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Numerical Investigation of the Fuel Tank Sloshing Condition of a Commercial Vehicle

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Research Article

Abstract

This study investigates the impact of baffles on fuel sloshing behavior within truck fuel tanks using numerical simulations. The volume of the fluid multiphase model is employed to analyze the flow dynamics of 25% diesel fuel in a 250 L tank, modeled in a 3D domain. Two configurations were compared: a tank with baffles and one without. The primary focus is to analyze fuel distribution within the intake port region during vehicle acceleration and deceleration maneuvers. The simulated scenario mimics a realistic driving situation. The vehicle accelerates from 0 km/h to 60 km/h over 10 s, followed by a 3-s braking period to reach a complete stop (0 km/h) at the 13-s mark. The simulation then observes the fuel behavior within the tank for an additional 7 s while the vehicle remains stationary. Results reveal significant differences in fuel behavior between baffled and unbaffled tanks. In the absence of baffles, the sloshing motion is substantial, leading to a complete depletion of fuel in the intake port region for a duration of 3 s during both the acceleration and deceleration phases (between 10 and 13 s). Compared to a standard tank, the presence of baffles significantly reduced the sloshing amplitude by approximately 70%. Furthermore, baffles led to a 50% decrease in pressure variations on the tank walls. Temporary fuel starvation can negatively impact engine performance and combustion efficiency. Conversely, the presence of baffles within the tank effectively mitigates sloshing and ensures continuous fuel presence at the intake port the entire simulation. This suggests that baffles play a crucial role in maintaining a stable and consistent fuel supply to the engine, even during dynamic vehicle maneuvers.

Keywords: Baffles; Fuel tank sloshing; Fuel intake; Numerical simulation

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1. Introduction

The design of fuel tanks in internal combustion engine vehicles requires meticulous consideration to ensure uninterrupted fuel intake across various driving scenarios. One critical aspect of this assessment involves guaranteeing continuous fuel delivery to the engine under diverse driving conditions, particularly at low fuel levels. Rapid acceleration and braking can induce significant fuel movement within the tank, potentially disrupting fuel supply continuity [1].

Fuel tank sloshing represents a significant phenomenon in commercial vehicles, exerting substantial influence on their stability, safety, and overall performance. As these vehicles traverse diverse terrains and encounter dynamic driving conditions, understanding fuel behavior within the tank becomes crucial. Sloshing analysis is essential because of its occurrence during vehicle acceleration, deceleration, cornering, and sudden maneuvers. Uncontrolled sloshing can lead to fuel starvation, engine misfires, and compromised vehicle handling. For commercial vehicles, which are characterized by large fuel tanks accommodating significant fuel volumes, the effects of sloshing become more pronounced [2]. Severe sloshing induces structural stresses that can impact vehicle components and overall durability.

Recent studies have proposed various solutions to control fuel sloshing, maintain flow continuity, and minimize pressure forces acting on tank walls. Singal et al. [3] demonstrated that baffles significantly reduced the sloshing amplitude and provided a damping effect, ensuring uninterrupted fuel delivery to the engine in a kerosene-filled tank. Severe sloshing occurs in the fuel tanks of partially filled rockets, satellites, submarines, and liquid transport trucks. In these large tanks containing substantial fuel volumes, extensive liquid movement creates hydrodynamic stresses, leading to imbalances and structural failures. This phenomenon can negatively impact vehicle stability and safety, generate noise and vibrations, induce component fatigue, and hinder accurate fuel level measurement [4],[5].

Fuel sloshing has been the subject of recent research, highlighting the importance of carefully considering flow dynamics in systems prone to such behavior. Numerical simulations and analyses offer valuable tools for addressing these issues. Computational Fluid Dynamics (CFD) analyses provide a cost- and time-efficient approach, eliminating the need for physical testing of numerous design models [6]. Jeon et al. [7] investigated the impact of sloshing motion on the boil-off gas and thermodynamic properties of cryogenic liquid fuel tanks through a combined experimental and numerical approach using a phase-change model.

CFD enables the calculation of waves and splashes using the Volume of Fluid (VOF) method for free surface determination, proving useful for solving sloshing problems. The literature includes both experimental and numerical studies on fuel sloshing. Nicolici and Bilegan [8] employed CFD to examine the wave amplitude and pressure applied to tank walls. Their findings suggested that sloshing is influenced by the elasticity of the tank walls. Pal [9] employed numerical simulations to explore how flexible composite liners in cylindrical tanks affect sloshing behavior. Their findings revealed significant differences in the sloshing response compared with rigid tanks.

Kim et al. [10] used the Navier-Stokes equations to solve for impact pressure on tanks with and without baffles, comparing the results with those of a free boundary. They concluded that the employed method offered acceptable accuracy in predicting the impact pressure on an inclined boundary. Additionally, they discovered that prismatic tanks with baffle plates could experience significantly higher impact pressures compared with unbaffled tanks, highlighting that internal elements may not always be effective in reducing impact pressure. Arslan et al. [11] conducted a numerical analysis to study sloshing in the fuel tank of a heavy vehicle equipped with an emergency braking system. This study involved designing fuel tank models with and without anti-slosh baffles and analyzing their performance at different filling levels. The results showed that the use of anti-slosh baffles significantly reduced the impact pressures on the tank walls and minimized the sloshing phenomenon.

Jin et al. [12] conducted studies to determine the effect of baffles on sloshing and pressure formation on walls. They analyzed the impact of placing obstacles at various heights within the tank on the pressure values. Frosina et al. [4] performed a combined experimental and numerical examination of sloshing phenomena in a test bench designed according to the specifications of Fiat Chrysler Automobiles for a vehicle fuel tank. The comparison results yielded a maximum error margin of 5.6% in predicting free surfaces and liquid centroid locations. Wu and He [13] investigated fuel sloshing in automobile tanks using the VOF method. They studied the effects of fill level, excitation frequency, amplitude, and sloshing direction on sloshing characteristics like free surface dynamics, dynamic pressure, sloshing force, and moment. Higher excitation frequencies and amplitudes intensified sloshing, causing significant liquid surface breaking. Dynamic pressure peaked at the liquid level with periodic oscillations. Sloshing force and moment increased with higher fuel levels but plateaued eventually. Lateral sloshing generated higher forces than longitudinal sloshing, with minimal difference in moments. These findings offer insights for designing safer and more efficient fuel tanks.

Prior research has primarily focused on the impact of internal baffles. Reddy [14] investigated the sloshing effect on a linearly moving partially filled diesel tank using CFD. This study focused on determining the sloshing behavior in the tank and significantly reducing the sloshing by using porous baffles. Two vertical transverse porous baffles were used to compare the pressure acting on the front wall of the tanker in models with and without baffles. The results demonstrated that the use of porous baffles significantly reduced the pressure on the front wall of the tank. Zhu et al. [15] examined the thermodynamic interactions of sloshing in horizontal tanks of heavy-duty trucks carrying liquid hydrogen, analyzing the effects of sloshing magnitude and duration. They observed that sloshing increased heat transfer within the tank, lowered the vapor temperature, and increased the liquid temperature. Their research revealed a link between acceleration forces and the severity of liquid sloshing, highlighting the importance of considering this factor when designing heavy-duty truck tanks filled with liquid hydrogen.

Korkmaz and Guzel [16] explored how baffles affect sloshing, which is the violent wave motion in partially filled tanks. They tested tanks with zero, one, and two baffles, measuring liquid surface movement and pressure on the tank walls. Their findings showed that baffles, especially a single one, significantly reduce sloshing forces by absorbing wave energy and restricting liquid motion. Adding a second baffle offered minimal additional benefit at most frequencies, except when the frequency was close to the natural frequency of the tank with one baffle. Sanapalaa et al. [17] used simulations to examine violent sloshing (harsh liquid motion) in a 2D tank. They found that air pockets form during sloshing, which lowers the impact pressure on the walls. The pressure on the roof is much higher than on the sides. They also identified how factors like water depth and shaking intensity affect the impact pressure.

Wang [18] developed a 3D numerical model using the VOF method to investigate the anti-sloshing effects of various baffle configurations in partially filled tank vehicles. Their study showed that adding baffles reduced the longitudinal force and pitch moment peak values. Additionally, baffles increased the fundamental sloshing frequency by 50%–200%, thereby lowering the risk of resonance in tank vehicles. Zhao et al. [19] examined recently how internal structures in tanks, like racks in nuclear power plants, affect liquid sloshing. They found these structures reduce sloshing intensity but increase pressure on tank walls during shaking, suggesting a trade-off between calming the liquid and introducing new forces to consider for safety.

This study provides critical insights into the effectiveness of baffles in mitigating fuel sloshing within a truck fuel tank. While numerous investigations have explored tank sloshing, limited research has focused on its impact on maintaining engine fuel supply. The model without baffles exhibited a temporary disruption in fuel delivery at the intake port during deceleration, highlighting the potential for engine issues such as starvation. Conversely, the model with baffles ensured uninterrupted fuel delivery, demonstrating their effectiveness in maintaining fuel supply continuity. Furthermore, the baffles dampened the sloshing behavior, altering the pressure distribution on the tank walls and potentially reducing the structural stresses on the tank.

2. Numerical Studies

2.1. 3D Model and Computational Mesh

A 3D model of a pickup truck fuel tank was developed for the design analysis, as depicted in Figure 1. Two fuel tank configurations were used in this study. The first tank model (Figure 1a) was designed without baffles, whereas the second model (Figure 1b) featured two separator baffles with 15-mm holes. Table 1 presents the dimensional specifications of the fuel tank. Figure 1c shows the baffle configurations.

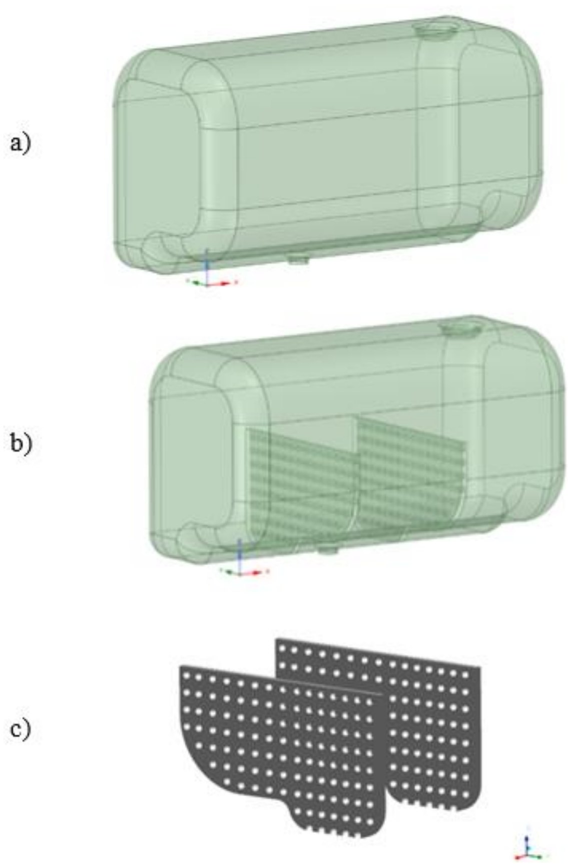

Fig. 1. a) Without-baffles and b) with-baffles tank model

Table 1. Tank dimensions

Parameters	Measurement
Volume	250 L
Length	1000 mm
Width	500 mm
Height	550 mm
Compartment Height	350 mm
Hole Diameters	15 mm

The 3D model was meshed using ANSYS Fluent 2020R1 software, employing tetrahedral cells. The y^+ value was maintained between 30 and 300 during mesh generation. In addition, parameters such as Skewness and Orthogonal Quality were considered to assess mesh quality, with values constrained between 0 and 1. For optimal accuracy, the Skewness value should not exceed 0.95, and the Orthogonal Quality value should not fall below 0.15. In this study, the mesh element quality adhered to these criteria. The mesh for the tank without baffles comprised approximately 2,000,000 cells, whereas the model with baffles comprised approximately 3,800,000 cells. Figure 2 depicts the mesh models for the tank without and with baffles, respectively. In addition, Figure 3 illustrates the computational mesh values.

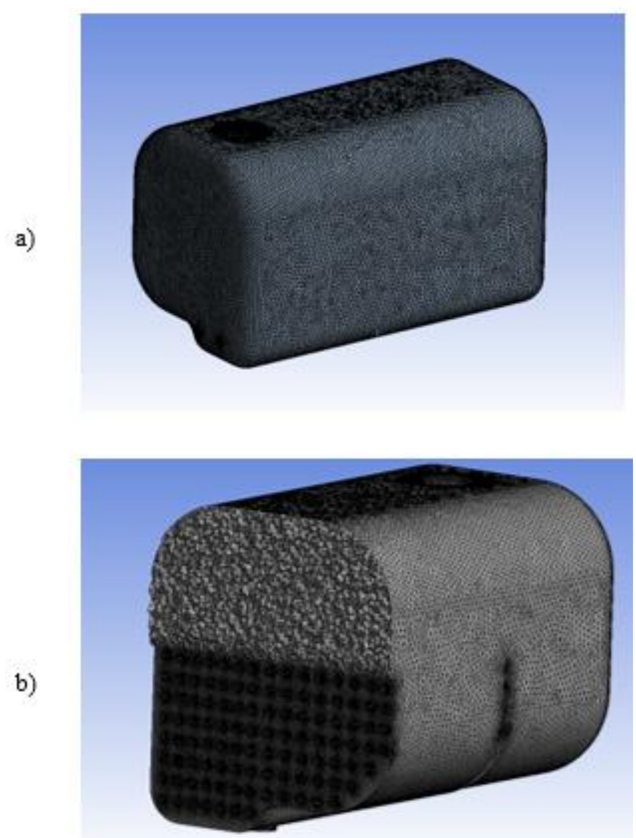

Fig. 2. a) Without-baffle mesh and b) with-baffle mesh

Table 2. (a) Orthogonal and (b) skewness values

	Mesh metric	Orthogonal quality
a)	Min	0.15033
	Max	0.99759
	Average	0.78484
	Standard deviation	0.11450
b)	Min	4.5363x10^{-6}
	Max	0.84967
	Average	0.21389
	Standard deviation	0.11613

To guarantee the accuracy of the numerical simulations and minimize mesh-induced errors in the solution, a mesh independence study was undertaken. Mesh quality parameters are given on Table 2. The analysis model was discretized using four distinct element sizes (Figure 3): 50 mm (a), 25 mm (b), 20 mm (c), and 10 mm (d). Subsequently, a critical parameter (e.g., pressure at a designated location within the tank) was evaluated for each mesh configuration. By comparing the results, the element size that yielded minimal variations in the chosen parameter was identified as the optimal selection for further analysis. This approach ensured that the numerical model accurately captured the physics of the sloshing phenomenon and provided reliable results.

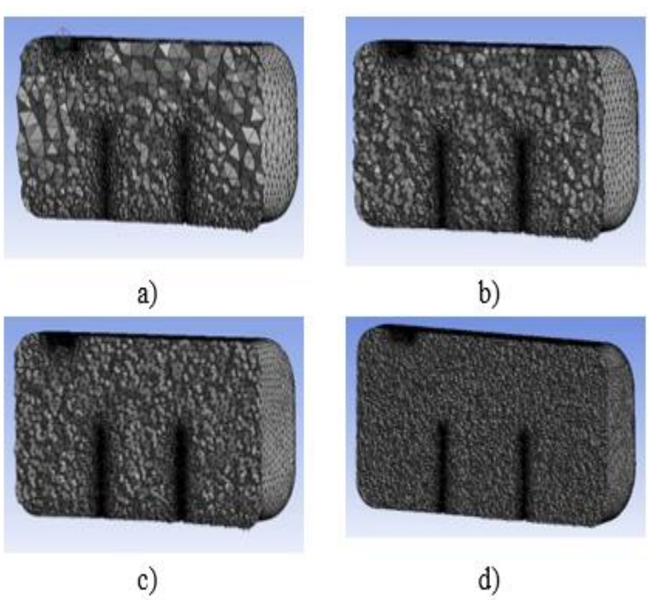

Fig. 3. Defined cell sizes for mesh independence study: a) 50 mm, b) 25 mm, c) 20 mm, and d) 10 mm

The defined cell sizes for the mesh independence study are illustrated in Figure 4, including sizes of 50, 25, 20, and 10 mm. During the independence study, analyses were conducted for 0.5 s. Pressure measurements were obtained from a designated point with identical coordinates attached to the lower corner of the fuel tank for each model. It was observed that pressure values were closely aligned in the analysis model with a 10-mm cell size. Consequently, analyses were continued using the 10-mm cell size model.

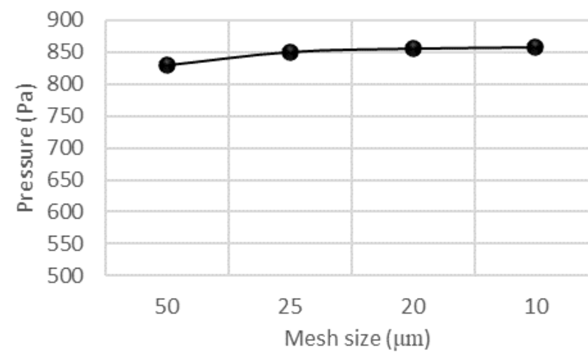

Fig. 4. Pressure variation depending on the mesh element size

2.2. Computational Model of Boundary Conditions

The VOF model within ANSYS FLUENT 2020 R1 was employed to simulate the multiphase flow in the simulations. When the tank was in motion, the fuel inside was defined as diesel. The VOF model specified two phases: air and diesel, with diesel occupying approximately 25% of the total tank volume. The density and viscosity of the diesel liquid were set at 830 kg/m³ and 2.87 mPa.s, respectively. For turbulence modeling, the k-ε realizable turbulence model was used.

The simulated scenario is presented in Figure 5 depicts a realistic driving situation that allows for effective evaluation of baffle impact on fuel sloshing within a truck fuel tank. Here is a breakdown of the key elements:

Vehicle acceleration: The simulation began with the truck shown in Figure 5a in a stationary state. It then accelerated at 1.66 m/s² for 10 s, reaching a speed of 60 km/h, mimicking a typical scenario for a truck starting its journey. This phase was crucial for analyzing fuel movement under dynamic conditions where sloshing was most prominent. Time-dependent acceleration values were applied in the +x direction to simulate this realistic acceleration profile.

Deceleration and stop: Following the acceleration phase, the truck underwent a controlled deceleration maneuver. The deceleration occurred over 3 s, bringing the vehicle to a complete stop at 13 s. This translated to a deceleration of 5.53 m/s², as shown in Figure 5b. This scenario allowed the observation of how baffles influenced fuel behavior during braking, a critical situation where fuel could surge toward the front of the tank due to the inertia of the liquid.

Stationary observation: The simulation continued for an additional 7 s with the vehicle remaining stationary. This period provided valuable insights into fuel settling behavior within the tank after dynamic maneuvers of acceleration and deceleration. By observing fuel distribution during this stationary phase, the effectiveness of baffles in promoting a stable fuel distribution could be assessed, even after the initial sloshing had subsided and the fluid motion began to dissipate due to gravitational forces (defined as 9.81 m/s² in the -z direction) acting on the fuel. This scenario allowed for a robust evaluation of how baffles influenced fuel sloshing within a truck fuel tank. By incorporating elements like acceleration, deceleration, and a stationary phase, the simulation captured the dynamic fuel movement experienced during typical truck operation.

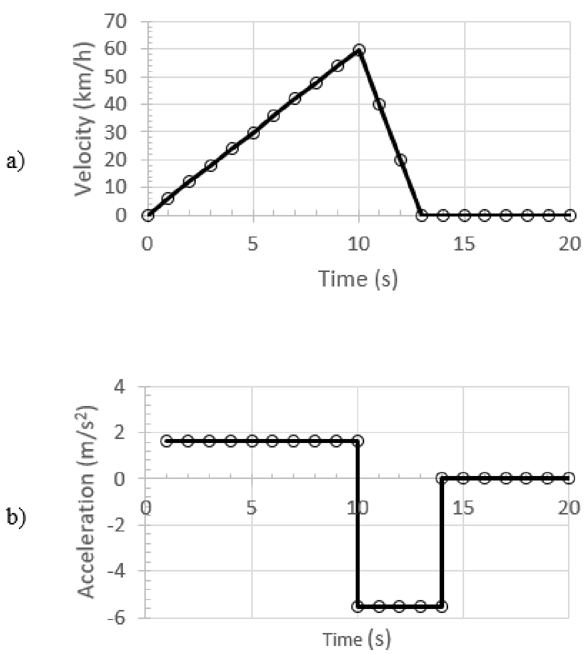

Fig. 5. Time-dependent variation, a) velocity and b) acceleration

In the VOF model, the interface between fluids is determined using a single set of momentum equations, with the volume fraction of each fluid tracked within each computational cell throughout the control volume, as outlined by [12]. This approach involves solving phase and continuity equations to compute the pressure values and volume fractions at each point along the interface.

To establish the location of the interface and quantify the liquid volumes, the VOF model employs a function denoted as F, introduced by [20]. This function defines the volume fraction (F) as the ratio of the volume of the liquid phase (V_{phase}) to the total volume (V_{total}) of the cell. Specifically, when F = 0, the cell is entirely filled with phase 1, whereas $F = 1$ denotes complete filling with phase 2. For values of F between 0 and 1, the interface location and the ratio of Phase 1 to Phase 2 within the cell are determined, providing critical information about the distribution of fluids in the computational domain.

The time variation of the F function is defined by Eq. (1), which is solved together with the Navier-Stokes and continuity equations [20].

Volume fraction equation:

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} + w\frac{\partial F}{\partial z} = 0 \tag{1}$$

The continuity equation for a control volume in Cartesian coordinates can be expressed as given in Eq. (2).

Continuity equation:

$$\frac{1}{\rho}\frac{D\rho}{Dt} + \nabla\vec{V} = 0 \tag{2}$$

In the equation, ρ represents the density, u the velocity, and t the time. The term $\partial\rho/\partial t$ shows how density changes over time.

Since the density is constant for incompressible fluids, equality takes the form of Eq. (3).

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{3}$$

Here, u, v, and w represent the velocity components, and x, y, and z represent the corresponding coordinate axis directions.

The momentum balance (Navier-Stokes equations) is expressed as in Eq. (4).

$$\rho\frac{D\vec{V}}{Dt} = -\nabla\vec{P} + \rho\vec{g} + \mu\nabla^2\vec{V} \tag{4}$$

In the equation, represents the pressure, the gravitational acceleration, μ the dynamic viscosity, and the fluid velocity.

The x-momentum can be derived as in Eq. (5):

X-momentum equation:

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho g_x \tag{5}$$

Similar momentum equations can be written for the y and z directions.

3. Results and Discussion

This study investigates the sloshing phenomenon in the fuel tanks of trucks during acceleration and braking, which essentially involve changes in speed and acceleration. The analysis results reveal significant sloshing in the fuel within the tank without baffles during truck acceleration in the -x direction, which aligns with the motion of the truck. This sloshing leads to complete depletion of fuel in the intake port region between 11 and 13 s, as illustrated in Figure 6a. Conversely, in the fuel tank with baffles under identical conditions, fuel continuity at the intake port is maintained, as depicted in Figure 6b. These findings suggest that with-baffle fuel tanks offer a superior solution to the sloshing problem. The baffles likely dampen fluid motion within the tank, preventing the formation of large waves that can disrupt fuel flow toward the intake port. This ensures a consistent fuel supply to the engine, even during dynamic driving maneuvers.

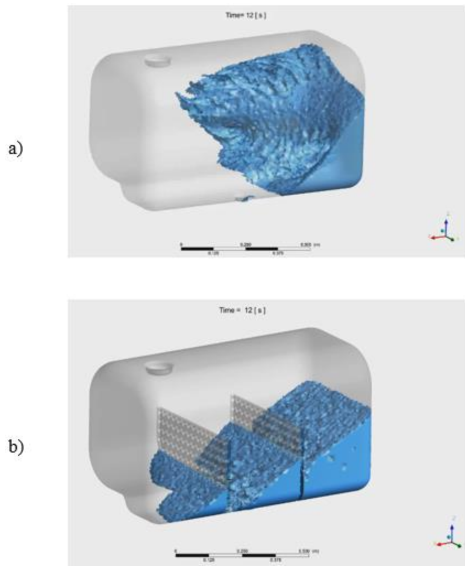

Fig. 6. Pressure variation depending on the mesh element size

Figure 7 illustrates the temporal evolution of fuel distribution in the without-baffle fuel tank over time. As the vehicle accelerates at 1.66 m/s², fuel concentration occurs in the direction opposite to the vehicle's motion. Subsequently, when the vehicle initiates braking at 10 s with an acceleration of 5.53 m/s², fuel rapidly migrates toward the front of the tank, resulting in concentration in that region. Consequently, a temporary lack of fuel is observed in the intake port of the tank for approximately 1-2s, which persists for a few seconds. However, upon the vehicle stopping, fuel is redistributed back to the intake port. These observations highlight the dynamic nature of fuel movement within the without-baffle fuel tank during both acceleration and deceleration phases. The concentration of fuel toward the front of the tank during these maneuvers, coupled with the temporary lack of fuel in the intake port, underscores the limitations of the without-baffle fuel tank design in mitigating the sloshing problem and ensuring fuel continuity.

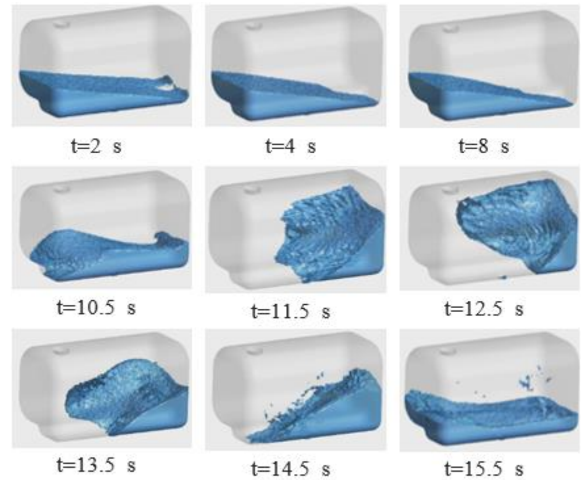

Fig. 7. Detailed without-baffles analysis results

Figure 8 presents the time variation of sloshing occurring in the with-baffles tank. During vehicle acceleration, the fuel inside the tank is directed toward the rear of the tank with a slope of approximately 40% in the first 10 s. Subsequently, as the vehicle decelerates, the fuel undergoes reverse acceleration. However, owing to the presence of baffles in the tank, fuel does not abruptly accumulate in front of the tank. Instead, fuel accumulation initially occurs in each compartment, with later transfer to the front side through the holes in the compartments. This mechanism ensures that the intake port does not experience fuel depletion during sloshing. In contrast to the without-baffle tank, where fuel concentration toward the front during acceleration and deceleration leads to temporary fuel starvation in the intake port, the with-baffle tank demonstrates a more controlled fuel distribution. The tank with baffles maintains fuel continuity, reducing the sloshing amplitude by approximately 70%. The baffles prevent rapid fuel accumulation in the front of the tank, resulting in a more uniform fuel flow and enhanced fuel continuity.

The compartmentalized design of the with-baffle tank, facilitated by baffles with perforated holes, effectively controls fuel movement within the tank. This prevents the formation of large sloshing waves and ensures a more uniform fuel distribution, even during dynamic maneuvers. The reduction in the sloshing amplitude further contributes to improved fuel delivery and engine performance.

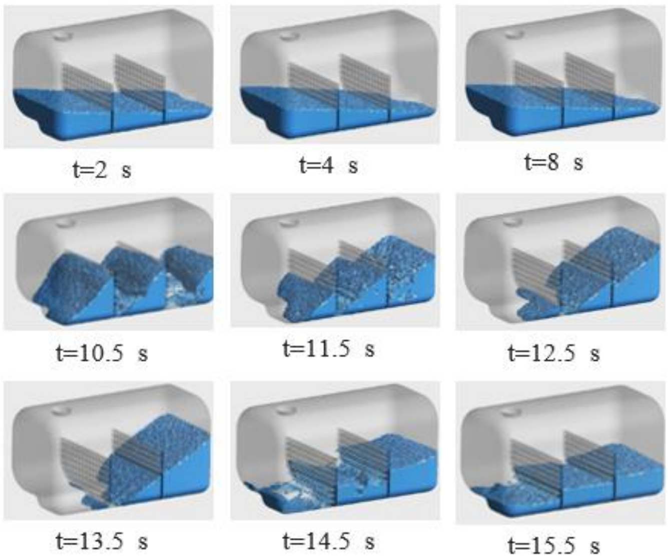

Fig. 8. Detailed with-baffles analysis results

Figure 9 illustrates the time variation of the fuel and air phases at the midpoint of the intake port in both the with-baffle and without-baffle models. The graph depicts values between 0.5 and 1 representing the fuel phase, whereas values between 0 and 0.5 represent the air phase. In the with-baffles model, a continuous distribution of fuel is observed within the intake port throughout the analysis timeframe. This indicates a stable and consistent fuel supply to the engine, which is facilitated by the presence of baffles that prevent fuel depletion or starvation in critical regions of the tank.

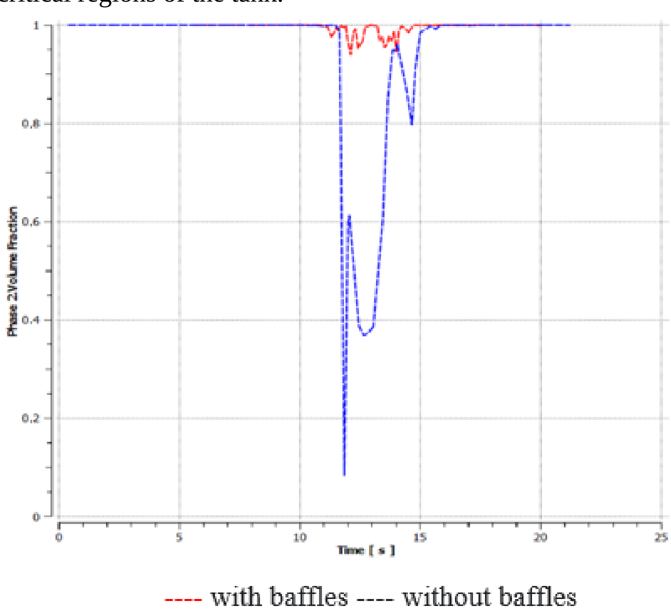

Fig. 9. Air-fuel phase change in the intake port region

Conversely, in the without-baffle model, the presence of the air phase instead of fuel is noted in the intake port between the 10th and 15th seconds. This observation highlights the occurrence of fuel starvation over time and the temporary occupation of the intake port by air. Such fluctuations in fuel presence within the intake port can negatively impact engine performance and combustion efficiency, underscoring the limitations of the without-baffles tank design in maintaining fuel continuity.

Figure 10 provides a detailed insight into the distribution of fuel-air phases within the intake port, offering a closer examination of the sloshing dynamics within the tank. In the with-baffles model, the fuel is consistently observed within the intake port throughout the analyzed timeframe. This continuous presence of fuel indicates a stable and uninterrupted flow of fuel into the intake port, facilitated by the compartmentalized design of the tank with baffles. Conversely, in the without-baffle model, a notable absence of fuel within the intake port region is observed between 11.5 and 14.5 s. This intermittent lack of fuel suggests potential disruptions or fluctuations in flow dynamics, which are likely attributed to sloshing motion within the tank. Such variations in fuel presence within the intake port may have implications for engine performance and combustion efficiency, as inconsistent fuel supply can impact the combustion process. The contrasting observations between the with- and without-baffle models underscore the effectiveness of baffles in maintaining fuel continuity and mitigating sloshing-induced disruptions. By compartmentalizing the tank and preventing excessive fuel movement, baffles ensure a more stable fuel distribution within critical regions of the tank, such as the intake port. This, in turn, contributes to optimized engine performance and enhanced combustion efficiency in commercial vehicles.

Figure 11 provides a visual representation of the pressure distribution on the inner walls of both the with- and without-baffle tanks. A comparison between the pressure distributions in the two tank designs highlights the advantages of the with-baffle tank in controlling and distributing pressure more effectively. In the with-baffles tank, the tank is divided into compartments with perforated grids, which promote a more homogeneous pressure distribution at lower values throughout its inner walls. This design feature effectively dampens the sloshing motion within the tank and minimizes the pressure concentration, creating a more balanced environment inside the tank. As a result, the with-baffle tank enhances durability and safety by reducing the occurrence of high-pressure forces that could compromise the tank's structural integrity. Additionally, the pressure fluctuations on the tank walls were reduced by approximately 50% with baffles, enhancing the stability and durability of the fuel tank. Conversely, the without-baffle tank exhibits a non-uniform pressure distribution with concentration in certain regions. This uneven pressure distribution leads to the formation of high-pressure forces within the tank, which can pose risks to its structural integrity and safety.

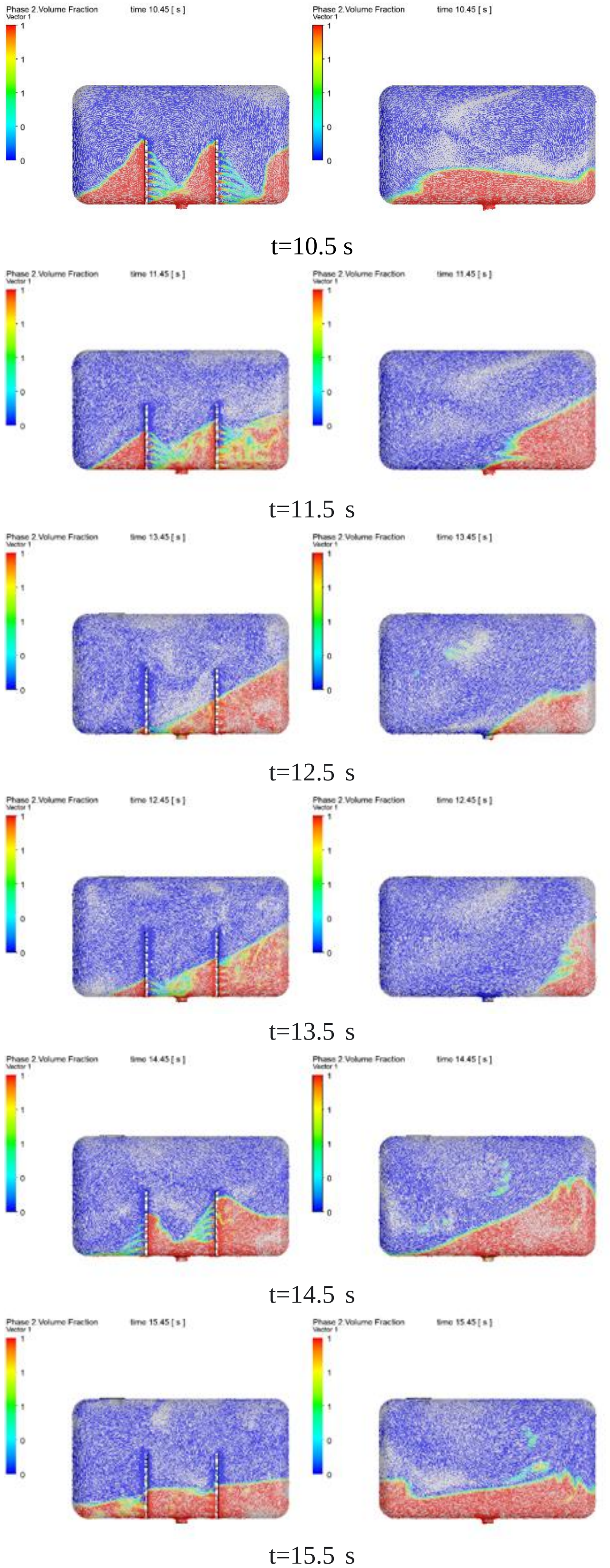

Fig. 10. Fuel-air distribution in the intake region for the with- and without-baffle models

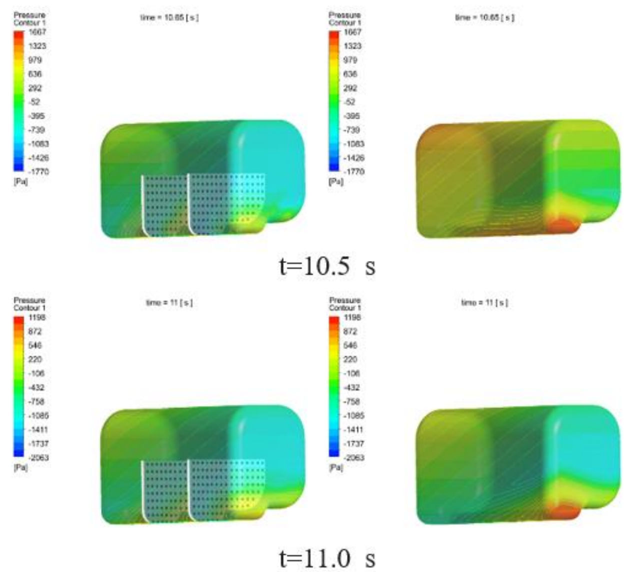

Fig. 11. Pressure distributions occurring on the walls of the fuel tank for the with- and without-baffle models.

3. Conclusion

This study uses numerical simulations to investigate the impact of fuel sloshing on a partially filled (25%) 250 L pickup truck fuel tank under dynamic driving conditions. The analysis compared the behavior of two models: one with and one without porous baffles. The results provided compelling evidence for the effectiveness of baffles in mitigating the negative effects of sloshing. The presence of porous baffles significantly reduced the overall magnitude of sloshing within the fuel tank, resulting in a more stable fuel distribution that minimizes disruptive effects on fuel intake continuity. By dampening the sloshing fluid motion during acceleration and deceleration, baffles ensure a consistent fuel supply to the engine, thereby reducing the risk of fuel starvation and potential engine performance issues. Moreover, the baffle design improved the stability of the fuel within the tank, as evidenced by a more balanced and homogeneous pressure distribution across the tank walls compared with the unbaffled model. This reduction in pressure fluctuations mitigates potential structural stresses on the tank, enhancing the long-term durability and safety of the fuel system.

Recommendations for future research

Investigating the effects of different fill ratios and baffle configurations on sloshing behavior can lead to further optimizations in fuel tank design. In addition, considering the impact of fluid properties on fuel dynamics and exploring the influence of tank geometry on sloshing characteristics hold promise for improving vehicle stability, safety, and fuel efficiency.

Nomenclature

F	: volume fraction function
V_{phase}	: volume of the liquid phase (m^3)
V_{total}	: total volume of the cell (m^3)
ρ	: density (kg/m^3)
u	: velocity in the x-direction (m/s)
v	: velocity in the y-direction (m/s)
w	: velocity in the z-direction (m/s)
t	: time (s)
P	: Pressure (Pa)
g	: gravitational acceleration (m/s^2)
μ	: dynamic viscosity (Pa.s)

Conflict of Interest Statement

The authors declare that there are no conflicts of interest in the study.

CRediT Author Statement

Yusuf Yılmaz: Writing-original draft, Validation,
Ali Kibar: Conceptualization, Data curation, Re-editing
K. Süleyman Yiğit: Formal analysis, Supervision

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