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Comparison of two-phase flow correlations for hypothetical production well.

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Abstract. *The industry of petroleum and gas commonly face the concurrent flow of liquid and gas in pipes. There is a great difficulty in calculating the pressure drop and liquid hold up that are the most important unknowns. For both calculations, the common practice is to use experimental correlations while assuming steady state. This assumption is reasonable due to the long periods of time that wells and pipelines operate and keep their production in a steady condition. Among the correlations most commonly used in the industry there are the modified correlations of Hagedorn and Brow as presented by Guo* et al. *(2007), as well as the correlation of Beggs and Brill (1973). These however don't consider crucial physical phenomena such as the iteration of the phases considering the topology of the interface. For such description a phenomenological approach should be considered for more accurate results. This paper presents a systematic comparison among the industry's most used correlations as well other well-established multiphase flow correlations and more physically based models proposed by Barbosa and Hewitt (2006) and Petalas and Aziz (2000). Some of these correlations wore already compared by Woldesemayat and Ghajar (2006) and Hafemann (2015) for calculations of void fraction and the behavior of the heat transfer in a production well, respectively. The main focus is than to compare the results from the usual correlations and these two more physically based formulations. Due to the lack of field data for both the liquid hold up and the pressure drop the comparison is be based on a mean tendency of the correlations used for the simulations.*

Keywords: *Two-Phase flow, Production Well, Numerical Modelling, Liquid Hold up, Pressure Drop*

1. INTRODUCTION

Two-phase flows are a common feature in several industries, such as: Oil and Gas, Energy Production, Refrigeration, and on. In the specific case of the oil and gas industry the most critical two-phase flows occur in the production well. Because this is the region where the oil flows from the formation to the surface.

This region of the production well, therefore, need to be described accurately so that the any miscalculations become less relevant within the production prediction context. In this scenario, it is necessary to consider that empirical models, often have a limited range of application, and are mostly inadequate for general purpose simulations, as these do not consider the proper physical interactions of the two-phase flow process. For that a more phenomenological approach, that considers a better understanding of the physical processes involved for each of the flow patterns, is more adequate.

2. METHODOLOGY

In order to calculate the liquid hold up, the pressure drop and temperature inside the well the two-fluid model is adopted. The base formulation consists of determining the derivatives for each flow equation (Momentum and Energy) assuming steady state, and integrate the result with the use of a high order Runge-Kutta method. This formulation was then adapted to accept the use of the black oil model for the production fluids, providing values for the fluid proprieties for all the correlations used in the comparison.

The momentum equation provides the means to calculate the pressure drop from each step in the integration. This is divided into three parts: a frictional, a gravitational, and one that arises from the acceleration of the flow, the total pressure drop being the sum of all three. The energy equation is used to compute the heat transfer from the wall, and thermodynamic equilibrium is assumed between the pahses in each step. Thrugh the integration of the energy equation a change in enthalpy is calculated. With the knowledge of local pressure and enthalpy, a local temperature can be calculated using the Black Oil Model. It is necessary to note that the acceleration part of the pressure drop will only exist when phase change is involved (for single diameter pipes). This couples both equations (Momentum and Energy) that now must be solved iteratively to determine the acceleration pressure drop and its effect in the kinetic temperature drop. The empirical correlations and the phenomenological formulations present different methods for determining the frictional loss. Each of these has its own method implemented in the code. For those correlations that just present a way to determine the liquid hold up, the Friedel correlation Friedel (1979) for two-phase flow pressure drop calculation is used.

3. RESULTS AND DISCUSSION

In order to compare the two-phase correlations two methods of comparison are proposed. First a hypothetical simulation of a adiabatic petroleum well during production and a comparison based on the work of Owen (1986).

To better understand the figures the following table must be considered, this relates the correlation used in the simulation with its proper reference and the index used here on.

Table 1. Numbering of correlations for use in figures.

Name	Index	Reference
Barbosa & Hewitt (2006)	1	Barbosa and Hewitt (2006)
Beggs & Brill (1973)	2	Beggs and Brill (1973)
Mod. Hagedorn & Brown (1965)	3	Hagedorn and Brown (1965) and Guo *et al.* (2007)
Friedel (1979)	4	Friedel (1979)
Chexal & Lellouche (1986)	5	Chexal and Lellouche (1986)
Toshiba (1989)*	6	Coddington and Macian (2002)
Dix (1971)*	7	Coddington and Macian (2002)
Rouhani I	8	Rouhani and Axelsson (1970)
Modified Dix	9	Woldesemayat and Ghajar (2006)
Smith (1969)	10	Smith (1969)
Petalas & Aziz (2000)	11	Petalas and Aziz (2000)

3.1 Hypothetical Production Well

To test the correlations with a more substantial situation, a hypothetical scenario of a production oil well is used in to simulate the resulting two-phase flow. The criteria for selecting this specific simulation is due to its good application to the correlations of the Black-Oil model, as well as the fact that it presents a scenario that stress the correlations.

The following table presents the parameters for this test.

Table 2. Simulation Parameters

	Bottom hole pressure (psia)	*Well length (m)*	*Points*	*Tubbing inner diameter (m)*	*Oil Flow rate (bbl/d)*
Data	4868.3	5000	5001	0.127	700
	Oil API	*Gas Specific Gravity*	*Gas Oil Ratio (SCF/stb)*	*Botton hole Temperature (K)*	
Data	28.8	0.6	500	395	

Figure 1 shows the results for the hypothetical simulation. The results vary in a wide range, and in the most extreme scenarios the absolute deviations exceed 100%. The correlations with the highest deviations from the group mean (not presented in the figure for better viewing) for hold up are the modified Hagedorn and Brown (Hagedorn and Brown, 1965) and the Beggs and Brill (Beggs and Brill, 1973) correlations. The other correlations present a similar curve that is in consonance with what is presented by the evaporation of refrigerants inside capillary tubes (Chexal and Lellouche, 1986) and is the expected result here.

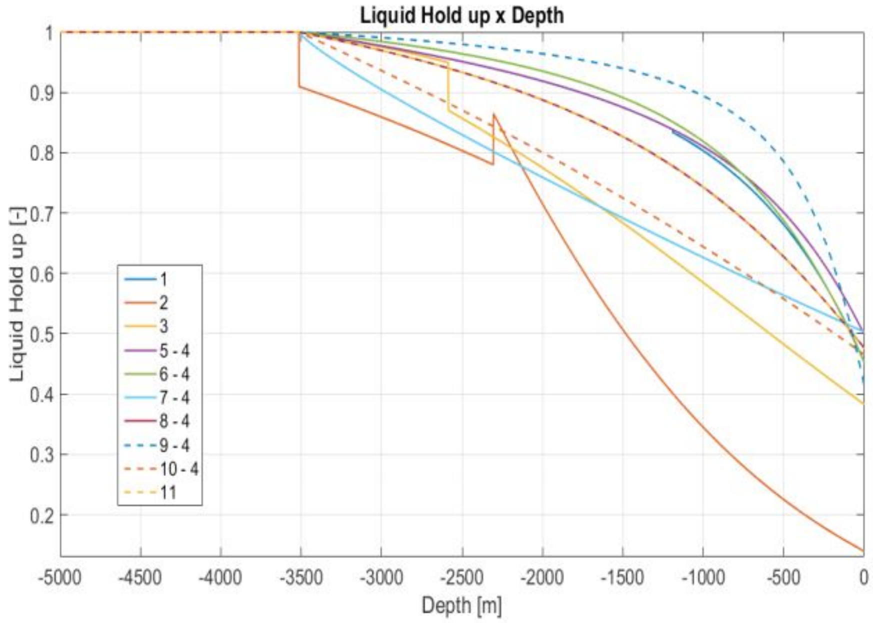

Figure 1. Hypothetical simulation results for liquid hold up.

Figures 2 e 3 present the absolute pressure for the same correlations and models. In this comparison however, all curves present the same trend. That was unexpected since the gravitational pressure drop predicted by both industry standards ((Hagedorn and Brown, 1965) and (Beggs and Brill, 1973)) were not in consonance with the others. The most marking effect of the holdup discrepancies is the lower pressure drop presented by those correlations.

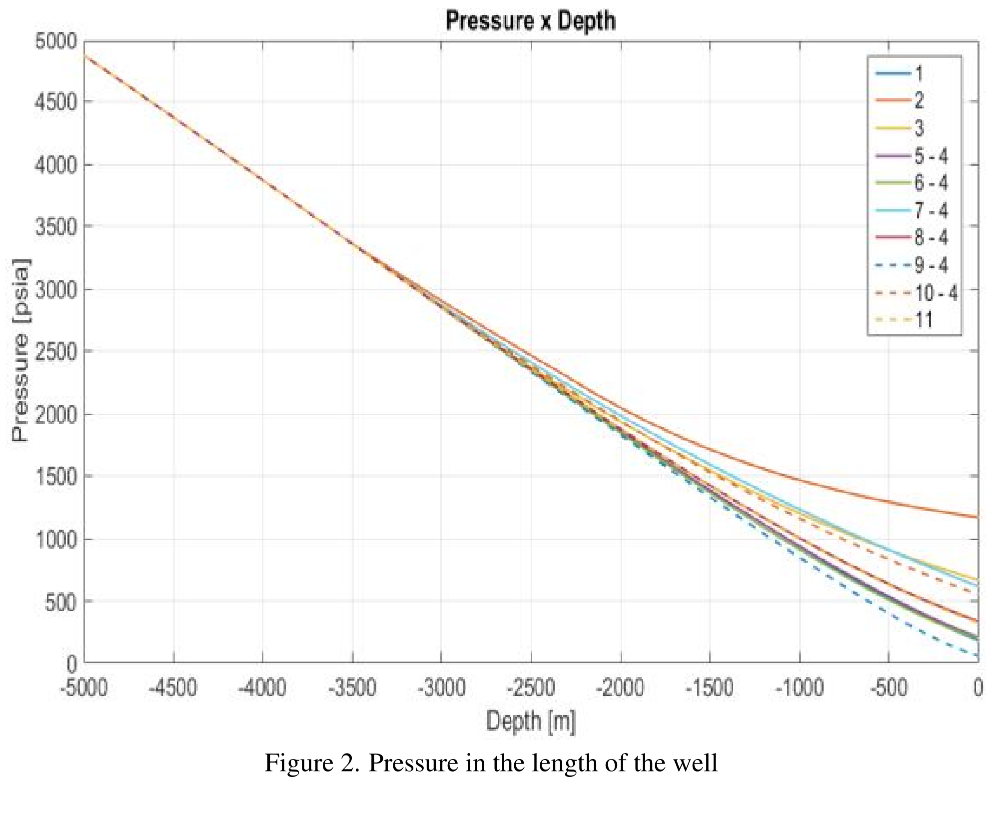

Figure 2. Pressure in the length of the well

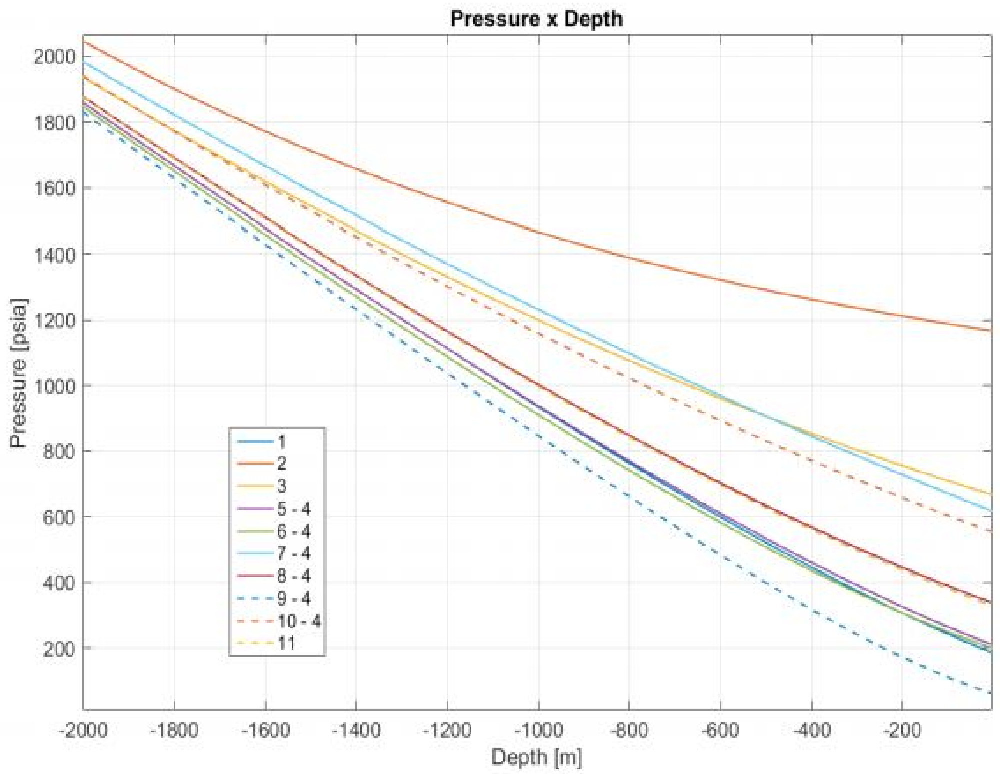

Figure 3. Pressure in the final parcel of the well

3.2 Air-Water Results

The comparison with Owen (1986) experiments is used to compare the correlations under air-water conditions. The of the test facility consists of a vertical tube with controlled mass flow rates of water and air simultaneously. Measurements of pressure gradient were taken and used to compare the two-phase correlations of this work. The base study consist on using the same correlations, just switching the fluids proprieties to those of air and water. Besides that, now the treatment for the problem is isothermal, which means that the equation of energy is no longer solved for the flow.

The database had 791 experimental results, varying both water and air fluxes, as well as the pressure and temperature in the inlet of the tubing. Figure 4 shows the results of the experiments of Owen (1986). Clearly the method presented by Barbosa and Hewitt (2006) achieve better results in comparison with the others, but in to the results from the hypothetical scenario, now, the standard correlations of the industry got reasonably good results.

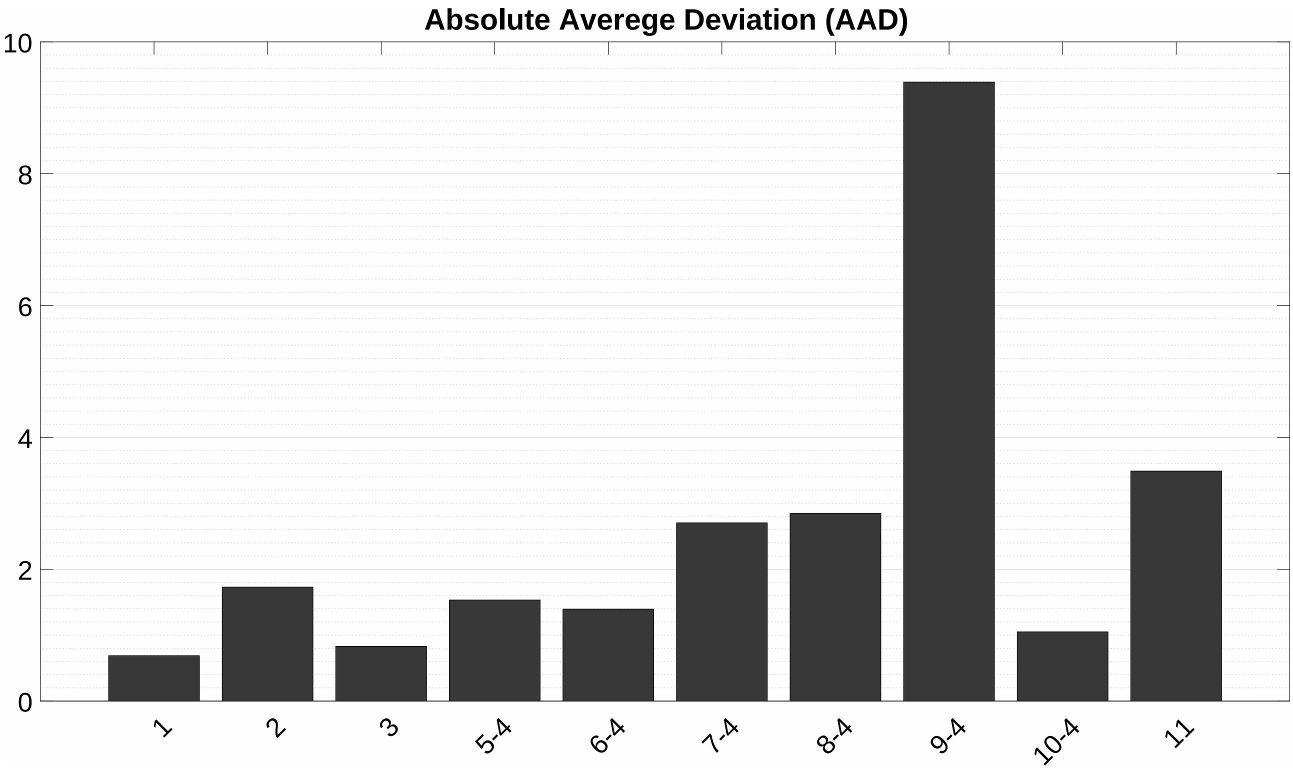

Figure 4. Pressure in the final parcel of the well

Table 3 shows some useful data to consider. First is the numerical values of the plot presented before, confirming the results visually presented, but mainly, the number of successful simulations for each correlation. It is clear that the phenomenological approach increases the instability of the solution, this happens in both the Barbosa & Hewitt and Petalas & Aziz approaches. In the case of the second it is clear that some problem occurred during the simulations (probably resulting from implementation errors), and this data (and implementation) is still being evaluated and revised in order to better understand why it performed so poorly. This point is of great importance for the suitability of correlation usage, they must be robust enough to face different scenarios while still describing the flow accurately. As expected the drift- flux correlations where more stable and achieved better ranking by number of simulations. It is good to notice that the Smith correlation achieved good result and worked the most times among all others.

Table 3. Summary of simulations

Row	RMS	AAD	Bias	Non-successful	Successful	Total	Percent
Barbosa & Hewitt	1,081895	0,689091	0,125136	114	677	791	85,59
Beggs & Brill	96,09352	1,729438	-0,35832	84	707	791	89,38
Hagedorn & Brwon	0,764843	0,830639	-0,75999	45	746	791	94,31
Chexal-Lellouche	37,11746	1,533679	-0,06019	29	762	791	96,33
Toshiba	96,06891	1,395692	-0,23264	43	748	791	94,56
Dix	98,22941	2,7031	0,249095	52	739	791	93,43
Rouhani	957,9607	2,849932	-1,92503	29	762	791	96,33
modified Dix	23010,61	9,390467	-7,62884	30	761	791	96,21
Smith	8,560377	1,04908	-0,38404	29	762	791	96,33
Petalas & Aziz	41,94206	3,489758	3,324693	583	208	791	26,30

4. CONCLUSION

As a preliminary conclusion of the results obtained so far it is clear that the industry's standard correlations have difficulties in the hypothetical scenario tested. The results presented in both the phenomenological approaches, Barbosa and Hewitt (2006) and Petalas and Aziz (2000) appear to be the most representative of the phenomena as their results fit the median result.

Analyzing the air-water results, on the other hand, it is clear that the correlation Petalas and Aziz (2000) is not properly working for the scenario proposed, more studies on why of this phenomena are occurring. But it is clear that Barbosa and

Hewitt (2006) is the best correlation for this situation, with better results and even acceptable number of stable simulations (more than 85% of successful runs).

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