International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

An Experimental Study on Two Phase (Air-Water) Flow Characteristics in a Horizontal Pipe at Atmospheric Conditions

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Abstract- **This paper outlines an experimental investigation of two phase (air-water) flow characteristics or regimes in a horizontal steel pipe at atmospheric conditions. The two phase flow phenomenon finds application in the chemical, petroleum, nuclear and power industries. The detailed analysis of different flow patterns or flow regimes and void fraction is carried out here. These flow patterns are governed by different physical mechanism; influence the mass, momentum and heat transfer rates and hence results into the complication in the analysis of two phase flow. Based on an investigation made by many researchers, an experimental set up has been fabricated to obtain different flow regimes by varying flow velocity of water and air simultaneously in horizontal test section of a 0.0239 m diameter pipe. In the present study, to identify the flow patterns video graphic evidences are used with high resolutions camera images. The observed flow patterns are are closely agreed with those specified in literature survey which classified as stratified wavy, stratified smooth, elongated bubbly (slug), bubbly flow and annular flow regimes. The physical mechanisms that govern the transition between these regimes are also identified and discussed.**

Keywords— Two Phase Flow, Flow Characteristics, Void Fraction, Transition Mechanisms.

NOMENCLATURE:-

A-Cross sectional area of test section, m^2
D- Internal diameter of test section, m
L-Length of test section, m
Q_W – Volume Flow Rate of Water, m^3/s
Q_A – Volume Flow Rate of Air, m^3/s
m_w - Mass Flow Rate of Water, kg/s
m_A - Mass Flow Rate of Air ,kg/s
V_A – Superficial Velocity of Air, m/s
V_W – Superficial Velocity of Water, m/s
α – Void Fraction
h_A–Manometer Reading of Water For Air Flow Measurement, m
h_G–Manometer Reading of Mercury For Water Flow Measurement, m
μ_A-Dynamic Viscosity of Air, Ns/m^2
μ_W- Dynamic Viscosity of Water, Ns/m^2
ρ_A -Density of Air, kg/m^3
ρ_W -Density of Water, kg/m^3
ρ_G- Density of Mercury, kg/m^3
Re - Reynolds Number
V_A –Superficial Air Velocity = (Q_A / A), (m/s)
V_W– Superficial Water Velocity = (Q_W /A), (m/s)
V_m-Mixture Velocity = $(V_A + V_W)$, m/s

I INTRODUCTION

The term 'two-phase flow' is applied to mixtures of different fluids having different phases, such as air and water, or oil and natural gas. Depending on the flow regime one might find gas bubbles, liquid slugs, or waves in a two-phase flow. These are all accompanied with severe pulsations in pressure, void fraction and momentum fluxes. The knowledge of these fluctuations is of considerable importance to the development of the two-phase flow technology and its application to engineering problems. A fluctuating two-phase flow can excite vibrations which is much more complex because it depends upon two-phase flow regime, i.e. characteristics of two-phase mixture and the void fraction. Recently the accidents caused by flow-induced vibration have significantly increased resulting enormous economic loss to enterprises. Therefore to ensure longer life and operate heat exchanger with best efficiency, it is necessary to study damage caused by flow-induced vibration and the criteria for assessing and preventing vibration. A two phase flow may vary from nearly all liquid to all gas flow depending upon the respective distribution of individual phases. By varying the quantity of liquid and gas flowing within pipe different types of flow regimes can be obtained. Oshinowo [1] carried out experiments in a 0.025 m diameter pipe in vertical upward and downward co-current air-water flow. He observed coring

International Journal of Engineering Research & Technology (IJERT)
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bubbly, bubbly- slug, falling film, froth and annular (annular-mist flow) patterns. Yamazaki and Yamaguchi [2] studied two phase phenomenon in a 0.025 m diameter pipe using air-water as working fluids. The flow patterns were observed by visual observation and photographic techniques. Paras [3] studied experimentally two phase flow in a 0.0195 m diameter pipe oriented downwards. He used air-water as working fluids and observed slug flow with successive Taylor bubbles separated by water slugs. Bubbly flow involved axially random distribution of bubbles but a definite tendency to move to the center of pipe. Lamari [4] has presented discussion in his thesis about an experimental investigation of two-phase (air-water) flow regimes in a horizontal tube at near atmospheric conditions. For observation of flow patterns in the test section, video tapes were used. The observed flow patterns were classified into stratified wavy, plug, slug, and annular flow regimes. In this thesis, the physical mechanisms that govern the transition between these regimes were identified and discussed. Troniewski and Spisak [5] investigated two phase flow with air-mineral oil as working fluids in three different pipe diameters of 0.001, 0.015 and 0.0254 m, respectively. The flow patterns were determined by visual observation in stream of special light passing through it, in addition to the photographic techniques. He classified the two phase flow in eight different flow patterns namely, film Smooth flow, wavy flow, froth, annular, bubbly, plug, core and stalactite flows.

Usui and Sato [6] investigated two phase flow with air-water fluid combination at atmospheric pressure in a 0.016 m diameter round tube. He observed four distinguished flow patterns namely, bubbly flow, slug flow, falling film flow and annular flow. In the bubbly region the bubbles had a tendency to move toward the center of tube due to lift force acting on bubbles caused by velocity gradient in continuous phase. Abdullah and Al-Khatab [7] analyzed two phase flow phenomenon in a 0.038 m diameter downward oriented tube using air-water as working fluids. Flow regime map was determined on the basis of direct visual observations. Annular, slug .Wang et al. [8] did two phase flow investigation for air-oil mixture in a 0.029 m vertically downward pipe. A combined method of visual observation and pressure drop fluctuation analysis was used to identify the flow patterns. Large bubbles were observed in bubbly flow at low air velocities. At higher velocities gas bubbles were observed to collapse into small bubbles with spherical shapes. The intermittent flow pattern was defined to accommodate the slug and churn flow because of its pulsation characteristics. Subramanian [9] has presented a paper on elementary aspects of two-phase flow in pipes. In this paper, how the different types of flow regimes i.e. Bubble, churn. Stratified, slug and annular flow are obtained by varying the velocity of gas and liquid. Mitra [10] has presented a dissertation work in fluid-elastic instability and FIV due to two phase flow of air-water and steam-water cross flow. The parameters contributing the onset of instability are the critical fluid velocity, the frequency of vibration, the damping ratio and the void fraction. Bhagwat [11] has presented in his dissertation about study of flow patterns and void fraction in vertical downward two phase flow. The complexity in the two phase flow is primarily due to the turbulent mixing of two phases, compressible nature of the gas phase, mass flow rates of individual phases, fluid thermo physical properties, channel geometry and orientation etc. Kim et al [12**]** have presented the paper on FIV of two phase flow with wire coil insert at the atmospheric pressure in an upward vertical tube with four different coil insert, using air-water mixture. Mohammadi [13]has studied the pipeline vibration normally occur in petroleum, natural gas and chemical industry because of unsteady flow, the change of flow direction, pipe diameter, etc. Antonio Lopes Gama et al [14] have presented a paper on an experimental investigation on the relationship between piping vibration and the two-phase flow rate. Woo Gun Sim et al. [15] are investigated the characteristics of two-phase flow in a vertical pipe to provide information for understanding the excitation mechanisms of flow-induced vibration.

II METHODOLOGY

From the above literature review on flow patterns studied by different investigators it is clear that there are no quantitative measures to decide upon the existence of distinguished flow patterns. It is clear that the flow patterns are governed by the pipe geometry, orientation and the physical properties of fluid combination used. Hence an experimental set up has been fabricated to obtain different flow regimes by varying flow velocity of water and air simultaneously as shown below in the fig. 1

II A EXPERIMENTAL SET UP

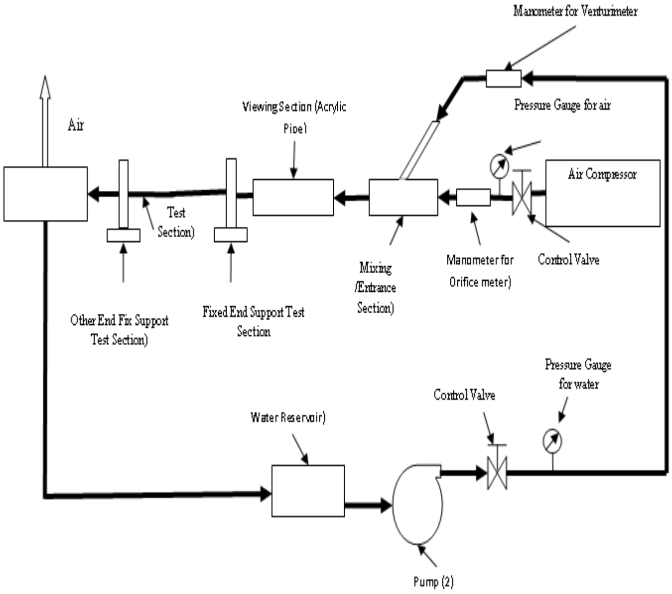

Fig. -1. Experimental Set Up for two phase flow characteristics.

Fig. (1) shows the schematic diagram of the experimental set-up to different flow régimes. It consists of a centrifugal pump (1.5hp, 1440 rpm) which is used to pump the water through a test section from a water reservoir .The flow rate of water from the pump is regulated using flow control valve which is measured by calibrated venturimeter with the help of manometer. To have two phase flow (Air-Water), an air compressor (0-7 kg/cm^2, 2 hp, 2850 rpm) is

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used to provide compressed air at regulated outlet pressure using flow control valve. The flow rate of air is measured by calibrated orifice meter with the help of manometer. Both air and water is passed through a mixing section to form different flow patterns. The viewing section is provided with glass view port of 0.5 m in length and 0.0256 m in diameter for observing different flow characteristics obtained. The test section is made of steel material of 0.0239 m in diameter and 1.2m length fixed at one ends for cantilever condition and fixed at both end at both end fixed condition.

II B INSTRUMENTATION AND TESTING PROCEDURE:-

In order to obtain the different flow regimes through a test section due to two phases (air-water), test section is properly aligned horizontally and fixed at one ends for cantilever condition and fixed at both end at both end fixed condition. After checking the cable connection, all the required equipment's in the set up are switched on i.e. pump and compressor along with video camera. At the beginning, mass flow rate of water and mass flow rate of air are kept higher by opening the control valve fully to obtain a annular flow pattern and the corresponding manometer reading of venturimeter & orificemeter are noted to determine velocity of water and velocity of air respectively. An annular flow pattern is observed and recorded using high speed high resolution camera. From the velocity of water and air, corresponding volume flow rate of water and air, mass flow rate of water and air and void fraction is calculated from the formulae. Similarly other flow patterns such as bubbly, elongated bubbly, stratified smooth and stratified wavy are obtained by varying simultaneously mass flow rate of water and mass flow rate of air and from the velocity of water and air, corresponding volume flow rate of water and air, mass flow rate of water and air and void fraction is calculated from the formulae for each flow patterns as shown in the Table 1. And the corresponding flow patterns are observed and recorded using high speed high resolution camera as shown in fig 4. The observed flow patterns are then compared with those obtained literature as shown in the fig. 3.In order to obtain different flow patterns, the range of void fraction for different flow patterns observed in the present study is given in the Table 2.From the reading of experimental analysis, the graph of mixture velocity against void fraction is plotted for each flow patterns as shown in the fig. 5.

II C MEASUREMENTS OF INPUT PARAMETERS

1 Volume Flow Rate of air , Q_A ,m^3/s

An orifice meter is used to measure the volume flow rate of air. This device determines the superficial air velocity by measuring the manometer reading of water. Orificemeter was placed with sufficient upstream and downstream straight-run piping to ensure that the airflow was fully developed at the location where it was being measured.

2 Volume Flow Rate of Water, Q_w , m^3/s

A venturimeter is used to measure the volume flow rate of water. It is placed in a 0.0127 m steel tube with sufficient upstream and downstream straight-run piping to ensure that the water flow was fully developed. This device determines the superficial velocity of water by measuring the manometer reading of mercury.

II D MEASUREMENTS OF OUTPUT PARAMETERS:-

The output two-phase flow parameters to be measured are the mixture velocity of water and air and the void fraction,

D.1 Mixture Velocity, $V_m = (V_A + V_W)$,m/s

It is sum of the superficial velocity of water and the superficial velocity of water.

D .2 Void Fraction = α

The void fraction is one of the most important parameters used to characterize the two phase flow. There are different definitions associated with void fraction such as local void fraction, cross sectional void fraction and volumetric void fraction based on the technique used to measure void fraction. The volumetric void fraction is the ratio of the air volumetric flow rate over the mixture volumetric flow rate written as,

$\alpha = Q_A / (Q_A + Q_w)$, [11]

Where Q_A and Q_w are the volumetric flow rates of air and water phases, respectively.

$Q_A = C_{do} \times a_A \times \sqrt{2gh_A}$, m^3/s

And $Q_W = C_{dv} \times a_W \times \sqrt{2gh_W}$, m^3/s , (16)

II E FLOW PATTERNS:-

In horizontal two-phase flow, because of the density differences of the air and water phases, gravity causes the gas, the less dense phase, to migrate to the top of the channel. As a result, horizontal two-phase flow has flow patterns that are not axisymmetrical.

(i) Annular flow regime: In this regime, the liquid is swept up around the perimeter of the tube in an annular form, while the faster moving air flows in the core of the tube and entrain small droplets of liquid dispersed in the form of a mist. Small bubbles of gas may also be entrained in the liquid film. This regime occurs at a relatively high mass flow rate of the gas phase.

(ii) Bubble flow: This flow pattern is characterized by bubbles of air randomly dispersed in a continuous liquid phase. The bubbles are relatively small in comparison with the diameter of the tube. Because of gravity, the gas bubbles tend to travel in the upper half of the tube.

(iii) Elongated bubbly (slug) flow: In this flow, the air phase is present in the form of elongated bubbles transported in an aerated continuous liquid phase in the upper half of the tube.

(iv) Stratified smooth flow: In this flow, the air phase travels along the upper half of the tube while the liquid flows along the bottom with no significant interfacial waves. The gravity separation is complete, and the stratified flow regime occurs at relatively low air and liquid mass flow rates.

(v) Stratified wavy flow: As the air velocity increases, the faster moving air causes waves at the air-water interfaces, resulting in a wavy flow pattern. The faster moving liquid slugs are usually associated with sudden pressure pulses and severe pressure oscillations that can cause damage to downstream equipment.

II F FLOW PATTERN TRANSITION MECHANISMS IN HORIZONTAL FLOWS (FIG. 2):-

The brief descriptions of the mechanisms that govern the transitions between flow patterns are discussed as shown below in Fig.2

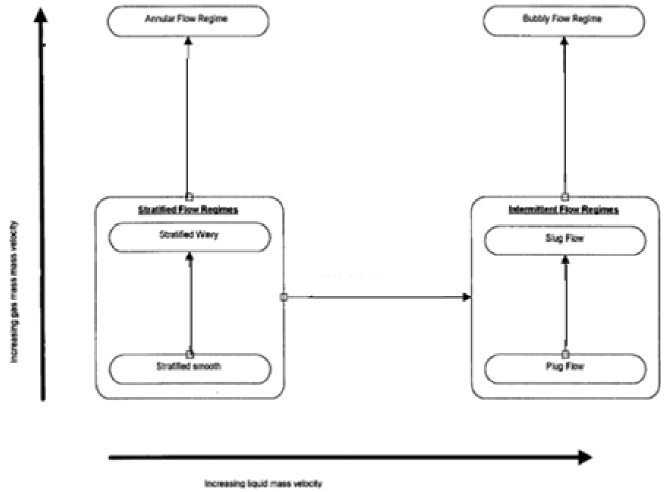

Fig. 2 Flow Pattern Transition Mechanisms [4]

At the beginning, the flow stratified flow i.e. heavy phase (air-water) is flowing at the bottom of pipe and lighter phase (air) is at the upper side of the pipe. Various transition mechanisms are as follows:

F.1 Transition to Annular Flow

Two mechanisms have been suggested for the transition from stratified to annular flow. Hoogendoorn concluded that annular flow is established by entrainment and deposition mechanism. However, others argued that annular flow is initiated by large-amplitude waves reaching the top of the tube. If these waves are frequent, the liquid is unable to drain along the walls of the pipe before the following wave adds more liquid to the top of the tube. Lin and Hanratty indicated that both mechanisms are operative. They observed that at low liquid flow rates, the transition to annular flow takes place mainly because of entrainment and deposition, while at high liquid flow rates the transition is initiated by wave disturbances.

F.2 Transition from Stratified Wavy to Elongated Bubbly or Slug Flow

Taitel and Dukler suggested that the transition from stratified wavy to intermittent (slug) flow occurs when a finite amplitude wave becomes unstable and grows to reach the top wall of the tube. Lin and Hanratty observed that the amplitude of the waves grows with an increase in the air velocity. Then the waves coalesce and form larger waves. These larger waves can subsequently either break up or form a pseudo-slug flow or coalesce with a large-amplitude wave to form a slug flow. The coalescence or break-up of these waves depends on whether enough liquid is present in front of the point of coalescence to sustain the fast moving slug.

F.3 Transition to Dispersed Bubble Flow

The semi- theoretical models of Taitel and Dukler postulate that the transition to dispersed bubble flow regime occurs when the turbulent forces in the water phase are strong enough to overcome the buoyancy forces that tend to separate the phases. This suggests that the bubble flow regime occurs at high water mass velocities.

F.4 Transitions between Stratified Smooth and Stratified Wavy Flow Regimes

It is generally accepted that the transition from stratified smooth to stratified wavy is governed by wave generation phenomena. The waves are initiated by the fast moving air on the free surface of the stratified water phase.

III. OBSERVATIONS:-

Table 1 Reading of Experimental Analysis:-

Sr.No.	Type Of Flow Patterns – Visual Inspection	Volume Flow Rate of Water,m³/s Q_W	Volume Flow Rate of Air,m³/s Q_A	Velocity of Water (m/s) V_W	Velocity of Air (m/s) V_A	Range of Velocity		Mixture Velocity m/s V_m	Void Fraction, α
						Velocity Of Water,m/s	Velocity Of Air,m/s		
1	Annular Flow	0.00014	0.001023	0.1376	1.1218	1.11195-1.1218	8.3384-27.7807	9.4601	0.8814
2		0.00014	0.002046	0.1370	1.1168			17.7936	0.9372
3		0.00014	0.003120	0.1370	1.1168			26.5454	0.9579
4		0.00014	0.003393	0.1364	1.1119			28.7671	0.9613
5		0.00014	0.003409	0.1370	1.1168			28.8975	0.8814
1	Elongated Bubbly Flow	0.00006	0.000915	0.0591	0.4815	0.2780-1.1267	6.9764-8.3384	7.9395	0.9394
2		0.00014	0.000856	0.1382	1.1267			8.1031	0.8610
3		0.00003	0.001023	0.0341	0.2780			8.6163	0.9677
4		0.00005	0.001023	0.0516	0.4203			8.7586	0.9520
5		0.00005	0.001023	0.0516	0.4203			8.7586	0.9520
1	Bubbly Flow	0.00013	0.000971	0.1296	1.0559	0.9397-1.1119	7.9105-9.1342	8.9663	0.8822
2		0.00013	0.001023	0.1283	1.0454			9.3837	0.8886
3		0.00014	0.001073	0.1364	1.1119			9.8572	0.8872
4		0.00013	0.001121	0.1346	1.0969			10.2311	0.8928
5		0.00012	0.001211	0.1153	0.9397			10.8058	0.9130
1	Stratified Wavy Flow	0.00009	0.001334	0.0921	0.7503	0.3322-0.7503	10.8719-15.1474	11.6222	0.9354
2		0.00004	0.001483	0.0408	0.3322			12.4157	0.9732
3		0.00006	0.001618	0.0645	0.5253			13.7094	0.9617
4		0.00006	0.001859	0.0577	0.4699			15.6173	0.9699
5		0.00005	0.001968	0.0516	0.4203			16.4594	0.9745
1	Stratified Smooth Flow	0.00005	0.000647	0.0499	0.4069	0.2101-0.5147	5.2736-10.5473	5.6806	0.9284
2		0.00003	0.000971	0.0258	0.2101			8.1206	0.9741
3		0.00004	0.001253	0.0408	0.3322			10.5446	0.9685
4		0.00006	0.001294	0.0632	0.5147			11.0620	0.9535
5		0.00003	0.001518	0.0258	0.2101			12.5779	0.9833

Table 2 Range Of Void Fractions for Different Flow Patterns Observed In the Present Study:-

Sr.No.	Flow Pattern	Velocity of water, m/s	Velocity of air, m/s	Range of Void Fraction
1	Annular Flow	1.11-1.12	8.33-27.78	0.8814 - 0.9614
2	Bubbly Flow	0.93-1.11	7.91-9.13	0.8822 - 0.9130
3	Elongated bubbly (slug) flow	0.27-1.12	6.97-8.33	0.8610-0.9677
4	Stratified Wavy Flow	0.33-0.75	10.87-15.14	0.9354-0.9745
5	Stratified Smooth Flow	0.21-0.51	5.27-10.54	0.9284 - 0.9833

International Journal of Engineering Research & Technology (IJERT)
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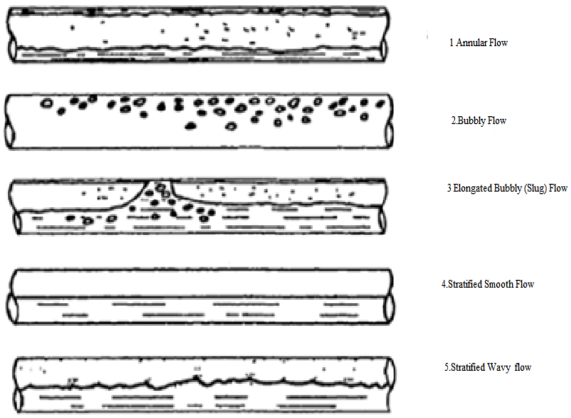
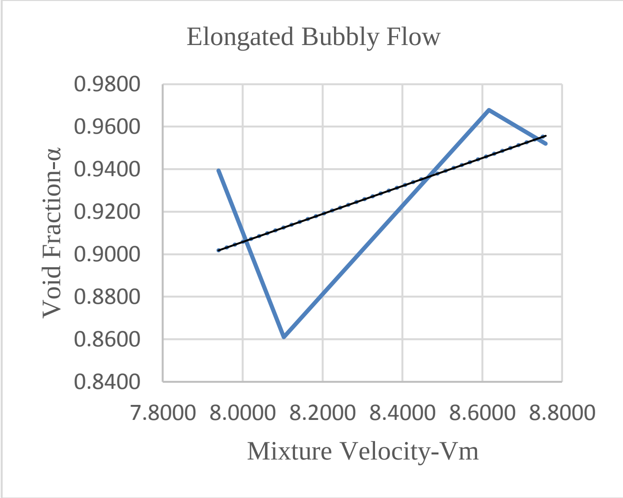
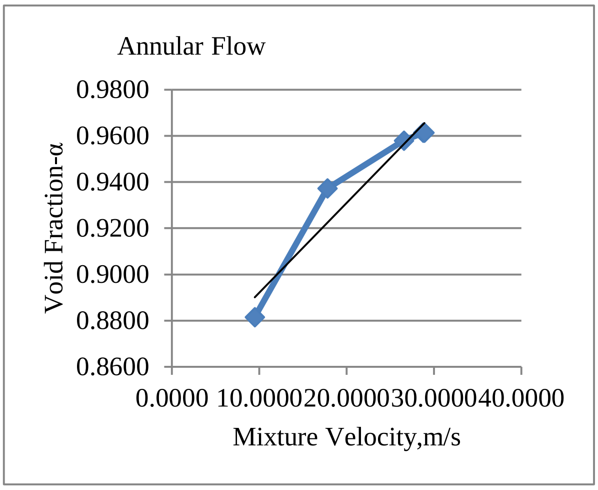
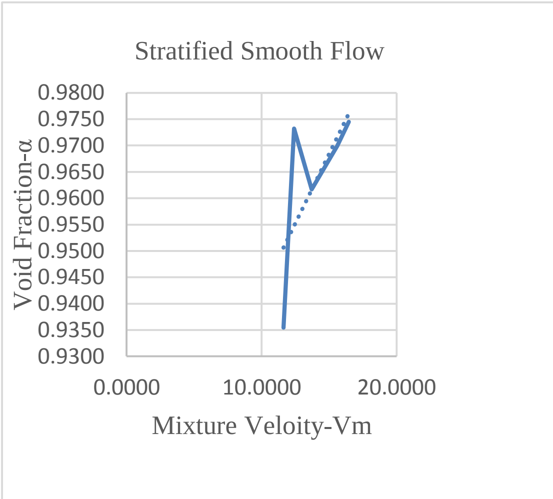
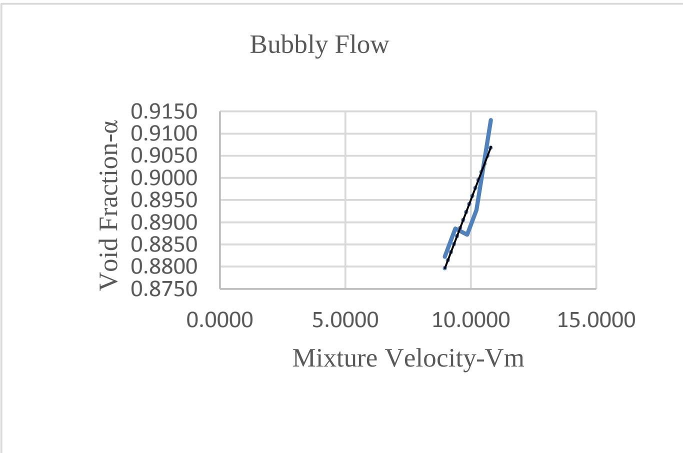


Fig. 3:-Flow Regimes or Flow Characteristics For Horizontal Flows [4]









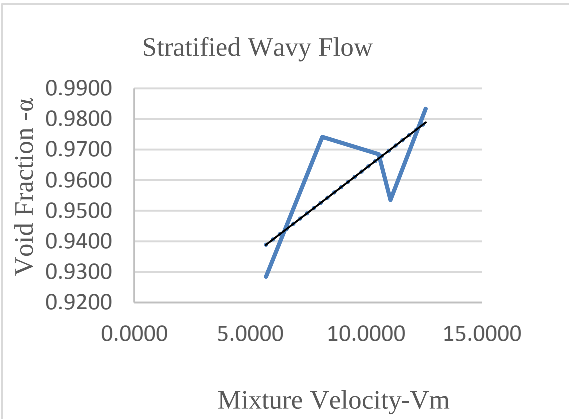


Fig. 5 Graph of Mixture Velocity V_s Void Fraction

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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4. CONCLUSION: -

From the results presented on flow regimes, it is seen that the existence of flow patterns in two phase flow highly depends upon the experimental setup and flow variables. The present experimental study of flow patterns was carried out by varying flow velocity of water and air simultaneously .The observed flow patterns are closely agreed with those specified in literature survey. These are classified to in five major flow patterns: bubble, stratified smooth, stratified wavy, elongated bubbly (slug), and annular flow regimes. The transition of the flow patterns from one to another is gradual and hence there are no well defined sharp transition boundaries between the individual flow patterns. From the results obtained it is seen that the void fraction is a function of the flow patterns and varies with respect to the individual phase mass flow rate. It is also seen that the void fraction is least for bubbly flow while it attains a maximum value as the flow regime transits to the annular flow pattern. From the graph of mixture velocity Vs void fraction for all patterns, it is observed that as mixture velocity increases, void fraction increases. Almost all patterns appears in turbulence nature as their corresponding Reynolds numbers for air and water are more than 2000 which produces severe pulsations in pressure resulting vibration in the pipe.

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