International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Calculating Sloshing Impact on Tanker Walls for Fluids at Varying Accelerations

S V V SN Murthy[1], **G. Kishore**[2]

[1]Department of Mechanical Engineering, Sri Sunflower College of Engineering and Technology, Ghantasalamandal, Krishna District, Lankapalli, Andhra Pradesh 521131

[2]Associate Professor, Department of Mechanical Engineering, Sri Sunflower College of Engineering and Technology Ghantasalamandal, Krishna District, Lankapalli, Andhra Pradesh 521131

1. Introduction

1.1 Fuel Tank

A **fuel tank** (or **petrol tank**) is a safe container for flammable fluids. Though any storage tank for fuel may be so called, the term is typically applied to part of an engine system in which the fuel is stored and propelled (fuel pump) or released (pressurized gas) into an engine. Fuel tanks range in size and complexity from the small plastic tank of a butane lighter to the multi-chambered cryogenic Space Shuttle external tank.

Plastic (high-density polyethylene HDPE) as a fuel tank material of construction, while functionally viable in the short term, has a long term potential to become saturated as fuels such as diesel and gasoline permeate the HDPE material.

1.2 Fuel Tank Construction

While most tanks are manufactured, some fuel tanks are still fabricated by metal craftsmen or hand-made in the case of bladder-style tanks. These include custom and restoration tanks for automotive, aircraft, motorcycles, and even tractors. Construction of fuel tanks follows a series of specific steps. The craftsman generally creates a mockup to determine the accurate size and shape of the tank, usually out of foam board. Next, design issues that affect the structure of the tank are addressed - such as where the outlet, drain, fluid level indicator, seams, and baffles go. Then the craftsmen must determine the thickness, temper and alloy of the sheet he will use to make the tank. After the sheet is cut to the shapes needed, various pieces are bent to create the basic shell and/or ends and baffles for the tank. Many fuel tanks' baffles (particularly in aircraft and racecars) contain lightening holes. These flanged holes serve two purposes; they reduce the weight of the tank while adding strength to the baffles. Toward the end of construction, openings are added for the filler neck, fuel pickup, drain, and fuel-level sending unit. Sometimes these holes are created on the flat shell, other times they are added at the end of the fabrication process. Baffles and ends can be riveted into place. The heads of the rivets are frequently brazed or soldered to prevent tank leaks. Ends can then be hemmed in and soldered, or flanged and brazed (and/or sealed with an epoxy-type sealant) or the ends can be flanged and then welded. Once the soldering, brazing or welding is complete, the fuel tank is leak-tested.

1.3 Parts of A Tanker

1) **Storage of Fuel:** the system must contain a given quantity of fuel and must avoid leakage and limit evaporative emissions.
2) **Filling:** the fuel tank must be filled in a secure way, without sparks.
3) **Pressure Guage Or Level Indicators:** Provide a method for determining level of fuel in tank, and gauging in order to know the remaining quantity of fuel in the tank can be measured or evaluated.
4) **Venting**: over-pressure is not allowed in the tanker. So the fuel vapors must be managed through valves.
5) **Feeding Pump** to the engine or from the sources through this pump.
6) **Anticipate Potentials** for damage and provide safe survival potential.

1.4 Types of Fuel Tank

1.4.1 Automative Fuel Tank

The maximum distance a combustion-engine powered car with a full tank can cover is the product of the tank capacity and its fuel efficiency (as in miles per gallon). While larger tanks increase the maximum distance, they also take up more space and (especially when full) add to the total weight, requiring higher fuel consumption for the same performance. Fuel-tank capacity is therefore the result of a trade-off in design considerations. For most compact cars, the capacity is in the range 45–65 liters (12–17 US gal); the original model Tata Nano is exceptional with its 15 liters (4 US gal) fuel tank. SUVs and trucks tend to have considerably larger fuel tanks.

For each new vehicle a specific fuel system is developed, to optimize the use of available space. Moreover, for one car model, different fuel system architectures are developed, depending on the type of the car, the type of fuel (gasoline or diesel), nozzle models, and region.

Two technologies are used to make fuel tanks for automobiles:

- Plastic high-density polyethylene (HDPE) fuel tanks made by blow molding. This technology is increasingly used as it now shows its capacity to obtain very low emissions of fuel (see Partial zero-emissions vehicle). HDPE can also take complex shapes, allowing the tank to be mounted directly over the rear axle, saving space and improving crash safety. Initially there were concerns over the

low fracture toughness of HDPE, when compared to steel or aluminum. Concern for safety and long term ability to function should be considered and monitored.
- Metal (steel or aluminum) fuel tanks welded from stamped sheets. Although this technology is very good in limiting fuel emissions, it tends to be less competitive and thus less on the market, although until recent times automotive fuel tanks were almost exclusively made from sheet metal.

Modern cars often feature remote opening of the fuel tank fuel filler flap using an electric motor or cable release. For both convenience and security, many modern fuel tanks cannot be opened by hand or otherwise from the outside of the car.

1.4.2 Reserve Tank

Sometimes called the reserve tank is a secondary fuel tank (in many cars/bikes it contains around 15% of the capacity of the primary tank) these are more commonly found on bikes, older cars (some without a fuel gauge) and vehicles designed for long distance or special use. A light on the instrument panel indicates when the fuel level dips below a certain point in the tank. There is no current standard, although some efforts are made to collect this data for all automobiles.

In vehicles modified for endurance the primary tank (the one that comes with the car) is made into a reserve tank and a larger one installed. Some 4x4 vehicles can be fitted with a secondary (or sub-tank) by the dealership.

1.4.3 Racing Fuel Cell

A *racing fuel cell* has a rigid outer shell and flexible inner lining to minimize the potential for punctures in the event of a collision or other mishap resulting in serious damage to the vehicle. It is filled with an open-cell foam core to prevent explosion of vapor in the empty portion of the tank and to minimize sloshing of fuel during competition that may unbalance the vehicle or cause inadequate fuel delivery to the motor (fuel starvation). The designation "racing" is often omitted due to familiarity and because this type of gas tank is also used on street vehicles. The omission can lead to confusion with other types of fuel cells. See Fuel cell (disambiguation).

1.4.4 Placement and Safety

For safety considerations, in modern cars the fuel tank is usually located ahead of the rear axle, out of the crumple zones of the car.

Automobiles such as the Ford Pinto or the models that still use the Ford Panther platform (Ford Crown Victoria, Lincoln Town Car, and Mercury Grand Marquis) are notorious for having the fuel tank behind the rear axle. Since 1980 new Ford models corrected this problem and had the fuel tank in front of the rear axle.

General Motors 1973-1987 C/K pickup trucks have the fuel tank located outside the frame. According to the Center for Auto Safety this creates a fire hazard. In automotive applications, improper placement of the fuel tank has led to increased probability of fire in collisions. Circa 1990, General Motors faced over a hundred product liability lawsuits related to fires allegedly caused by GM's decision to place the fuel tanks in its pickup trucks outside the protection of the vehicle's frame. In 1993, reportage on this matter for NBC News created a scandal over vehicles rigged to catch fire for the television camera.

Ford's Pinto also sparked controversy for putting the fuel tank in a poorly reinforced area which can cause deadly fires and explosions if the car got into a rear end collision, costing Ford US$125 million.

Condensation may occur in half-filled fuel tanks. Top off the fuel tanks after the engine is operated. Fuel tank should include some consideration for draining and sediment from the bottom of the tanks.

Likewise for safety reasons, the filler could no longer be in the middle back of the car in the crumple zone and thus had to be on the side of the car. Which side is a series of trade-offs: driver's side is easier to access, and mechanically simpler for gas cap locks; passenger side is safer (away from passing traffic in roadside fill-ups). Asymmetric sliding doors may also dictate placement and some minivan doors will collide with a fill-up in progress.

1.4.5 Aircraft

Aircraft typically use three types of fuel tanks: integral, rigid removable, and bladder.

1) Integral tanks are areas inside the aircraft structure that have been sealed to allow fuel storage. An example of this type is the "west wing" commonly used in larger aircraft. Since these tanks are part of the aircraft structure, they cannot be removed for service or inspection. Inspection panels must be provided to allow internal inspection, repair, and overall servicing of the tank. Most large transport aircraft use this system, storing fuel in the wings, belly, and sometimes tail of the airplane.
2) Rigid removable tanks are installed in a compartment designed to accommodate the tank. They are typically of metal construction, and may be removed for inspection, replacement, or repair. The aircraft does not rely on the tank for structural integrity. These tanks are commonly found in smaller general aviation aircraft, such as the Cessna 172.
3) Bladder tanks, or fuel cells, are reinforced rubberized bags installed in a section of aircraft structure designed to accommodate the weight of the fuel. The bladder is rolled up and installed into the compartment through the fuel filler neck or access panel, and is secured by means of metal buttons or snaps inside the compartment. Many high-performance light aircraft, helicopters and some smaller turboprops use bladder tanks. One major down-side to this type of tank is the tendency for materials through extensive use making them brittle causing cracks. One major plus side is the ability to utilize as much of the aircraft as possible to store fuel.
4) Combat aircraft and helicopters generally use self-sealing fuel tanks.

1.5 Shape of Storage Tankers [12]:

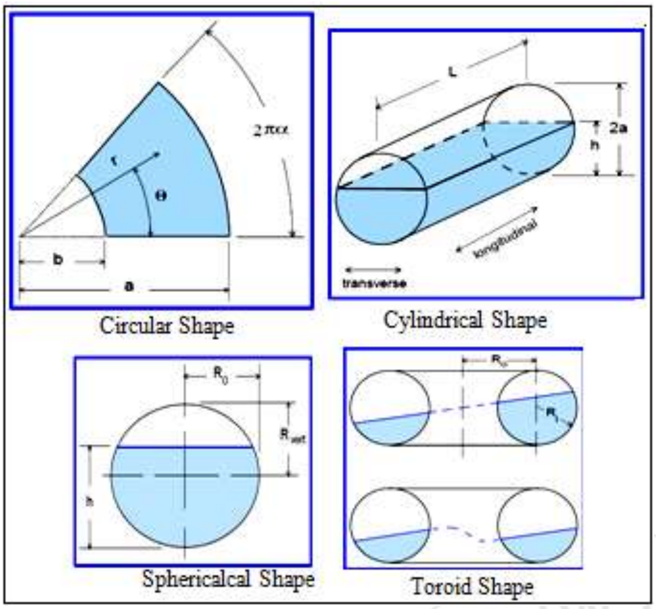


Figure 1.2: Schematic Diagrams of Spherical, Cylindrical, Spherical and Toroid Shaped Tankers.

Pressure vessels can theoretically be almost any shape, but shapes made of sections of spheres, cylinders, and cones are usually employed. A common design is a cylinder with end caps called heads. Head shapes are frequently either hemispherical or dished (tori spherical). More complicated shapes have historically been much harder to analyze for safe operation and are usually far more difficult to construct.

1.6 Sloshing

In fluid dynamics, sloshing refers to the movement of two or more immiscible fluids (generally liquid and gas) inside another object (which is, typically, also undergoing motion). Feather of the sloshing is that the liquid must have a movable free surface. Sloshing is a common phenomenon of fluid motion and always occurs in partly filled tank. Such as propellant slosh in spacecraft tanks and rockets (especially upper stages), cargo slosh in ships and trucks transporting liquids (for example oils like petroleum, diesel, gasoline and LNG), the stored liquid slosh in nuclear reactors and reservoirs tanks in earthquake, wave motion near the port, and so on. Sloshing motion is a complicated fluid movement. When frequency of external excitation is close to natural frequency of liquid in partly filled tank or amplitude of excitation is very large, sloshing motion in the tank will be severe. Thus the impact force to the side or ceiling of tank will be significantly strong and destroy the structure.

Sloshing can cause serious problems so that necessary prevention is essential. For example, in aerospace field, sloshing of the liquid for attitude adjustment of the Earth Satellite may cause instability of it without careful treatment. In working process of launch vehicle, sloshing of liquid propellant in fuel tank will disturb the normal operation of vehicle control system that generates instable propulsion power. In earthquake, sloshing motion in oil tank will bring about large hydrodynamic pressure and impact loads, which might destroy the structure of tank. Seriously, fire disaster or wide-area environmental pollution will occur, which are extremely dangerous, especially for nuclear reactor. On sea, ship motion of tankers in waves might cause sloshing in partly filled tank, which will lead to instability of tankers. Severe sloshing motion may produce large impact force to tank wall and structure and destroy them. The leakage of oil or LNG is a big threatens to environment and personal safety. However, if sloshing is made reasonable used; it will become advantageous to us. Such as the roll-reduction tank that use the force and moment provided by sloshing motion in the tank to reduce the ship motion in wave. In skyscrapers there are always boxes whose natural frequencies are different from the building to reduce amplitude of damping. From the example mentioned above, in order to control or make use of sloshing motion, study and research of mechanism of sloshing is necessary.

1.6.1 How Slosh Loads are Developed on the Tanker

The slosh loads depends upon the two major important factors they are
1) Type of disturbance and
2) Tanker shape

Based upon these two factors earlier many experiments were conducted to find the effect of tanker geometry [1]. The disturbances can be occurred due to seismic excitations or when the vehicle hits a brake and even when we hit any obstacle. Even at steady state the fluid will have motion inside the tanker due to the nature of the fluid.

Liquid sloshing strongly influences the directional dynamics and safety performance ofhighway tank vehicles in a highly adverse manner. Hydrodynamic forces and moments arising from liquid cargo oscillations in the tank under steering and/ or braking maneuvers reduce the stability limit and controllability of partially-filled tank vehicles. Anti-slosh devices such as baffles are widely used in order to limit the adverse liquid slosh effect on directional performance and stability of the tank vehicles. This is mainly due to the displacement of free surface motion of the liquid. Free surface is the top surface layer of the fluid or liquid.

1.6.2 Dependent Factors of Sloshing

As per the early work that was conducted on the sloshing effect the few factors were responsible for the effect of sloshing. They are listed below:
1) Amplitude and frequency of the tank motion [2], [1]
2) Liquid-fill depth [1][2]
3) liquid properties and
4) Tank geometry[1]

2. Literature Review

Several people made several dissertations on the effect of sloshing and found many parameters that are responsible for this effect and some made the computational dynamic analysis by using powerful software tools. Few performed experimental analysis to demonstrate the effect of sloshing. A major part of them are mentioned below.

2.1 Analytical Approach

The first attempt towards an accurate prediction of the sloshing-induced dynamic pressures over the internal girders and the walls of the fuel tanks was made by **Abramson (1966)**. He applied linear theories, based on the potential formulation of the velocity field.

The analysis of the liquid motion in cylindrical and spherical tanks and in ring and circular sector compartmented tanks **(Armenio and Rocca, 1996).** Experimental tests have been carried out in order to validate the mathematical models and to understand the effect of the geometrical and physical variables on the free surface oscillation. The study was mostly devoted to aerospace applications; nevertheless, it has represented the starting point of the many successive numerical and experimental researches in several areas.

Numerical work a host of researchers have done numerical simulation either by using self-made program or by using commercial CFD packages **(Modi and Seto, 1997; Kim et al., 2002; Frandsen, 2002).** The fluid used in solving the nonlinear sloshing is assumed to be homogeneous, isotropic and viscous, and exhibits only limited compressibility. Various models and techniques have been used to solve this problem, some of which are cited briefly in a chronological fashion.

Sakai et al. (1984) investigated the sloshing behavior of floating-roofed oil storage tanks through theoretical analysis and model testing. The analysis employed theory of fluid-elastic vibration to study the interaction between a roof and the contained liquid. The theory was verified by shake table experiments with three large models of single deck type and double deck type of floating roofs.

Popov et al. (1992) have studied liquid sloshing in rectangular road containers undergoing a turning or braking maneuver. The steady state solution in terms of liquid heights, forces and overturning moments are derived analytically from the hydrostatic equations. Numerical studies were carried out and compared with experimental results.

The problem of damping the sloshing in tanks with sharp-edged baffles (thin inserts which partially span the longitudinal and transverse cross- section) was investigated by **Buzhinskii (1998).** It was assumed that the domains of significant vortex motion of the fluid will be localized in small neighborhoods of the sharp edges of the baffles.

Celebi and Akyildiz (2002) have simulated the problem of fluid motion in partially filled rectangular tanks using the volume of fluid formation to track the free surface. They solved the complete Navier–Stokes equation in primitive variables by the use of the finite difference approximations. The study also included the use of a vertical baffle to have a pronounced effect in shallow water.

Pal (1999) used the finite element technique to study the dynamics of in viscid, incompressible liquid inside thin-walled, flexible, composite cylindrical tanks under small displacements in a coupled manner. The finite element equation of motion for both the tank wall and the fluid domain was formulated. Both rigid and flexible tank systems were analyzed to demonstrate the effects of tank flexibility on the slosh characteristics and the structural response. An experimental setup was made to study sloshing frequencies, sloshing displacements and hydrodynamic pressure. It was found that liquid slosh frequencies in rigid containers decrease with the decrease in liquid depth and increase in container width.

The NASA monograph by **Dodge and Franklin (2000)** is the extension of Abramson’s work (1966) that lucidly explains the mathematical background of the complex problem and the boundary conditions.

Kim (2001) investigated the sloshing flows in two- and three-dimensional liquid containers. The computational results were compared with experimental data and showed a favorable agreement of impact pressure as well as the global fluid motion.

2.2. Experimental Approach

Experimental work the large liquid movement in tanks creates slightly localized impact pressure on tank walls and also displays a violent disturbance in the fluid. Hence, this highly nonlinear nature of the problem I is the greatest hindrance in solving such a problem analytically and even computationally.

Furthermore, a number of assumptions need to be made so that the solutions could not deviate from the actual values. Hence, the experimental solution may be considered to be the best method to study the sloshing effect. A brief account of experimental researches carried out so far has been discussed in the following sections.

Mikelis and Journee (1984) have designed a proto type of the cargo tanks used to transport liquid cargo in ships. They have studied that the integration of pressures around the tank walls yields to overall forces and moments that are transmitted by the liquids onto the tank structure and consequently on the ship. It has also been experimentally studied how a semi-frozen liquid will have sloshing as compared to complete liquid cargo. They have found that damping is prominent in case of frozen cargo.

Focus of **Yalla and Kareem’s (2000)** paper is to provide a better understanding of this phenomenon, which is caused by the coupling that is introduced through the mass matrix of the combined system. The effectiveness of liquid dampers in controlling structural motions under wind and earthquake loadings has been demonstrated in the oryand practice.

Bredmoseetal(2003) have studied the horizontal sloshing both experimentally and numerically. They give the idea that tank acceleration may give rise to two very different types of responses which often coexist: a violent brief impact of the liquid on the container wall and large amplitude sloshing motions.

Violent impacts induce very large peak pressures which can be analyzed by means of the pressure–impulse theory. After the initial stages of liquid acceleration/deceleration along-lasting sloshing motion induces moderate-to-large pressures on the tank walls. Interaction of lengthwise and span wise waves generated by periodic and quasi- periodic parametrically forced sloshing in a rectangular channel has been studied experimentally.

The article on 'Violent Sloshing' by **Bredmoseetal (2004)** describes experimental and numerical solutions on how steep waves are forced by strong vertical motion of the tank. An in-depth study of sloshing effect in elevated water tanks due to seismic vibration was studied by **El Damattyetal (2005**). The tank, studied here, is a truncated cone with a superimposed cylindrical cap. Shake table testing is conducted to determine the fundamental frequencies. Excellent agreements are shown between the experimental and analytical results. The tank material taken is a thin sheet metal and the plate deformation is also determined.

2.3 Computational Study

Ling Hou et al. studied sloshing performance in a 2-D rectangular tank. In this study, transient analysis is performed under single and multiple-coupled external excitations for two different frequencies using ANSYS-FLUENT software. Volume of fluid (VOF) method was used to track the free surface of liquid and dynamic mesh technique to impose external excitation. The result shows that at coupled excitations and near resonant excitation frequencies, sloshing behavior will become violent and sloshing loads, including impact on the top wall, will be intensified.

J.H. Jung et al. investigated the effect of the vertical baffle heights on the liquid sloshing in a three-dimensional (3D) rectangular tank with 70% water fill level. He selected various ratios of baffle height (h_B) to initial liquid height (h).For simulation of 3D incompressible, viscous, two-phase flow in a tank partially filled with liquid and equipped with baffles, the volume of fluid (VOF) method based on the finite volume method has been used. Result shows that after a certain height (critical height) of baffle, the liquid does not reach at roof top and when baffle height is greater than liquid fill level, free liquid surface exhibit linear behavior in each section.

KritThreepopnartkul et al studied the effect of baffles on reducing severe sloshing inside moving rectangular tank. He used Finite volume method for analyzing fluid sloshing in tank. Computational models were used to investigate effects of baffles. This study has been done using C++ codes implemented in the Open Source software i.e. Open FOAM. The whole simulation was done experimentally as well as computationally and both the results were digitized using the image processing techniques having the average error less than 3.73%.

S. Rakheja et al. studied effectiveness of different design of baffle, including lateral, oblique, conventional and partial under longitudinal and lateral acceleration for different fill levels in a 3-D truck tank. This analysis was done using ANSYS-FLUENT software with volume of fluid (VOF) model for tracing of interface between two fluids. The result shows that the conventional lateral baffles are more effective to fluid slosh under longitudinal acceleration only while the oblique baffle helps to reduce both longitudinal as well as lateral slosh forces.

Kingsley et al. studied about design and optimization of 3-D rectangular container for sloshing and impact using VOF technique. They performed the investigation using numerical simulation as well as experimental validation. For numerical simulation k-Ɛ turbulence model for viscous effects and an acceleration user defined function (UDF) input was imposed for motion of tank.

Bernhard Godderidge et al. used experimental and commercial CFD code to study sway-induced sloshing flow in a rectangular tank. During investigation they compared homogeneous and inhomogeneous multiphase approach for fluid density and viscosity. The comparison between the computational and experimental results shows that the homogeneous model gives less accurate results for peak pressures up to 50% as compared to inhomogeneous multiphase model.

A.VakilaadSarabi et al studied the effect of ground motion on sloshing inside a rectangular tank. For this purpose they used computational fluid dynamics (CFD) simulation tool Open FOAM (Open Field Operation and Manipulation).A VOF technique is used to assure an accurate description of water displacement. Results shows that the intensity of sloshing and pressure loads depend on the tank geometry, fill level, amplitude, frequency of excitation.

A. Di Nardo et al evaluated the behavior of liquid fuel storage tanks of cylindrical shape (diameter = 10 m, height = 11m) when subjected to an earthquake. The analysis was done with the help of CFD software. The simulations were made for different filling levels, subjecting to 7 different acceleration inputs. Results are presented and show that sloshing of fluid depends on excitation frequency and filling levels.

3. Methodology and Solving

The sloshing is the phenomena that occur in the semi filled tanker due to the external disturbances or excitation. Our problem deals with the effect of sloshing impact upon the tanker. In order to reduce this effect we introduce baffle plates. The tanker we consider is a model that is used widely to store and carry light petroleum products the dimensions of tanker are shown fig 3.1. The dimensions are tabulated below in table 3.1.

Table 3.1: Specifications of the tanker

S. No	*Designation of tanker*	*Dimensions in mm*
1	Length (L)	4780
2	Width (W)	2236
3	Height (H)	1270
4	Thickness of sheet metal (t)	3.3 (VOF < 25 Liters)
5	Total trailer length (L_t)	4980

The above specifications mentioned are as per IS 13187[7] "Road Tankers for light-petroleum products."

3.1 Computational Fluid Dynamics Packages

The first solution of sloshing problem was done in 1933 which determine pressure on rectangular, vertical dam when it is subjected to horizontal acceleration. After this a tremendous amount of work was executed in the field of sloshing. Till 1990‟s these analysis were analytical and cumbersome process which requires calculation of Laplace's Equation so that boundary conditions will be satisfied. After the invention of computer and advent of modern computing capabilities, liquid sloshing phenomenon including its nonlinearity can studied and simulated computationally and numerically with higher amount of accuracy. The availability of affordable high performance computing hardware and the introduction of user-friendly interfaces have led to the development of commercial CFD packages. Several general-purpose CFD packages have been developed in past decade. Prominent among them are: PHONICS, FLUENT, SRAT-CD, CFX, FLOW-3D and COMPACT. Most of them are based on the finite volume method.

3.1.1 Volume of Fluid (VOF) Method

The tracking of the material deformations can be performed by the VOF (Volume of Fluid) method or the Young method which is attractive for solving a broad range of non-linear problems in fluid and solid mechanics such as, sloshing and explosion applications, because it allows arbitrary large deformations and enables free surfaces to evolve. Moreover, the Lagrangian phase of the VOF method is easily implemented in an explicit ALE finite-element method. In this method, different material occurrences are considered by their respective volume fractions on the element level.
The position of the interface is then oriented by the normal $\vec{n}$ so that it divides the element into two volumes, which correctly matches the element volume fraction (Figure). The interface position is used to calculate the volume of the fluid flowing across cell sides. As the X-advection, Y –advection and Z-advection are calculated in separate steps, it is sufficient to consider the flow across one side only.

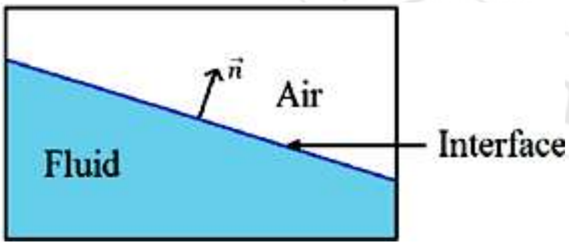


Figure 3.2: Interface between two materials, fluid and air.

3.2 Procedure

The physical model used for present study is shown in figure. Present model consists of a 3-dimensional liquid storage spherical tank which is partially filled with water (ρ=999.98 kg/m3, μ=0.00103 kg/m-s). The tank dimensions are 2.236*1.27*4.78 m3. Water fill level in tank is 60% of total height of tank and the rest part is occupied with air. The tank is supposed to go under sloshing effect which creates pressure and forces on tank wall. During computation, pressure is monitored at a certain point on the right wall in order to record the sloshing loads.

We investigated the effect of slosh impact pressures over the wall of the tanker by another types of fluids. The fluids like kerosene, water, and diesel are investigated to find the slosh impact over the wall.

3.3 Geometric Modelling & Analysis

A 3-Dimensional spherical tank of dimension 4.78m length, 1.27m height, 2.236m width is produced using CREO PARAMETRIC v3.0.We can see that in figure 3.3. The dimensions are considered according to fig 3.1 and table 3.1
In present study, simulation of fluid sloshing in a 3-dimensional spherical storage tank is done by using ANSYS FLUENT v.13.0. In ANSYS, workbench platform is used for modeling geometry and generation of mesh. After meshing, mesh file is exported to FLUENT solver and Post-processing is done.

Three fluids diesel, kerosene, and water are considered as basic fluid materials. Their properties re mentioned in table 3.2.

Table 3.2: Standard Properties of fluids used for analysis

S. No	*Name of Fluid*	*Name of Property*	*Value*	*Units*
1	Diesel	Density	730	Kg/m3
		Viscosity	0.0024	Kg/(m-s)
		Specific Heat	2090	j/(kg-k)
		Thermal Conductivity	0.149	w/(m-k)
2	Kerosene	Density	780	Kg/m3
		Viscosity	0.0024	Kg/(m-s)
		Specific Heat	2090	j/(kg-k)
		Thermal Conductivity	0.149	w/(m-k)
3	Water	Density	998.2	Kg/m3
		Viscosity	0.001003	Kg/(m-s)
		Specific Heat	4182	j/(kg-k)
		Thermal Conductivity	0.6	w/(m-k)

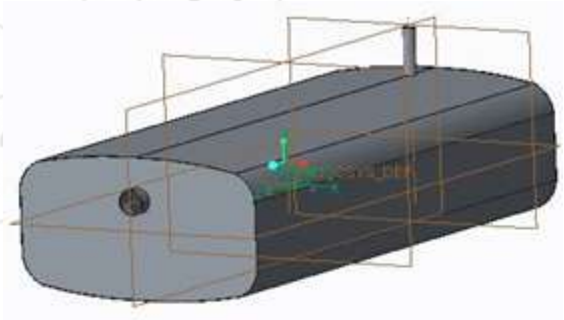


Figure 3.3: Tanker Geometry modeled in CREOPARAMETRIC 3.0

3.3.1 Mesh Generation

After creation of geometry, meshing is done in meshing tool. In present case uniform triangular mesh is generated for all cases.

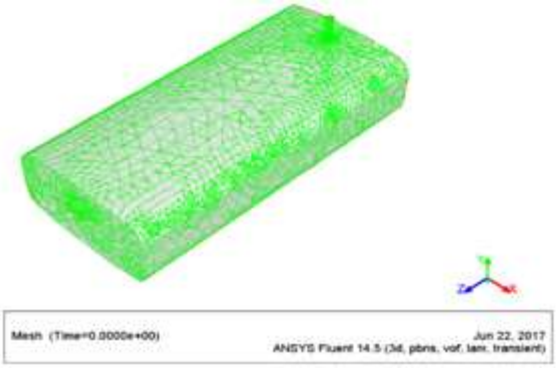


Figure 3.4: Meshing of tank

3.3.2 Fluent Setup

Once meshing is being done, mesh file is exported to CFD code FLUENT. In the present study 3-D, double precision fluent solvers with serial processing is used. Following procedure is followed in Fluent:

1) In setup, it is scaled to proper units if required and mesh quality is checked.
2) Pressure based transient solver is used with explicit formulation and gravitational field is enabled.
3) Multiphase model with volume of fluid (VOF) method is used, and turbulent model is considered.
4) Air and water are used as two different immiscible fluids and aluminum is used as solid material.
5) Air is considered as primary phase and water as secondary.
6) For sinusoidal motion of tank acceleration imposed in the form of momentum source input.
7) For simulation following operating conditions are chosen:
   - Operating pressure:-101325 Pa
   - Gravitational acceleration:

   X= -9.81 m/s^2
   Y= 0 m/s^2
   Z=-9.81 m/s^2

Operating density:-1.225 kg/m3

1) Baffle, baffle shadow and rectangular tank are considered as wall. Following solution method is adapted:-

Solution Methods
Pressure-Velocity Coupling
Scheme
Fractional Step
Spatial Discretization
Gradient
Green-Gauss Node Based
Pressure
Body Force Weighted
Momentum
First Order Upwind
Volume Fraction
Geo-Reconstruct
Transient Formulation
First Order Implicit
☑ Non-Iterative Time Advancement
☐ Frozen Flux Formulation

Figure 3.5: Solution Methods

- Pressure-velocity coupling : Fractional step
- Gradient : least square cell based
- Pressure : Body force weighted
- Momentum : Power law
- Volume fraction : Geo-Reconstruct
- Transient formulation :Non-iterative time advancement

10. Non-iterative relaxation factor:-
    - Pressure : 0.8
    - Momentum : 0.6
11. For filling of water in tank, region of cell is adapted and then adapted cell is patched by water.
12. To display results in 3-D model Iso-surface option has been selected. It is used to track points on free surface of water.
13. Time Stepping Method: Explicit formulation is used for simulation of sloshing. Hence for stability condition and avoid divergence, value of global Courant Number should not exceed 250. In variable time method:

Variable Time Step Settings
Global Courant Number 2
Ending Time (s) 0.45
Minimum Time Step Size (s) 1e-05
Maximum Time Step Size (s) 0.0025
Minimum Step Change Factor 0.5
Maximum Step Change Factor 1.5
Number of Fixed Time Steps 1
User-Defined Time Step none

Figure 3.6: Variable Time Step Settings

3.3.3 Closure

Post-processing process is carried to obtain the results at regular time periods as we set in Variable Time Step Settings which is shown in Fig: 3.5. Results were obtained in the form pressure, Volume Fraction of both the phases which we introduce. Same procedure will be carried out for other fluids like Diesel (Liquid) and Kerosene (liquid). Results will be discussed in next chapter.

4. Results and Discussions

4.1 Results for the tanker with Air as primary fluid and Kerosene as secondary fluid:

4.1.1 Sloshing impact pressure that was exerted on the tanker

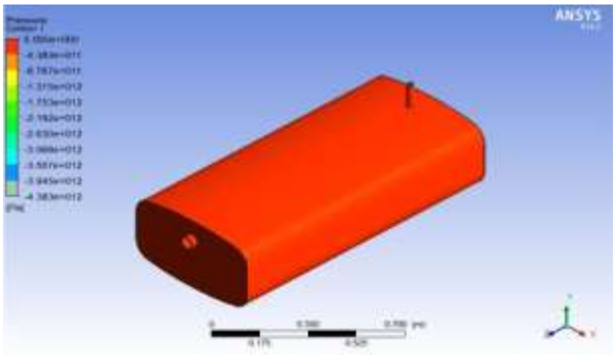


Figure 4.1: Pressure Distributed on the Tanker Wall.

The above record shows the distribution of pressure on the tank periphery. The fluid inside oscillate inside the tanker in order to exert pressure on the walls. The minimum pressure on the wall is -4.3833e+12 [Pa] and the maximum exerted pressure on the walls of the tanker is 207.842 [Pa].

4.1.2 The volume fraction of the Kerosene fluid inside the tanker

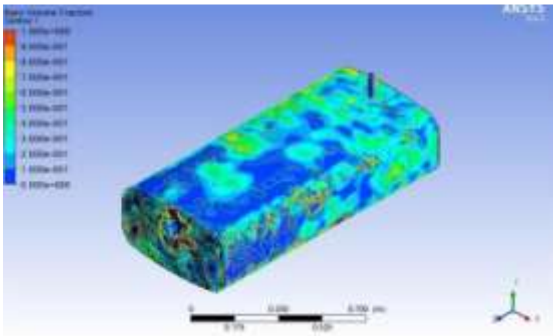


Figure 4.2: Volume Fraction of Kerosene fluid inside the tanker

The volume fraction is the ratio of volume of the fluid to the volume of fluids. The volume fraction has no units and can be denote by φ. The minimum value of volume fraction of the kerosene fluid in the tanker is 0 and maximum value is 1.

4.2 Results for the tanker with Air as primary fluid and Diesel as secondary fluid:

4.2.1 Sloshing impact pressure exerted on the wall:

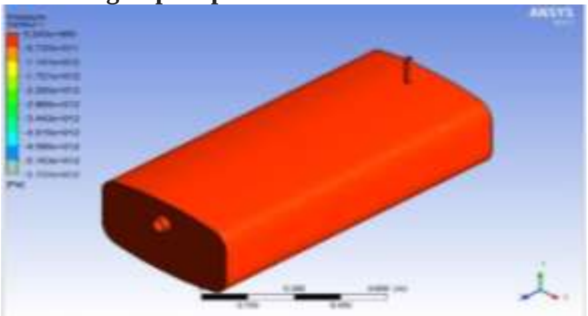


Figure 4.3: Pressure distributed on the Tanker Wall for Diesel

The above record shows the distribution of pressure on the tank periphery. The fluid inside oscillate inside the tanker in order to exert pressure on the walls. The minimum pressure on the wall is -5.7363e+12 [Pa] and the maximum exerted pressure on the walls of the tanker is 201.654 [Pa].

4.2.2The volume fraction of the Diesel fluid inside the tanker

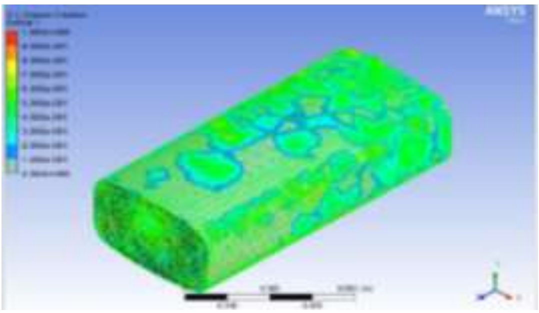


Figure 4.4: Volume Fraction of Diesel fluid inside the tanker

The volume fraction is the ratio of volume of the fluid to the volume of fluids. The volume fraction has no units and can be denote by φ. The minimum value of volume fraction of the kerosene fluid in the tanker is 0 and maximum value is 1.

4.3Results for the tanker with Air as primary fluid and Water as secondary fluid:

4.3.1 Sloshing impact pressure exerted on the wall:

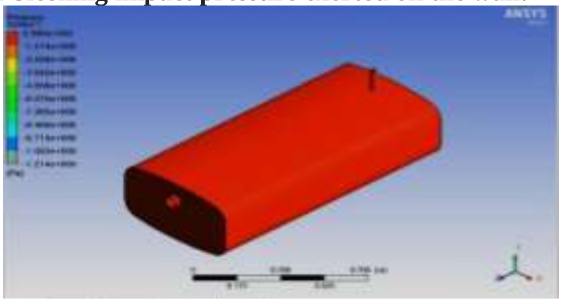


Figure 4.5: Pressure distributed on the Tanker Wall for Water

The above record shows the distribution of pressure on the tank periphery. The fluid inside oscillate inside the tanker in order to exert pressure on the walls. The minimum pressure on the wall is -1.21409e+09 [Pa] and the maximum exerted pressure on the walls of the tanker is 259.016 [Pa]. The value of pressure depends upon the amount of gravitational acceleration which we introduce in the command. Based on the real life scenario we apply that value to read out the pressure that was developed in it. The inputs are considered from the

4.3.2The volume fraction of the Diesel fluid inside the tanker

The volume fraction is the ratio of volume of the fluid to the volume of fluids. The volume fraction has no units and can be denote by φ. The minimum value of volume fraction of the kerosene fluid in the tanker is 0 and maximum value is 1. The volume fraction is shown in fig 4.4.

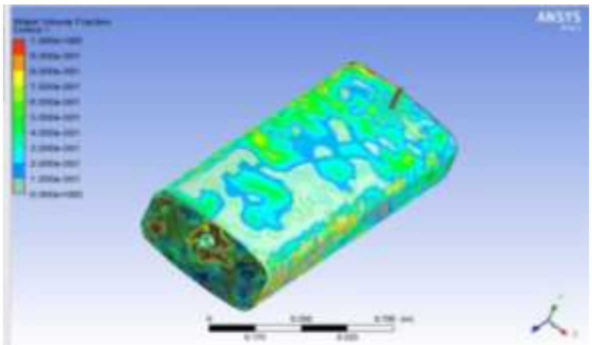


Figure 4.6: Volume Fraction of Diesel fluid inside the tanker

4.4 The Velocity Plot for Iterations made to all fluids:

For the value given gravitational acceleration of -9.81 m/s2 we consider 10 iterations to plot for a global courant number not exceeding 250. Then the velocity plot in X-direction, Y-direction and Z-direction is plotted which is shown in fig 4.6 for diesel, in fig 4.7 for kerosene, and in fig 4.8 for water.

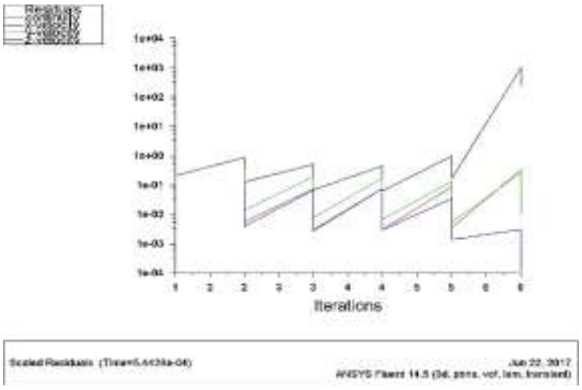


Figure 4.7: The Velocity Plot for Diesel

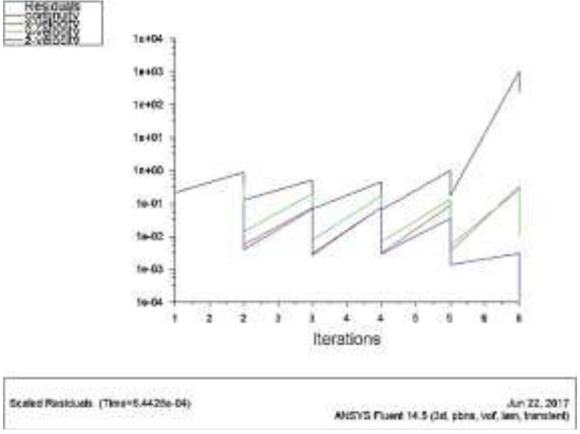


Figure 4.8: The Velocity Plot for Kerosene

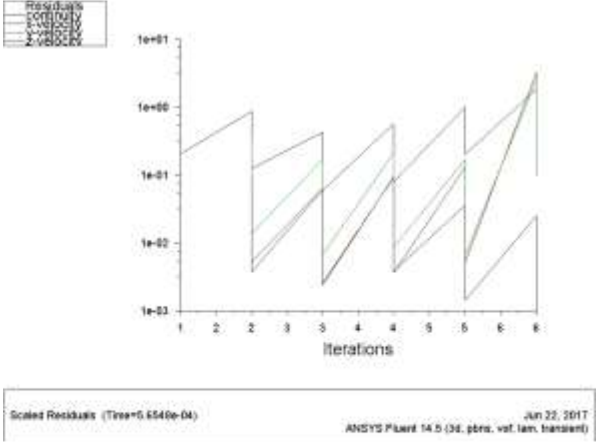


Figure 4.9: The Velocity Plot for Water

Table 4.1: Pressure reading at = 9.81 m/s^2

S. No	Name Of Fluid	Acceleration (m/s^2)	Pressure Value (Pascal)
1	Diesel	9.81	201.654
2	Kerosene	9.81	207.842
3	Water	9.81	259.016

4.5 Comparison plot for Dynamic Pressures for three fluids when acceleration=10 m/s^2

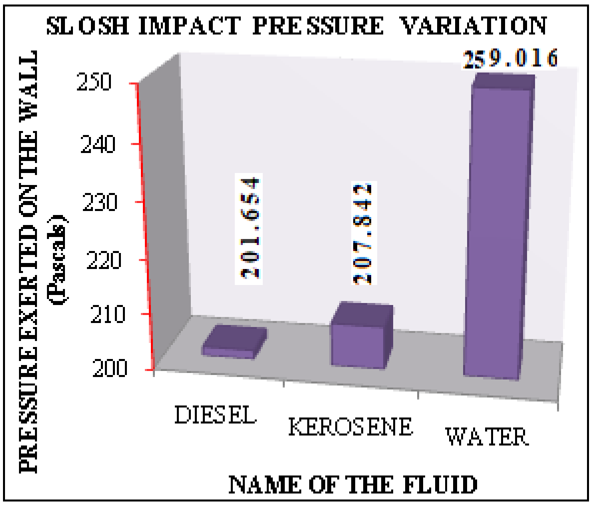


Figure 4.9.1: Pressure Exerted on the Wall for different fluids.

From fig 4.8 we can say that the impact pressure that experience on the tanker walls due to sloshing varies with the density of the fluid. As the density of the fluid increases the slosh impact pressure increases. That we observe through computation too.

4.6 Results for the tanker with Air as primary fluid and Kerosene as secondary fluid at gravitational acceleration= 15m/s^2:

4.6.1 Pressure Distribution in a tanker when Air as primary phase and Kerosene as secondary phase:

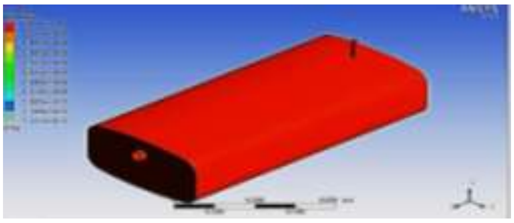


Figure 4.9.2: Pressure distributed on the Tanker Wall when a=15 m/s^{2}for kerosene.

The above record shows the distribution of pressure on the tank periphery. The fluid inside oscillate inside the tanker in order to exert pressure on the walls. The minimum pressure on the wall is -1.33086e+10 [Pa] and the maximum exerted pressure on the walls of the tanker is 309.169 [Pa].

4.6.2 Pressure Distribution in a tanker when Air as primary phase and Diesel as secondary phase:

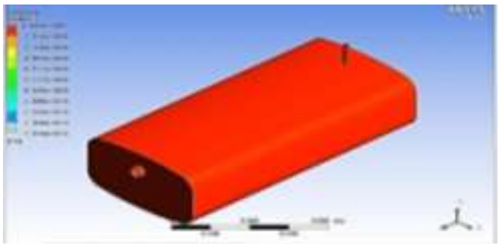
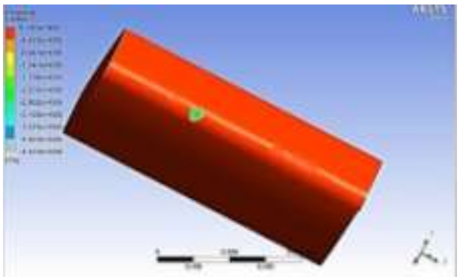


Figure 4.9.3: Pressure distributed on the Tanker Wall when a=15 m/s^2 for Diesel.

The above record shows the distribution of pressure on the tank periphery. The fluid inside oscillate inside the tanker in order to exert pressure on the walls. The minimum pressure on the wall is -1.55423e+10[Pa] and the maximum exerted pressure on the walls of the tanker is 257.692 [Pa]. The value of pressure depends upon the amount of gravitational acceleration which we introduce in the command. Based on the real life scenario we apply that value to read out the pressure that was developed in it. The inputs are considered from the

4.6.3 Pressure Distribution in a tanker when Air as primary phase and Water as secondary phase:



4.6.4Pressure distributed on the Tanker Wall when a=15 m/s^2 for Water.

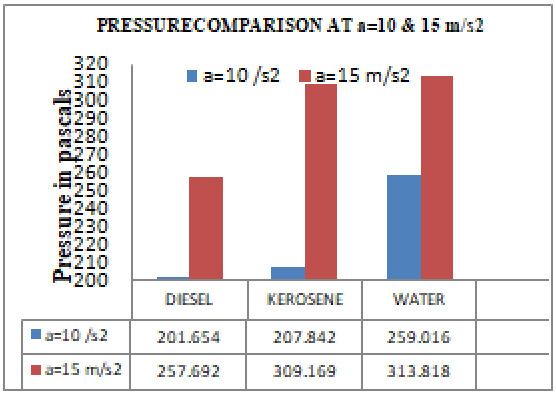
The above record shows the distribution of pressure on the tank periphery. The fluid inside oscillate inside the tanker in order to exert pressure on the walls. The minimum pressure on the wall is -4.47032e+10[Pa] and the maximum exerted pressure on the walls of the tanker is 313.818 [Pa].

4.7 Comparison plot for Dynamic Pressures for three fluids when acceleration= 15 m/s^{2}g

4.7.1 Variation of pressure for all fluids at a=15m/s^2

When the acceleration is applied at X= -15m/s^2, Y= 0 m/s^2, Z= -15 m/s^2 the sloshing pressure that is experienced on the tanker is gradually increasing. Here the properties of liquids are considered as the vital issue that influences the effect of slosh. Which we can observe in figs 4.9, 4.9.1 and 4.9.2, that the distribution of pressure on the periphery of the tanker. The results were expressed in the

4.8 Comparison of pressures at a=10 m/s^2 and a=15m/s^2



	DIESEL	KEROSENE	WATER	
🟦 a=10 /s2	201.654	207.842	259.016	
🟥 a=15 m/s2	257.692	309.169	313.818	

Figure 4.9.6: Pressure comparison of fluids at different accelerations

From the above fig 4.9.4 we cay most assuredly say that the acceleration increases the effect of sloshing impact increases on the tanker walls. The liquid properties are responsible for the variation in the impact pressure that was created on the wall of the tanker.

5. Conclusion

Three fluids having disparate properties are supposed to periodical oscillations inside the tanker with gravitational accelerations 9.81 m/s^2 and 15 m/s^{2}induced by the fluid to hit the tanker periphery. The acceleration is directly proportional to the slosh impact pressure. Those cyclic high pressures will cause the failure of the tanker wall.

Many investigations found many factors that truly influence the sloshing impact. This present study based on the liquid properties and acceleration of the fluid through this computational study shows the effect of sloshing on the real life can definitely reduce the life of the material or may cause severe damage if it is a crude oil due to cyclic and sudden impacts.

6. Future Scope

In this project we just examined the effect of sloshing on the tanker wall for different fluids with variable accelerations.

This project we can extendhow to reduce this type of abnormal impacts. Effect of sloshing can be reduced inside by placing some baffle plate. So we can continue this work to find the pressure reduction on the wall.

References

[1] Avin N. Mohan, (2014) "Finite Element Analysis on Trapezoidal Tank to Suppress Sloshing Effect," Dissertation, presented to M. G University in partial fulfillment of the requirements for the degree of M.Tech, [4, pp. 121-125].

[2] Puneet Kumar Nema, (2014) "Computational study of sloshing behavior in 3-D rectangular tank with and without baffle under Seismic Excitation" Dissertation, presented to N. I. T Rourkela in partial fulfillment of the requirements for the degree of M.Tech, [5, pp. 23-27].

[3] P.K. Panigrahy, U.K. Saha, D. Maity 2009. "Experimental studies on sloshing behavior due to horizontal movement of liquids in baffled tanks." Ocean Engineering [36, pp. 213-222.]

[4] V. Singal , Jash Bajaj, NimishAwalgaonkar, SarthakTibdewal (2014), "CFD Analysis of a Kerosene Fuel Tank to Reduce Liquid Sloshing", Procedia Engineering. [Vol 69: pp. 1365 – 1371].

[5] KritThreepopnartkul, ChakritSuvanjumrat, "The Effect of Baffles on Fluid Sloshing inside the Moving Rectangular Tank", Journal of Research and Applications in Mechanical Engineering. [Vol. 1 No.2].

[6] Dongming Liu, Pengzhi Lin 2009. Three-dimensional liquid sloshing in a tank with baffles. Ocean Engineering [36, 202-212].

[7] IS 13187 (1991) "Road tankers for light petroleum products" Chemical Engineering Plants and Related Equipment [15, pp. 1-2]

[8] T. Kandasamy, S. Rakheja, A.K.W. Ahmed, (2010), "An Analysis of Baffles Designs for Limiting Fluid Slosh in

Partly Filled Tank Trucks", The Open Transportation Journal. [Vol. 4: 23-32].

[9] Derek Wilkinson, Brian Waldie, M.I. Mohamad Nor, Hsio Yen Lee (2000)"Baffle plate configurations to enhance separation in horizontal primary separators" Department of Mechanical &Chemical Engineering, 6(4), 221-226