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Numerical Unveiling the Dynamics of Glycerin-Water Mixing: Insights into Compatibility and Behavior

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ABSTRACT

Investigating glycerin-water mixing dynamics in a vertical container with variable velocities is crucial for optimising industrial processes and understanding fluid behavior in diverse applications. Despite having several studies in the open literature that discussed the electrical and physical properties of glycerol/water mixtures, this study specifically investigates the dynamic interactions of glycerin-water mixing in a vertical container with variable water and glycerin intake velocities using ANSYS fluent v.16.1, to evaluate the associated spatial distribution inside the container. When glycerin and water are mixed, the combination form is a homogenous solution. The optimal glycerin-to-water ratio is conditional on the application at hand. At a mixing speed of 0.1 m/s, glycerin and water exhibit a phenomenon in which the glycerin collects on one side of the container while the water stays put on the other side. The density difference between the two substances accounts for the observed separation. The velocity curves slow down as the fluids disperse inside the container, but the increased density of the glycerin side causes it to slow down even more. When the glycerin's velocity is increased to 0.2 m/s, the behavior of mixture changes, resulting in the displacement of water and the appearance of a brush-like shape. It is recommended to conduct a specific research to investigate essential factors like temperature, additives to improve the practical applications of glycerin-water mixing.

Keywords:
Fluid dynamics; glycerin-water mixing; two phase flow; computational fluid dynamics (CFD)

1. Introduction

As the population of the world and industrial activities have widely grown accompanied with dwindling supplies of fossil fuels, alternative energy demands have increasingly been needed [1,2]. Carbon dioxide is a greenhouse gas produced in huge quantities through the combustion of fossil fuels, therefore it is a prime contributor to both climate change and global warming [3]. Although 33

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Gt of CO2 emitted globally in 2019, this amount has slightly increased due to sharp increase in CO2 emissions. Also, about half of the emitted CO2 is taken up by land plants, trees, and certain sections of the ocean [4]. However, CO2 emission is still a main challenge threating our planet. To overcome this problem, substantial efforts have been paid on developing feasible alternatives and greener production methods to replace fossil fuels [5]. There is a connection between glycerol emissions and CO2 emissions in this regard. Glycerol conversion can result in CO2 emissions when it is utilized as a feedstock for the production of biodiesel. Glycerol can also be used sustainably, such as in the manufacturing of biofuels, which lowers the overall carbon footprint of its use. Glycerol use and management properly can have a positive effect on CO2 emissions. For seven decades, glycerol has been a principal of research into two-phase flows. Some of the preliminary data is narrow in scope and has major discrepancies. Here we offer a big dataset of physical property data collected in recent research [6]. The majority of the tests were conducted across a large temperature, salinity, and concentration gradient. Density, surface tension, interfacial tension, contact angle, and viscosity are only a few examples. Trihydric alcohol glycerol has a viscosity of 15.0 Poise at 20 ºC; it mixes well with water and ethanol but not at all with hydrocarbons. When electrolytes are added to aqueous solutions, the viscosity rises while temperature and water content both drop. Glycerol has a surface tension of 63.4 dyn/cm at 20 oC, which is not too much below that of water (72.5 dyn/cm) but significantly greater than that of other organic liquids [7]. Strong intramolecular attractive interactions between the functional groups of the molecule and strong attractions between surrounding glycerol molecules are likely responsible for the very high boiling point of glycerol, 290 oC at atmospheric pressure [8].

The behavior of water forms an open challenge up to date [9,10], and the function of water and its peculiar features in the chemistry of life have fascinated generations of scientists. The genesis and preservation of life depend on water's complicated and vital interactions with proteins at the nanoscale level. Protein biological activities and interactions with other proteins and substrates are largely determined by their hydration shell structures [11,12].

The large network of hydrogen bonds between H_2O molecules in three dimensions is crucial to the way water behaves. While the structure of water depends on temperature, pressure, and chemical composition, molecular motions in water necessitate the constant breaking and reorganization of individual hydrogen bonds on a picosecond time scale, resulting in a dynamic equilibrium among assemblages of different oligomers and polymer species (clusters).

The complex electric permittivity of glycerol/water mixtures has been measured as a function of frequency between 1 MHz and 40 GHz, as published by Behrends *et al.,* [13] at six temperatures between 10 and 50 °C when the mole fractions of glycerol ranged from 0 to 0.9. The static permittivity-based effective dipole orientation correlation factor shows unremarkable behavior over a wide range of combination compositions. At high water content, the relaxation time distribution parameter suggests a fluid with a dynamically heterogeneous structure. Possibly both a glycerol-rich and a water-rich microphase exist.

Broadband dielectric spectroscopy (BDS) and differential scanning calorimetry (DSC) were used by Hayashi *et al.,* [14] to investigate the relaxation dynamics of glycerol-water mixtures. The DSC tests were achieved at temperature between 138 and 313 K, while the BDS investigations included a frequency range of 1 Hz to 250 MHz, was done at the temperatures ranging from 173 to 323 K. Dielectric loss "master plots" developed experimentally for glycerol-rich mixtures indicate a temperature dependency shared by the primary dielectric relaxation process, the high frequency "excess wing," and the dc-conductivity.

Glass-like water-glycerol mixtures were simulated using out-of-equilibrium molecular dynamics (MD) by Jahn *et al.,* [15]. They looked at how compression/decompression at a fixed temperature may cause a mixture to go from a low-density (LDA) to a high-density (HDA) amorphous state. Scientists discussed their findings on the molecular level shifts that underlie the LDA-HDA transition. The LDA-to-HDA transition is characterised by the movement of water molecules from the second to the first hydration shell and the filling of the first interstitial shell, as seen in pure glassy water. Interestingly, the same thing happens around the OH groups in glycerol. Therefore, a rise in the density during the LDA-HDA transition is facilitated in part by the glycerol OH groups.

Using terahertz-time-domain spectroscopy (THz-TDS) in the frequency range of 0.3-3.0 THz at temperatures ranging from 80 to 305 K, Kölbel *et al.,* [16] studied the model glass former glycerol and its aqueous mixes. It was shown theoretically that the decreased Raman intensity and the decreased density of states are connected to the infrared absorption coefficient determined with THz-TDS, and this was confirmed by agreement with experimental data. At a water concentration of about 5 wt.%, small water clusters formed, and the number of water-water hydrogen bonds increased, both of which contribute to a reduction in the barriers on the potential energy surface, resulting in a change in the structural dynamics of the sample.

Based on the above discussed studies, it is fair to admit the absence of a specific study to analyse the dynamic interactions of the homogeneous solution of water and glycerin in a closed container. Specifically, the influence of variable water and glycerin intake velocities on the dynamics and flow patterns and subsequent spatial distribution within the container is the main focus of the current study. To conduct this research, computational modelling is being used to carry out a thorough computational fluid dynamics simulation. The developed model helps to forecast velocity profiles, volume percent, and other relevant features under different conditions.

2. Problem Description and Mathematical Formulation

This study dives into the dynamics of a water-glycerin combination in a closed container, when the water and glycerin is introduced at different velocities. Figure 1 depicts a container with 100 mm (height) and 50 mm (width) dimensions. The glycerin and water supply tubes of 5 mm in diameter, are located at the base of the container on the right and left sides, respectively. The downward pull of gravity is felt by the system. Three sites are chosen to measure the average velocity of the mixture: a one is at 32 mm below the top surface, another one is at 32 mm lower down, while the third is selected at 32 mm above the bottom surface. Inlet velocities were changed according to five cases used in this research: Case 1 (water and glycerin, both at 0.1 m/s), Case 2 (water and glycerin, both at 0.2 m/s), Case 3 (water and glycerin, both at 0.1 m/s), Case 4 (water and glycerin, both at 0.3 m/s), and Case 5. The container starts out full with air, and when the two liquids are added, they are combined. Table 1 lists some of glycerin, water, and air's qualities for the next examination.

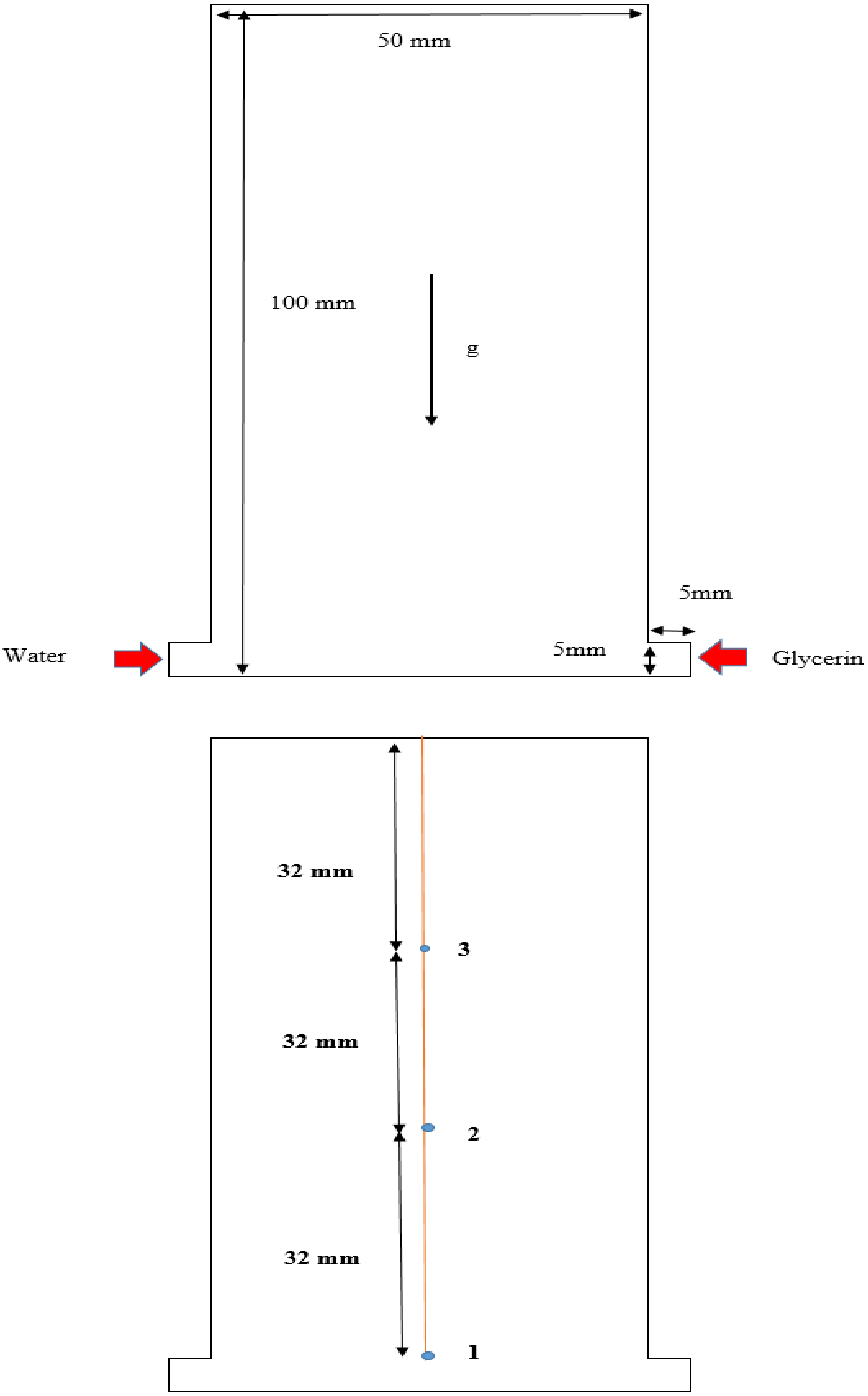

Fig. 1. Dimensions and coordinates of the case study

Table 1
The properties of glycerin, water, and air

Properties	Glycerin	Water	Air
Density kg/m^3	1259.9	998.2	1.225
Specific heat J/kg K	2427	4182	1006.43
Thermal conductivity W/m K	0.286	0.6	0.0242
Viscosity kg/m s	0.799	0.001003	1.7894e-05

3. Simulation Procedure and the Numerical Test

There is a series of checkpoints that must be met and approved before the present numerical simulation study can be carried out. When it is tried to condense these concepts, give special attention to these two aspects:

1. One way to reduce the amount of inaccuracy in the numerical findings is to take extra care while making the grids and examining the density of the grid components.
2. Checking whether the utilised numerical model yields reliable results.

The grids that make up the examined region are generated and constructed using a programme called Gambit. After completion, the grid structure may be seen in its final form in Figure 2. In each example, the density of the components was deduced from the value of the ratio. The summarised findings of this study are demonstrated in Table 2. The component count in Case 2 is sufficient to guarantee satisfaction, and this result is open to examination. This procedure is known as the grid independence test [17-20].

Quantitative identifier: in order to answer this question, ANSYS-Fluent was relied using the finite volume technique. The convective terms of the matrix system are solved by using the high-resolution technique. To establish a correlation between speed and pressure, the SIMPLEC technique was applied. When the error in the calculation is less than or equal to 10^{-6} for energy equations and 10^{-8} for momentum equations, the results may be relied upon [21-24].

Table 2
Grid independency test for the inlet velocity of 1 m/s

Component density	Case	Total cell number	Velocity (m/s)	Difference %
0.1	1	32064	0.87	3.44
	2	90440	0.88	0.11
	3	112600	0.89	0.44
	4	210400	0.894	--
0.2	1	31010	0.76	7.89
	2	75130	0.78	1.28
	3	163550	0.79	0.63
	4	160000	0.795	--
0.3	1	22065	0.91	2.19
	2	60441	0.93	1.07
	3	130204	0.94	0.53
	4	110000	0.945	--

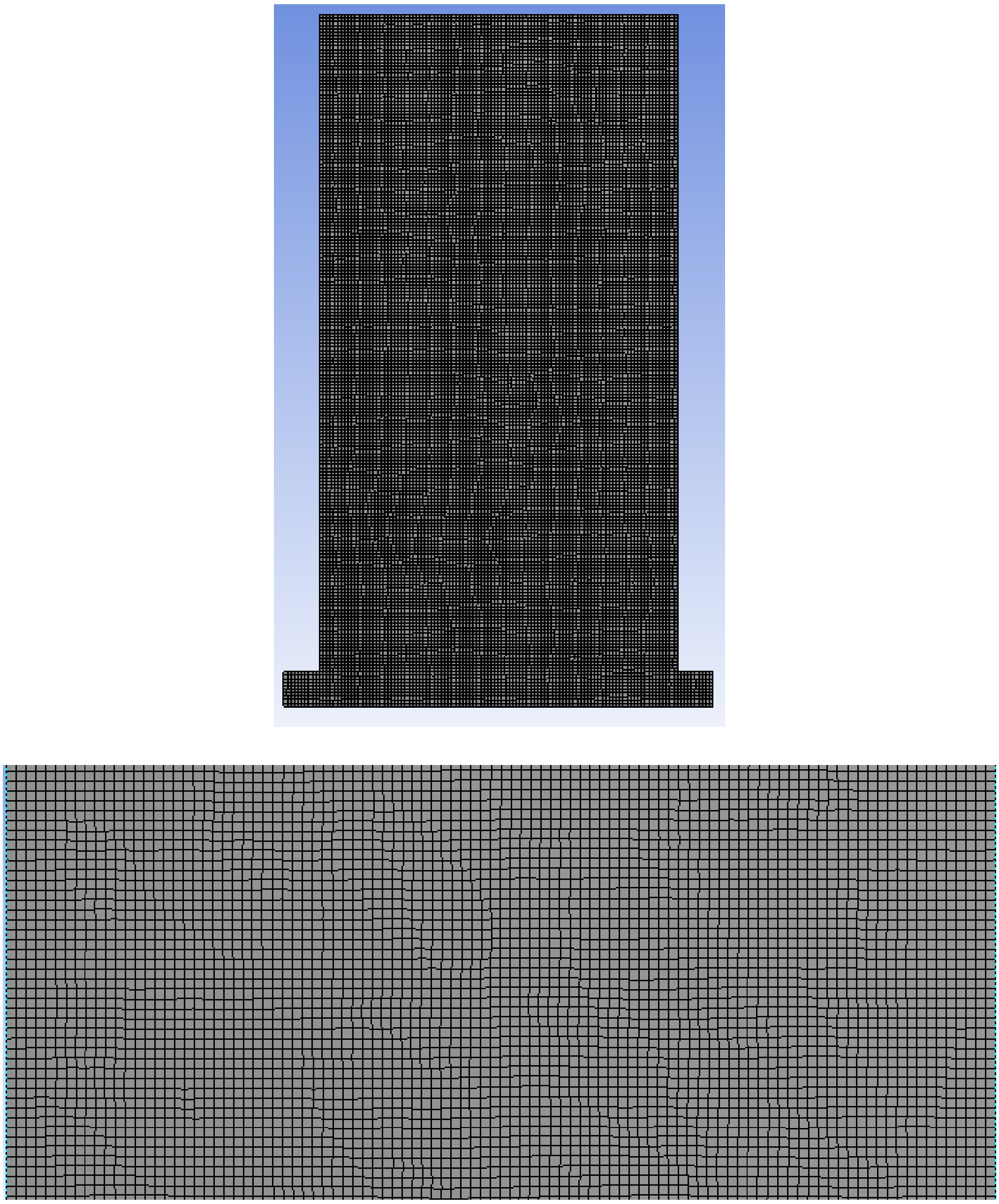

Fig. 2. Mesh generation for the container

4. Results and Discussion

The procedure of blending glycerin with water involves the integration of these two components to produce a homogeneous solution. Glycerin, known as glycerol in scientific terms, is a transparent and thick liquid that is widely utilised in various industries and products. Due to its hygroscopic nature, glycerin demonstrates a tendency to readily dissolve when introduced to water. It is important to recognise that the optimal proportion of glycerin to water is dependent on the specific application or objective being considered. Therefore, it is crucial to follow prescribed guidelines or seek guidance from relevant sources in order to determine accurate proportions that are tailored to specific circumstances. The several cases of the mixing scenarios ($V_{water}/V_{Glycerin}$) are presented below.

4.1 $V_{water}/V_{Glycerin} = 1$

In this section, it is undertaking thorough the examination of the mixing behaviour demonstrated by the combination of glycerin and water when introduced into a container from the lower section with a velocity of 0.1 m/s. The objective of this investigation is to acquire a comprehensive comprehension of the dynamic interactions among these fluids and the subsequent spatial distribution within the container. Figure 3 depicts the temporal evolution of the liquid fraction of glycerin over various time intervals, spanning up to 480 seconds. As previously mentioned, the glycerin is introduced into the container from the right-hand side, where it primarily accumulates without undergoing substantial mixing with water. In contrast, the concentration of glycerin on the left-hand side is approximately 50%. The differential concentration distribution is a result of the contrasting densities between glycerin and water. Due to its higher density, glycerin has a tendency to separate and form discernible strata within the aqueous layers. Therefore, following a time period of 480 seconds, it is apparent that the container contains both glycerin and water, yet they have not fully mixed. The presence of a vertical line within the container serves as a distinct boundary, effectively separating the areas where glycerin and water are predominantly located. The ongoing introduction of fluids into the container leads to their separation, hindering complete homogenization and preserving their distinct distributions.

The velocity contours within the container during the filling process are depicted in Figure 4. At the inlet of both fluids, the velocity attains its maximum magnitude of 0.1 m/s. Consequently, as the fluids disperse throughout the expanded volume of the container, the velocity gradually diminishes. The decrease in velocity can be ascribed to the enlargement of the fluid's available area for movement, resulting in a deceleration of the flow rate. It is worth mentioning that the velocity at the midpoint of the bottom surface exhibits the lowest value as a result of the collision between glycerin and water occurring at that specific location. The presence of their interaction impedes the smooth motion, leading to a localised reduction in speed. Furthermore, the velocity on the side of the container containing glycerin exhibits a lower magnitude in comparison to the side containing water. The observed discrepancy can be attributed to the increased density of glycerin, which hinders its mobility and results in a comparatively reduced flow rate in comparison to water.

Generally, the thorough examination of the intermingling dynamics between glycerin and water within a vessel unveils discernible patterns. The phenomenon of glycerin accumulation primarily on one side, resulting in the formation of distinct layers, occurs due to inadequate mixing with water. The arrangement of glycerin and water in space is affected by the variable densities of these fluids. The velocity contours observed within the container are indicative of the complex interaction between fluid dynamics and the constraints imposed by the higher density of glycerin. This interplay gives rise to diverse flow patterns. This comprehensive analysis contributes to the advancement of our comprehension regarding the complex blending dynamics observed during the introduction of glycerin and water into a container at a velocity of 0.1 m/s.

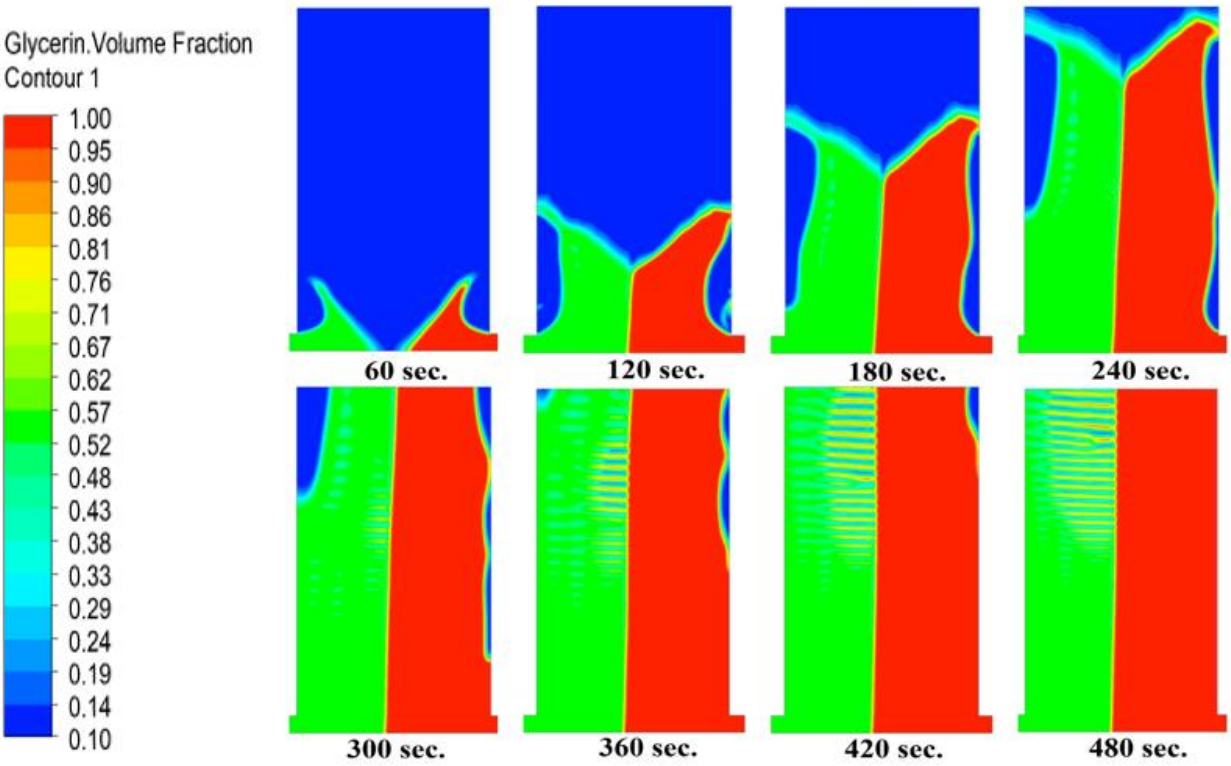

Fig. 3. Glycerin volume fraction during the mixing process at various time steps

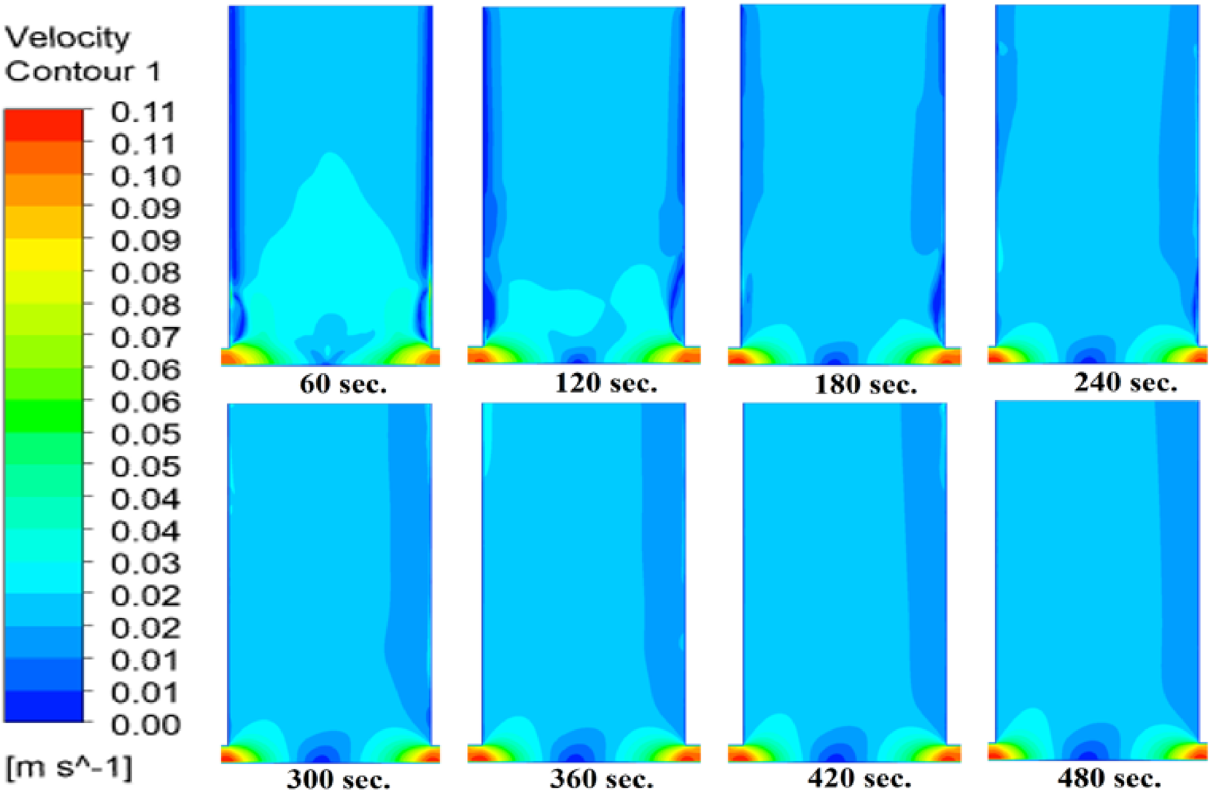

Fig. 4. Velocity of the mixture during the mixing process at various time steps

Figure 5 illustrates the liquid fraction of water, specifically focusing on its progression within the left side of the container. The significant mass of glycerin, coupled with its concurrent ascent within the receptacle alongside the water, impedes the flow of water towards the rightward region.

Consequently, the water predominantly remains confined to the left side of the container. The observed phenomenon can be ascribed to the variances in buoyancy and density between glycerin and water. Due to its higher density relative to water, glycerin exhibits a propensity to descend and amass at the lowermost region of the receptacle. When glycerin ascends, it displaces the water, resulting in the water being propelled towards the left side of the container and impeding its motion towards the right. The observed behavior exemplifies the influence of density-driven stratification on the spatial arrangement of fluids within the container. The increased weight of glycerin serves as a hindrance, impeding the uniform dispersion of water throughout the container. As a result, the water remains localized to one side, whereas the glycerin occupies the opposing side. The present analysis offers a rationale for the observed phenomenon and emphasises the complex interaction among buoyancy, density, and fluid dynamics. The significant mass of glycerin and its increasing velocity contribute to the spatial segregation of water, highlighting the intricate dynamics exhibited by these fluids when mixed within a vessel.

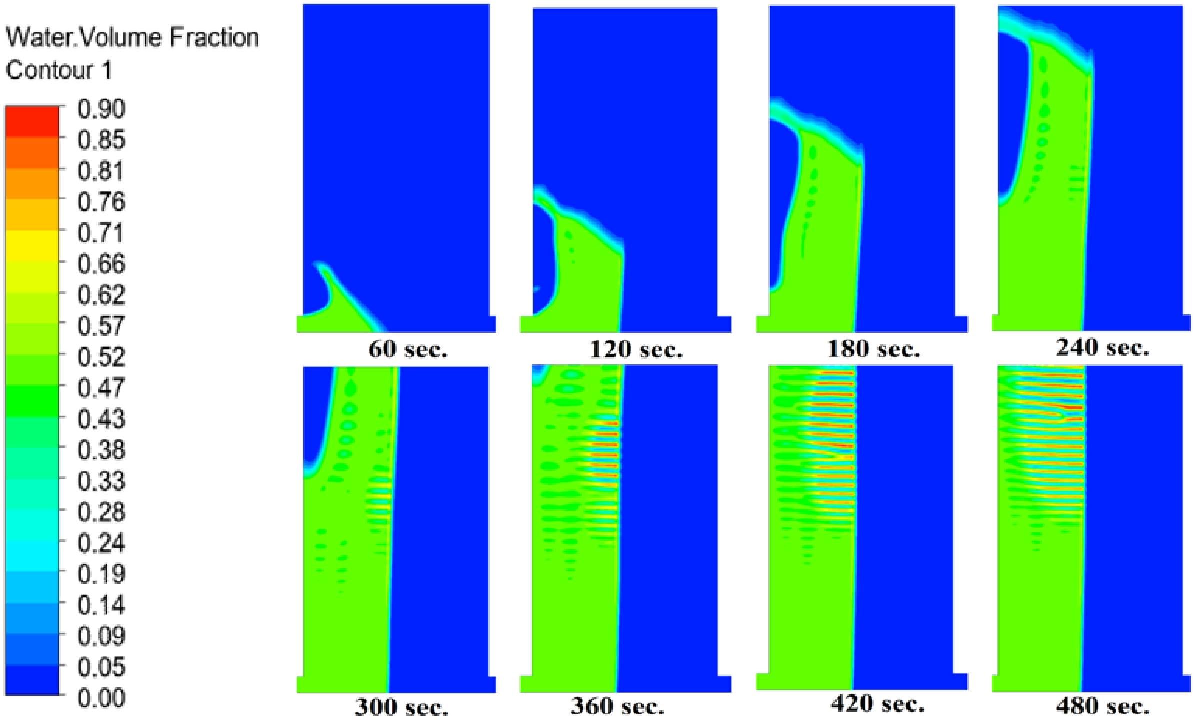

Fig. 5. Water volume fraction during the mixing process at various time steps

Figure 6 presents a comprehensive depiction of the velocity of the mixture at distinct elevations, namely points 1, 2, and 3, over different time intervals. The objective of this analysis is to provide a comprehensive understanding of the fluid flow dynamics within the container and examine how alterations in fluid levels affect the distribution of velocity. At the 50-second mark, the velocity attains its maximum value due to the presence of air movement inside the container. The initial high velocity of a fluid system is subject to various influences, including initial conditions and external forces. Nonetheless, as the receptacle becomes progressively inundated with larger quantities of water and glycerin, the mean velocity gradually diminishes. The inclusion of these denser fluids within the container generates a hindrance to the overall fluid motion, resulting in a gradual decrease in average velocity over a period of time. At the 100-second mark, the fluid level has reached point 1. At this juncture, the average velocity undergoes a significant decline due to the elevated viscosity of the water and glycerin blend in comparison to air. The increased viscosity of the fluid imposes limitations on its flow, leading to a notable decrease in velocity. In contrast, the reduction in velocity occurs at a relatively smaller rate at points 2 and 3, where air is still present. The persistent existence of air at these locations facilitates relatively unhindered fluid motion and alleviates the influence of viscosity on the decrease in velocity. The present analysis provides a rationale for the observed discrepancies in velocity distribution at various elevations within the container. The dynamic relationship between fluid characteristics, such as viscosity and density, and the inclusion of air has a significant impact on the temporal variations in velocity. The observed decline in average velocity can be ascribed to the progressive augmentation of water and glycerin volume within the container, resulting in heightened resistance to fluid motion. Furthermore, the significant decrease in velocity observed at point 1 highlights the influence of high viscosity in hindering the flow of fluid. In contrast, the presence of air at points 2 and 3 contributes to a relatively less pronounced reduction in velocity. In general, Figure 6 offers significant insights into the velocity dynamics of the mixture contained, thereby illuminating the complex interplay between fluid properties, fluid levels, and velocity distribution.

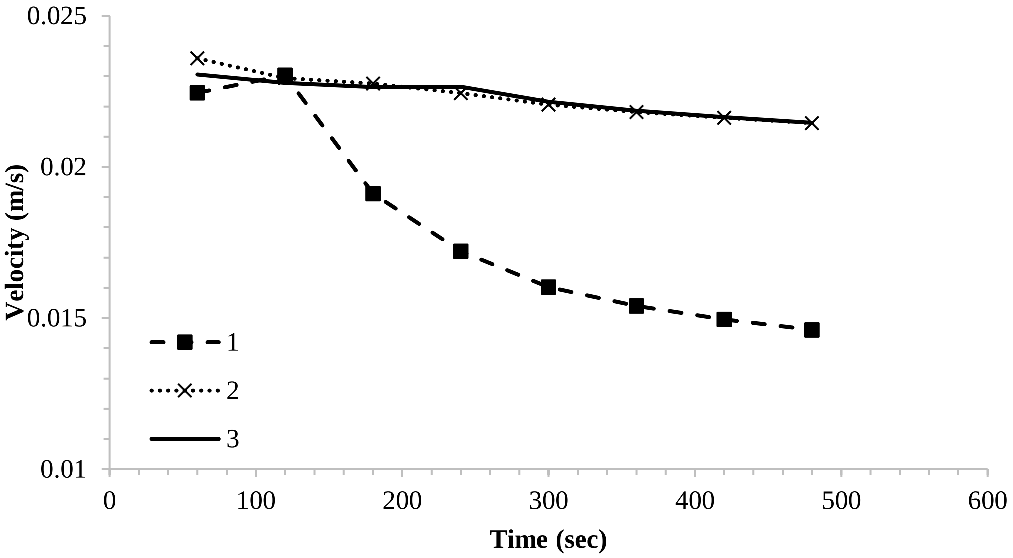

Fig. 6. Average velocity of the mixture at point 1, 2, and 3

4.2 $V_{water}/V_{Glycerin} = 0.5$

This section provides an explanation of the behaviour exhibited by the mixture when the flow rate or velocity of glycerin is increased twofold to 0.2 m/s (as depicted in Figure 7). The heightened speed of glycerin results in an amplified capacity, resulting in its occupation of the right section of the domain. In the aquatic region, there is a phenomenon where glycerin layers blend together, forming a brush-like arrangement. The application of pressure by glycerin results in the displacement of water towards the left wall, thereby causing a substantial increase in the rate of flow. The visual representation of the volume fraction of water is depicted in the colour green within the same figure. In order to conduct a more comprehensive analysis of the composition's behaviour, Figure 6 illustrates the velocity measurements taken at three specific locations, namely points 1, 2, and 3. The velocity patterns bear resemblance to those illustrated in Figure 6, albeit with modified values. At the 50-second mark, the velocity is estimated to be approximately 0.035 metres per second. Over time, there is a significant decrease in the velocity at point 1, primarily due to the increased viscosity of the fluids.

The rationale behind these observations can be attributed to the increased flow rate resulting from the doubled velocity of glycerin. The augmented quantity of glycerin causes the displacement of water, resulting in its accumulation on the left side of the domain. The phenomenon of fluid displacement and intermixing results in the formation of a brush-like arrangement within the aqueous region. The pressure generated by glycerin causes the water to move towards the left wall, resulting in an increased flow rate compared to the previous situation. The observed velocity distribution at the specified points is consistent with the patterns observed in Figure 6, as previously reported. However, as a result of the modified conditions, there are variations in the velocity values. At the 50-second mark, the velocity is observed to be approximately 0.035 m/s, indicating the presence of an initial high velocity attributed to the increased flow rate. As the temporal dimension advances, the impact of fluid viscosity becomes increasingly significant, resulting in a pronounced deceleration in velocity at point 1 around the 120-second mark.

The present analysis offers a comprehensive comprehension of the behaviour and dynamics exhibited by the mixture when subjected to a doubled glycerin flow rate. The augmented velocity of glycerin has a dual effect on the distribution and arrangement of fluids within the given domain, as well as on the resultant flow rates and velocity patterns. Through a thorough examination of the initial observations and a comprehensive justification of the findings, this analysis contributes to the advancement of our understanding regarding the intricate behaviour demonstrated by the mixture.

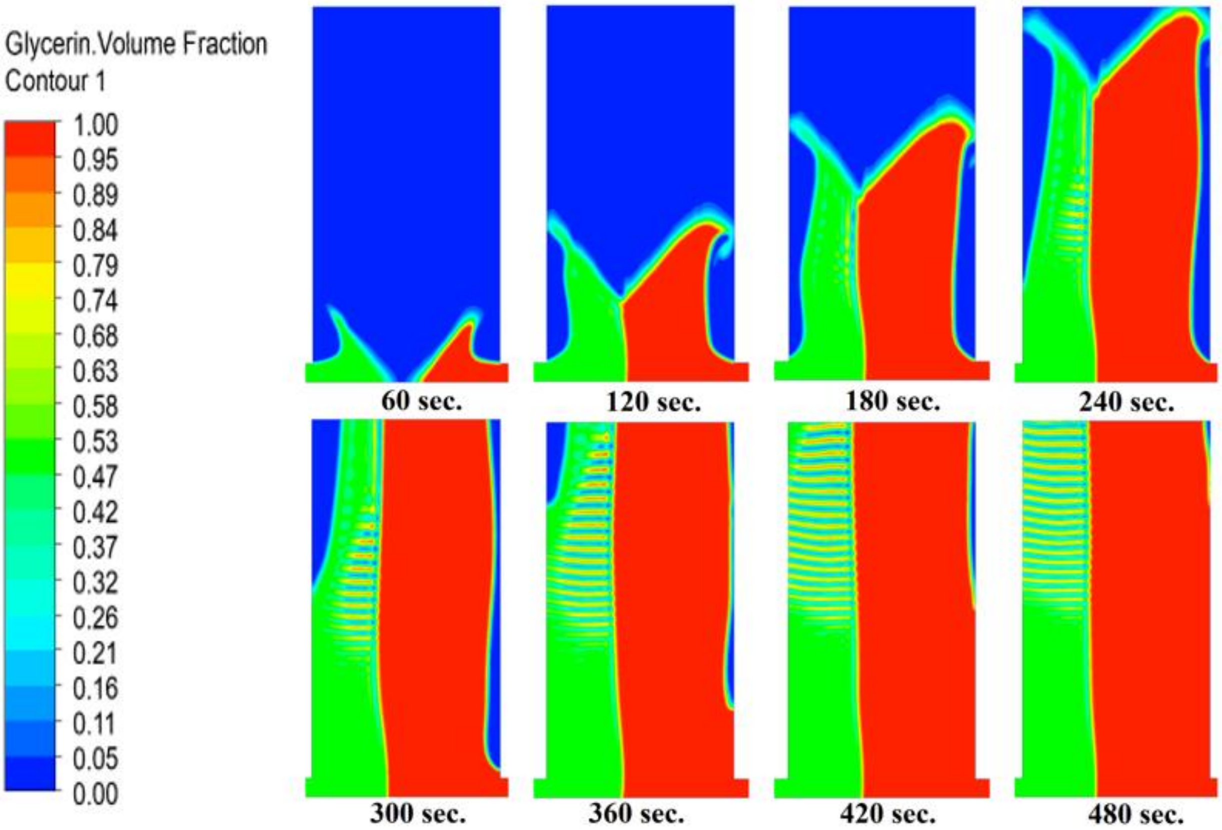

Fig. 7. Glycerin volume fraction during the mixing process at various time steps (Glycerin inlet velocity = 0.2 m/s)

The velocity of the mixture for the three mentioned points (1, 2, and 3) is illustrated in Figure 8. The velocity behaves as the same Figure 6, with different values. The velocity at 50 s is around 0.035 m/s, then at 120 s, the velocity at point 1 reduces sharply, due to the high viscosity of the fluids.

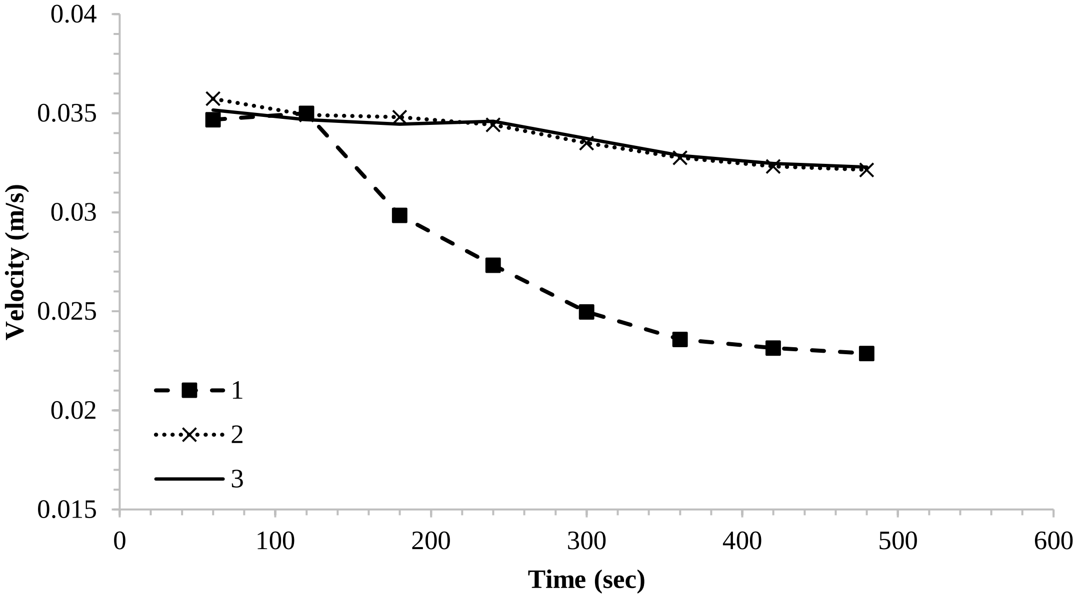

Fig. 8. Average velocity of the mixture at point 1, 2, and 3 (Glycerin inlet velocity = 0.2 m/s)

4.3 $V_{water}/V_{Glycerin} = 2$

The liquid fraction distribution of Glycerin within a container is illustrated in Figure 9, where the inlet velocity of Glycerin is 0.1 m/s and the inlet velocity of water is 0.2 m/s. The provided figure demonstrates a distinct concentration of Glycerin on the right side of the container, with its penetration into the water occurring predominantly on the left side. The observed concentration disparity can be attributed to the hydrodynamic pressure exerted by the water, which is influenced by its comparatively higher flow rate in comparison to Glycerin. As a result, the water exerts a significant force that propels the Glycerin in the direction of the right wall of the container. The interaction between the two liquids results in the emergence of a discernible V-shaped pattern within the receptacle, as visually depicted in Figure 9. Figure 10 offers additional insights into the distribution of average velocity within the container for the Glycerin-water mixture. The region exhibiting the highest velocity is situated on the left side of the domain, precisely at the point of water ingress. The increased velocity observed near the water inlet is a result of the greater flow rate of water in comparison to Glycerin. Significantly, the convergence of the two fluid substances results in the emergence of a swirling pattern within the given space, which serves as a clear indication of their dynamic interplay. The velocity on the lower surface experiences a minimum value as a result of the counteracting motion between the Glycerin and water.

Upon analysis of Figure 11, which depicts the mean velocity of the mixture comprising Glycerin, water, and air at the specific time of 50 seconds, it becomes apparent that the average velocity remains consistently around 0.035 m/s across all vertical positions within the container. As the levels of Glycerin and water within the domain increase, there is a more pronounced decrease in the average velocity at point 1 in comparison to the other two points. The observed difference can be ascribed to the increased viscosity demonstrated by glycerin and water. At the 480-second mark, the average velocity decreases to 0.025 m/s at point 1, while recording values of 0.032 m/s at points 2 and 3.

The examination of Figures 9, 10, and 11 yields significant observations regarding the dynamics of the Glycerin-water mixture within the confines of the container. The observed differences in concentration, the formation of vortices, and the distribution of velocities serve to emphasise the dynamic interaction between the two liquids and their influence on the fluid dynamics as a whole. The aforementioned findings enhance our overall comprehension of the flow properties and dynamics of Glycerin and water within the container. This, in turn, facilitates a more knowledgeable examination and incorporation of design factors for relevant applications.

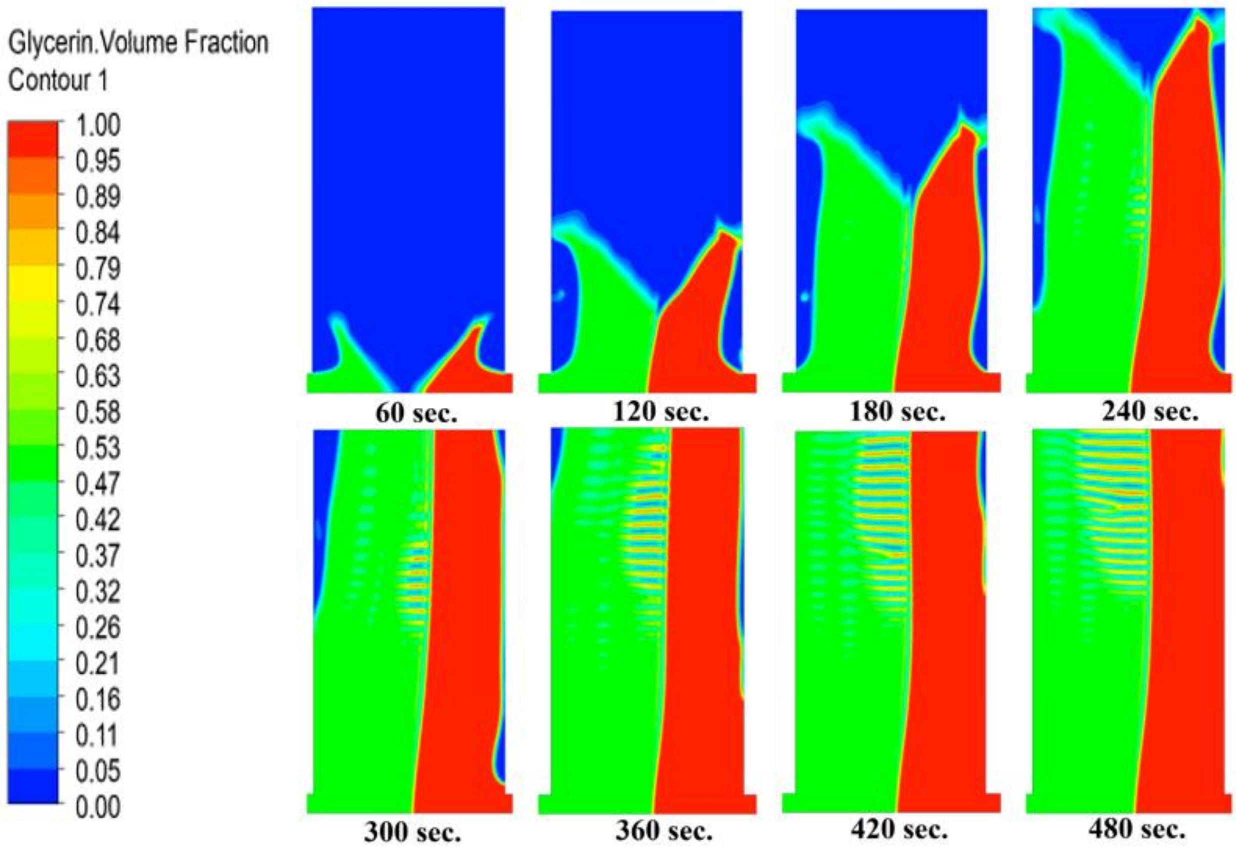

Fig. 9. Glycerin volume fraction during the mixing process at various time steps (water inlet velocity = 0.2 m/s)

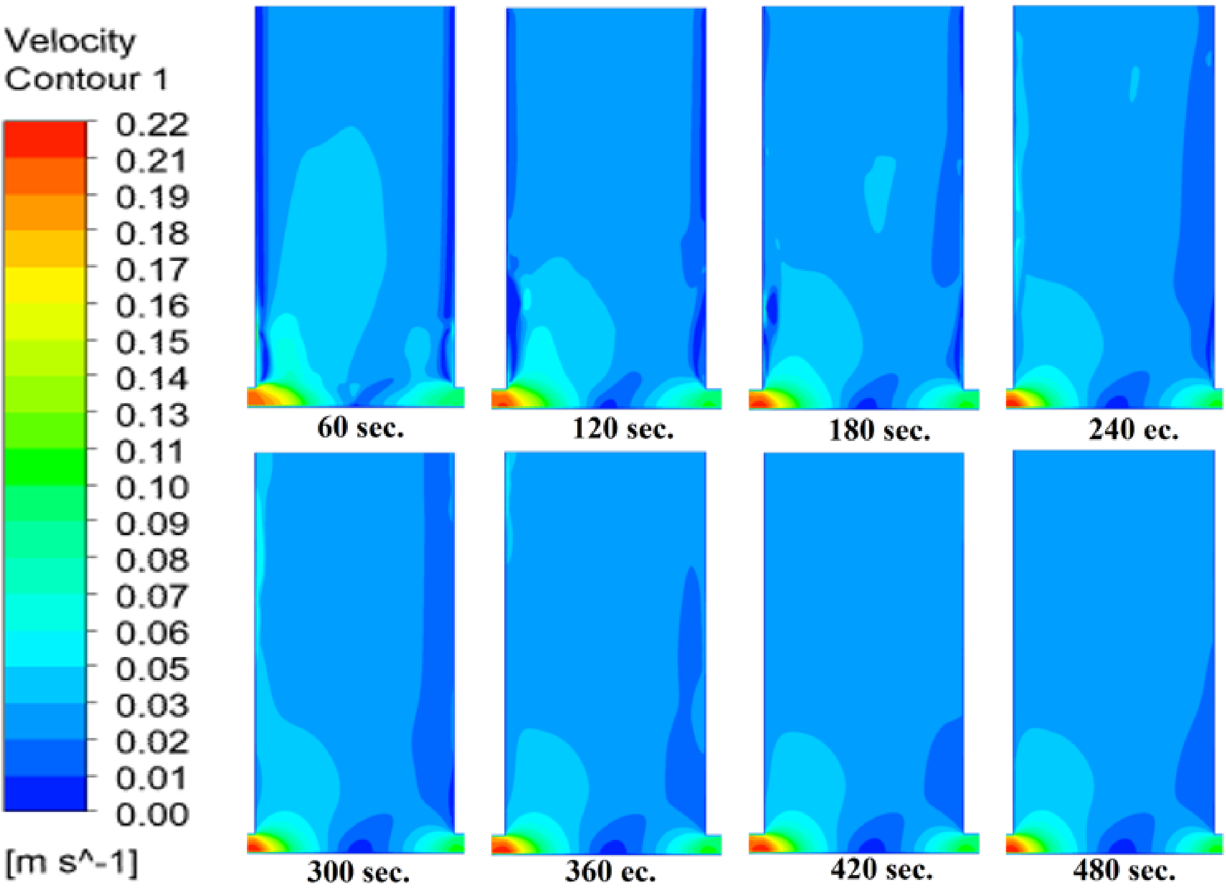

Fig. 10. Velocity of the mixture during the mixing process at various time steps (water inlet velocity = 0.2 m/s)

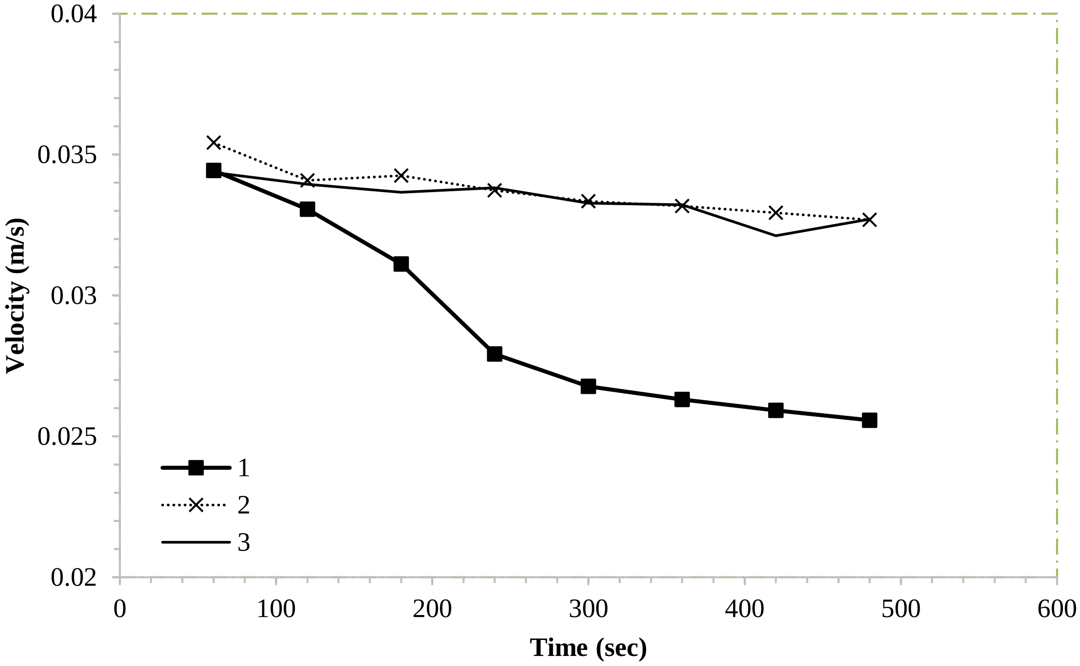

Fig. 11. Average velocity of the mixture at point 1, 2, and 3 (water inlet velocity = 0.2 m/s)

4.4 $V_{water}/V_{Glycerin} = 2/3$

The velocity of the fluid plays a crucial role in the process of filling a container, as higher velocities result in reduced filling times while maintaining the characteristics. Figure 12 depicts the process of mixing between Glycerin and water at different time intervals, ranging up to 480 seconds. The velocities of Glycerin and water are 0.3 m/s and 0.2 m/s, respectively. In the provided scenario, the Glycerin is situated in the right section of the container, exerting pressure on the water and causing it to be displaced towards the left side. The observed behaviour of the mixture consistently aligns with the previously described observations. Figure 13 illustrates the velocity profile of the mixture at different positions within the container. Although the behaviour demonstrates similarities to the previous analysis, there are noticeable differences in the velocity measurements. At the 50-second mark, the velocity at point 1 initiates at 0.058 m/s and gradually decreases to 0.038 m/s. In contrast, the initial velocity of the mixture at point 3 is measured to be 0.059 m/s. Over a duration of 480 seconds, there is an observed reduction in velocity to 0.052 m/s.

Upon analysing Figure 12 and Figure 13, it becomes evident that the increase in velocities, observed in both Glycerin and water, leads to a more rapid filling of the container. The displacement of water towards the left side is attributed to the greater velocity of Glycerin, resulting in the exertion of pressure and subsequent dominance on the right side. The velocity profiles observed at different locations display fluctuations in the magnitudes of velocity, which suggest the dynamic nature of the fluid flow taking place within the container. The aforementioned findings emphasise the influence of fluid velocities on the filling process and the subsequent behaviour of the mixture. Increasing velocities can effectively reduce filling time, making this knowledge particularly valuable for practical applications that prioritise time efficiency.

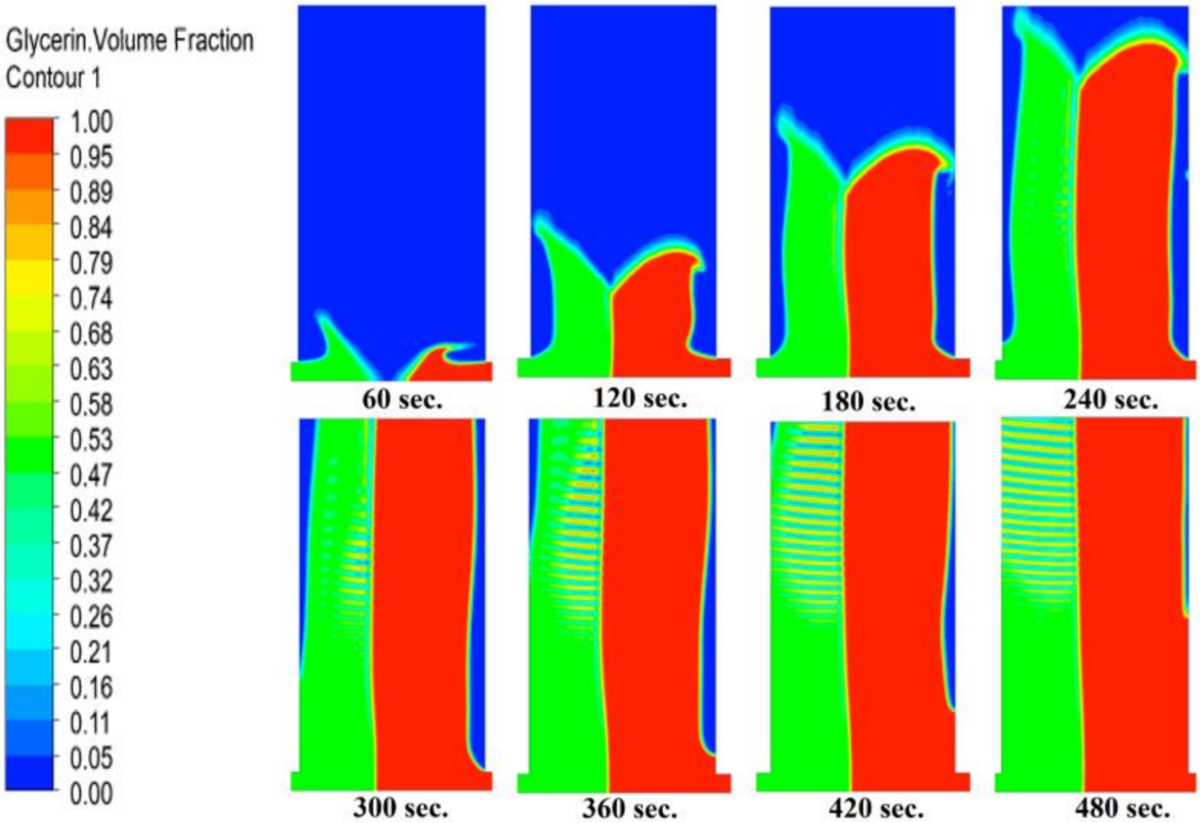

Fig. 12. Glycerin volume fraction during the mixing process at various time steps (water inlet velocity = 0.2 m/s and glycerin velocity = 0.3 m/s)

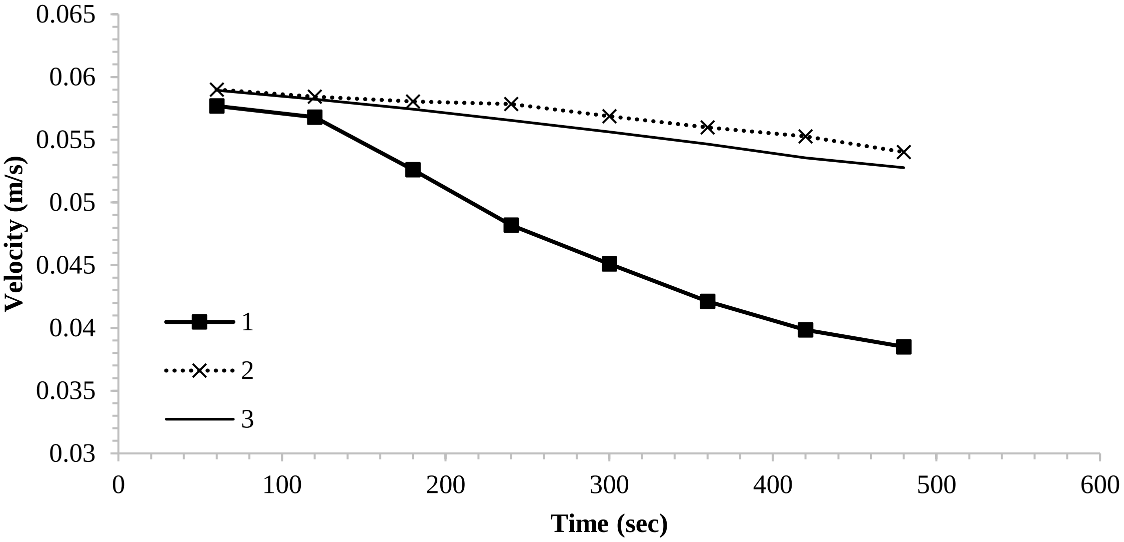

Fig. 13. Average velocity of the mixture at point 1, 2, and 3 (water inlet velocity = 0.2 m/s, and glycerin velocity = 0.3 m/s)

4.5 $V_{water}/V_{Glycerin} = 3$

The fluid velocity is a crucial factor in the container filling process, and augmenting the velocities can lead to a decrease in the required filling time, while preserving the previously described behaviour. Figure 14 presents a graphical depiction of the mixing phenomenon occurring between glycerin and water, with glycerin flowing at a velocity of 0.1 m/s and water flowing at a velocity of 0.3 m/s. The figure illustrates the progression of the mixture over time, with data points recorded at regular intervals up to a duration of 480 seconds. In the given situation, the glycerin primarily occupies the right side of the container, causing the water to be displaced towards the left side. Notwithstanding the greater density of glycerin, the hydrodynamic force resulting from the water's elevated flow rate facilitates the displacement of glycerin. The behaviour is consistent with the observations previously discussed. To obtain additional understanding, Figure 15 depicts the velocity distribution of the mixture at various locations within the container. While the general behaviour remains consistent with the previous analysis, there exist variations in the velocity values. At the 50-second mark, the velocity at point 1 commences at 0.052 m/s and progressively diminishes to 0.039 m/s. Likewise, at point 3, the initial velocity of the mixture is recorded as 0.045 m/s, which gradually decreases to 0.044 m/s after a duration of 480 seconds. It is worth noting that the velocity at point 2 consistently surpasses that at point 3 across all instances. The observed discrepancy can be ascribed to the placement of point 2 at the central region of the domain, where the mixture displays heightened mobility and dynamism.

The findings derived from the examination of Figure 14 and Figure 15 provide evidence supporting the notion that augmenting the velocities of glycerin and water results in a reduction in the duration required to fill the container. Despite glycerin's elevated density, the force exerted by the water flowing at a high velocity enables its displacement towards the left side of the container. The velocity profiles observed at various locations within the container exhibit variations in velocity magnitudes, thereby indicating the dynamic characteristics of fluid flow. The findings underscore the notable impact of fluid velocities on the process of filling and the subsequent behaviour of the mixture. The acceleration of velocities can expedite the filling process of the container, rendering this knowledge pertinent and advantageous for situations where temporal efficiency is a crucial consideration.

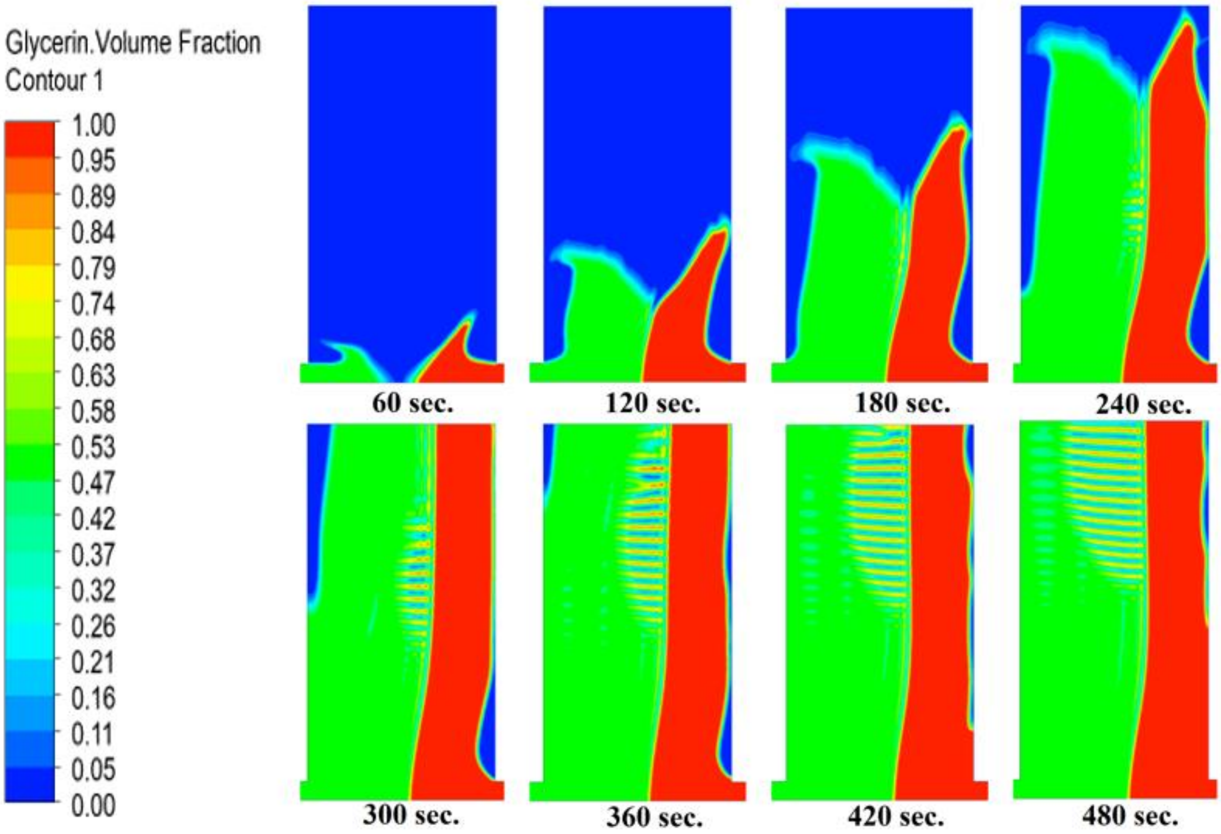

Fig. 14. Glycerin volume fraction during the mixing process at various time steps (water inlet velocity = 0.3 m/s and glycerin velocity = 0.1 m/s)

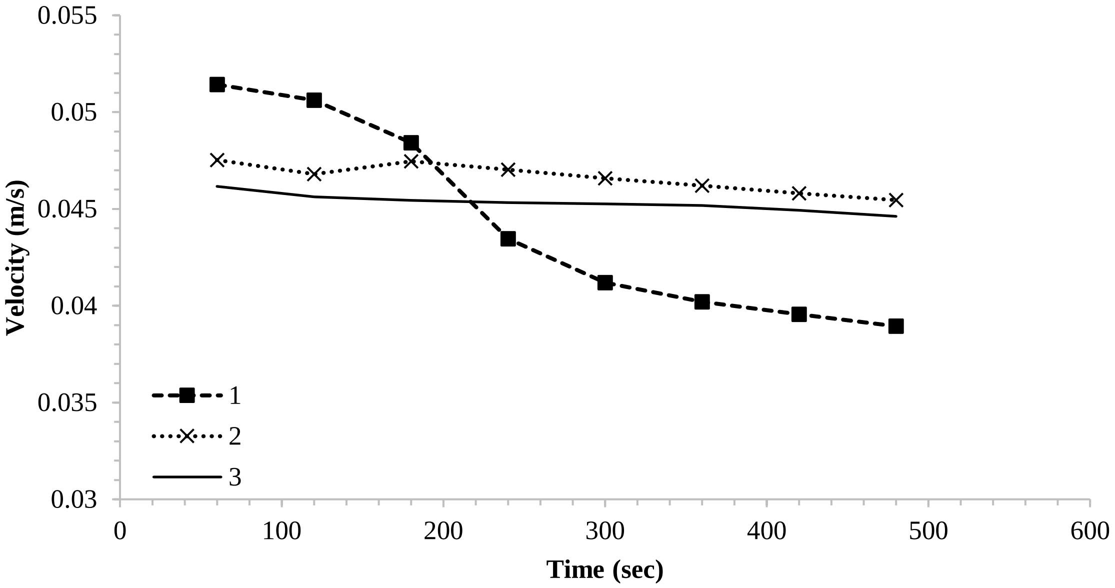

Fig. 15. Average velocity of the mixture at point 1, 2, and 3 (water inlet velocity = 0.3 m/s, and glycerin velocity = 0.1 m/s)

4.6 Comparison of Different Scenarios of Variable Velocities of Glycerin and Water

This section provides a thorough examination of the fluid mixing characteristics in the scenarios, which encompass variable velocities of glycerin and water. In order to facilitate the analysis, Figure

16 presents the contours of glycerin concentration within the container for all cases at different time intervals (up to 240 seconds). The figure clearly demonstrates that when the velocity of one fluid is increased relative to the other, there is a corresponding increase in the concentration of the faster-moving fluid within the container. As a result, the slower-moving fluid is displaced in the opposite direction. The observed distinct visual separation between the fluids can be attributed to their disparate densities and viscosities, which prevent them from effectively blending together under the specified circumstances. Additional understanding of the fluid dynamics can be garnered by referring to Figure 17, which illustrates the velocity profiles at point 1 for the different scenarios. The characteristics of these profiles are determined by the inlet velocities of each fluid. The point of maximum velocity, denoted as point 1, is achieved when the water velocity is measured at 0.2 m/s and the glycerin velocity is recorded at 0.3 m/s. At a time of 50 seconds into the operation, the velocity reaches a value of 0.058 m/s. The observed value exhibits a 150% increase compared to the scenario where both fluids possess a velocity of 0.1 m/s. Additionally, it demonstrates a 75% increase relative to the situation where the water velocity is 0.2 m/s and the glycerin velocity is 0.1 m/s. The aforementioned results underscore the notable influence of different inlet velocities on the resultant velocity profiles, thereby illustrating the reliance of fluid dynamics on the particular flow circumstances.

Furthermore, Figure 18 illustrates the velocity profile of the mixture at point 3 across all scenarios. In a manner akin to the preceding analysis, the velocity at this juncture is subjected to the influence exerted by the inlet velocities of both fluids. Nevertheless, the velocity in this particular scenario undergoes a minor reduction in all instances as a result of the higher density of both water and glycerin in comparison to air. The findings derived from the analysis of Figure 16, Figure 17, and Figure 18 highlight the notable variations in fluid behaviour within the container and underscore the importance of inlet velocities in influencing the dynamics of their mixing process. The lack of effective mixing of the fluids under the specified conditions can be attributed to the disparities in their densities and viscosities. The examination of velocity profiles at various locations offers quantitative analysis of fluid flow characteristics and their fluctuations in relation to diverse inlet velocities.

The present analysis enhances our comprehension of fluid mixing dynamics in the presence of different velocities, shedding light on the difficulties encountered in achieving uniform mixing in systems characterised by disparate fluid properties. The implications of these findings extend to a range of disciplines in which the process of fluid mixing holds significant importance, including chemical processes, environmental engineering, and industrial applications. Consequently, these findings offer the potential for improved optimisation of mixing systems, thereby enhancing overall performance and efficiency.

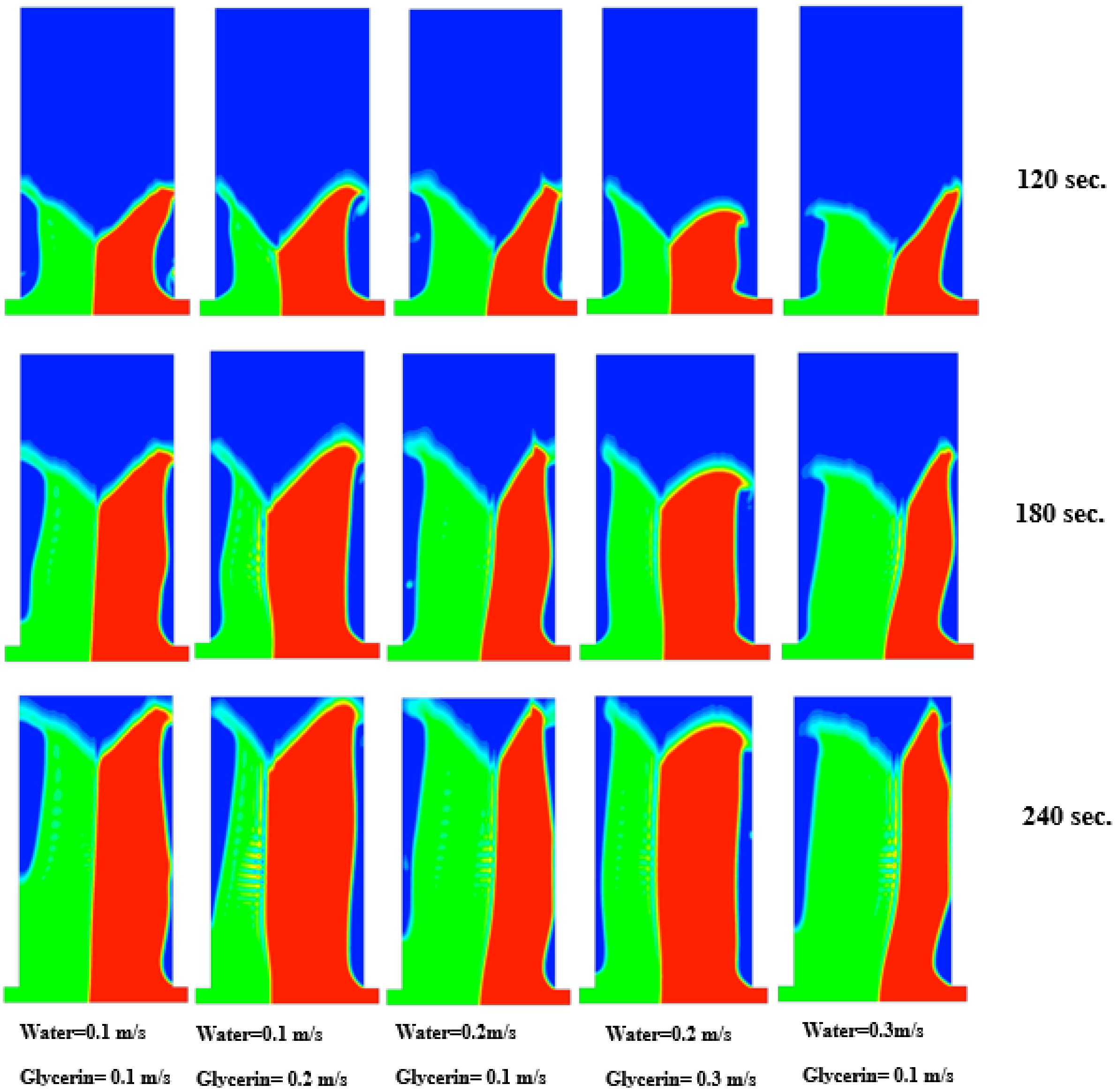

Fig. 16. Glycerin volume fraction

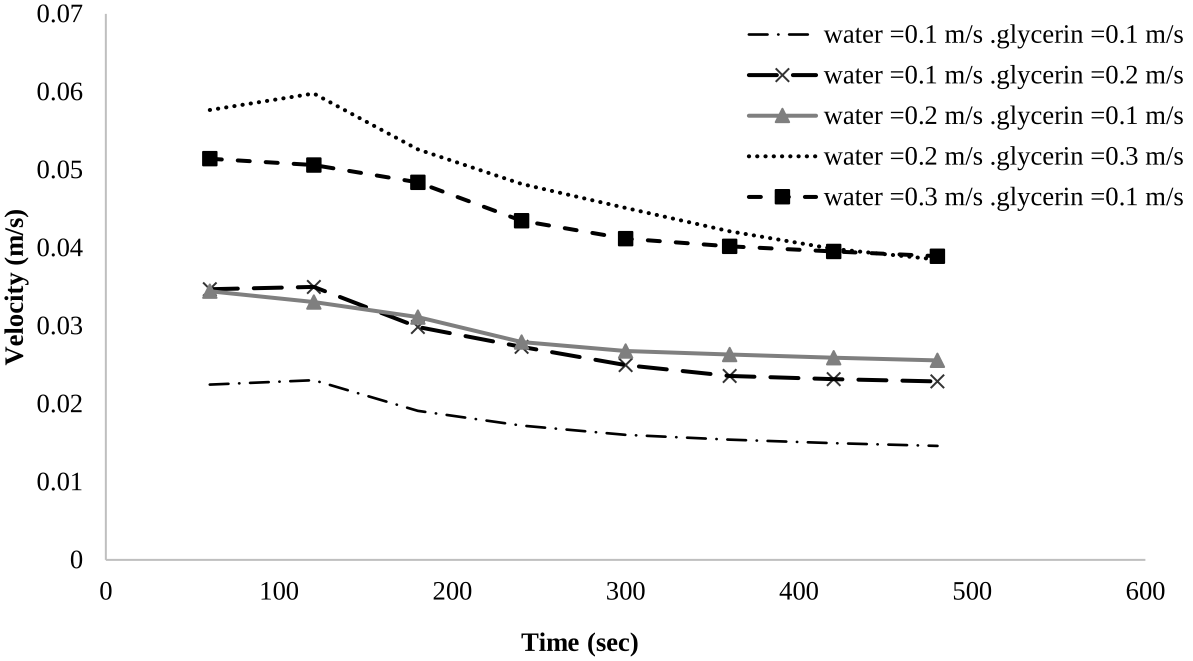

Fig. 17. Average velocity of the mixture at point 1 for various cases of inlet flows

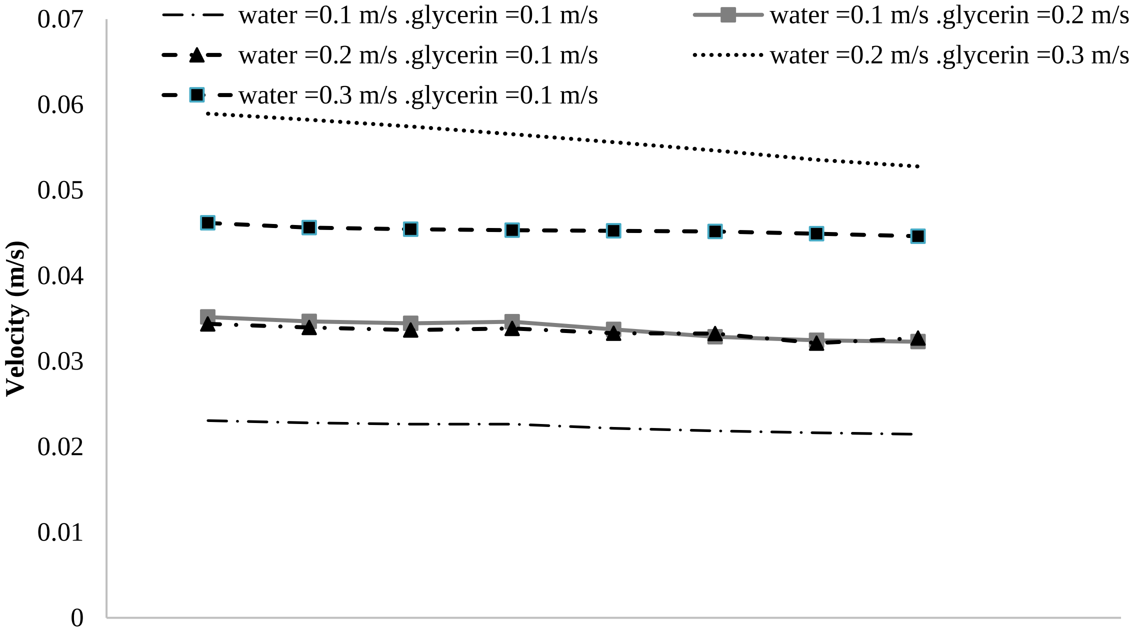

Fig. 18. Average velocity of the mixture at point 3 for various cases of inlet flows

5. Conclusions

This research focused on the compatibility and blending properties of glycerin and water, revealing vital insights into their mixing behavior. The numerical findings showed how glycerin content can affect viscosity, surface tension, and miscibility, while assessing their physical characteristics and interactions. These discoveries have important ramifications for fields like chemical engineering, where effective mixing procedures are essential for maximising output and obtaining desirable product properties. The most important finding of this research are as follows.

- The formation of a uniform mixture is observed when glycerin and water are combined, yielding a homogeneous solution. The ideal ratio of glycerin to water is contingent upon the particular context or purpose of use.
- When glycerin and water are combined with a velocity of 0.1 m/s, a phenomenon occurs where glycerin accumulates on one side of the container, while water remains on the other side. This separation is attributed to the disparity in density between the two substances.
- The velocity contours exhibit a reduction in velocity as the fluids disperse within the container, with the glycerin side displaying lower velocity owing to its comparatively greater density.
- The behavior of the mixture undergoes a transformation as the velocity of glycerin is elevated to 0.2 m/s, leading to the displacement of water and the emergence of a brush-like configuration.
- The velocity of fluid particles at variable elevations within the container exhibits a gradual decline over time, with a more notable reduction observed at higher levels owing to heightened viscosity.
- At elevated glycerin velocities (0.3 m/s), the displacement of water towards the left side of the container occurs, leading to accelerated filling durations.
- The velocity profiles observed at various spatial points within the container exhibit fluctuations in the magnitudes of velocity, which serve as evidence for the dynamic characteristics of fluid flow.
- The reduction of filling time can be achieved by increasing velocities, thereby rendering it crucial for applications that priorities time efficiency.
- The behavior that has been observed highlights the intricate interaction between fluid properties, such as density and viscosity, and the impact of velocity on the process of mixing.
- The aforementioned discoveries enhance comprehension regarding the dynamics and behavior of glycerin-water mixtures, thereby facilitating the development and enhancement of pertinent applications.

The current investigation of the glycerin and water mix has positive consequences on the chemical engineering sector, among others. It can aid in the optimisation of production procedures, the construction of effective mixing systems, and the choice of appropriate glycerin-water ratios. Future studies may focus on researching applications in the pharmaceutical, cosmetic, or food processing industries. Specifically, it is favorable to study the effects of temperature and additives on mixing behavior, besides creating computational models for fluid flow optimisation and mixing pattern prediction.

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