ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 6 | Issue: 5 | May 2020 || Journal DOI: 10.36713/epra2013 || SJIF Impact Factor: 7.032||ISI Value: 1.188

FLOW PATTERNS IN VERTICAL PIPES, TWO PHASES GAS-LIQUID FLOW

Antonio Valiente Barderas
Department of Chemical Engineering.
Faculty of Chemistry,
National Autonomous University of Mexico,
Mexico City, Mexico

Carlos Álvarez Maciel
Department of Chemical Engineering.
Faculty of Chemistry,
National Autonomous University of Mexico,
Mexico City,
Mexico

ABSTRACT

For the design of fluid flow to two phases gas-liquid in vertical pipe, it is essential to know the flow pattern. In an earlier article [8], the authors presented the flow patterns that exist when the pipe is horizontal. This article presents some of the studies on flow patterns in vertical pipes and includes examples that clarify the use of maps.

KEYWORDS: *Two-phase flow, gas-liquid, vertical pipes. Flow patterns.*

1. INTRODUCTION

In the design of two-phase flow pipes, the engineer is primarily concerned with the calculation of pressure drop, which can be estimated quite accurately. It has been recognized for years that in order to improve the prediction of the different constituent parameters of this phenomenon, which are the volumetric fraction of each phase (holdup), pressure drop, heat and mass transfer, as well as other hydraulic parameters, it was necessary to consider the detailed structure of the flow configuration. These configurations, which are related to the distribution of phases within the pipe, are called flow patterns or regions.

Many experimental and theoretical work has been carried out to predict the pressure drop and the type of flow pattern produced in the pipes, but so far no general correlation has been found, This is due to the existence of a certain number of complications that hinder the use of a single correlation. The largest of these in the two-phase flow is the variety of flow patterns that can occur. The type of flow pattern found depends on fluid properties, expenses, and equipment geometry. Although no general correlation has been found applicable to all flow types, correlations have been developed for specific flow patterns. One of the first to do a visual classification of flow patterns was Alves [1]. Flow patterns are empirically correlated based on the mass and volumetric flows and properties of fluids. The mechanism of momentum transfer varies with the flow pattern.

2. FLOW PATTERNS IN VERTICAL PIPES

Two flow directions in vertical pipes can be presented: upstream and downstream. The series of flow patterns existing in the upstream is different from that present in the downstream. In both directions, flow patterns have an axis of symmetry, which matches that of the pipe, as the effect of the force of gravity acts on this axis, unlike the horizontal flow, where this force acts perpendicular to the axis of symmetry of the pipe. Although they have similarities to upstream patterns with their downstream counterpart, they are often treated independently.

2.1 Upstream vertical flow patterns

Nicklin and Davidson [2] visually classified these patterns into five categories (Figure 1). A brief description of each of them is as follows:

Bubble flow

The liquid flows upwards conforming to the continuous phase, and the gas is dispersed in the liquid in the form of individual bubbles. These bubbles are distributed throughout the cross section of the pipe, and increase their number, size and speed by increasing the flow of gas. The speed of a bubble differs greatly from the speed of the liquid phase. Occurs at surface gas speeds of less than 0.6 m/s. It is also known as aerated flow.

<u>Plug flow (Slug flow)</u>

When the gas flow increases, the bubbles fuse together forming elongated bullet-shaped gas plugs, hence the bullet flow name, whose top tip is parabolic. These elongated plugs are called Taylor bubbles, and are surrounded by a thin film of liquid. These plugs are separated by liquid plugs or pistons, in which there are usually smaller bubbles in a dispersed form. As the gas plugs ascend, the liquid descends through the film around them, reaching the liquid piston immediately below Taylor's bubble. Liquid plugs are faster than gas. It is given for surface gas speeds between 0.6 and 9 m/s. It is also often called plug flow, piston flow or battering flow.

<u>Churn flow</u>

By increasing the speed of the gas, the liquid descending around the gas plugs practically stops, causing instability in Taylor's bubbles and their consequent rupture. The liquid begins to flow in a turbulent and oscillating way. Both phases flow in the form of a turbulent mixture, the structural elements of which are in an ongoing process of collapse and reform. It comes in a wide range of gas surface speeds. It is also known as froth flow or transition flow.

<u>Annular flow</u>

The liquid flows upwards like a film over the inner walls of the pipe, forming a ring, the center of which the gas ascends. As the speed of the gas phase is higher than that of the liquid phase, the gas drags a portion of the liquid in the form of droplets, which flow at the speed of the gas. As the gas speed increases, the drag of the liquid in the form of droplets increases and, in turn, the thickness of the liquid film decreases. It occurs with surface gas speeds greater than 9 m/s and with surface liquid speeds of less than 0.6 m/s. It is also often referred to as film flow or climbing film flow.

<u>Mist flow</u>

At very high gas speeds, the amount of liquid carried by the gas phase increases until the liquid film disappears. The liquid phase then flows in the form of droplets scattered in the gas, which constitutes the continuous phase. It is available at surface gas speeds of 20 m/s at 30 m/s. It is also called dispersed flow, fog flow, spray flow, or droplet flow.

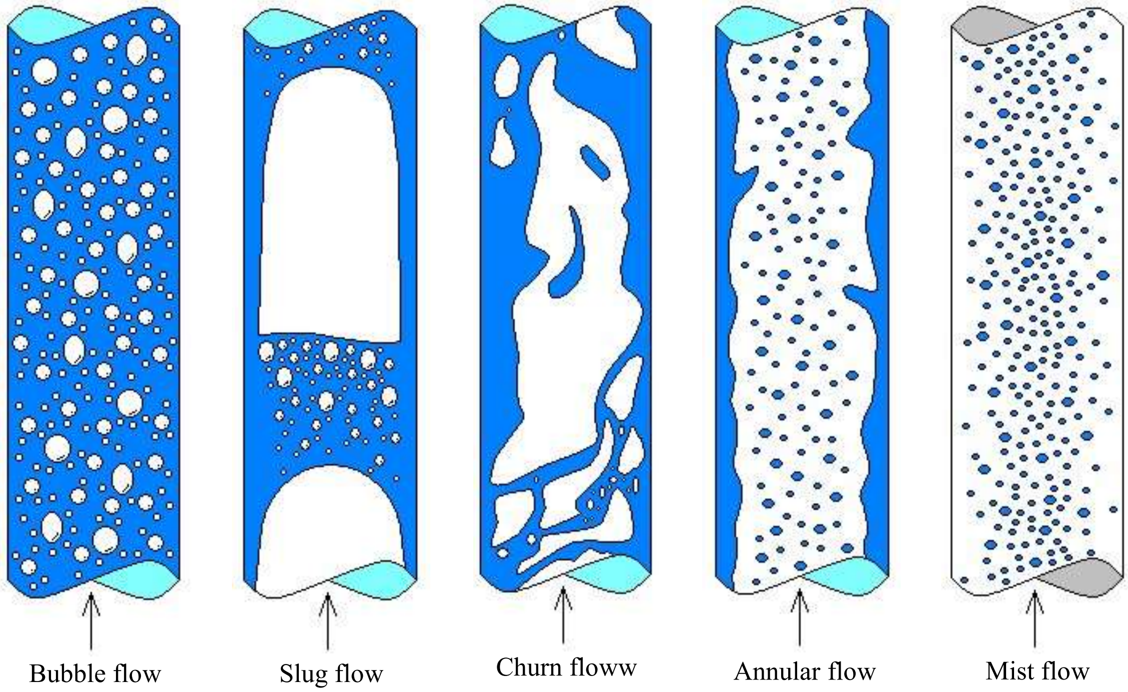


Figure 1.- Upstream patterns to two phase gas-liquid system in vertical pipes.

2.2 Vertical downstream patterns

Oshinowo and Charles [3] visually classified the patterns by obtaining six types of flow, three of which fall into a single category (Figure 2). In this way, flow patterns can be regrouped as follows:

Nucleated Bubble Flow (Coring-bubble flow)

The gas phase is dispersed in the liquid phase, in the form of individual bubbles. These bubbles descend along with the liquid, but unlike the upward bubble flow, they are not scattered in the cross section of the pipe. As they descend, the bubbles migrate to the tube's axis of symmetry forming a core of bubbles of different shapes and sizes.

Bubbly-slug flow

The gas phase descends into bullet-shaped plugs, i.e. forming Taylor bubbles, the top end of which is rounded and free of smaller bubbles, and its lower end forms a small sting of foam, caused by the drain of the liquid. In this way, the liquid plugs have a large number of small bubbles, concentrating mainly on the upper end of the liquid cap. As the gas speed increases, Taylor's bubbles are distorted in a downward spiral motion, closer to the inner walls of the tube.

Froth flow

This flow pattern is similar to the ascending *Churn flow*, as the gas plugs are very unstable and stirred with liquid. The mix of phases is turbulent, but it is not as hectic as that of its ascending counterpart.

Falling film flow

It is similar to the upstream annular flow, as the liquid descends through the walls of the pipe in the form of a film, and the gas descends through the center of the tube. The surface of the liquid is wavy and a portion of it is dragged by the gas in the form of droplets. At very low gas and liquid speeds, dry spots occasionally occur on the inner wall of the tube. At high liquid speeds, the film contains small gas bubbles and its thickness increases. This flow pattern encompasses the downstream bubbly-film flow and the annular flow, described by Oshinowo and Charles[3]

Mist flow

Its description is similar to the ascending mist flow, as the liquid flows in the form of fine droplets scattered in the gas, which constitutes the continuous phase. It was described by Oshinowo and Charles[3] as a boundary case of the film downflow, where gas flows at a speed high enough to drag all the liquid, forming a mist or a shower of droplets. For this reason, these researchers also called it annular-mist flow.

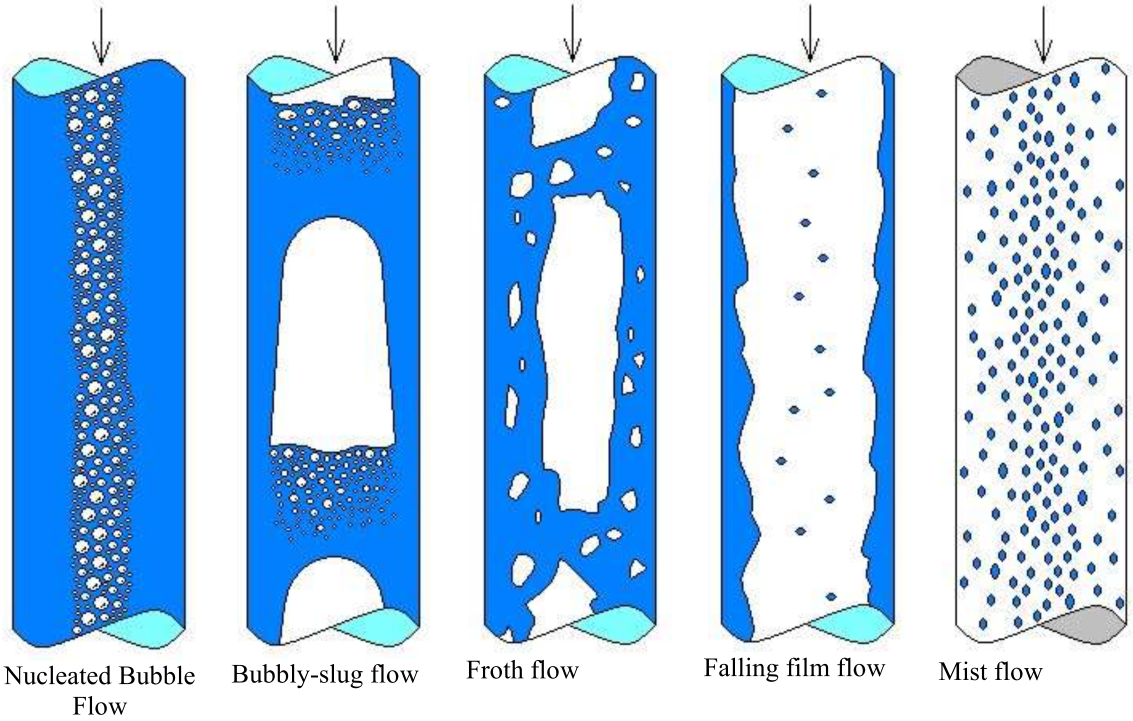


Figure 2.- Downward flow patterns to two phase gas-liquid system in vertical pipes.

2.3.Vertical flow patterns can also be classified into groups according to the distribution of phases, in the same way as horizontal flow patterns:

Segregated Flow:

Each phase flows in the form of a layer or sheet. In upstream: annular flow. In downstream: downgrade film flow.

Intermittent Flow:

Each phase flows alternately and periodically. In ascending flow: bullet and scrambled flows. In downstream flow: bubbling bullet flows and foam.

Distributed Flow:

One phase is scattered in the other, which flows continuously. In upstream: bubble and mist flows. In downstream: nucleated bubble and mist flows.

3. PREDICTION OF FLOW PATTERNS IN VERTICAL PIPES

Based on the work of Griffith and Wallis [4], Oshinowo and Charles [3] correlated flow patterns using dimensional groups, obtaining a map of dimensional upstream patterns (Figure 3), which was tested with experimental data of their own and other researchers. In addition, they extended their method to obtain a map of dimensional downflow patterns (Figure 4), which they tested only with their own experimental data, since in the literature there was not until then a similar study for flow to two descending phases. To determine the flow type using Oshinowo-Charles maps, the Oshinowo-Charles (Ox and Oy) parameters must first be calculated, which are:

$$Ox = \frac{Fr_{2F}}{\sqrt{\Lambda}} \qquad (1)$$

$$Oy = \sqrt{R_V} \qquad (2)$$

Where:

Ox and Oy abscissa in maps of Oshinowo-Charles.

Fr_{2F} - Froude number for two-phase flow

$$Fr_{2F} = \frac{v_{2F}^2}{gD} \qquad (3)$$

v_{2F} = mixture‘s superficial velocity m/s:

$$v_{2F} = v_{SL} + v_{SG} \qquad (4)$$

D - internal diameter of the pipe in m.

□ = Dimensional liquid property correction group:

$$\Lambda = \left(\frac{\mu_L}{\mu_W}\right)\left[\left(\frac{\rho_W}{\rho_L}\right)\left(\frac{\sigma_W}{\sigma_L}\right)^3\right]^{1/4} \qquad (5)$$

$\square_L$ y $\square_W$ = viscosities of the liquid and water, respectively.

$\square_L$ y $\square_w$ = densities of liquid and water, respectively.

$\square_L$ y $\square_W$ = surface tension of the liquid and water, respectively.

R_V = ratio of gas and liquid volumes:

$$R_V = \frac{Q_G}{Q_L} = \frac{W_G\,\rho_L}{W_L\,\rho_G} \qquad (6)$$

$$R_V = \frac{Q_G}{Q_L} = \frac{W_G\,\rho_L}{W_L\,\rho_G} \qquad (6)$$

The use of Froude's number on these maps is because this dimensional group relates the acting forces of inertia and gravity to the moving fluids within the vertical pipes. In this way, Froude's number indicates the mastery of one of the forces mentioned over the other. The boundaries between the different vertical flow patterns on both maps (Figure 3 and 4) are not lines but gradual transition bands, similar to the boundaries of the Baker map[9] . Therefore, these maps provide a rough idea of the likely flow pattern of being found in vertical pipes where gas-liquid mixtures flow. To build these maps, Oshinowo and Charles worked with air-water and air-water systems, and used data for water-water vapour, air-heptane, natural gas-crude oil and nitrogen-mercury systems. Consequently, the range of physical properties for each phase is very wide, where the great applicability of these maps for any gas-liquid biphasic system. Unlike Baker parameters, whose property correction factors are generally very close to 1, the correction factors present in the Oshinowo-Charles parameters differ significantly from the unit, actually correcting the physical properties of fluids other than air and water.

Oshinowo and Charles also investigated the flow patterns present in the connections, especially in the U-elbows. They found flow patterns similar to those mentioned above for vertical flow. The only difference between these patterns and those found in the connections is the influence of centrifugal and gravitational forces, which cause the appearance of dry areas in the wall of the connection, the reversal of the liquid film in the upstream and downstream annular flows, and the migration of the bubbles to the wall with a lower radius of curvature in the upstream and downward bubble flows. To predict the type of flow present in the connections, they discovered that the flow pattern in these fittings depends on the pattern developed in the straight pipe prior to the connection. Therefore, they can be predicted using the Oshinowo-Charles maps in Figures 3 and 4.

Prediction of upstream patterns can also be made from surface velocity maps, such as the graph presented by González Ortiz [5] (Figure 5), in which the surface velocity of the gas against that of the liquid is plotted. This researcher and his collaborators developed their flow pattern map based on previous maps and experiments with air-water systems. The foam flow described by them, is a particular case of scrambled flow where the liquid flows at almost the same speed of the gas.

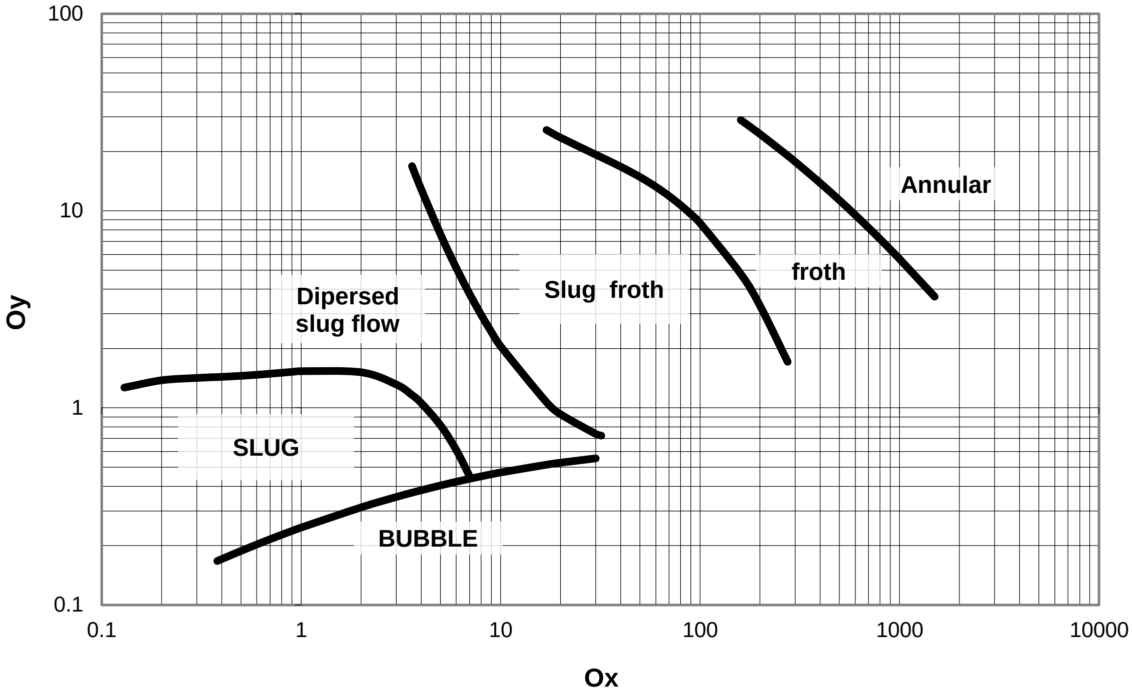


Figure 3.- Map of Oshinowo-Charles patterns for upstream vertical flow in gas-liquid systems. (1974).

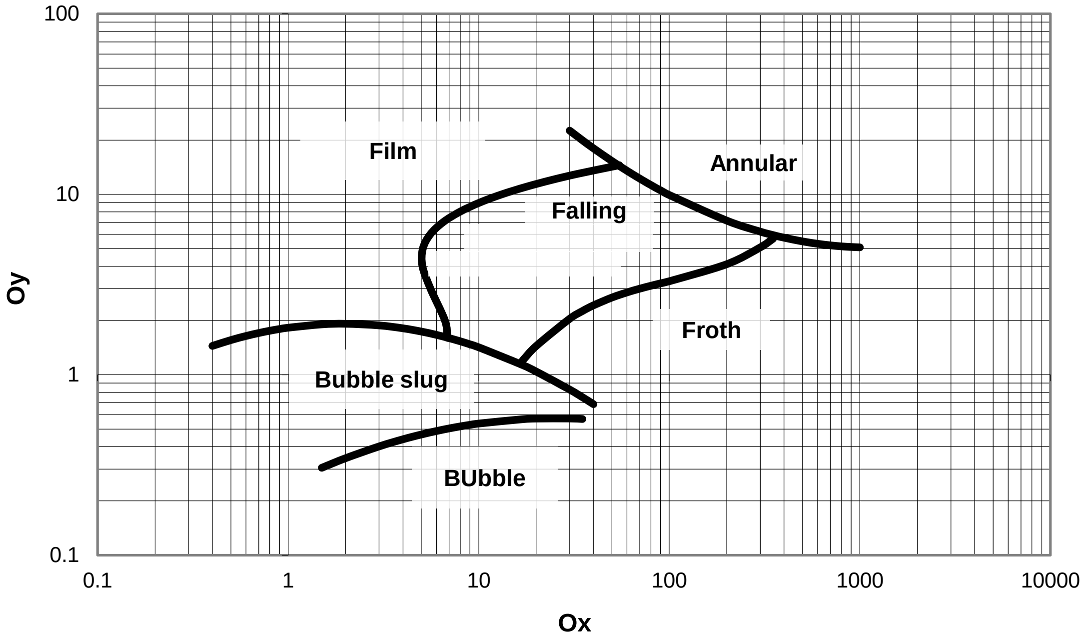


Figure 4.- Map of Oshinowo-Charles patterns for downstream vertical flow in gas-liquid systems. (1974)

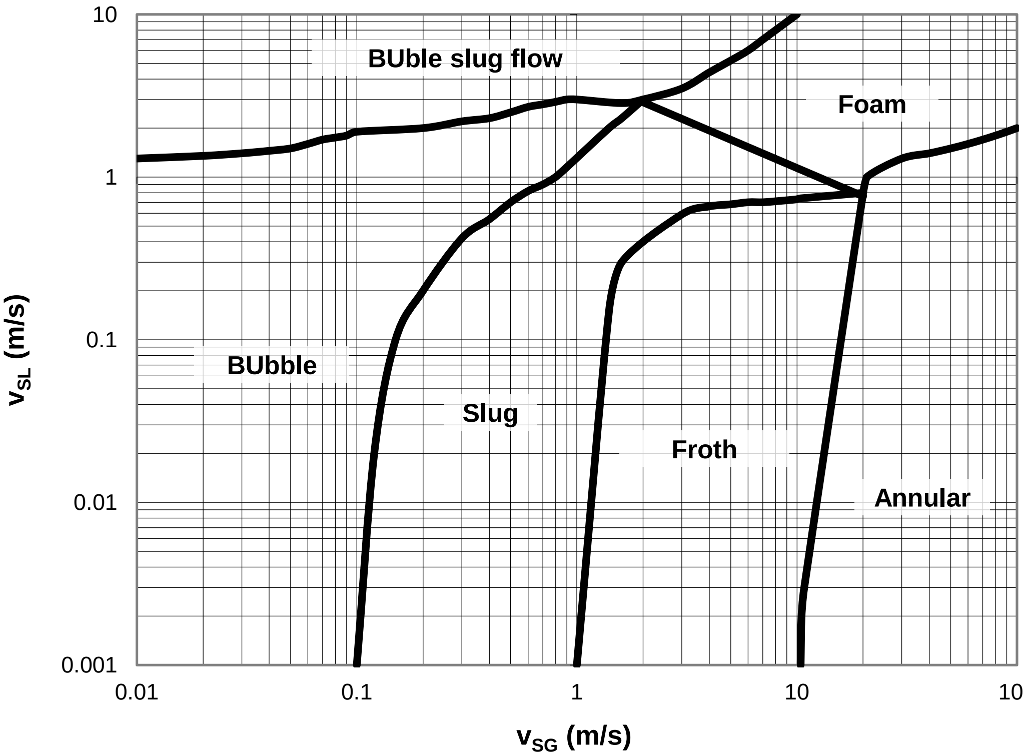


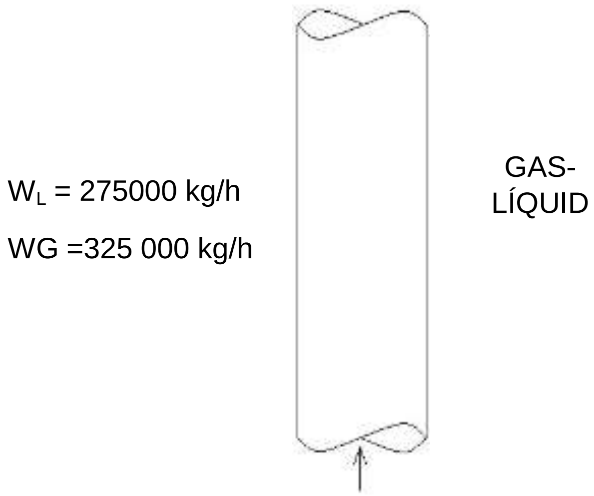
Figure 5.- Map of Gonzalez Ortiz patterns for upstream vertical flow in gas-liquid systems. (1992)

In Núñez Alba's work[6] [7] the maps of Oshinowo-Charles (Figures 3 and 4) are shown at coordinates of surface speeds.; other maps of upstream and downstream vertical flow patterns are also presented that work.

Example

What is the pressure drop per meter of vertical tube obtained in a 18-inch pipe 40, if 275000 kg/h of liquid pass through it with a density of 537 kg/m³, viscosity of 0.1 cp and 5.7 dinas/cm of surface tension? In addition, 325000 kg/h of vapours with density of 32 kg/m³ and viscosity of 0.01 cp pass through the pipe.

1.-TRANSLATION.



2.-Planning

2.1.-Flow pattern

It can be obtained by the map of González Ortiz or using Oshinowo-Charles for upstream.

3.-CALCULATIONS

3.1.-Flow pattern

D = 16.876 in = 0.4287 m

A = 0.1443 m²

González Ortiz¨s map.

$$v_{SG} = \frac{325000\,\frac{kg}{h}}{3600\,\frac{s}{h}\left(32\,\frac{kg}{m^3}\right)\left(0.1443\,m^2\right)} = 19.55\,\frac{m}{s}$$

$$v_{SL} = \frac{275000\,\frac{kg}{h}}{3600\,\frac{s}{h}\left(537\,\frac{kg}{m^3}\right)\left(0.1443\,m^2\right)} = 0.986\,\frac{m}{s}$$

The flow is foam and is very close to the borders with scrambled and annular flows.

Map of Oshinowo-Charles:

$$v_{2F} = 0.986\,\frac{m}{s} + 19.55\,\frac{m}{s} = 20.54\,\frac{m}{s}$$

$$\mathrm{Fr}_{2F} = \frac{\left(20.54\,\frac{m}{s}\right)^2}{9.81\,\frac{m}{s^2}\left(0.4287\,m\right)} = 100.28$$

The properties of water are obtained from tables, for which it is considered a temperature of 20 °C, because it is an average ambient temperature.

$$\Lambda = \left(\frac{0.1cp}{1cp}\right)\left[\left(\frac{997\,\frac{kg}{m^3}}{537\,\frac{kg}{m^3}}\right)\left(\frac{72.75\,\frac{dina}{cm}}{5.7\,\frac{dina}{cm}}\right)^3\right]^{1/4} = 0.788$$

$$Ox = \frac{100.28}{\sqrt{0.788}} = 112.96$$

$$R_V = \frac{325000\,\frac{kg}{h}\left(537\,\frac{kg}{m^3}\right)}{275000\,\frac{kg}{h}\left(32\,\frac{kg}{m^3}\right)} = 19.83$$

$$Oy = \sqrt{19.83} = 4.45$$

Result.

The flow is foaming bullet and is located near the border with the foam flow. In conclusion, the flow pattern determined by these maps is a frothy flow in the transition of bullet and scrambled flows.

CONCLUSIONS

The flow to two phases gas-liquid in vertical pipes is frequently presented in industrial and petrochemical plants, hence the importance of knowing the flow pattern that can occur. In this article we have presented the possible flow patterns and how to identify them using maps. The interested reader can learn through the Internet, specialized literature and You Tube of other ways to identify those flow patterns.

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