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Design Variations of Internal Baffle Walls to Reduce the Sloshing Effect in a Downscaled Flexitank

Muhammad Danial[1], Yong Tze Mi[1]*, Muhammad Rusydi[1], Nor Izwan Shah[1],Alycia Yap Ching Hui[1],Ch'Ming Wei[1], Nofrizalidris Darlis[1], Norrizal Mustaffa[1], Omar Abu Hassan[1], Shaiful Rizal Masrol[1], Jumadi Abdul Sukor[1], Khairul Nizam Mustafa[2], Muhamad Mohshein Hashim[2]

1 *Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor, MALAYSIA*

2 *My Flexitank Industries Sdn. Bhd., 08000 Sungai Petani, Kedah, MALAYSIA.*

*Corresponding Author: tmyong@uthm.edu.my
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Abstract

The research conducted was focused on a critical objective—to minimize sloshing in flexitanks, a phenomenon arising from the dynamic movement of liquid cargo within containers. The primary motivation behind this endeavour was to mitigate risks associated with sloshing, including instability, potential leakage, and structural damage that could compromise transported materials. Employing an experimental approach, a downscaled flexitank underwent thorough testing in a state-of-the-art transportation simulator, featuring internal baffle wall designs such as Slot, Circular, 90% Plate, Rectangular, and Cross-X. In adherence to the rigorous standards outlined by ASTM D999-2015, the experiment meticulously measured sloshing stop time and resistance, utilizing the sophisticated technology of a Flexible Bend Sensor. Calibration of the sensor is crucial for precision, involved manipulating it with a protractor, with resulting data cross-verified against actual protractor angles. The transportation simulator underwent three cycles, facilitating the systematic collection of data for each internal baffle wall design. Graphical representations depicted the time taken for sloshing to subside at speeds of 5, 10, and 15. The Cross-X design emerged as exceptionally effective, achieving sloshing reduction in under seven seconds, while the slot design demonstrated commendable performance at speeds 5-10 but faced challenges at 15. This careful observation emphasises the importance of designing baffle wall solutions to diverse transportation conditions, providing valuable insights for optimizing cargo stability across varying velocities.

1. Introduction

Flexitanks are liquid containers that can hold up to 24,000 liters and are flexible enough to be folded for storage. They're used in vineyards, loaded into 20-foot containers on trucks, and filled directly from winery tanks. Once used for transporting wine, they're disposed of due to hygiene reasons. Unlike barrels or casks, flexitanks are disposable, and their foldable nature cuts down storage expenses.

Liquid movement inside containers, known as sloshing, happens during transportation in various areas like cargo ships carrying liquids or huge storage systems Internal baffle walls, placed inside tanks, are meant to control liquid movement the wall's position and design depend on factors like the application, desired outcome, and properties of the liquid [1]. Sloshing, or the movement of liquid inside a container, causes problems in various areas like transportation and engineering. It can lead to instability, structural damage, and safety concerns, making containers vulnerable to strain, leaks, and reduced efficiency during transport. Flexitanks face increased stress due to sloshing, risking damage to the container and potential spills [2]. The project aims to accomplish two main goals: firstly, to create and construct various internal baffle wall designs, and secondly, to assess their effectiveness in minimizing sloshing within a downsized flexitank. The literature review is essential due to previous studies on these designs. The study examined two common cross-shaped baffle designs, denoted as Type I ("+") and Type II ("X"), frequently utilized in road tankers in Mexico. Both designs aim to divide the tanker's interior into approximately equal-sized compartments. The height and placement of the baffles play a crucial role in mitigating sloshing within the horizontal, cylindrical, circular-cross-section container used in the industry. Simulation results indicate a significant impact on reducing liquid sloshing, with Type II baffles demonstrating a 45% reduction in stabilization times compared to tankers without baffles. The local effect of the baffles is observed in the decreased motion of the liquid, resulting in a reduction of the total energy available for continued movement [3]. Next, the slot-baffle design is commonly used in water treatment tanks to enhance mechanical mixing effectiveness and reduce excessive sloshing in accelerated liquid tanks. Multiple slot configurations have been generated to analyze energy dissipation performance. In the first case, the dimensions of the slots correspond to half of the width of the baffle, which is 0.5 meters. In the second case, the dimensions of the slots are decreased by 0.5, 0.4, and 0.3 meters along the y-axis. In Case 3, the symmetrical version of Case 2, the slot width exhibits an increment in the y direction. Numerical simulations were conducted using a tank geometry of 1 meter in length, 1.2 meters in height, and 1 meter in width. The slot configurations considered for Case 3 showed the best dissipation performance [4]. Next, this study focuses on evaluating the functions and effectiveness of a baffle plate, a commonly used and relatively straightforward configuration for a baffle wall, in mitigating sloshing in tanks. The research employs a comparative analysis to assess the impact of including a baffle plate within the cylindrical tank. The study reveals that the presence of a baffle plate leads to a more consistent sloshing behavior characterized by a gradual decrease over time. This suggests that the baffle plate plays a significant role in reducing sloshing magnitude and improving the overall stability of fluid dynamics within the cylindrical tank. The study emphasizes the importance of considering the tank's cylindrical shape, highlighting its influence on sloshing dynamics and the interaction between the fluid and the baffle plate [5]. Next, the primary advantage of perforated vertical baffles is their ability to allow liquid to pass through, thereby reducing impact pressure on the baffles and enhancing safety in partially filled containers, commonly observed in contemporary road tankers carrying fuel oils.

This study aims to evaluate various baffle arrangements to mitigate sloshing, provide empirical data for validating numerical models, and propose an efficient baffle configuration suitable for a range of frequencies. The research introduces a novel passive baffle design—vertical baffles equipped with orifices. Experimental results for liquid sloshing in a rectangular tank with both vertical and perforated baffles show good agreement. The perforated baffle, particularly valuable for LNG tankers, is identified as an effective arrangement, allowing an increase in payload without compromising safety by reducing sloshing amplitudes at higher excitation frequencies [6]. Next, the circular internal baffle wall design is a method for controlling fluid flow within a container using circular baffles. A research study examined the impact of pierced hole size on liquid sloshing reduction. The most optimal circular baffle is C18, with a central maintenance hole and 18 small apertures distributed around its circumference. The tank's cross-sectional area should be 57.34% of the open area of all circular baffles [7].

1.1 Significance

This research supports Sustainable Development Goals (SDGs) by improving internal baffle wall designs in downscaled flexitanks. It aims to reduce sloshing, protecting marine ecosystems from cargo spills and preserving food quality during transportation, aligning with SDG 2 (zero hunger). By preventing spills and leaks, it also promotes cleaner water sources. Analyzing and enhancing baffle wall designs further enhances liquid transportation efficiency, reducing material waste and resource consumption. These efforts contribute significantly to responsible production practices, enhancing overall sustainability in liquid transportation.

2. Methodology

In this project, the internal baffle wall's design plays a critical role in minimizing sloshing impact. A comprehensive literature review is essential due to previous studies on these designs, emphasizing the importance of carefully selecting the most effective design for sloshing reduction.

Each design is then visually depicted and developed using SolidWorks software (version 2022) to ensure precise measurements and dimensions. Next, linear low-density polyethylene (LLDPE) is a flexible and strong plastic sheeting film, surpassing regular LDPE in conformability and tensile strength. It is often blended with other films to enhance their flexibility and strength. Widely used in pond lining, LLDPE's high strength is crucial for preventing leaks. It is chosen for applications requiring a film to absorb shocks without tearing or puncturing, making it a versatile material in various industries [8]. Subsequently, the designs are fabricated using LLDPE material from MYF and tested on the Transportation Simulation Tester Machine at speeds of 5, 10, and 15. This systematic process allows for thorough examination, development, and testing of each internal baffle wall design's efficacy in reducing sloshing impact.

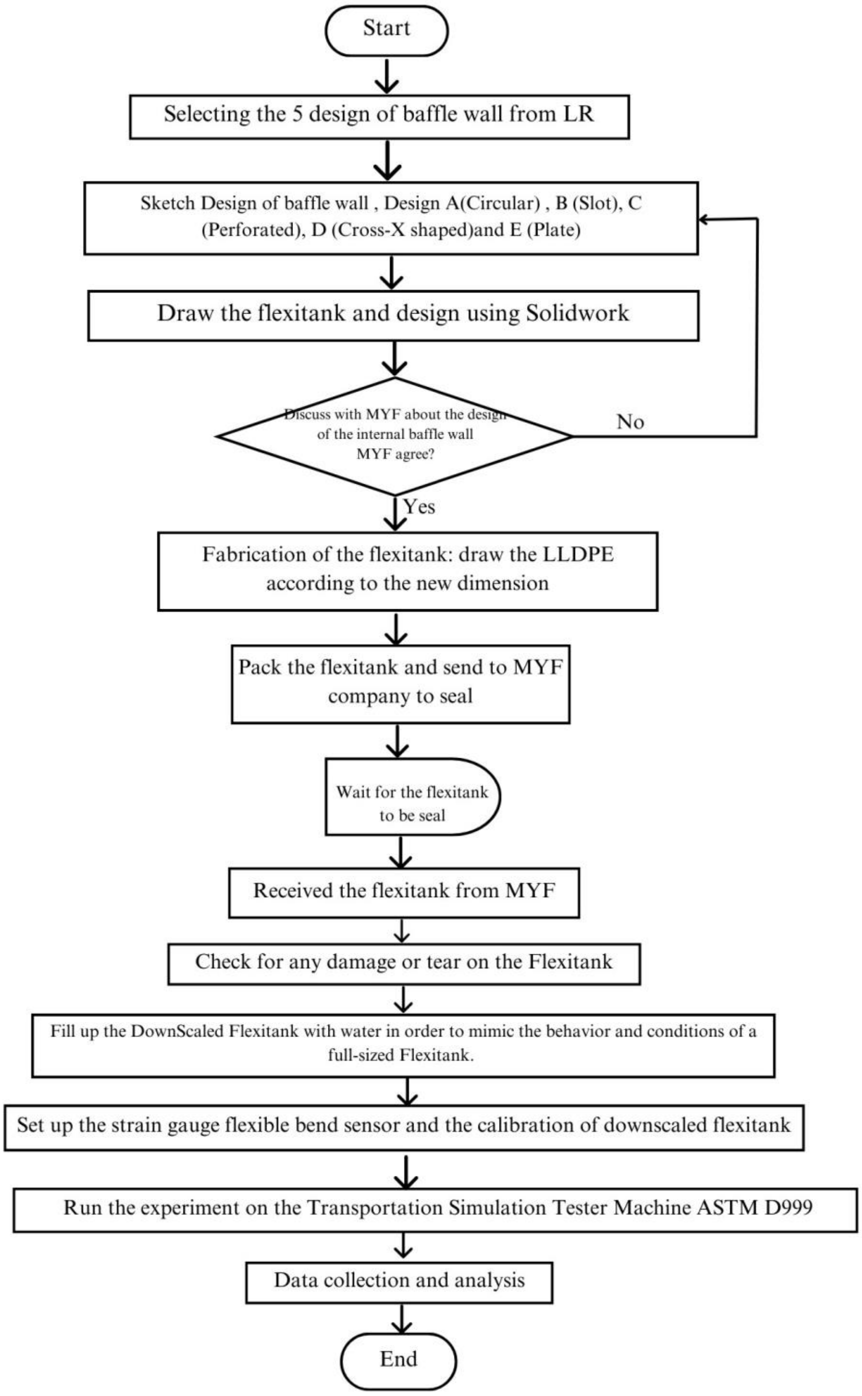
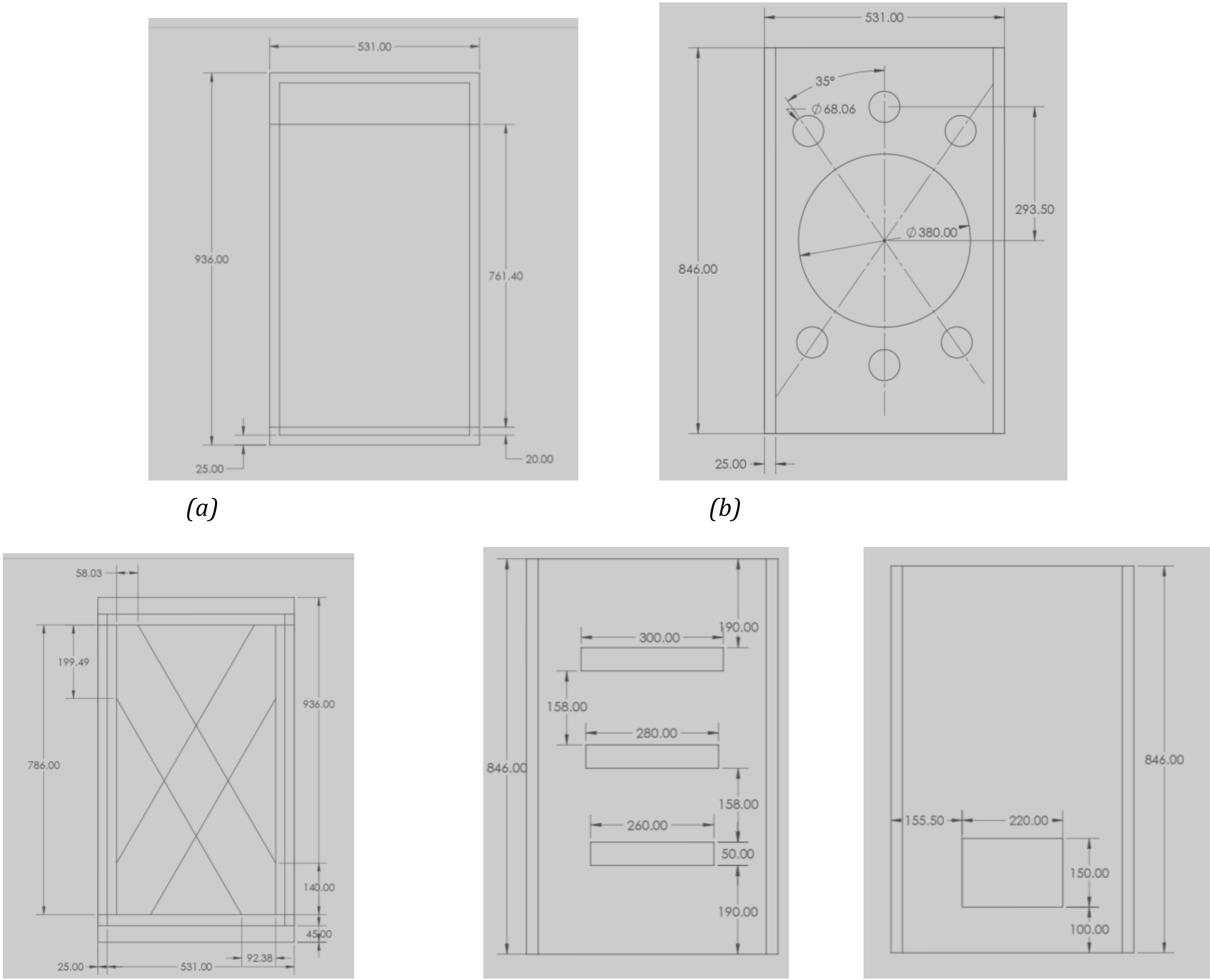


Fig. 1 Flow *chart*

2.1 Solidwork Drawing

After the design is sketch, the design will be created in complete dimension and parameter in solidworks 2022. This will give a more detail view of the design and it will be helpful to avoid any error in measurement during the fabrication process. Fig 2 *(a) Plate 90%, (b) Circular, (c) Corss-X, (d) Rectangular, (e) Slot*



(a) *(b)*

(c) *(d)* *(e)*

Fig 2. *Horizontal Baffle Wall Dimension*

2.2 Fabrication

There will be two main goals in the fabrication process for this project. which are the horizontal baffle wall design and the downscaled flexitank. Drawing the dimension of the downscaled flexitank on the LLDPE sheet to provide a rough view is the first step in the fabrication process. After that, cut the LLDPE sheet to the dimensions shown in the drawing. Then, draw the dimension of the horizontal internal baffle wall. A total of 27 samples were fabricated.

2.3 Equipment Setup

The equipment setup process must be followed before beginning the downscaled flexitank testing to guarantee that every part functions as intended during the testing period. MYF Sdn Bhd's downscaled shipping container to help with the testing of the flexitank. The downscaled shipping container is eight times smaller than it was before. The shipping container's original dimensions were 239 cm in height, 234 cm in width, and 601 cm in length. The downscaled shipping container, on the other hand, is just 32.375 cm in height, 30.5 cm in width, and 76.25 cm in length.

The downscaled shipping container is used to simulate real-world situations in a safe environment. This will also make it possible to conduct the experiment safely and affordably. The downscaled flexitank is placed into the downscaled shipping container. After placing the downscaled flexitank inside the downscaled shipping container, the process of filling the downscaled flexitank with water is started. Since, the volume of the downscaled flexitank is 47.875 litres, only 46.875 litres of water is required after subtracting the safety requirement by MYF Sdn. Bhd. The water was obtained from the nearest tap water in Makmal Sistem Pengujian of Universiti Tun Hussein Onn Malaysia Campus Pagoh. By using a 2-litre jug, the water is measured and stored in a large bucket.

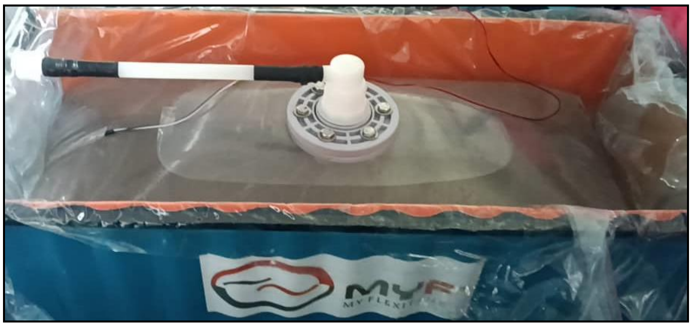


Fig. 3 *Downscaled Flexitank setup*

2.4 Testing Method

Two distinct testing methods are employed: one measures the time required for sloshing to cease, while the other gathers sloshing resistance data using a flexible sensor. The sensor used in the study was the 2.2 Inches Flexible Bend Sensor, and its calibration was completed before the testing of the downscaled flexitank. For the time taken, the transportation simulation machine is activated, executing controlled movements at 5, 10, and 15 speeds. After three cycles at each speed, the machine is deliberately powered down. At this pivotal point, a stopwatch is employed to precisely measure the duration for the sloshing motion within the downscaled flexitank to settle. For the sloshing geometrical change, the data collection process involved employing a flexible bend sensor to measure the sloshing resistance. Following three cycles of operation in the transportation machine simulation, data was collected continuously for 2.5 seconds while the machine remained active.

3. Result and Discussion

The results of this study on the effects of variation horizontal baffle wall design towards the reduction of liquid sloshing in a downscaled flexitank. The results are determined from measuring the sloshing resistance by using the Flexible sensor and the time taken for the sloshing to stop.

3.1 Observation of Downscaled Flexitank

The sealing process involved sending three sets of downscaled flexitank samples to MYF, each containing nine downscaled flexitanks representing various internal baffle wall designs. However, due to valve stock limitations, only five of the 27 downscaled flexitanks were sealed, although MYF had the capacity for all. Consequently, the 90% Plate, Cross-X, Slot, Circular, and Rectangular designs were chosen for sealing. Upon arrival from MYF, the downscaled flexitanks underwent inspection. Unfortunately, after examining all but one, irreparable damage was found in a downscaled flexitank with a Rectangular internal baffle wall design, showing a tear on its upper side. This damage likely occurred during transportation from MYF to UTHM Pagoh. Another downscaled flexitank displayed minor damage as well.

Fig 4. *Damage downscaled flexitank (Rectangular)*

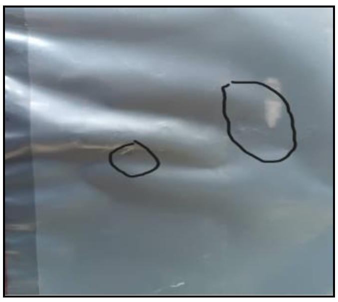


Fig 5. *Minor damage downscaled flexitank*

3.2 Observation after testing

After completing the time-based testing, an assessment was undertaken to inspect the downscaled flexitanks. A tear was identified at the lower section of the downscaled flexitank featuring the Cross-X design. This tear could be linked to potential structural weakening resulting from minor damages incurred during transportation. However, the remaining downscaled flexitanks showed no notable damage and are deemed suitable for continued testing. Due to the damage incurred, the downscaled flexitank featuring the cross-X design cannot proceed with the sloshing flexible sensor testing. Consequently, the comparison will focus on the downscaled flexitank without an internal baffle wall and the slot design. The selection of the slot design is attributed to its notable characteristic of having the second shortest time for the sloshing to dissipate among the downscaled flexitanks tested

Fig 6 *Tear damage (Cross-X)*

3.3 Time Taken of Sloshing

The collected data was recorded. Each data corresponds to a different speed- 5,10 and 15, respectively.

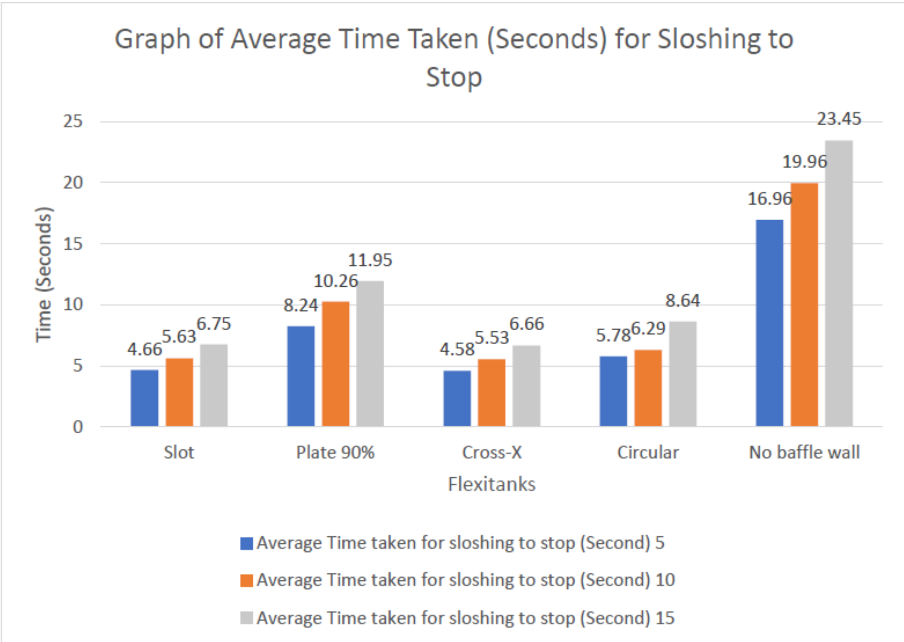


Fig 7 *Graph of Average Time Taken (Seconds) for Sloshing to Stop*

The analysis of Figure 4.7 reveals that at a transportation speed of 5, the downscaled flexitank without a baffle wall exhibited the longest average time for sloshing to subside, taking nearly 17 seconds, whereas the slot and cross-X baffle wall designs achieved the quickest average time, under 5 seconds. At 10 speed, all downscaled flexitanks experienced an increase in sloshing stop time, with the no baffle wall variant taking over 20 seconds, while the slot and cross-X designs remained the fastest at under 6 seconds. At 15 speed, the no baffle wall downscaled flexitank showed the longest duration at 23.45 seconds, while the slot and cross-X designs

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maintained their quick sloshing stop times, averaging under 7 seconds.The data suggests a clear correlation between transportation speed and sloshing duration, with higher speeds resulting in increased sloshing force and longer durations. The flexitanks with no baffle wall consistently had the longest sloshing stop times, emphasizing the importance of internal baffle walls. The slot and cross-X designs consistently demonstrated effectiveness in reducing sloshing, providing faster stabilization even at higher speeds. Circular and 90% plate designs showed some control over liquid movement but fell short compared to the slot and cross-X designs, which efficiently distributed forces, improving stability, and mitigating resonance effects for enhanced structural integrity during transit.

3.4 Recorded data of sloshing resistance using flexible sensor

The data collection process involved employing a flexible bend sensor to measure the sloshing resistance. Figure 10 presents a detailed analysis of sloshing behavior, particularly comparing the slot design with the absence of a baffle wall. Notably, a six-second interval was observed between the initiation of the first sloshing wave and the subsequent one. Within this timeframe, distinctions in the durations of the initial waves were evident: the slot design exhibited a 1.3-second wave, while the no wall design endured a slightly longer period of 1.6 seconds. Following the first wave, a significant contrast emerged within the subsequent five seconds. The slot design demonstrated rapid reduction in sloshing residue, achieving a state of subdued motion. Conversely, the no wall design exhibited lingering sloshing residue, indicating a less controlled and more persistently agitated state. At speed 5, the slot design showcased superior stability and controllability, expediting the dampening of sloshing motion within the crucial five-second period after the initial wave. The overall performance of the slot design for speed 5 was characterized by the faster dissipation of the sloshing wave compared to the no-wall design

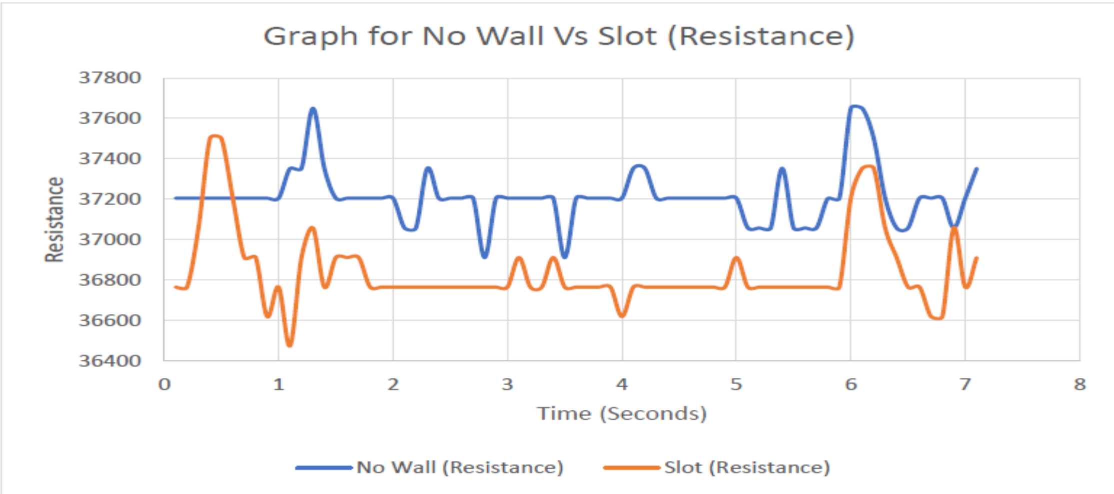

Fig 10 *Resistance for speed 5*

At a speed setting of 10, Figure 11 illustrated the dynamic behavior of sloshing in both the slot design and the absence of a baffle wall. Three distinct sloshing waves occurred within a brief five-second span, indicating an intensified force behind the sloshing as the speed increased. Notably, the slot design exhibited greater resistance compared to the no wall design, with a broader range of resistance levels fluctuating between approximately 36,000 ohms and 37,500 ohms, while the no wall design remained within a consistent band of 36,000 ohms to 37,000 ohms.

The gap between sloshing waves in the slot design suggested its ability to partially subdue waves before the subsequent one commenced, indicating success in reducing the impact of sloshing waves, particularly at higher speeds.

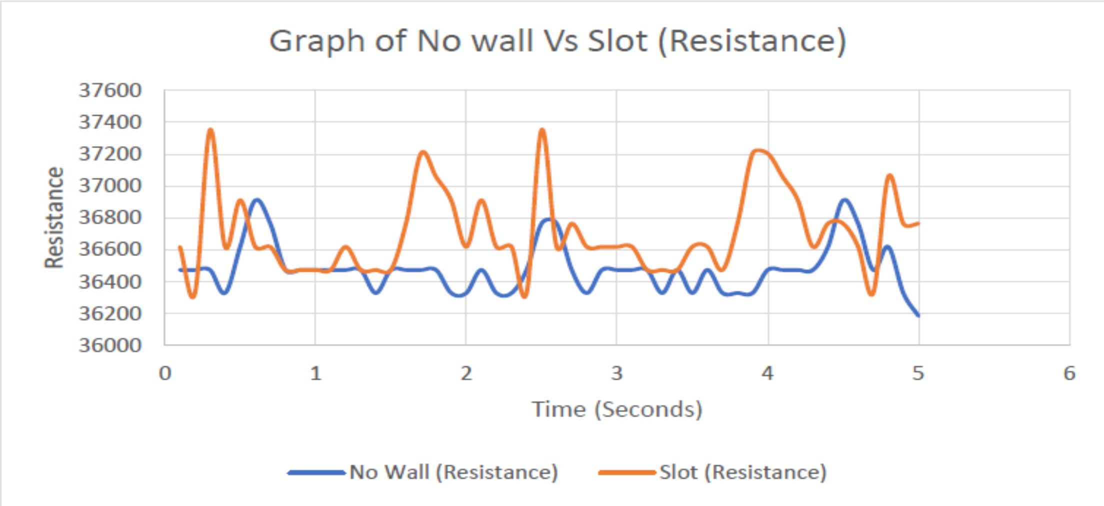

Fig 11 *Resistance for speed 10*

In Figure 12, the resistance behavior of both the no wall and slot designs was graphically represented. The no wall design exhibited relatively stable resistance levels, with minimal fluctuations within the narrow range of 36,000 to 36,500 ohms. In contrast, the slot design demonstrated more erratic resistance values, fluctuating notably between 36,500 and 38,000 ohms. Despite the increase in speed, there was no discernible gap in the sloshing pattern for the slot design, suggesting potential challenges in subduing successive sloshing movements as speed escalated. The comparison between the slot and no wall designs unveiled interesting insights. At lower speeds, the slot design showed superior ability to manage sloshing forces, maintaining more stable resistance levels within a narrower range. However, at higher speeds, both designs faced intensified sloshing forces, revealing distinct characteristics and emphasizing the importance of a comprehensive approach that considers both immediate effectiveness and long-term resilience in handling sloshing resistance across varying speed scenarios.

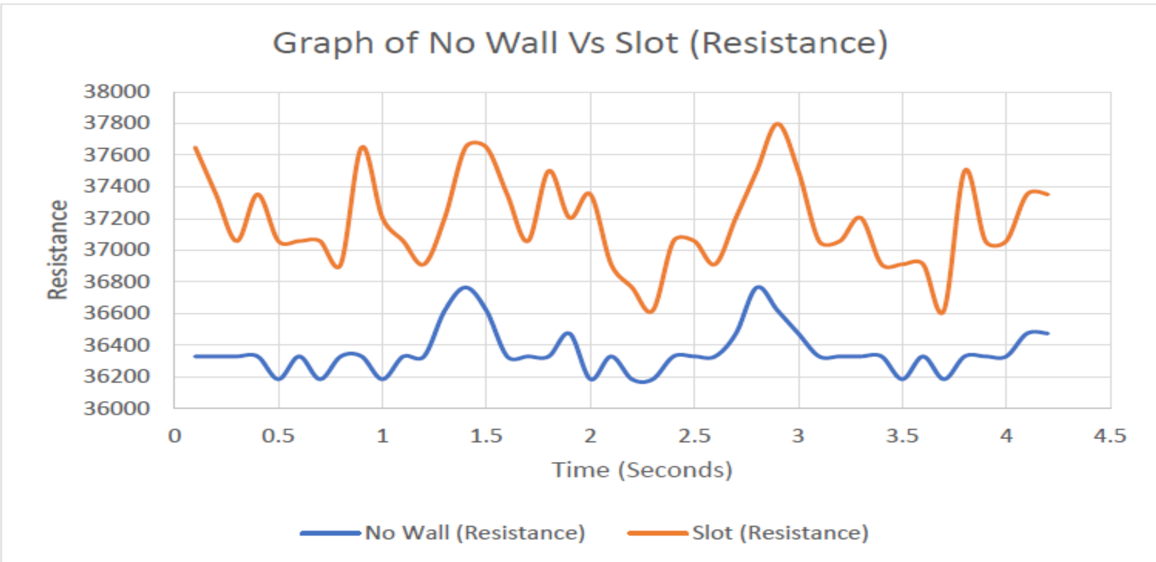

Fig 12 *Resistance for speed 15*

In Izwan's earlier research, the average time for sloshing to subside in a flexitank with one baffle wall at speeds of 5, 10, and 15 was recorded for two compartments. Compartment 1 showed times of 6.84s, 7.48s, and 10.56s, while Compartment 2 had times of 7.89s, 8.22s, and 11.38s [9]. A subsequent study incorporating Cross-X baffles demonstrated significantly shorter average times for sloshing cessation, measuring 4.58s, 5.53s, and 6.66s at the respective speeds. This comparison suggests that the introduction of Cross-X baffles had a notable impact on reducing the time required for sloshing to subside, implying potential improvements in the stability or containment efficiency of the flexitank under investigation.The comparison of the current project's practical results with the theoretical data on the Cross-X baffle wall configuration yielded a noteworthy outcome. The practical findings demonstrated that the Cross-X baffle wall design significantly and rapidly reduced sloshing within the flexitank, closely aligning with the theoretical expectations. This alignment between theory and practice validated the effectiveness of the Cross-X baffle wall, highlighting its consistent and reliable performance in mitigating sloshing within the flexitank.

4. Conclusion

The project aimed to fabricate and assess downscaled flexitanks with various internal baffle wall designs to reduce sloshing. Despite encountering challenges, successful results confirmed the significance of the internal baffle wall in minimizing sloshing impact. Two observations were noticed. Firstly, post-sealing measurements at MYF deviated from the initial drawing, indicating a discrepancy. Secondly, a tear in the downscaled flexitank with Cross-X baffle, likely from transportation damage, surfaced post-sloshing time test. Calibration results and the trendline equation validated the sensor's reliability and linearity, crucial for precise angle detection in robotics, medical devices, and industrial automation. The time test emphasized the Cross-X design's superiority, efficiently reducing sloshing in under seven seconds, especially at higher speeds. In contrast, the slot baffle was effective at lower speeds but showed challenges at 15, urging caution in higher speed applications. Findings shed light on liquid movement in downscaled flexitanks and the efficacy of baffle wall designs in sloshing reduction, guiding full-scale flexitank design. Transportation speed influenced sloshing force, and different baffle designs offered varied capacities to mitigate its impact.

5. Recommendation

Several recommendations can enhance future studies in the field of reducing sloshing in downsized flexitanks. Firstly, it is advised to conduct additional trials and measurements to strengthen the statistical significance of the findings, enabling more precise conclusions about the effectiveness of diverse internal baffle walls. Moreover, for the fabrication process, attention should be given to optimizing the designated location for placing the LLDPE sheet, ensuring a spacious and clean environment, and utilizing calibrated tools for accurate measuring and cutting. Maintaining a clutter-free floor space is essential for safety and efficiency during the cutting process. Additionally, design improvements could enhance the effectiveness of reducing sloshing force. Considerations include implementing curved edges for the Cross-X design to disperse force evenly, changing slot shapes to oval, reducing the size of circular designs, and modifying plate designs to achieve 80% or less coverage for potential optimization.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

The authors confirm contribution to the paper as follows: ***study conception and design; data collection****;* ***analysis and interpretation of results****; and* ***draft manuscript preparation:*** *Muhammad Danial Bin Amir Saifuddin, Yong Tze Mi. All authors reviewed the results and approved the final version of the manuscript. Other authors contributed in establishment of the project, data, guidance and other contributions that lead to this project success.*

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This guide contains examples of common types of APA Style references. Section numbers indicate where to find the examples in the Publication Manual of the American Psychological Association (7th ed.).

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