International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 10 (November 2014) www.ijirae.com

Finite Element Analysis on Trapezoidal Tank to Suppress Sloshing Effect

Avin N. Mohan
M.Tech in Machine Design,
M.G. University

Abstract*— In this thesis, different configurations of anti-slosh baffles are proposed to damp or suppress the effect of sloshing on a fuel tank. Sloshing is the periodic oscillations of the free surface of the liquid in a partially filled container due to the external disturbances. Many studies have been conducted mathematically and experimentally in order to analyse the effect of sloshing on the fuel tank. In this work a numerical analysis is performed using ANSYS 15.0 and is compared with the experimental results to validate the results. A trapezoidal fuel tank with gasoline diesel as the liquid medium is used for the analysis. Series of numerical experiments have been carried out to estimate the pressure developed on the tank wall and the free surface displacement of the liquid diesel from the static mean level. Simulations compared the sloshing effect on tank with and without baffles and later on different baffle configurations. The slosh waves, during the causes of travel hits the baffles or hindrance plates and dies out. It was found from the CFD transient simulation of the gasoline diesel liquid interface that the sloshing is suppressed considerably with the introduction of baffles in the tank. Among the different configurations the criss-cross baffle gives the best damping effect.
***Keywords*— Sloshing, Anti-slosh Baffles, ANSYS, CFD, Trapezoidal fuel tank**

I. INTRODUCTION

Fluid motion in partially filled tanks may cause large structural loads if the period of tank motion is close to the natural period of fluid inside the tank. This phenomenon is called sloshing. Sloshing means any motion of a free liquid surface inside a container. Depending on the type of disturbance and container shape, the free liquid surface can experience different types of motion including simple planar, non-planar, rotational, irregular beating, symmetric, asymmetric, quasi-periodic and chaotic. The amplitude of the slosh, in general, depends on the nature, amplitude and frequency of the tank motion, liquid-fill depth, liquid properties and tank geometry.

II. AIM OF STUDY

The objectives of this study are to perform numerical analysis of the rectangular tank set up, the experimental data of which are available from the previous works and validate the results with ANSYS Fluent V15 and thereby altering the tank design in order to obtain the tank configuration with best sloshing suppression effect. Different baffle configurations are considered for analysis namely vertical, ring and criss-cross baffles. For the analysis procedure liquid diesel is taken as the fuel. Numerical results give a good compromise with the experimental result done in the previous journals and with thereby the judgement is made on the new tank configurations that it will give similar results in the real life scenario.

III. NUMERICAL ANALYSIS PROCEDURE

III.1 Trapezoidal tank and baffle configurations

The 3D model of the trapezoidal tank with the dimensions nearly matching the volume capacity of the rectangular tank is developed to investigate the pressure developed in the tank walls due to liquid (diesel) sloshing and the volume fraction at different time steps of each configuration and the degree of suppression of these parameters with the use of baffles.

III.2 Measurement of wall pressure

When a container is subjected to linear instability, a series of waves are formed in the liquid and so the liquid gets displaced, and hence exerts a pressure on the walls of the container. This pressure varies with time. The wall pressure at two different frequencies, 0.25 cycles/sec and 0.5 cycles/sec are taken into consideration for rectangular tank configuration in order to validate the experimental result and thereafter for the trapezoidal tank configuration acceleration of 2.25m/s2 is applied to obtain the real life scenario of a vehicle in motion. The pressure at fill level or liquid height of 30% and 60% and for each baffle configurations is noted. The pressure difference between each baffle configuration is studied to understand the effect of sloshing.

III.3 Analysis of volume fraction

The amount of liquid available at the inlet of the fuel intake pipe is analysed in order to study the effect of scavenging of fuel due to the sloshing effect. Different baffle configurations are taken into consideration for the analysis.

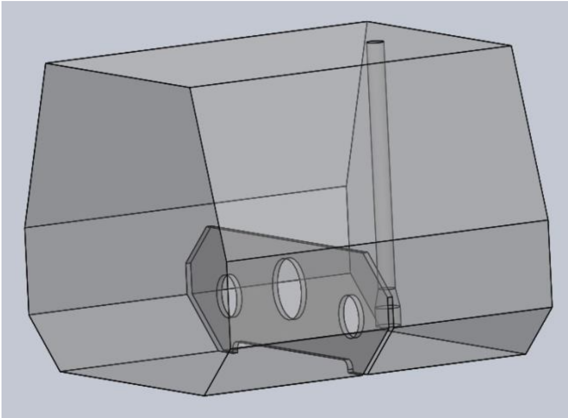

Fig. 1 Trapezoidal tank with vertical baffle

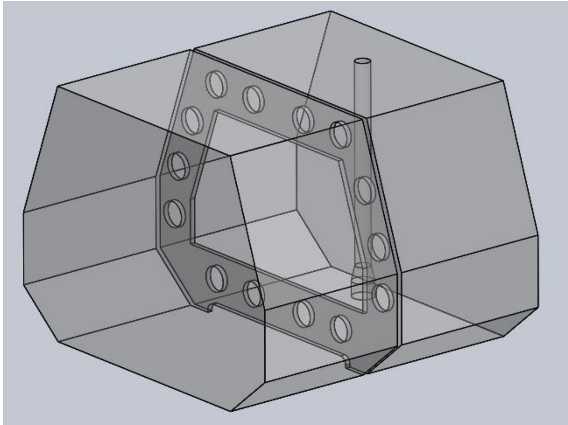

Fig. 2 Trapezoidal tank with ring baffle

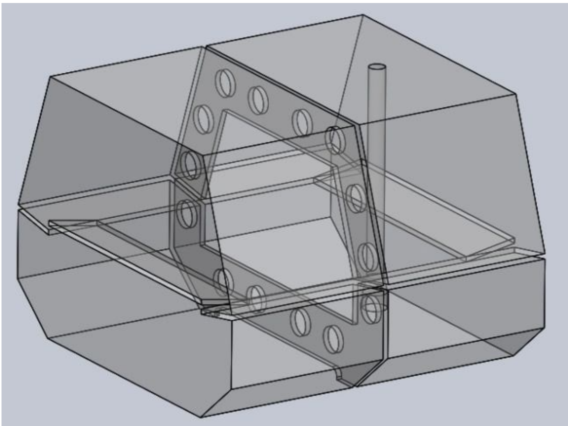

Fig. 3 Trapezoidal tank with criss-cross baffle

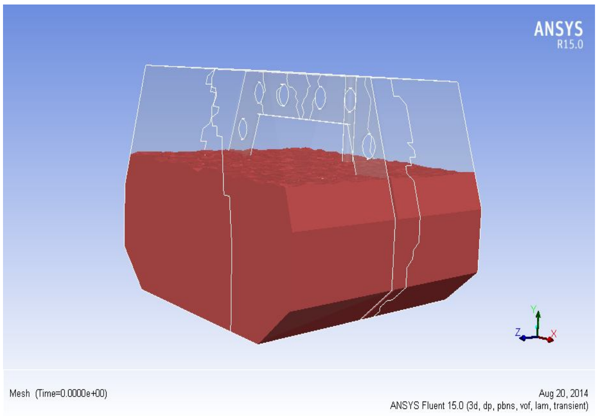

Fig. 4 Trapezoidal tank with ring baffle filled with 60% diesel

IV. RESULT AND DISCUSSION

Sloshing is the superposition of surface waves. Several forces determine the nature of these waves. When the fluid is not rotating, relevant forces are surface tension and gravity. With rotation, centrifugal and coriolis forces are also present. Driving force is the acceleration of the walls of the container. Motion of the container can be specified by three translations and three rotations about the centre of mass of the liquid. The combined effect of translations and rotations of liquid diesel is quite important as the diesel present in the tank behaves slightly compressible. The numerical analyses provide us with a host of findings which conform to the theory and the finding of previous researchers. The pressure of tank wall with varying depth is measured. For the trapezoidal tank acceleration of 2.25 m/s2 is applied for determining the pressure at wall. The pressures are plotted with respect to the volume fraction of the liquid at the inlet of the suction pipe is also captured to analyse the fuel scavenging and the relation of pressure amplitude with fill depth and also its variation is found with the use of suppression techniques.

IV.I Trapezoidal Tank and different baffle configuration

The trapezoidal tank is subjected to acceleration and deceleration of 2.25m/s2 simultaneously varying on each time step of 0.5s. The pressure at the walls and volume fraction at the intake of pickup pipe is plotted to determine the effect of diesel slosh on trapezoidal tank. The without baffle condition of both rectangular and trapezoidal tanks subjected to 2.25m/s2 acceleration and deceleration is compared to obtain the tank having best sloshing suppression and least scavenging or scarcity of fuel at the pick-up pipe intake.

A. *Effect of depth on liquid pressure:*

The trapezoidal tank when it is filled with 30% fuel of the tank (fig.5) capacity is subjected to a repetitive acceleration and deceleration of 2.25m/s2 for each 0/5 second time step. The plot shows that the pressure increases and decreases sharply over a range of 1110 Pa with the highest and lowest pressures in the cycle being 1180 Pa and 1060 Pa,

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 10 (November 2014) www.ijirae.com

respectively. This movement of liquid between the two opposite walls results in an alternate rise and fall of pressure at the walls.

The pressure variation under similar frequency of excitation and at the same locations with a fill level of 60% in trapezoidal tank (fig.6) is analysed. The pressure increases and decreases alternatively for every half-cycle but the range of pressure variation is found to have increased marginally. This occurs because when the diesel mass flows from one side to other, the inner liquid moves slightly slower and quietly as compared to the free surface liquid. The free surface layers suffer maximum displacement in the vertical direction, and also experience hydraulic jump on hitting the walls. The highest pressure experienced is 2260 Pa with the lowest being 2160 Pa. This shows a difference of 1100 Pa as observed with 30% fill level. The increase in maximum pressure happens as a result of the increase in the diesel column near the wall.

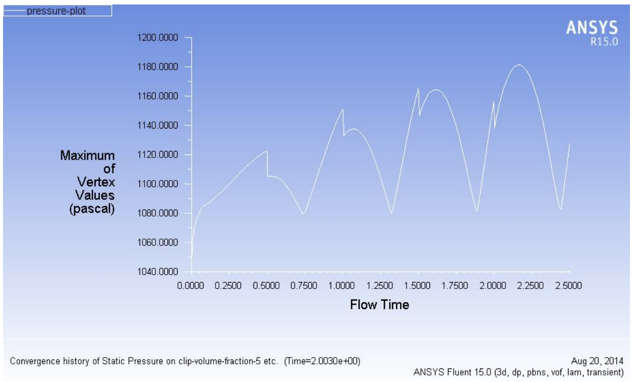

Fig. 5 Pressure plot for 30% fill level of trapezoidal tank without baffle

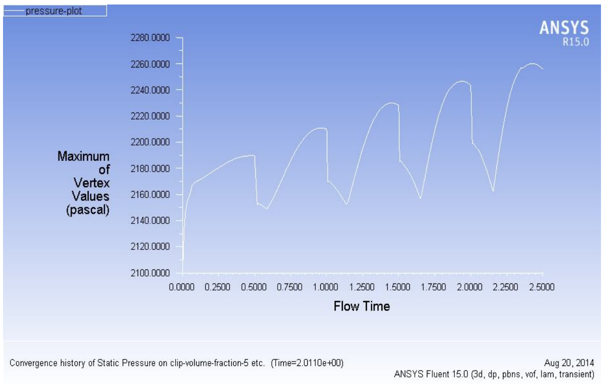

Fig. 6 Pressure plot for 60% fill level of trapezoidal tank without baffle

B. *Effect of baffle on sloshing suppression:*

For the trapezoidal tank different baffle configurations are taken into consideration for the sloshing analysis with 30% and 60% fill level. The fluid is displaced in large amount in the case of tank without baffles accompanied by the hydraulic jump. For the tank configuration with baffle the hydraulic jump and free surface displacement is reduced considerably. The tanks with vertical, ring and criss-cross baffles are taken into consideration. The volume fraction of fuel available at the pick-up pipe is plotted to read the consistency of fuel availability at the intake pipe. Fig.7 shows the fuel scavenging at 1.2 second time for trapezoidal tank without baffle at 30% fill level. It is evident that for 60% fill level the fuel availability at the pick-up pipe will be consistent (Fig 8). The volume fraction plot of trapezoidal tank without baffles at 60% fill level and for the tank with baffles for all configurations the fuel supply at the pick-up intake is consistent.

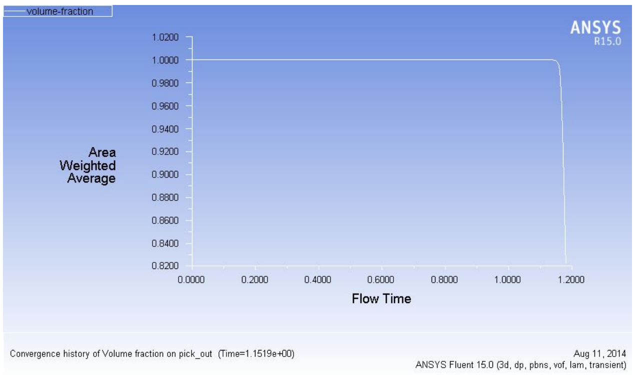

Fig. 7 Volume fraction for 30% fill of trapezoidal tank without baffle (2.25m/s2)

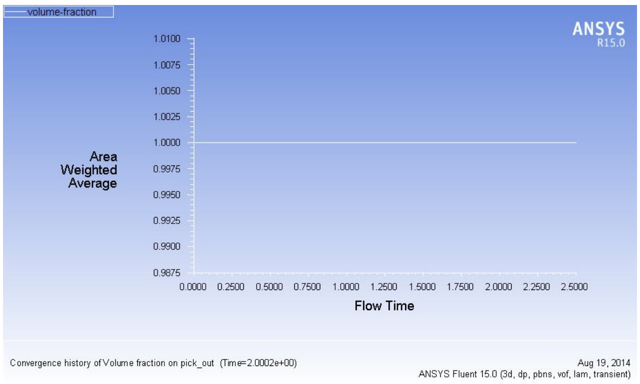

Fig. 8 Volume fraction of trapezoidal tank with baffle (for all configuration)

C. *Comparison of surface displacement with different baffle orientations:*

It is observed that the surface displacement varies with orientation of baffles. This is because, on hitting the baffles, the kinetic energy of the moving fluid gets dissipated and therefore the fluid does not have enough energy to climb up. The phenomenon of sloshing, which is defined as the displacement of unrestrained free surface, eventually decreases thus proving the earlier research on use of baffles as the most possible suppression technique of sloshing. In the present study, an innovative design of baffles, modified ring type (criss-cross) is used which proves to be more efficient than the earlier used types.

D. *Comparison of pressure with and without baffles:*

Initially, analyses were conducted without any baffle, and then the same procedures were repeated by incorporating a vertical, a ring baffle and a criss-cross baffle. The results show that the maximum variation in pressure observed for the three cases are (1120 Pa, 2230 Pa), (1110 Pa, 2200 Pa) and (1090 Pa, 2170 Pa) for 30% and 60% fill level respectively (fig.9 & fig.10). The irregular change of pressure in the given time periods could be attributed to the setup vibrations and other unknown forces. The observations show that the criss-cross baffles are the best choice as they reduce the pressure to the maximum extent. This happens because the criss-cross baffle not only suppresses the velocity of impact of the fluid at the walls but also retards the vertical motion of the liquid near the other two adjacent walls, thereby suppressing the wave amplitude. The turbulence is created due to its sharp edges at all the walls and thereby, dissipating the violent energy to all the walls. This reduces the stress on the impact walls.

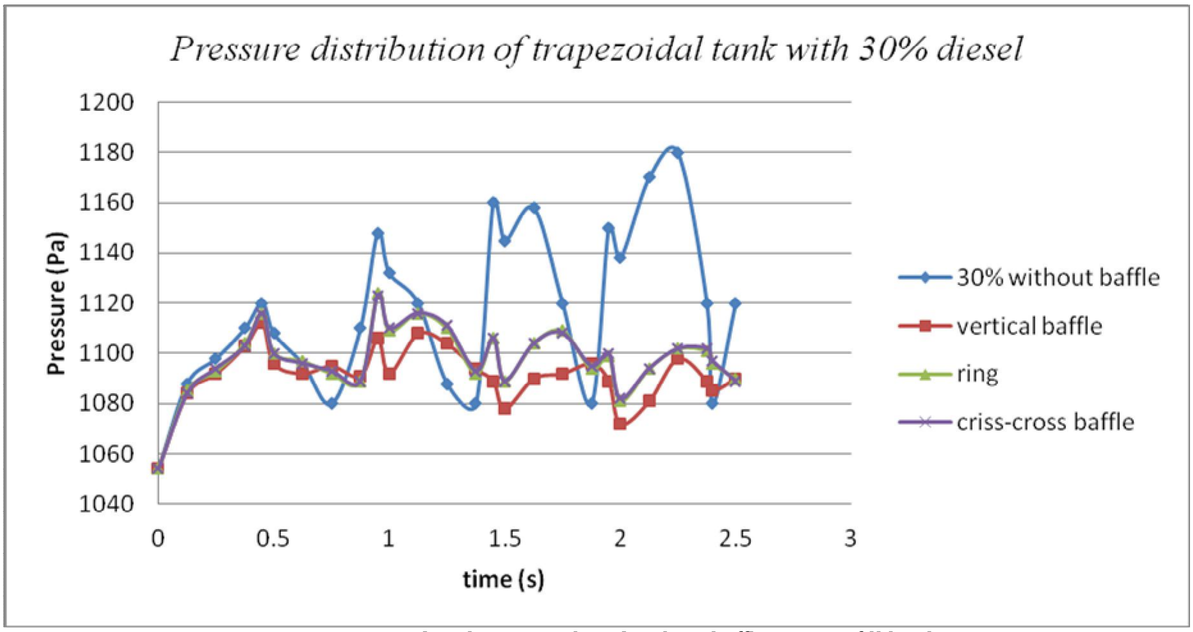

Fig.9 Pressure distributions with and without baffles at 30% fill level

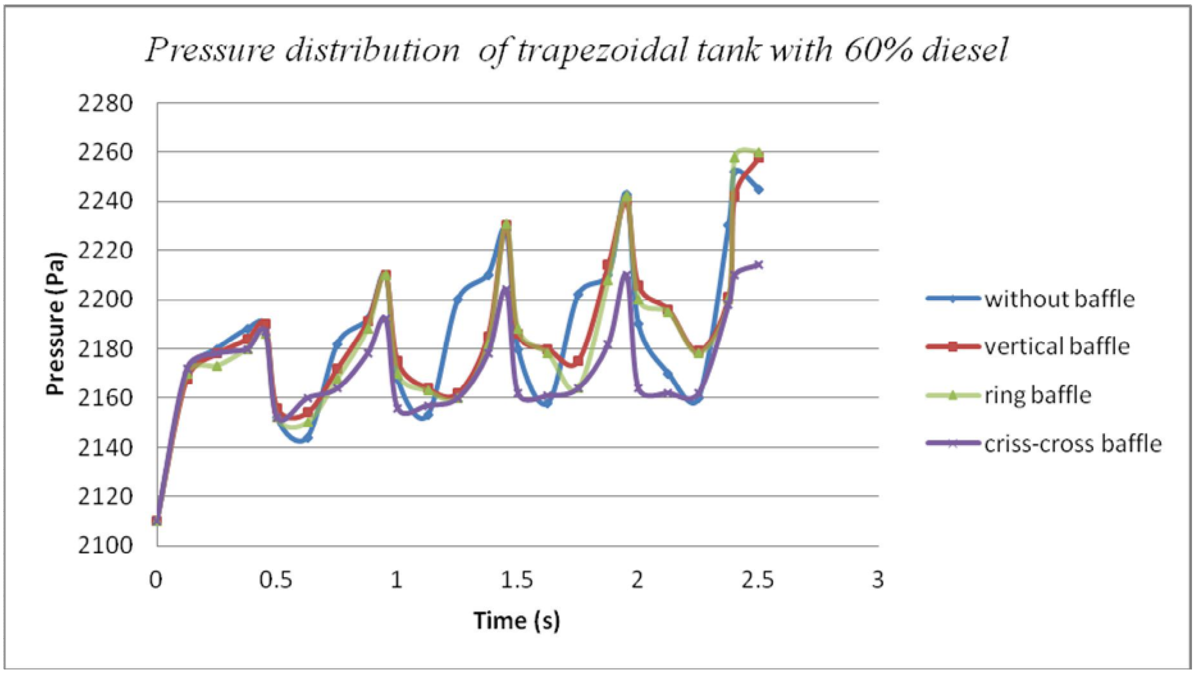

Fig. 10 Pressure distributions with and without baffles at 60% fill level

V. CONCLUSIONS

Liquid sloshing in various shaped tanks has received considerable attention over the past few decades. The need for an accurate evaluation of the sloshing-induced loads has largely been felt in aerospace vehicles, ocean-going vessels and road vehicles, where the effect of free liquids on board can produce problems related both to loss of stability of the vehicles and to structural damages.

In the present investigation, pressures with varying fill depths of a rectangular and trapezoidal tank have been measured. The pressures are plotted with respect to time. The volume fraction to determine the availability of fuel at suction pipe is also captured and also its variation with the use of suppression techniques have been found. The experiments with ring baffle and criss-cross baffle show encouraging results which have not been reported in open literature. In summary, the following conclusions are made.

a) The pressure exerted on the walls varies in a similar nature as that of the applied excitation or acceleration.

b) The pressures at the walls show a considerable fluctuation near the free surface of the liquid compared to the deeper surfaces in the tank. Viscous or self-damping effects increase with increase in the mass of the liquid, thereby decreasing the sloshing effects for a given excitation. Hence, turbulence and hydraulic jump are prominent when the fill depth in the tank is lesser.

c) The maximum free surface displacement of the liquid in the rank, for a particular excitation, raises the most when the tank is least filled. In other word, sloshing of liquid decreases with increase in height. This is because of the self-damping property of the liquid by which it absorbs the energy supplied at the walls.

d) The introduction of baffles in the tank decreases the sloshing effect by a considerable amount. This is because the sharp-edged baffles create turbulence in the flow field thereby dissipating the excess kinetic energy to the walls.

e) Non-conventional baffles are used in the tanks, e.g. verticals baffles with large sized holes, ring baffles, criss-cross baffles. The results show that the criss-cross baffles are more effective as compared to the conventional horizontal baffles and vertical baffles. The ring baffles absorb the energy at all the walls and dissipate them to all the walls rather than by concentrating on particular two walls normal to the direction of excitation. In the case of criss-cross baffles the free surface displacement and hydraulic jump is suppressed by the horizontal ring baffle at different heights of the tank by placing series of horizontal baffles along with the ring, for the effective suppression and reduction in the effective pressure the horizontal parts can be drilled with orifices. Hence for the entire range of liquid fill level, criss-cross baffles gives the best results.

ACKNOWLEDGMENT

I would greatly indebted and glad to express my sincere thanks to my guide **Mr.Nithish Babu**, Assistant Professor, Department of Mechanical Engineering for his intellectual guidance, valuable suggestions and spending her precious time for successful completion of my project.

I extend my hearty thanks to our class coordinator **Mr.RAJESH.R** Associate Professor, Department of Mechanical Engineering for his enterprising attitude, timely suggestions and supports for the each move of this project work.

REFERENCES

[1] Kim, Y., 2001. Numerical simulation of sloshing flows with impact load. Applied Ocean Research 23, 53–62.

[2] Frandsen, J.B., 2002. Sloshing effects in periodically and seismic excited tanks. Fifth World Congress on Computational Mechanics July 7–12, 2002. Vienna, Austria

[3] Kim, J.W., Shin, Y.S., Bai, K.J., 2002. A finite-element computation for the sloshing motion in LNG tank, ISOPE 2002, Fukuoka, Japan.

[4] Xu, L., Dai, L., 2003. A mechanical model for dynamic behaviour of large amplitude liquid sloshing in partially filled tank vehicles. In: Proceedings of IMECE'03 2003, ASME International Mechanical Engineering Congress. Washington, DC.

[5] 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, 213-222

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

[7] Ling Hou, Fangcheng Li and Chunliang Wu 2012. A Numerical Study of liquid Sloshing in a Two-dimensional Tank under External Excitations. Journal on Marine Science Application 11, 305-310
M.A. Goudarzi,, S.R. Sabbagh-Yazdi 2012, Analytical and experimental evaluation on the effectiveness of upper mounted baffles with respect to commonly used baffles. Ocean Engineering 42, 205-217

[8] Vaibhav Singal , Jash Bajaj, Nimish Awalgaonkar, Sarthak Tibdewal 2014, CFD Analysis of a Kerosene Fuel Tank to Reduce Liquid Sloshing. Elsevier, Procedia Engineering 69, 1365 – 1371US patent no. US 6564961 B1 Trapezoidal fuel storage tank. 20 May 2003

