CFD simulation of stratification in liquefied natural gas (LNG) tank

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ABSTRACT – Rollover happen when two stratified Liquefied Natural Gas (LNG) reaches density equilibrium and release large amount of vapor in short period causing over-pressurization of the storage tank. The novelty of the present work is to study the relationship between stratification effect with the independent parameter of filling rate, density condition and initial depth of heel LNG by using Computational Fluids Dynamic (CFD) software. Present study also focuses on the review of stratification, different composition effect, filling method and behavior, heat leakage and rollover in both numerical and experimental way. Work done by previous researchers was selected to perform validation test by using numerical simulation and a relative percentage error of 8.76% was obtained showing well agreement between present study simulation with experimental result. The independent parameters which is filling rate, initial depth of heel LNG, and density condition effect on stratification was discussed with detailed. Generally, case study simulation result shows that lower filling rate, deeper height of heel LNG, and smaller initial density difference between two LNG are recommended to reduce stratification level.

1. INTRODUCTION

Liquefied Natural Gas (LNG) is a substance produced from the natural gas via various cooling process to the temperature of -160 0C at atmospheric pressure of 101kPa [1-2]. LNG is not a pure substance but formed by various hydrocarbons and non-hydrocarbon like methane, ethane, propane, butane, nitrogen, carbon dioxide, and etc. [1]. Typically, methane with chemical formula CH_4 exists with a high fraction within the natural gas if compared to other components but the composition of the natural gas can vary widely depend on the gas source [3]. Typical composition of natural gas which makeup from large volume of methane (> 85%) along with the other component but the composition of LNG is varying for different country [3]. The consequence of mixing varies LNG qualities inside a storage tank is density stratification and in the end lead to serious safety concern named rollover. When stratified LNG come to equilibrium (density of two liquid become equality due to convection), the interface between two layer become unstable and mixes rapidly in the end. In this moment, liquid from the lower layer that is superheated gives off a large amount of vapor that rises to the surface, which may exceed the safety venting capability of tank and cause seriously damage [4]. However, the effect of stratification can be minimized by using correct filling method depend on the circumstances. So present study is focus on evaluate and simulate the filling behaviour to minimize the density difference (stratification) in order to reduce the consequence of rollover.

2. METHODOLOGY

Since the experiment is uncovering in this study, so the validation of the simulation result is done by comparing it to nearest published studies in term of density and volume fraction under same parameter. 2.1 to 2.4 showed the parameter introduced.

Table 1.1 Physical properties of tank

Parameter	Volume	Diameter	Height
Tank Dimensions	200,000 m^3	72m	49.12m

Table 2.2 Operation Condition of filling behaviour

Parameter	Fiilling Method	Filling LNG	Heel LNG
Operating Condition	Bottom feed	Lighter	Denser

Table 2.3 LNG properties for heel and feed

	Feed LNG	Heel LNG
Density,ρ(kg/m^3)	-1.286T +109.39 +ρ_0	-1.147T+131.38+ρ_0
Viscosity,μ(10^{-4}Pa.s)	1.2	1.5
Thermal Conductivity,λ(W/mK)	0.2	0.2
Specific heat, C_p(kJ/kgK)	3.4	3.0
Initial Temperature, T(°C)	159.15	158.45

Table 2.4 Feed condition of LNG

Parameter	Density difference $-(\rho-\rho_0)/\rho_0$ x 100	Initial Depth of Heel LNG, H_0/D x100	Feed Rate, (10^3 m^3/h)	Feed Time (t)
Feed Condition	8	17.9	1.1	4.4

3. RESULTS AND DISCUSSIONS

The simulation is carry out by density condition, feed rate and initial depth of the heel LNG in order to predict the most efficiency way to reduce the stratification effect. From the Figure 3.1, present study noticed that the level of stratification increase when the filling rate increase.

By making the comparison between lowest feed rate with highest filling rate, four clearly satisfied layer was formed at highest feed rate but this phenomenon does not appear and form at lowest filling rate. This filling rate stratification directly relationship goes positively with the studies did by Tamura [3]. Graphically, stratification can be determined by study the gradient of the graph (density versus vertical height). With the gradient of 0.0383, flowrate of 0.8m/s shows highest slopping, which is can be remarked as strongest stratification existing along the vertical height of the tank. According to the related work by previous researchers which was discussed before, a lot of superheated heat due to heat leakage form tank wall will be trapped and accumulated within the boundary formed of stratified layer and contributed to rollover.

The number of superheated trapped will increases with more number of stratified layer formed, and also, the large density difference between two fluids.

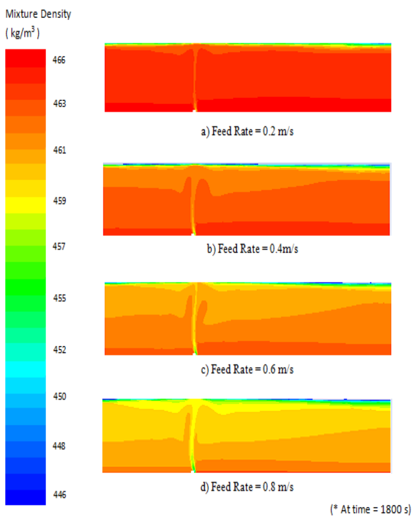

Figure 3.1 Contour distribution of Mixture Density for Different Filling Rate at 1800s

4. CONCLUSION

As a summary, low filling rate, small initial relative density difference, and deeper heel were shows to minimize the level of stratification. Stratification level are highly depending on the mixing behavior between feed and heel LNG. General speaking, higher mixing behavior reduced stratification level for all cases except the filling rate cases. Although higher filling rate produced better mixing behavior, but it does not guarantee reduced in stratification level. More researchers must be contacted to study the true criteria that affect the stratification level by different filling rate.

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