Abstract

In this Thesis three types of fluids are used to study the effect of sloshing in a tanker. Sloshing is the phenomena that occur in a partially filled tanker. Sloshing is the periodical oscillations in a tanker due to the external disturbances. In some stable conditions sloshing generally leads to cyclic stress and fatigue in thin walled tank structures. If that effect is nearer to the natural frequency of the tanker then beating phenomenon takes place which leads to severe collapse. Earlier various studies were made experimentally and numerically to analyze the effect of sloshing on the fuel tank. In this work transient analysis is performed using ANSYS 14.5. A Sequence of numerical experiments has been carried out to estimate the pressure developed over the tanker wall and the free surface displacement of the fluids from its mean static level. Simulations are compared for the three different fluids to validate the effect of sloshing on the tanker. This is performed for variable accelerations and the results are compared. It was found from CFD transient simulation of fluids interface with tanker periphery.

Keywords: Sloshing, ANSYS, VOF, Elliptical fuel storage tanker

I. INTRODUCTION

The tankers that are transporting undergo motion in the liquid due to its nature. When the tank is semi-filled or partially filled the fluid inside will slosh. Sloshing takes in different ways and there few mechanism that the liquid experience when it was subjected to external disturbances or excitations. This kind of slosh creates huge impact over the tanker body. Then the liquid will move to and fro. Such phenomenon is called as sloshing. If this sloshing frequency is equal to the natural frequency of the tanker body then beating phenomenon takes place. That leads to a blast or complete collapse of the tanker. Especially in aerospace applications these slosh loads will result the instability of the vehicle. These slosh loads will be experienced due to two main reasons, namely type of disturbance and due to the shape of the tanker. Due to sloshing hydro dynamic forces and moments will be posed on the tanker body that will cause cyclic loading on the tanker periphery.

II. MODELLING AND ANALYSIS

The tanker we consider for analysis follows Indian standard notation. The dimensions of the tanker are considered from IS 13187. Based on these dimensions we modeled the tanker in CREO PARAMETRIC 3.0 and analysis was carried in ANSYS Fluent 14.5. The dimensions are tabulated below in table-1

<table>
<thead>
<tr>
<th>S. No</th>
<th>Designation of tanker</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length (L)</td>
<td>4780</td>
</tr>
<tr>
<td>2</td>
<td>Width (W)</td>
<td>2236</td>
</tr>
<tr>
<td>3</td>
<td>Height (H)</td>
<td>1270</td>
</tr>
<tr>
<td>4</td>
<td>Thickness of the sheet metal</td>
<td>3.3 (VOF &lt; 25 liters)</td>
</tr>
<tr>
<td>5</td>
<td>Total Trailer Length (L_t)</td>
<td>4980</td>
</tr>
</tbody>
</table>

The model of the tanker is elliptical in shape which we can observe in fig 1.

Fig. 1: The shape of the tanker in CREO 3.0
The above tank that is modeled using CREO PARAMETRIC 3.0 is exported to ANSYS for simulation. We use VOF (Volume of Fluid) method to execute the simulation because it allows arbitrary large deformations and enables free surfaces to evolve.

### III. 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 (\( \rho = 999.98 \text{kg/m}^3, \mu = 0.00103 \text{kg/(m-s)} \)). The tank dimensions are 2.236*1.27*4.78 m\(^3\). 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. The properties that are considered are portrayed in table-2.

#### Table – 2

<table>
<thead>
<tr>
<th>S. NO</th>
<th>NAME OF FLUID</th>
<th>NAME OF PROPERTY</th>
<th>VALUE</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DIESEL</td>
<td>DENSITY</td>
<td>730</td>
<td>Kg/m(^3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VISCOITY</td>
<td>0.0024</td>
<td>Kg/(m-s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPECIFIC HEAT</td>
<td>2090</td>
<td>J/(kg-k)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>THERMAL CONDUCTIVITY</td>
<td>0.149</td>
<td>w/(m-k)</td>
</tr>
<tr>
<td>2</td>
<td>KEROSENE</td>
<td>DENSITY</td>
<td>780</td>
<td>Kg/m(^3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VISCOITY</td>
<td>0.0024</td>
<td>Kg/(m-s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPECIFIC HEAT</td>
<td>2090</td>
<td>J/(kg-k)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>THERMAL CONDUCTIVITY</td>
<td>0.149</td>
<td>w/(m-k)</td>
</tr>
<tr>
<td>3</td>
<td>WATER</td>
<td>DENSITY</td>
<td>998.2</td>
<td>Kg/m(^3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VISCOITY</td>
<td>0.0001003</td>
<td>Kg/(m-s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPECIFIC HEAT</td>
<td>4182</td>
<td>J/(kg-k)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>THERMAL CONDUCTIVITY</td>
<td>0.6</td>
<td>w/(m-k)</td>
</tr>
</tbody>
</table>

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:
     \( X = -9.81 \text{ m/s}^2 \)
     \( Y = 0 \text{ m/s}^2 \)
     \( Z = -9.81 \text{ m/s}^2 \)
   - Operating density: -1.225 kg/m\(^3\)
8) Baffle, baffle shadow and rectangular tank are considered as wall.
9) Following solution method is adapted:
   - Scheme- Fractional setup, Gradient-green-gauss node based, pressure-boy force weighted, momentum-first order upwind, volume fraction-geo-reconstruct
   - 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.
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:
- Global courant number - 2,
- Ending time - 0.45,
- Min. time step factor - 1e-05,
- Max. Time step factor - 0.0025,
- Min. step change factor - 0.5,
- Max. Step change factor - 1.5.
This is the procedure for all the fluids with varying properties. At two gravitational accelerations 9.81 m/s² and 15 m/s² the results were plotted.

IV. RESULTS AND DISCUSSIONS

A. For acceleration = 9.81 m/s²

Fig. 2: Pressure Exerted on the Tanker Wall for Kerosene.

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].

Fig. 3: Pressure Exerted on the Tanker Wall for Diesel.

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].

B. For Water

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].
As the density of the fluid increases the slosh impact pressure increases.

C. For acceleration=15 m/s²

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].
The minimum pressure on the wall is $-1.55423\times10^{10}$ [Pa] and the maximum exerted pressure on the walls of the tanker is 257.692 [Pa].

The minimum pressure on the wall is $-4.47032\times10^{10}$ [Pa] and the maximum exerted pressure on the walls of the tanker is 313.818 [Pa].

When the acceleration is applied at $X= -15$ m/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.
<table>
<thead>
<tr>
<th>S. No</th>
<th>Name Of Fluid</th>
<th>Pressure at ( a = 9.81 \text{ m/s}^2 ) (Pascal)</th>
<th>Pressure at ( a = 15 \text{ m/s}^2 ) (Pascal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diesel</td>
<td>201.654</td>
<td>257.692</td>
</tr>
<tr>
<td>2</td>
<td>Kerosene</td>
<td>207.842</td>
<td>309.169</td>
</tr>
<tr>
<td>3</td>
<td>Water</td>
<td>259.016</td>
<td>313.818</td>
</tr>
</tbody>
</table>

The liquid properties and tanker shape are responsible for the variation in the impact pressure that was created on the wall of the tanker.

V. CONCLUSION

Three fluids having disparate properties are supposed to periodical oscillations inside the tanker with gravitational accelerations \( 9.81 \text{ m/s}^2 \) and \( 15 \text{ m/s}^2 \) 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.

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.

REFERENCES


[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