Reduction in Sloshing Using Baffle Plate

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Abstract : Our project is an innovation to solve the water loss problems in today's water tankers and increase its handling and riding quality. This innovation is one of the ways to solve the problem, cost effectively. The project is based on the phenomenon of sloshing and ways to overcome it. This can be achieved using baffle plate system. More importantly sloshing also affects the riding and handling quality of the truck and it is a notable issue that must be resolved as it subsequently affects the safety of the driver and everyone around. The main aim is to reduce the sloshing effect and water le from water tankers by baffle plates. Furthermore, simulation is carried out using ANSYS. The results obtained are tabulated and compared for certain parameter and conditions. The results provide sufficient numerical values and proofs stating the importance of baffle plate system.

Keywords : Water Tanker, Baffle Plate, Sloshing, Water loss, Riding quality, Handling quality, Ansys Fluent, Milk, Water.

1. INTRODUCTION

Baffles are damping devices that are used to reduce or remove unwanted vibrations and disturbances. The study is performed in order to understand the importance of Baffle system in water tankers. The baffle plate have been designed and placed normal to the flow of water to obstruct and reduce the vibrations generated within the moving water truck. In this study, tanks without baffle and tanks with baffle plate are considered by taking water and skimmed as fluid medium. Stimulation is conducted on both types of systems by considering water and milk as fluid medium using Ansys Fluent. The results obtained are tabulated and compared for certain parameter and conditions. The results provide sufficient numerical values and proofs stating the importance of baffle plate system. In road tankers, the free surface of liquid cargo may experience large excursions for even very small motions of the container. The resulting dynamic load shifts in the roll and pitch planes could influence the roll and pitch moments, and mass moments of inertia of the fluid cargo, and may contribute to degradation of the handling and directional stability limits. This problem is common in fuel tanks of automobiles, aircrafts and large ships and tankers. Reported studies on dynamics of partly filled tank vehicle combinations have invariably shown that the roll dynamics and braking properties of such vehicles are strongly influenced by fluid slosh in an adverse manner It has been shown that the free surface oscillations of low viscosity fluids in partly-filled tank trucks persist over long durations, and can lead to significantly lower roll stability limits and braking performance. The magnitudes of dynamic load shift, slosh forces and moments are strongly dependent upon the fill volume and the tank geometry. Baffles are commonly used as effective means of suppressing the magnitudes of fluid slosh, apart from enhancing the integrity of the tank structure, although only a few studies have assessed roles of baffles design factors in view of the braking and roll dynamics performance.

2. LITERATURE REVIEW:

K.M. Tehrani et al. [1] did a 3-D transient analysis of the sloshing in a cylindrical tank. The tank was subjected to both longitudinal and lateral acceleration and sometimes the combination of accelerations in both directions. The fuel was filled in the tank at two different fill levels. The study was performed both with and without baffles in ANSYS FLUENT. The baffle was of conventional type having a central orifice. The result was described in terms of amplification factor 9 which was the ratio of transient force to mean force. The study shows that where the amplification factor without baffles was around 2, it significantly reduced as we use baffles.

J.H. Jung et al. [2] took a 3-D rectangular tank and filled it with the water up to 70%. They studied the sloshing behavior with different heights of baffles. He made a parameter (h/B) where h is the height of the baffle and B is the liquid height in the start of the analysis. They found that as we increase the height the sloshing reduces and after a certain (h/B) value, also called the critical value the water doesn't touch the roof. The liquid surface also shows the linear behavior after this height. The VOF model was used to track the surface.

S. Rakheja et al. [3] checked the effectiveness of the baffles placed with different orientation inside a cylindrical tank. VOF (Volume of Fluid) multiphase model was used for tracking the interface of the two fluids. The baffles used include lateral, conventional, partial and oblique. The tank was subjected under combined acceleration with different fill levels. The study shows that the conventional baffle with a central orifice is useful in reducing the longitudinal sloshing forces while the oblique baffles are good in reducing the sloshing forces and moments in both lateral and longitudinal directions and in other planes.

Bernhard Godderidge et al. [4] took a rectangular tank subjected to sway induced sloshing. They conducted the study both experimentally and computationally using CFD analysis. For the density and viscosity of the fluid, they took both homogeneous and inhomogeneous multiphase approach and then compared the computational and experimental results. The results after comparison show that the homogeneous approach gives 50 % less accurate results for peak pressures with respect to the inhomogeneous multiphase model.

Kingsley et al. [5] A multidisciplinary design and optimization (MDO) method is presented. They basically focused on the design prospect of the liquid containers. For that they used a rectangular tank and both numerical simulation and experiments have been done. The numerical results were validated with the experimental ones. VOF model for multiphase interface tracking, $k - \mathcal{E}$ model for turbulence has been used.

D. Takabatake et al. [6] studied the damage caused to the liquid storage tanks during Earthquake in Tokachi-oki, Japan in 2003. Earthquakes generally occur in Japan. They observed that sloshing causes the structural damages to the petroleum tanks. To reduce this, they used a splitting wall as a new anti-sloshing device. Experiments were done and then numerical simulation was done. The results were almost same. The new proposed anti- sloshing devices reduced the sloshing effectively. Based on the numerical simulation, the proposed device can be also effective against earthquake ground motion

Eswaran et al. [7] used a cubic tank to study the effects of baffles on sloshing filed partially. VOF model along with ADINA software was used for the numerical analysis.

Vaibhav Singal et al. [8] a partially filled kerosene tank was used for the sloshing analysis. Computational study was done in the tank both with and without baffles. VOF as multiphase model and ANSYS FLUENT software for finite volume method were used. The baffles reduce the sloshing effectively

3 . METHODOLOGY

Resourcing data: The resourcing of data is a basic step but one of the most important. This data will be collected from new papers, companies, research papers and so on. This data will be used to compare the previously existing problems and situations to today's scenario and our experimental outputs and calculations. We will also use the numerical calculations and formulas to solve our objectives.

Analysis of flow of water in a water tanker: This step includes the numerical calculations of the amount of sloshing that occurs in the water tanker. This also includes the experimental analysis of sloshing using stimulation software (Ansys).

Analysis of flow of water in a water tanker consisting of Baffle Plates: This step includes the numerical calculations of the amount of sloshing that occurs in the water tanker with baffle plates. This also includes the experimental analysis of sloshing using stimulation software (Ansys).

Comparing the result of sloshing: All the results motioned above are compared and will be proved that baffle plates are more effective and best to reduce sloshing. This is proven by comparing the results of the stimulation. Also, on how the vehicle performance (riding and handling quality) is affected with and without baffle plates.

***Result*:** The best probable, effective method is chosen of all to fulfill the objectives of the project.

4.. MATHEMATICAL FORMULATION

Theoretical Calculation: By assume each Tanker company contains 3 trucks, 3 trucks make a total of 30 rounds. 30/2 = 15 rounds with full tank water
Ex: Place X has a 9.9 sq km radius. **Each tanker travels – 8km approx./ round**. Total Km travelled with full water 4x15=60km
Let us assume the truck travels in a speed of 20km/hour.1hr = 20km Assume 60 drops/minute.3 x 60 minutes = 180 minutes

There is no scientific definition of the volume of a faucet drip, (numbers are rounded), we are going to use 1/4 milliliter (ml) as the volume of a faucet drip.

One liter = 4,000 drops
1minute = 60 drops
180 minutes= 10,800 drops
10,800 drops = 2.7 liters
Assume 100 trucks travel per day.
2.7 liters x 100 =2700 liters.

Volume of Fluid Model: The problem consists of two phases i.e., water and air/ milk and air. For tracking the free surface of the all the phases multiphase volume of fluid (VOF) model has been used. This permits the simulation of large amplitude slosh, and also includes the separation of the free surface. In theVOF model, a single set of momentum equations is shared by the fluids, and the volume fraction of each of the fluid in each computational cell is tracked throughout the domain. VOF model solves phase and the total continuity equation, and the result is pressure and volume fraction which pointsout where the interface is.

Volume Fraction: The VOF formulation works for two or more fluids (or phases). Adding an extra phase to a model, a new variable is introduced to represent the volume fraction of that phase in the cell. For every control volume,

$$\sum_{p=1}^{n} \alpha_d = 1$$

Where α_d represents the volume fraction for a particular phase p and n is the no of phases present in the computational cell. The value of α_p ranges between 0 to 1. 0 represents the cell is empty, 1 represents the cell is full of the particular phase p. An intermediate value between 0 to 1 shows that there is an interface of one or more fluids.

$$\alpha_{water} + \alpha_{air} = 1$$

Dynamic Sloshing Forces: The sloshing forces are derived from the distributed pressure through integration over the wettedarea of the wall cell,

$$F_x = \sum_{e}^{wet\ area} P_e \overrightarrow{A_e}.\vec{\imath}$$

$$F_y = \sum_{e}^{wet\ area} P_e \overrightarrow{A_e}.\vec{\jmath}$$

$$F_z = \sum_{e}^{wet\ area} P_e \overrightarrow{A_e}.\vec{k}$$

Where F_x, F_y, F_z are the resultant slosh force acting on the tank wall along the fixed x, y, z axes due to pressure P_e acting on the cell "e" with the area vector $\overrightarrow{A_e}, \vec{\imath}, \vec{\jmath}, \vec{k}$ are the unit vectors in the x, y and z direction respectively.

Sloshing Moment: Sloshing moment also affects the stability. The moment is caused because of the variation in the cg coordinate. Affects the directional response of the vehicle. The roll, yaw and pitch moments about a point "o" are obtained upon integrating the moment corresponding to each cell over the wetted area:

$$\vec{M} = \sum_{e}^{wet\ area} \overline{r_e} \times F_e$$

Where $\vec{F_e}$ is the force vector caused by a cell "e" on the boundary, $\vec{r_e}$ is the position vector of cell "e" with respect to "o" and $\vec{M}$ is the moment vector about point "o". The coordinate of this point "o" is (0, -R, 0), where R is the tank radius.

Turbulence Modeling: The standard k-ε model is a semi-empirical model based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε). The k-ε model has been used in our study.
Momentum equations remains the same, the viscosity term becomes an effective viscosity μ_{eff} and is determined by the sum of the molecular viscosity μ and a turbulent viscosity μ_t. The turbulent (or eddy) viscosity μ_t is:

$$\mu_t = \rho C_u \frac{k^2}{\varepsilon}$$

Where C_u is an empirically derived proportionality constant.

Closure: Equations which govern the flow in sloshing is explained. All equations are solved by CFD codes. Continuity, Navier-stokes and VOF technique is discussed. The equations for calculating forces and moments developed due to sloshing are explained.

5. RESULTS

Comparison of Sloshing of water in a tank without baffle plates and with baffle plate

Tank without baffle plate

The colour contour indicates the amount of water force inside the tanker. The Fig 1 shows the existence of red region indicating a greater force water acts on the tank walls

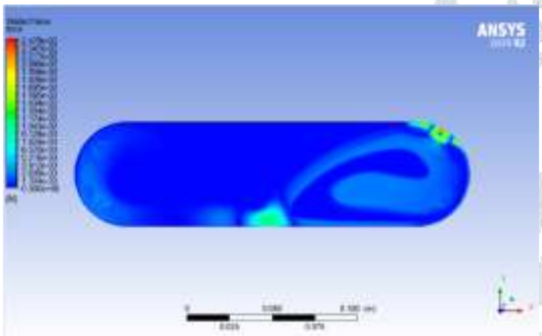

Fig 1 Water force at 100th time step in a tank without Baffle plate

Tank with baffle plate

The colour contour indicates the amount of water force inside the tanker. The Fig 2 shows that the colour red does not exist and showing that lesser water force acts on the tank walls.

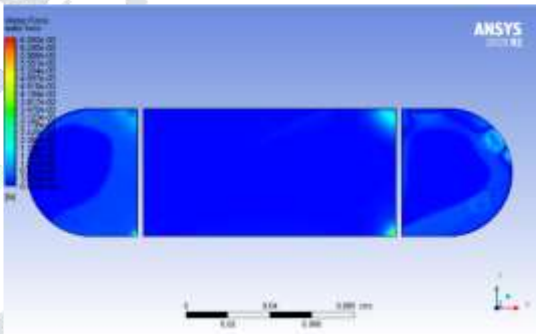

Fig 2 Water force at 100th time step in a tank With Baffle plate

The water force as shown in Fig 3 is acting on all parts of the tank wall and creating turbulence within the tank. The force is more and uncontrolled.

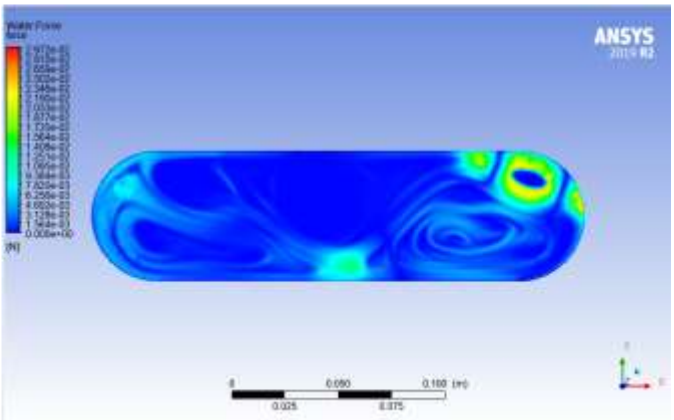

Fig 3 Water force at 300th time step in a tank without Baffle plate

The water force as shown in Fig 4 is distributed and hence making all the force acting inside the tank more balanced. The turbulence creating inside is very less.

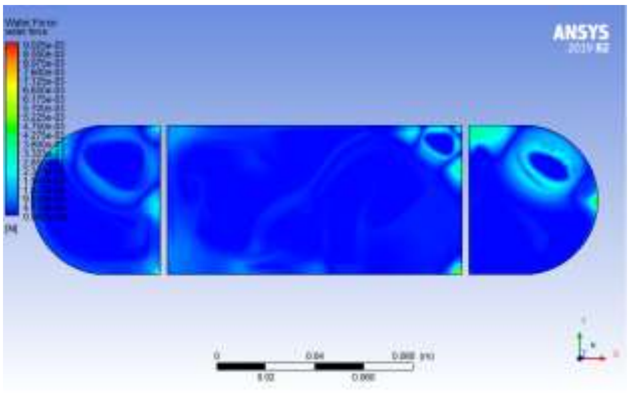

Fig 4 Water force at 300th time step in a tank with Baffle plate

Table 1 Water force in tank with baffle and without baffle plate

Conditions	*100th time step*	*200th time step*	*300th time step*
Without baffles	0.000940924 N	0.00216688 N	0.00237146 N
With baffle plates	0.00056782 N	0.00089338 N	0.00081861 N

On comparing the above the results, it is clear that the force acting on the tank wall is less with a tank having baffle plate than that of the tank not having any baffle.

Tank without baffle plate

The sloshing of water as shown in Fig 5 shows the initial stage of sloshing inside a water truck. The water is pulled to back of the truck and hence creating drag which affects the vehicle motion

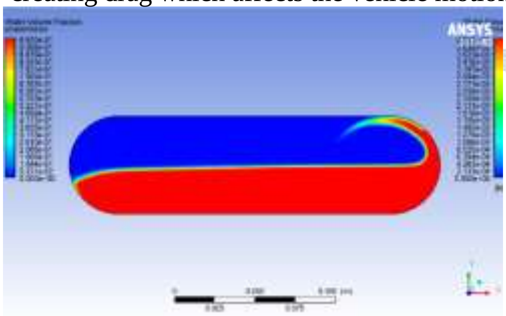

Fig 5 Water sloshing obtained at 20th iteration in a water tank without baffle plate

Tank with baffle plate

The sloshing of water as shown in Fig 6 shows the initial stage of sloshing inside a water truck with baffle plate. As the tank is split into three compartments, the sloshing motion is also split and hence reducing the drag in the vehicle.

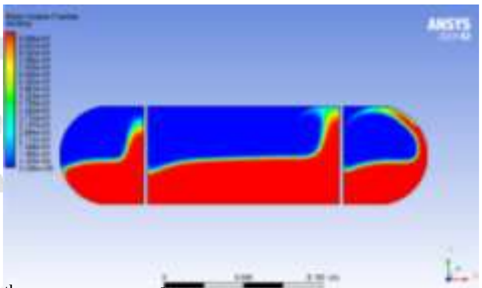

Fig 6 Water sloshing obtained at 20th iteration in a water tank with baffle plate

The sloshing of water at 80th iteration as shown in Fig 7 describes the force at which the water is sloshed creating a lot on water turbulence within the tank.

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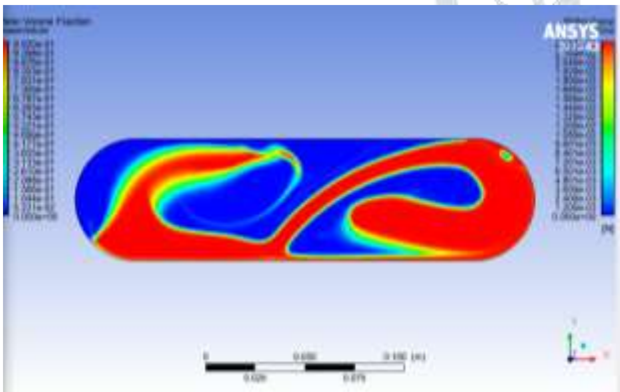

Fig 5 Water sloshing obtained at 80th iteration in a water tank without baffle plate

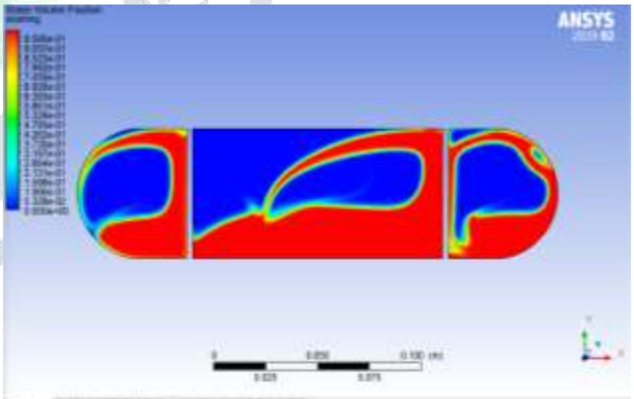

Fig 6 Water sloshing obtained at 80th iteration in a water tank with baffle plate

On comparing the above animations on sloshing, the sloshing occurring inside the tank with no baffle system is uncontrolled and is increasing at every 20th time step, where in, the sloshing inside the tanker with baffle pates is more stable and the sloshing reduces every 20th time step

Comparison of Sloshing of milk in a tank without baffle plates and with baffle plate

Tank without baffle plate

The sloshing of milk as shown in Fig 7 shows the initial stage of sloshing inside a milk truck. The milk is pulled to the back of the truck and hence creating drag which affects the vehicle motion. As the milk is more viscous, the drag force will be greater.

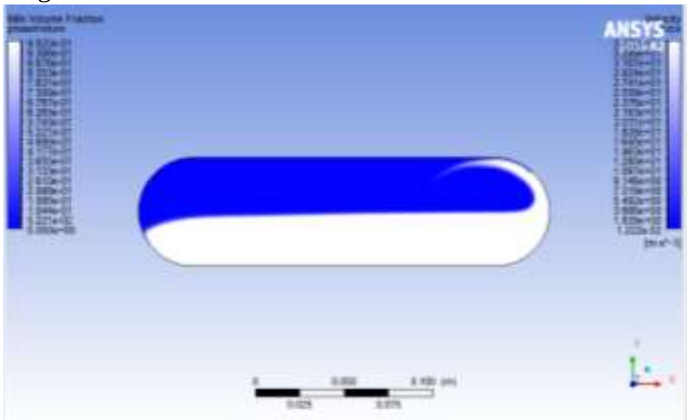

Fig 7 Milk sloshing obtained at 20th iteration in a milk tank without baffle plate

The sloshing milk at 80th iteration as shown in Fig 9 describes the force at which the milk is sloshed creating a lot on turbulence within the tank.

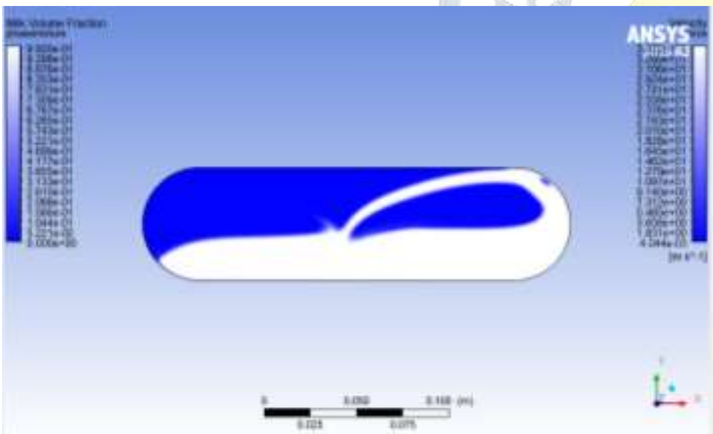

Fig 9 Milk sloshing obtained at 80th iteration in a milk tank without baffle plate

Tank with baffle plate

The sloshing of milk as shown in Fig 8 shows the initial stage of sloshing inside a milk truck with baffle plate. As the tank is split into three compartments, the sloshing motion is also split and hence reducing the drag force in the vehicle.

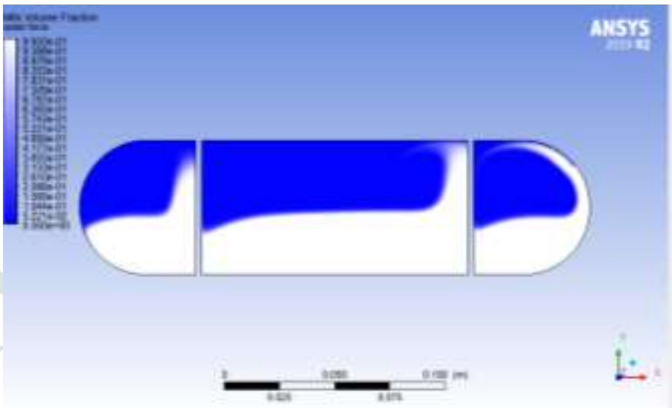

Fig 8 Milk sloshing obtained at 20th iteration in a milk tank with baffle plate

The sloshing of milk at 80th iteration inside a truck with baffle plate is as shown in Fig 10 describes how the sloshing is split into 3 compartments and hence reducing the sloshing acting on the tank walls

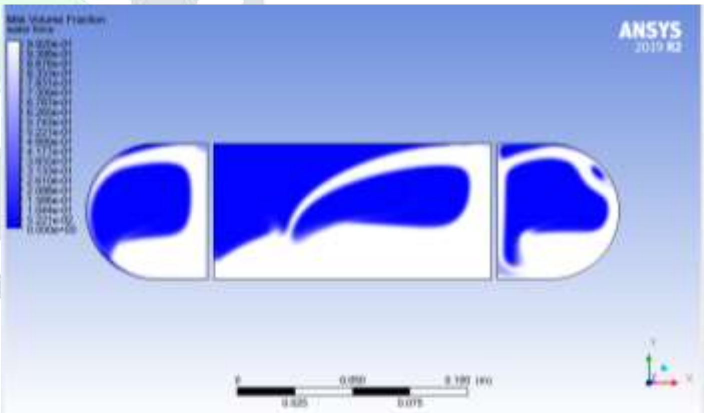

Fig 10 Milk sloshing obtained at 80th iteration in a milk tank with baffle plate

On comparing the above animations on sloshing of milk, the sloshing occurring inside the tank with no baffle system is uncontrolled and is increasing at every 20th time step, where in, the sloshing inside the tanker with baffle pates is more stable and the sloshing reduces every 20th time step

Table 2: Force Acting by Sloshing Of Milk in tank without baffle plate and with baffle plate

Conditions	*100th time step*	*200th time step*	*300th time step*
Without baffles	0.000842614 N	0.0025585 N	0.00209001 N
With baffle plates	0.000778166 N	0.001290 N	0.00099071 N

On comparing the above results, it is clear that the force acting on the tank wall by milk is less inside the tank having baffle plate than that of the tank not having any baffle.

5. CONCLUSIONS

For a partially filled tank with water or skimmed milk, sloshing forces and moments are developed as it is subjected to linear acceleration/ deceleration. After simulating the problem in the ANSYS and analysing the results, we can conclude that:

- The magnitude of sloshing and moment forces are comparatively higher in a tankers containing milk than tankers containing water, whereas the fluctuations on sloshing and forces are comparatively higher in a tankers containing water than tankers containing milk.
- The fluctuations and magnitude of sloshing and moment forces are higher in tankers which does not have any baffle system.
- The water trucks or the milk trucks having baffle plates will have more effective breaking.
- The rolling moment during curves and corners is less in trucks having baffle plates.
- The handling and riding quality are better in trucks having baffle plates.
- By using baffle plates, the trucks are more under control of the drivers during an awful road conditions and accident prone situations because of which, the driver is more safer and has less chances of accidents.

6. REFERENCES

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