International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-3, Issue-4, April 2015

Two Phase Flow Measurement and CFD Analysis in an Air lift loop

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***Abstract*— Our paper is based on two-phase flow and its measurement (water + air/vapour). This is frequently encountered in thermal and nuclear power plants, R&A/C and cryogenic applications, chemical industries and biotechnology. We are designing and fabricating an experimental setup on which we are demonstrating two phase flow. Here we are arranging a vertical tube with two water inlets and three air inlets. By varying air and water flow rates following things are demonstrated and calculated:**

1. Flow regime identification through visualization 2. Void Fraction Measurement 3. Pressure drop measurement

Here we are going to analyze the flow of air + water mixture using Computational Fluid Dynamics (CFD).
CFD is an advanced technique that solves many complex fluid dynamics problems.

***Index Terms*— Computational Fluid Dynamic -Analysis, Pressure drop, Two-phase, Void Fraction.**

I. INTRODUCTION

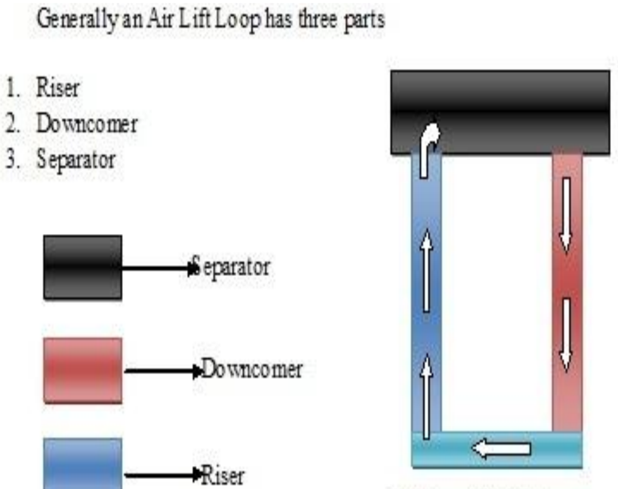
Two-Phase flow is defined as simultaneous flow of two different immiscible phases separated by an infinitesimal thin interface. The simpler case of Two-phase flow denotes the simultaneous flow of two different phases. Two-phase flows can be liquid and gas, liquid and solid (e.g.: slurries), or gas and solid (e.g. dusts, aerosols etc). In energy technology, we are most often concerned with Two-phase flows of a liquid and a gas. Liquid-gas mixtures of two different chemical components (e.g. air and water) are called two component mixtures. Mixtures of a liquid and its vapour are called single-component flows

In Void fraction is one of the most important parameters used to characterize two-phase flows. It is the key physical value for determining numerous other important parameters, such as the two-phase density and the two-phase viscosity, for obtaining the relative average velocity of the two phases and is of fundamental importance in models for predicting the flow pattern transitions, heat transfer and pressure drop.

Pressure losses in two-phase (gas –liquid) flow are different from single-phase flow. An interface exists in most cases and gas slips past the liquid with a surface of varying degree of roughness depending upon the flow pattern. Each phase flows through a smaller area than if it flow alone causing high pressure losses when compared to single-phase flow. Additionally this segregated flow changes at any point along the flow path during the fluctuating flows. Under the conditions of disturbed phases, protection of fluid mixture properties like density and viscosity becomes a challenge for the design engineer.

A. *Air lift loop:*

Circulation loops have been described where the driving mechanism for fluid flow is the temperature difference. The differential heating of the loop brings a density difference of the fluid. If the fluid is liquid, it may also change into vapor phase depending on the operating condition. Due to its own merits Air lift loops require in-depth investigations. Air Lift Loops are extensively used as mixing devices and reactors in chemical engineering. As the loop circulation rate cannot be controlled directly, its design is often a challenge to the engineers. The flow phenomenon in a loop is complex as it is single phase in some part of the loop while it is two phase in the riser and in the separator. Experimental studies are required to investigate this complex flow phenomenon and to check the validity of any model developed for the prediction of loop behavior.



Generally an Air Lift Loop has three parts

1. Riser
2. Downcomer
3. Separator

Fig 1: Air Lift Loop

B. *Computational Fluid Dynamics:*

Broadly, the strategy of CFD is to replace the continuous problem domain with a discrete domain using a grid. In the continuous domain, each flow variable is defined at every point in the domain. For instance, the pressure p in the continuous 1D domain shown in the figure below would be given as

$$p = p(x);\ 0 < x < 1$$

In the discrete domain, each flow variable is defined only at the grid points. So, in the discrete domain shown below, the pressure would be defined only at the N grid points.

$$p_i = p(x_i);\ i = 1, 2, \ldots\ldots\ldots N$$

Manuscript received April 02, 2015.

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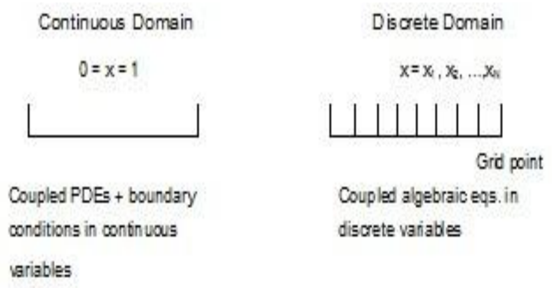
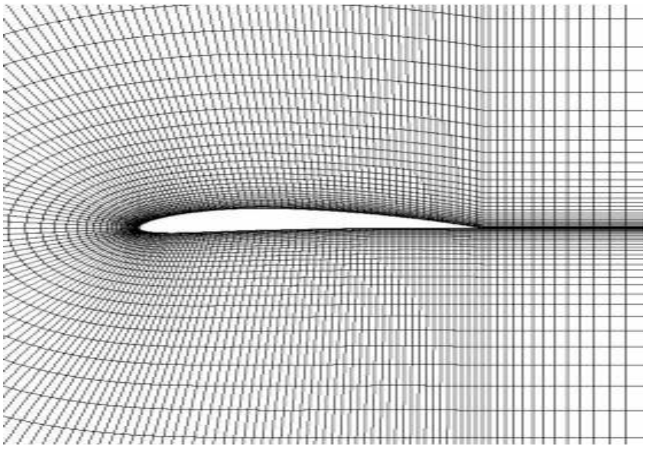


In a CFD solution, one would directly solve for the relevant flow variables only at the grid points. The values at other locations are determined by interpolating the values at the grid points. The governing partial differential equations and boundary conditions are defined in terms of the continuous variables p, V etc. One can approximate these in the discrete domain in terms of the discrete variables p_i, V_i etc. The discrete system is a large set of coupled, algebraic equations in the discrete variables. Setting up the discrete system and solving it (which is a matrix inversion problem) involves a very large number of repetitive calculations and is done by the digital computer. This idea can be extended to any general problem domain. The following figure shows the grid used for solving the flow over an airfoil.



II. THEORETICAL BACKGROUND:

A. Flow Regimes:

When a liquid is vaporized in a heated channel the liquid and the vapor generated take up a variety of configurations known as flow patterns. The geometrical and topological configurations of the interfaces determine the flow regime or flow pattern. These are idealizations of the real situation useful for modeling. Their definition and discrimination between flow regime is, however, often quite subjective. The particular flow pattern depends on the conditions of pressure, flow and heat flux and channel geometry. In transparent channels at low velocities it is possible to distinguish the flow pattern by direct visual observation.

B. Flow Patterns in Vertical Flow

The flow patterns encountered in vertical flow are

1. Bubbly flow
2. Slug or Plug flow
3. Churn flow
4. Annular flow
5. Wispy-Annular flow

BUBBLY FLOW: In the Bubbly flow, the gas or vapor phase is distributed as discrete bubbles in a continuous liquid phase. At one extreme the bubbles may be small and spherical and at the other extreme the bubbles may be large with a spherical cap and a flat tail.

SLUG FLOW: In Slug flow, the gas or vapor bubbles coalesce into long vapor regions that have approximately the same diameter as that of the pipe. The nose of the bubble has a characteristic spherical cap and the gas in the bubble is separated from the pipe wall by a slowly descending film or liquid. The liquid flow is contained in liquid slugs, which separate successive gas bubbles.

CHURN FLOW: Churn flow is formed by the breakdown of the large vapor bubbles in the slug flow. The gas or vapor flows in a more or less chaotic manner through the liquid, which is mainly displaced to the channel wall. The flow has an oscillatory or time varying character; hence, the descriptive name ‘churn’ flows. The region is also referred to as semi-annular or slug annular flow.

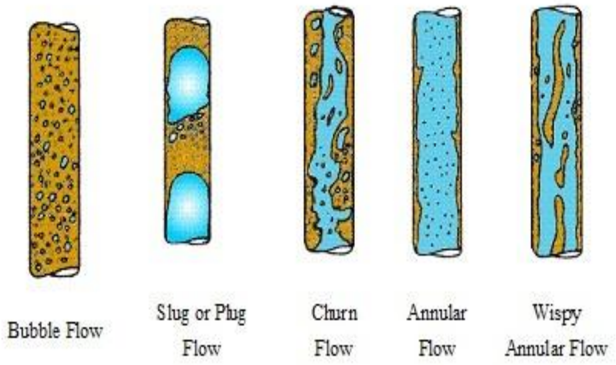


Fig: Two-Phase Flow Patterns in Vertical Tube

ANNULAR FLOW: In Annular flow, a liquid film forms on the pipe wall with a continuous central gas or vapor core. Large coherent waves are usually present on the surface of the film and the continuous break up of these waves, forms a source for droplet entrainment, which occurs in varying amounts in the central gas core.

WISPY-ANNULAR FLOW: In Wispy-Annular flow, the region takes the form of a relatively thick liquid film on the walls of the pipe together with a considerable amount of liquid entrained in a central gas or vapor core. The liquid in the film is aerated by small gas bubbles and the entrained liquid phase appears as large droplets, which have agglomerated into long irregular filaments or wisps revealed in tensile testing for fracture due to shrinkage or elongation.

C. Flow Pattern Transitions in Vertical flow:

The most important transitions in flow pattern in vertical flow are:

BUBBLE-SLUG TRANSITION: This transition occurs as a result of *bubble coalescence* leading to gradual bubble growth and the formation of large Taylor-type bubbles which occupy the whole pipe cross-section. Typically, the transition to slug flow occurs when the void fraction is around 25-30%. In highly turbulent flows, break-up of the bubbles may be postulated to occur (though this is rarely seen in actual bubble flows) to offset the progression of the coalescence. However, recent information seems to indicate that this view of the transition may be quite wrong. It seems more likely that void waves are formed in the flow, and that, within these waves, the bubbles become closely packed and are better able to coalesce, leading to plug flow.

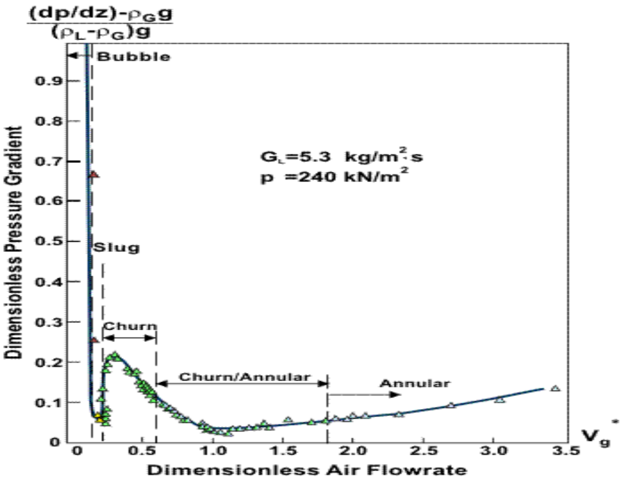
PLUG-CHURN TRANSITION: This has been an area of major controversy. Probably the main difficulty has been a semantic one - "Churn flow" which is essentially a developing plug or slug flow. However, churn flow as defined here does exist in fully developed flow, and has the following unique characteristics:

a. The regime is entered from slug flow by the formation of flooding-type waves and these persist as characteristics of the regime throughout. Such waves are absent in both slug flow and annular flow but are formed repeatedly in the churn flow regime and transport the liquid upwards.

b. In between successive flooding waves, the flow of the liquid phase in the film region near the wall reverses direction, and is eventually entrained by the next upward-moving wave.

The onset of churn flow is accompanied by a sharp increase in pressure gradient.

CHURN–ANNULAR TRANSITION: As the gas velocity is increased after the churn flow regime has been entered, the pressure gradient initially decreases and then passes through a minimum value .The flooding waves (and their associated intensive gas-liquid interactions) promote large pressure gradients, and as they disappear, the pressure gradient reduces



Graph: Data for pressure gradient in fully developed air-water flow in a vertical tube.

Eventually, however, the pressure gradient increases again as the gas flow rate increases. The onset of true annular flow is defined as that corresponding to the point at which there is no flow reversal within the liquid film. This might correspond approximately to the pressure drop minimum. Another definition might be the flow reversal point .It is clear that, though both churn and annular flow have the characteristic of having a liquid layer at the wall and a gas core in the centre of the pipe, their flow behavior is quite different. The definition of the exact point of transition is, nevertheless, quite difficult.

ANNULAR–WISPY ANNULAR TRANSITION: This is supposed to occur approximately at a critical liquid momentum flux though, again, identification of the transition is to some extent subjective.

D. Definition and Measurement Methodology:

a) Void Fraction:

Void Fraction is defined as the amount of gas phase present at the experimental section to the total amount of gas phase and liquid phase at that section.

Void Fraction Measurement methods

Online, continuous, two-phase flow measurement is often necessary, particularly in the oil and gas, nuclear energy and chemical processing industries. Reliable measurements of the void fraction and flow pattern identification are important for accurate modeling of two-phase systems. Void fraction can be measured using a number of techniques, including radiation attenuation (*X*-ray or neutron beams) for line or area averaged values, optical or electrical contact probes for local void fraction, impedance technique using capacitance sensors and direct volume measurement using quick-closing valves. The use of the different techniques depends on the applications, and whether a volumetric average or a local void fraction measurement is desired. The radiation attenuation method can be expensive and from a safety aspect difficult to implement, while intrusive probes disturb the flow field. On the other hand, the impedance measurement technique is practical and cost-effective method for void fraction measurement. The technique is non-intrusive and relatively simple to design and implement. Impedance or capacitance sensors have been used successfully to measure time and volume averaged void fraction, and its instantaneous output signal has been used to identify the flow pattern.

The various methods used to measure void fraction are:

1 Ultrasonic Method
2 Pulse Echo Method
3 Transmittance Method
4 Magnetic Fluid Method
5 Capacitance Sensor System
6 Electrical Measurement
7 Light attenuation Technique
8 Conducting Probe Technique
9 Quick Close Valves

From the above mentioned we used Conducting Probe Technique:

The principle of two phase flow measurement by the conductivity probe is based upon the electrical resistance difference between the vapor and the liquid phases. In a vapor-water flow, the vapor phase can be considered as electrically conducted. When the conductivity probe contacts with the continuous liquid, the circuit is closed. Moreover a vapor will break the circuit. Thus the probe works like a switch, yielding a two-state signal. Such a signal shows a nearly immediate response to water contact with the probe tip but a delayed response to vapor contact, due to required de-wetting time of probe tip. To calculate the accurate void fraction, this delay effect must be minimized. Minimization of this delay is obtained by the proper design of the probe tip and treatment of signal.

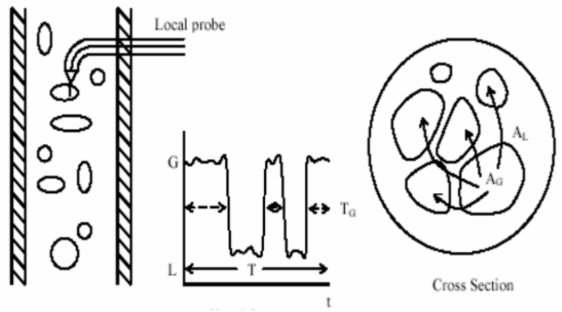


Fig: Void fraction measurement and cross-section showing voids.

b) Pressure Drop:

The knowledge of two-phase pressure drop over the wide range of system pressures is important in design and development of compact heat exchangers, nuclear reactors and cryogenic and refrigeration equipment. Flow of gas and liquid occurs frequently in pipelines and well bores where the accurate calculation of a pressure drop is of considerable interest to the petroleum industry. Similar conditions exist in the chemical and nuclear industries where two-phase mixtures coexist. In the petroleum sector, gas-liquid mixtures are transported overlong distances in a common line under large pressure drops which influence the design of the system.

Other important areas where pressure drop measurement is necessary can be cited in gas lift operations and wellhead gathering system. Practically all oil well production design involves evaluation of flow lines under two-phase flow conditions. However, the uncertainties in flow regime determination greatly affect the pressure drop prediction. Hence a method is desired for accurate calculation of pressure losses.

Pressure Transducers are used in general to measure the pressure drop in a gas-liquid two phase flows. There are three types of pressure transducers

1. Absolute Pressure Transducer
2. Gauge Pressure Transducer
3. Differential Pressure Transducer

ABSOLUTE PRESSURE TRANSDUCER: An Absolute pressure transducer provides an output voltage which is proportional to the difference between the applied pressure and a perfect vacuum. In such a unit, the pressure-sensing element is completely evacuated and sealed; the Hi pressure port is not present and input pressure is applied through the Low port

GAUGE PRESSURE TRANSDUCER: A Gauge Pressure transducer provides an output voltage which is proportional to the difference between the applied pressure and the ambient pressure. In such a unit, the input pressure is through the Hi port and the ambient pressure is applied through the open Lo port.

DIFFERENTIAL PRESSURE TRANSDUCER: A Differential Pressure Transducer provides an output voltage which is proportional to the difference between two applied pressures. In such a unit, the higher of the two pressures is applied through the Hi port and the lower through the Lo port.

III. EXPERIMENTAL SET-UP AND PROCESSING CIRCUIT

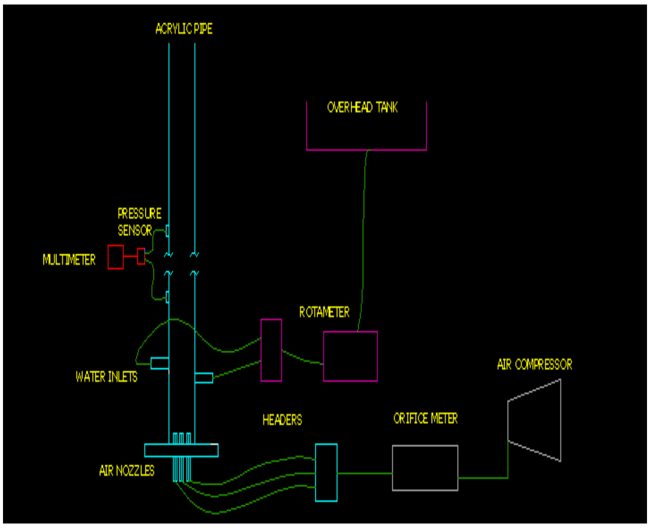


Fig: Experimental set-up drawn using AUTO-CAD

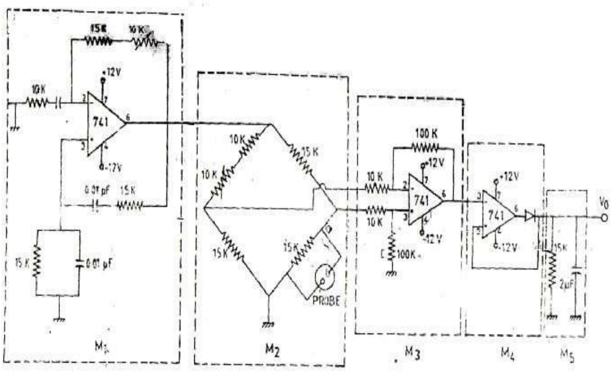


Fig: Processing Circuit for Prob.

A. Specifications:

1. Total height of the setup : 4.26 m
2. Dimensions of acrylic tank : 1m * 0.5m * 0.6m
3. Thickness of acryic tank : 0.006m
4. Length of acrylic pipes : 3 m
5. Inner diameter of acrylic pipe: 0.044 m
6. Outer diameter of acrylic pipe: 0.050 m
7. Rotameter(for air flow) : 0 to 10 LPM
8. Air compressor : 20 kg/cm^2
9. Dc voltage regulator output :15 V
10. Multimeter(for void fraction): 0 to 10 V
11. Multimeter (for pressure drop): 0 to 100mV

12. Pressure transducer : 0 to 5 psi
13. Ultrasonic doppler flowmeter :0 to 100 LPM

B. *Air Lift Loop Module*

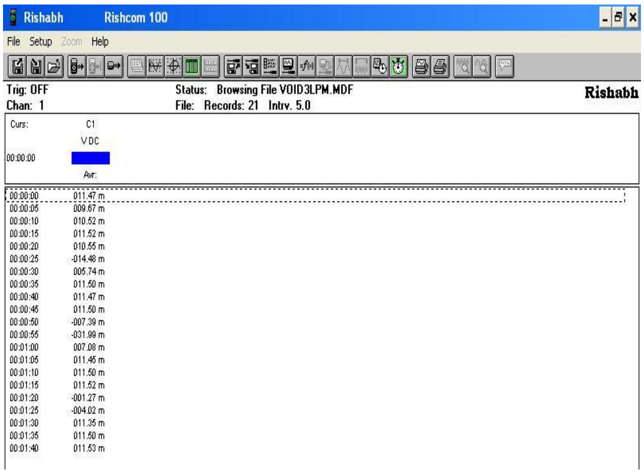
Fig: Fabricated Air Lift Loop

C. *Geometrical dimensions of the Air Lift Loop*

S.NO	DESCRIPTION	LENGTH "mm"	WIDTH "mm"	HEIGHT :mm"	TUBE DIAMETER "mm"	MATERIAL	QTY.
1	SEPARATOR	1000	500	600	-	Acrylic Resin	1
2	RISER	3000	-	-	Inner Dia: 44 Outer Dia: 50	Acrylic Resin	2
3	DOWNCOMER	3000	-	-	Inner Dia: 44 Outer Dia: 50	Acrylic Resin	1
4	HORIZONTALSECTION	775	-	-	Inner Dia: 44 Outer Dia: 50	PVC	1
5	90^0 ELBOW	-	-	-	50	PVC	1
6	T-JOINT	-	-	-	50	PVC	2

IV. EXPERIMENTAL RESULTS:

A. *Void Fraction:*



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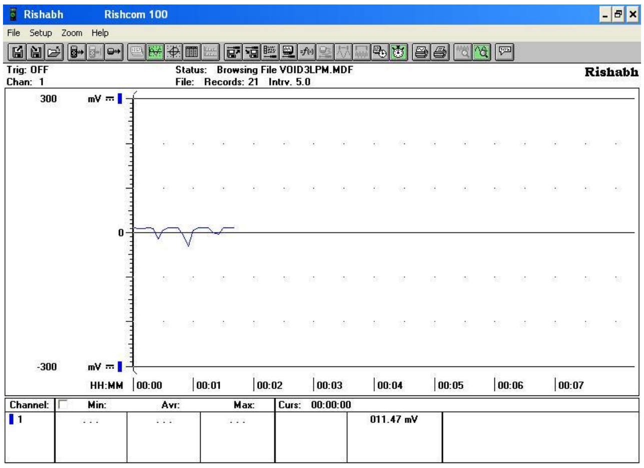
Curs:        C1
             VDC
00:00:00
             Avr:
00:00:00     011.47 m
00:00:05     009.67 m
00:00:10     010.52 m
00:00:15     011.52 m
00:00:20     010.55 m
00:00:25    -014.48 m
00:00:30     005.74 m
00:00:35     011.50 m
00:00:40     011.47 m
00:00:45     011.50 m
00:00:50    -007.39 m
00:00:55    -031.99 m
00:01:00     007.08 m
00:01:05     011.46 m
00:01:10     011.50 m
00:01:15     011.52 m
00:01:20    -001.27 m
00:01:25    -004.02 m
00:01:30     011.35 m
00:01:35     011.50 m
00:01:40     011.53 m
```

Table: Voltage fluctuations when the level of water is 5cm in the Separator while measuring the void fraction (air flow rate 3LPM)



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Channel:   Min:   Avr:   Max:   Curs: 00:00:00
1          ...    ...    ...          011.47 mV
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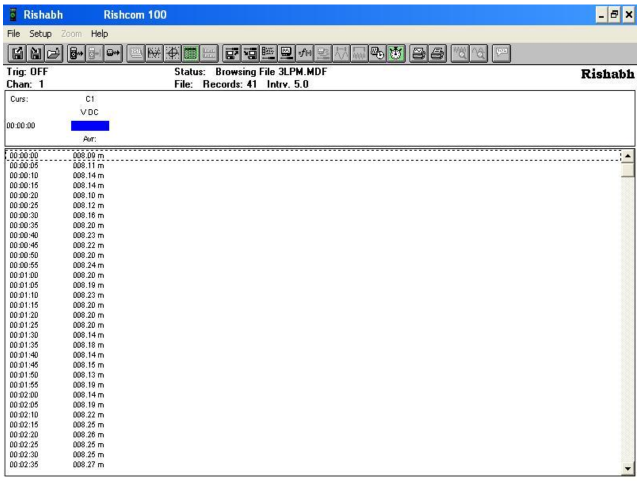
Graph: Voltage V/S Time when the level of water is 5cm in the Separator while measuring the void fraction (air flow rate 3LPM).

B. *Pressure Drop:*



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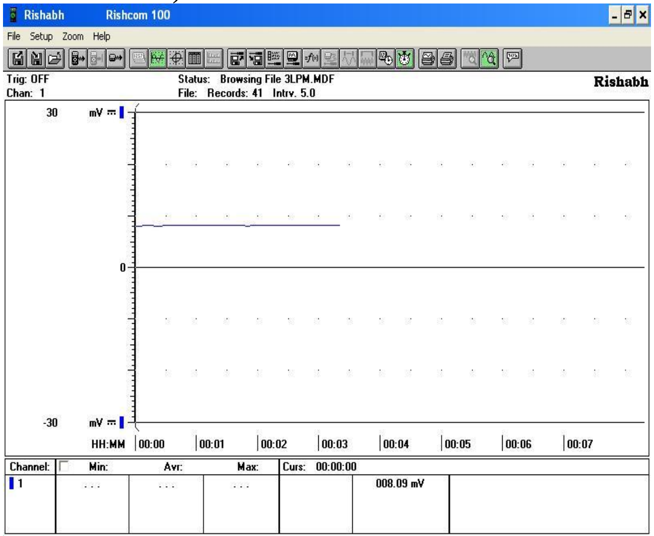
Curs:        C1
             VDC
00:00:00
             Avr:
00:00:00     008.09 m
00:00:05     008.11 m
00:00:10     008.14 m
00:00:15     008.14 m
00:00:20     008.10 m
00:00:25     008.12 m
00:00:30     008.16 m
00:00:35     008.20 m
00:00:40     008.23 m
00:00:45     008.22 m
00:00:50     008.20 m
00:00:55     008.24 m
00:01:00     008.20 m
00:01:05     008.19 m
00:01:10     008.23 m
00:01:15     008.20 m
00:01:20     008.20 m
00:01:25     008.20 m
00:01:30     008.14 m
00:01:35     008.18 m
00:01:40     008.14 m
00:01:45     008.15 m
00:01:50     008.13 m
00:01:55     008.19 m
00:02:00     008.14 m
00:02:05     008.19 m
00:02:10     008.22 m
00:02:15     008.25 m
00:02:20     008.26 m
00:02:25     008.25 m
00:02:30     008.25 m
00:02:35     008.27 m
```

Table 9: Voltage fluctuations when the level of water is 15 cm in the Separator while measuring the pressure drop (air flow rate 3LPM)



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Trig: OFF                Status:  Browsing File 3LPM.MDF
Chan: 1                  File:  Records: 41  Intrv. 5.0
Channel:   Min:   Avr:   Max:   Curs: 00:00:00
1          ...    ...    ...          008.09 mV
```

Graph 9: Voltage V/S Time when the level of water is 15cm in the Separator while measuring the pressure drop (air flow rate 3LPM)

V. CFD ANALYSIS RESULTS

The Analysis software used is ANSYS-FLUENT

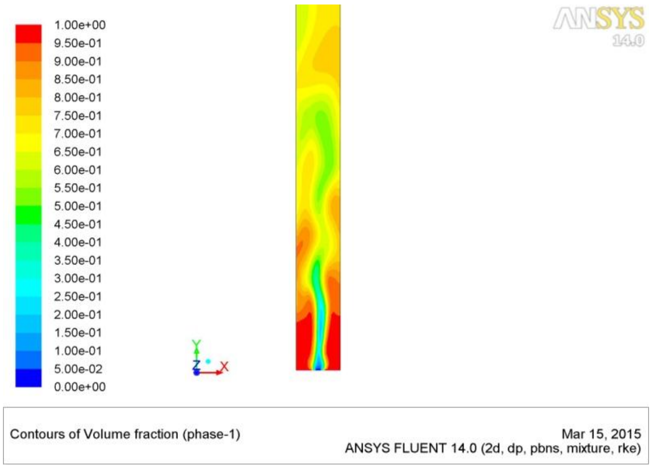

Fig: Analysis with single Air inlet

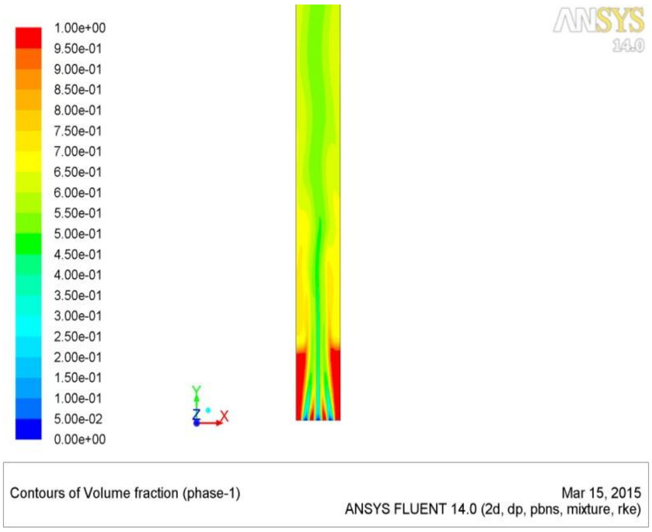

Fig: Analysis with triple Air inlet

*****RED IS WATER AND BLUE IS AIR***

VI. CONCLUSION:

The experimental investigation about Two-phase flow in an Air Lift Loop has been described in this project. The mixture of water and air is used for the demonstration of Two-phase flows in the present study.

The indigenously designed and fabricated experimental facility constitutes an external Air Lift Loop. This is fully instrumented with arrangements for the measurement of air flow tare, circulation rate, local void fraction and pressure drop. All the measurements were done online with the help of a pc based Data Acquisition System.

The demonstration of various Flow regimes is done by varying the air flow rate in the Air Lift Loop.

With normal liquid level, it was observed that the performance of the Air Lift Loop was much influenced by the air flow rate but relatively insensitive to the variation of liquid level.

With the increase of air flow rate, the void fraction through the riser and the circulation rate through the loop increases while the riser pressure drop decreases.

With the increase of air flow rate, though, the frictional pressure drop increases, the associated increase in void fraction decreases the gravitational component of the pressure drop. As a result the total pressure drop decreases.

The behavior of Air lift loop reported in this chapter is not only important for understanding the hydrodynamics of Air Lift Loop as such, but also for the other two phase natural circulation loop in general. If in a rectangular two phase natural circulation loop heating is done in the lower horizontal limb, two phase flows will occur in the vertical riser. The characteristics of this flow behavior can be grossly understood from the present study.

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