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Numerical Investigation and Experimental Validation of Pumping Phenomenon Occurred under Liquid Sloshing Using Perforated Baffle

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Keywords：Liquid sloshing, pumping phenomenon, perforated plate, external excitation.

ABSTRACT

Liquid sloshing is phenomenon presented in the tank partially filled with liquid under the external excitations. The aim of this paper is to study a hydrostatic pump created using a perforated baffle. Two perforated baffles are used to divide the tank into three volumes with two connecting chambers in the tank bottom. A numerical simulation is performed to predict the pumping phenomenon occurred under the liquid sloshing in the tank subjected to sinusoidal excitation. The volume of fluid (VOF) method based on the finite volume method is used to simulate two phase flow problem. The distribution of the static pressure and the velocity in whole volume of the tank are presented and analyzed to understand the operating mode of the hydrostatic pump. The pressure and the velocity evolution over time are presented in five different points for each connecting chamber. The results show that the imbalance pressure can create the pumping phenomenon between the volumes of the tank. An experimental setup with sinusoidal movement is developed and the hydrostatic pump in the tank partially filled with liquid is studied experimentally. The comparison between the numerical and the experimental results for the liquid motion shows a good agreement.

INTRODUCTION

Commercial The liquid sloshing occurs when a partially filled tank is subjected to an external excitation. The sloshing phenomena in the moving tank are of interest in a many engineering fields such as road tankers, aerospace vehicles, elevated water towers, liquefied natural gas carriers and petroleum cylindrical tanks. It can present under different external excitations types. Under certain conditions, the sloshing becomes violent and can cause structural damage. Analytically, numerically and experimentally, the sloshing phenomena are studied in a great amount of work. For example, Ibrahim et al. (2001) analyzed the sloshing phenomenon of an incompressible fluid in a rectangular container subjected to an external rotational excitation. Kim (2001) investigated the sloshing in the two and three-dimensional tanks using a finite difference method. Chen et al. (2005) developed finite difference method to study the liquid motion in the partially filled containers. They showed that the sloshing violence increases linearly with the increase of the Reynolds number for a constant frequency value, whereas for a constant Reynolds number the sloshing displacement depends significantly on the external excitation frequency. Mnasri et al. (2010) developed a two-dimensional model based on CFD code simulation. They investigated the interaction between the free surface and moving bodies. Hou et al. (2012) investigated numerically the liquid motion in a rectangular tank subjected to external excitations. They used the volume of fluid (VOF) to predict the free surface evolution and the dynamic mesh technique to impose the external excitations. Their study compares the effect of a single excitation and multiple coupled excitations. Their results showed that the sloshing is more violent in the case of multiple coupled excitations. In addition, their study confirms that the sloshing becomes very violent for the case of the resonant frequency. Zhang et al. (2014) studied the sloshing of liquid using two different methods, moving particle semi-implicit (MPS) method and the level-set method. Their results showed that the two methods give a good agreement comparing with the experimental results. Whereas, the MPS method is better for predict the free surface evolution and the second pressure peak. Meziani et al. (2014) examined

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the effect of the capillary on the liquid sloshing in a container subjected to an external dynamical excitation. Their study revealed that the consideration of the surface tension strongly affects the behavior of liquid sloshing in the container.

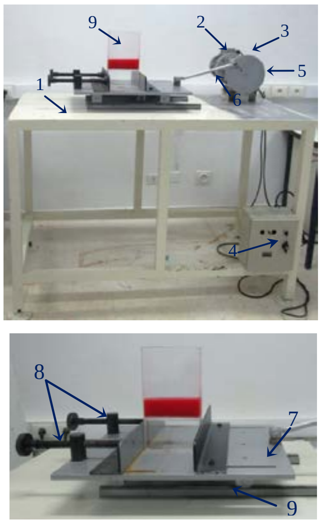
The baffle effect on reducing the liquid sloshing is also interest of many researchers. Many baffle type, number and position are studied in order to increase the efficiency on reducing the liquid motion. The effect of the conventional baffle (vertical and horizontal) is investigated in several works. Liu et al. (2009) studied the effect of the vertical and the horizontal baffle in a partially filled tank. Their study showed that sloshing is more reduced using the vertical baffle than using the horizontal one. Bouabidi et al. (2013) studied the effect of the vertical baffle height on liquid sloshing in an accelerating rectangular tank. They showed that the liquid motion decreases with the increase of the vertical baffle height. Wu et al. (2012) analyzed the use of the vertical baffle. The number and the height effect of the vertical baffle are studied and discussed. The results revealed that the baffle efficiency significantly depends on its characteristics. Jung et al. (2012) studied the vertical baffle effect in 3D rectangular tank with different heights. They concluded that the increase of the baffle height can considerably reduce the liquid motion. Jin et al. (2014) conducted a series of experiments to examine the effect of horizontal perforated plates with different values of frequency and amplitude of an external sinusoidal excitation. Their study showed that the amplitude and the frequency of the external excitation affect considerably the behavior of the sloshing. In addition, they showed that the horizontal perforated plate can significantly reduce the free surface evolution in the tank. In order to more minimize the liquid sloshing, the ring baffle is used as a more efficient solution for reducing the liquid motion. Xue and Lin (2011) investigated the sloshing phenomenon in a partially filled prismatic tank equipped with ring baffle. The study confirms that the ring baffle can considerably reduce the liquid motion. In addition, the ring baffle is more efficient when it is placed near the free surface. Akyıldız et al. (2013) carried out a series of experiments to study the liquid motion in a cylindrical container equipped with ring baffles subjected to an external rolling motion. Different fill depth, rolling frequencies and angle are tested. They concluded that the ring baffle represents an efficient solution to reduce the sloshing in the tank. Panigrahy et al. (2009) studied experimentally the effect of the three different baffles, horizontal, vertical and ring baffle. Their results revealed that the ring baffle is more efficient on reducing the sloshing more than the conventional baffle. All these studies presented below analyzed and discussed the sloshing phenomenon in the partially filled tank and the baffle efficiency on reducing the sloshing violence in the tank.

In this paper, we are interested on the study of the pumping phenomenon created under the liquid sloshing in a partially filled tank. Two perforated baffles are used to divide the tank into three volumes.

The hydrostatic pump created using the perforated baffle is examined using numerical and experimental way. A numerical simulation of the liquid sloshing phenomena in a rectangular tank using computational fluid dynamic (CFD) code is performed. An experimental setup with sinusoidal movement is developed to study the pumping phenomenon.

EXPERIMENTAL SETUP

As shown in figure 1, an experimental setup is developed to study experimentally the liquid sloshing in the partially filled tanks.



1- Table
2- Electrical motor
3- Speed reducer
4- Frequency inverter
5- Pulley
6- Connecting rod
7- Moving table
8- System of clamps
9- Guide rollers system
10- Battery cell

Fig. 1. Test bench.

The tank is attached to a moving table using a system of clamps. This system provides a good setting of different tank configurations. The table movement is assured by a guide rollers system. The transformation of the rotation movement of the motor to the translation of the table is obtained by a connecting rod and a pulley. The liquid sloshing strongly depends on the frequency value of the external excitation. Thus, the test bench is equipped by a frequency inverter power control. In addition, a speed reducer is installed in order to obtain a precision variation of the frequency.

In Figure 2 and 3 shows the 2d representation of the partially filled tank and the perforated baffle respectively. The tank is defined by the length L=0.162 m, the height equal to H=0.2 m and the breadth b=0.03 m. The battery cell is partially filled with water with the height equal to h=0.05m. The tank is prepared with plexiglass to observe the fluid flow.

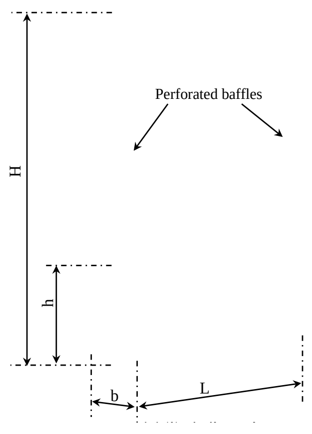


Fig. 2. Tank Geometry

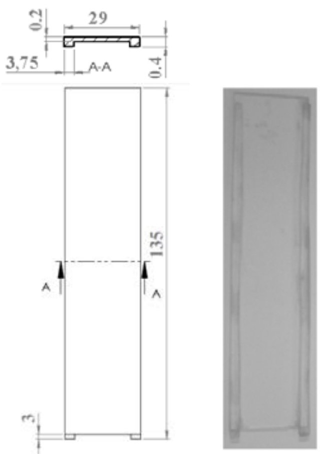


Fig. 3. Perforated baffle

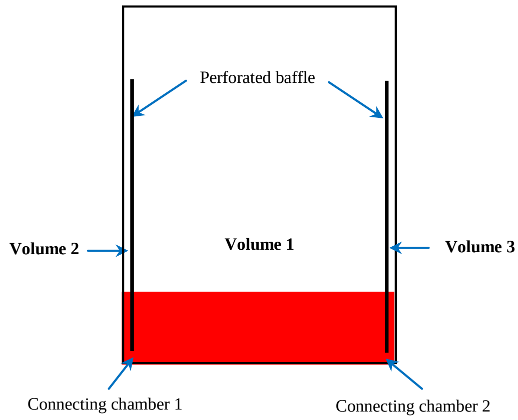


Fig. 4 2d dimensions of tank with perforated baffle

The perforated baffles are used to divide the tank into three volumes: volume 1, volume 2 and volume 3 with connecting between the volumes as shown in figure 4. The connecting chamber between the volumes is located in the bottom. In addition, the pressure equivalence between in the top of the different volumes is necessary for the function of the pump.

MATHEMATICAL MODEL AND NUMERICAL APPROACH

In this section, we present a numerical simulation of the liquid sloshing phenomenon in the partially filled container. The liquid is the water with density equal to 1000 kg/m^3.

The commercial CFD code "Fluent" has been used to present the local flow characteristics in the tank. For the external excitation, a User Defined Function (UDF) is developed on language "C++" and interpreted in "Fluent".

The phenomenon of liquid sloshing in a rigid tank for an incompressible, immiscible fluid is governed by the continuity and the Navier-Stockes equations written as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\mu(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}) + F_i \quad (2)$$

Where u_i represent the velocity components, ρ represents the density, p represents the pressure and μ represents the viscosity.

F_i is the external body force written as follows:

$$F_i = \rho g_j + \rho \frac{\partial^2 X}{\partial t^2} \quad (3)$$

Where X represents the external sinusoidal excitation defined as follow:

$$X = A\sin(\omega t) \quad (4)$$

Where A and ω represents the amplitude and the angular frequency respectively. In this work, the amplitude is equal to $A=0.1$ m and the angular frequency is equal to $\omega=9.6$ rad.

The tank is partially filled with liquid. Thus, the present application is defined as a two-phase flow problem. To track the free surface evolution, the VOF method is used in the numerical simulation. This method is used in several applications for the simulation of the two-phase problem. Each of the two phases is represented by its volume fraction. In each computational cell, the fluid density is a defined as a function of the volume fraction of the two phases given as follow:

$$\rho = \alpha_l \rho_l + \alpha_g \rho_g \quad (5)$$

Where α_l and α_g are the volume fractions of the liquid (water) and the gas (air) phases respectively. ρ_l and ρ_g represents the densities of the liquid and the gas phases respectively.

The Navier-Stokes equations and the standard k-ε turbulence model equations were solved using a finite volume discretization method [16-17]. The turbulence kinetic energy k and its dissipation rate ε are given as follow:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \quad (6)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon \quad (7)$$

G_k and G_b are the generation of turbulence kinetic energy (kg.m^{-1}.s^{-3}) respectively due to the mean velocity gradients and buoyancy. Y_M is the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate.

The turbulent viscosity μ_t (Pa.s) is given by:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \quad (8)$$

The default values of the constants $C_{1\varepsilon}$, $C_{2\varepsilon}$, C_μ, σ_k and σ_ε are given as follows:

$$C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92, C_\mu = 0.09, \sigma_k = 1.0 \text{ and } \sigma_\varepsilon = 1.3 \quad (9)$$

RESULTS AND DISCUSSIONS

Liquid Motion

Figure 4 shows the numerical and the experimental results of the liquid motion in the tank with perforated baffles. From these results, it has been noted that the liquid motion appeared in volume 1 and the liquid level variation appeared in volume 2 and volume 3. Due to the sloshing phenomena, the liquid level on the walls of in volume 1 increases. We note that the perforated baffles constitute the left and the right walls of volume 1 with the two connecting chambers in the bottom.

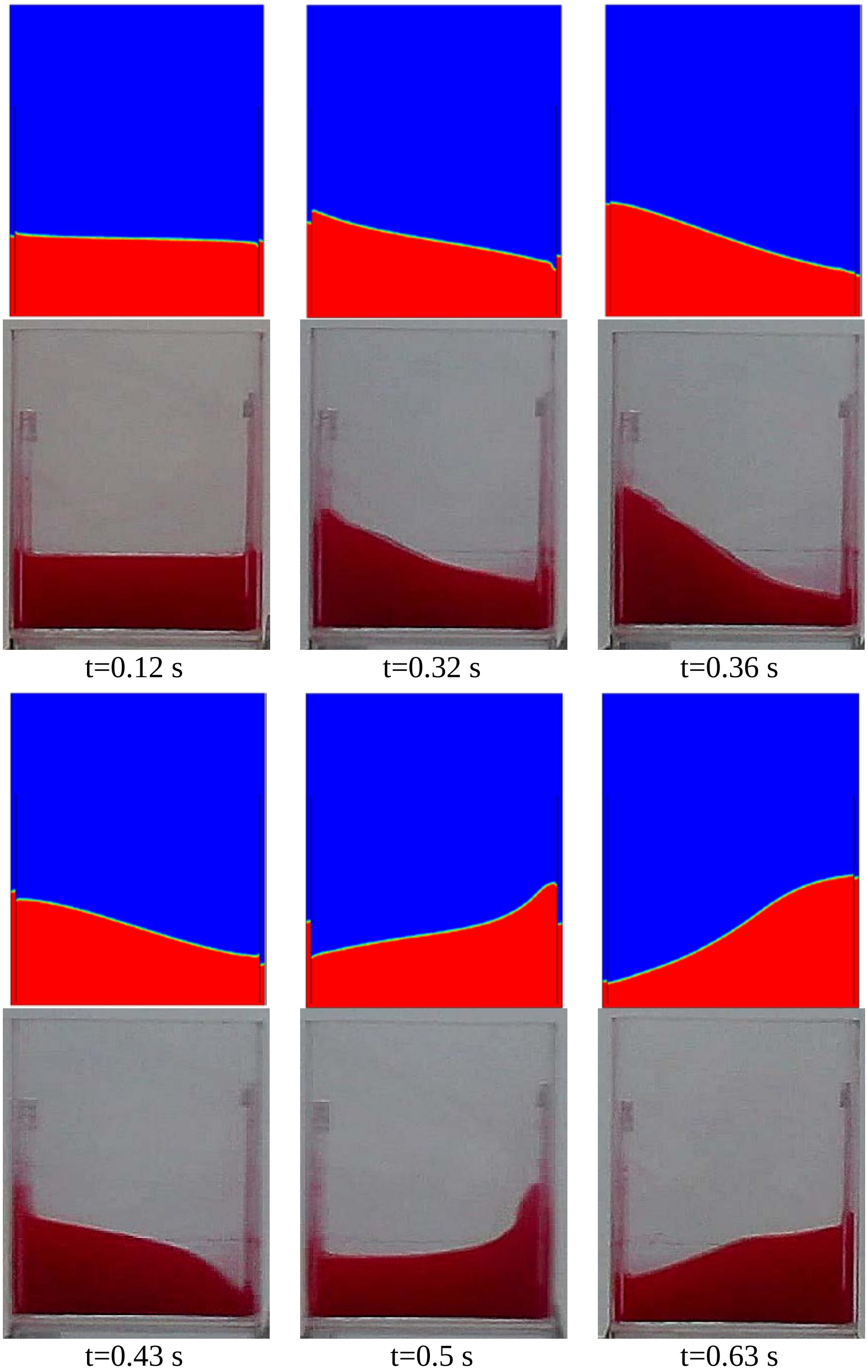
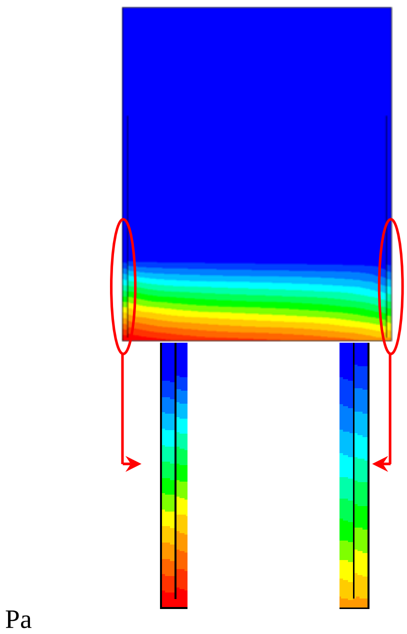


Fig. 4 Liquid motion

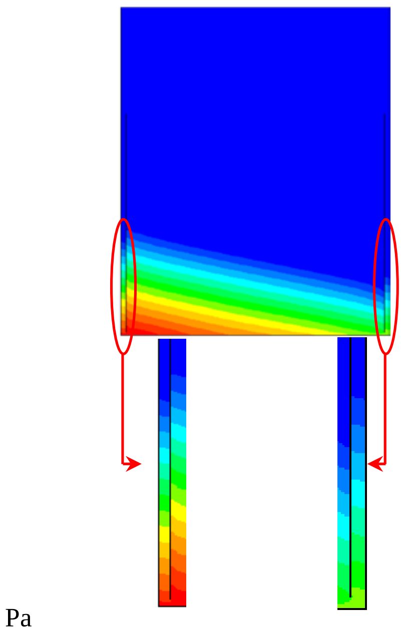
At t=0.12 s, the liquid sloshing appeared in volume 1. Thus, the pumping phenomenon occurs and the liquid level variation is observed in volume 2 and volume 3. At this instant, the liquid moves from the right to the left. The pumping occurs from volume 1 to volume 2 and from volume 3 to volume 1. Therefore, the liquid level increases in volume 2, whereas it decreases in volume 3. The fluid continues the penetration from volume 1 to volume 2 and from volume 3 to volume 1. At t=0.25 s, the fluid level in volume 2 continues to increase, whereas the liquid level in volume 3 continues to decrease. At t=0.32 s, the fluid level in volume 2 reaches the same liquid level on the baffle from the side of volume 1. However, the liquid level in volume 3 decreases and becomes very weak. At t=0.36 s, the liquid motion starts to change the direction and moves from the left to the right. At this instant, the liquid level in volume 2 and volume 3 remains in the same level although the liquid level on the perforated baffles from the side of volume 1 is changed. At t=0.43 s and t=0.63 s, the liquid level in volume 2 decreases, whereas it increases in volume 3.

Static Pressure Distribution

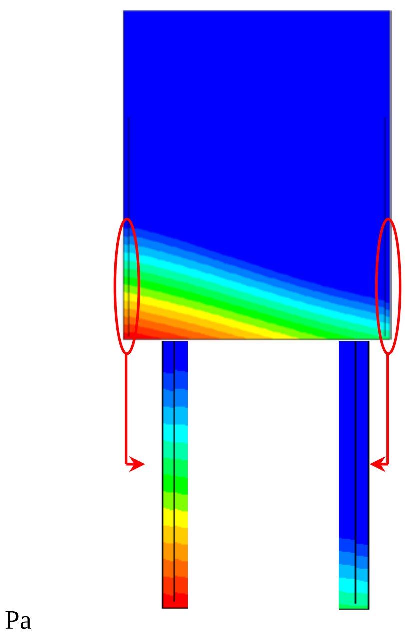
The static pressure distribution in the whole tank volume is presented figure 6.



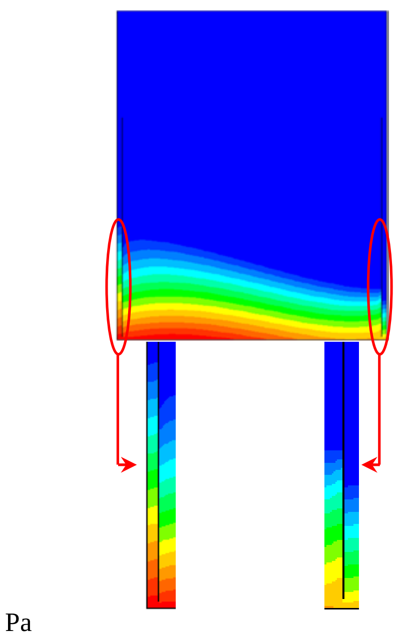
t=0.12 s



t=0.25 s



t=0.32 s



t=0.36 s

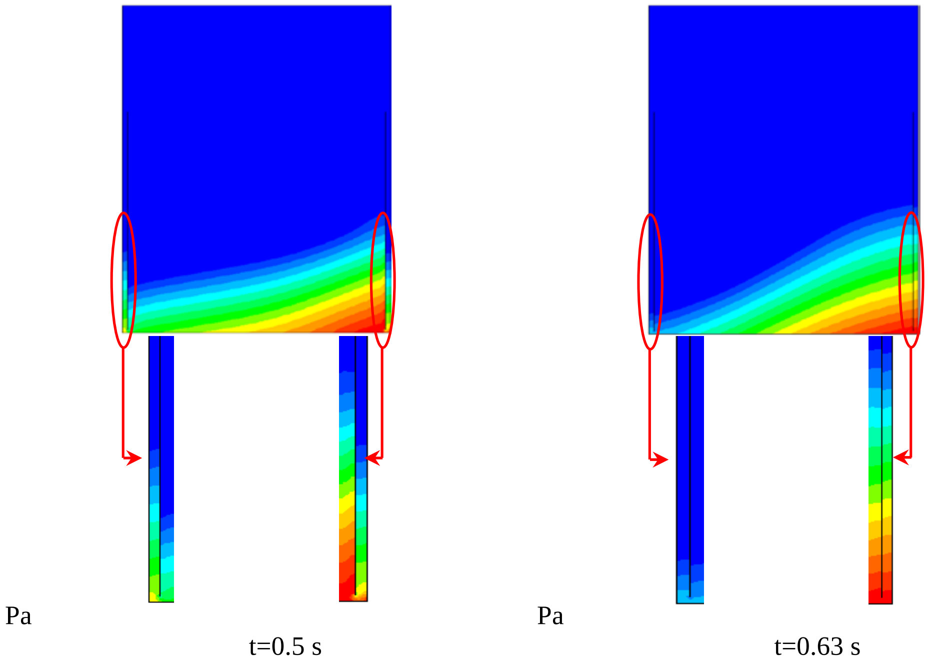


Fig. 6. Static pressure distribution

According to these results, it has been noted that the liquid motion creates a compression and a depression zones in the bottom corners of tank. The location of the compression and the depression zones depends on the liquid motion direction. When the liquid moves from the right to the left, the compression zones appeared in the left corner in the tank bottom. However, the depression zones appeared whole volume of air.

Initially, we have a pressure equilibration between the two sides of the two connecting chambers. Under the external excitation, the static pressure distribution in the whole volume 1 changes under the liquid motion. Thus, an imbalance in the pressure values starts to appear in the level of the connecting chambers. For the first connecting chamber, the pressure increases from the side of volume 1 and becomes more important than the pressure value from the side of volume 2. For the second connecting chamber, the pressure decreases and becomes less important than the pressure value from the side of volume 3. Since the fluid flow occurs from the high pressure zones to the weak pressure zones, the liquid penetrates from volume 1 to volume in the level of the first connecting chamber. However, the liquid penetrates from volume 3 to volume 1 in the level of the second connecting chamber.

At t=0.12 s, the compression zones appear in the bottom left corner of volume 1, whereas the depression zones appears in the right bottom corner. Therefore, the pressure value from the side of volume 1 becomes more important than the pressure value from the side of volume 2 for the first connecting chamber. However, the pressure value from the side of volume 1 becomes less important than one from the side of volume 3 for the second connecting chamber. In these conditions, the liquid flow occurs from volume 1 to volume 2 in the level of the first connecting chamber, whereas the fluid flow occurs from volume 3 to volume 1 in the level of the second connecting chamber. The same conclusion can be drawn for the instants t=0.25 s and t=0.32 s. The liquid continues to penetrate from volume 1 to volume 2 and from volume 3 to volume 1.

At t=0.36 s, the liquid motion starts to move from the left to the right. Thus, the compression zones start to appear in the right bottom corner of volume 1, whereas the depression zones start to appear in the left bottom corner. Therefore, the imbalance pressure starts to change. In the level of the first connecting chamber, the pressure value from the side of volume 1 becomes less important than the pressure value from the side of volume 2, whereas it becomes more important from the side of volume 1 than form the side of volume 3 in the level of the second connecting chamber. Therefore, the fluid flow starts to occur from volume 2 to volume 1 and from volume 1 to volume 3 at this instant. The same conclusion can be drawn for the instants t=0.5 s and t=0.63 s.

As a conclusion, the pumping phenomenon is based on the imbalance pressure created under the liquid sloshing. The pumping occurs from the high pressure zones to the weak pressure zones.

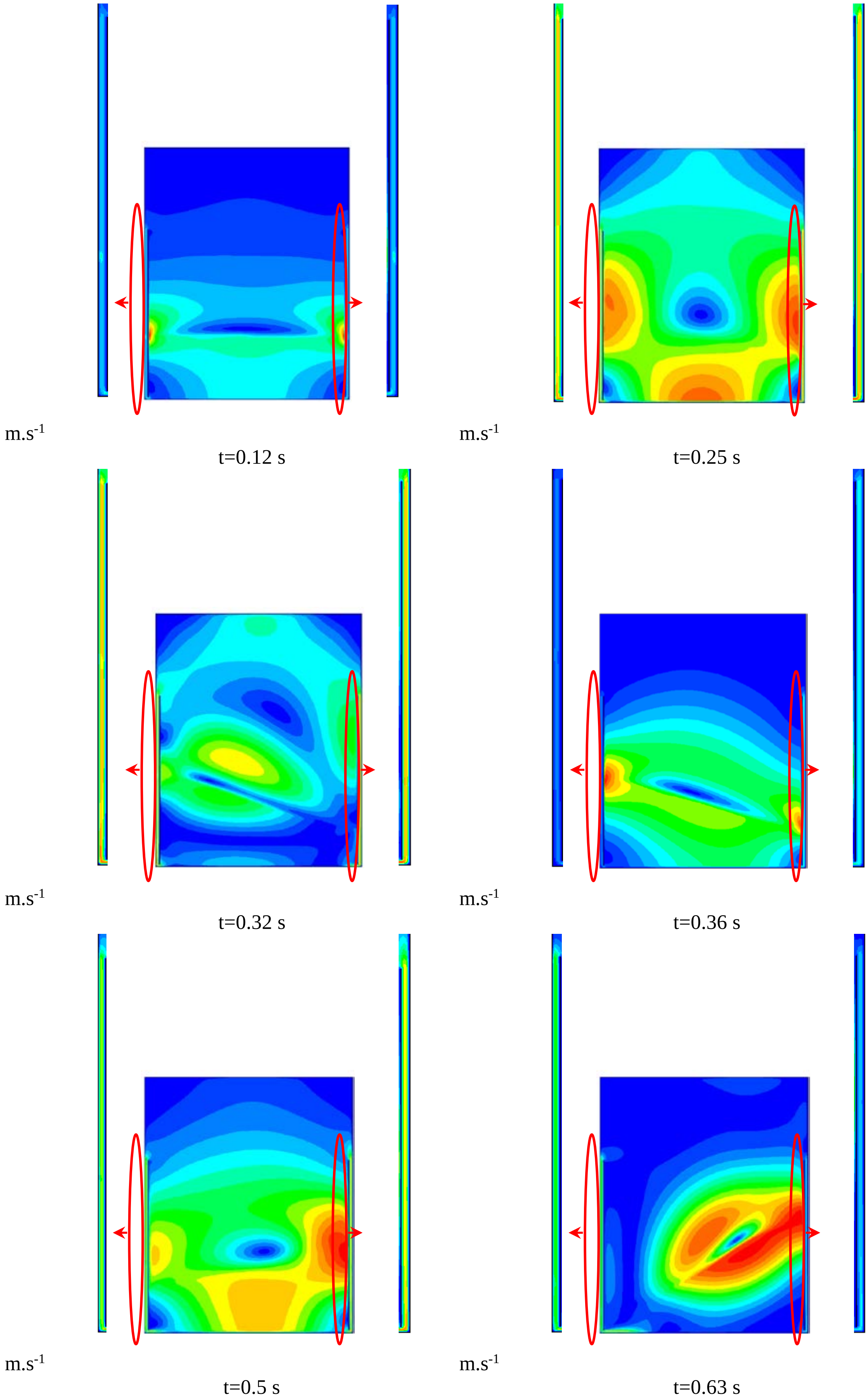


Fig. 7. Velocity distribution

Velocity Field

The distribution of the velocity volume in the whole volume of the tank is presented in figure 7. In volume 1, the velocity field corresponds to the liquid sloshing occurred under the external excitation. However, the velocity field in volume 2 and volume 3 corresponds to the fluid flow occurred under the pumping phenomenon.

Globally, it has been noted that the velocity in volume 2 and volume 3 is uniform. In fact, if a quantity of fluid penetrates in volume 2 or 3, a quantity of air exits from the outlet. However, if a quantity of liquid exits from volume 2 or 3 to volume 1, a quantity of air penetrates in volume 2 or 3. Thus, the fluid flow occurs in the whole volume 2 or 3 with uniform value.

At t=0.12 s, the velocity appears with weak value in volume 2 and volume 3. These values mean that the pumping starts to occur at this instant. At t=0.25 s, the velocity value is observed very important in the two volumes 2 and 3. It means that fluid flow is very important and the pumping under the connecting chambers occurs with significant value. At t=0.32, the same conclusion of the previous instant can be drawn. The pumping continues to occur and the velocity value in volume 2 and volume 3 is observed very important. For these different instants, the liquid motion occurs from the right to the left and the pumping occurs from volume 1 to volume 2 and from volume 3 to volume1.

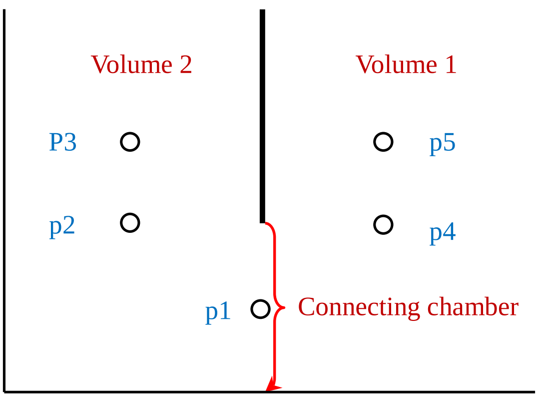
At t=0.36 s, the liquid starts to change the direction and moves from the left to the right. Globally, the lowest velocity value in volume 2 and volume 3 is observed at this instant. In volume 2, the velocity value is observed very weak. This value indicates that the pumping between the volume 1 and volume 2 is very weak. In volume 3, the velocity is observed slightly important than in volume 2. Thus, the pumping between volume 1 and volume 3 is important than between volume 1 and volume 2. From this instant, the pumping will be occurring from volume 2 to volume 1 and from volume 1 to volume 3.

At t=0.5 s, the velocity returns to reach important value in volume 2 and volume 3. These values indicate that the fluid flow under the two connecting chambers occurs with significant value. At t=0.63 s, the liquid the velocity field is observed very important in volume 2 than in volume 3. These values show that the liquid continues to penetrate from volume 2 to volume 1. However, the liquid pumping from volume 1 to volume 3 is very weak.

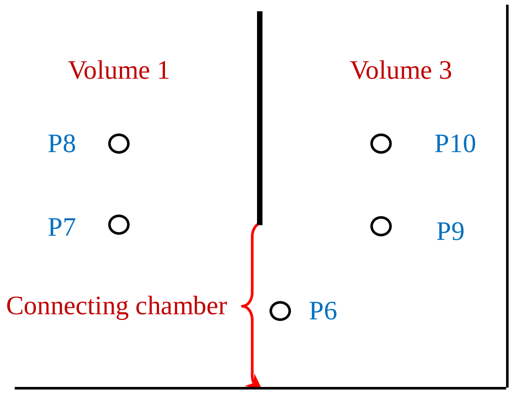
FLUID FLOW CHARACTERISTICS

In order to more understand the hydrostatic pump, we are in tested in this section to track the fluid flow characteristics in level of the two connecting chambers. The results are presented for the two connecting chamber.

For each connecting chamber, the results are presented in five different points: p1, p2, p3, p4, p5 for the first connecting chamber and p6, p7, p8, p9 and p10 for the second connecting chamber. The point locations are chosen in order to track the operating mode of the hydrostatic pump. The first one (p1 for the first connecting chamber, p6 for the second connecting chamber) is located in the center of the connecting chamber between the two volumes in order to track the fluid flow in the connecting chamber. Such explained above, the function of the hydrostatic pump is based on the imbalanced pressure created under liquid sloshing. Therefore, we choose two points in volume 2 (p2, p3) and two other points in volume 1 (p4, p5) close to the connecting chamber for the first connecting chamber. For the second connecting chamber, we choose two points in volume 3 (p9, p10) and two other points in volume 1 (p7, p8) close to the connecting chamber. The coordinates of the different points are given in figure 8.



(a) First connecting chamber between volume 1 and volume 2



(b) Second connecting chamber between volume 1 and volume 3

Fig. 8. Point location

First Connecting Chamber

Figure 9 (a) presents the pressure evolution over time for the first connecting chamber. According to these results, we can classify the pressure behavior on the three different intervals. The first interval corresponds to the first half motion period. In this interval, the liquid moves from the right to the left and the pumping occurs from volume 1 to volume 2. The second interval corresponds to the beginning of the second half motion period. In this interval, the liquid starts to change the motion direction. The third interval corresponds to the rest of the period time. During this interval, the liquid moves from the left to the right and the pumping occurs from volume 2 to volume 1.

During the first interval, the pressure globally increases over time in the different points. During the first half period, the liquid moves from the right to the left and the pressure increases in the left bottom corner of the tank. The pressure value in the points located in volume 1 is upper than the pressure value in the points located in the volume 2. In fact, the point p4 and p5 are characterized by the maximum pressure value. However, the points p2 and p3 are characterized by the minimum pressure value.

At the end of this interval, the pressure value becomes more important in the points of volume 2 than in the points of volume 1. In fact, the pressure value increases in the left corner of volume 1 under the liquid sloshing. First, the pressure in the connecting chamber from the side of volume 1 becomes upper than the pressure from the side of volume 2 and the pumping occurs. Over time, the compression zones pass from volume 1 to volume 2. Therefore, the pressure value increases in the bottom of volume 2. At the end, the compression zones are totally passed in the bottom of volume 2. At this time, the pressure in the second volume bottom is upper than in the first volume bottom.

The second interval is considered a transitional interval. It starts by a significant decrease in the pressure value for the different points. Then, the pressure returns to increase. In the beginning, the liquid starts to change the direction and the pressure in the left corner of the tank starts to decrease. In this return to move in the opposite direction, the liquid characterized by high level exerts significant pressure on the tank bottom. Therefore, an increasing in the pressure value is observed.

The third interval is characterized by the decrease of the pressure value for the different points. During this interval, the liquid sloshing occurs from the left to the right. Thus, the pressure decreases in the left corner and increases in the right corner of the tank. In the other hand, we note that the pressure value in the points located in volume 2 is upper than the pressure value in the points located in the volume 1. The highest value is observed in the points p2 and p3, whereas the lowest value is observed in the points p4 and p5. Since the pumping occurs from the high pressure interval to the weak pressure interval, the liquid penetrates from volume 2 to volume 1 during this interval of time.

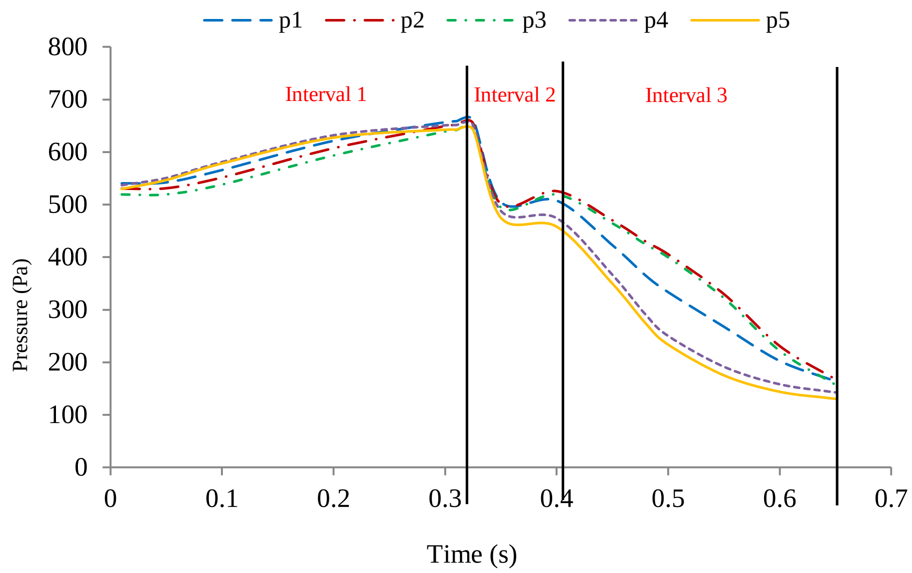
Globally, the point p1 located in the connecting chamber center is characterized by pressure value between the points of volume 1 and the points of volume 2 during the different intervals. During the first interval, the pressure in p1 is upper than one in p4 and p5 and lower than one in p2 and p3. The exception is observed at the end of this interval in which the point p1 is characterized by the highest pressure value. During the third interval, the pressure value in p1 is less than one in p4 and p5 and upper than in p2 and p3.

Figure 9 (b) shows the evolution of the velocity in the different chosen points: p1, p2, p3, p4 and p5. We divide the velocity curve according to the same division of the pressure curve in 3 intervals. Such results show that the velocity has the same behavior over time for the different points. During the first interval, the velocity starts to increase until reaches its maximum value. Then, the velocity returns to decrease. These results indicate that liquid pumping from volume 1 to volume 2 occurs with different rate flow. The maximum pumped quantity corresponds to the maximum velocity, whereas the minimum correspond to the minimum velocity value. In the second interval, the velocity reaches its minimum value. This interval corresponds to the change of the liquid motion direction. Thus, the pumping due to the compression and the depression intervals is minimal at this time. During the third interval, the velocity behavior is the same of the first interval. The velocity increases until reaches its maximum. Then, it returns to decrease. However, the velocity values during the third interval are more important than during the first interval. Thus, the liquid return from volume 2 to volume 1 occurs with very important velocity than the liquid penetration from volume 1 to volume 2.

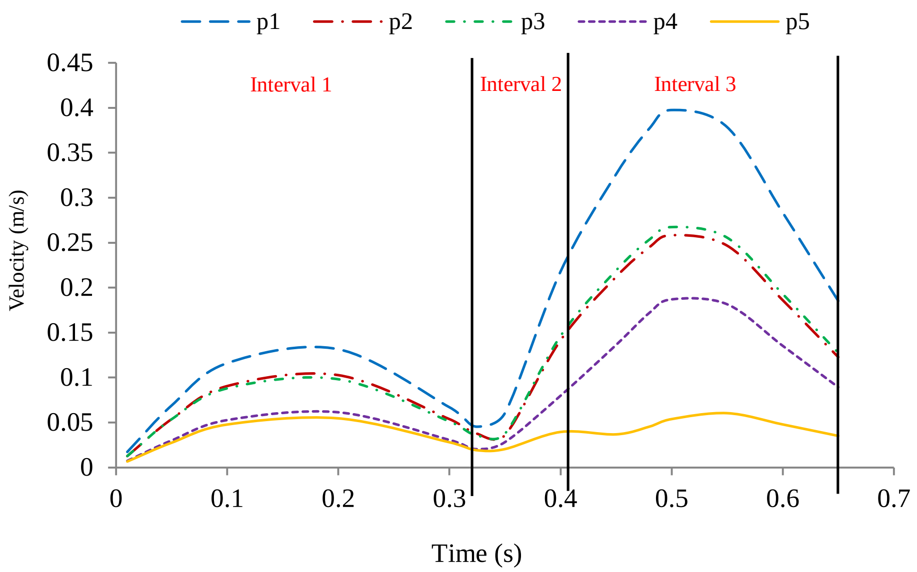
For the different considered intervals, the numerical results show that the velocity evolution depends significantly on the pressure evolution. The maximum velocity of the fluid flow corresponds to the maximum pressure imbalance between the points of volume 1 and volume 2, whereas the minimum is observed for the minimum pressure imbalance. Thus, the pumping occurs with significant velocity when the difference pressure from the two sides of the connecting chamber is important.

In the other hand, we note that the point p1 located in the connecting chamber center is characterized by the maximum velocity value during the different intervals.

For the points located in the second volume p2, p3, we observed that the velocity value is nearly the same for the different points. These results show that the fluid flow due to the pumping phenomena is the same for the two phases of the second volume.



(a) Evolution of the static pressure over time



(b) Evolution of the velocity over time

Fig. 9. Fluid flow characteristics for the first connecting chamber in points p1, p2, p3, p4, and p5

Second Connecting Chamber

Figure 10 presents the fluid flow characteristics for the second connecting chamber. The behavior of the static pressure evolution can be divided into two intervals. The first interval corresponds to the first half period, whereas the second corresponds to the second half period time.

During the first interval, the liquid penetrates from volume 3 to volume 1. Then, it penetrates from volume 1 to volume 3 during the second interval. For the different chosen points, the static pressure starts to decrease during the first half period of the external excitation. These points are located in the right bottom corner of the tank. These zones correspond to the zones of the depression under the liquid sloshing. During the second half period, the static pressure increases over time in the different points. In fact, the liquid changes the direction and moves from the left to the right.

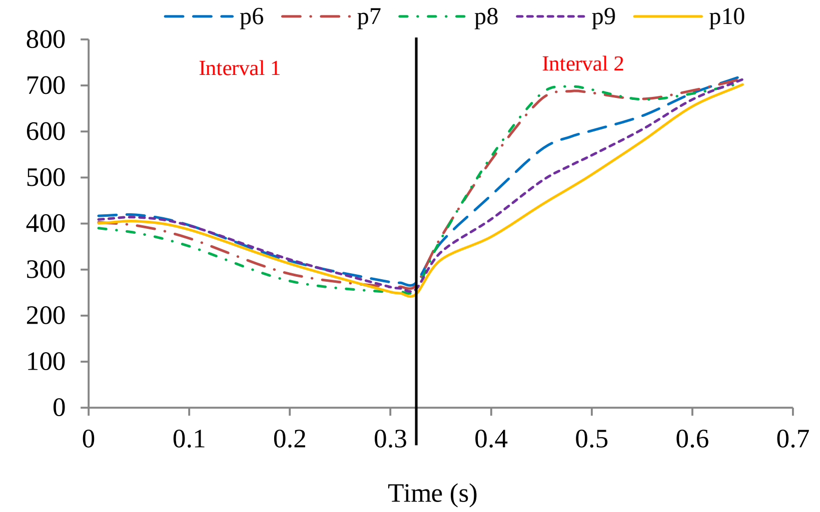
During the first interval, the pressure value in the points located in volume 3 (p9, p10) is very important than the pressure value in the points located in volume 1 (p7, p8). However, the pressure is very important in the points located in volume 1 (p7, p8) than in the points located in volume 3 (p9, p10) during the second interval. These results are expected since the pumping occurs from the high pressure zones to the weak pressure zones. In fact, the pumping occurs from volume 3 (high pressure zones) to volume 1 (weak pressure zones) during the first interval, whereas the pumping occurs from volume 1 (high pressure zones) to volume 3 (weak pressure zones) during the second interval.

The evolution of the velocity in the different points chosen for the second connecting chamber is shown in figure 10 (b). The velocity behavior is also divided in 2 intervals according to the same division of the pressure curve.

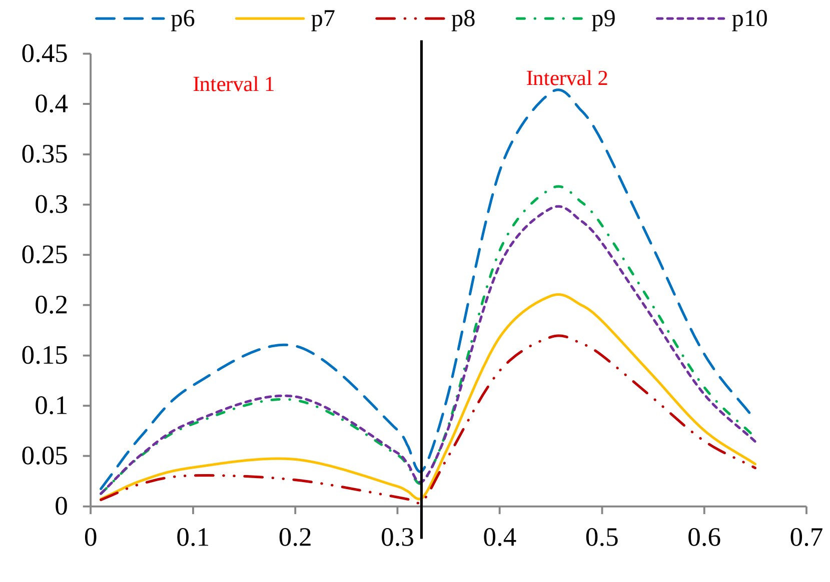
Such results indicate that the velocity behavior is nearly the same for the different chosen points. The velocity starts to increase until reaches its maximum value.

In the other hand, it has been noted that the velocity value for the case of the pumping from volume 1 to volume 3 is very significant than for the case of the pumping from volume 3 to volume 1. These results are expected since the maximum difference pressure value between the points located in volume 3 and volume 1 is observed for the second half period of the external excitation.

For the points located in volume 3 (p9, p10), the velocity value is nearly the same. The maximum value of velocity is observed in the point (p6) located in the center of the connecting chamber.



(a) Evolution of the static pressure over time



(b) Evolution of the velocity over time

Fig. 10. Fluid flow characteristics for the second connecting chamber in points p6, p7, p8, p9 and p10

CONCLUSION

In the present paper, the pumping phenomenon occurred under liquid sloshing is investigated. The operating mode of the hydrostatic pump created using the perforated baffle is studied and analyzed using numerical and experimental way.

A numerical simulation of the liquid motion in the tank equipped by a perorated plate is performed. The volume of fluid (VOF) method based on the finite volume method was used to simulate incompressible viscous two phase flow in a tank partially filled with liquid. All numerical results are conducted using the commercial CFD code "FLUENT". The liquid motion in the tank is presented and the pumping between the chambers of the tank is predicted over time. The results show that the use of the perforated plate can create the hydrostatic pump in the tank.

The static pressure distribution over time in the whole volume of the tank are presented and discussed. These results confirm that operating mode of the pump is based on the imbalance pressure created under the liquid motion. The pumping occurs from the high pressure zones to the weak pressure zones. The velocity distribution is also presented over time. The velocity fields appear under the liquid motion and under the pumping phenomenon.

In addition, the pressure evolution over time in five different points is investigated for each connecting chamber. The results confirm that hydrostatic pump is based on the imbalance pressure. The velocity evolution in the same chosen points is also presented and discussed. The velocity behavior is the same for the different points. The velocity value depends significantly on the pressure imbalance presented in the connecting chamber. The maximum value corresponds to the maximum pressure imbalance between the points of the second volume and the first volume. However, the velocity is very weak when the pressure value is similar in the points of volume 1 and volume 2. The velocity is observed very important for the pumping occurred from volume 2 to volume 1 than for the pumping occurred from volume 1 to volume 2.

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