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TÍTULO DO TRABALHO:

COMPUTATIONAL TOOL FOR HORIZONTAL FLOW SIMULATION USING THE LOCKHART AND MARTINELLI CORRELATION: DEVELOPMENT AND COMPARISON WITH FIELD DATA

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Abstract

Oil and gas mixtures are the most common ones among the two-phase flows present in the petroleum industry and that, to a great extent, occur in horizontal pipelines. Therefore, several authors seek a better understanding of the characteristics of pressure profiles related to such flows. Among the various correlations developed, that of Lockhart and Martinelli, presented in 1949, is considered to be one of the first classical approaches to horizontal two-phase flow and, although more recent publications have shown new approaches, the considerable simplicity of this relationship maintains it as one of the main and more widely used. Later, with the introduction of personal computers in the 1980s, there was significant advance in such studies, especially with the development of simulators. Thus, the importance of computational aid for the calculations of pressure loss was evidenced as they involve a large amount of information and considerable complexity of the equations. However, such simulators still lack free and wide applications, which becomes a barrier in the constant search for a better understanding of horizontal two-phase flow. Therefore, the present work presents a computational tool for applying the Lockhart and Martinelli correlation, followed by the application of experimental data and their comparisons for the proposed tool.

Introduction

Two-phase flow, defined as the simultaneous flow of liquid and gas, and, for the present study oil and gas, is notably frequent in different industrial activities. More specifically, in the petroleum industry, its occurrence takes place throughout the fluid path, from production to transport. As for the two-phase character, this results from the reduction of pressure and temperature, resulting in the release of gas previously dissolved in the oil. Thus, along the route from the reservoir, there are sections, to a greater or lesser extent, in which the flow is horizontal, bearing its own problems and characteristics.

In this sense, multiphase flow and its adversities have been recognized since 1797 (BROWN, 1977) and the horizontal case, such as along a subsea pipeline for transport to central processing facilities, gained greater prominence throughout the years. Therefore, in the quest to solve the pressure gradient question, several authors have developed correlations for the pressure drop of two-phase flows. In addition, the use of, not only correlations and mechanistic models, but also personal computers after their introduction in the early 1980s lead to multiphase flow simulators in oil wells, with the basic goal of determining the pressure and temperature gradient, which proved to be useful tools in the development and planning of oil and gas production and transport systems (NASCIMENTO, 2013). In turn, the study of two-phase flow in horizontal pipelines is essential for the optimization of projects – such as surface equipment, pipes, pumping equipment, among others –, as many systems are designed based on the expected pressure drop, and for the operation and maintenance of downstream facilities.

Finally, even though there is a considerable number of improvements in the understanding of two-phase flows, it is still necessary to reach a greater integration of the study of their pressure gradient to the free application of computational models and simulators.

Methodology

The present work basis itself on the computational calculation of correlations to analyze the applicability of more accessible computational tools. And, although there are several correlations available for predicting pressure loss, the one chosen for this work was the Lockhart and Martinelli, which is known to be one of the most widely used (BROWN, 1977), and significantly simple.

This correlation was presented from the results of experimental work carried out on pipes from 0.0586 inches to 1.017 inches (LOCKHART; MARTINELLI, 1949). The correlation was developed from two basic assumptions: (i) the static pressure drop of the liquid phase and the gas must be the same for all flow patterns (when there is no appreciable radial static pressure difference); and (ii) the sum of the volume occupied by each phase must be equal to the total volume of the pipeline. Therefore, such assumptions imply that the flow pattern does not change along the length of the tube, so slug flow is excluded from this investigation (MEKISSO, 2004).

In their correlation, the authors introduced a new parameter, called X, which is a dimensionless variable as a function of the ratio of the weight rates of liquid and gas, ratio of densities and the diameter of the tube (BROWN, 1977). Thus, the parameter X, which is commonly referred to as the Lockhart & Martinelli parameter, relates the single-phase pressure drops for liquid and gas, as can be expressed as follows:

$$X = \sqrt{\frac{(\Delta P/\Delta L)_L}{(\Delta P/\Delta L)_G}} = \sqrt{\frac{(\Delta P)_L}{(\Delta P)_G}}$$

Essentially, the two-phase pressure gradient is related to the pressure gradient for each of the phases by the multipliers φg and φL. Furthermore, during the development of the correlation, the authors proposed four types of flow mechanisms, categorized according to Table 1.

Table 1. Lockhart and Martinelli mechanisms

Viscous-viscous (vv)	When both liquid and gas have viscous flow
Viscous-turbulent (vt)	When the liquid’s flow is viscous, and gas is turbulent
Turbulent-viscous (tv)	When the liquid’s flow is turbulent, and the gas is viscous
Turbulent-turbulent (tt)	When both liquid and gas have turbulent flow

In its turn, the computational tool was written using Microsoft Excel and VBA (Virtual Basic for Applications), which consisted of, essentially, two routines: one for simply calculating the two-phase pressure drop based on the liquid pressure drop and the other for reinforcing the result by calculating the two-phase pressure drop based on the gas.

As for the benchmark the tool was developed based on Brown's (1977) example, to which it showed a good agreement. In turn, the field data used in this study was obtained from Hemeida's work "Two-Phase Flow in Flowlines" (1989), consisting of tests conducted on Saudi flowlines of 4- and 8-inch diameters and varying oil rates and lengths. The 17 input data sets used for this work are presented through Tables 2 and 3.

Table 1. General dimensions

Test No.	Diameter (in)	Length (ft)	Rate (stb/d)	Pressure upstream (psia)	Average line temperature (°F)	Average oil viscosity (cP)
1	4	2241	12156	606	176.5	1.35
2	4	2241	12484	645	176	1.3
3	4	2241	12204	614	176	1.33
4	4	2241	11594	567	175	1.35
5	4	2310	11720	537	176	1.4
6	4	2310	4513	267	158.5	1.85
7	4	2310	4370	265	163.5	1.8
8	4	2310	4022	251	160	1.82
9	4	2310	3892	249	153	2.0
10	8	19938	15440	571	146.5	1.53
11	8	19938	15522	576	146.5	1.52
12	8	19938	12212	528	146.5	1.51
13	8	19938	16882	508	138.5	1.81
14	8	8204	6590	268	146.5	2.04
15	8	8204	4630	220	133.5	2.28
16	8	8204	3533	207	130	2.38
17	8	8204	6750	264	142	2.13

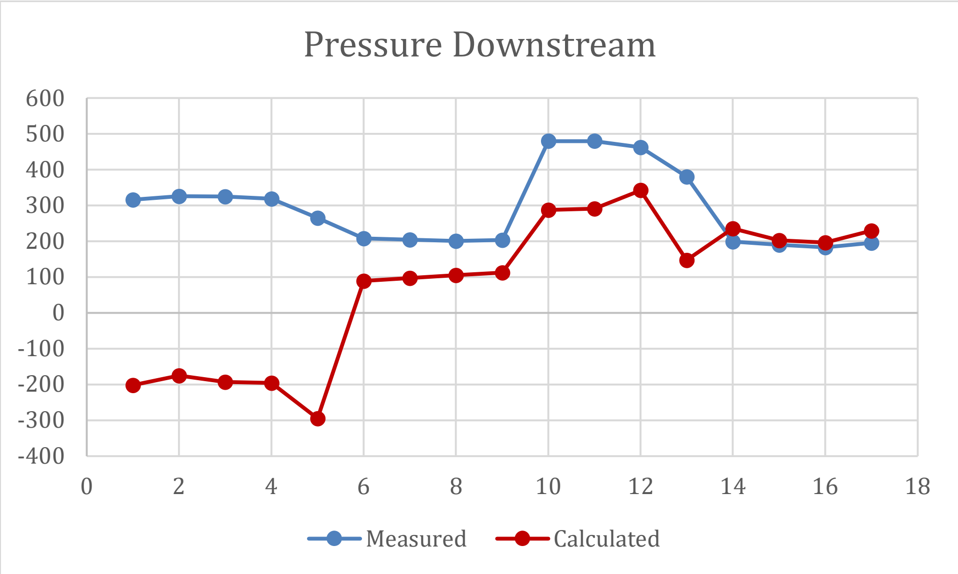
Table 3. Fluid properties

Gas-liquid ratio (scf/bbl)	483
Oil specific gravity	0.86544
Gas specific gravity	1.2408
Gas viscosity (cP)	0.0127
Oil Surface Tension (dynes/cm)	29

Results and Discussion

The results obtained from the computational procedure to calculate the pressure drop didn't show good agreement with experimental results, as can be seen in Figure 1, with an average percent difference of 68.78%.

Figure 1. Pressure Downstream



The general disagreement can be pointed out to be a result of incompatibility between the diameters presented in the authors work results – 0.0586 inches to 1.017 inches (BROWN, 1977) – and the ones from the field data – 4- and 8in. It is possible to notice, however, that for the last 4 tests the errors have a drop in their value, which can be related to the combination of lower flowrates and a bigger diameter, so that there's less turbulence and, therefore, a smaller pressure drop.

It is also important to mention that for these tests the flow configuration consists of high flow rates in small diameter, and therefore higher fluid velocities, which lead to higher pressure losses, as the measured results show. However, there is the consideration of non-systematic errors, which are known to be eliminated nor corrected, and can be pointed as the reason behind the higher errors.

Conclusions

It is possible to conclude that the computational tool developed through Microsoft Excel and VBA for predicting pressure drop with the Lockhart and Martinelli correlation didn't give good results, in a sense that some possible reasons can be listed, such as the diameter range applicability and also confirming that the developments in the quest to solve the two-phase pressure drop issue are of significance importance to the related calculations and that other correlations would lead to better fits and integration of the study of pressure gradients to the free application of computational models.

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