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Comparison between experimental data and the Dukler model for pressure loss in horizontal pipelines

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Abstract

The two-phase flow consisting of oil and gas is the most frequently observed among the other two-phase flows. Furthermore, aside from being present in several industrial activities, it is remarkably present in the petroleum sector: from production to transport, such that accurate prediction of the pressure drop is imperative for the design of these systems. From the 80s onwards, the introduction of personal computers became an ally of the use of empirical correlations, enabling the development of simulators, which, however, still lack free applications. Not only that, but computational aid is also essential in view of the ever-growing amount of information and the complexity of the equations involved. Thus, this work presents the results of the application of field data to a computational tool for predicting pressure losses in horizontal pipes, which had as basis the Dukler correlation. Such results show that there's a good fit of the measured data to the calculated one, with an average percent error of -5.5%.

Keywords

pressure loss; Dukler; computational tool.

Introduction

The simultaneous flow of oil and gas is remarkably frequent in different industrial activities, and, more specifically in the oil industry, its occurrence can be noted throughout the petroleum chain, from its production to its transport. Thus, along this route, there are sections, to a greater or lesser extent, in which the flow is horizontal, bearing its own problems and characteristics.

In the search for a better understanding and resolution of the problems and difficulties associated with the two-phase horizontal flow, numerous empirical correlations were presented over time, being the first in the 60s, to predict pressure drop in pipelines [1].

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 [2]. In turn, the study, in the quest to model or correlate the behavior of pressure along a two-phase flow, is essential for the optimization of projects and operation, as their planning is elaborated based on the predicted pressure drop.

Therefore, although different authors have developed correlations for the pressure drop of two-phase flows, there's still a necessity to reach a greater integration of the study of pressure gradients 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 Dukler Case I, which is known to be one of the best [2], and yet can be considered simple, once it considers a two-phase mixture for calculations similar to a single-phase approach.

The Dukler Method

Dukler et al first published work on two-phase horizontal flow in 1964 and, later, in 1969, such that the first part consists of a comparison between determined correlations, while the second comprises the development of the Dukler's correlation itself [3]. The method proposes two cases based on similarity analysis so that equations to calculate the Reynolds number and the friction factor were suggested based on the analogy between single- and two-phase flows [4]. Furthermore, both methods were based on a simple correlation that doesn't require the determination of flow patterns.

Therefore, initially, the properties of the liquid and gas under flow conditions are calculated and then, from equations described by Dukler, a two-phase Reynolds number is calculated, making it possible to determine a two-phase friction factor and, hence, the pressure drop. The Dukler Case I, of importance to this work, assumes that there is no slip between the phases, that is, the slip velocity is assumed to be zero, and thus the equations are given for a homogeneous flow.

More particularly, for Case I, although most horizontal flows are highly unstable, the assumption of a smooth, non-slip flow can be significantly useful. Thus, the key concept of this case is that the holdup is defined as shown in Eq. (1) and Eq. (2):

$$\lambda_L = \frac{liquid\ volumetric\ flow\ rate}{total\ volumetric\ flow\ rate} \tag{1}$$

$$\lambda_L = \frac{liquid\ superficial\ velocity}{total\ superficial\ velocity} \tag{2}$$

Therefore, this method is essentially simple, there the two-phase mixture is treated as a single fluid equivalent, in a way that resembles a calculation for a pressure drop in single-phase flow [1].

Computational Procedure

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 pressure drop and the other for iteratively optimizing the calculation for the pressure drop. Figure 1 shows the general flowchart of the steps to calculate the pressure drop in pipelines through the Dukler Case I correlation.

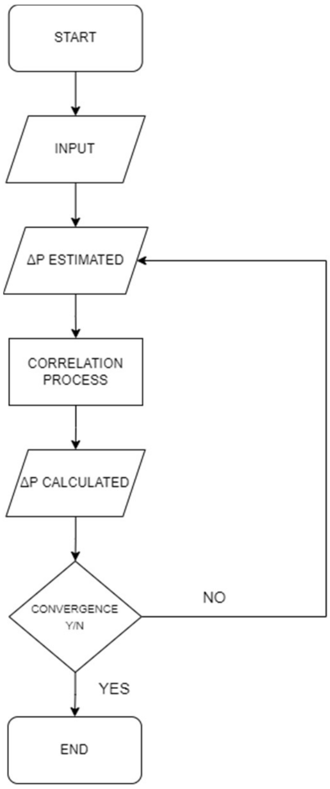

Figure 1. Dukler Case I Flowchart.

Field data

The data used in this study was obtained from reference [5], consisting of tests conducted on Saudi flowlines of 4- and 8-inch diameters and varying oil rates and lengths. The 16 input data sets used for this work are presented through Tab. 1 to Tab. 3.

Table 1. Line dimensions and flow rate.

Test No.	Diameter (in)	Length (ft)	Rate (stb/d)
1	4	2241	12156
2	4	2241	12484
3	4	2241	12204
4	4	2241	11594
5	4	2310	4513
6	4	2310	4370
7	4	2310	4022
8	4	2310	3892
9	8	19938	15440
10	8	19938	15522
11	8	19938	12212
12	8	19938	16882
13	8	8204	6590
14	8	8204	4630
15	8	8204	3533
16	8	8204	6750

Table 2. Pressure and Temperature and oil viscosity.

Test No.	Pressure upstream (psia)	Average line temperature (°F)	Average oil viscosity (cP)
1	606	176.5	1.35
2	645	176	1.3
3	614	176	1.33
4	567	175	1.35
5	267	158.5	1.85
6	265	163.5	1.8
7	251	160	1.82
8	249	153	2
9	571	146.5	1.53
10	576	146.5	1.52
11	528	146.5	1.51
12	508	138.5	1.81
13	268	146.5	2.04
14	220	133.5	2.28
15	207	130	2.38
16	264	142	2.13

Table 3. Fluid properties.

Gas-liquid ratio (scf/bbl)	483
API gravity	32
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 showed good agreement with experimental results for most of the tests, as can be seen in Fig. (1), with an average percent difference of 24.7%.

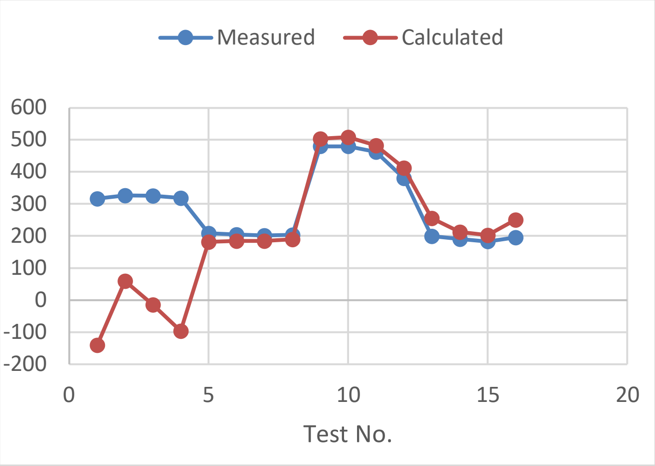

Figure 1. Pressure Downstream.

For the first 5 tests, it is possible to notice considerably higher errors. In this sense, it is 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 not to be eliminated nor corrected, and can be pointed as the reason behind the higher errors. Furthermore, when the computational tool was used to calculate the optimized iterative result for pressure drop there was some discrepancy. For example, for test no. 8, which is the best fit case, the iterative routine pointed a pressure drop of 65.8 psia rather than the measured 46 psia. These differences can be cited as resulting from discrepancies between mathematical calculations and real measurements subjected to numerous possible influencing factors.

Conclusions

It's possible to conclude that the computational tool developed through Microsoft Excel and VBA for predicting pressure drop with the Dukler Case I correlation gave good results, proving that the integration of the study of pressure gradients to the free application of computational models is a tangible matter.

Acknowledgments

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