

EXPERIMENTAL STUDY ON VARIOUS FLOW REGIME OF TWO PHASE FLOW USING AIR AND WATER

Submitted in partial fulfillment of the requirements for the
award of Bachelor of Technology Degree in Chemical
Engineering

By

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**DEPARTMENT OF CHEMICAL ENGINEERING
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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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This is to certify that this Project Report entitled " **EXPERIMENTAL STUDY ON VARIOUS FLOW REGIMES OF TWO PHASE FLOW USING AIR AND WATER**" is a bonafide work of **Mr. JOKHOO PRASAD (Reg No.40690009)** in partial fulfilment of the requirements for the award of "**Bachelor of Technology in Chemical Engineering**" who can carry out the project under my supervision from July 2023 to November 2023. After the completion of the project, a journal publication of the work carried out shall be done.

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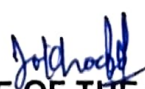
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DECLARATION

I **JOKHOO PRASAD** (Reg. No.40690009) hereby declare that the Project Report entitled **EXPERIMENTAL STUDY ON VARIOUS FLOW REGIME OF TWO PHASE FLOW USING AIR AND WATER** done by us under the guidance of **Dr. MICHAEL RAHUL SOOSAI**, Assistant Professor, Department of Chemical Engineering, Sathyabama Institute of Science and Technology and **S.SADHUKHAN AGM (OPERATION) INRPK, Superintendent (O) KARP &KARP-2** Bhabha Atomic Research Centre kalpakkam is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Chemical Engineering.

DATE: 21-10-2023

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SIGNATURE OF THE CANDIDATE

DECLARATION

I **DILIP KUMAR** (Reg. No.40690006) hereby declare that the Project Report entitled **EXPERIMENTAL STUDY ON VARIOUS FLOW REGIME OF TWO PHASE FLOW USING AIR AND WATER** is done by us under the guidance of **Dr. MICHAEL RAHUL SOOSAI**, Assistant Professor, Department of Chemical Engineering, Sathyabama Institute of Science and Technology and **S. SADHUKHAN AGM (OPERATION) INRPK, Superintendent (O) KARP &KARP-2**, Bhabha Atomic Research Centre kalpakkam is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Chemical Engineering.

DATE: 31-10-2023

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A handwritten signature in blue ink, reading "Dilip Kumar", written diagonally across the signature line.

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JOKHOO PRASAD

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ABSTRACT

In this Project, we conducted experimental investigations on the flow characteristics of two-phase air-water flows within a vertical pipe. Throughout our experiments, we observed varying flow patterns of air-water mixtures within the pipe, depending on the specific flow rates of both air and water. As a result, we formulated a flow pattern map that categorizes the flow behavior in the vertical pipe based on the superficial velocities of the liquid and gas phases. Our generated flow pattern maps were subsequently compared with those found in the existing literature, revealing a significant degree of alignment.

The objective of the project is to obtain the efficiency of the ALP in various flow regime and also find the best operating range of ALP.

In the present study we have used on 25 NB riser tube connected by an 8 NB airline, the riser tube is submerged in the water to provide the submergence to the air lift pump to work. Air is passed at different flow rate accordingly the flow rate of water is changed based on the air flow rate as well as two phase flow regime. Various two phase flow regime is observed which gives different efficiency of air lift pump to work. The main aim of study of the present two phase flow characteristics is to improve the ALP performance.

Air-lift pumps are becoming increasingly prevalent in applications demanding dependable pumps with minimal maintenance needs. They are particularly useful when dealing with corrosive, abrasive, or radioactive fluids, such as those encountered in nuclear applications. The primary goal of this study is to assess the performance of the ALP operating under specific conditions and optimize the relevant parameters. The research has demonstrated that the ALP's capacity and efficiency depend on various factors, including the rate of air mass flow, submergence ratio, size of the riser pipeline, length of the riser pipe, and, to a limited extent, the properties of the liquid to be pumped. The best efficiency range of the ALP operation was found to be in the Slug flow regime obtained between **0.2-1.0 m/s** of superficial velocity of air. It is concluded that the submergence greatly affect the air lift performance. At higher submergence efficiency as well as liquid flow rates are higher. Maximum flow rate of liquid is obtained in slug- churn flow regime at superficial velocity of air between **1.0-1.5 m/s**. The best operating range of ALP is at superficial velocity of air between **0.5-1.3 m/s**.

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION OF TWO PHASE FLOW

Two-phase flow (Gas liquid phase) in vertical pipe are encountered in various types of Process Equipment like air lift pump, steam generator, heat exchanger and condenser etc. The prediction of two-phase flow pattern is important in design, operation and safety analyses of this equipment. Figure 1.1 shows the various two phase flow profile for varying air flow rate in vertical pipe filled with water. The mass transfer, heat transfer, and momentum transfer characteristics of a two-phase flow are significantly influenced by the specific flow pattern it exhibits. In the case of vertical pipe air-water two-phase flows, there are a total of five distinct flow regimes that can be identified.

- (1) BUBBLE FLOW
- (2) SLUG FLOW
- (3) CHURN FLOW
- (4) ANNULAR FLOW
- (5) MIST FLOW

The Identifying these flow regimes is crucial due to their significant impact on heat and mass transfer processes. Bubble flow is characterized by small bubbles moving vertically upward within the pipe, with sizes much smaller than the pipe diameter. These bubbles are dispersed somewhat randomly throughout the liquid within the pipe. The transition from bubble to slug flow happens when these small bubbles collide, and some of these collisions lead to coalescence, resulting in larger bubbles comparable in size to the pipe diameter. This transition is known as slug flow. Bubble flow is a transient regime, and given sufficient residence time in the pipe, it will evolve into slug flow. When the liquid flow rate is low, a highly disturbed flow with an oscillatory nature occurs in the transition region between slug flow and the annular flow regime. This distinctive flow pattern is called churn flow, characterized by violent fluctuations in pressure gradient and liquid holdup. The annular and mist flow regime is commonly obtained in gas-liquid mixtures with superficial velocity of gas flow greater than 10 m/s. In this regime, there is an

upward-moving, continuous, and smooth to wavy liquid film on the tube wall, with rapidly moving gas at the central core containing entrained liquid droplets in varying concentrations. The liquid film can either be completely laminar or laminar near the wall and turbulent closer to the gas-liquid interface. Annular flow commonly obtained in evaporators, gas pipelines, and steam heated equipments. As the gas flow rate increases further, the liquid film becomes progressively thinner, and the number of droplets in the core flow increases. Eventually, the film detaches from the wall, leading to pure mist flow.

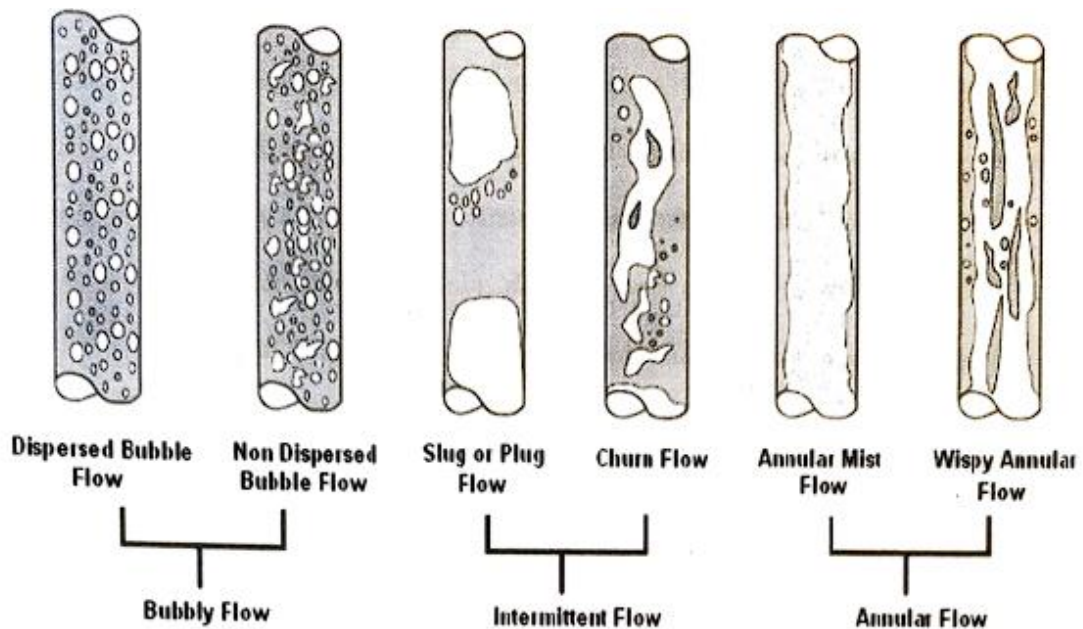


Fig 1.1 Two phase (air water) flow profile in vertical tube

1.2 INTRODUCTION OF AIR LIFT PUMP

Air-lift pumps are increasingly being employed in situations that demand dependable pumps with minimal maintenance requirements. These pumps are particularly valuable when dealing with corrosive, abrasive, toxic, or radioactive fluids. An air-lift pump functions by raising either liquid or a mixture of liquids with solid material inside a vertical riser pipe. This is achieved by introducing compressed air into the lower section of the pipe, which is partially submerged in the liquid. As a result, the mixture's density inside the riser pipe becomes lower than that of the liquid in the down comer. Consequently, the mixture within the riser pipe starts to ascend, thus balancing the hydrostatic head in the other leg of the system. The study shows that capacity and efficiency of air lift pump is function of the air flow (Q_a), percentage submergence, and pipeline size and riser pipe length. The air-lift pump operates most efficiently within the slug flow regime and at the boundary of the slug-churn flow transition regime. It is employed to elevate liquid or slurry from a well or vessel, especially in situations where a submerged mechanical pump is impractical or where simple construction is required. In its most basic form, a vertical riser tube is partially submerged in the liquid within the vessel, and air is introduced at or near the base of the tube. Because the air has a lower density compared to the liquid, it creates a buoyant air-liquid mixture inside the air-lift pipe, causing it to rise and be discharged from the upper end of the pump. An alternate U-tube air-lift configuration, which utilizes a down comer leg for submergence, is illustrated in the figure below. The principles behind ALP were understood as early as 1882, although practical applications didn't emerge until the beginning of the twentieth century. One of the key advantages of air-lift pumps is their mechanical simplicity. Furthermore, they offer several benefits over other types of pumps. They lack moving parts, require no lubrication, and are free from wear-related issues. They are well-suited for use in corrosive environments and zigzag wells where usual pumps may not be suitable. Consequently, the mechanical maintenance of air-lift pumps is theoretically less expensive and more reliable. Additionally, air-lift pumps are relatively straightforward to fabricate, even if they are not readily available from suppliers. Generally, when the static liquid level in the source tank is high air-lift pumping is most efficient. However, it should be noted that air-lift pumps have lower efficiency compared to some other pump

types and require a substantial submergence depth to achieve high efficiency. In nuclear reprocessing plants, air-lift pumps are employed to transfer radioactive solutions, but they generate a considerable amount of air, leading to airborne activity concerns. The primary factor influencing the performance of an ALP is the presence of various two-phase flow regimes within the riser pipe during operation.

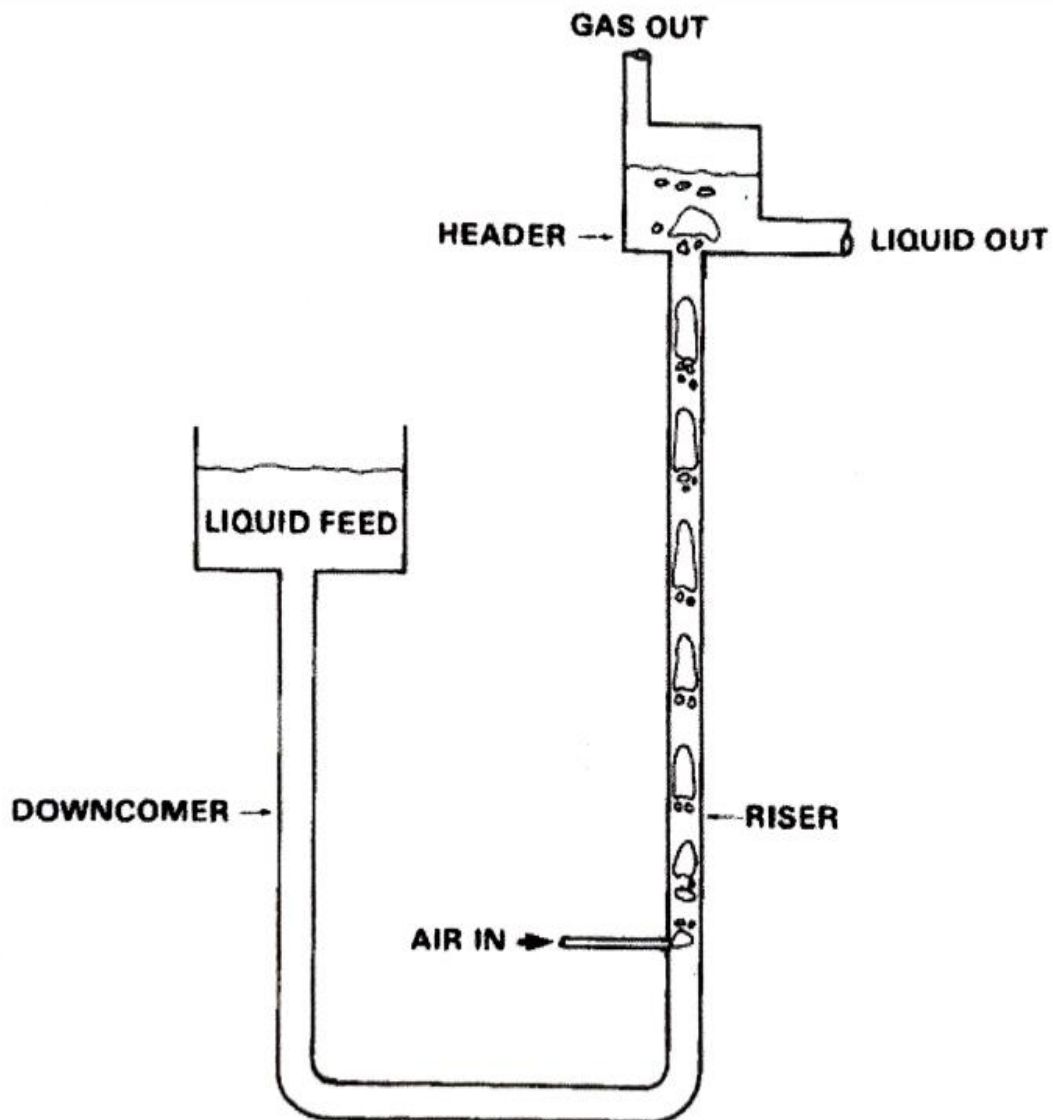


Fig 1.2 Air lift u- tube arrangement

1.2.1ADVANTAGES OF AIR LIFT SYSTEM

- a) No moving parts.
- b) Low maintenance.
- c) Consistent performance.
- d) Remote transfer of liquid.
- e) Metered flow.
- f) Pump is very reliable.
- g) Very simple principle is a clear advantages.
- h) Only air with a high pressure than liquid is required.

1.2.2DISADVATAGES OF AIR LIFT SYSTEM

- a) Low efficiency.
- b) De-entrainment problem.
- c) Minimum submergence is required.

1.2.3FACTORS AFFECTING AIR LIFT SYSTEM

- a) Riser pipe diameter.
- b) Submergence ratio.
- c) Temperature of liquid.
- d) Density of liquid to be pumped.
- e) Liquid viscosity.

1.2.4APPLICATION OF AIR LIFT SYSTEM

- a) ALP are used in zigzag deep wells where regular pump cannot be used.
- b) It is used for transferring of radioactive liquid because it has no moving part so no maintenance required throughout the life of the pump.
- c) ALP is used in radioactive waste immobilization plants.
- d) ALP is also used in the mining inside the deep sea.

1.3 EFFICIENCY OF AIR LIFT PUMP

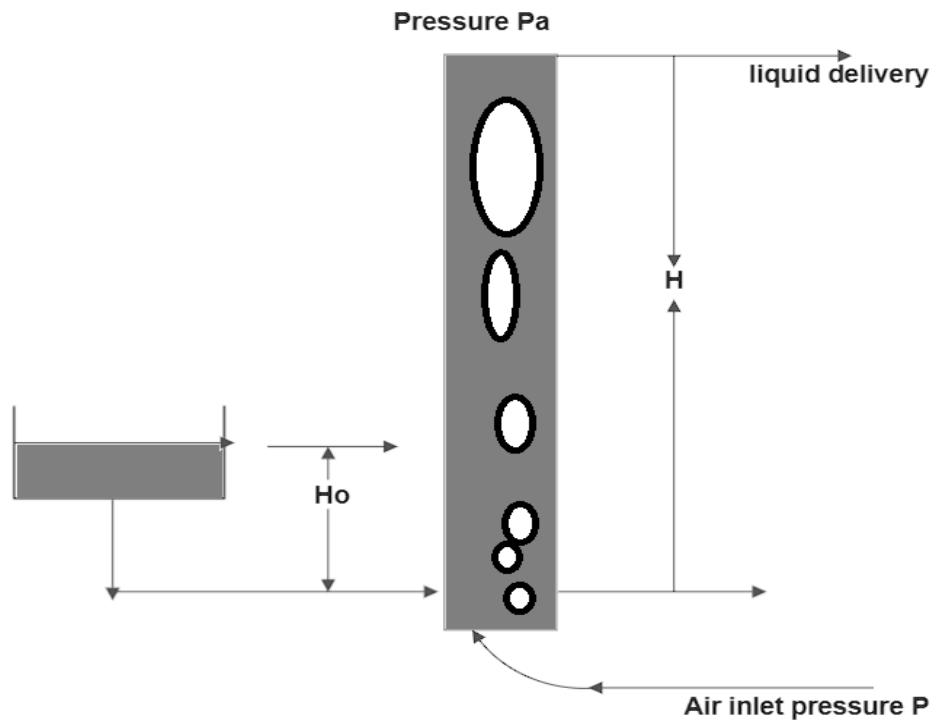


Fig 1.3 ALP Schematic diagram for efficiency calculation

The efficiency of the ALP is given by:

$$\eta = [Mg(H - Ho)] / \left[\left(\frac{m}{\rho_a} \right) Pa \cdot \ln \left(\frac{P}{Pa} \right) \right] \dots\dots\dots(1.3)$$

$$\% \text{ Submergence} = \frac{Ho}{H} \times 100$$

- Where, η = efficiency, H = Total height of lift (m), Ho = submergence height (m)
- M = Mass of water lifted (kg), g = acceleration due to gravity (m/s^2)
- m = mass of air (kg) , ρ_a =density of air(kg/m^3)
- Pa = atmospheric pressure (N/m^2).
- P is the inlet pressure of air (N/m^2)

CHAPTER-2

LITERATURE REVIEW

Air lift pumps are widely used in chemical, steel, mining and nuclear reprocessing industries. They are suitable for vertical transportation of the fluids for which mechanical impellers are not available or undesirable such as for corrosive, abrasive, toxic or radioactive fluids. Now even the flow control of air lift pump is more difficult as compared to turbo-machinery pumps because the performance of the air lift pump depends on state of multiphase flow of air-water in vertical pipe. In development of such air lift pump for prediction of performance, especially understanding the behavior of multiphase flow is much important for designing and for its optimum performance. In theory, air lift pumps could be designed to work with different mixtures of air and liquid phases, but in reality, they primarily operate within the slug flow regime. This specific flow pattern remains stable across a wide range of air and liquid velocities, a phenomenon well-documented by Tait et al. (1980) and Clark (1984). Within the slug flow regime, we observe the presence of large air bubbles surrounded by a liquid annular film that adheres to the pipe wall. These air bubbles are separated by liquid slugs that extend across the entire tube diameter, occasionally containing smaller air bubbles. Despite extensive literature about slug flow, contemporary design approaches continue to depend on semi-empirical equations, exemplified by those formulated by Shaw and O'Neill. However, these equations tend to lose accuracy when applied to non-standard air lift pump designs. Air lift pumps find extensive use in various applications, including underwater exploration, lifting coarse particle suspensions, transferring radioactive and corrosive fluids, and extracting sludge in sewage treatment plants. The present study is concerned with the application of ALP in pumping radio-active and corrosive liquid transfer. In this scenario, the flow occurring in the pump riser involves a two-phase flow consisting of air and water. The flow patterns observed in the riser of an air lift pump directly correspond to the upward flow within a vertical pipe. As the ratio of air to water increases, different two-phase flow patterns can be observed:

- a) Bubbly flow: In this pattern, you'll notice relatively small and uniform-sized gas bubbles.
- b) Slug flow: This regime is defined by the presence of large, bullet-shaped gas

bubbles, accompanied by smaller gas bubbles dispersed throughout the liquid.

c) Churn flow: Churn flow exhibits high instability, featuring an oscillatory nature where the liquid near the riser tube wall moves up and down.

d) Annular flow: Within this pattern, the liquid partly moves as an annular film along the tube wall and partly as small drops dispersed within the central gas flow.

These flow patterns are observed as the air-to-water ratio varies, providing insight into the behaviour of two-phase flows in vertical pipelines.

Sharma and Sac de va conducted a study on the performance factors affecting large-diameter ALP operating in shallow depths. They established a connection between pump performance and the type of flow regime observed in the uptake pipe. Additionally, De-Cachard research in 1996 experimentally demonstrated that slug flow is the most dominant flow pattern within the practical operating range of smaller dia air lift pumps. However, limited research exists regarding the impact of liquid properties such as surface tension, viscosity, and pipe geometry on ALP performance. For instance, Khalil and Mansour (1990) conducted experiments to investigate the effects of introducing a surfactant into the pumped liquid. Their findings indicated that even a small concentration of surfactant consistently enhances pump capacity and efficiency. They further noted that surfactant concentration greatly affect the pump performance. More recent research conducted by Iguchi and Terauchi (2001) explored the influence of riser pipe-wall wettability on the transition between bubbly and slug regimes in vertical air-water two-phase flow. They achieved this by altering the inner wall of an acrylic pipe through the application of a hydrophilic substance or liquid paraffin, which subsequently led to noticeable variations in flow patterns. Flow pattern maps were developed to account for various pipe wall wettability conditions. Researchers conducted experiments to investigate the impact of liquid viscosity on flow patterns in vertical air-liquid two-phase flow. They employed various liquids, like water and glycol solution, and found that flow pattern transitions are significantly influenced by liquid viscosity. Further they examined the effect of tube diameter on air lift pump performance. They noted that for Reynolds numbers below 500, liquid slugs exhibited a turbulent velocity profile. Additionally, they studied the influence of surface tension on bubble rise velocity for tube diameters ranging from 3 to 20 mm. The effect of air injection methods on bubble size and distribution was also studied. Researcher explored the effect of bubble size distribution on the

performance of an ALP using air admission through a perforated disc. They found that reducing bubble size or enhancing the number of holes led to an increase in liquid discharge. Lastly, Khalil et al. (1999) conducted experiments highlighting the substantial impact of initial bubble size and bubble distribution within the riser pipe on ALP performance. Achieving a well-mixed homogeneous mixture within the riser was found to minimise slip and enhance ALP efficiency.

Several flow regime maps for two-phase flow in vertical tubes can be found in the literature. These maps define transition boundaries in a two-dimensional coordinate system based on data from experiments and observations. The selection of parameters for these published maps can be classified into two main categories, as described by Taitel et al. (1980):

a) The first category of flow pattern maps utilizes dimensional coordinates, such as the superficial velocity of gas (U_g) and liquid (U_l), or the superficial momentum fluxes (ρU_g^2 and ρU_l^2). These coordinates define the transition boundaries when specific pipe sizes and fluid properties are considered. However, it's essential to recognize that variations in these variables can lead to shifts in the position of boundaries between different flow patterns.

b) The second group employs dimensionless coordinates to make the results applicable to various pipe sizes and fluid properties beyond those used to establish the curves. Griffith and Wallis (1961) sought to derive dimensionless coordinates based on theory, resulting in U_m^2/gd and U_g/U_s , where U_m represents the mixture velocity, U_s signifies the slug velocity, U_g denotes the superficial velocity of gas within the pipe, g stands for acceleration due to gravity, and d represents the riser pipe diameter. These dimensionless coordinates govern the transition from slug to annular flow regime. To investigate ALP performance under varying flow patterns, this study extended the air flow rate range to encompass a wide spectrum of flow regimes. Furthermore, pipes of varying lengths were employed to assess the impact of uptake pipe length, while maintaining a consistent submergence ratio, on pump performance.

In theory, air lift pumps have the potential to function with various degrees of mixing between the air and liquid phases. However, in practical applications, most air lift pumps predominantly operate within the slug flow regime. This regime remains stable over a wide range of air and liquid velocities. In slug flow, the primary characteristic involves large air bubbles surrounded by a thin annular film

of liquid in contact with the pipe wall. These air bubbles are interspersed with slugs of liquid that extend across the entire diameter of the tube, and some of these liquid slugs may contain smaller air bubbles. Early theoretical approaches in this context focused on energy balance, aiming to equate the energy stored in the compressed air introduced at the base of the pump with the useful work required to lift the liquid up to vent pot of the ALP. Assuming isothermal operation and a pump with 100% efficiency, the volume of free air (at atmospheric pressure), denoted as V_g , needed to lift a certain volume of water (V_w) to a height of L meters can be expressed as follows:

$$\frac{V_g}{V_w} = \frac{\rho g L}{P_2 \ln\left(\frac{P_0}{P_2}\right)} \quad (1)$$

In the equations above, P_0 represents the inlet air pressure at the bottom where the air was introduced, while P_2 represents the discharge pressure, typically corresponding to atmospheric pressure. However, in the context of ALP, there are energy losses attributable to factors such as losses in the bulk flow and the slippage the liquid. These losses often resulted in early air lift pumps achieving energy efficiencies in the range of 25% to 35%. Consequently, the theoretical energy balance could not be applied directly without incorporating an energy efficiency term. Over time, modified energy balance equations in various forms have been introduced in the literature and continue to be recommended for air lift pump design. Nevertheless, it's important to note that the energy balance alone is insufficient for precise design, as the actual pump efficiency is rarely known until a pump is constructed or a design undergoes a more thorough analysis of two-phase flow. In situations where low submergence or narrow bore diameters are employed, these energy balance equations tend to overestimate flow rates to a significant degree.

Nicklin's work in 1963 introduced a valuable analysis of ALP, focusing on momentum balance. This analysis dissected the pressure gradient within the air lift tube into two components: the hydrostatic head and friction losses term. The hydrostatic head was determined based on the hold-up of both liquid and gas phases, which was calculated using a two-phase flow drift-flux model. From an

energy balance perspective, losses due to bubble slippage were considered in predicting the hold-up, while friction losses were incorporated directly using a modified Darcy equation initially developed for single-phase flow (Dabolt and Clark, 1985).

.Dabolt and Plummer (1980) presented a comprehensive dataset for air lift pumps ranging from 12 to 50 mm in diameter, specifically applied in the context of nuclear fuel reprocessing. Their investigation identified the submergence ratio, which represents the ratio of submergence to the total pump height, as the primary variable influencing lift performance. Consequently, they introduced a design equation as follows:

$$V_a = \frac{\ln(1 - \frac{V_w}{A})}{B} \quad (2)$$

The equation includes variables such as V_a (the required air volume to lift a volume of water V_w), A , and B , which are quadratic functions influenced by the submergence ratio. These coefficients vary with the pipe diameter. To account for frictional losses occurring before the sparger and within the air lift tube, as well as pressure considerations in the vent pot and feed tank, the geometric submergence ratio was adjusted to an effective submergence ratio. This equation demonstrated improved agreement with data compared to previous design methods used in the context of nuclear fuel reprocessing. However, it should be noted that this correlation for coefficients A and B is applicable only within the range of pipe diameters from 12 to 50 mm. It is worth mentioning that despite numerous methods available for predicting liquid flow rates in ALP, none of these equations combines theoretical soundness with accurate performance prediction, making it a challenging aspect of design.

2.1AIR WATER FLOW PATTERN IN VERTICAL PIPE

Two-phase flow (Gas liquid) in vertical pipe is encountered in various type of Process Equipment like air lift pumps, boiler, heat exchangers and condensers. The knowledge of two phase flow pattern is important in design and in efficient operation of these equipment. Typical two-phase flow pattern map in the vertical pipe line is presented in Figure. 2.1. Figure.2.1 shows the various two phase flow

profile map for varying air flow rate in a vertical pipe filled with liquid water. At a lower air flow rate, air forms small diameter bubbles dispersed in a liquid uniformly. As the air flow rate increases the flow pattern changes progressively to Slug flow, churn flow, annular flow and finally to dispersed or mist flow.

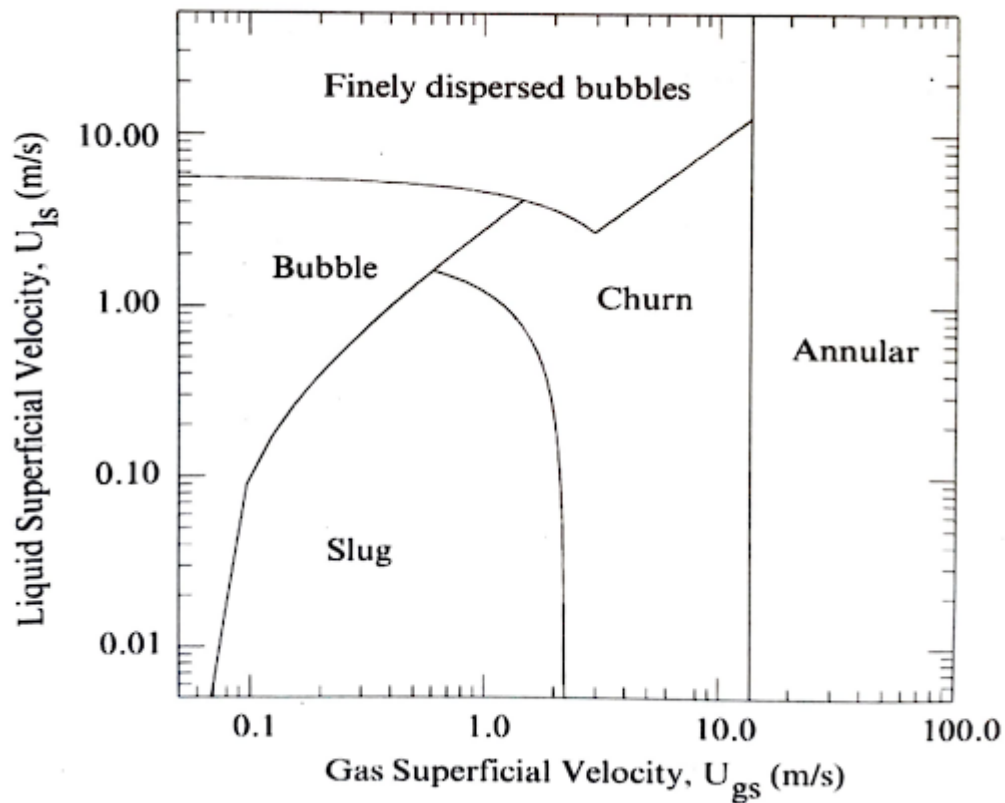


Figure 2.1 Two phase flow regime map in vertical pipe

A) **Bubbly flow:** In this flow pattern, gas is dispersed within the continuous liquid phase. Researchers have categorized this flow pattern into two types: dispersed bubbly flow and low liquid input bubbly flow.

Dispersed bubbly flow: This flow pattern is observed across the entire range of pipe diameters and inclinations. In this scenario, the gas phase is dispersed as small bubbles within the continuous phase.

Low liquid input bubbly flow: At low liquid superficial velocities, small gas bubbles of approximately uniform size are present and uniformly distributed within the liquid phase. Occasionally, some coalescence may occur in the bulk of the flow.

- B) **Slug flow:** In this flow pattern, when the gas superficial velocity increases, the individual gas bubbles start to merge and create elongated, smooth bubbles with a distinctive cap or bullet-shaped front. These elongated bubbles are commonly known as Taylor bubbles, and they have a cross-section similar in size to that of the pipe. They are surrounded by a thin liquid film and are spaced apart from the pipe wall.
- C) **Churn/ froth flow:** As the gas superficial velocity continues to increase within the slug regime, the Taylor bubble at the liquid-gas interface becomes increasingly distorted. This distorted bubble moves in a churning motion, resulting in irregularly shaped regions of both gas and liquid. This flow pattern is referred to as froth slug or churn-turbulent flow.
- D) **Annular flow:** In this flow regime, the gas phase occupies the core of the tube, while the liquid forms a thin film around the tube's periphery. Additionally, the liquid exists as entrained drops within the gas core. There are two variations of this flow pattern: In this variation, entrained liquid exists as relatively large drops, and the liquid film contains gas bubbles.
- Annular mist flow: In this flow pattern, gas occupies the central core, while the liquid flows along the periphery. The core gas contains entrained liquid, but the drops are not large; instead, they have tiny sizes.

2.2 FLOW PATTERN TRANSITION MECHANISM

Understanding which flow regime occurs under specific conditions is crucial, as each flow pattern exhibits distinct hydrodynamic characteristics. These characteristics, in turn, impact properties such as pressure drop and heat and mass transfer capabilities. Therefore, identifying flow patterns and their transitions is of paramount importance. Flow regime transitions depend on various factors, including gas-liquid velocities, fluid properties, pipe orientation, pipe diameter, and operating conditions.

While experimental methods are the most popular for flow pattern identification, empirical and mechanistic models also play a role in identifying flow regime transitions. Researchers have developed mechanistic models for commonly encountered vertical flow patterns.

2.3 TRANSITION FROM BUBBLY TO SLUG FLOW

In the realm of gas-liquid two-phase flow, the transition from bubbly flow to slug flow has garnered significant attention from researchers in recent years. This transition occurs frequently in industries such as chemical, biological, and nuclear, and it entails notable variations in flow characteristics. These variations encompass interfacial structure, heat transfer and mass transfer mechanisms, drag forces, and pressure drops. Accurate prediction of the transition boundary is vital for discerning these characteristics and establishing constitutive equations. Understanding the intricate physical mechanisms at play during the transition process is crucial for improving flow regime predictions.

Early research by Radovcich and Moissis suggested that bubble coalescence induces the transition. In bubbly flow, bubbles are randomly dispersed in the liquid phase, with occasional coalescence or break-up. When the rate of coalescence exceeds that of break-up, the transition occurs. Various criteria based on experimental observations and theoretical analyses have been proposed to determine the transition. Many other researchers proposed different void fraction values as transition criteria under different flow conditions. These criteria generally showed good agreement with experimental data across a wide range of conditions.

To address the limitations of void fraction criteria, new criteria based on bubble dynamics have emerged. Instead of focusing solely on void fraction, these criteria incorporate the behavior of individual bubbles using population balance models (PBM) or interfacial area transport equations (IATE). PBM describes coalescence and breakage processes of scattered bubbles in bubbly flow, predicting the bubble size distribution for flow regime prediction. IATE, initially developed for determining interfacial transfer terms, can predict two-phase flow structure dynamically based on the evolution of interfacial area concentration (IAC) influenced by bubble behavior. Researchers have used parameters like the attenuation coefficient of void fraction waves or linear analysis to trigger these transitions. However, this mechanism doesn't account for all transition scenarios, as evidenced by some experimental phenomena in specific flow conditions.

In summary, the transition from bubbly flow to slug flow in gas-liquid two-phase flow is a complex phenomenon with significant industrial implications. Multiple mechanisms and criteria have been proposed to describe this transition, but further research and experimental evidence are needed to comprehensively understand and predict this phenomenon across various flow conditions.

According to McQuillan, Whalley, bubbly flow is observed at low air superficial velocities, regardless of the water flow rate. Generally, as the gas superficial velocity increases, more bubbles are generated, leading to an increase in bubble density. This decrease in the distance between bubbles can eventually result in coalescence. Researchers qualitatively demonstrated that the probability of coalescence becomes significantly higher when the void fraction exceeds 30%. They inferred that this marks the transition to a different flow regime. Taitel et al. (1980) similarly attributed the transition to the gradual coalescence of a sufficient quantity of bubbles into large Taylor bubbles. Taitel et al. (1980) found that this transition from bubbly to slug flow typically occurs around a critical void fraction (α) of 25% of the pipe volume, as represented by line A in Figure 2.2.

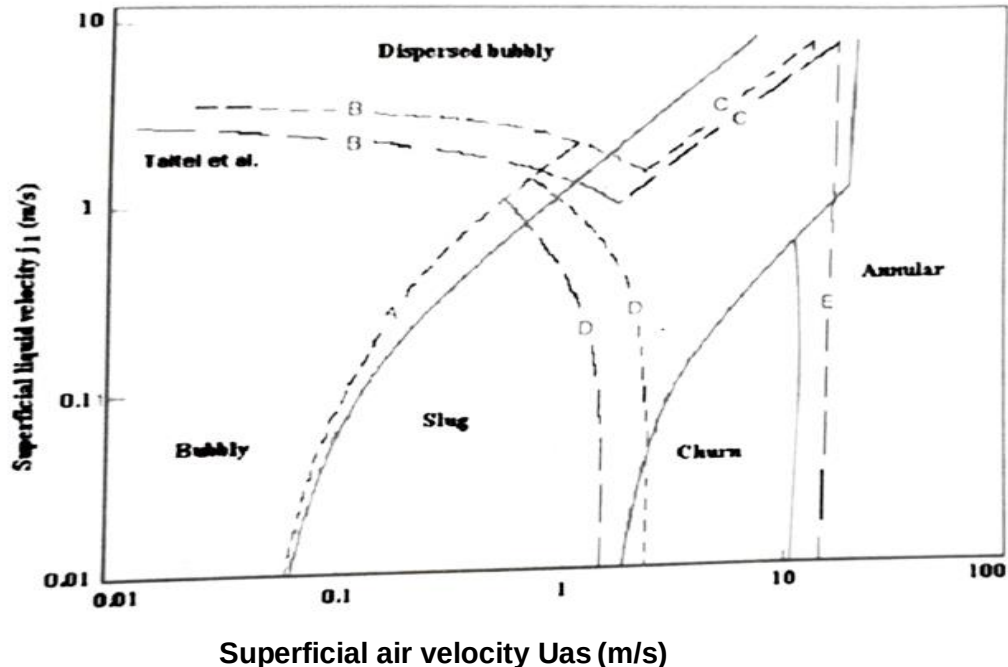


Fig 2.2 Flow regime map for vertical up-flow showing flow transition

CHAPTER-3

3.1 AIM

The aim of the project is to collect the data of water flow rate v/s air flow rate in various flow regime at different submergence ratio by using the experimental setup, comparing values at various submergence ratio and calculating the efficiency of the air lift pump, also find out maximum efficient operating range.

3.2 SCOPE

The project is meant to determine the flow regime in which best efficiency of ALP is obtained by varying the air flow rate at constant submergence in the vertical transparent riser pipe.

During the two phase flow of gas –liquid mixtures in a vertical pipe, the phases may distribute in a different flow pattern. The each flow patterns depends on the flow rate of fluid, fluid properties and the riser pipe size. Mass and Heat transfer rate, Frictional losses, back mixing rate and resident time distribution all depends on flow pattern. Gas liquid slug flow pattern in vertical tube found many industrial applications. It occurs in process equipment like vapor-liquid contactors, vapor separators, thermosyphon reboilers, and gas liquid chemical reactors, two phase oil and gas pipelines as well as oil and gas geothermal wells.

CHAPTER-4

EXPRIMENTAL STUDIES METHODS & METHODOLOGY

4.1 EXPERIMENTAL SET UP: Schematic diagram of experimental setup is shown in fig 4.1. Which consist 25 NB acrylic uptake line with 8 NB ss airline coming from compressor through rotameter one vent pot is connected on top to separate the air and water. The length of acrylic uptake line is 2m. Air flow rate is measured through rotameter and water flow rate is measured in a pre-calibrated bucket at different submergence i.e., at 65%, 55%, 42% and 35%.

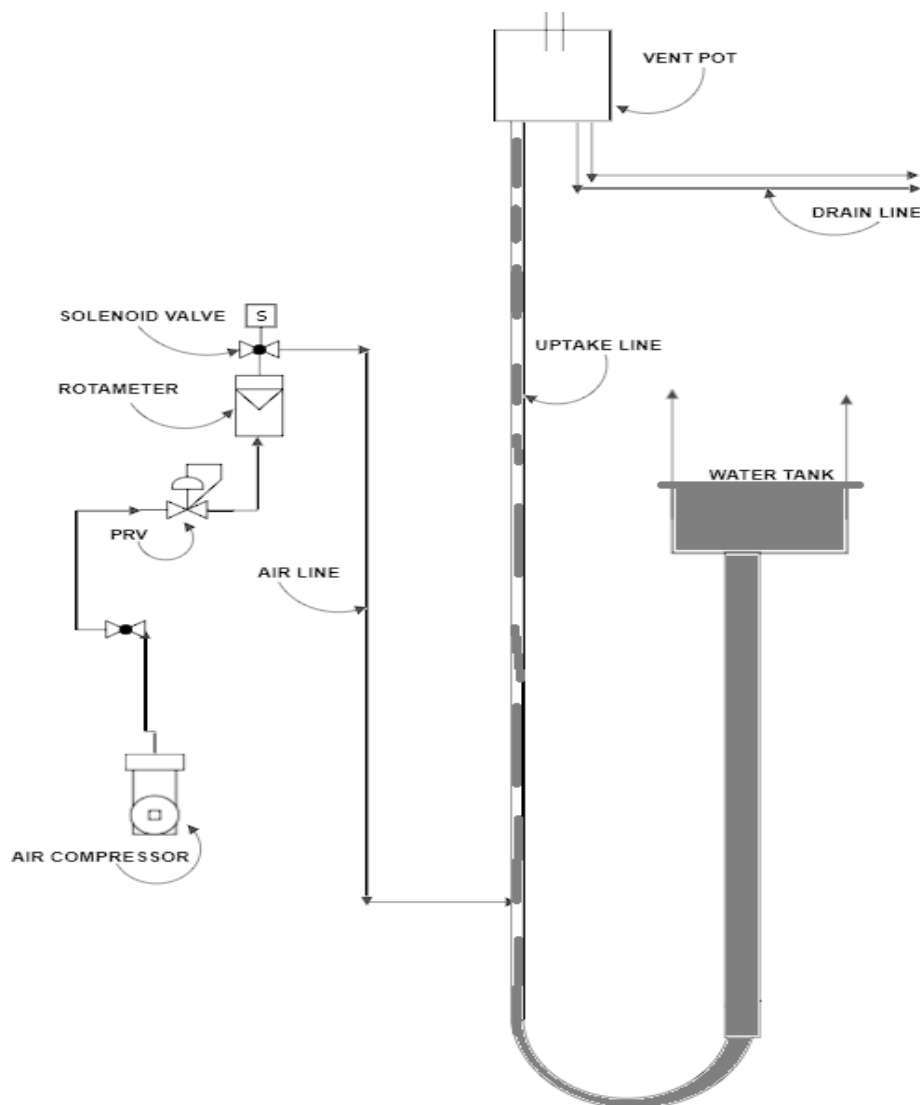


Fig 4.1 Schematic diagram of experimental setup

4.2 EXPERIMENTAL PROCEDURE

- Fill the source tank with water.
- Measure the submergence in uptake line.
- Start the air flow in riser pipe.
- Note down the air flow rate, air pressure, calculate the liquid flow rate.
- Calculate the air superficial velocity.
- Calculate the efficiency of the ALP.
- Increase the air flow rate.
- Repeat the experiment at different air flow rates.
- Take the flow regime photo at different air superficial velocity.
- Increase the submergence by increasing the water level in tank.
- Repeat the experiment at different submergence ratio.
- Collect the data at different submergence ratio, draw the graphs of air flow rate v/s water flow rate and ALP Efficiency v/s air superficial velocity.
- Find out the maximum efficient regime and optimum operating range.

4.3 METHODOLOGY

- Experimental estimation of different flow regime of two phase flow using air and water in ALP system by varying the flow rate of air.
- Repeating the experiment at various submergence.
- Theoretical calculation of efficiency of ALP.
- Comparison of results at different submergence.

4.4 ACTUAL SETUP



Fig 4.2 Actual Experimental setup

4.5 MATERIAL USED.

1. Water.
2. Compressed air.
3. Transparent Acrylic Pipe.
4. PVC Drain hose.
5. Calibrated PVC Bucket.
6. Stainless steel vent pot.
7. 25 NB Stainless steel foot piece with 8 NB airline.
8. 300 liter water tank.
9. 100 liter plastic bucket.

CHAPTER- 5

RESULTS AND DISCUSSIONS

5.1 EXPERIMENTAL OUTCOMES

Four experimental runs were carried out at different submergence ratio (65, 55, 42 and 35%) by varying the air flow rate from zero to 4500 lph. Initially up to certain flow rate the liquid flow rate is zero hence the efficiency of ALP is zero. As the air flow rate increases liquid flow starts and the two phase flow regime also changes as superficial velocity of air increases. At each superficial velocity of air water flow rate is noted and the efficiency of ALP is calculated by equation no. (3) Which is tabulated below for each submergence. Experimental data shows that maximum efficiency of ALP obtained in slug flow regime at superficial velocity range of 0.2-1.0 m/s of air and maximum flow obtained in slug-churn transition range.

5.1.1 FLOW REGIME IN TWO PHASE FLOW

Various two phase flow regime is obtained during the experimental run, Images of such flow regime is attached below.

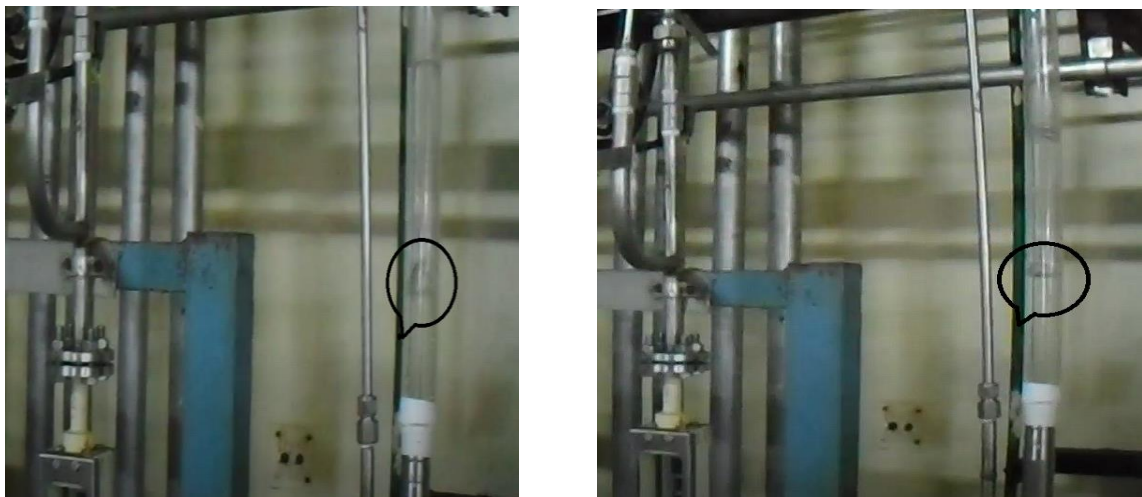


Fig 5.1 Bubble flow regime images

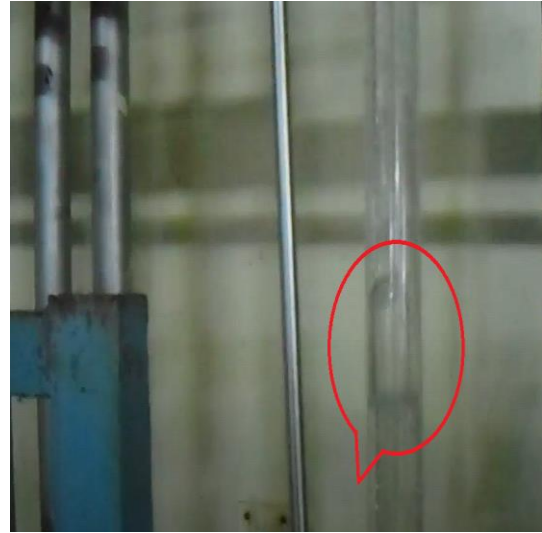


Fig 5.2(a) Slug flow regime images

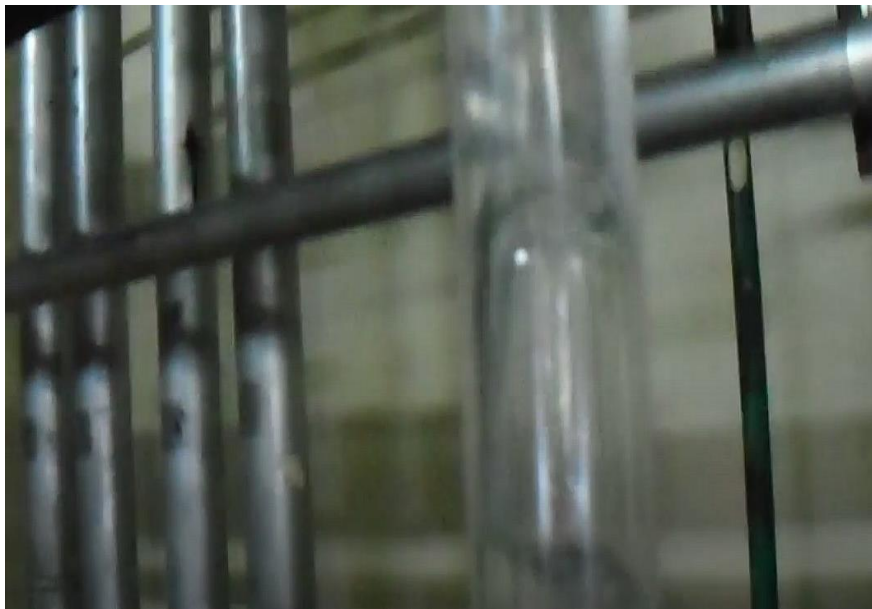


Fig 5.2 (b) Slug flow regime image

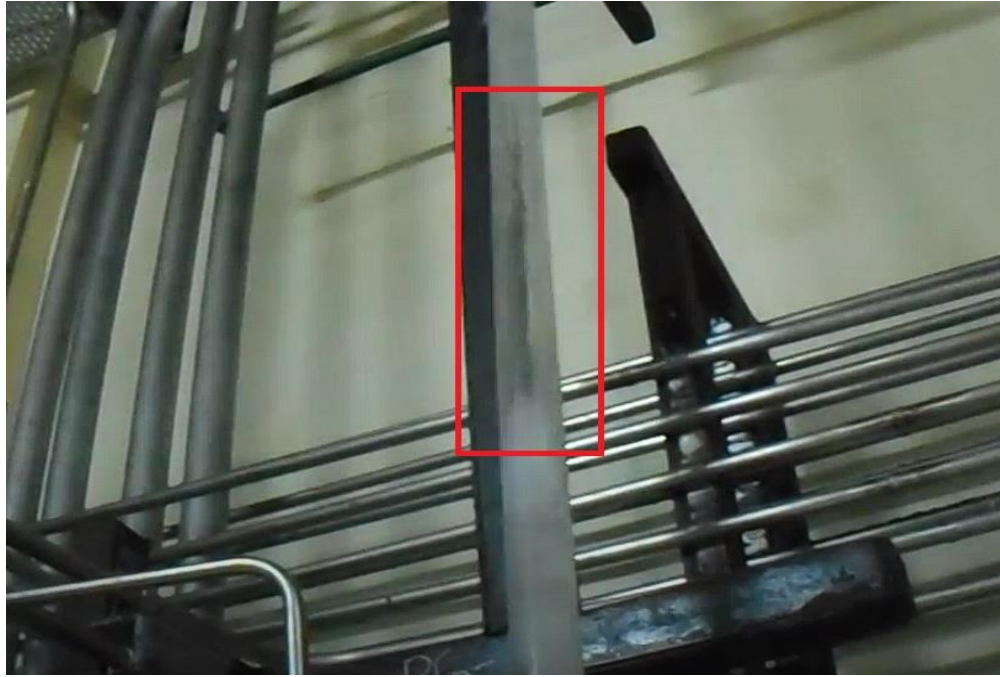


Fig 5.3 churn flow regime image

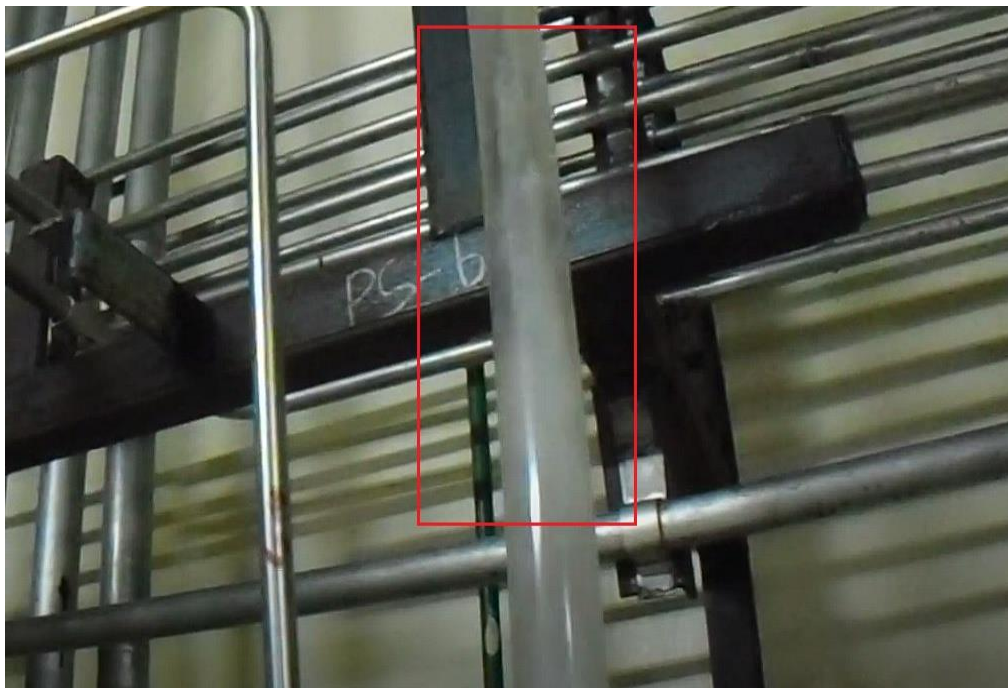


Fig 5.4 annular flow regime image

Table 5.1 Data at 65% submergence

M(kg)	H (m)	Ho (m)	ρ(kg/m³)	Va (l)	m(kg)	P (N/m²)	Pa (N/m²)	ln (P/Pa)	% η	Uas (m/s)	Uws (m/s)
0	3.3	2.15	1.3	200	0.26	121590	101325	0.182	0	0.08	0
100	3.3	2.15	1.3	400	0.52	121590	101325	0.182	15.93	0.16	0.04
200	3.3	2.15	1.3	600	0.78	121590	101325	0.182	21.24	0.24	0.08
450	3.3	2.15	1.3	800	1.04	122603	101325	0.191	34.28	0.31	0.18
600	3.3	2.15	1.3	1100	1.43	122603	101325	0.191	33.24	0.43	0.24
730	3.3	2.15	1.3	1300	1.69	123617	101325	0.199	32.81	0.51	0.29
1050	3.3	2.15	1.3	1900	2.47	124630	101325	0.207	31.01	0.75	0.41
1150	3.3	2.15	1.3	2000	2.6	125643	101325	0.215	31.06	0.79	0.45
1300	3.3	2.15	1.3	2200	2.86	126656	101325	0.223	30.77	0.86	0.51
1440	3.3	2.15	1.3	2400	3.12	127670	101325	0.231	30.16	0.94	0.57
1440	3.3	2.15	1.3	2800	3.64	128683	101325	0.239	25.00	1.10	0.57
1420	3.3	2.15	1.3	3200	4.16	129696	101325	0.247	20.88	1.26	0.56
1380	3.3	2.15	1.3	3600	4.68	130709	101325	0.255	17.49	1.42	0.54
1320	3.3	2.15	1.3	4100	5.33	131723	101325	0.262	14.26	1.61	0.52
1280	3.3	2.15	1.3	4500	5.85	131723	101325	0.262	12.60	1.77	0.50

5.1.2 AIR LIFT PUMP PERFORMANCE AT 65% SUBMERGENCE

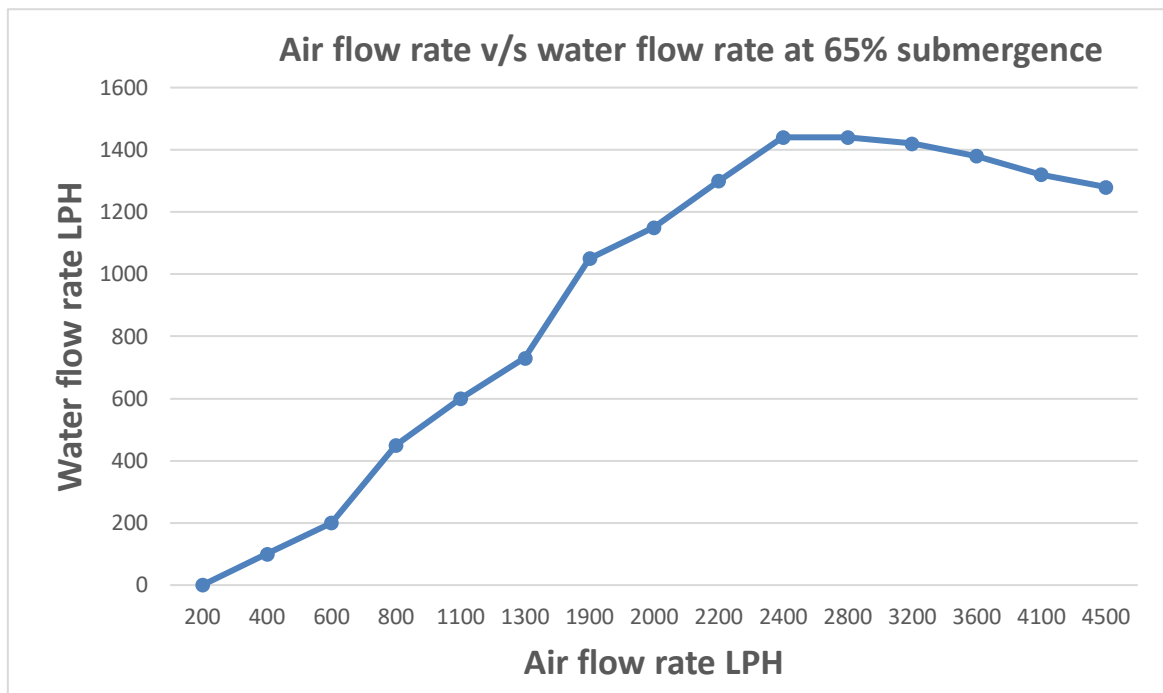


Fig 5.5(a) Air flow rate v/s water flow rate at 65% submergence

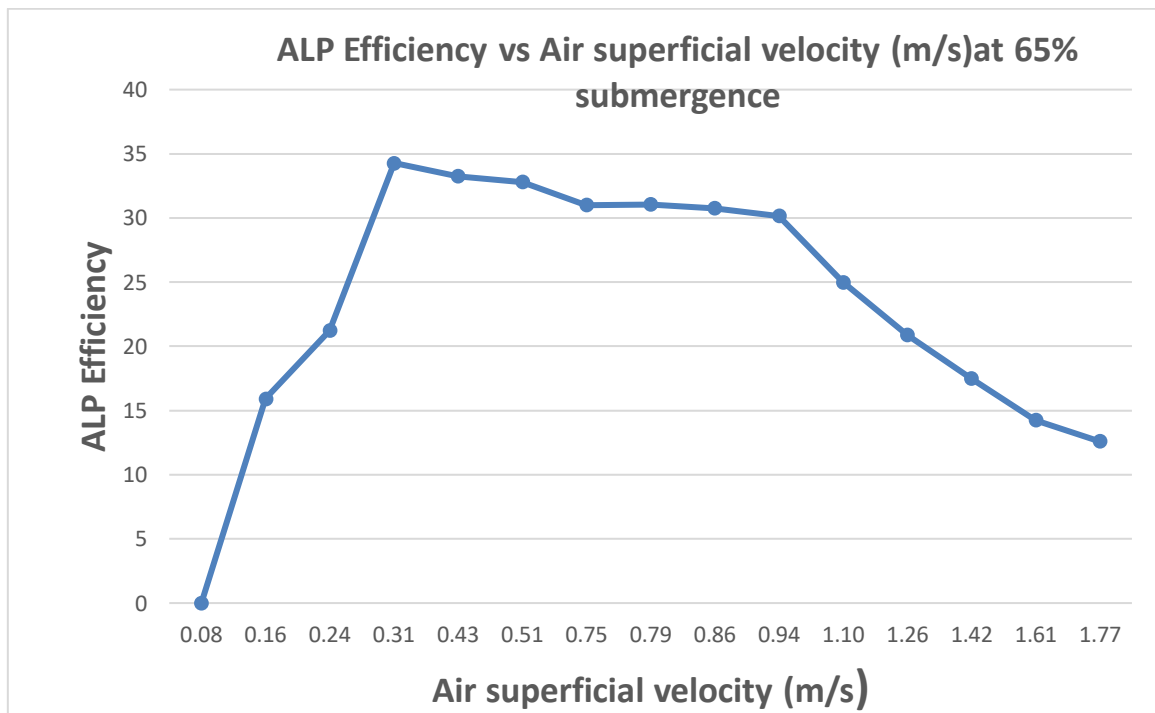


Fig 5.5(b) ALP Efficiency vs Air superficial velocity (m/s) at 65% submergence

Table 5.2 Data at 55% submergence

M(kg)	H (m)	Ho (m)	$\rho_a(\text{kg}/\text{m}^3)$	Va (l)	m(kg)	P (N/m^2)	Pa (N/m^2)	In (P/Pa)	% η	Uas (m/s)	Uws (m/s)
0	3.3	1.8	1.3	300	0.39	119564	101325	0.166	0	0.12	0
45	3.3	1.8	1.3	500	0.65	119564	101325	0.166	7.90	0.20	0.02
360	3.3	1.8	1.3	1000	1.3	120577	101325	0.174	30.05	0.39	0.14
660	3.3	1.8	1.3	1600	2.08	122603	101325	0.191	31.43	0.63	0.26
750	3.3	1.8	1.3	2000	2.6	123617	101325	0.199	27.39	0.79	0.29
880	3.3	1.8	1.3	2500	3.25	125643	101325	0.215	23.76	0.98	0.35
950	3.3	1.8	1.3	3000	3.9	127670	101325	0.231	19.90	1.18	0.37
1020	3.3	1.8	1.3	3500	4.55	129696	101325	0.247	17.14	1.38	0.40
1120	3.3	1.8	1.3	4000	5.2	131723	101325	0.262	15.50	1.57	0.44
1100	3.3	1.8	1.3	4500	5.85	136789	101325	0.300	11.83	1.77	0.43

5.1.3 AIR LIFT PUMP PERFORMANCE AT 55% SUBMERGENCE

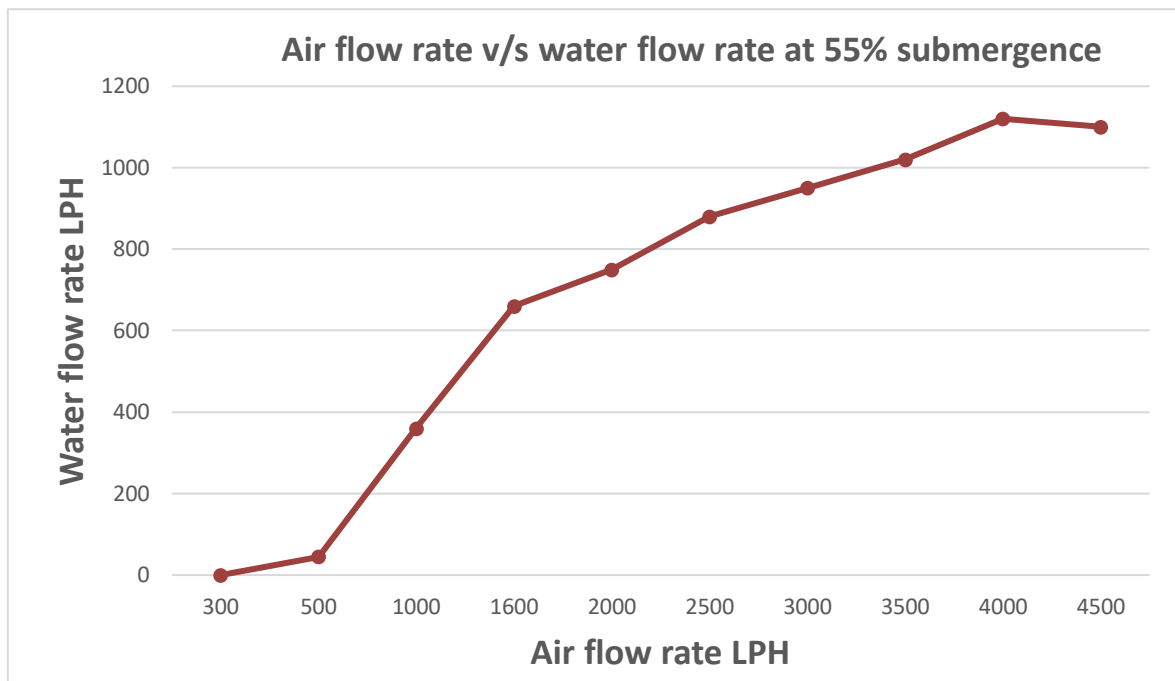


Fig 5.6(a) Air flow rate v/s water flow rate at 55% submergence

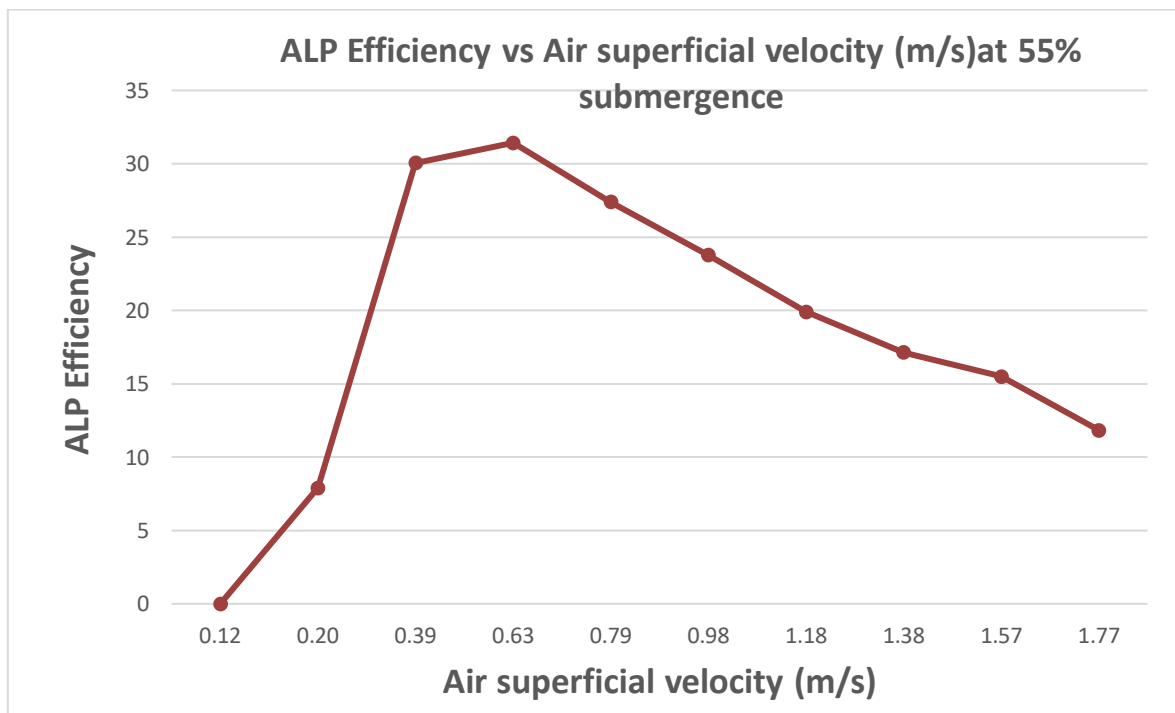


Fig 5.6(b) ALP Efficiency vs Air superficial velocity (m/s) at 55% submergence

Table 5.3 Data at 42% submergence

M(kg)	H (m)	H _o (m)	ρ_a (kg/ m^3)	V _a (l)	m(k g)	P (N/m ²)	P _a N/m ²)	In (P/Pa)	% η	U _{as} (m/s)	U _{ws} (m/s)
0	3.3	1.4	1.3	500	0.65	116524	101325	0.140	0	0.20	0
45	3.3	1.4	1.3	800	1.04	117537	101325	0.148	6.97	0.31	0.02
180	3.3	1.4	1.3	1200	1.56	118550	101325	0.157	17.57	0.47	0.07
270	3.3	1.4	1.3	1600	2.08	119564	101325	0.166	18.75	0.63	0.11
390	3.3	1.4	1.3	2000	2.6	120577	101325	0.174	20.62	0.79	0.15
460	3.3	1.4	1.3	2500	3.25	121590	101325	0.182	18.56	0.98	0.18
520	3.3	1.4	1.3	3000	3.9	122603	101325	0.191	16.73	1.18	0.20
620	3.3	1.4	1.3	3500	4.55	123617	101325	0.199	16.39	1.38	0.24
600	3.3	1.4	1.3	4000	5.2	126656	101325	0.223	12.37	1.57	0.24
580	3.3	1.4	1.3	4500	5.85	131723	101325	0.262	9.04	1.77	0.23

5.1.4 AIR LIFT PUMP PERFORMANCE AT 42% SUBMERGENCE

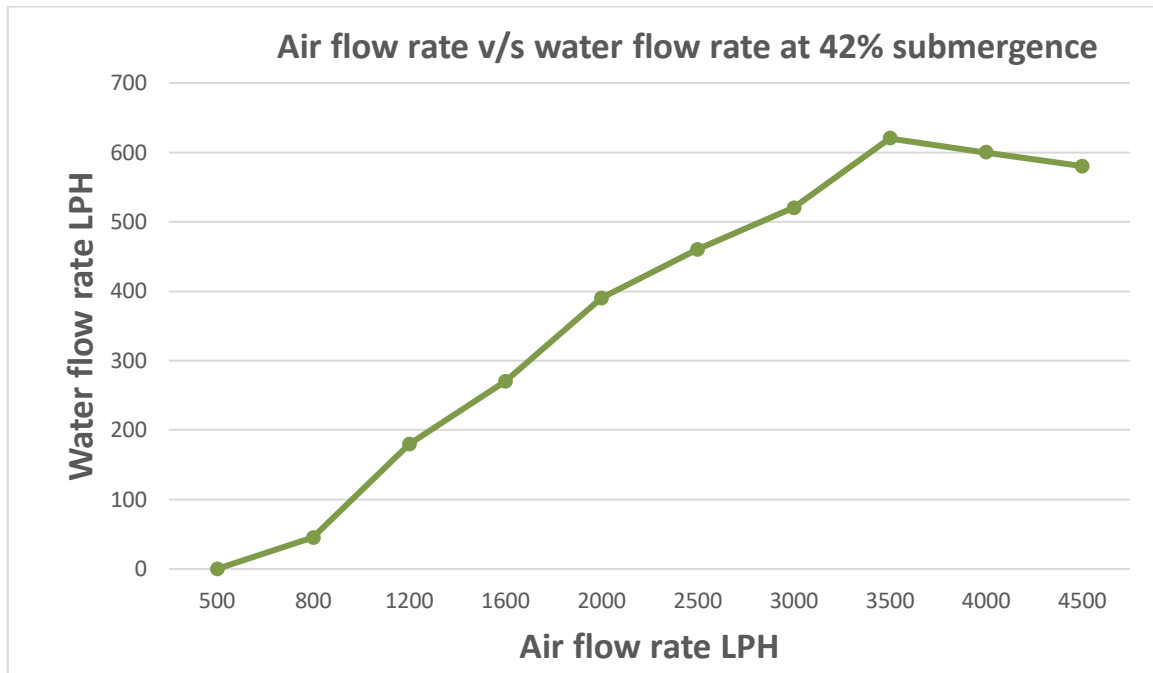


Fig 5.7(a) Air flow rate v/s water flow rate at 42% submergence

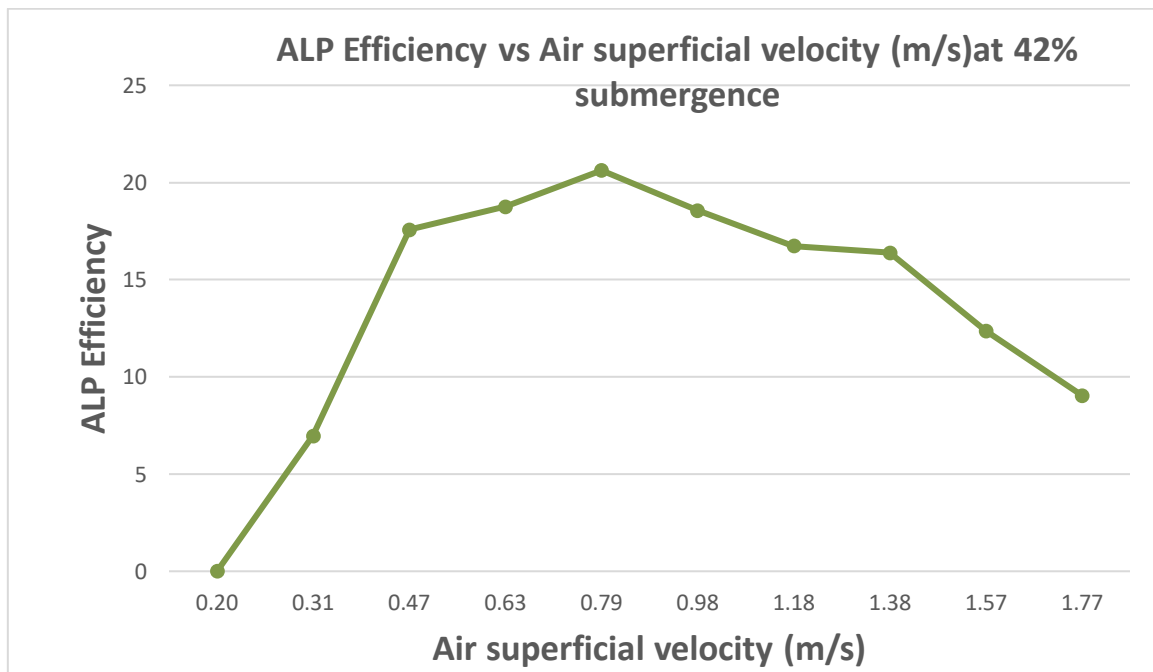


Fig 5.7(b) ALP Efficiency vs Air superficial velocity (m/s) at 42% submergence

Table 5.4 Data at 35% submergence

M(kg)	H (m)	H_o (m)	ρ_a(kg /m³)	V_a (l)	m(k g)	P (N/m²)	P_a N/m²)	ln (P/P_a)	% η	U_{as} (m/s)	U_{ws} (m/s)
0	3.3	1.2	1.3	500	0.65	116523.75	101325	0.140	0	0.20	0.20
40	3.3	1.2	1.3	1000	1.3	117537	101325	0.148	5.48	0.39	0.24
135	3.3	1.2	1.3	1400	1.82	119563.5	101325	0.166	11.85	0.55	0.24
270	3.3	1.2	1.3	1800	2.34	121590	101325	0.182	16.73	0.71	0.23
375	3.3	1.2	1.3	2100	2.73	123616.5	101325	0.199	18.26	0.83	0.24
440	3.3	1.2	1.3	2500	3.25	125643	101325	0.215	16.63	0.98	0.25
510	3.3	1.2	1.3	3000	3.9	129696	101325	0.247	14.00	1.18	0.26
580	3.3	1.2	1.3	3500	4.55	131722.5	101325	0.262	12.84	1.38	0.26
570	3.3	1.2	1.3	4000	5.2	131722.5	101325	0.262	11.04	1.57	0.27
560	3.3	1.2	1.3	4500	5.85	134762.25	101325	0.285	8.87	1.77	0.28

5.1.5 AIR LIFT PUMP PERFORMANCE AT 35% SUBMERGENCE

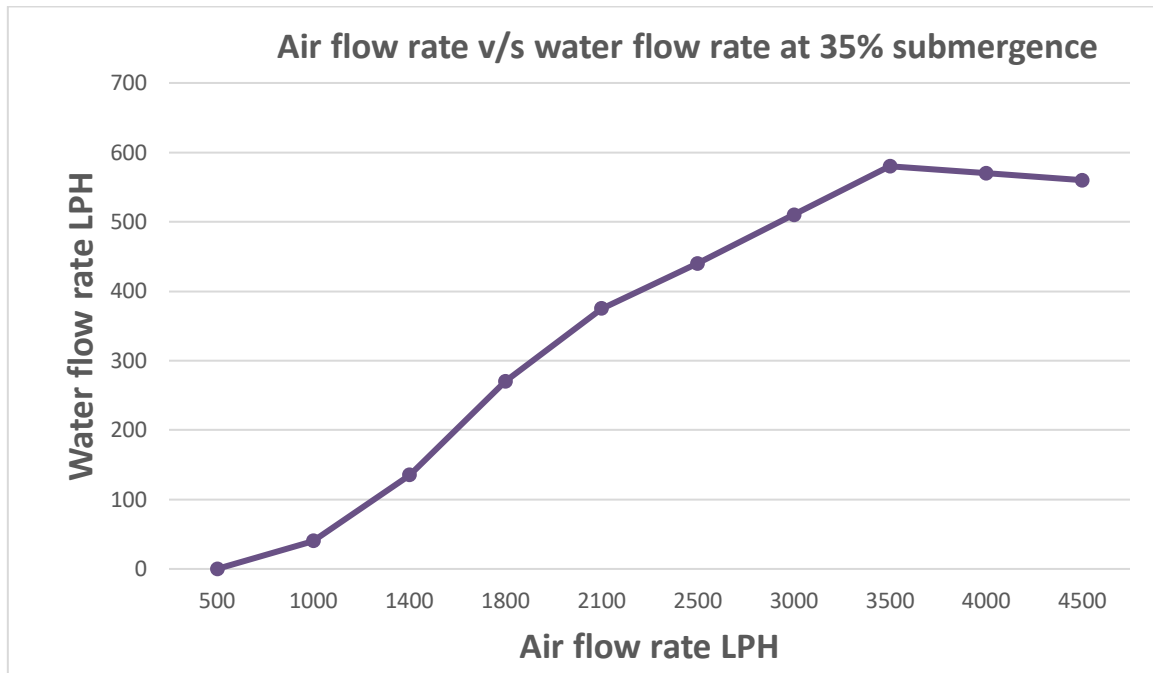


Fig 5.8(a) Air flow rate v/s water flow rate at 35% submergence

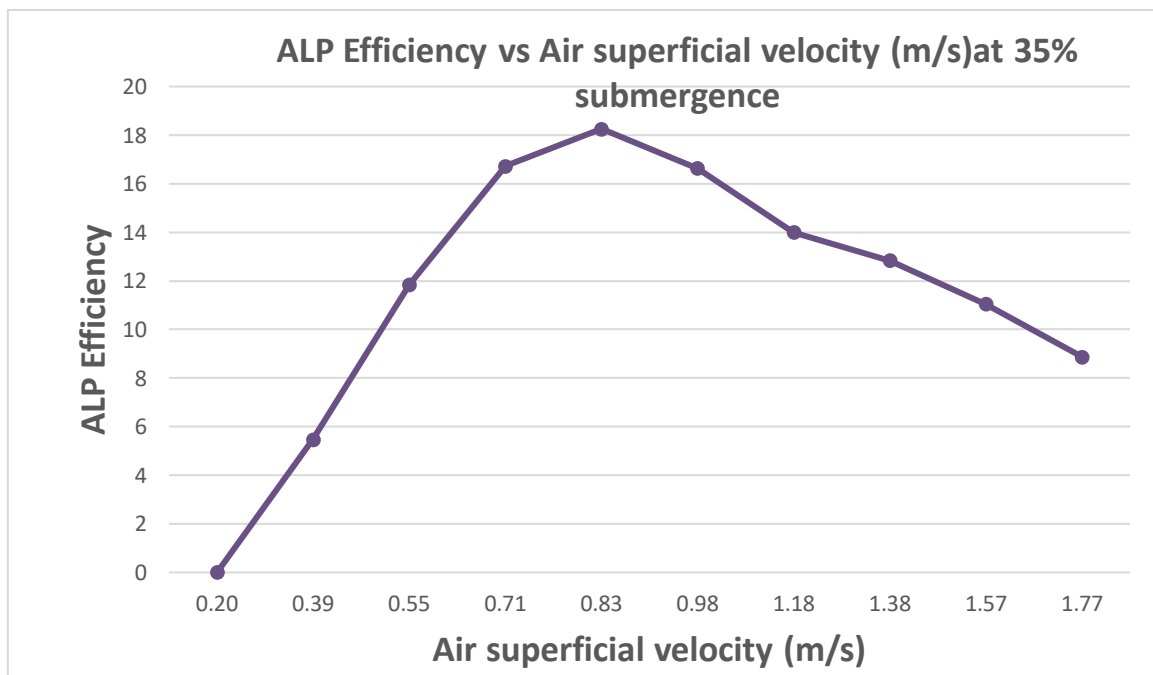


Fig 5.8(b) ALP Efficiency vs Air superficial velocity (m/s) at 35% submergence

5.1.6 PERFORMANCE COMPARISON OF ALP AT VARIOUS SUBMERGENCE

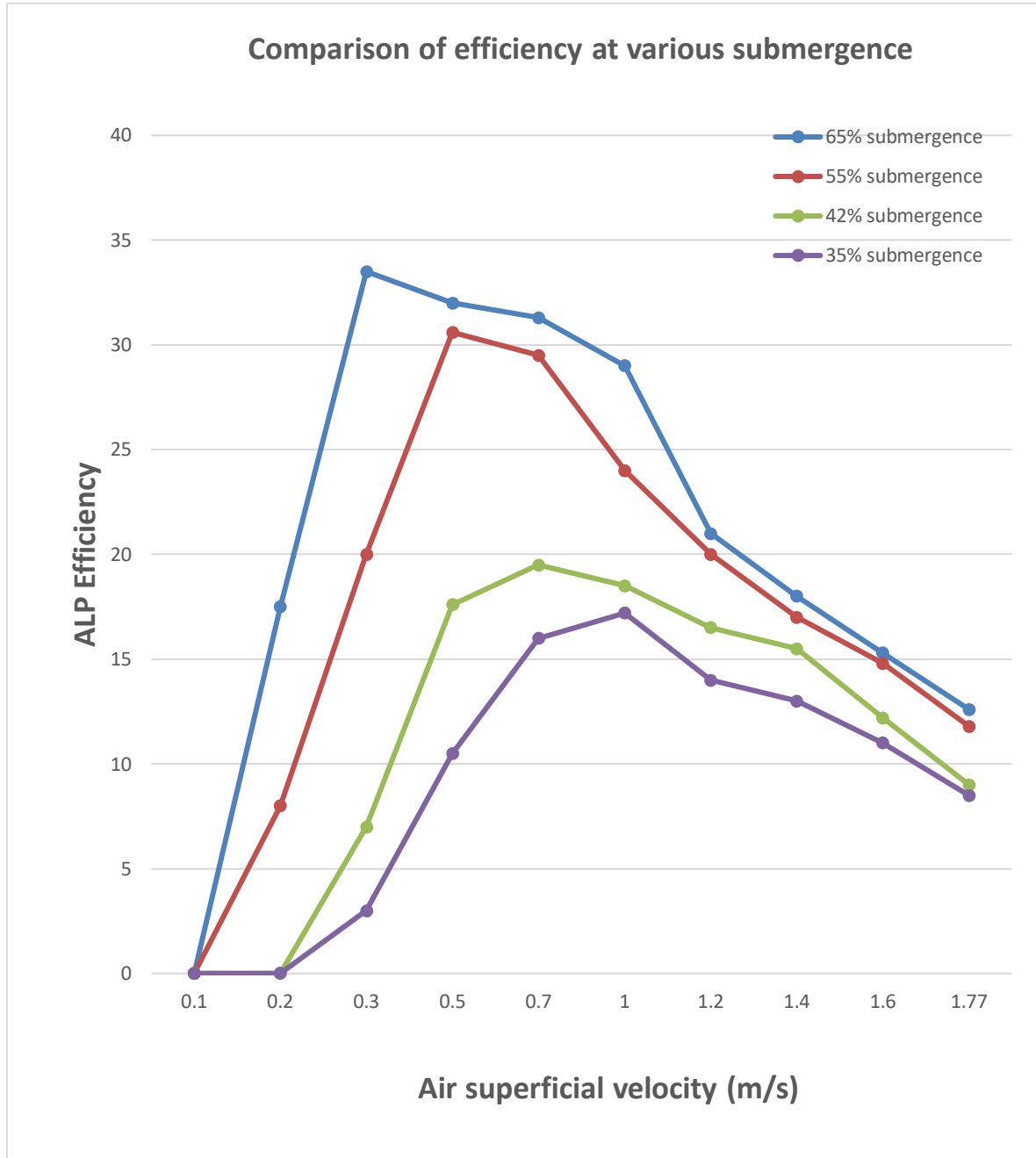


Fig 5.9 Performance comparison of ALP at various submergence

5.2 RESULT SUMMARY

1. Bubble flow regime obtained below **0.1m/s** of air superficial velocity.
2. There is no flow in bubble flow regime below **80%** submergence.
3. Slug flow regime obtained between **0.2-1.0 m/s** of superficial velocity of air.
4. Maximum efficiency of ALP obtained in **slug flow regime**.
5. Churn flow regime obtained between **1.1- 10 m/s** of superficial velocity of air.
6. Maximum liquid flow rate obtained in **churn flow regime**.
7. Annular flow regime obtained above **10 m/s** of superficial velocity of air.
8. In **Annular flow regime** both efficiency as well as liquid flow rate are minimum.
9. The best operating range of ALP is determined by optimum of efficiency and liquid flow rate and that is at superficial velocity of air between **0.5-1.3 m/s**.

5.3 MODEL CALCULATIONS

Volumetric flow rate, $Q = 800 \text{ LPH} = 2.22 \times 10^{-4} \text{ m}^3/\text{s}$.

Dia of riser pipe (d) = 30mm = 0.03m.

Cross sectional area (A) = $[(3.14 \times 0.03 \times 0.03)/4]$
 $= 7.065 \times 10^{-4} \text{ m}^2$

Air superficial velocity

Air superficial velocity = $Q/A = (2.22 \times 10^{-4}) / (7.065 \times 10^{-4})$
= 0.314 m/s

Mass of water lifted (M) = 450 kg

Value of $g = 9.81 \text{ m/s}^2$

Height of lift (H) = 3.3 m

Submergence height (H_o) = 2.1m.

Mass of air used (m) = 1.04 kg

Density of air (ρ_a) = 1.3 kg/m³

Atmospheric pressure (P_a) = 101325 N/m²

Air inlet pressure (P) = 122603 N/m²

Efficiency of air lift pump

$$\eta = [Mg(H - H_o)] / \left[\left(\frac{m}{\rho_a} \right) Pa \cdot \ln \left(\frac{P}{Pa} \right) \right] \dots (1.3)$$

By substituting all the values in equation 3

$\eta = 0.3428$

% η = 34.28%

CHAPTER- 6

6.1 CONCLUSION

Various flow regime of two phase flow studied by using the experimental setup study shows that the flow regime is the function of superficial velocity of air as the superficial velocity of air increases the flow regime also changes from bubbly to slug and slug to churn and further annular flow. Bubble flow regime obtained below 0.1m/s of air superficial velocity. Slug flow regime obtained between 0.2-1.0 m/s of superficial velocity of air. Experimental results shows that liquid flow rate through ALP increases as submergence increases. Maximum efficiency is obtained in slug flow regime at superficial velocity of air between 0.3-1.0 m/s. Maximum flow rate of liquid is obtained in churn flow regime at superficial velocity of air between 1.0-1.5 m/s. best operating range of ALP is at superficial velocity of air between 0.5-1.3 m/s. Based on the experimental results following conclusion is presented.

1. Submergence greatly affect the ALP performance.
2. At higher submergence efficiency as well as liquid flow rate is higher.
3. Maximum efficiency is obtained **in slug flow regime** at superficial velocity of air between **0.3-1.0 m/s**.
4. Maximum flow rate of liquid is obtained in churn flow regime at superficial velocity of air between **1.0-1.5 m/s**.
5. The best operating range of ALP is at superficial velocity of air between **0.5-1.3 m/s**.

6.2 FUTURE WORK

1. Different liquid can be tested to see the viscosity and density effect on flow rate.
2. Heating of liquid can be done to measure the temperature effect on the fluid flow.
3. Modeling of ALP performance can be done to validate the experimental results.

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Project

by Dilip Kumar

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ABSTRACT

In this Project, we conducted experimental investigations on the flow characteristics of two-phase air-water flows within a vertical pipe. Throughout our experiments, we observed varying flow patterns of air-water mixtures within the pipe, depending on the specific flow rates of both air and water. As a result, we formulated a flow pattern map that categorizes the flow behavior in the vertical pipe based on the superficial velocities of the liquid and gas phases. Our generated flow pattern maps were subsequently compared with those found in the existing literature, revealing a significant degree of alignment.

The objective of the project is to obtain the efficiency of the ALP in various flow regime and also find the best operating range of ALP.

In the present study we have used on 25 NB riser tube connected by an 8 NB airline, the riser tube is submerged in the water to provide the submergence to the air lift pump to work. Air is passed at different flow rate accordingly the flow rate of water is changed based on the air flow rate as well as two phase flow regime. Various two phase flow regime is observed which gives different efficiency of air lift pump to work. The main aim of study of the present two phase flow characteristics is to improve the ALP performance.

Air-lift pumps are becoming increasingly prevalent in applications demanding dependable pumps with minimal maintenance needs. They are particularly useful when dealing with corrosive, abrasive, or radioactive fluids, such as those encountered in nuclear applications. The primary goal of this study is to assess the performance of the ALP operating under specific conditions and optimize the relevant parameters. The research has demonstrated that the ALP's capacity and

efficiency depend on various factors, including the rate of air mass flow, submergence ratio, size of the riser pipeline, length of the riser pipe, and, to a limited extent, the properties of the liquid to be pumped. The best efficiency range of the ALP operation was found to be in the Slug flow regime obtained between **0.2-1.0 m/s** of superficial velocity of air. It is concluded that the submergence greatly affect the air lift performance. At higher submergence efficiency as well as liquid flow rates are higher. Maximum flow rate of liquid is obtained in slug- churn flow regime at superficial velocity of air between **1.0-1.5 m/s**. The best operating range of ALP is at superficial velocity of air between **0.5-1.3 m/s**.

CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION OF TWO PHASE FLOW

Two-phase flow (Gas liquid phase) in vertical pipe are encountered in various types of Process Equipment like air lift pump, steam generator, heat exchanger and condenser etc. The prediction of two-phase flow pattern is important in design, operation and safety analyses of this equipment. Figure 1.1 shows the various two phase flow profile for varying air flow rate in vertical pipe filled with water. The mass transfer, heat transfer, and momentum transfer characteristics of a two-phase flow are significantly influenced by the specific flow pattern it exhibits. In the case of vertical pipe air-water two-phase flows, there are a total of five distinct flow regimes that can be identified.

- (1) BUBBLE FLOW
- (2) SLUG FLOW
- (3) CHURN FLOW
- (4) ANNULAR FLOW
- (5) MIST FLOW

The Identifying these flow regimes is crucial due to their significant impact on heat and mass transfer processes. Bubble flow is characterized by small bubbles moving vertically upward within the pipe, with sizes much smaller than the pipe diameter. These bubbles are dispersed somewhat randomly throughout the liquid within the pipe. The transition from bubble to slug flow happens when these small bubbles collide, and some of these collisions lead to coalescence, resulting in larger bubbles comparable in size to the pipe diameter. This transition is known as slug flow. Bubble flow is a transient regime, and given sufficient residence time in the pipe, it will evolve into slug flow. When the liquid flow rate is low, a highly disturbed flow with an oscillatory nature occurs in the transition region between slug flow and the annular flow regime. This distinctive flow pattern is called churn flow, characterized by violent fluctuations in pressure gradient and liquid holdup. The annular and mist flow regime is commonly obtained in gas-liquid mixtures with superficial velocity of gas flow greater than 10 m/s. In this regime, there is an upward-moving, continuous, and smooth to wavy liquid film on the tube wall, with

4 rapidly moving gas at the central core containing entrained liquid droplets in varying concentrations. The liquid film can either be completely laminar or laminar near the wall and turbulent closer to the gas-liquid interface. Annular flow commonly obtained in evaporators, gas pipelines, and steam heated equipments. As the gas flow rate increases further, the liquid film becomes progressively thinner, and the number of droplets in the core flow increases. Eventually, the film detaches from the wall, leading to pure mist flow.

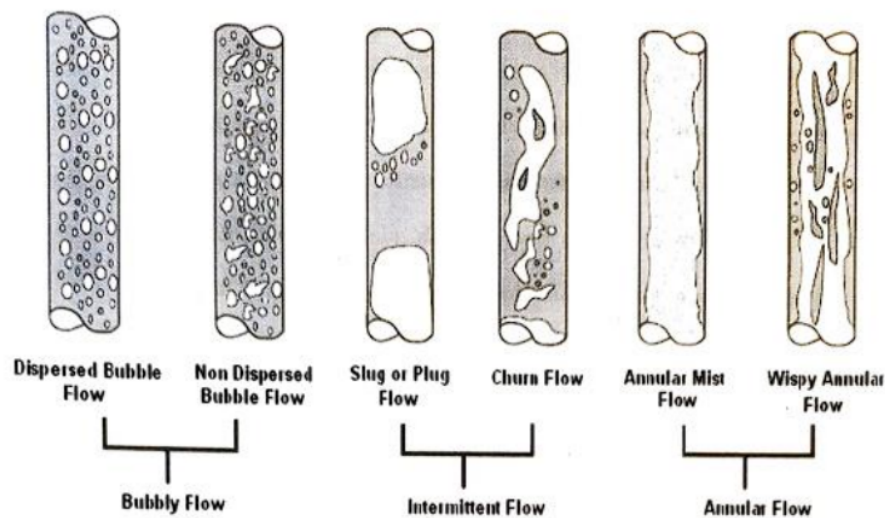


FIG 1.1 Two phase (air water) flow profile in vertical tube.

1.2 INTRODUCTION OF AIR LIFT PUMP

Air-lift pumps are increasingly being employed in situations that demand dependable pumps with minimal maintenance requirements. These pumps are particularly valuable when dealing with corrosive, abrasive, toxic, or radioactive fluids. An air-lift pump functions by raising either liquid or a mixture of liquids with solid material inside a vertical riser pipe. This is achieved by introducing compressed air into the lower section of the pipe, which is partially submerged in the liquid. As a result, the mixture's density inside the riser pipe becomes lower than that of the liquid in the down comer. Consequently, the mixture within the riser pipe starts to ascend, thus balancing the hydrostatic head in the other leg of the system. The study shows that capacity and efficiency of air lift pump is function of the air flow (Q_a), percentage submergence, and pipeline size and riser pipe length. The air-lift pump operates most efficiently within the slug flow regime and at the boundary of the slug-churn flow transition regime. It is employed to elevate liquid or slurry from a well or vessel, especially in situations where a submerged mechanical pump is impractical or where simple construction is required. In its most basic form, a vertical riser tube is partially submerged in the liquid within the vessel, and air is introduced at or near the base of the tube. Because the air has a lower density compared to the liquid, it creates a buoyant air-liquid mixture inside the air-lift pipe, causing it to rise and be discharged from the upper end of the pump. An alternate U-tube air-lift configuration, which utilizes a down comer leg for submergence, is illustrated in the figure below. The principles behind ALP were understood as early as 1882, although practical applications didn't emerge until the beginning of the twentieth century. One of the key advantages of air-lift pumps is their mechanical simplicity. Furthermore, they offer several benefits over other

types of pumps. They lack moving parts, require no lubrication, and are free from wear-related issues. They are well-suited for use in corrosive environments and zigzag wells where usual pumps may not be suitable. Consequently, the mechanical maintenance of air-lift pumps is theoretically less expensive and more reliable. Additionally, air-lift pumps are relatively straightforward to fabricate, even if they are not readily available from suppliers. Generally, when the static liquid level in the source tank is high air-lift pumping is most efficient. However, it should be noted that air-lift pumps have lower efficiency compared to some other pump types and require a substantial submergence depth to achieve high efficiency. In nuclear reprocessing plants, air-lift pumps are employed to transfer radioactive solutions, but they generate a considerable amount of air, leading to airborne activity concerns. The primary factor influencing the performance of an ALP is the presence of various two-phase flow regimes within the riser pipe during operation.

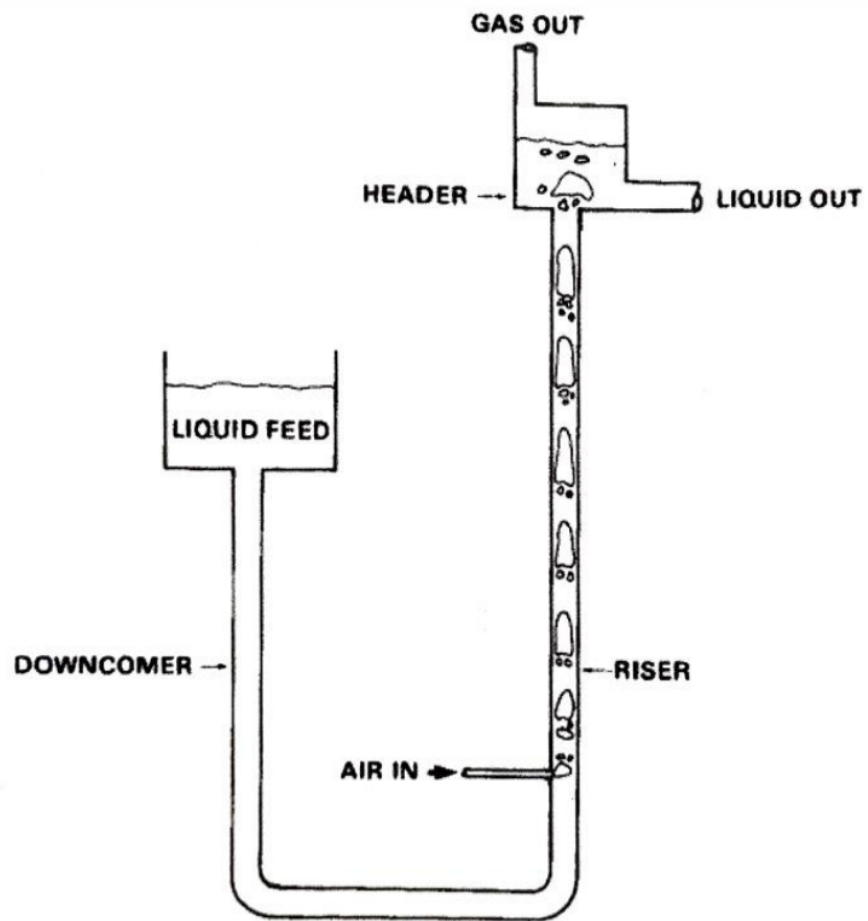


Fig 1.1.2 Air lift u- tube arrangement.

1.2.1 Advantages of air lift systems

- a) No moving parts.
- b) Low maintenance.
- c) Consistent performance.
- d) Remote transfer of liquid.
- e) Metered flow.
- f) Pump is very reliable.
- g) Very simple principle is a clear advantages.
- h) Only air with a high pressure than liquid is required.

1.2.2 Disadvantages of air lift system

- a) Low efficiency.
- b) De-entrainment problem.
- c) Minimum submergence is required.

1.2.3 Factors affecting capacity of air lift system

- a) Riser pipe diameter.
- b) Submergence ratio.
- c) Temperature of liquid.
- d) Density of liquid to be pumped.
- e) Liquid viscosity.

1.2.4 Application of air lift system

- a) ALP are used in zigzag deep wells where regular pump cannot be used.
- b) It is used for transferring of radioactive liquid because it has no moving part so no maintenance required throughout the life of the pump.
- c) ALP is used in radioactive waste immobilization plants.
- d) ALP is also used in the mining inside the deep sea.

1.3 EFFICIENCY OF AIR LIFT PUMP.

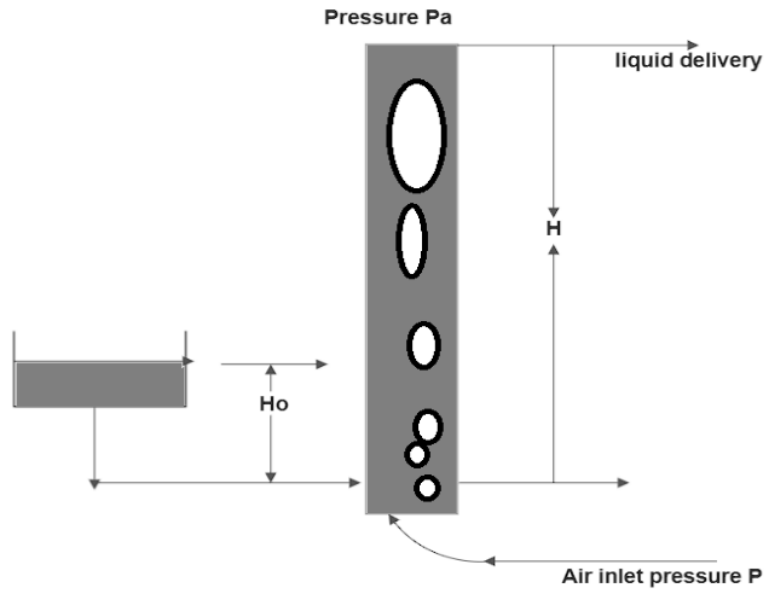


Fig 1.3 ALP Schematic diagram for efficiency calculation.

The efficiency of the ALP is given by:

$$\eta = [Mg(H - Ho)] / \left[\left(\frac{m}{\rho_a} \right) Pa \cdot \ln \left(\frac{P}{Pa} \right) \right] \dots\dots\dots(1.3)$$

$$\% \text{ Submergence} = \frac{Ho}{H} \times 100$$

- Where, η = efficiency, H = Total height of lift (m), Ho = submergence height (m)
- M = Mass of water lifted (kg), g = acceleration due to gravity (m/s^2)
- m = mass of air (kg), ρ_a = density of air (kg/m^3)
- Pa = atmospheric pressure (N/m^2).
- P is the inlet pressure of air (N/m^2)

CHAPTER-2

2.0 LITERATURE REVIEW

Air lift pumps are widely used in chemical, steel, mining and nuclear reprocessing industries. They are suitable for vertical transportation of the fluids for which mechanical impellers are not available or undesirable such as for corrosive, abrasive, toxic or radioactive fluids. Now even the flow control of air lift pump is more difficult as compared to turbo-machinery pumps because the performance of the air lift pump depends on state of multiphase flow of air-water in vertical pipe. In development of such air lift pump for prediction of performance, especially understanding the behavior of multiphase flow is much important for designing and for its optimum performance. In theory, air lift pumps could be designed to work with different mixtures of air and liquid phases, but in reality, they primarily operate within the slug flow regime. This specific flow pattern remains stable across a wide range of liquid and air velocities, a phenomenon well-documented by Tate (1980) and Clark (1984). Within the slug flow regime, we observe the presence of large air bubbles surrounded by a liquid annular film that adheres to the pipe wall. These air droplets are split up by liquid slugs that extend across the entire tube diameter, occasionally containing smaller air bubbles. Despite extensive literature about slug flow, contemporary design approaches continue to depend on semi-empirical equations, exemplified by those formulated by Shaw and O'Neill. However, the equations tend to lose accuracy when applied to non-standard air lift pump designs. Air lift pumps find extensive use in various applications, including underwater exploration, lifting coarse particle suspensions, transferring radioactive and corrosive fluids, and extracting sludge in sewage treatment plants.

The present study is concerned with the application of ALP in pumping radio-active and corrosive liquid transfer. In this scenario, the flow occurring in the pump riser involves a two-phase flow consisting of air and water. The flow patterns observed in the riser of an air lift pump directly correspond to the upward flow within a vertical pipe. As the ratio of air to water increases, different two-phase flow patterns can be observed:

- a) Bubbly flow: In this pattern, you'll notice relatively small and uniform-sized gas bubbles.
- b) Slug flow: This regime is defined by the presence of large, bullet-shaped gas

bubbles, accompanied by smaller gas bubbles dispersed throughout the liquid.

c) Churn flow: Churn flow exhibits high instability, featuring an oscillatory nature where the liquid near the riser tube wall moves up and down.

d) Annular flow: Within this pattern, the liquid partly moves as an annular film along the tube wall and partly as small drops dispersed within the central gas flow.

These flow patterns are observed as the air-to-water ratio varies, providing insight into the behaviour of two-phase flows in vertical pipelines.

Sharma and Sac de va conducted a study on the performance factors affecting large-diameter ALP operating in shallow depths. These researchers established a connection between the performance of pumps and the specific flow regime observed in the uptake pipe. Furthermore, in 1996, De-Cachard conducted experimental research demonstrating that slug flow is the dominant flow pattern within the practical operating range of smaller diameter air lift pumps. However, there is limited research available regarding the influence of liquid properties, such as surface tension, viscosity, and pipe geometry, on the performance of Air Lift Pumps (ALP). For example, Khalil and Mansour (1990) conducted experiments to investigate the effects of introducing a surfactant into the pumped liquid. Their findings consistently indicated that even a small concentration of surfactant enhances both the capacity and efficiency of the pump. They also noted that the concentration of the surfactant significantly affects pump performance. More recent research by Iguchi and Terauchi (2001) explored the impact of riser pipe-wall wettability on the transition between bubbly and slug flow regimes in vertical air-water two-phase flow. This was achieved by altering the inner wall of an acrylic pipe using a hydrophilic substance or liquid paraffin, resulting in noticeable variations in flow patterns. Flow pattern maps were developed to account for various pipe wall wettability conditions. Additionally, researchers conducted experiments to investigate the influence of liquid viscosity on flow patterns in vertical air-liquid two-phase flow. They employed various liquids, like water and glycol solution, and found that flow pattern transitions are significantly influenced by liquid viscosity. Further they examined the effect of tube diameter on air lift pump performance. They noted that for Reynolds numbers below 500, liquid slugs exhibited a turbulent velocity profile. Additionally, they studied the influence of surface tension on bubble rise velocity for tube diameters ranging from 3 to 20 mm. The effect of air injection methods on bubble size and distribution was also

studied. Researcher explored the effect of bubble size distribution on the performance of an ALP using air admission through a perforated disc. They found that reducing bubble size or enhancing the number of holes led to an increase in liquid discharge. Lastly, Khalil et al. (1999) conducted experiments highlighting the substantial impact of initial bubble size and bubble distribution within the riser pipe on ALP performance. Achieving a well-mixed homogeneous mixture within the riser was found to minimise slip and enhance ALP efficiency.

Several flow regime maps for two-phase flow in vertical tubes can be found in the literature. These maps define transition boundaries in a two-dimensional coordinate system based on data from experiments and observations. The selection of parameters for these published maps can be classified into two main categories, as described by Taitel et al. (1980):

a) The first category of flow pattern maps utilizes dimensional coordinates, such as the superficial velocity of gas (U_g) and liquid (U_l), or the superficial momentum fluxes (ρU_g^2 and ρU_l^2). These coordinates define the transition boundaries when specific pipe sizes and fluid properties are considered. However, it's essential to recognize that variations in these variables can lead to shifts in the position of boundaries between different flow patterns.

b) The second group employs dimensionless coordinates to make the results applicable to various pipe sizes and fluid properties beyond those used to establish the curves. Griffith and Wallis (1961) sought to derive dimensionless coordinates based on theory, resulting in $U^2 M/gd$ and U_g/U_s , where U_m represents the mixture velocity, U_s signifies the slug velocity, U_g denotes the superficial velocity of gas within the pipe, g stands for acceleration due to gravity, and d represents the riser pipe diameter. These dimensionless coordinates govern the transition from slug to annular flow regime. To investigate ALP performance under varying flow patterns, this study extended the air flow rate range to encompass a wide spectrum of flow regimes. Furthermore, pipes of varying lengths were employed to assess the impact of uptake pipe length, while maintaining a consistent submergence ratio, on pump performance.

In theory, Air Lift Pumps have the potential to exhibit various degrees of mixing between the air and liquid phases. However, in practical applications, the majority of Air Lift Pumps predominantly operate within the slug flow regime. This regime is known for its stability across a wide range of air and liquid velocities. In slug flow,

the primary characteristic involves the presence of large air bubbles surrounded by a thin annular film of liquid in contact with the pipe wall. These air bubbles are interspersed with slugs of liquid that extend across the entire diameter of the tube, and some of these liquid slugs may contain smaller air bubbles. Early theoretical approaches in this context focused on the energy balance, with the aim of equating the energy stored in the compressed air introduced at the base of the pump with the useful work required to lift the liquid up to the vent pot of the ALP. Assuming isothermal operation and a pump with 100% efficiency, the volume of free air (at atmospheric pressure), denoted as V_g , needed to lift a certain volume of water (VW) to a height of L meters can be expressed as follows:

$$\frac{V_g}{V_w} = \frac{\rho g L}{P_2 \ln\left(\frac{P_0}{P_2}\right)} \quad (1)$$

In the given equations, P_0 denotes the initial air pressure at the inlet, typically at the bottom where the air is introduced, and P_2 represents the discharge pressure, often equivalent to atmospheric pressure. However, concerning Air Lift Pump (ALP) applications, there are inherent energy losses attributed to factors like bulk flow losses and liquid slippage. These losses frequently resulted in early air lift pumps achieving energy efficiencies within the range of 25% to 35%. As a result, it was impractical to directly apply the theoretical energy balance without incorporating an energy efficiency factor. Consequently, over time, various adjusted energy balance equations in different forms have been introduced in the article and continue to be recommended for air lift pump design. Nonetheless, it is crucial to understand that the energy balance on its own does not suffice for precise design. This is due to the fact that the actual pump efficiency is seldom known until a pump is constructed or a design undergoes a more comprehensive analysis of two-phase flow. In cases where low submergence levels or narrow bore diameters are utilized, these energy balance equations tend to overestimate flow rates to a significant extent.

In 1963, Nicklin's work provided a significant contribution to the analysis of Air Lift Pumps (ALP), with a primary focus on the momentum balance. This analysis involved a detailed examination of the pressure gradient within the air lift tube, which was divided into two distinct components: the hydrostatic head and friction losses. The determination of the hydrostatic head relied on calculating the hold-up

of both the liquid and gas phases, a process facilitated by employing a two-phase flow drift-flux model. When considering the energy balance, the prediction of hold-up took into account losses resulting from bubble slippage, and friction losses were directly incorporated using a modified Darcy equation initially developed for single-phase flow, as introduced by Dabolt and Clark in 1985.

Dabolt and Plummer (1980) presented a comprehensive dataset for air lift pumps ranging from 12 to 50 mm in diameter, specifically applied in the context of nuclear fuel reprocessing. Their investigation identified the submergence ratio, which represents the ratio of submergence to the total pump height, as the primary variable influencing lift performance. Consequently, they introduced a design equation as follows:

$$V_a = \frac{\ln(1 - \frac{V_w}{A})}{B} \quad (2)$$

The equation comprises variables like V_a (representing the air volume required to lift a water volume V_w), A , and B , which are quadratic functions influenced by the submergence ratio. These coefficients are subject to variation with changes in pipe diameter. In order to accommodate frictional losses occurring prior to the sparger and within the air lift tube, as well as pressure considerations in the vent pot and feed tank, the geometric submergence ratio was adjusted to an effective submergence ratio. This equation demonstrated a more favourable agreement with empirical data when compared to previous design methods applied in the context of nuclear fuel reprocessing. However, it is important to emphasize that this correlation for coefficients A and B is only valid within the range of pipe diameters spanning from 12 to 50 mm. It's worth noting that despite the availability of numerous methods for predicting liquid flow rates in Air Lift Pumps (ALP), none of these equations successfully combine both theoretical soundness and precise performance prediction. This challenge remains a significant aspect of the design process.

2.1 AIR WATER FLOW PATTERN IN VERTICAL PIPE

Two-phase flow (Gas liquid) in vertical pipe is encountered in various type of Process Equipment like air lift pumps, boiler, heat exchangers and condensers.

The knowledge of two phase flow pattern is important in design and in efficient operation of these equipment. Typical two-phase flow pattern map in the vertical pipe line is presented in Figure. 2.1. Figure.2.1 shows the various two phase flow profile map for varying air flow rate in a vertical pipe filled with liquid water. At a lower air flow rate, air forms small diameter bubbles dispersed in a liquid uniformly. As the air flow rate increases the flow pattern changes progressively to Slug flow, churn flow, annular flow and finally to dispersed or mist flow.

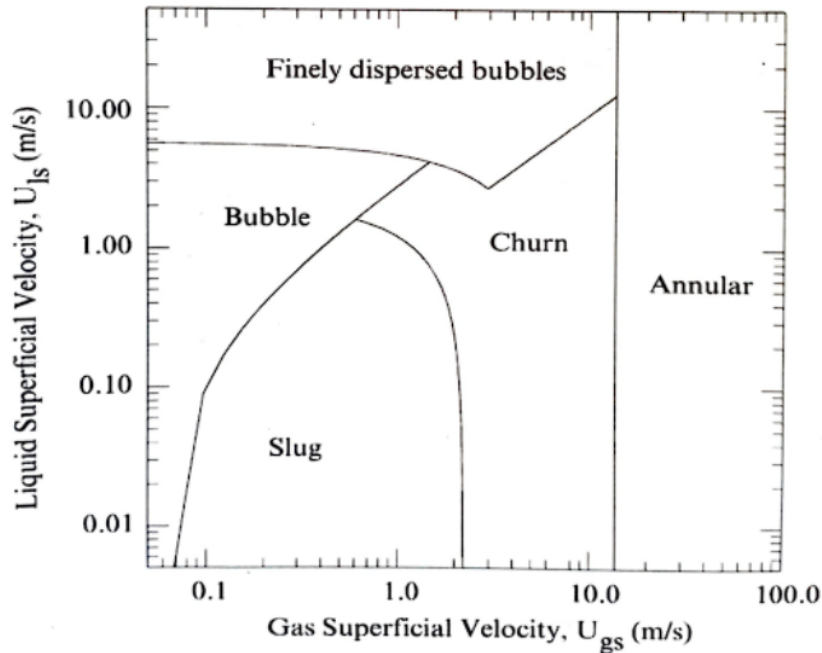


Figure 2.1 Two phase flow regime map in vertical pipe.

- A) **Bubbly flow:** In this flow pattern, gas is dispersed within the continuous liquid phase. Researchers have categorized this flow pattern into two types: dispersed bubbly flow and low liquid input bubbly flow.

Dispersed bubbly flow is a flow pattern that can be observed across a wide

range of pipe diameters and inclinations. In this situation, the gas phase is dispersed in the form of small bubbles within the continuous liquid phase.

Low liquid input bubbly flow, on the other hand, is characterized by the presence of small gas bubbles of roughly uniform size and their even distribution within the liquid phase, particularly at low liquid superficial velocities. Occasionally, some coalescence may occur within the bulk of the flow.

B) **Slug flow:** In this flow pattern, when the gas superficial velocity increases, the individual gas bubbles start to merge and create elongated, smooth bubbles with a distinctive cap or bullet-shaped front. These elongated bubbles are commonly known as Taylor bubbles, and they have a cross-section similar in size to that of the pipe. They are surrounded by a thin liquid film and are spaced apart from the pipe wall.

C) **Churn/ froth flow:** In the transition from the slug regime to churn or froth flow, as the gas superficial velocity increases, the Taylor bubble at the interface between the liquid and gas phases becomes more distorted. This distorted bubble moves in a churning motion, leading to the formation of irregularly shaped areas containing both gas and liquid. This flow pattern is commonly known as froth slug or churn-turbulent flow.

D) **Annular flow:** In this flow regime, the gas phase occupies the core of the tube, while the liquid forms a thin film around the tube's periphery. Additionally, the liquid exists as entrained drops within the gas core. There are two variations of this flow pattern: In this variation, entrained liquid exists as relatively large drops, and the liquid film contains gas bubbles.

Annular mist flow: In this flow pattern, gas occupies the central core, while the liquid flows along the periphery. The core gas contains entrained liquid, but the drops are not large; instead, they have tiny sizes.

2.2 FLOW PATTERN TRANSITION MECHANISM

Recognizing the specific flow regime that occurs under given conditions is essential, as each flow pattern possesses unique hydrodynamic traits. These characteristics, in turn, have a significant influence on factors like pressure drop, as well as the heat and mass transfer capabilities. Consequently, the identification

of flow patterns and their transitions holds great significance. The transitions between these flow regimes are contingent on a variety of factors, including the velocities of the gas and liquid, fluid properties, pipe orientation, pipe diameter, and the operational conditions in place.

While experimental methods are the most popular for flow pattern identification, empirical and mechanistic models also play a role in identifying flow regime transitions. Researchers have developed mechanistic models for commonly encountered vertical flow patterns.

2.3 TRANSITIONING FROM A BUBBLY FLOW REGIME TO A SLUG FLOW REGIME

In the realm of gas-liquid two-phase flow, the transition from bubbly flow to slug flow has garnered significant attention from researchers in recent years. This transition occurs frequently in industries such as chemical, biological, and nuclear, and it entails notable variations in flow characteristics. These variations encompass interfacial structure, heat transfer and mass transfer mechanisms, drag forces, and pressure drops. Accurate prediction of the transition boundary is vital for discerning these characteristics and establishing constitutive equations. Understanding the intricate physical mechanisms at play during the transition process is crucial for improving flow regime predictions.

Early research by Radovcich and Moissis suggested that bubble coalescence induces the transition. In bubbly flow, bubbles are randomly dispersed in the liquid phase, with occasional coalescence or break-up. When the rate of coalescence exceeds that of break-up, the transition occurs. Various criteria based on experimental observations and theoretical analyses have been proposed to determine the transition. Many other researchers proposed different void fraction values as transition criteria under different flow conditions. These criteria generally showed good agreement with experimental data across a wide range of conditions.

To address the limitations of void fraction criteria, new criteria based on bubble dynamics have emerged. Instead of focusing solely on void fraction, these criteria

incorporate the behavior of individual bubbles using population balance models (PBM) or interfacial area transport equations (IATE). PBM describes coalescence and breakage processes of scattered bubbles in bubbly flow, predicting the bubble size distribution for flow regime prediction. IATE, initially developed for determining interfacial transfer terms, can predict two-phase flow structure dynamically based on the evolution of interfacial area concentration (IAC) influenced by bubble behavior. Researchers have used parameters like the attenuation coefficient of void fraction waves or linear analysis to trigger these transitions. However, this mechanism doesn't account for all transition scenarios, as evidenced by some experimental phenomena in specific flow conditions.

In summary, the transition from bubbly flow to slug flow in gas-liquid two-phase flow is a complex phenomenon with significant industrial implications. Multiple mechanisms and criteria have been proposed to describe this transition, but further research and experimental evidence are needed to comprehensively understand and predict this phenomenon across various flow conditions.

As per the findings of McQuillan and Whalley, bubbly flow is typically witnessed at low air superficial velocities, irrespective of the water flow rate. In general, when the gas superficial velocity rises, it results in the generation of a greater number of bubbles, subsequently increasing the overall bubble density. This decrease in the distance between bubbles can eventually result in coalescence. Researchers qualitatively demonstrated that the probability of coalescence becomes significantly higher when the void fraction exceeds 30%. They inferred that this marks the transition to a different flow regime. Taitel et al. (1980) similarly attributed the transition to the gradual coalescence of a sufficient quantity of bubbles into large Taylor bubbles. Taitel et al. (1980) found that this transition from bubbly to slug flow typically occurs around a critical void fraction (α) of 25% of the pipe volume, as represented by line A in Figure 2.3.

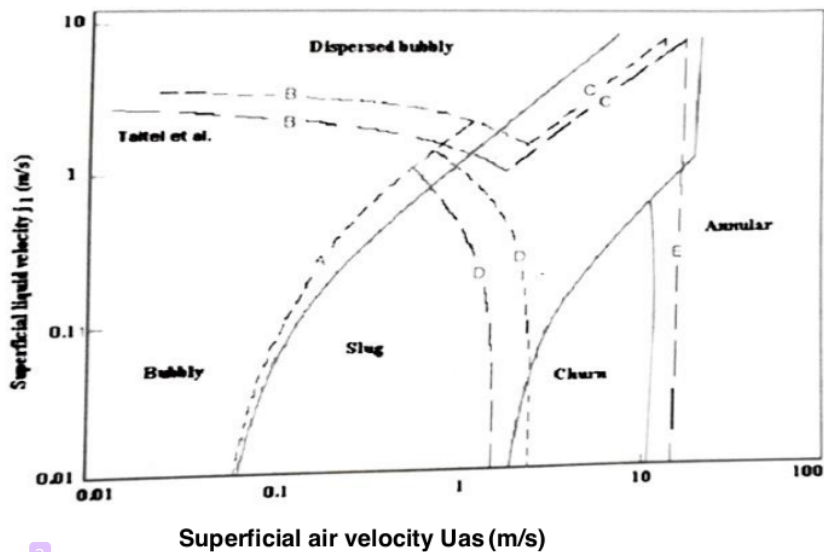


Fig 2.3: Flow regime map for vertical up-flow showing flow transition

CHAPTER-3

3.1 AIM

The aim of the project is to collect the data of water flow rate v/s air flow rate in various flow regime at different submergence ratio by using the experimental setup, comparing values at various submergence ratio and calculating the efficiency of the air lift pump, also find out maximum efficient operating range.

3.2 SCOPE

The project is meant to determine the flow regime in which the best efficiency of ALP is obtained by varying the air flow rate at constant submergence in the vertical transparent riser pipe.

During the two phase flow of gas –liquid mixtures in a vertical pipe, the phases may distribute in a different flow pattern. Each flow pattern depends on the flow rate of fluid, fluid properties and the riser pipe size. Mass and Heat transfer rate, Frictional losses, back mixing rate and resident time distribution all depend on flow pattern. Gas liquid slug flow pattern in vertical tube found many industrial applications. It occurs in process equipment like vapor-liquid contactors, vapor separators, thermosyphon reboilers, and gas liquid chemical reactors, two phase oil and gas pipelines as well as oil and gas geothermal wells.

CHAPTER-4

EXPRIMENTAL STUDIES METHODS & METHODOLOGY

4.1 EXPERIMENTAL SET UP: Schematic diagram of experimental setup is shown in fig 4.1. Which consist 25 NB acrylic uptake line with 8 NB ss airline coming from compressor through rotameter one vent pot is connected on top to separate the air and water. The length of acrylic uptake line is 2m. Air flow rate is measured through rotameter and water flow rate is measured in a pre-calibrated bucket at different submergence i.e., at 65%, 55%, 42% and 35%.

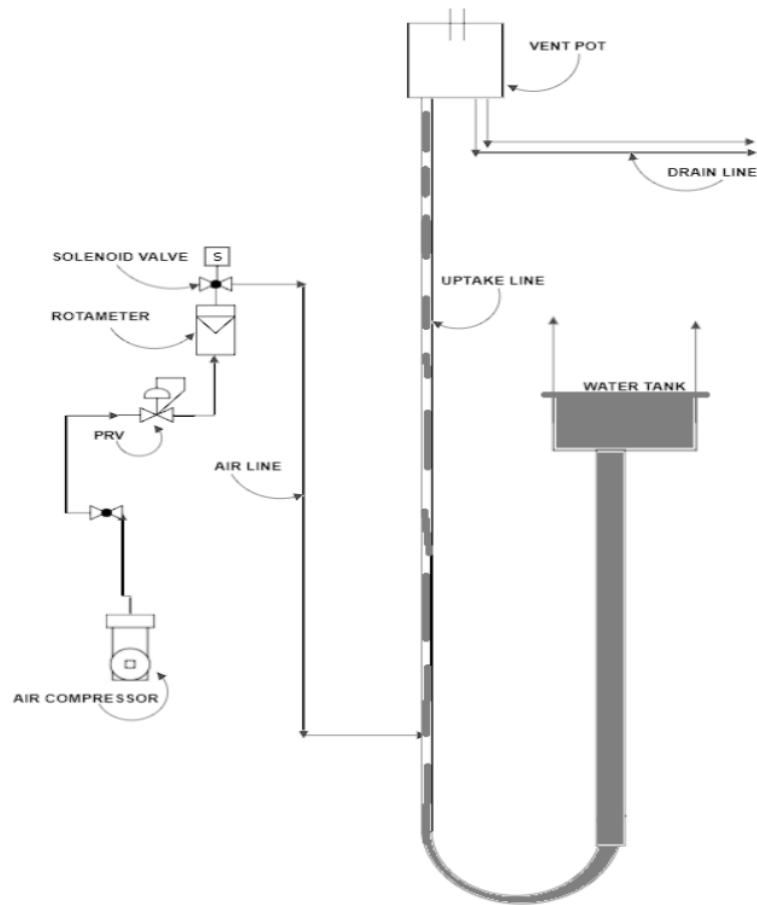


Fig 4.1 Schematic diagram of experimental setup.

4.2 EXPERIMENTAL PROCEDURE

- Fill the source tank with water.
- Measure the submergence in uptake line.
- Start the air flow in riser pipe.
- Note down the air flow rate, air pressure, calculate the liquid flow rate.
- Calculate the air superficial velocity.
- Calculate the efficiency of the ALP.
- Increase the air flow rate.
- Repeat the experiment at different air flow rates.

- Take the flow regime photo at different air superficial velocity.
- Increase the submergence by increasing the water level in tank.
- Repeat the experiment at different submergence ratio.
- Collect the data at different submergence ratio, draw the graphs of air flow rate v/s water flow rate and ALP Efficiency v/s air superficial velocity.
- Find out the maximum efficient regime and optimum operating range.

4.3 METHODOLOGY

- Experimental estimation of different flow regime of two phase flow using air and water in ALP system by varying the flow rate of air.
- Repeating the experiment at various submergence.
- Theoretical calculation of efficiency of ALP.
- Comparison of results at different submergence.

4.4 ACTUAL SETUP



Figure 4.4 actual Experimental setup.

4.5 MATERIAL USED.

1. Water.
2. Compressed air.
3. Transparent Acrylic Pipe.
4. PVC Drain hose.
5. Calibrated PVC Bucket.
6. Stainless steel vent pot.
7. 25 NB Stainless steel foot piece with 8 NB airline.
8. 300 liter water tank.
9. 100 liter plastic bucket.

CHAPTER- 5

RESULTS AND DISCUSSIONS

5.1 EXPERIMENTAL OUTCOMES

Four experimental runs were carried out at different submergence ratio (65, 55, 42 and 35%) by varying the air flow rate from zero to 4500 lph. Initially up to certain flow rate the liquid flow rate is zero hence the efficiency of ALP is zero. As the air flow rate increases liquid flow starts and the two phase flow regime also changes as superficial velocity of air increases. At each superficial velocity of air water flow rate is noted and the efficiency of ALP is calculated by equation no. (3) Which is tabulated below for each submergence. Experimental data shows that maximum efficiency of ALP obtained in slug flow regime at superficial velocity range of 0.2-1.0 m/s of air and maximum flow obtained in slug-churn transition range. Images of various flow regime is attached below.

5.1.1 Flow regimes in two phase flow.

5.1.1.1 Bubble flow regime images.



3
Fig 5.1.1.1(a)



Fig 5.1.1.1(b)

5.1.1.2. Slug flow regime images



Fig 5.1.1.2(a)



Fig 5.1.1.2(b)

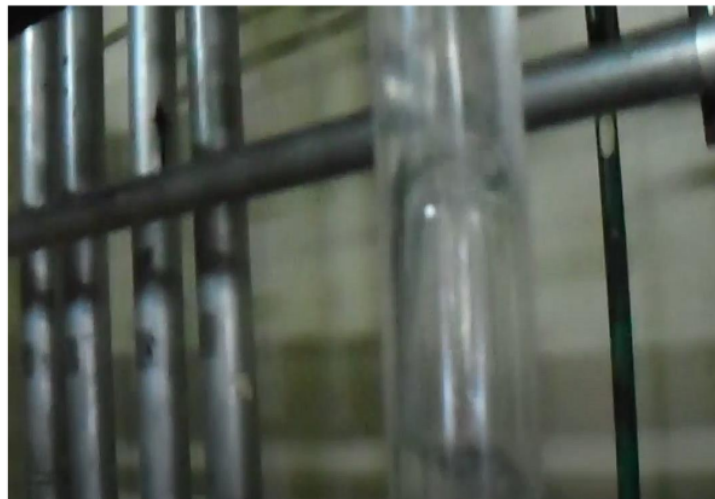


Fig 5.1.1.2(c)

5.1.1.3. Churn and annular flow regime images

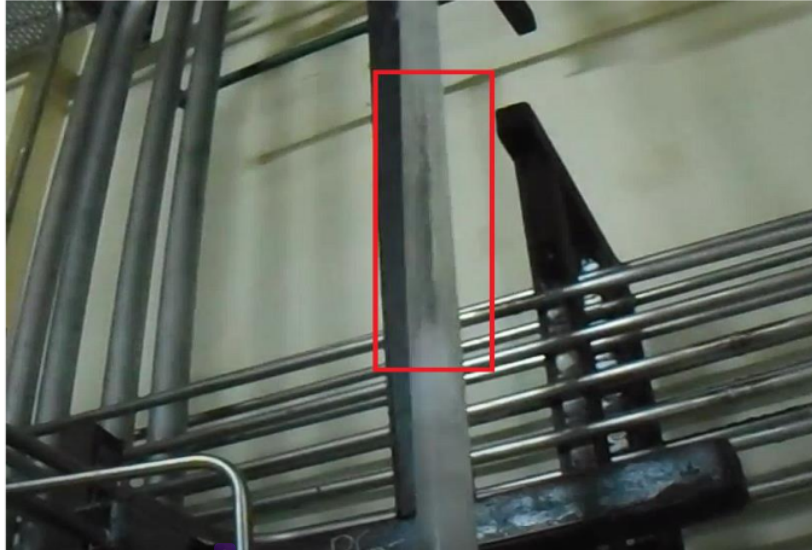


Fig 5.1.1.3(a) churn flow regime

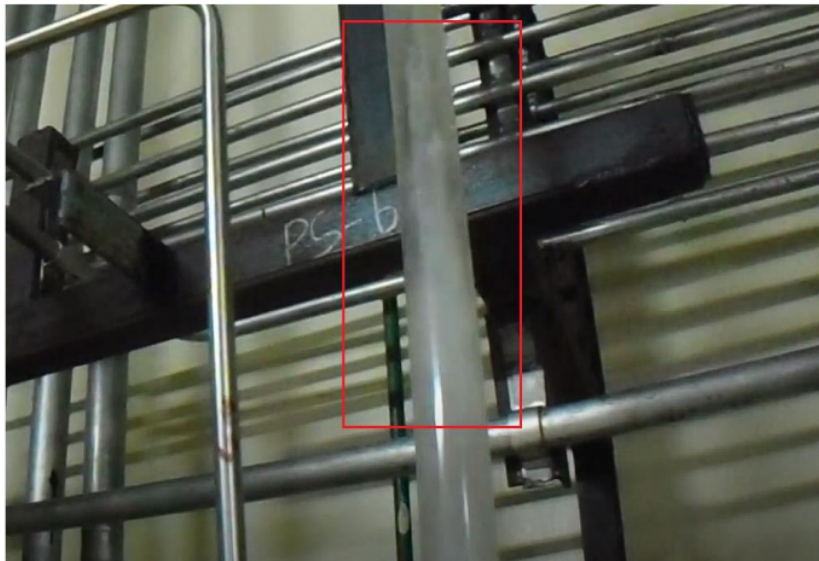


Fig 5.1.1.3(b) annular flow regim

Table 5.1.2 Data at 65% submergence.

M(kg)	H (m)	Ho (m)	$\rho a(\text{kg}/\text{m}^3)$	Va (l)	m(kg)	P (N/m²)	Pa (N/m²)	ln (P/Pa)	% η	Uas (m/s)	Uws (m/s)
0	3.3	2.15	1.3	200	0.26	121590	101325	0.182	0	0.08	0
100	3.3	2.15	1.3	400	0.52	121590	101325	0.182	15.93	0.16	0.04
200	3.3	2.15	1.3	600	0.78	121590	101325	0.182	21.24	0.24	0.08
450	3.3	2.15	1.3	800	1.04	122603	101325	0.191	34.28	0.31	0.18
600	3.3	2.15	1.3	1100	1.43	122603	101325	0.191	33.24	0.43	0.24
730	3.3	2.15	1.3	1300	1.69	123617	101325	0.199	32.81	0.51	0.29
1050	3.3	2.15	1.3	1900	2.47	124630	101325	0.207	31.01	0.75	0.41
1150	3.3	2.15	1.3	2000	2.6	125643	101325	0.215	31.06	0.79	0.45
1300	3.3	2.15	1.3	2200	2.86	126656	101325	0.223	30.77	0.86	0.51
1440	3.3	2.15	1.3	2400	3.12	127670	101325	0.231	30.16	0.94	0.57
1440	3.3	2.15	1.3	2800	3.64	128683	101325	0.239	25.00	1.10	0.57
1420	3.3	2.15	1.3	3200	4.16	129696	101325	0.247	20.88	1.26	0.56
1380	3.3	2.15	1.3	3600	4.68	130709	101325	0.255	17.49	1.42	0.54
1320	3.3	2.15	1.3	4100	5.33	131723	101325	0.262	14.26	1.61	0.52
1280	3.3	2.15	1.3	4500	5.85	131723	101325	0.262	12.60	1.77	0.50

5.1.2 Air lift pump performance at 65% submergence.

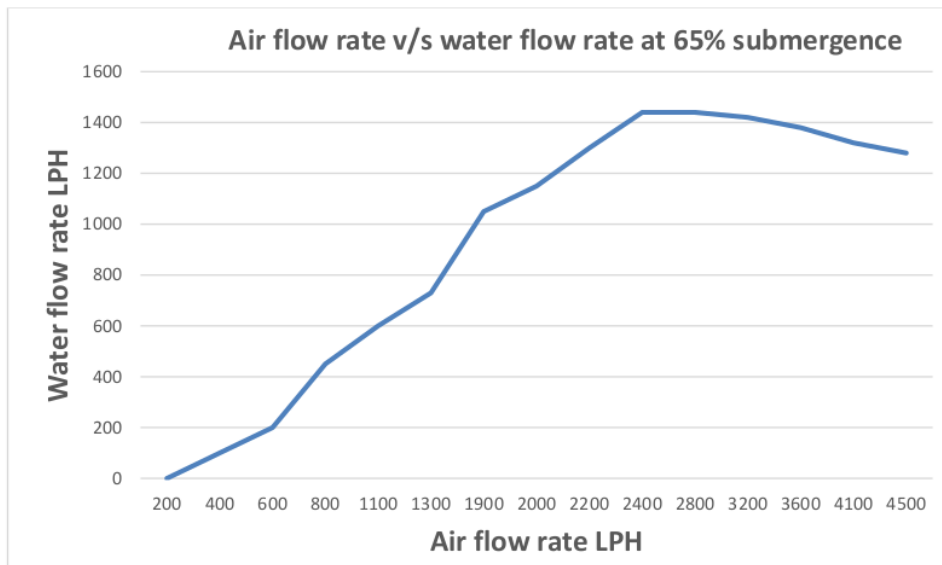


Fig 5.1.2(a) Air flow rate v/s water flow rate at 65% submergence.

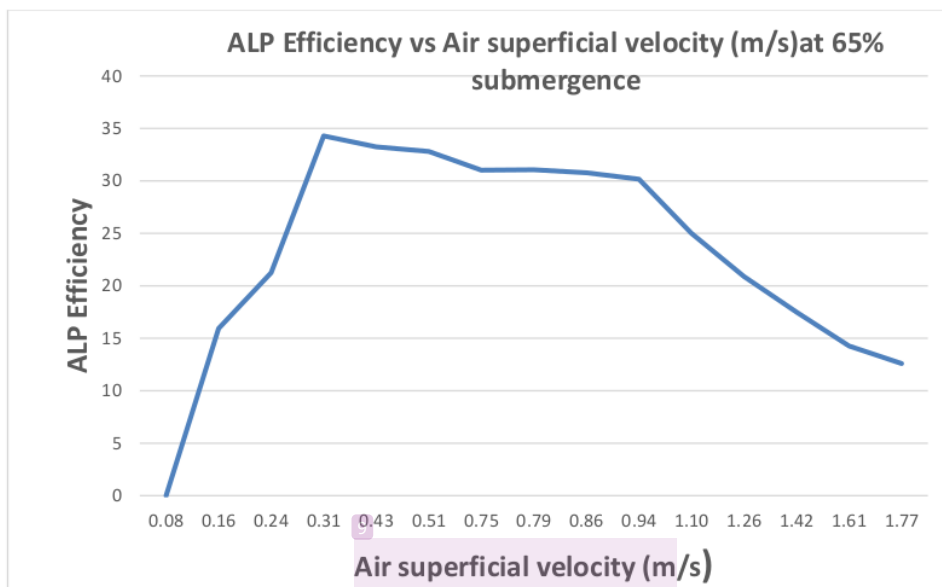


Fig 5.1.2(b) ALP Efficiency vs Air superficial velocity (m/s) at 65% submergence.

Table 5.1.3 Data at 55% submergence.

M(kg)	H (m)	Ho (m)	$\rho_a(\text{kg}/\text{m}^3)$	Va (l)	m(kg)	P (N/m^2)	Pa N/m^2	In (P/Pa)	% η	Uas (m/s)	Uws (m/s)
0	3.3	1.8	1.3	300	0.39	119564	101325	0.166	0	0.12	0
45	3.3	1.8	1.3	500	0.65	119564	101325	0.166	7.90	0.20	0.02
360	3.3	1.8	1.3	1000	1.3	120577	101325	0.174	30.05	0.39	0.14
660	3.3	1.8	1.3	1600	2.08	122603	101325	0.191	31.43	0.63	0.26
750	3.3	1.8	1.3	2000	2.6	123617	101325	0.199	27.39	0.79	0.29
880	3.3	1.8	1.3	2500	3.25	125643	101325	0.215	23.76	0.98	0.35
950	3.3	1.8	1.3	3000	3.9	127670	101325	0.231	19.90	1.18	0.37
1020	3.3	1.8	1.3	3500	4.55	129696	101325	0.247	17.14	1.38	0.40
1120	3.3	1.8	1.3	4000	5.2	131723	101325	0.262	15.50	1.57	0.44
1100	3.3	1.8	1.3	4500	5.85	136789	101325	0.300	11.83	1.77	0.43

5.1.3 Air lift pump performance at 55% submergence.

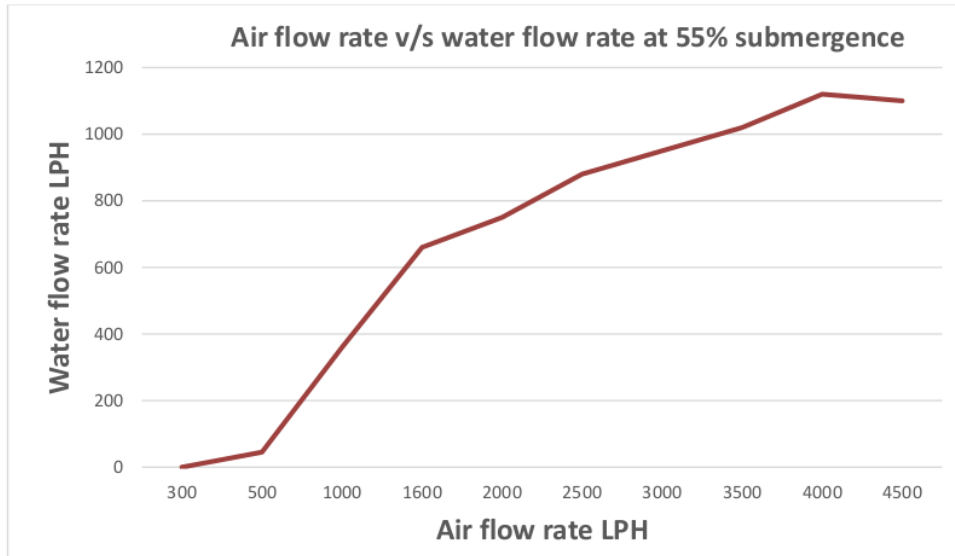


Fig 5.1.3(a) Air flow rate v/s water flow rate at 55% submergence.

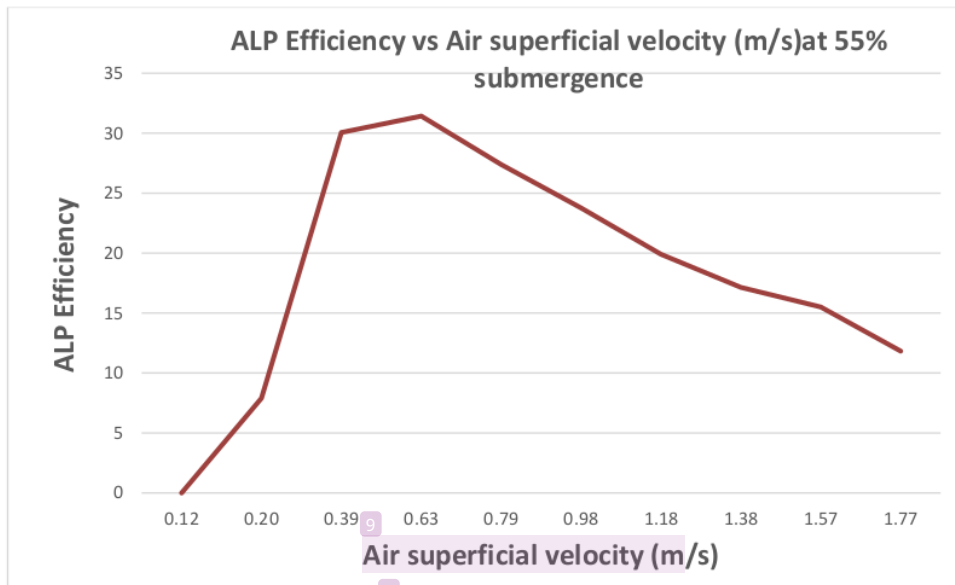


Fig 5.1.3(b) ALP Efficiency vs Air superficial velocity (m/s) at 55% submergence.

Table 5.1.4 Data at 42% submergence.

M(kg)	H (m)	Ho (m)	$\rho_a(\text{kg}/\text{m}^3)$	Va (l)	m(k g)	P (N/m²)	Pa N/m²)	ln (P/Pa)	% η	Uas (m/s)	Uws (m/s)
0	3.3	1.4	1.3	500	0.65	116524	101325	0.140	0	0.20	0
45	3.3	1.4	1.3	800	1.04	117537	101325	0.148	6.97	0.31	0.02
180	3.3	1.4	1.3	1200	1.56	118550	101325	0.157	17.57	0.47	0.07
270	3.3	1.4	1.3	1600	2.08	119564	101325	0.166	18.75	0.63	0.11
390	3.3	1.4	1.3	2000	2.6	120577	101325	0.174	20.62	0.79	0.15
460	3.3	1.4	1.3	2500	3.25	121590	101325	0.182	18.56	0.98	0.18
520	3.3	1.4	1.3	3000	3.9	122603	101325	0.191	16.73	1.18	0.20
620	3.3	1.4	1.3	3500	4.55	123617	101325	0.199	16.39	1.38	0.24
600	3.3	1.4	1.3	4000	5.2	126656	101325	0.223	12.37	1.57	0.24
580	3.3	1.4	1.3	4500	5.85	131723	101325	0.262	9.04	1.77	0.23

5.1.4 Air lift pump performance at 42% submergence.

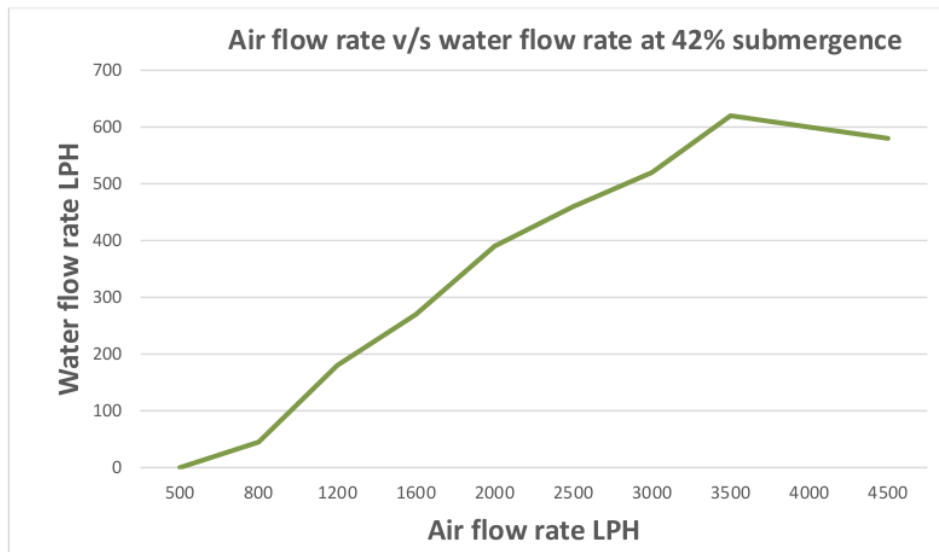


Fig 5.1.4(a) Air flow rate v/s water flow rate at 42% submergence.

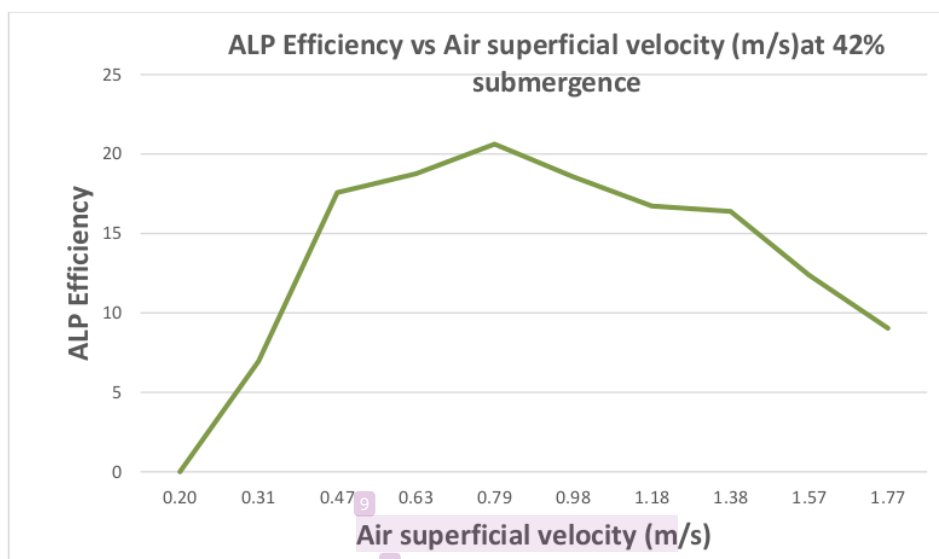


Fig 5.1.4(b) ALP Efficiency vs Air superficial velocity (m/s) at 42% submergence.

Table 5.1.5 Data at 35% submergence.

M(kg)	H (m)	Ho (m)	ρ_a(kg /m³)	Va (l)	m(k g)	P (N/m²)	Pa N/m²)	ln (P/Pa)	% η	Uas (m/s)	Uws (m/s)
0	3.3	1.2	1.3	500	1.3	0.65	116524	101325	0.140	0	0.20
40	3.3	1.2	1.3	1000	1.3	1.3	117537	101325	0.148	5.48	0.39
135	3.3	1.2	1.3	1400	1.3	1.82	119564	101325	0.166	11.85	0.55
270	3.3	1.2	1.3	1800	1.3	2.34	121590	101325	0.182	16.73	0.71
375	3.3	1.2	1.3	2100	1.3	2.73	123617	101325	0.199	18.26	0.83
440	3.3	1.2	1.3	2500	1.3	3.25	125643	101325	0.215	16.63	0.98
510	3.3	1.2	1.3	3000	1.3	3.9	129696	101325	0.247	14.00	1.18
580	3.3	1.2	1.3	3500	1.3	4.55	131723	101325	0.262	12.84	1.38
570	3.3	1.2	1.3	4000	1.3	5.2	131723	101325	0.262	11.04	1.57
560	3.3	1.2	1.3	4500	1.3	5.85	134762	101325	0.285	8.87	1.77

5.1.5 Air lift pump performance at 35% submergence.

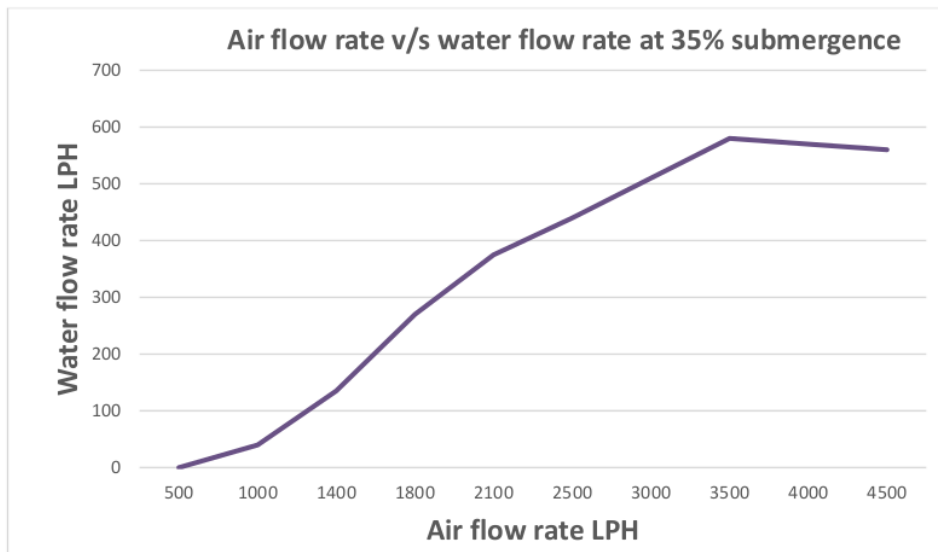


Fig 5.1.5(a) Air flow rate v/s water flow rate at 35% submergence.

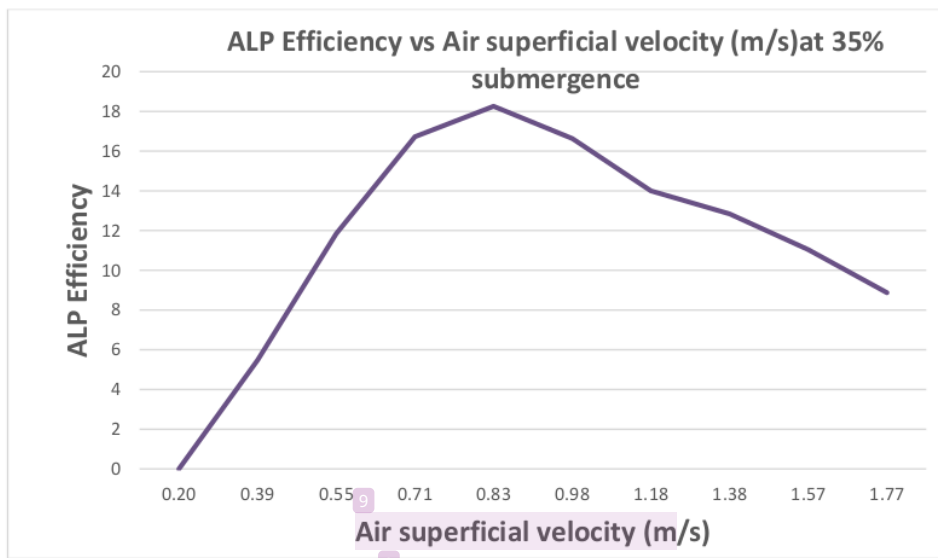


Fig 5.1.5(b) ALP Efficiency vs Air superficial velocity (m/s) at 35% submergence.

5.1.6 Performance comparison of ALP at various submergence.

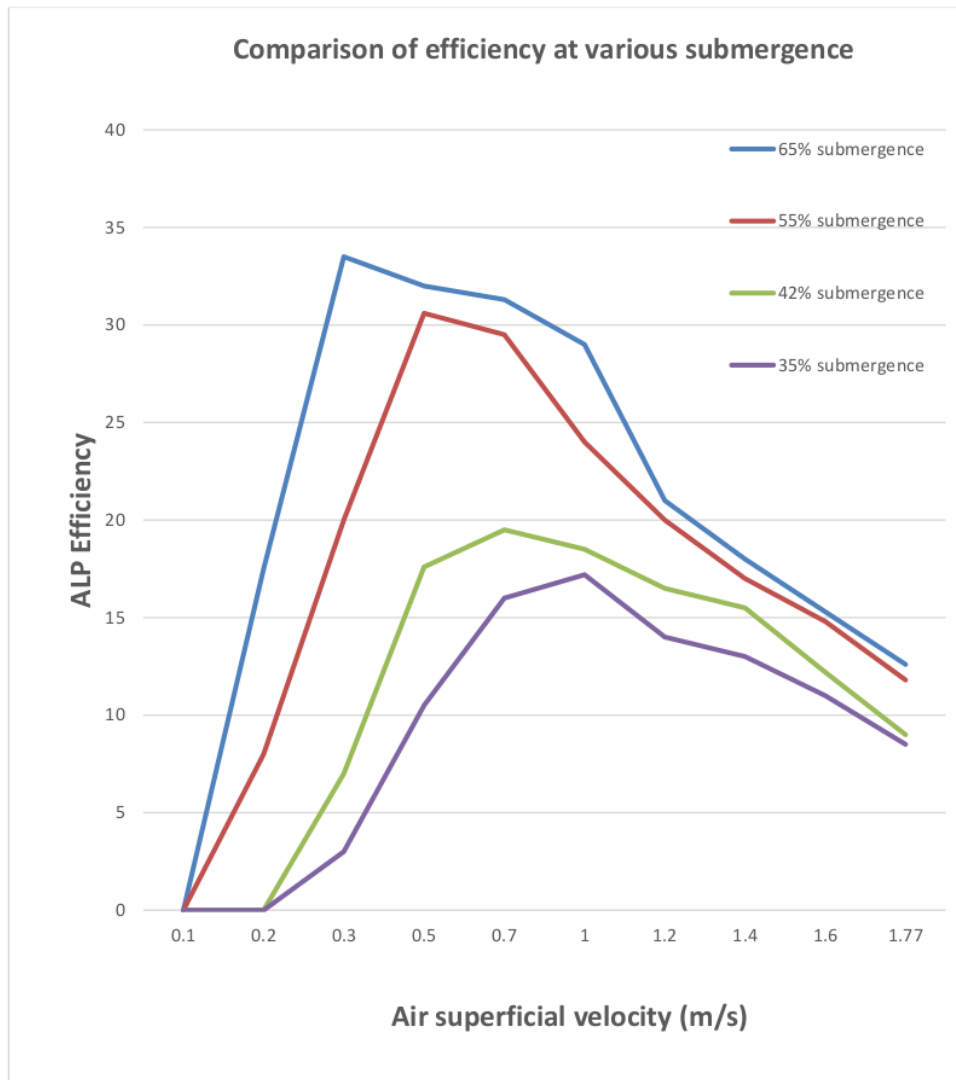


Fig 5.1.6 Performance comparison of ALP at various submergence.

5.1.7 Result summary.

1. Bubble flow regime obtained below **0.1m/s** of air superficial velocity.
2. There is no flow in bubble flow regime below **80%** submergence.
3. Slug flow regime obtained between **0.2-1.0 m/s** of superficial velocity of air.
4. Maximum efficiency of ALP obtained in **slug flow regime**.
5. Churn flow regime obtained between **1.1- 10 m/s** of superficial velocity of air.
6. Maximum liquid flow rate obtained in **churn flow regime**.
7. Annular flow regime obtained above **10 m/s** of superficial velocity of air.
8. In **Annular flow regime** both efficiency as well as liquid flow rate are minimum.
9. The best operating range of ALP is determined by optimum of efficiency and liquid flow rate and that is at superficial velocity of air between **0.5-1.3 m/s**.

5.1.8 MODEL CALCULATIONS.

Volumetric flow rate, $Q = 800 \text{ LPH} = 2.22 \times 10^{-4} \text{ m}^3/\text{s}$.

Dia of riser pipe (d) = 30mm = 0.03m.

Cross sectional area (A) = $[(3.14 \times .03 \times .03)/4]$
 $= 7.065 \times 10^{-4} \text{ m}^2$

Air superficial velocity

Air superficial velocity = $Q/A = (2.22 \times 10^{-4}) / (7.065 \times 10^{-4})$

= 0.314 m/s

Mass of water lifted (M) = 450 kg

Value of g = 9.81 m/s^2

Height of lift (H) = 3.3 m

Submergence height (Ho) = 2.1m.

Mass of air used (m) = 1.04 kg

Density of air (ρ_a) = 1.3 kg/m^3

Atmospheric pressure (Pa) = 101325 N/m^2

Air inlet pressure (P) = 122603 N/m^2

Efficiency of air lift pump

$$\eta = [Mg(H - Ho)] / \left[\left(\frac{m}{\rho_a} \right) Pa \ln \left(\frac{P}{Pa} \right) \right] \dots (1.3)$$

By substituting all the values in equation 3

$\eta = 0.3428$

% η = 34.28%

CHAPTER- 6

6.1 CONCLUSION.

Various flow regime of two phase flow studied by using the experimental setup study shows that the flow regime is the function of superficial velocity of air as the superficial velocity of air increases the flow regime also changes from bubbly to slug and slug to churn and further annular flow. Bubble flow regime obtained below 0.1m/s of air superficial velocity. Slug flow regime obtained between 0.2-1.0 m/s of superficial velocity of air. Experimental results shows that liquid flow rate through ALP increases as submergence increases. Maximum efficiency is obtained in slug flow regime at superficial velocity of air between 0.3-1.0 m/s. Maximum flow rate of liquid is obtained in churn flow regime at superficial velocity of air between 1.0-1.5 m/s. best operating range of ALP is at superficial velocity of air between 0.5-1.3 m/s. Based on the experimental results following conclusion is presented.

1. Submergence greatly affect the ALP performance.
2. At higher submergence efficiency as well as liquid flow rate is higher.
3. Maximum efficiency is obtained in slug flow regime at superficial velocity of air between 0.3-1.0 m/s.
4. Maximum flow rate of liquid is obtained in churn flow regime at superficial velocity of air between 1.0-1.5 m/s.
5. The best operating range of ALP is at superficial velocity of air between 0.5-1.3 m/s.

6.2 FUTURE WORK

1. Different liquid can be tested to see the viscosity and density effect on flow rate.
2. Heating of liquid can be done to measure the temperature effect on the fluid flow.
3. Modeling of ALP performance can be done to validate the experimental results.

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