CFD ANALYSIS OF SLOSH IN TRUCK CONTAINERS USING BAFFLES

Balaji V[1] | Sriprashanth V[2]
[1](Dept of Mechanical Engg, Assistant Professor, Info Institute of Engg, Coimbatore, India, balajiaerospace@gmail.com)
[2](Dept of Mechanical Engg, Assistant Professor, Info Institute of Engg, Coimbatore, India, sriprashanth.v@gmail.com)

Abstract—*Sloshing is an important phenomenon in the fluid dynamics, in turn mainly considered for the designing of components in many industries for better vehicle stability. The goal of this work is to first study the sloshing pattern and then improves the tank design to reduce noise levels, stresses on the structure and optimize the baffle arrangements. Tanker trucks are the majorly preferred for transporting flammable or inflammable liquids from one location to another. When the liquid starts to slosh in the tank, it causes huge weight shifts and builds momentum and does not settle down quickly, results in a chance of accident or skid of vehicle. Further the effect of sloshing is controlled by introducing baffles inside the tank. The baffle plates are rigidly fixed inside the tank. The sloshing inside the tank increases the pressure. The modeling is done by using CREO PARAMETRIC 2.0, and then sloshing is analyzed by using CFD.*

Keywords— Slosh dynamics; Volume of Fluid; Baffles; Truck Carriers; CFD Analysis

1. INTRODUCTION

Sloshing is the free surface periodic motion of a liquid in partially filled tank or container. Motion of a fluid applies the load directly to the container walls; the inertial load exerted by the fluid is time-dependent and it is greater than the load exerted by a solid of the same mass. This makes analysis of sloshing especially important for transportation and storage tanks. During the acceleration of the vehicle, the liquid in the container will forced to move backward of the vehicle and hit the rear wall of the container. While the deceleration of the vehicle, the liquid in the tanker will forced to move as the direction of movement of vehicle and hits the front wall of the container. In case of sudden braking of vehicle, the liquid in the container will move with high velocity and hits the walls of the container with high force. It may cause instability to the vehicle and there is probability for an accident.

Slosh creates forces on the walls of the container in turn, the vehicle stability becomes worse by means structural oscillations produced during slosh disturbances. During the structural oscillations exerted on the container walls, the structural frequency coincides with an adjacent one, they may resonate and become unstable. Also sloshing disturbs the free volume of liquid present inside the tank cause a flow disturbances and slosh occurs towards the depletion of a liquid and results in starvation of propellant to the engine and thrust oscillations. If a Liquid is filled in an arbitrary shaped container under the load of external excitations, the liquid undergoes slosh in surface and bulk turbulence is occurred. The nature of turbulence is a group of different things that are linked in a close due to several effects such as sloshing; pressure gradient etc. may result worse in liquid container more vulnerable to structural damages.

Due to dynamic nature of sloshing the transportation vehicle is strongly affected by its performance and behavior. To control the vehicle while sloshing occurs, we required heavy braking and hence the size of the brake drum will be high.

Slosh suppression devices, therefore are used to damp the liquid motions and to prevent these kind of instability. The proper choice of control system sensing elements and gain values can enhance vehicle stability, thus reducing damping requirements (and therefore baffle weight). Devices are also used to reduce the structural load induced by the sloshing liquid to control liquid position within a tank, or to serve as deflector to protect tank bulkheads or other structure from the liquid impact loads caused by non-periodic motion,. Slosh induced forces and moments can also be effectively reduced by alternatives in tank design, such dividing as compartment, thus reducing the mass of the sloshing liquid and shifting the slosh frequencies.

Traditionally the nonlinear potential theory and experimentation on scaled models were used to assess the sloshing loads. The recent study on analysis of sloshing loads using Computational Fluid Dynamics (CFD) investigated by Goddridge et al. The results obtained from the sloshing natural frequency and the inertia of the system are affected by the fluid level. Potential flow theory has some limitations to proceed with analytical as well as experimental visualization; CFD is now introduced as the most viable tool for analyzing such fluid dynamics problems. Several studies were conducted on sloshing of fluids and the extensive review suggested by Ibrahim et al. Initial work started in the early 60's with the study of sloshing influence by liquid propellant on the flight performance for a jet propelled vehicles. The study exhibits a maximum sloshing occurs in square containers with 30 – 60% fluid level and that maximum sloshing forces occur at a fluid level ranging between 75 – 93%.

This project focuses on the liquid flow dynamics using 3D CFD model of an accelerating fluid inside a elliptical tanker is subjected to a sudden load impact. This paper describes about tanker truck, is accelerating on the road and experiences a sudden pressure change in liquid due to collision with another body on road resulting of liquid sloshing inside the container. This study involves the CFD modeling of the tanker and 3D simulation of the liquid inside the tanker for the pressure variation and water force impacted on the wall of the container.

2. LITERATURE SURVEY

The sloshing of fuel in a partly filled cylindrical tank equipped with baffle is performed with three-dimensional transient analysis under varying magnitude of constant longitudinal, lateral and combination of longitudinal and lateral acceleration of tank, and two different fill volume using CFD. The slosh resulted with amplification factor of slosh forces and moment and variation in the mass moment of inertia of fuel within a clean bore tank and a baffled tank, for two different magnitude of acceleration excitation and two different fill volumes and amplification factor reduces significantly by inserting transverse baffle [1]. Moreover, an analysis of effectiveness of different design of baffle, including lateral, conventional, partial and oblique under combined constant longitudinal and lateral acceleration for different fill level done with volume of fluid (VOF) model for tracing of interface between two immiscible fluids. The fluids under slosh shows that the conventional lateral baffle offers strong resistance to fluid slosh under longitudinal acceleration only while the oblique baffle helps to reduce longitudinal as well as lateral slosh forces and moment under combined longitudinal and lateral acceleration of the fuel tank.[2]. Furthermore, a numerical techniques is employed to simulate the sloshing effects on a rectangular container with the k-Ɛ turbulence model for viscous effects and an acceleration curve imposed as user defined function (UDF) with no inlet and outlet boundaries. A study is performed on structural damage of a containers caused by liquid sloshing and observed large petroleum tanks were damaged by sloshing during the earth quake happened on 2003 Tokachi-oki, Japan. Large earthquakes are predicted to occur within 50 years, which will cause the similar damage. In turn, development of a splitting wall as a new sloshing reduction device is resulted better and indicates effective to reduce sloshing against sinusoidal input motion and it can be also effective against earthquake ground motion. Besides, A study of effect of baffles on liquid sloshing for the partially filled cubic tank is carried out with numerical simulations using volume of fluid technique with arbitrary Langragian - Eulerian formulation.

3. MODELLING & MESHING

A three dimensional model of tank structure without and with baffles are modeled with the help of CREO Parametric 2.0 is shown in Fig 1 and Fig 2 respectively.

Fig 1 Wireframe model of Tank Without Baffles

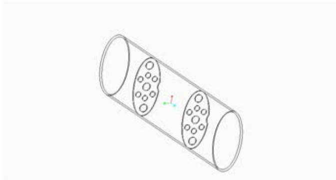

Fig 2 Wireframe model of Tank with Baffles

The baffles are designed with holes along the surface such way that it can able to allow the liquid to move other compartment easily with reduced slosh. The 3-D baffle is shown in fig 3.

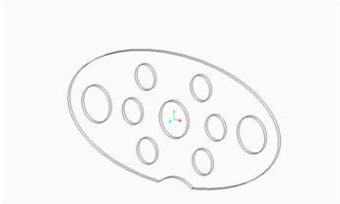

Fig 3 Wireframe model of a Baffle

A. Dimensions

i. Length of the Tank - 6000 mm
ii. Length of major axis of ellipse - 1500 mm
iii. Length of minor axis of ellipse - 800 mm
iv. Thickness of baffles - 10 mm
v. Thickness of tank wall - 10 mm
vi. Length of major axis of baffles - 1490 mm
vii. Length of minor axis of baffles - 790 mm
viii. Length of major axis of half baffle - 1490 mm
ix. Length of minor axis of half baffle - 3950 mm
x. Diameter of larger holes of baffles - 50 mm
xi. Diameter of smaller holes of baffles - 25 mm
xii. Diameter of larger holes of half baffles - 4 mm
xiii. Diameter of larger holes of half baffles - 2 mm

B. Meshing

Meshing of three dimensional models is done by using tetrahedral mesh elements for the entire domain. The Fig 4 represents the meshed view tank with baffles.

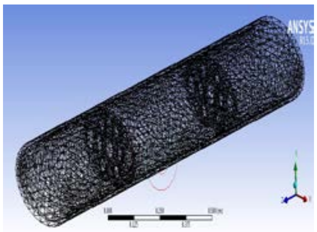

Fig 4 Meshed view

4. CFD RESULTS

A. Boundary Conditions

The following are the boundary conditions employed in the transient analysis of slosh.

i. Working fluid – Air & Water
ii. Type of Multiphase Method – Volume of Fluid
iii. Wall – No slip and smooth wall
iv. Vehicle Velocity – 13.66m/s and 16.88 m/s
v. Time step – 0.01 s
vi. Total Time – 20 s
vii. Relative pressure – 1 atm

B. CFD Simulation

The numerical results are solved using CFX solver for the boundary conditions mention in section 4. A for the different 3D models considered. The volume of liquid is considered for the multiphase flow in CFD with the volume fraction of water and air is 0.7 and 0.3 respectively. The simulation is performed with loading condition considered while applying brake on the vehicle. The Fig 5 represents the wall shear along with the streamlines, indicates the slosh on a vehicle container is moving at a velocity of 16.88m/s without baffles.

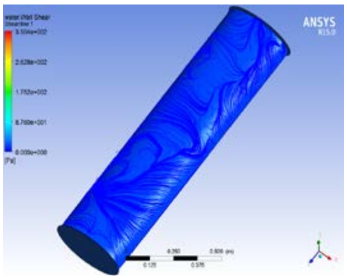

Fig 5 Wall shear & Streamline without baffle at 16.88 m/s

The Fig 6 represents the contours of Water force acting on the walls of the container walls without baffles during the slosh at a vehicle velocity of 16.88 m/s.

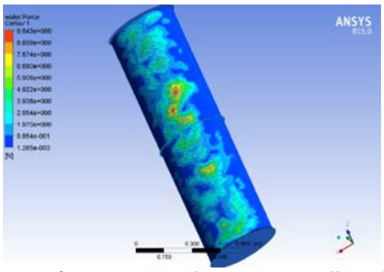

Fig 6 Water impact force acting on the container walls without baffle at vehicle velocity of 13.88 m/s

The Fig 7 represents the slosh load acting on the container without baffles with a vehicle velocity of 13.66 m/s.

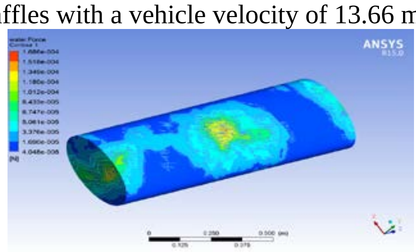

Fig 7 Water impact force acting on the container walls without baffle at vehicle velocity of 16.88 m/s

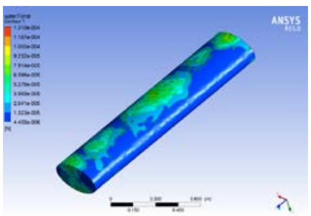

Fig 8 Water impact force acting on the container walls with baffle at vehicle velocity of 13.66 m/s

The Fig 8 and Fig 9 represent the water force acting on the container walls with a baffle during the water slosh at the vehicle velocity of 13.66 m/s and 16.88m/s. Fig 10 indicates the velocity streamline of the water inside the container with baffles at the vehicle velocity of 16.88 m/s

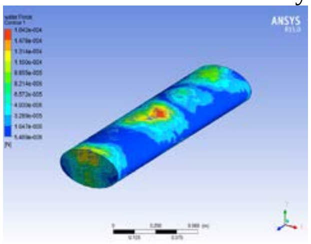

Fig 9 Water impact force acting on the container walls with baffle at vehicle velocity of 16.88 m/s

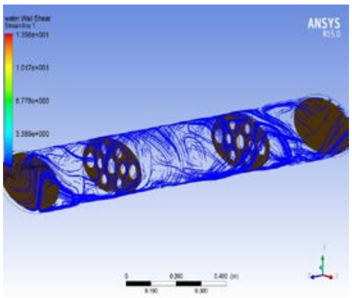

Fig 10 Velocity Streamline of Water slosh inside the container with baffles at 16.88 m/s

C. Results & Discussion

The water impact forces on container walls are studied with and without baffles of various velocities (13.66 m/s and 16.88 m/s) done using CFD. The results clearly indicate the

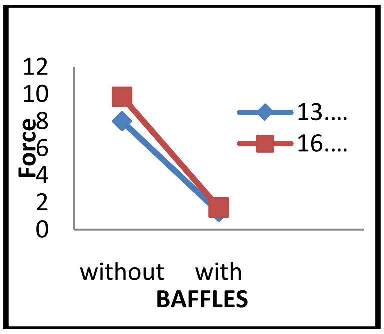

Chart 1 – Comparison of water impact force on container walls due to slosh during braking of vehicle.

Water forces majorly act heavily on sidewalls and centered top surface of container without baffles. As shown in fig 10, the streamlines describes with the usage of baffles the water sloshing movement is been lowered to maximum, compared to without baffles. Since the time period chosen to apply the braking for the tanker truck is assumed to be 20 seconds the water sloshing is clearly viewed in the streamlines for the taken velocities.

The chart 1 describes clearly that with the usage of baffles greatly reduces the sloshing inside the tank.

5. CONCLUSION

The comparison of pressure contours clearly shows that the pressure distribution on the tank surface is much better when baffle is present. Thus, tank with baffle is much better design for reduced sloshing. Volume of fluids is suitable to predict the maximum sloshing, the wall stress and liquid overflow. It is also concluded that baffles are effective means of preventing or minimizing sloshing intensity. However, baffles can change the model characteristics of a structure and increase in total weight. And there exist many design variables such as size, interval, installation position, the number of baffles having an effect on sloshing, which left for the future work.

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