SCALING AND MODELLING ARGUMENTS FOR A TWO-PHASE SLUG FLOW THROUGH A 90° HORIZONTAL ELBOW

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ABSTRACT

This paper describes a methodology to establish scaling laws to study the two-phase flow behavior without the typical experimental restrictions. For instance: numerical simulation limitations in turbulent flows, experimental data uncertainty, lacking of an universal model or correlation in two-phase flow, troubles on surface equipment operation, complex fluids, large diameter pipes and others. The main problem is when experimental data developed on small diameter pipes are applied to phenomenon occurring on large diameter pipes. Obviously, it does not exist a linear correlation for this case. In a similar way, it is not possible to suppose that the system will follow an identical behavior in air-water mixtures and mixtures like steam-water, gas-oil or many other no-Newtonian fluids.

An experimental investigation on both single phase (air and water flowing alone) and two-phase air-water slug flowing through a 90° horizontal elbow was undertaken. Three horizontal standard elbows were tested; all of them had short curvature radius with 1, 1.5 and 2 inches of internal diameter. Pressure taps on the elbows were located every 15° along the curvature radius by pairs, one on the internal wall and the other on the external. The mass flow was measured using a calibrated orifice plate and passed through the elbow. Expansion, pressure drop, pressure distribution and void fraction were involved in this study. A basic two-phase flow model has been modified in order to apply a technique based on non-dimensional parameters. This technique provides scaling arguments describing the two-phase horizontal flow behavior. Then, by simple analytical considerations on the original, the new data (based on non-dimensional parameters) are taking as a semi-empirical correlation. This methodology is called non-dimensional scaling, and some researchers have been working in this topic recently[1,2,3].

SCALING APPROACH METHODOLOGY

This work pretends to assess the applicability of data, obtained in reduced-scale experimental facilities, to the validation of several codes. For instance, the ones used in nuclear safety analysis and other applications. Banerjee et al.[4] developed a methodology based on the phenomena identification in order to obtain a reduced set of equations and nondimensional groups. These elements were used in a validation process in order to demonstrate that the important terms have been retained and also for assessing scaling of various facilities for several phenomena occurring in the process industries. This methodology includes:

1. Identify the active factors (those that impact the entry variables and system behavior).

2. Write and define the governing equations for each component, in each phase and their interconnections identified in step 1, using a lumped parameter approach to develop integral forms for mass, energy and momentum conservation equations.
3. Nondimensionalize the equations obtained in the last step.
4. Select reference parameters so that the nondimensionalization process leads to the dependent variables, except those characterizing the key system response in each equation, being of order 1.
5. Develop a magnitude order analysis, ordering the terms in the nondimensional equations according to magnitude of nondimensional coefficients and retain only the dominant terms in each equation clarifying the impact of each remaining term on the system response of interest.
6. Evaluate the reduced nondimensional equations using data from experimental facilities to determine their validity in predicting the system response.
7. Compare the nondimensional groups that dominate the system response of interest for the compute codes and experimental facilities, and thereby evaluate the applicability of the experimental data to assessments of numerical analysis methods.

Steps 2-4 provide a set of nondimensionalized equations that are used to predict a system response such as pressure drop, pressure distribution or void fraction analysis on two-phase air-water slug flow through a horizontal pipe. Characteristics of these equations are:

- All nondimensional variables except the key system response, are approximately of order 1. With nondimensional coefficient groups the magnitude of each term is determined .
- Nondimensional groups can be evaluated so that their magnitudes can be compared to identify the dominant terms in each equation and their impact on the key system response. So, only the dominant groups in each equation are retained.
- In order to clarify distortions on the nondimensional analysis, dominant groups must be compared between the experimental facility and the real process.

MODEL DEVELOPMENT

Local instantaneous equations constitute the rational basis for almost all two-phase flow modeling procedures. They are used directly in the study of bubble dynamics or film flows, or in averaged form, for example, in the study of pipe flows. Conservation equations in their integral balance form can be written and modified by several basic laws, taking the form:

$$\frac{\partial}{\partial t}\rho_k\psi_k + \nabla\cdot(\rho_k\psi_k V_k) + \nabla\cdot J_k - \rho_k\phi_k = 0 \qquad (1)$$

BALANCE	ψ_K	J_K	ϕ_K	ϕ_I
MASS	1	0	0	0
LINEAR MOMENTUM	V_k	$-T_k$	F	0
TOTAL ENERGY	$u_k + \frac{1}{2}V_k^2$	$q_k - T_k \cdot V_k$	$F \cdot V_k$	0

Selecting the proper reference parameters, the dimensionless equations finally take the form:

Linear momentum:

$$\frac{DV_k^*}{Dt^*} = -\nabla P_k^* - \frac{Gr}{\mathbf{Re}^2}\beta^* T^* g^* + \frac{1}{\mathbf{Re}}\nabla^*\cdot\tau_{ij_k}^* \qquad (2)$$

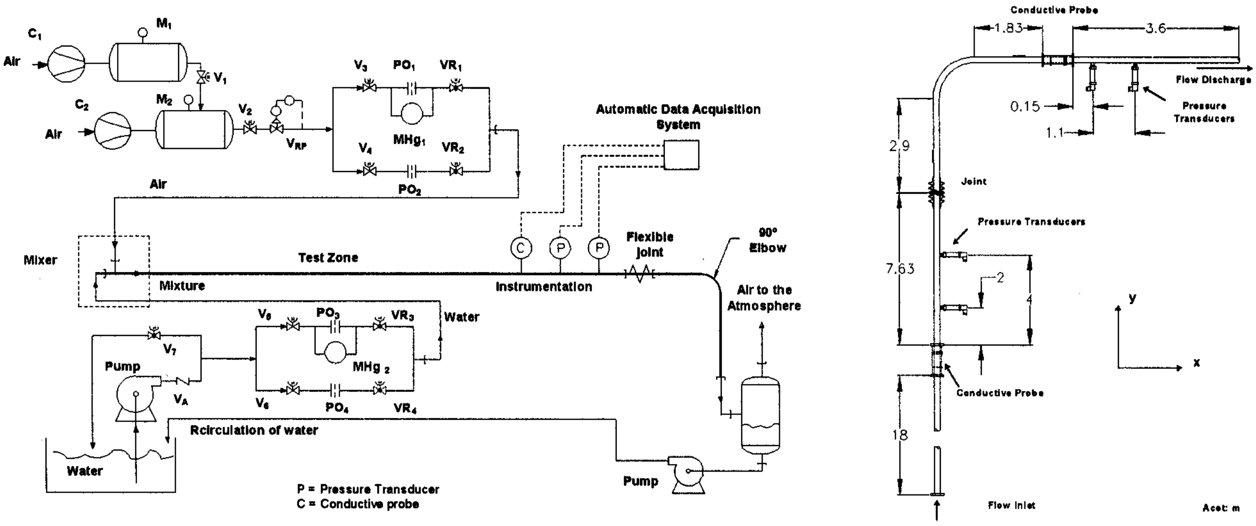
Energy:

$$\rho_k^* Cp_k^* \frac{DT_k^*}{Dt^*} = Ec\frac{Dp_k^*}{Dt^*} + \frac{1}{\mathbf{Re}\cdot\mathbf{Pr}}\nabla^*\cdot\left[k^*\nabla^* T_k^*\right] + \frac{Ec}{\mathbf{Re}}\Phi^* \qquad (3)$$

The mass balance is independent on any scale or dimensionless parameter, so it was omitted. Similar procedures will be following to determine the significant parameters take up in two-phase flow phenomena, particularly in slug flow through a 90° horizontal elbow.

EXPERIMENTAL SETUP

The flow was analyzed up and downstream the elbow using two pressure transducers and a calibrated two-ring conductive probe. By means of an Automatic Data Acquisition System (ADAS) composed by a high speed PC and a Data Acquisition Lab Card, the pressure signals were detected and processed almost in line every ten seconds. Using the cross-correlation technique the characteristic delay time for both signals were obtained and with the distance between the transducers it was possible to determine the characteristic slug velocity. Likewise the average voltage was calculated and by means of a transfer function the average pressure values were obtained, then the pressure drop could be known. The two-ring conductive probe was used to determine the slug holdup, length and frequency. A special electronic device was designed to detect changes on the conductive properties of the mixture, it was made possible to obtain a characteristic signal that represented the transit of a slug through the control volume composed by the two rings. Figure 1 shows the experimental setup used in this work.



a) *b)*

Figure 1.- a) Experimental test loop, b) Measuring stations.

An important parameter registered in the experimental analysis was the static pressure for different angular positions in the internal and external radii of the elbow. The curvature radius was 100 mm. The pressure taps were located as shown in figure 2, each one 15° separated from the other. The static pressure was measured using a calibrated pressure transducer; a 5 HP centrifugal pump provided the water flow, which was measured with a calibrated orifice plate. The elbow had a far enough smooth pipe length before and after the change of direction in order to avoid flow perturbations.

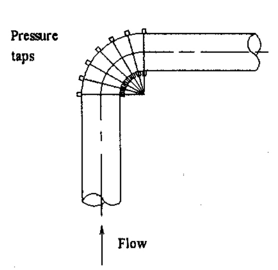


Figure 2. Experimental zone

EXPERIMENTAL RESULTS

The experimental facility above described allows to obtain a set of data concerning to pressure drop measurement on the 90° horizontal elbow. Three kinds of data were obtained: water flowing alone, air flowing alone and two phase air-water flowing through the elbow. Figure 3 shows the results when air is flowing alone through the elbow. It can be observed that the bigger pressure drop occurs precisely in the elbow, however, an increase on pressure is present too in this zone due to the fluid kinetic energy that provokes turbulence and momentum interchange between the fluid and the elbow. Figure 4 shows similar results when water flows alone into the pipe. It can be observed the same zone of pressure increase.

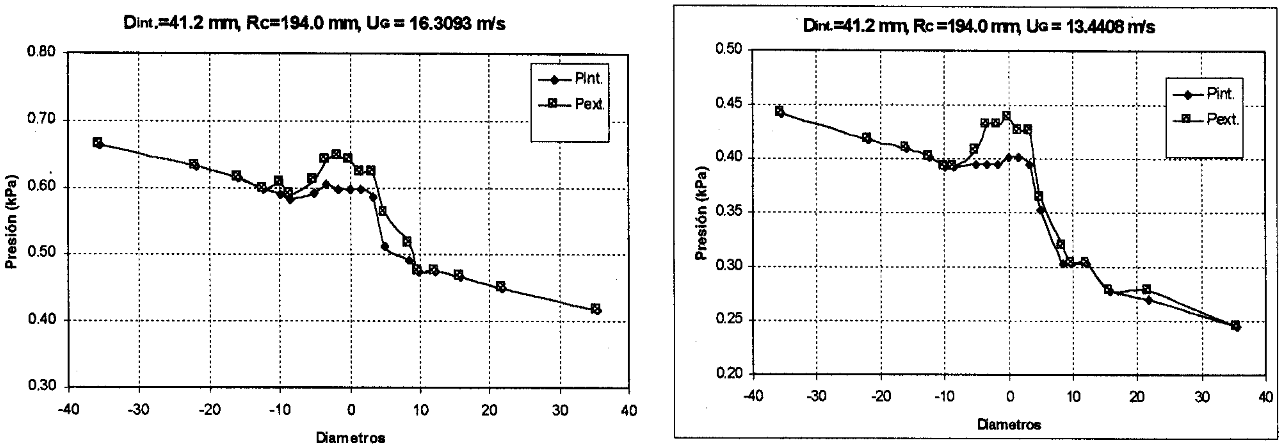


Figure 3. Experimental results, air flowing alone.

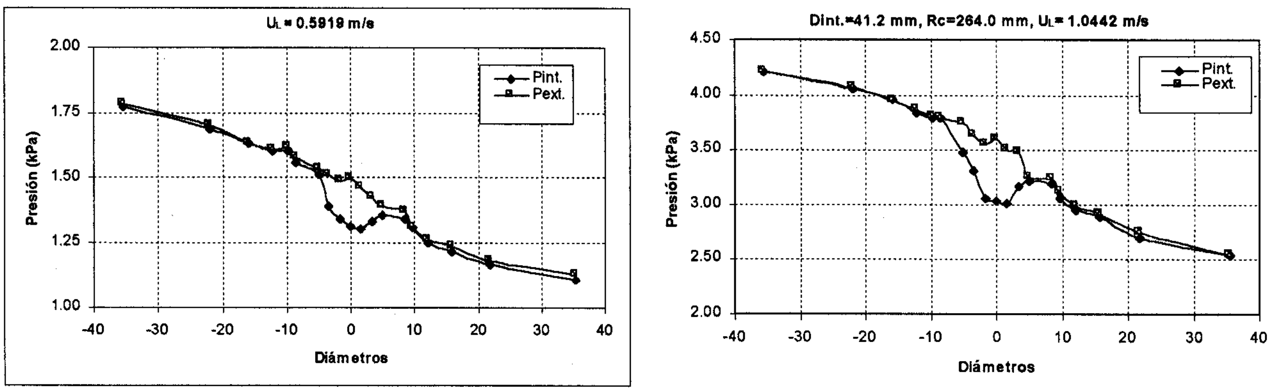


Figure 4. Experimental results, water flowing alone.

RESULTS COMPARISON

The previous experimental results indicate that the maximal radial pressure difference zones in a 90°-curved pipe are located between 15° and 45° depending on the Reynolds number and curvature radius. So, in all experimental works there are always measuring errors, the ones occurred here are mainly due to the perpendicularity of the pressure taps and elbow roughness, which provokes turbulence and perturbations in the flow field. It is important to know that the curvature ratio d/r used in this work were 2.2, 0.44 and 0.191 respectively. Finally, the focus of scaling and modeling laws in two-phase flow is to develop a methodology in order to estimate the applicability of experimental data (obtained in a reduced scale set) to validate software from numerical simulation.

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