# STUDY OF DIFFERENT FLOW REGIME FOR TWO PHASE GAS-LIQUID FLOW IN LARGE DIAMETER VERTICAL RISER

by

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## Abstract

Accurate prediction of flow regime for multiphase flow problems in vertical riser, has a very important role in proper prediction of liquid holdup and flow rate of different phases through that riser. This prediction has a huge impact on industries such as oil and gas, chemical and nuclear. Our study for this project is not to analyze change of phase at different pressure-temperature, but to understand the flow behavior of gas-liquid flow at different superficial velocity of gas and liquid in large diameter (25 mm-280 mm) vertical riser. At first, we studied a single taylor bubble rise in a non-inclined vertical riser as an axisymmetric 2D problem. Then we moved onto a 3D vertical riser to observe other non-symmetric flow regimes and compare our simulation result with experimental data obtained from literature. Finally, we have done a shut-in restart procedure, common in oil and gas well. We observed flow regimes and transition to churn flow. A critical reasoning for transition of different flow regime and the parameters affecting that are discussed in detail.

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# Chapter 1: Introduction

The application of multiphase flow in vertical pipe or vertically inclined pipe is very common all around us. In some industries such as oil and gas, chemical and nuclear industries, accurate observation of multiphase flow takes a very important role. For example, in oil and gas industry, inaccurate observation of multiphase flow in vertical pipe will lead to wrong production analysis from well, and that may lead to bankruptcy. So, to avoid this issue and properly design the pipe, multiphase flow observation through large diameter pipes has a crucial role. For the simplicity of our problem, we will consider two-phase gas-liquid flow for our analysis.

There has been very few published work done in two phase gas-liquid flow through vertical riser compared to horizontal pipe. There are fewer work on large diameter vertical risers. Also, almost all the experimental work has been done by visual observation, which is limited in understanding the transitions between flow regimes properly. So, the motivation for this project is to numerically analyze the different flow regime and transitions between them to understand the two phase flow behavior more accurately.

Gas-liquid two phase flow regimes and classified depending on the volume fractions and their shape in the mixture. In general they are most commonly classified as bubble flow, slug flow, Churn flow and annular flow. These different types of flows affect the mixture flow rate differently. For example, it is very hard to predict the flow rate in a churn or chaotic flow. With better understanding of flow regime, more accurate prediction of liquid holdup or production forecast can be done and suitable design for optimum performance can be made.

In this project, we are going to start with numerical simulation of a taylor bubble in a large diameter riser as Taha[1]. Then, we will numerically analyze the slug-churn transition experiment done by Barnea[2]. We want to do a numerical simulation of the experiment of air-water flow along large vertical pipe done by Lucas[3], as their experimental setup was most described in details. Our final goal would be to compare 2 different diameter vertical rise flow regime at same superficial velocities.

# Chapter 2: Background and Literature Review

Both liquid and gas coexist in two phase flow along vertical riser. These two different density fluids acts differently at various velocities with body force acting on them. Two phase flow in vertical riser is very common, and accurate prediction of this system has huge impact on industrial sector. Generating optimum design of a piping system requires proper knowledge of pressure drop in the system. This pressure drop in two phase flow is linked to the understanding of different flow regime in the system. In vertical riser, flow prediction becomes more difficult compared to horizontal pipe, due to body forces acting on it. When the tube diameter is greater than 10 mm, we assume negligible capillary effect. Our focus on this paper is the large diameter vertical riser which is more challenging according to the literature.

## 2.1 TYPES OF FLOW REGIME

Depending on the superficial velocity of liquid and gas, different bubble pattern has been observed visually and generally classified as bubble, slug, churn and annular flow as shown in figure 1. The pipe geometry, fluid properties, volume fractions of gas-liquid and surface tension can also affect these flow regimes. Commonly, at low gas superficial velocity with low volume fraction, bubble flow is observed. Increasing the gas velocity results in transition to slug flow by coalescing of small bubbles. Increasing the gas velocities more will result in breaking of that slug and leads to unstable chaotic flow. At higher gas velocities, the flow becomes annular (gas at center and layer of liquid at wall).

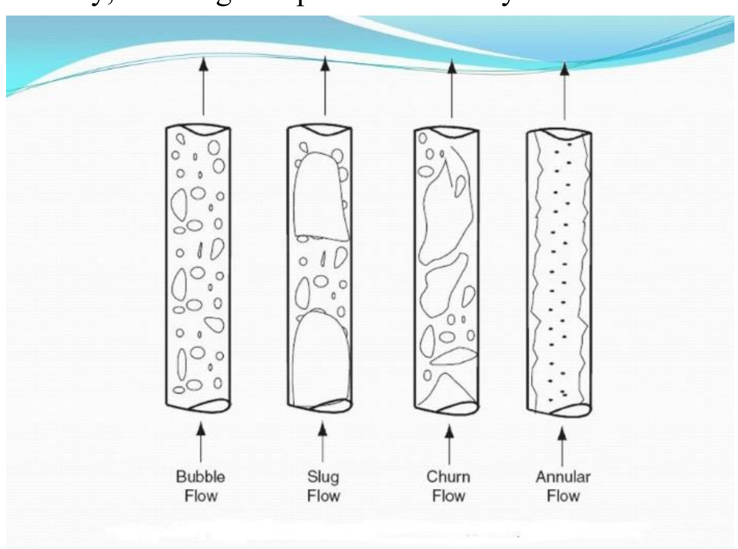



Figure 2.1: Vertical Upward two phase flow regime[Shoham,1982]

## 2.2 Previous Experimental Approach

As almost all industrial pipes are made of steel or non-transparent material, direct visual observation of these flow regime is impractical. All experiments to understand the flow has been done with transparent pipes. However it is extremely important to develop a correlation between different parameters for accurate prediction of these flow regimes. In this paper we will mostly focus on the correlation of superficial velocities of gas and liquid at different flow regime and transition between them. A good amount of experimental work has been done on 10 mm-100 mm diameter upward vertical flow at an early age, such as the air-water upward flow in 25 mm pipe from Taitel et al.[4]. Barnea [2] has his work to understand the transition between slug to annular flowDue to the recent increase in production, interest is more focused on larger diameter pipe. For example, 254 mm riser by Farman[5], and 280 mm rise by Schoppa. Despite this experimental approaches, a standard for these experimental setup has yet to be formed. Due to the slight differences in their experimental setup and lack of detailed information, it has been hard to recreate the same experiment at a later time. A detailed experiment has been done by Lucus[3], dedicated to close the gap between experimental and numerical approach to this upward vertical riser problem.

## 2.3 Numerical Approach

Very few numerical work has been done for the large diameter vertical riser due to the complexity of the problem. Farman[5] and Schoppa[6] has shown numerical simulation results from OLGA to show the deviation of the numerical simulated result from experimental result. Schoppa[6] has also shown a comparison with results from ANSYS Fluent and showed good agreement to the experiment. OLGA is a 1D simulation software developed from years of experimental data from actual oil wells. On the other hand ANSYS Fluent is a 3D solver with more accurate computation but more computational cost. Fluent has three multiphase models. They are Volume of Fluid (VOF), Mixture Model and Eulerian Multiphase Model. In our problem, VOF or

Eulerian model can be approached. Considering the problem statement and computational cost, we have decided to use VOF model in fluent for our analysis.

With an accurate numerical simulation of different flow regimes, correlation between the flows and transition between them can be closely observed and their identification process can be classified based on parametric values.

# Chapter 3: Problem Statement & Methodology

Main objective of this project is to analyze flow in large diameter vertical riser at different superficial velocities of liquid and gas. Two different diameter (25 mm and 254 mm) vertical riser is considered for this project. The superficial velocities will be chosen from the literature so that all the flow regime exists in that velocity region. Finally a comparison between those two different diameter flow pattern maps will be compared and analyzed.

## 3.1 SIMULATION-1

We started our initial simulation with the tutorial from ANSYS user manual on inkjet. The problem statement is to inject water into an air filled chamber and propagation of the water is observed over time. Gravitational body force is not considered for this problem.

Water:

Density = $998.2\ \frac{kg}{m^3}$

Viscosity = $0.001003\ \frac{kg}{m-s}$

Air:

Density = $1.225\ \frac{kg}{m^3}$

Viscosity = $1.7894e-05\ \frac{kg}{m-s}$

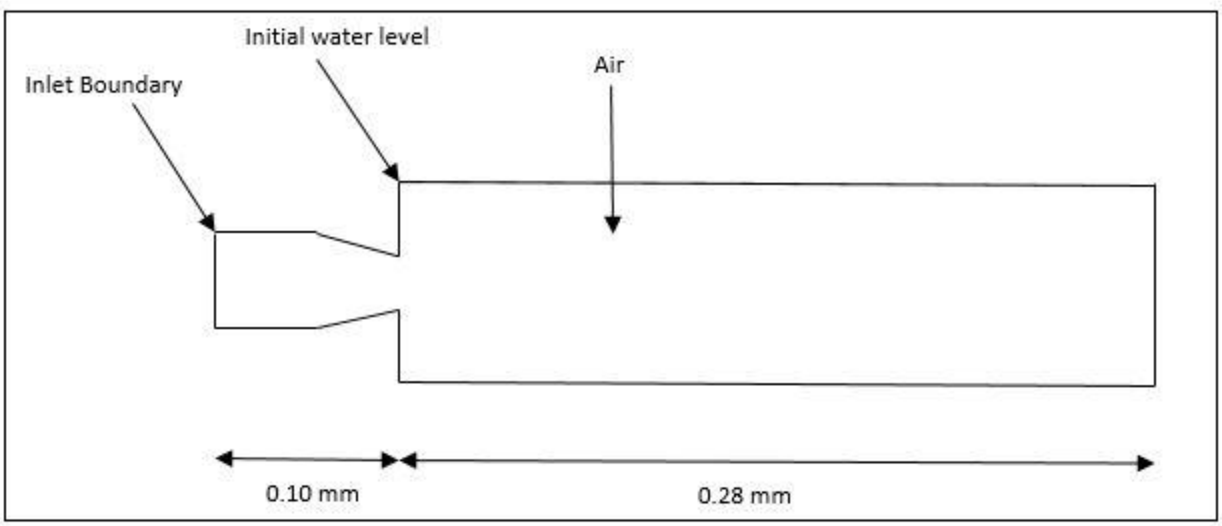



Figure 3.1: Schematic of water jet propagation in air chamber

### 3.2 SIMULATION-2

For our second initial simulation, we planned to simulate axisymmetric slug flow done by Taha[1]. However from the simulation results until now, we observe a non-symmetric behavior. So, we moved on to a propagation of taylor bubble only due to gravitational body force acting on it. We have used 2D geometry as the flow is symmetric.

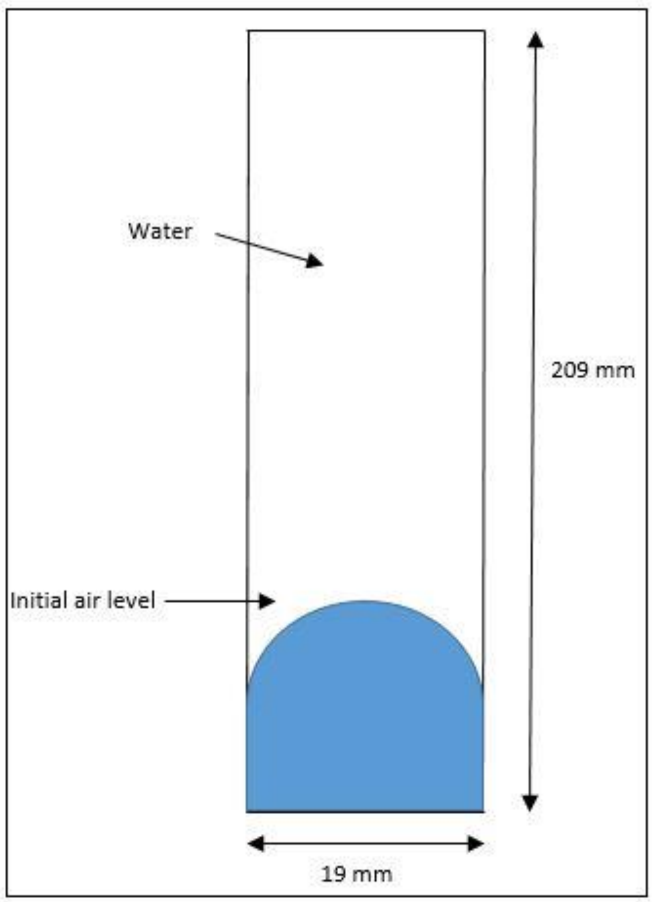



Figure 3.2: Schematic of rise of taylor bubble by gravitational body force

Structured mesh was created for the initial simulations. As recommended for the multiphase flow problems, a uniform mesh was created for the 2D geometry with sizing mesh method. An overview of the mesh for simulation-2 is shown in figure 3.3.

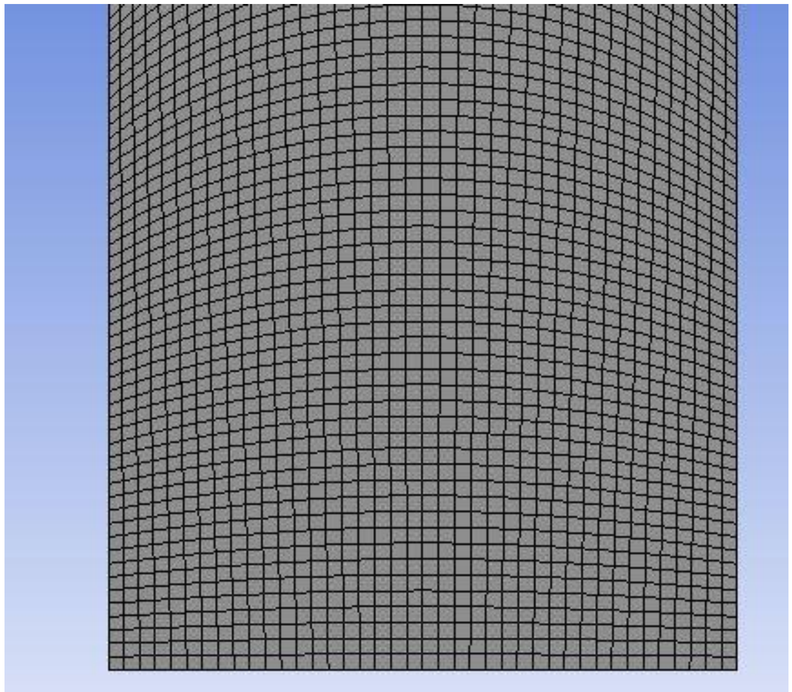


Figure 3.3: Uniform structured mesh near bottom of vertical riser

In figure 3.4, selected mesh quality is checked. From observation, most of the elements has orthogonal quality near 1, low skewness and low aspect ratio. These are all quality of a good mesh.

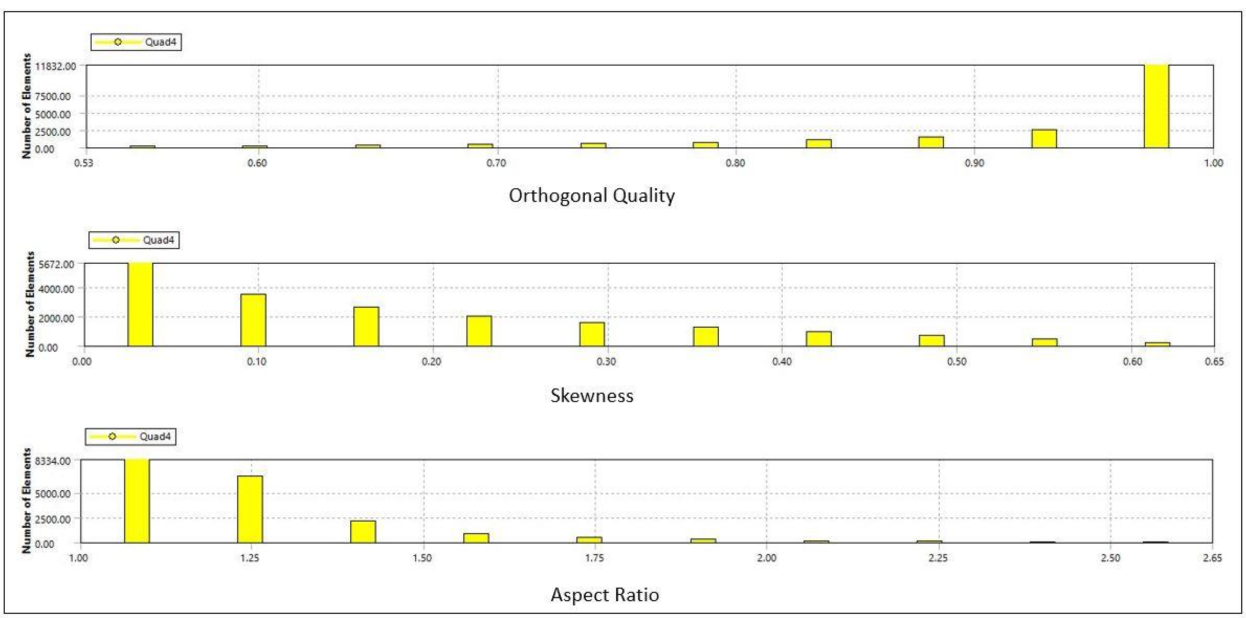



Figure 3.4: Mesh Quality

### 3.3 SIMULATION-3

We approached the axisymmetric taylor buble rise in a 25 mm vertical riser similar to Taha[1]. The case setup was for a taylor bubble rise in an infinite pipe. Taylor bubble velocity was defined by wall translational downward motion.

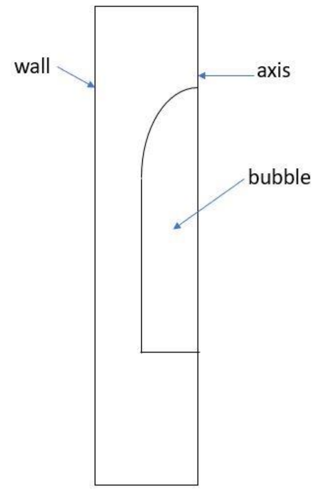



Figure 3.5: Schematic of axisymmetric taylor bubble rise

### 3.4 SIMULATION-4

For our 4th simulation, we have tried to validate our simulation result with experimental work done by Barnea[2] with 25 mm diameter vertical riser. Same experiment has been done by Taitel-Dukler[4] as well. Barnea's[2] paper was mainly focused on the effect of L/D ratio on flow regime and showing that with the increase in L/D ratio churn flow regime gradually disappear. Due to the limitation of resources, we only ran 3D simulation with L/D ratio 10. Figure 3.6 shows a schematic of the riser.

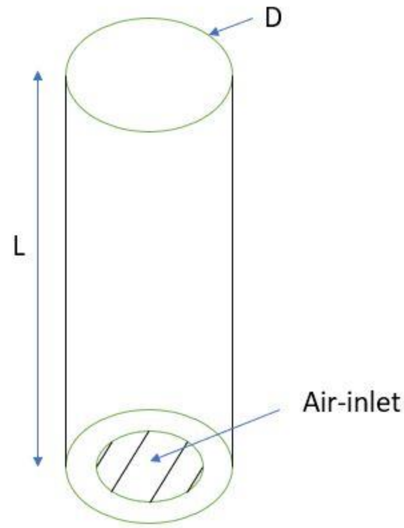



Figure 3.6: Schematic of 25 mm diameter vertical riser

Uniform structured mesh has been used. With structured mesh, number of elements was less. The element size was about 3 mm. With coarser mesh, smaller bubble was causing numerical instability and Fluent crashed. With finer mesh we may obtain more accurate result. However, it becomes nearly impossible with our resources, to satisfy CFL condition. The mesh chosen at a cross section is shown in Figure 3.7.

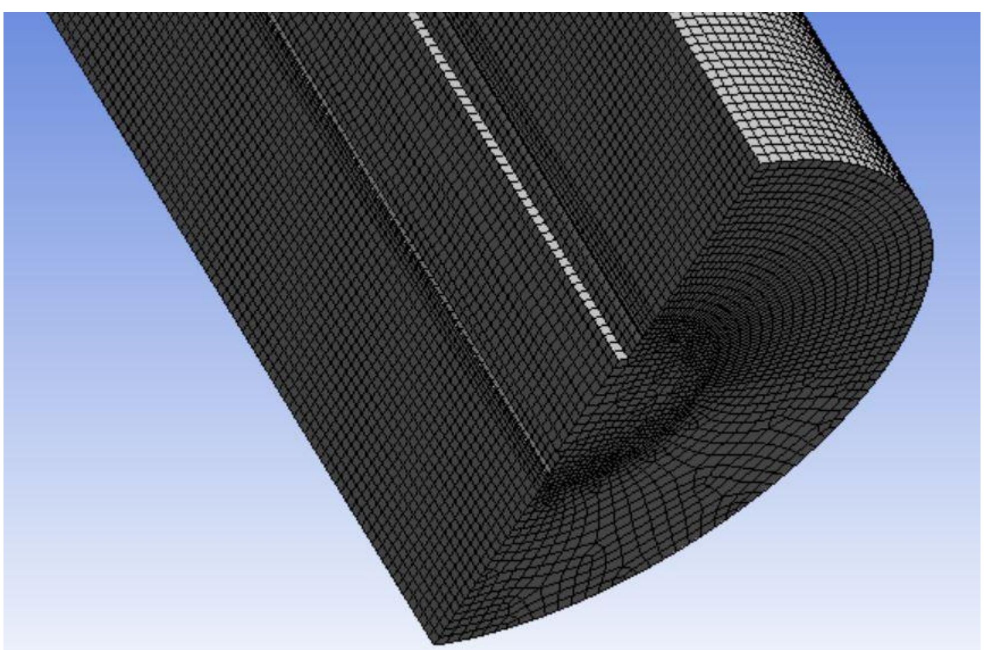


Figure 3.7: Mesh at a cross-section of 3D vertical riser

### 3.5 COMPUTATIONAL MODELING

For these simulations and for future simulation in ANSYS Fluent, Volume of Fluid (VOF) multiphase model with implicit body force has been used. Laminar viscous model has been considered for simulation 1 & 2. Both simulations were done with non-iterative method Fractional-step and PISO scheme. K-eps RNG turbulent model was used for the other simulations. Courant number was controlled using variable timestep size for stable solution. Scaling was done to improve control over CFL condition.

# Chapter 4: Result and Discussion

From simulation-1, we notice the propagation of a volume of water propagating through air chamber without gravitational body force acting on it. Figure 4.2 shows water volume at different time in the air chamber. We notice from the figure that the volume of water broke in two parts and oscillating as it is moving forward.

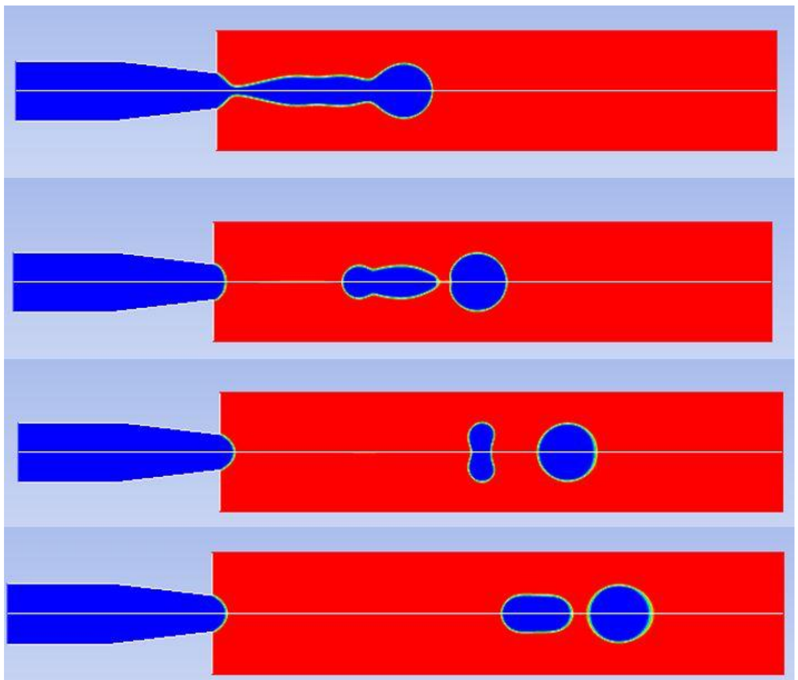


Figure 4.1: Volume fraction of water propagating through air chamber

From simulation-2, we observe the rise of a taylor bubble by gravitational body force. No external velocity or pressure has been applied as initial condition. Figure 4.2 shows the bubble volume fraction at different time. We notice that separation of smaller bubble occurs at the tail of the slug. This agrees with the literature for two phase slug flow.

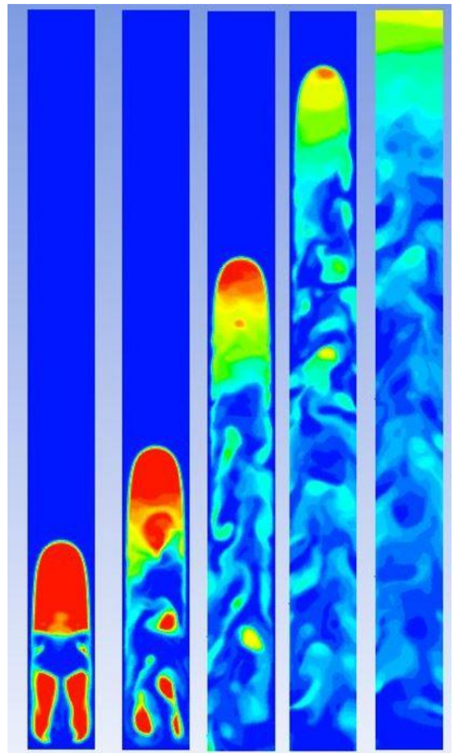


Figure 4.2: Taylor bubble rise in vertical riser

From Figure 4.3, we observe the bubble at two different Reynold's Number and the velocity vector representing liquid motion around the taylor bubble.

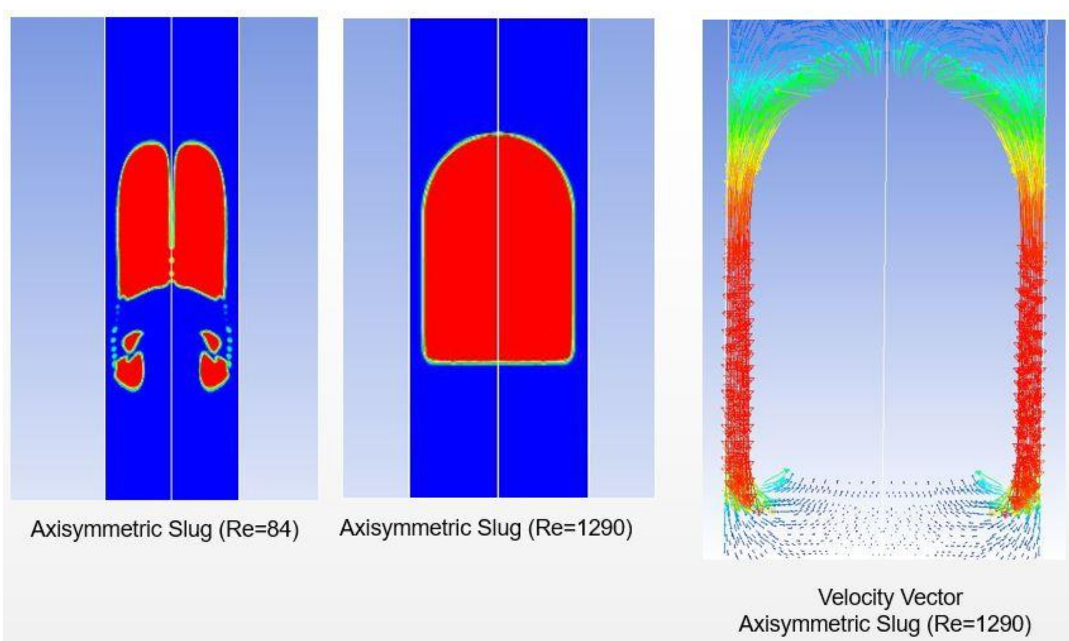



Figure 4.3: Axisymmetric taylor bubble rise at different Re

We observe that at low Reynolds Number, bubble breaks at the middle and there are shredding of small bubbles at the tail. At higher Re the bubble shape becomes stable. However, from Figure 4.4, we notice that when the bubble volume fraction becomes low due to shredding, it breaks in the middle. We also notice vortex forming at the tail of the bubble at very high Re.

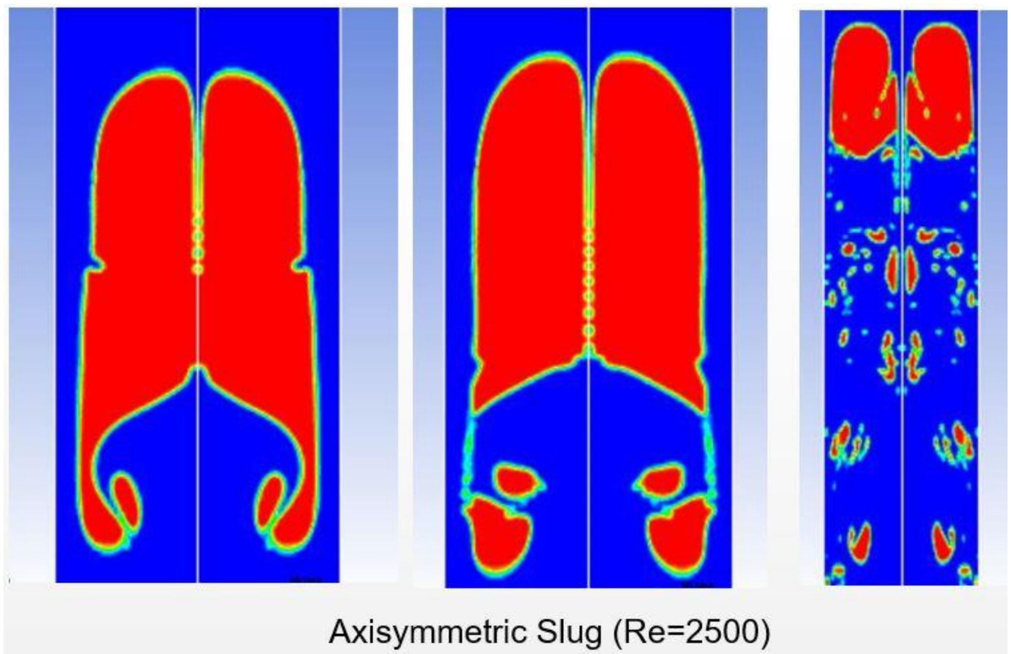
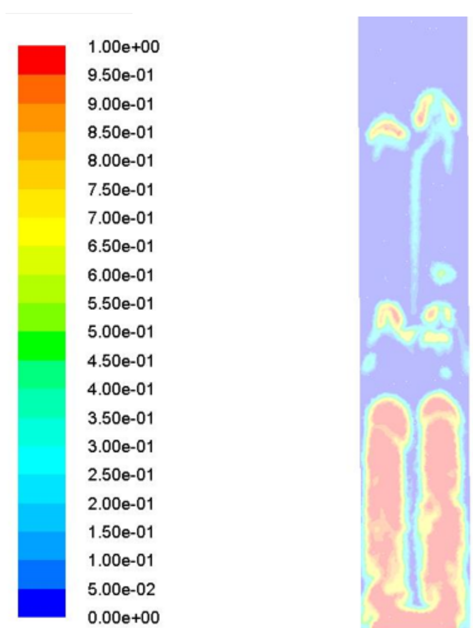



Figure 4.4: Axisymmetric taylor bubble rise at very high Re




| $U_{GS}$ m/s | $U_{LS}$ m/s | Air Volume Fraction | Flow Regime |
|---|---|---|---|
| 0.1 | 1 | 0.09 | Bubble |
| 1 | 0.01 | 0.99 | Slug |
| 8 | 0.01 | 0.998 | Churn |
| 15 | 0.01 | 0.999 | Annular |

Figure 4.5: 3D simulation of different flow regime at vertical cross-section

The table shown in Figure 4.5 is formed by taking four different flow combinations for 4 flow regimes. Boundary conditions were changed in the middle of simulation to optimize resources. As we notice, the bubble flow, slug flow and annular flow regime observed according to the data from Taitel-Dukler[4].

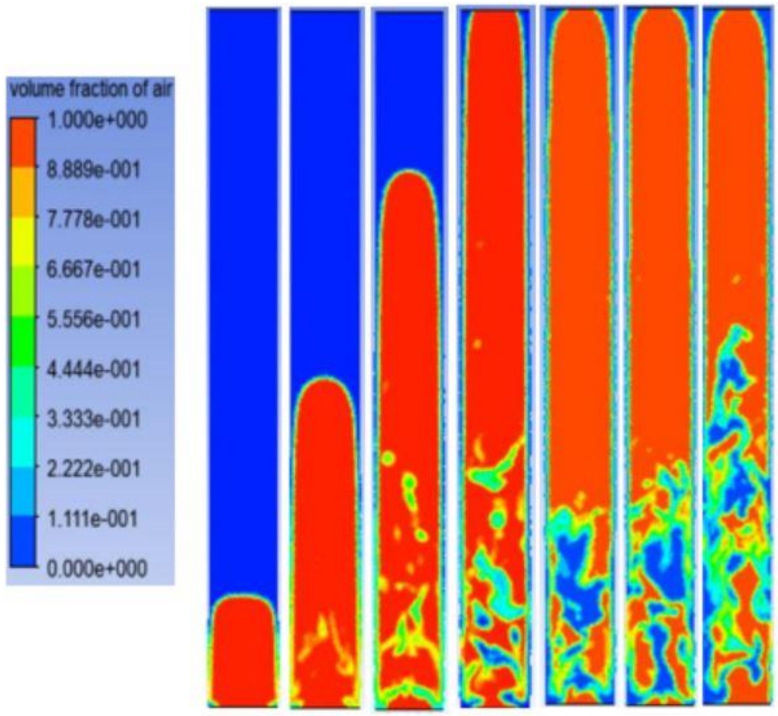



Figure 4.6: 3D simulation of air-flow in liquid filled vertical riser

Figure 4.6 shows air-flow in 25 mm liquid filled vertical riser at a cross-section for the same domain. We tried to analyze high air flow rate from bottom inlet in a liquid filled riser with no liquid inflow which is similar to shut-in restart process in oil and gas well. We noticed that most of the water is evacuated with an initial slug of air and developed churn flow regime. There is a small amount of water trapped in the riser moving chaotically jumping up and down.

# Chapter 5: Conclusion

Different flow regime and factors causing transition between them in large diameter upward vertical riser has been attempted to understand in this paper. Both volume fraction of air and air-water superficial velocities are critical parameters for transitions between flow regimes. We were not able to investigate the impact of pipe length and diameter due to lack of resources and limitation of time. Efficiently running VOF model in ANSYS Fluent has been understood and implemented. Good understanding of mesh requirements and CFL condition for multiphase flow problem has been obtained through this project. Difficulty in numerically study multiphase flow problem has been well understood.

## Future Work

Making a comparison between two different diameter and length pipe to analyze the influence of length and diameter on flow regime and transition between them. Developing flow pattern map for different diameter pipe and compare with highly cited literatures.

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