Report Master M1

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Data Visualization Exam

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Abstract

Dante Vitagliano once said that "Data visualization is the language of decision making. Good charts effectively convey information. Great charts enable, inform and improve decision making."

Data visualization is therefore seen as a crucial way to understand different phenomena and implicate the reader in them. Moreover, to communicate information clearly and efficiently, data visualization uses statistical graphics, plots, information graphics and other tools, *"Data visualization"* 2022.

To sum up, data visualization offers the reader the following benefits:

- explore the data and understand them,
- explore the patterns and structures,
- monitor different simulations,
- communicate with others.

This report illustrates the case study of a decompression of a tank, internally pressurised with water, following a rapid opening of a valve close to it. The study output results are then visualized using the ParaView software. It has been highlighted that the pressure waves propagates from the valve to the tank, while the velocity has the reverse behaviour. The fluid waves are modelled as a compressible liquid.

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Chapter 1

Study of a Tank Decompression

1.1 Problem Description

The study domain consists of a tank with a small outflow pipe (valve). Its $2D$ cross section is illustrated in figure (1.1).

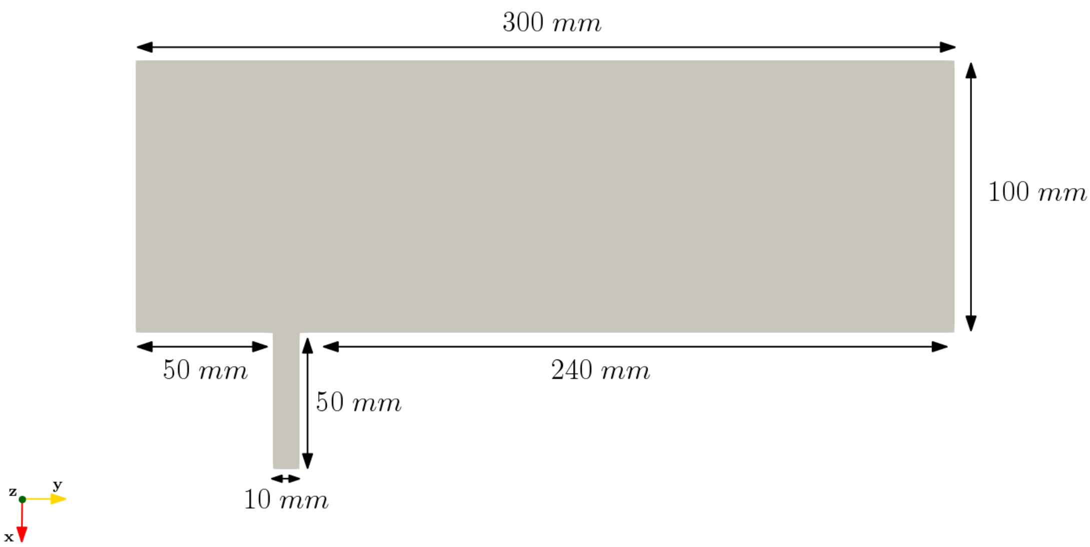

Figure 1.1: $2D$ Geometry of the tank under study with outflow pipe.

1.1.1 Governing Equations

From the tutorial in *"Decompression of a tank internally pressurised with water"* 2022, it is has been shown that the problem requires a model for compressibility ψ in the fluid. This aims at resolving the propagation of waves at a finite speed.

The governing equations are listed here-under.

The mass continuity equation is given in equation (1.1), as follows:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho U) = 0 \tag{1.1}$$

The barotropic relationship is given in equation (1.2), where K is the bulk modulus.

$$\frac{\partial \rho}{\partial p} = \frac{\rho}{\partial K} = \psi \tag{1.2}$$

The linearization of equation (1.2) leads to equation (1.3).

$$\rho \approx \rho_0 + \psi \times (p - p_0) \tag{1.3}$$

The momentum equation for Newtonian fluid is given in equation (1.4).

$$\frac{\partial \rho U}{\partial t} + \nabla(\rho U U) - \nabla \mu \nabla U = -\nabla p \tag{1.4}$$

1.1.2 Boundary Conditions

The geometry consists of some boundary conditions, as illustrated in figure (1.2).

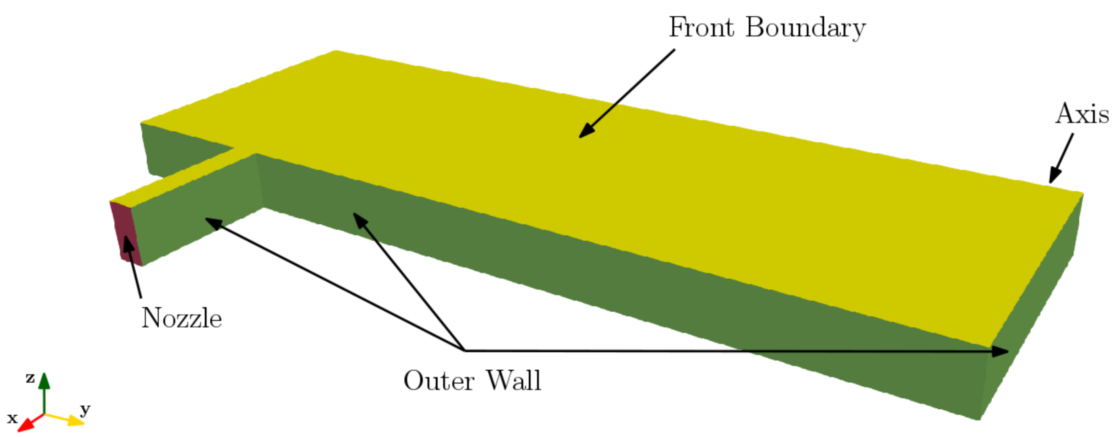

Figure 1.2: Boundary conditions of the geometry under study.

The boundary conditions are the following:

- The wall condition, which is given by the Outer Wall in figure (1.2),
- The symmetry plane, which is given by the axis in figure (1.2),
- The pressure outlet, which is given by the nozzle in figure (1.2). It is characterized by a null pressure value,
- The front and back boundaries, which are empty. In figure (1.2), only the front boundary is illustrated. However, the back boundary is the same outlet given in the back side.

1.1.3 Mesh Generation

The geometry domain under investigation is meshed using a structured mesh, as illustrated in figure (1.3). This later consists of a set of cells or arrays dividing the volume to small finite volumes.

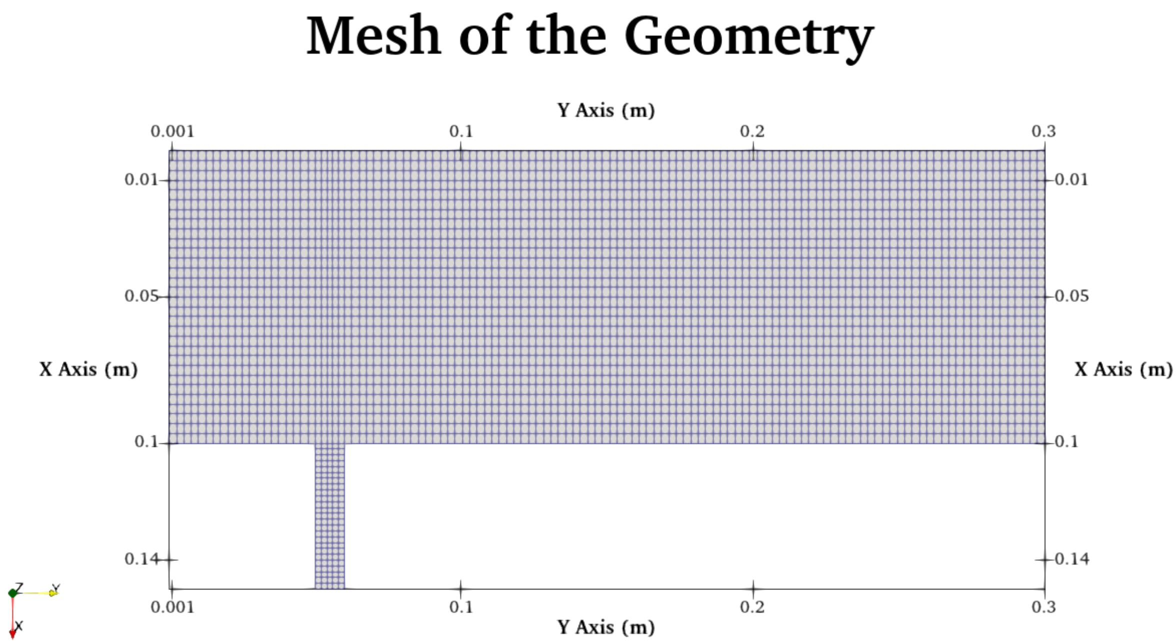

Figure 1.3: $2D$ Geometry domain meshing viewed in the XY plane.

From figure (1.3), one can notice that structured grids are aligned in the flow direction and the grid lines follow the contours of the geometry. This leads to more accurate results and a better convergence, *"Structured Grids in CFD "* 2022.

1.2 Results Analysis

For a better visibility of the geometry, this latter has been rotated by an angle of $(-\frac{\pi}{2})$ from the normal orientation of the horizontal X-axis.

In the results analysis section, the velocity and pressure profiles, viewed with ParaView software, will be analyzed and conclusions will be carried out. Moreover, it should be highlighted from *"Decompression of a tank internally pressurised with water"* 2022, that the fluid velocity is considered to be very small. However, the pressure wave propagates with the speed of sound in the water. The speed of sound is calculated using equation (1.5).

$$c = \sqrt{\frac{1}{\psi}} = 1483.2 m/s \tag{1.5}$$

1.2.1 Analysis of the Velocity Profile

In this section, we will be interested in the behavior of the velocity profile inside the tank versus the simulation time.

When running the different scenarios over time, one can notice that the liquid flows out through the nozzle, in the x-direction. For instance, figure (1.4) illustrates the velocity for a simulation time equal to $2 sec$. One can notice that there is a small flow of the liquid out through the nozzle. Its velocity magnitude reaches approximately $1.5 m/sec$, as given in figure (1.4).

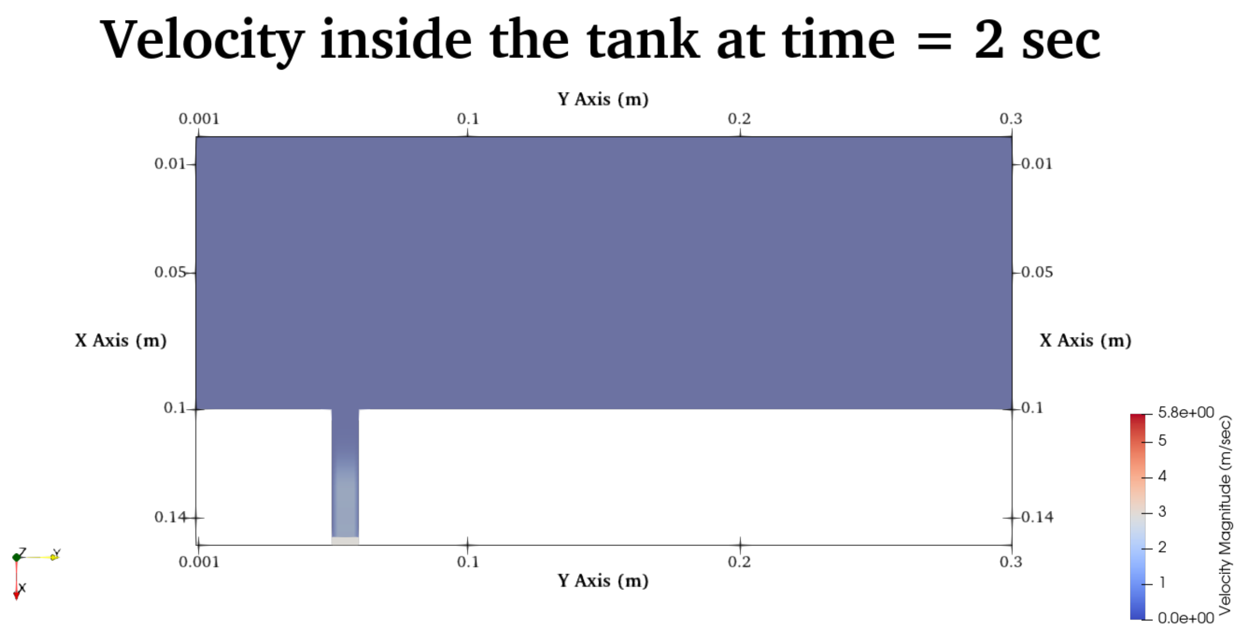

Figure 1.4: Scalar velocity profile inside the tank at time = 2 *sec*.

For a simulation time equal to $5sec$, the liquid flow continues to go throughout the nozzle with a velocity magnitude of approximately $3m/sec$, as illustrated in figure (1.5).

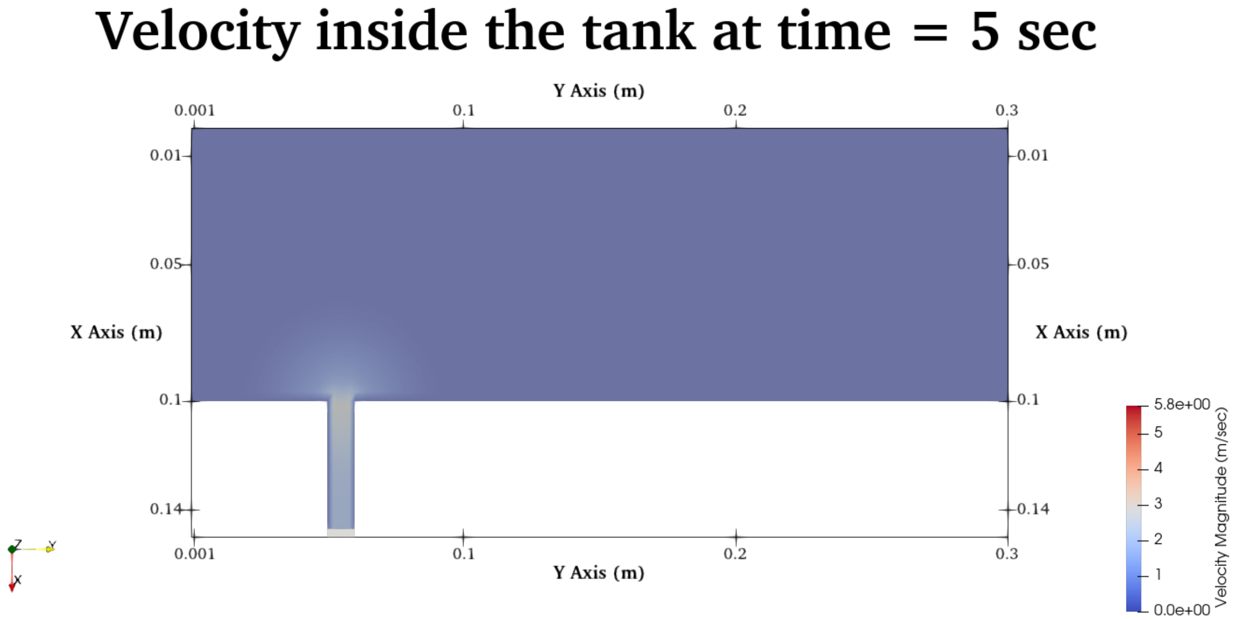

Figure 1.5: Scalar velocity profile inside the tank at time = 5 *sec*.

At the end of the simulation (time = $14sec$), the wave propagates out of the tank through the nozzle with a higher magnitude of velocity than at the start of the simulation, equal to $5.8m/sec$, as shown in figure (1.6).

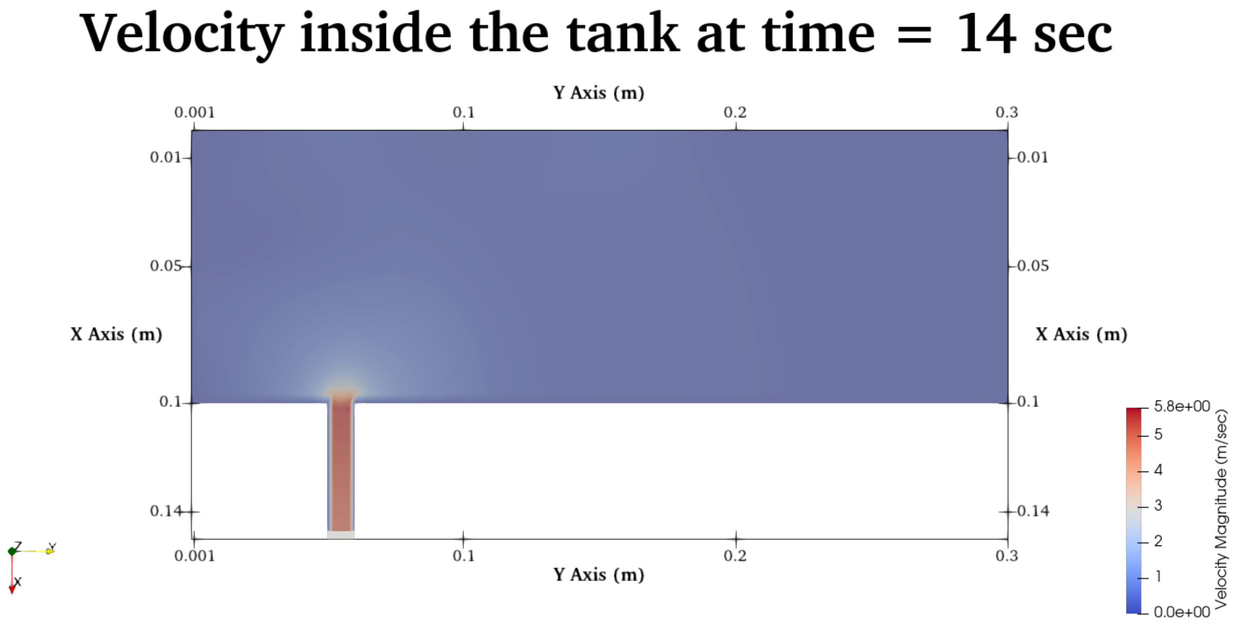

Figure 1.6: Scalar velocity profile inside the tank at end simulation time = 14 *sec*.

For a better visualization of the liquid flow through the tank, the *stream Tracer* and the *Ribbon* filters have been used in ParaView, as illustrated in figure (1.7). This photo demonstrates the velocity direction leaving the tank through the nozzle. The highest velocity magnitude is concentrated in the outlet face of the tank.

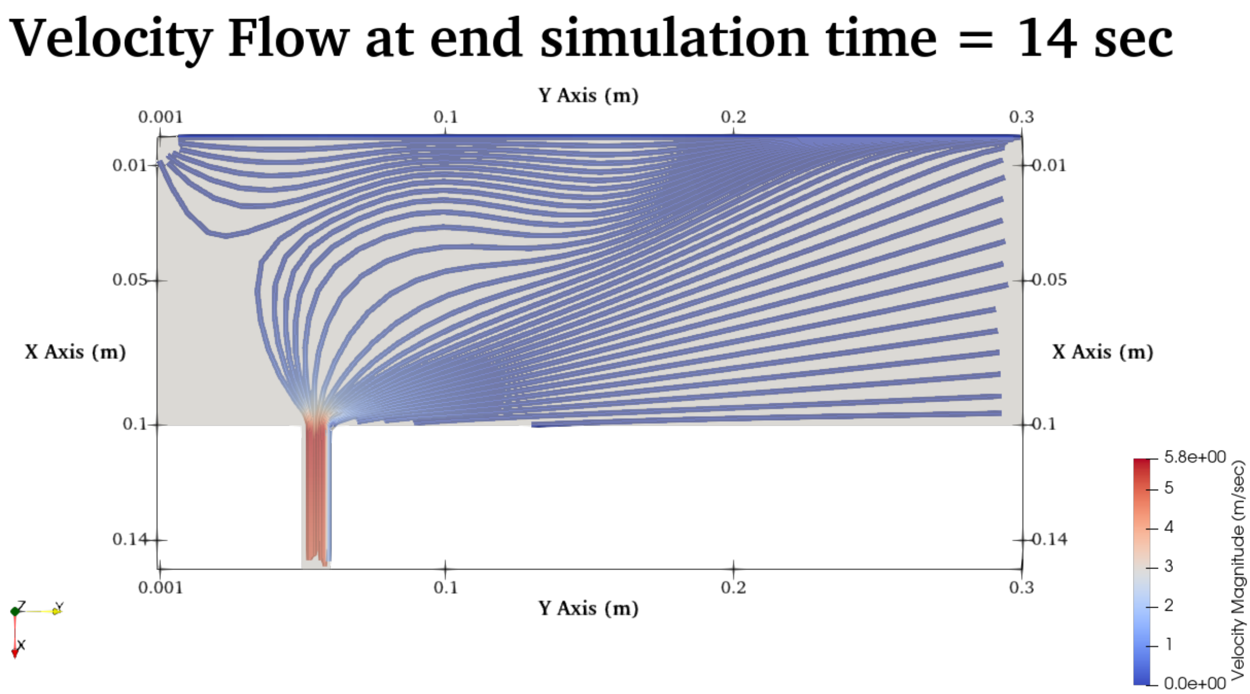

Figure 1.7: Velocity profile inside the tank at 14 *sec* using the *stream Tracer* & *Ribbon* filters.

This phenomenon is further demonstrated using the *Glyph* filter of ParaView. The vectors leaving the tank at the end simulation time of 14*sec* have been plotted in figure (1.8).

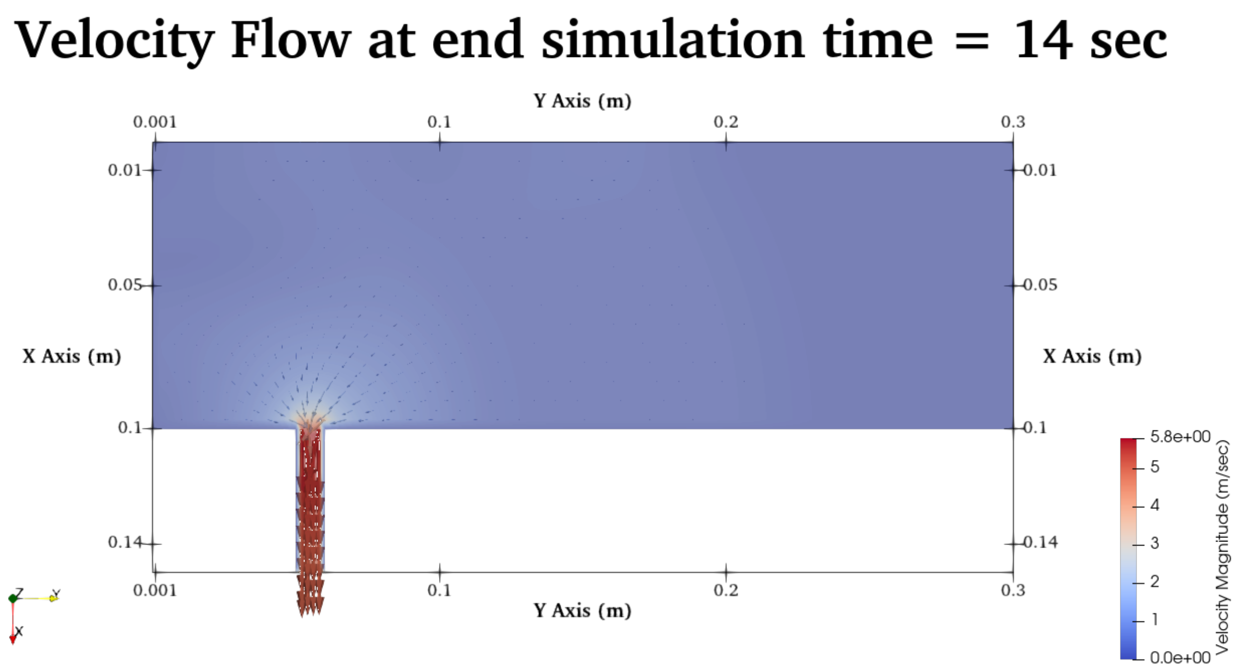

Figure 1.8: Velocity direction at end simulation time = 14 *sec* using the *Glyph* filter.

A zoom of the vectors illustrating the velocity direction is shown in figure (1.9). The vectors uniform distribution is controlled by setting the glyph mode to every N^{th} point.

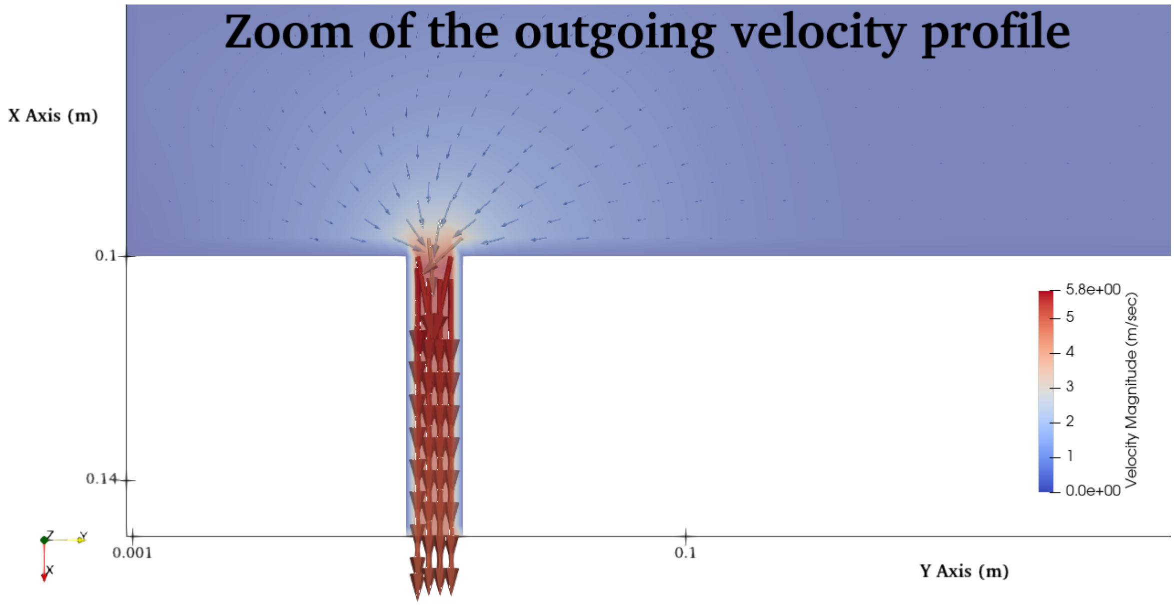

Figure 1.9: Zoom of the velocity direction at end simulation time 14 *sec* using the *Glyph* filter.

1.2.2 Analysis of the Pressure Profile

The pressure profile has been plotted at three different times: $2sec$, $5sec$ and $14sec$ in figures (1.10), (1.11) and (1.12), respectively. It has been shown that the propagation of the pressure wave has the reverse behavior of the velocity.

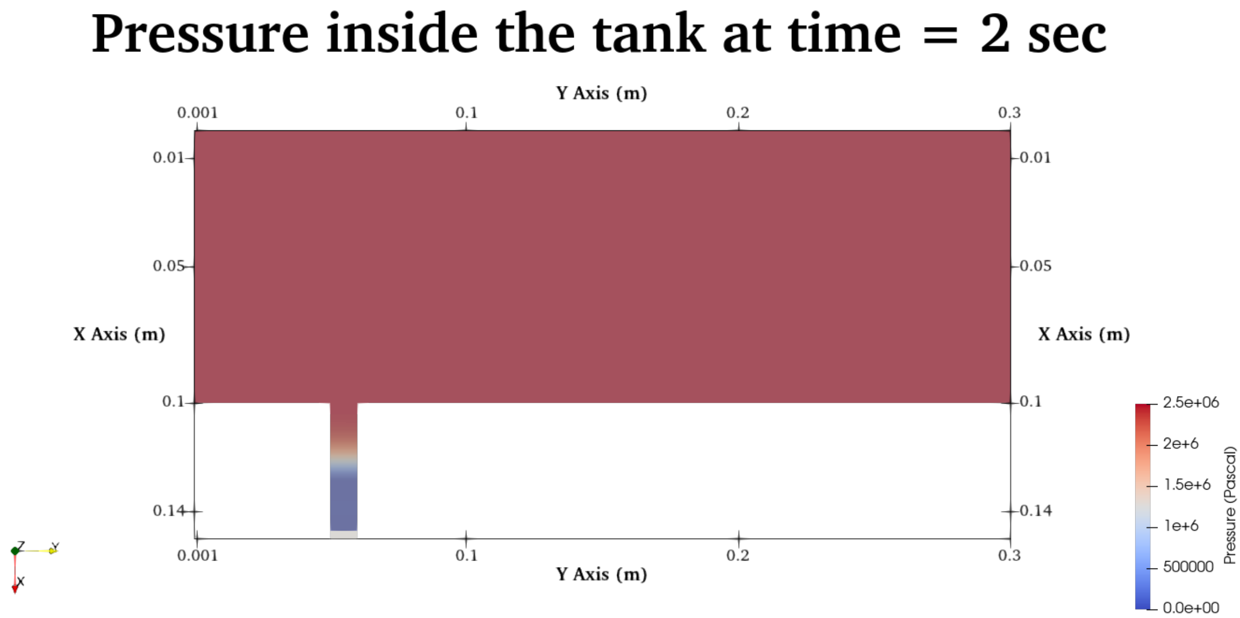

Figure 1.10: Scalar pressure profile inside the tank at time = 2 *sec*.

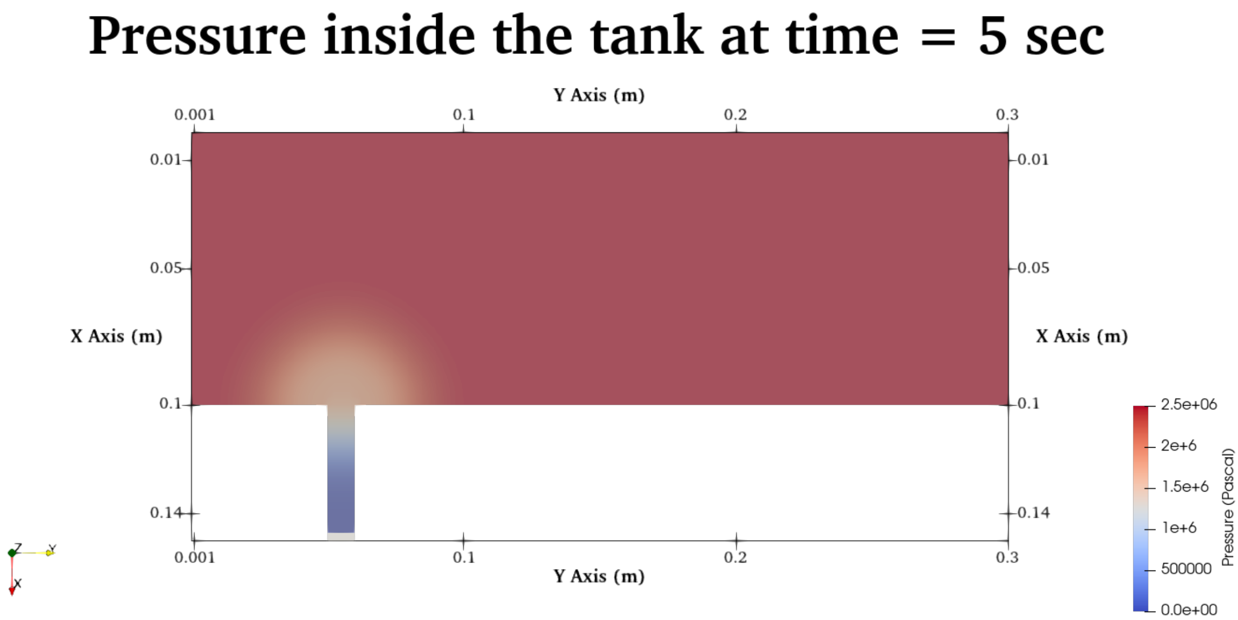

Figure 1.11: Scalar pressure profile inside the tank at time = 5 *sec*.

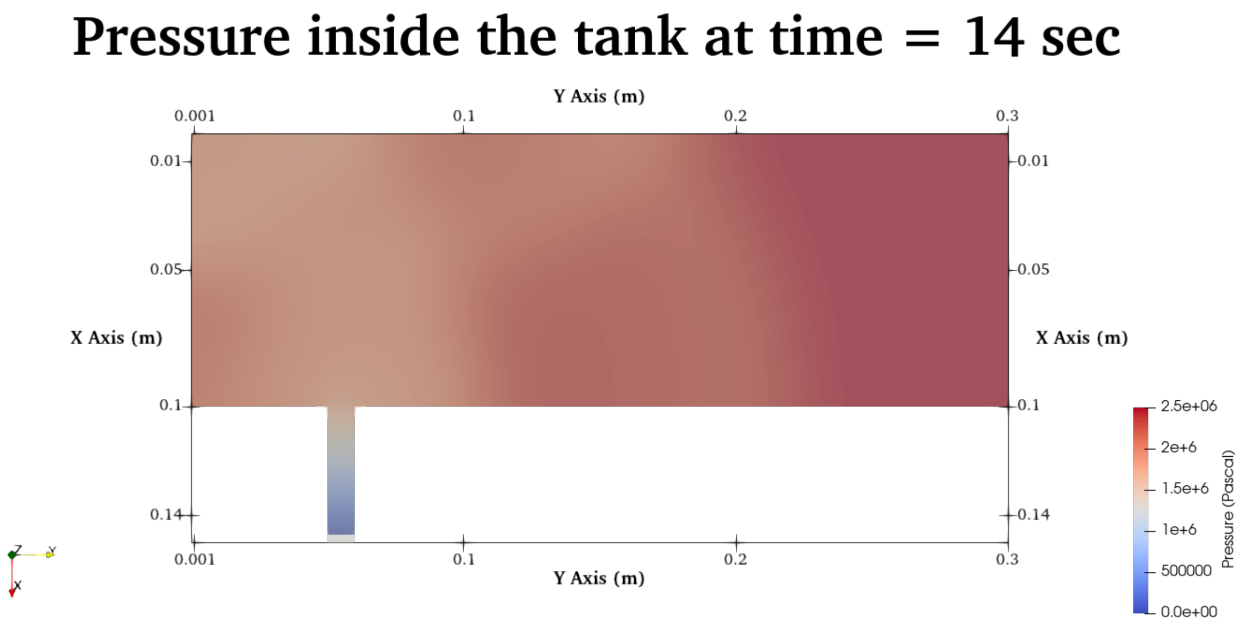

Figure 1.12: Scalar pressure profile inside the tank at time = 14 *sec*.

The three above figures (1.10), (1.11) and (1.12) show that the pressure is high inside the tank. To better view the results of the pressure wave propagation, the *contour* filter of ParaView software is used. The propagation phenomenon is illustrated in four case studies at the simulation times: 2*sec*, 5*sec*, 13*sec* and 14*sec*.

To do so, the pressure contours are plotted in ParaView as isosurfaces. For each isosurface, a defined pressure value is specified.

In the figure (1.13), the pressure contours are located in the inlet of the tank at a time of 2*sec*. It has been shown that the pressure wave goes through the nozzle to the opening of the tank at the first instances of the simulation. The pressure contours are represented by linear surfaces.

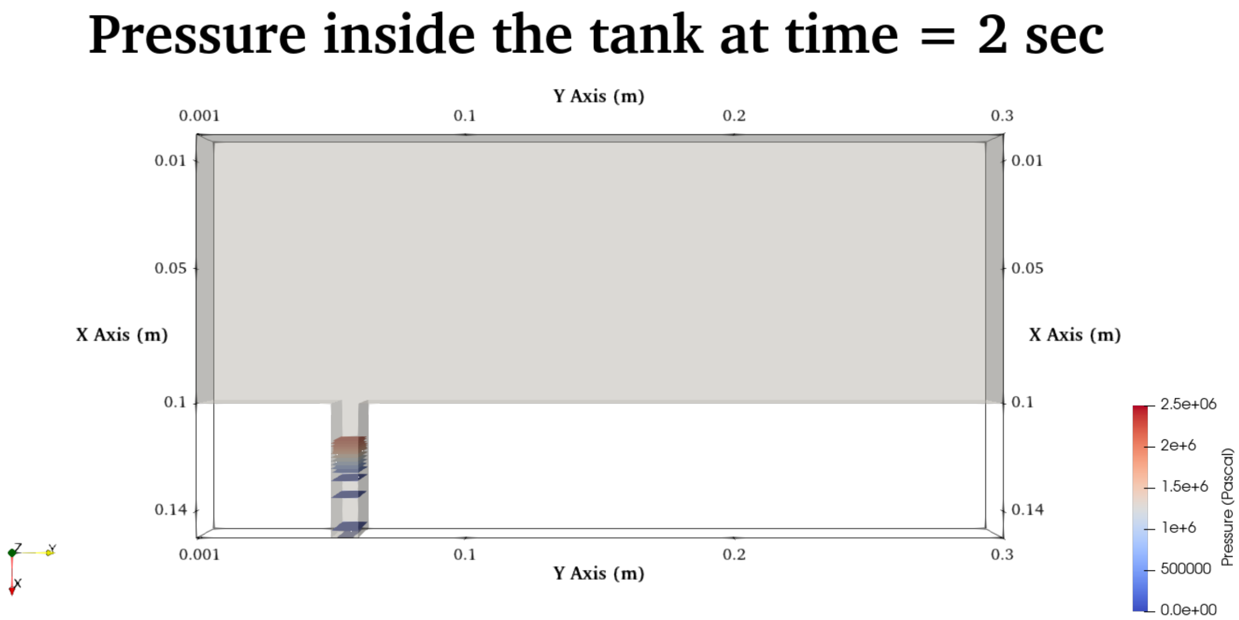

Figure 1.13: Pressure Contour inside the tank at time = 2 *sec*.

The pressure contours at a time of 5*sec* are illustrated in figure (1.14). One can see that the pressure wave flow starts to be transmitted in different direction of the tank through the nozzle. The pressure contours have curved surfaces as they access the inlet of the tank.

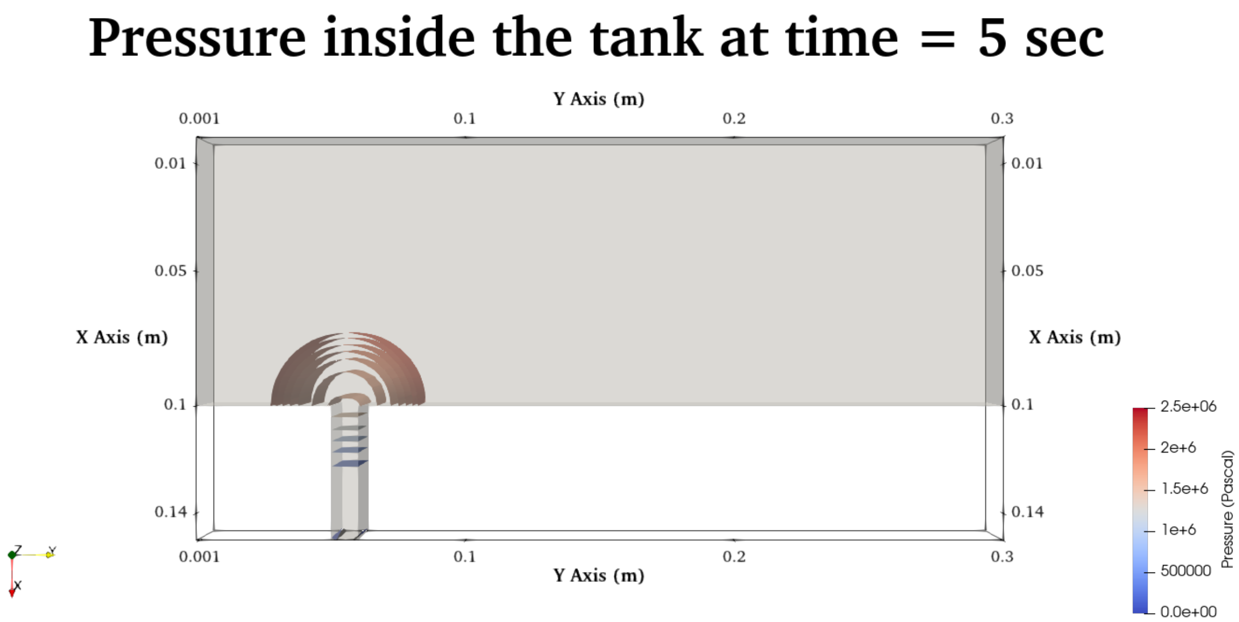

Figure 1.14: Pressure Contour inside the tank at time = 5 *sec*.

The pressure contours at a time of 13*sec* are illustrated in figure (1.15). One can notice that as the pressure wave reaches the inlet to the tank, some of it is transmitted into the tank and some of it is reflected.

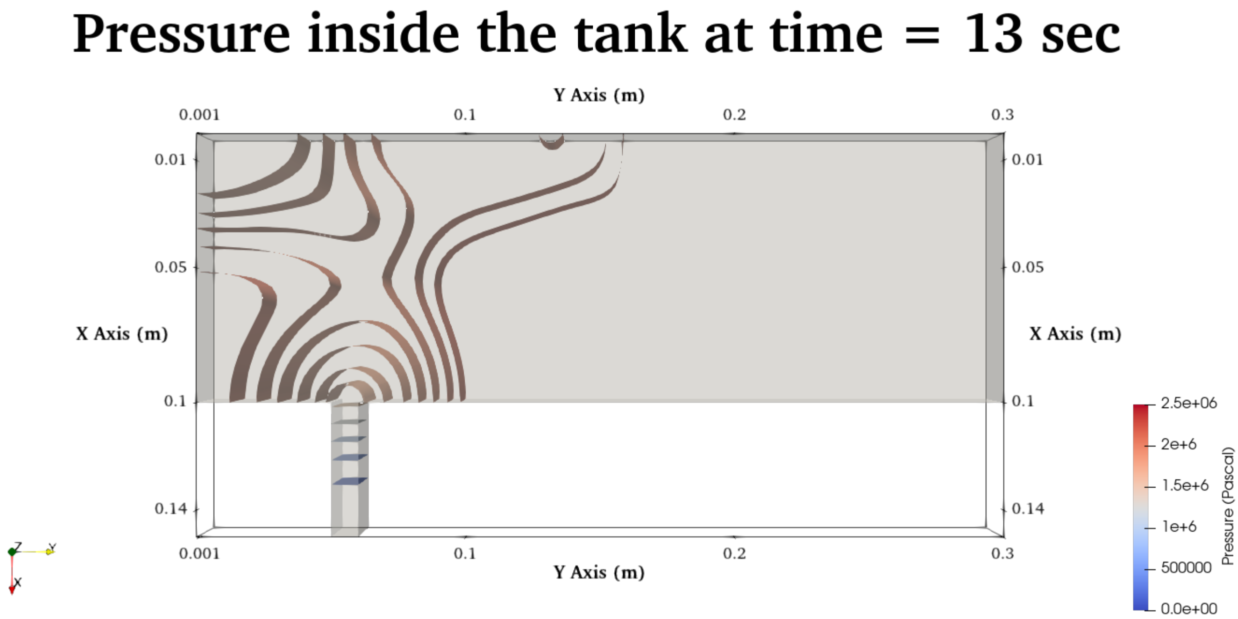

Figure 1.15: Pressure Contour inside the tank at time = 13 *sec*.

The transmission and reflection of the flow wave behaviour can be further seen in the animation of the pressure contours for different simulation instances, as illustrated in figure (1.16).

Figure 1.16: Animation of the Pressure Contours at different simulation time steps.

In what follows, we will be interested in viewing the different scenarios of the pressure and velocity evolution over time using some filters of the ParaView software.

1.2.3 Animations Relative to the Pressure and Velocity Behaviors

To visualize the behavior of the velocity and pressure for different time scenarios, the animations relative of these latter have been illustrated in figure (1.17) and (1.18).

Figure 1.17: Animation of the scalar velocity profile at different simulation time steps.

Figure 1.18: Animation of the scalar pressure profile at different simulation time steps.

One can notice from figures (1.17) and (1.18) that the pressure and velocity have the inverse behavior. When the fluid outgoes from the valve of the tank, the pressure inside the tank increases, while the maximum velocity is obtained at the tank outlet.

Next, the evolution of the velocity direction for different simulation time steps has been further investigated using the animation of the *Stream Tracer*, *Tube* and *Glyph* filters in ParaView. The results are given in figures (1.19) and (1.20). These latter demonstrate the transmission and reflection of the liquid flow wave propagation in the tank.

Figure 1.19: Animation of the Velocity Profile at different simulation time steps, using the *Stream Tracer* and *Tube* filters.

Figure 1.20: Animation of the Velocity Profile at different simulation time steps, using the *Glyph* filter.

In what follows, we will be interested in plotting the evolution of the pressure and velocity profiles over time and over a specified line.

1.2.4 Velocity and Pressure Results Plotting

Plotting over Line

The velocity and pressure profile have been plotted along a specified line for different x-coordinates, as illustrated in figure (1.21). The selected vertical line, presented in figure (1.21) goes from the nozzle to the bottom of the tank.

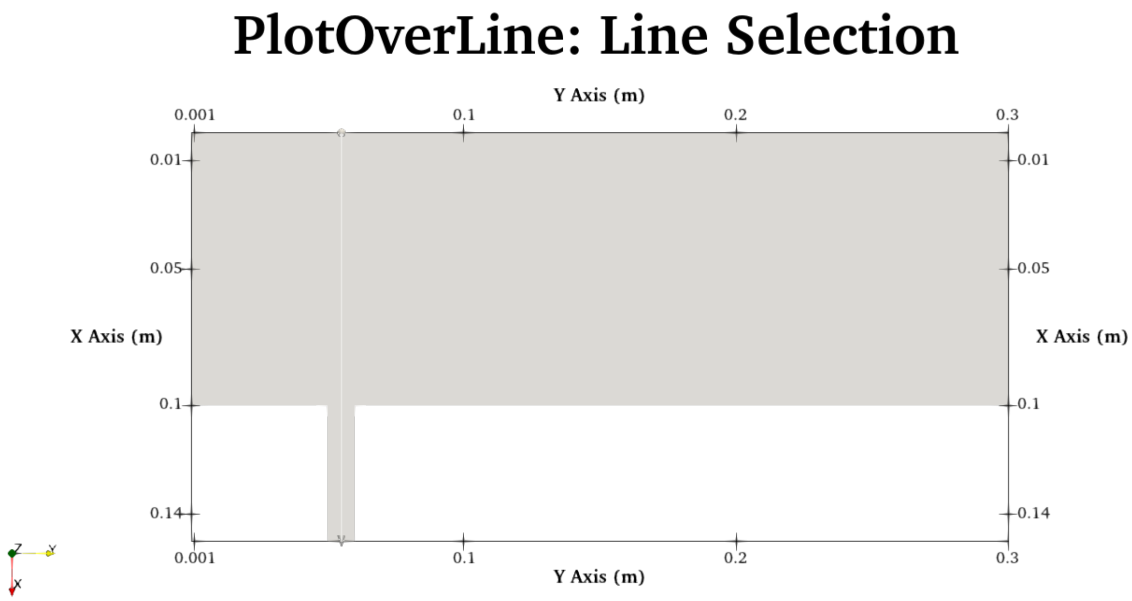

Figure 1.21: Line selection for the PlotOverLine feature in ParaView.

Considering the selected line, both the velocity and pressure behaviors have been plotted along the different x-coordinates at the beginning and end of the simulation.

For instance, figure (1.22) shows the behavior of the pressure and velocity at an initial time equal to $0sec$ at the beginning of the simulation.

At the bottom of the tank for an initial simulation time equal to $0sec$, the pressure is maximum and evaluated to $2.5e^6Pa$. This pressure remains constant until it reaches an x-coordinate of $0.145m$. Then, the pressure value decreases rapidly till it reaches a null value at an x-coordinate equal to $0.15m$, corresponding to the nozzle part as shown in figure (1.1). However, the velocity remains constant and having a null value along the selected line. This is predicted since the liquid is stagnant at the initial time of $0sec$.

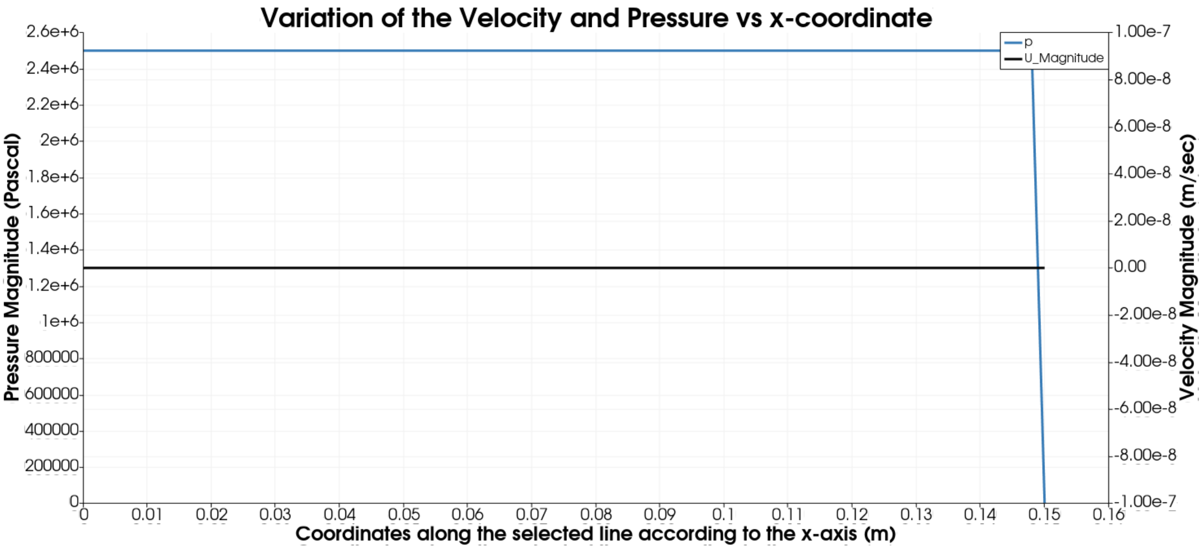

Figure 1.22: Variation of the Pressure and Velocity versus x-coordinates along the selected line at time = $0sec$.

In figure (1.23), the velocity and pressure variation have been plotted versus the different x-coordinates along the selected line.

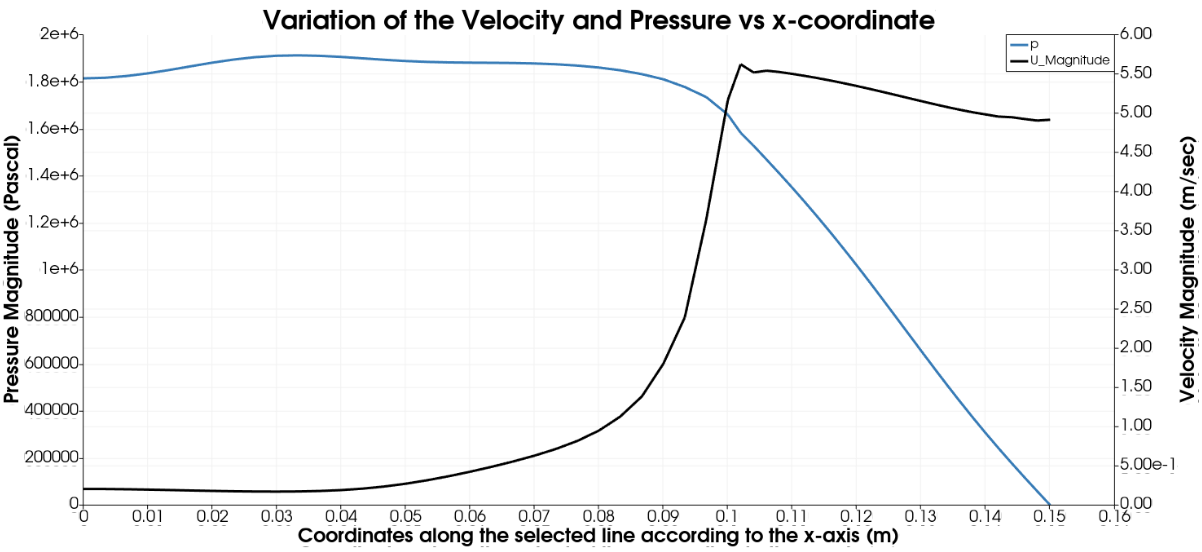

Figure 1.23: Variation of the Pressure and Velocity versus x-coordinates along the selected line at time = $14sec$.

On the one hand, at the end of simulation time equal to $14sec$, the pressure at the different points of the line going from the nozzle through the tank fluctuates around the pressure value of $1.8e^6 Pa$ from the null x-coordinate at the bottom of the tank until an x-coordinate equal to $0.09m$ at the valve opening. Then, the pressure decreases rapidly until it reaches a null value for an an x-coordinate equal to $0.15m$, corresponding to the nozzle part. This behavior is also shown in figure (1.12).

On the another hand, the velocity magnitude has a very small value close to $0m/sec$ until it reaches an x-coordinate equal to $0.05m$ inside the tank. Then, it increases rapidly until it reaches $5.6m/sec$ for a position slightly superior to $0.1m$, which corresponds to the inlet of the tank (valve). As the liquid goes out through the nozzle, the velocity magnitude along the line slightly decreases to $5m/sec$. This behavior is further shown in figures (1.6), (1.7) and (1.9).

Plotting over Time

To better visualize the pressure evolution over time, this latter has been plotted for a fixed position inside the valve $(0.102m, 0.054m)$ in the XY plane for different simulation scenarios. This is illustrated in figure (1.24). The point is presented in pink.

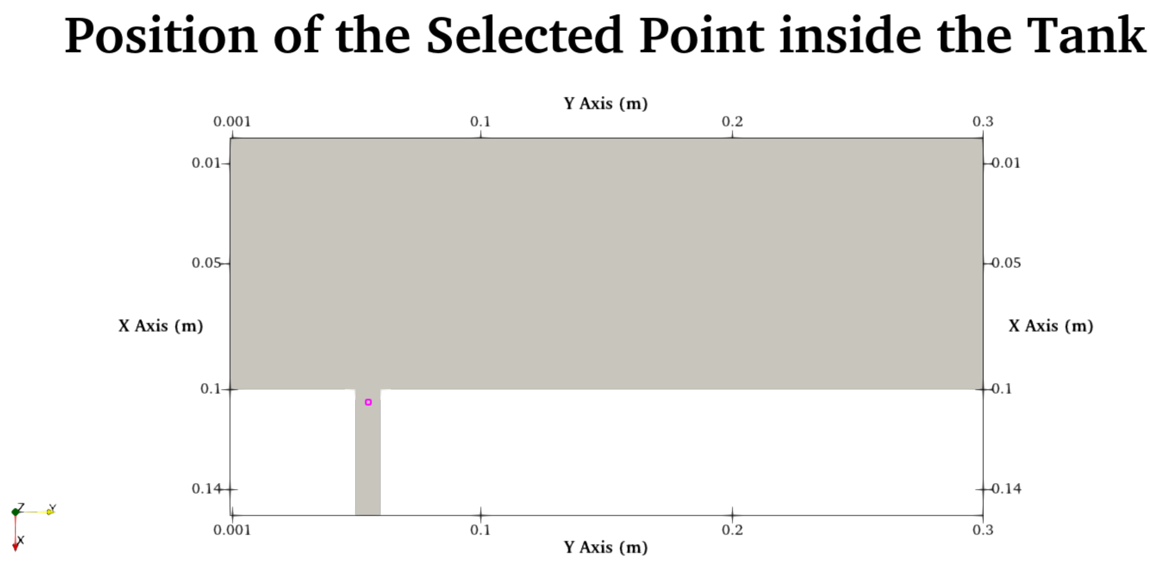

Figure 1.24: Position of the selected point inside the tank for the *PlotSelectionOverTime* feature in ParaView.

The pressure versus time curve is illustrated in figure (1.25). One can notice seven main regions in the given curve, as follows:

- In the time interval $[1s, 2s]$, there is a delay in the pressure curve and the pressure value is constant evaluated to $2.5e^6 Pa$,
- In the time interval $[2s, 4s]$, there is a decompression and the pressure decreases rapidly until it achieves a value of $7e^7$ at a time of $4sec$,
- At a time of $4sec$, there is a reflection of the pressure,

- In the time interval $[4s, 9s]$, there is an increase of the pressure until it reaches a value of $2.2e^6 Pa$ at a time of $9sec$,
- In the time interval $[9s, 12s]$, there is an increase of the pressure from $2.2e^6 Pa$ at $9sec$ to approximately $1.2e^6 Pa$ at $12sec$,
- At a time of $12sec$, there is a reflection of the pressure,
- In the time interval $[12s, 14s]$, there is a slight increase of the pressure from approximately $1.2e^6 Pa$ at $12sec$ to $1.6e^6 Pa$ at $14sec$.

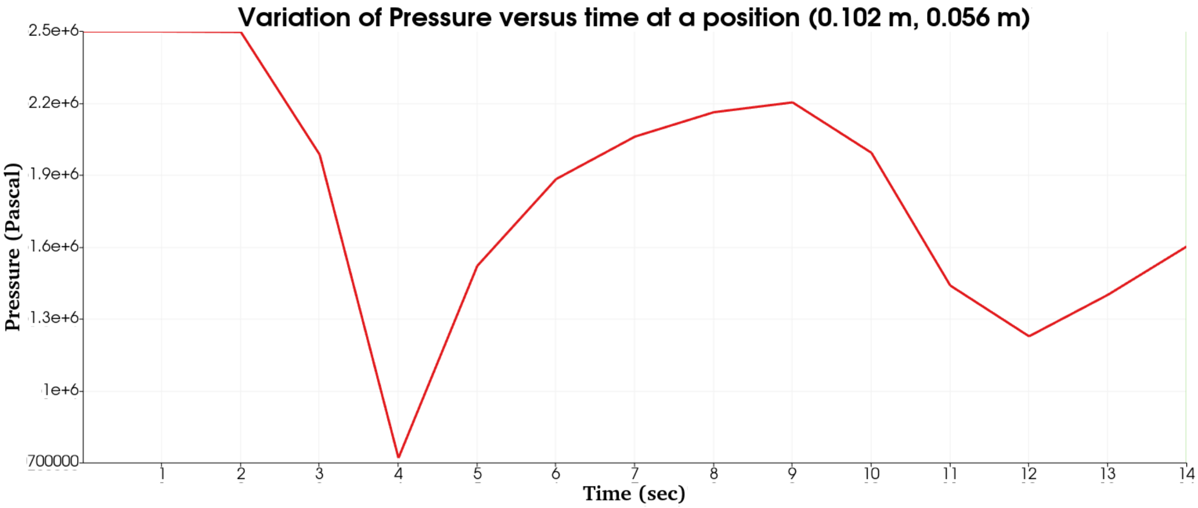

Figure 1.25: Variation of the pressure versus time for a fixed position (0.102m, 0.056m).

1.2.5 Conclusions

During the phenomenon of the rapid opening of a pipe valve close to a pressurised liquid-filled tank, one can deduce the following assessments:

- The propagation of the pressure wave into the tank generates transmission of this latter into different direction of the tank but also numerous reflections from the inside walls,
- The opening of the valve generates the outgoing of the liquid flow outside the tank and thus the velocity is higher in this region.

Following this work, it is evident that the data visualization is important to understand different physical behaviors and phenomena. This was made possible through the different filters, such as *Contour*, *Stream Tracer*, *Tube*, *Ribbon*, *Glyph*, and animations within the ParaView software.

References

"Data visualization" (2022). Wikipedia. URL: https://en.wikipedia.org/wiki/Data_visualization.

"Decompression of a tank internally pressurised with water" (2022). OpenFoam. URL: https://www.openfoam.com/documentation/tutorial-guide/3-compressible-flow/3.3-decompression-of-a-tank-internally-pressurised-with-water.

"Structured Grids in CFD " (2022). Design Engineering. URL: https://www.design-engineering.com/cfd-automeshing-1004028397-1004028397/.

Appendix A

Appendix: GitHub

The work, including the different states and generated animations and images, is also available in *GitHub*. The SSH key is the following:

git@github.com:Chaichas/Data_Visualization.git