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PREDICTION OF THE FLOW PATTERN TO TWO PHASES, VAPOR-LIQUID IN HORIZONTAL PIPES

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ABSTRACT

Flow pattern prediction is a priority for evaluating pressure drops in the two-phase flow. This article presents a review of some of the maps used to predict the type of flow present when vapors and liquids circulate in parallel current through horizontal pipes. Examples of the application are also presented.

KEYWORDS: ***Two-phase flow, flow of vapors and liquids in horizontal pipes, flow patterns, maps.***

1. INTRODUCTION

Knowledge of the parallel current flow of gases and liquids is essential for the design and operation of pipes where this phenomenon occurs, as well as in the design and operation of many equipment used in material processing. Chemical reactors, re-boilers, partial capacitors, and mass contact devices are typical examples of equipment in which gas and liquid flow in parallel currents. The design of these process equipment also requires knowledge of pressure drops, but in turn it is necessary to predict the heat and mass transfer coefficients for proper performance. 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 pressure drop and the type of flow pattern produced in pipes, but so far no general correlation has been found, similar to friction factor vs. graphs. This is due to the existence of a certain number of complications that make it difficult to use a single correlation. The largest of them in two-phase flow is the variety of flow patterns that can occur. The type of flow pattern found depends on fluid properties, flow rates, and equipment geometry.

Although no general correlation has been found applicable to all flow types, correlations have been developed for specific flow patterns. Flow patterns are empirically correlated based on the flows and properties of fluids. The mechanism of momentum transfer varies with the flow pattern, but it remains to be clarified whether the visual description of the pattern is sufficient to identify the regions where these mechanisms change. The boundaries between patterns are not accurate as there is a gradual change and, in many cases, these borders depend on the particular interpretations of the different researchers. The prediction of pressure drop is made by correlations of different kinds. The first to propose one of them was Lockhart and Martinelli [1], which depends on the type of flow. Currently there are semi-empirical correlations independent of the flow pattern present in the pipe, which brings us closer to the development of a general model of gas-liquid biphasic flow in the perhaps not distant future.

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1.1. FLOW PATTERNS IN HORIZONTAL PIPES

There are basically seven general types of flow patterns in horizontal pipes (Figure 1). These patterns, arranged in increasing order of gas flow to a constant liquid flow, are as follows:

Bubble flow

This flow is characterized by gas bubbles scattered in the liquid, which move at the top of the pipe at approximately the same liquid rate. It comes with surface gas speeds from 0.3 to 3 m/s and surface liquid speeds between 1.5 and 5 m/s. If the liquid speed is high, the bubbles are scattered throughout the tube, knowing this pattern as froth flow or scattered bubble flow.

Plug flow

Alternate liquid and gas plugs or pistons are present. The gas moves at the top of the pipe due to the force of gravity. It occurs at surface gas speeds of less than 0.9 m/s and surface liquid speeds of less than 0.6 m/s. It is also often called elongated bubble flow or piston flow.

Stratified flow

In this case the liquid flows into the bottom of the pipe and the gas at the top, producing a smooth and uniform gas-liquid interface. It occurs when the surface velocity of the liquid is less than 0.15 m/s and that of the gas fluctuates between 0.6 and 3 m/s. It is also known as stratified smooth flow.

Wave flow

It is similar to stratified, only in this case there are waves traveling in the direction of the flow. It occurs when the surface speed of the liquid is less than 0.3 m/s and that of the gas greater than 5 m/s. It is also often called stratified wavy flow.

Slug flow

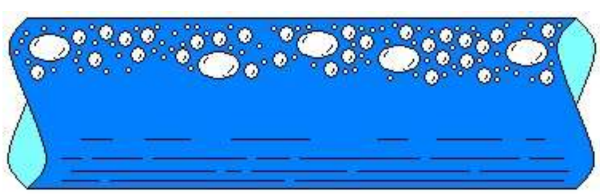
By further increasing the speed of the gas, the height of the waves increases to the point where they touch the upper inner surface of the tube and form a frothy battering ram. The speed of these battering rams is greater than the average speed of the liquid. Liquid battering rams cause severe vibrations in the equipment used due to the impact of the liquid at high speed against connections and returns. It also causes erosion in the internal walls of the system through which it flows. This type of flow should therefore be avoided. It comes in a wide range of surface speeds of both gas and liquid. It is also known as peak flow, pulsating flow, or tapping flow.

Annular flow

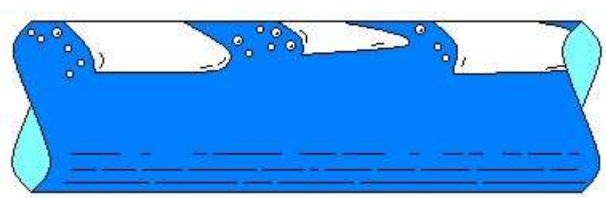
The liquid flows into a film around the inner wall of the tube, with the gas in the center. A portion of the liquid is dragged in the form of small droplets through the gaseous center. Occurs at surface gas speeds greater than 6 m/s. It is also known as film flow.

Dispersed flow

In this flow pattern virtually all liquid is dragged in the form of droplets in the gas. It occurs at surface gas speeds greater than 60 m/s. It is also often referred to as mist flow or fog flow or spray flow. When some portions of the inner wall of the tube are covered by a thin film of liquid, it is known as annular-mist flow.

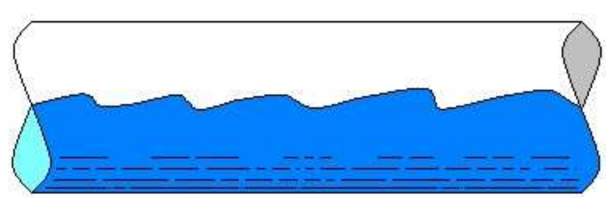


Bubble flow



Plug flow

Estratified flow



Wave flow

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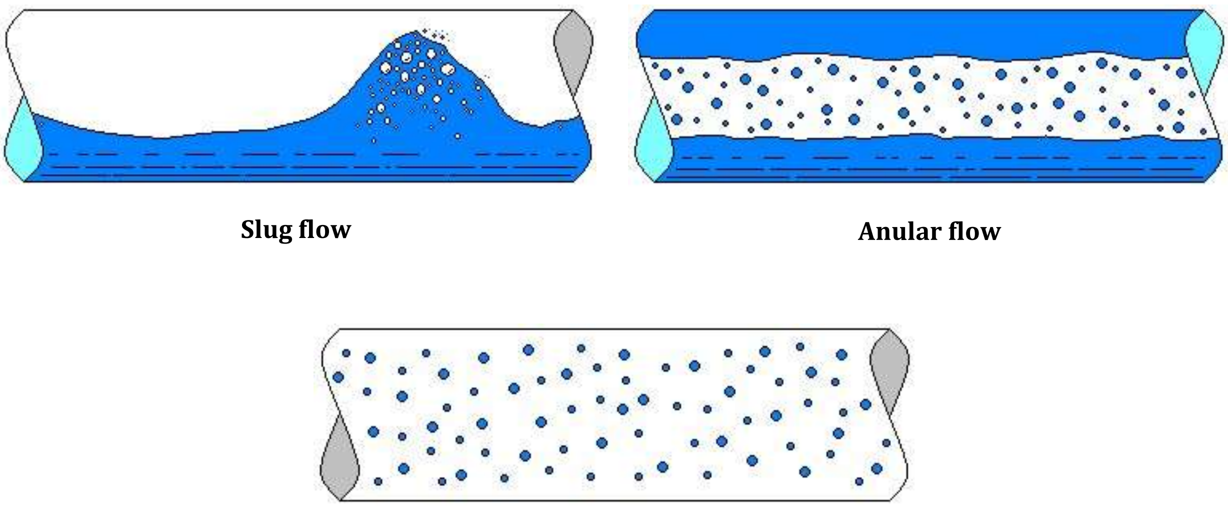

Slug flow

Anular flow

Dispersed flow

Figure 1.- Flow patterns to two phase gas-liquid system in horizontal pipes.

2. PREDICTION OF FLOW PATTERNS IN HORIZONTAL PIPES

The calculation of the pressure drop in the two phases flow depends ,on the flow pattern, therefore the first stage of the calculation requires the prediction of that pattern. The identification of flow patterns is perhaps one of the two-phase fluid flow areas that has caused the most controversy, due to the dependence on the technique used in experimentation (these can range from visuals, high-speed photography, high-resolution video, to pressure fluctuation detectors). Numerous charts have been prepared to roughly predict the pattern from flow conditions, fluid properties, and tube geometry.

From those charts, also called flow pattern maps, the engineer can predict with a certain degree of approximation what type of flow occurs in a given problem. Baker [2] presented one of these maps for horizontal flow from data provided by various authors (Figure 2). The edges, boundaries, or boundaries between the flow patterns present in this map are shown as functions of the speed mass of the gas phase and the mass flow ratio of both phases. These borders are not actually lines but transition zones between different flow patterns. When using it, the designer should be aware that the map provides an approximate idea of the most likely flow pattern to be obtained.

The map in Figure 2 was drawn from air and water data at atmospheric pressure and at room temperature. In order to use it for any other system, Baker used correction factors that would adjust the physical properties of water and air to those of other fluids and other pressure and temperature conditions. The data used by Baker correspond to experiments in pipes ranging in diameter from 1 inch to 4 inches. The regions of the different flow patterns do not change significantly for pipe diameters greater than 4 inches, but for diameters less than 1 inch, the wave flow region tends to disappear, modifying the areas corresponding to the stratified and annular flows.

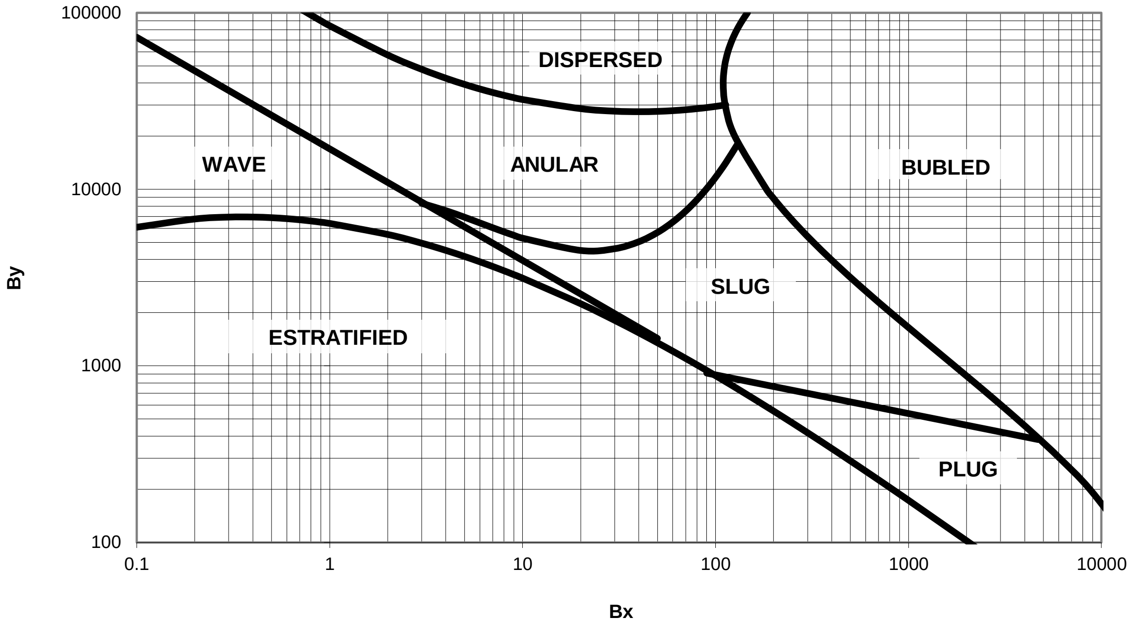

Figure 2.- Map of Baker patterns for horizontal flow in gas-liquid systems. (1954)

To determine the flow pattern using the Baker map, the Baker parameters (Bx and By) must first be calculated, which determines the expected flow type on the graph:

$$Bx = 0.0341 \frac{W_L}{W_G} \frac{\rho_G^{1/2} \mu_L^{1/3}}{\sigma_L \rho_L^{1/6}} \left[cp^{1/3} \right] \quad (1)$$

$$By = 7.092 \frac{W_G}{A\sqrt{\rho_G \rho_L}} \left[\frac{lb}{h\,ft^2} \right] \quad (2)$$

Where: Bx and By's abscissa and ordinate of Baker's map.

ρ_L- density of the liquid in kg/m3. ; ρ_G - gas density in kg/m3.

μ_L - viscosity of the liquid in centipoise. ; $\Box_L$ - surface tension of the liquid in kgf/m.

A - cross-sectional area of the tube flow in m2. WL - mass flow of the liquid in kg/h. WG - mass flow of the gas in kg/h.

Note: the units of each coordinate and the units of the variables present there. To transform dina/cm to kgf/m, multiply by 1.02x10-4

Example 1

What will be the expected flow pattern in a 6-inch horizontal pipe 40 through which 2800 kg/h of liquid flow with a density of 834 kg/m3, viscosity of 0.1 cp and surface tension of 6.25 dinas/cm? 9800 kg/h of steam with 30.75 kg/m3 density and a viscosity of 0.01 cp flow through the pipe.?

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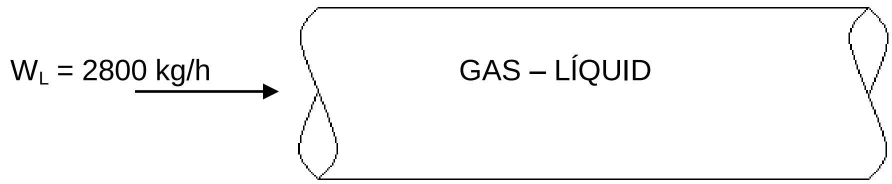
1.-TRASLATION



2.-Planning
2.1.-Discussion.
The type of flow present must be found by using Baker's parameters and map.
2.2.-Baker Parameters.

$$Bx = 0.0341 \frac{W_L}{W_G} \frac{\rho_G^{1/2}\,\mu_L^{1/3}}{\sigma_L\,\rho_L^{1/6}} \quad \left[cp^{1/3}\right] \qquad By = 7.092\,\frac{W_G}{A\sqrt{\rho_G \rho_L}} \quad \left[\frac{lb}{h\,ft^2}\right]$$

3. CALCULS

3.1.-Baker parameters

For a 6" nominal diameter pipe card 40, its internal diameter is:
D = 6.065 in = 0.154 m

$A = \frac{\pi}{4} D^2 = 0.018639\ m^2$

$$By = 7.092\,\frac{9800\,\frac{kg}{h}}{0.018639\,m^2\sqrt{30.75\,\frac{kg}{m^3}\left(834\,\frac{kg}{m^3}\right)}} = 23284$$

σ_L = 6.25 dina/cm = 6.37x10^{-4} kgf/m

$$Bx = 0.0341\left(\frac{2800\,\frac{kg}{h}}{9800\,\frac{kg}{h}}\right)\frac{\left(30.75\,\frac{kg}{m^3}\right)^{1/2}(0.1cp)^{1/3}}{6.37\times10^{-4}\,\frac{kgf}{m}\left(834\,\frac{kg}{m^3}\right)^{1/6}} = 12.83$$

3.2.Determination of the flow type.

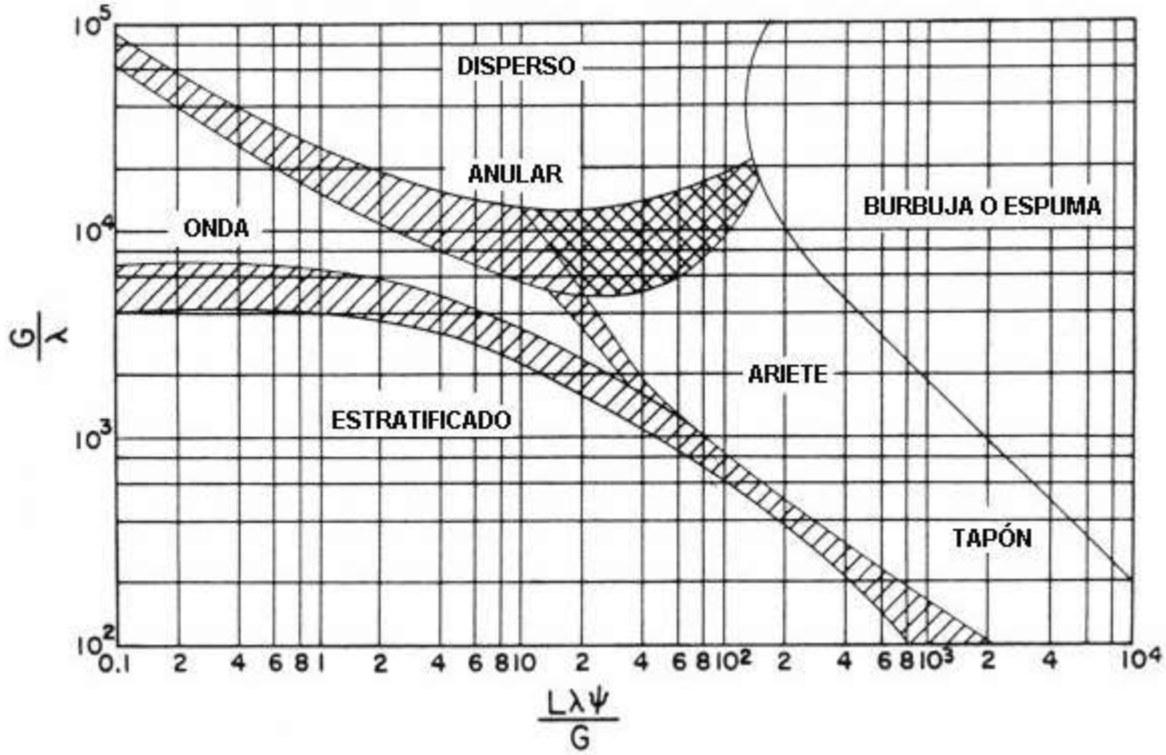
With the values of Bx and By, the flow pattern corresponding to the intersection of these values is located on the Baker map. You can see that the intersection occurs in the annular flow region.

4. RESULT

The flow obtained is annular.

As the boundaries of the different flow patterns are not very well delimited, in practice some modified versions of Baker's map have appeared, including one due to Scott [3] showing the boundaries of uncertainty:

Figure 4.- Map of Scott patterns for horizontal flow in gas-liquid systems. (1963)



Where:

$$\frac{L\lambda\psi}{G} = Bx \qquad (9)$$

$$\frac{G}{\lambda} = By \qquad (10)$$

$$\lambda = \left[\left(\frac{\rho_G}{0.075}\right)\left(\frac{\rho_L}{62.3}\right)\right]^{1/2} \qquad (11)$$

$$\psi = \left(\frac{73}{\sigma_L}\right)\left[\mu_L\left(\frac{62.3}{\rho_L}\right)^2\right]^{1/3} \qquad (12)$$

L – Mass velocity liquid phase in lb/(h ft2). G - Mass velocity gas phase in lb/(h ft2).
ρ_L- liquid density in lb/ft3. ;ρ_G - gas density in lb/ft3.; μ_L - viscosity of the liquid in centipoise. ; σ_L – surface tension of the liquid in dina/cm.

Surface Velocity graphs have been used more frequently in recent years, in which the boundaries of different flow regimes are presented with better precision. These graphs include those of Govier [4], Mandhane [5] and Taitel [6], which plots the surface velocity of the gas against that of the liquid. A modification of these maps is that presented by González Ortiz [9] (Figure 5), which was elaborated from experiments conducted with air-water systems.

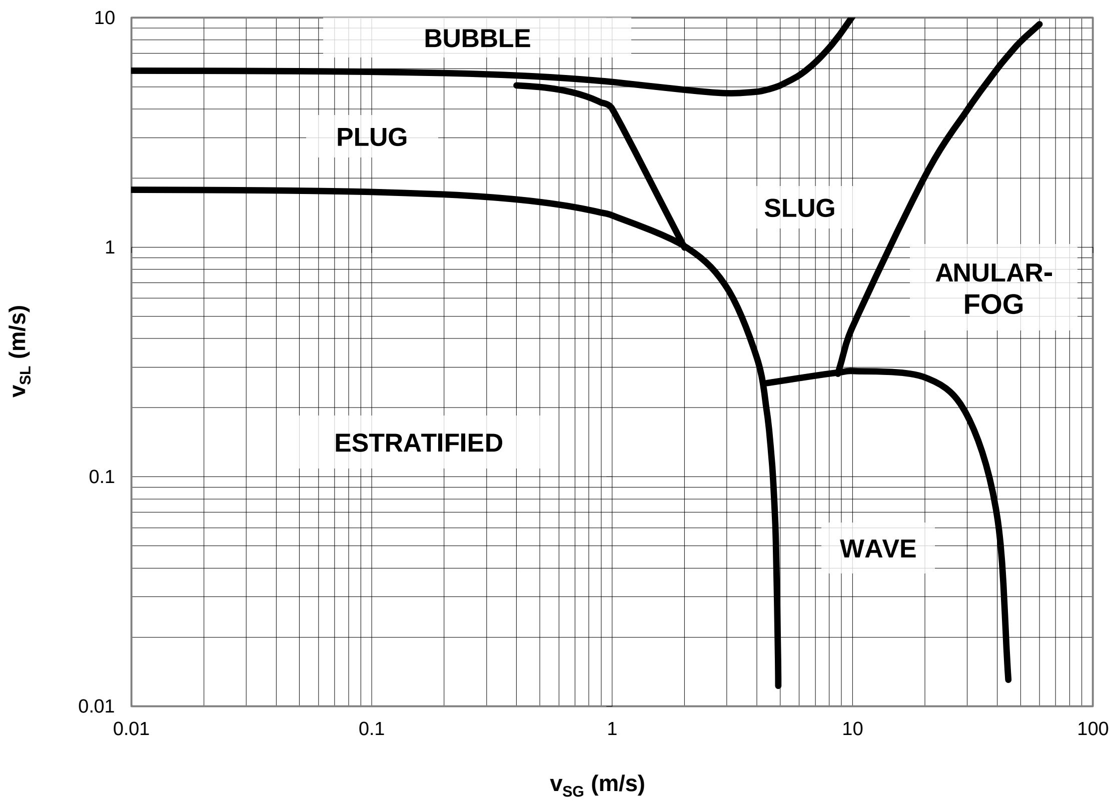


Figure 5.- Map of Gonzalez Ortiz patterns for horizontal flow in gas-liquid systems. (1995)

Such maps emerged when we noted that the factors of correction of properties relative to air and water generally have a unit value. In this way, surface speed maps are applicable for any system other than air-water. Surface velocity [7] in two-phase flow is the one that the fluid would have if it was flowing alone through the pipe, therefore it is equal to the volumetric flow or flow divided between the transverse area of the pipe:

$$v_S = \frac{Q}{3600\,A} = \frac{W}{3600\,\rho\,A} \qquad (13)$$

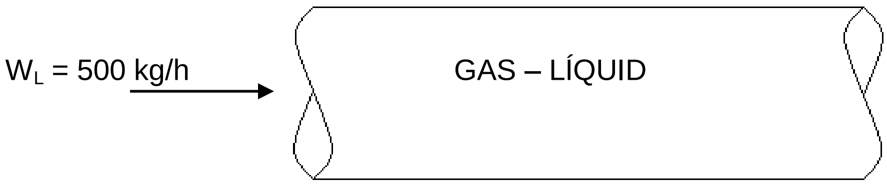
Where:
Vs - surface velocity of the fluid in m/s. ; Q - volumetric flow of the fluid in m3/h.
A - transverse area of the pipe in m2. ; W - mass flow of fluid in kg/h

Example 2

A mixture of liquid and steam flows through a 3-inch-diameter 40 horizontal pipe. If the steam flow is 1350 kg/h , and the liquid flow is 500 kg/h, evaluate the type of flow that arises if the properties of the fluids are: vapor density 1.25 kg/m3; liquid density 1000 kg/m3;

liquid viscosity 1 cp; surface tension of the liquid 15 dinas/cm.

1.-Translation



2.Planning.

2.1.-Discussion.

To obtain the flow pattern, Baker and González Ortiz maps will be used.

2.2.-Baker Parameters.

$$Bx = 0.0341 \frac{W_L}{W_G} \frac{\rho_G^{1/2} \mu_L^{1/3}}{\sigma_L \rho_L^{1/6}} \quad \left[cp^{1/3}\right] \qquad By = 7.092 \frac{W_G}{A\sqrt{\rho_G \rho_L}} \quad \left[\frac{lb}{h\,ft^2}\right]$$

2.3.- Surface velocity.

$$v_{SG} = \frac{W_G}{3600\,\rho_G A} \quad \left[\frac{m}{s}\right] \qquad v_{SL} = \frac{W_L}{3600\,\rho_L A} \quad \left[\frac{m}{s}\right]$$

3.-CALCULATIONS.

3.1.-Getting the flow pattern using Baker's map.

D = 3.068 in = 0.0779 m

A = 0.004769 m^2

σ_L = 15 dina/cm = 1.53x10^{-3} kgf/m

Bx = 2.918

By = 56777

On Baker's map, the coordinates Bx and By indicate scattered flow, but the point is almost over the boundary edge with the annular flow.

3.2.-Getting the flow pattern with the map of González Ortiz

$$v_{SG} = \frac{1350\,\frac{kg}{h}}{3600\,\frac{s}{h}\left(1.25\,\frac{kg}{m^3}\right)\left(0.004769\,m^2\right)} = 62.91\,\frac{m}{s}$$

$$v_{SL} = \frac{500\,\frac{kg}{h}}{3600\,\frac{s}{h}\left(1000\,\frac{kg}{m^3}\right)\left(0.004769\,m^2\right)} = 0.0291\,\frac{m}{s}$$

On Gonzalez Ortiz's map, the resulting flow is annular-fog, but the intersection of the coordinates is near the border with the wave flow.

3.RESULT

The most likely flow pattern is dispersed, due to the coincidence of this flow on both maps, but the possibility of the development of annular or wave flows within the pipe is not ruled out.

Baker and González Ortiz's maps, among many others, have been developed to determine the different flow patterns for Newtonian gas-liquid systems. Similarly, Chhabra and Richardson [8] made a map (Figure 7), based on Mandhane [5], in order to include the flow of non-Newtonian gas-liquid systems. This map is a graph of surface speeds, such as that of González Ortiz, and applies for pseudoplastic and dilating liquids (liquids whose behavior is given by the law of power), and for viscoelastic liquids (polymeric solutions), that is, applies for liquids whose viscosity does not depend on time. As Newtonian liquids behave according to the law of power (with exponent equal to 1), then this map also applies to Newtonian gas-liquid systems. For more details regarding non-Newtonian liquids and their rheology, the reader is recommended to consult the works of Valiente Barderas[10], Schetz and Fuhs[11], and Chhabra and Richardson[8].

The boundaries between the flow patterns in the map in Figure 7 are also neither lines but transition regions. The intermittent flow on this map covers plug and battering ram flows. To design systems where non-Newtonian gas-liquid mixtures flow, using this map, it is advisable to avoid this flow region due to its instability and possible damage to the pipe caused by plugs or battering rams. This is achieved by properly selecting the surface speeds of both phases, which are a function of the most common flows of the liquid and gas.

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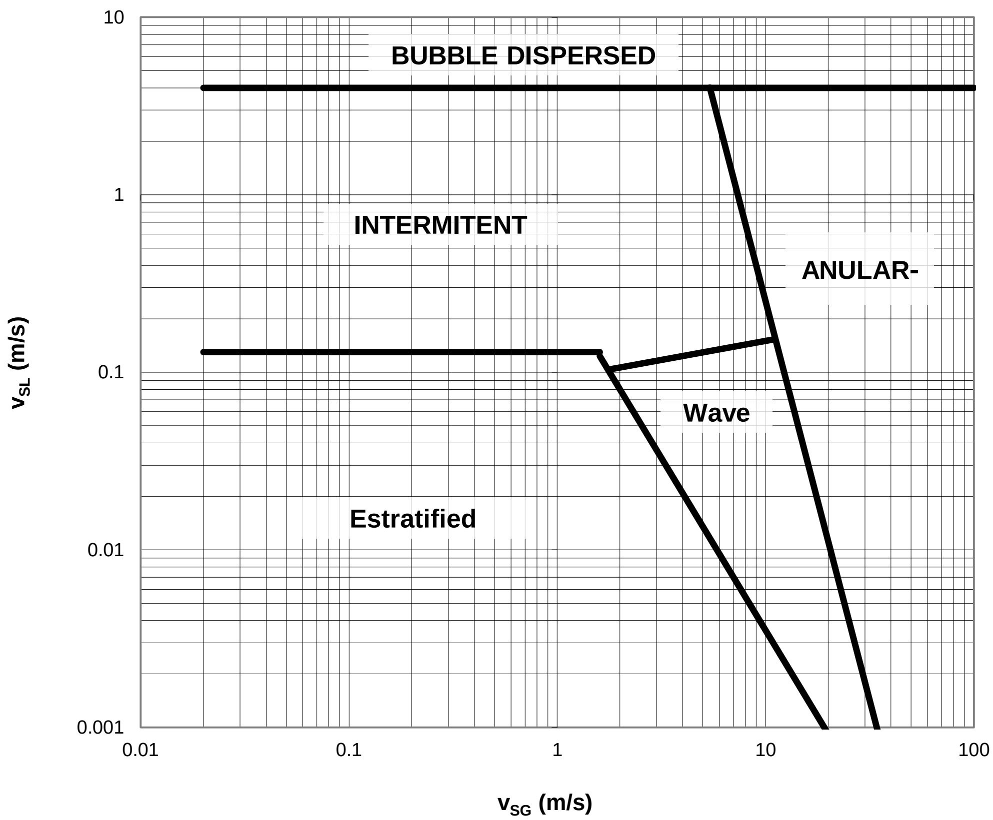

Figure 7.- Chhabra-Richardson pattern map for horizontal flow in gas-liquid systems. (1984)

4. CONCLUSIONS

For the prediction of the type of flow to two phases when circulating vapors in parallel current with liquids inside horizontal pipes is very useful the application of so-called flow pattern maps, some of them based on fluid speeds and others on more complex equations and combinations of variables. For more information on other maps of horizontal flow patterns to two gas-liquid phases, it is advisable to consult the works of Nuñez Alva [12] and the Varela Juárez [13] brothers, as well as the appropriate addresses on the Internet and You Tube.

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