Figure B the fluid movement is unicellular and values are higher in the case of $AL = 1$. The figure C shows the velocity vectors that describing the movement in the cavity, the fluid particles are heated on the walls because of the heat input from outside to inside, stood along the last walls and takes higher values. Figure D shows the variations of temperature profiles along the height ($z$), we always note that the increase in values over the height is remarkable for the value of the higher elevation. Figure E introduce a very good agreement between our calculations and measurements on site for temperature values. Figure F shows the comparison between the values of velocity vectors for the three form factors of the tank, we can say that the values are higher for $AL = 1$. The density values of heat fluxes are higher near the walls for the three form factors shown in Figure G, then begins to decrease because those are the walls that heat the liquid. All figures shows strong and significant effect on the level of the LNG value variation. Furthermore, concerning the values of velocity and stream functions we calculated are similar to those found by other authors.
4. CONCLUSION

The study of natural convection in a storage tank is interesting from a practical point of view. In this study we presented a numerical simulation to evaluate the temperature fields, the stream functions, velocity vectors and the variation of the heat flux density in the gas phase of LNG. The results are in good agreement with the experimental readings observed in actual operating conditions. The results presented in this work also show the sensitivity of the form factor AL corresponding to different levels of tank, these results support the cause not completely filled storage tank and also avoid low liquid levels during storage LNG.

5. NOMENCLATURE

D : Dimensional Diameter
H : Dimensional Height
Al : Form Factor H / D
T : Dimensional Temperature
Ta : Ambient Temperature
T0 : Storage Temperature of LNG
U : Dimensional Velocity
ψ : Dimensional Stream Function
ur : Dimensional Radial Velocity
uz : Dimensional Axial Velocity
Ra : Rayleigh Number, \( \frac{g \beta \Delta T H^3}{\alpha v} \)
p* : Hydrostatic Pressure, \( p + \rho_0 g z \)
Pr : Prandtl Number, \( \nu / \alpha \)
β : Coefficient of Thermal Expansion
α : Thermal Diffusivity
λ : Thermal Conductivity
μ : Dynamic Viscosity
ν : Kinematic Viscosity
he : Thermal Coefficient of Heat Exchange
ρ : Volumetric Mass
Cp : Specific Heat Density
g : gravity
t : time

REFERENCES