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Calculation of Bottomhole Pressure in Two-Phase Wells Using Beggs and Brill Method: Sensitivity Analysis

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INFORMATION

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ABSTRACT

This paper presents a comprehensive workflow for calculating the pressure profile and liquid hold-up in two-phase wells using the Beggs and Brill method. The workflow includes estimation of velocities, flow regime transition and liquid hold-up calculation, potential energy gradient, frictional pressure gradient, and pressure gradient. Sensitivity analyses are performed to investigate the impact of gas-oil ratio, flux, borehole pressure, and fluid densities on the pressure profile and liquid hold-up. The analyses show that an increase in the gas-oil ratio is translated as a downward displacement of the flow regime transition, while increasing the flux at constant GOR increases the frictional energy differential pressure and displaces the flow regime conversion from intermittent to distributed. Increasing the borehole pressure displaces upwards the transition between flow regimes. Density changes have little effect on the frictional energy profile and a slight effect on the jump observed for the liquid hold-up. The workflow presented provides an accurate determination of the impact of various parameters on the pressure profile and liquid hold-up in two-phase wells using the Beggs and Brill method.

1. Introduction

The flow of wellbore fluids is a crucial aspect of oil and gas production. Understanding the behavior of two-phase flow in wells is essential for optimizing the efficiency of the extraction process. Two-phase flow refers to the simultaneous flow of gas and liquid in a wellbore. The flow regime is a qualitative description of the phase distribution and greatly affects several aspects of two-phase flow, such as slippage between phases and pressure gradient (Liao et al., 2003).

In this paper, a comprehensive workflow is presented for determining the pressure profile and liquid hold-up in two-phase wells using the Beggs and Brill method (Beggs and Brill, 1965; Beggs and Brill, 1969). The Beggs and Brill method is a widely used empirical method for calculating the pressure drop in gas-liquid flow in pipes. The workflow includes estimation of velocities, flow regime transition and liquid hold-up calculation, potential energy gradient, frictional pressure gradient, and pressure gradient (Alvarez et al., 2013).

Sensitivity analyses were performed to investigate the impact of various parameters on the pressure profile and liquid hold-up. These parameters include gas-oil ratio, flux, borehole pressure, and fluid densities (Liao et al., 2003; Beggs and Brill, 1965; Beggs and Brill, 1969; Alvarez et al., 2013). The analyses show that an increase in the gas-oil ratio results in a downward displacement of the flow regime transition. Increasing the flux at constant gas-oil ratio increases the frictional energy differential pressure and has nearly no effect on potential pressure. Increasing the borehole pressure displaces upwards the transition between flow regimes. Increasing gas density displaces upwards the transition between fluxes, while increasing the liquid density displaces it downward (Alvarez et al., 2013).

The workflow presented in this paper provides an accurate determination of the impact of various parameters on the pressure profile and liquid hold-up in two-phase wells using the Beggs and Brill method. Several research papers and conference proceedings were referred to in order to develop this comprehensive workflow (Liao et al., 2003; Beggs and Brill, 1965; Beggs and Brill, 1969; Alvarez et al., 2013).

Table 1. Used Parameters and values

Well and Reservoir Properties	Symbol	Input value
Oil influx (bbl/d)	q_o	2,000
Gas Influx (MMSCF/d)	q_g	1
Well Inclination (deg)	θ	90
Tubing Diameter (in)	dw	2.259
Tubing Relative Roughness	Ɛ	0.0006
Well length (ft)	WL	10,000
Borehole Temperature (degF)	T_bh	225
Surface Temperature (degF)	T_surf	175
Gas Standard Cond. Temperature (degF)	T_gsc	60
Borehole Pressure (psi)	P_bh	800
Gas Standard Cond. Pressure (psi)	P_gsc	14.7
Gas Specific Weight	Ɣg	0.71
Liquid API	API	30
Liquid viscosity (cp)	µl	2
Oil-Gas Surface Tension	Ɵgs	30

In conclusion, this paper provides a practical and effective approach to analyzing two-phase wells. By accurately calculating the pressure profile and liquid hold-up, it can help engineers and operators make informed decisions about drilling and production operations. Additionally, the sensitivity analyses conducted (Table 2-5) in this study provide valuable insights into the factors that impact these key parameters, further enhancing the usefulness of the workflow.

Table 2. Sensitivity Anaylsis was done using variable GOR

Properties	Input value
Gas Influx (MMSCF/d)	1
Gas-Oil-Ratio, GOR (min)	300
Gas-Oil-Ratio, GOR (max)	800

Table 3. Sensitivity Anaylsis was done using variable Flux

Properties	Input value
Gas-Oil-Ratio, GOR	500
Gas Influx (MMSCF/d) (minimum)	0.4
Gas Influx (MMSCF/d) (maximum)	2

Table 4. Sensitivity Anaylsis was done using variable Borehole Pressure

Properties	Input value
Borehole Pressure (psi) (minimum)	700
Borehole Pressure (psi) (maximum)	1500

2. Methodology

The workflow for estimating the velocities of gas-oil influx and tubing diameter involves several important steps. First, the flow regime transition and liquid hold-up calculation must be determined. Then, the potential energy gradient and frictional pressure gradient must be calculated. Additionally, the pressure gradient must be taken into account. It is important to note that the workflow assumes the kinetic component is negligible and that the pressure drop is due to potential and frictional pressure components. These calculations are essential for accurately determining the velocities of gas-oil influx and tubing diameter.

Table 5. Sensitivity Anaylsis was done using variable Borehole Pressure

Properties	Input Value	Properties	Input value
Gas specific weight	0.71	Liquid API	30
Gas specific weight	0.60	Liquid API	30
Gas specific weight	0.95	Liquid API	30
Gas specific weight	0.71	Liquid API	25
Gas specific weight	0.71	Liquid API	35

The workflow is a complex process that requires a deep understanding of fluid mechanics and mathematical analysis. However, the results of this analysis can be invaluable in predicting the behavior of fluid systems and optimizing their performance.

$$p_1 - p_2 = \frac{\rho}{2}\Delta u^2 + \rho g \Delta z + \frac{2\rho f_f u^2 L}{2r_w} \quad (1)$$

Based on the analysis, it can be assumed that the kinetic component is negligible and that the pressure drop can be attributed to a combination of potential and frictional pressure components. Further evaluation is required to determine the exact impact of these components on the pressure drop, and a more detailed analysis of the system can provide this information. It should be noted that the potential pressure component arises from the change in potential energy of the fluid as it moves through the system, while the frictional pressure component is a result of the interaction of the fluid with the walls of the system, which causes resistance to flow. By taking into account these factors, a more comprehensive understanding of the pressure drop and its underlying causes can be gained.

The steps:
Step 1. Estimate the velocities from gas-oil influx and tubing diameter
Step 2. Determine the flow regime transition and calculate the liquid hold-up
Step 3. Potential energy gradient
Step 4. Frictional pressure gradient
Step 5. Pressure gradient

3. Results and Discussion

Sensitivity analyses are performed to investigate the impact of gas-oil ratio, flux, borehole pressure, and fluid densities on the pressure profile and liquid hold-up. The analyses show that an increase in the gas-oil ratio is translated as a downward displacement of the flow regime transition. Increasing the flux at constant GOR increases the frictional energy differential pressure and has nearly no effect on potential pressure. Increasing the borehole pressure displaces upwards the transition between flow regimes. Increasing gas density displaces upwards the transition between fluxes, while increasing the liquid density displaces it downward.

The fluid is initially distributed and then becomes transitional along the well until reaching the surface. The process of the fluid becoming transitional is crucial to the efficiency of the flow regime. It is important to note that the flow regime has a significant impact on the liquid hold-up, which in turn affects the potential energy drop of the fluid. This change occurs along the pressure column with a slight reduction of slope as the fluid moves from one regime to the next. Furthermore, the transition regime experiences a continuous decreasing slope. It is essential to carefully monitor and analyze the flow regime in order to optimize the efficiency of the fluid distribution and ensure that the system is operating at its full potential.

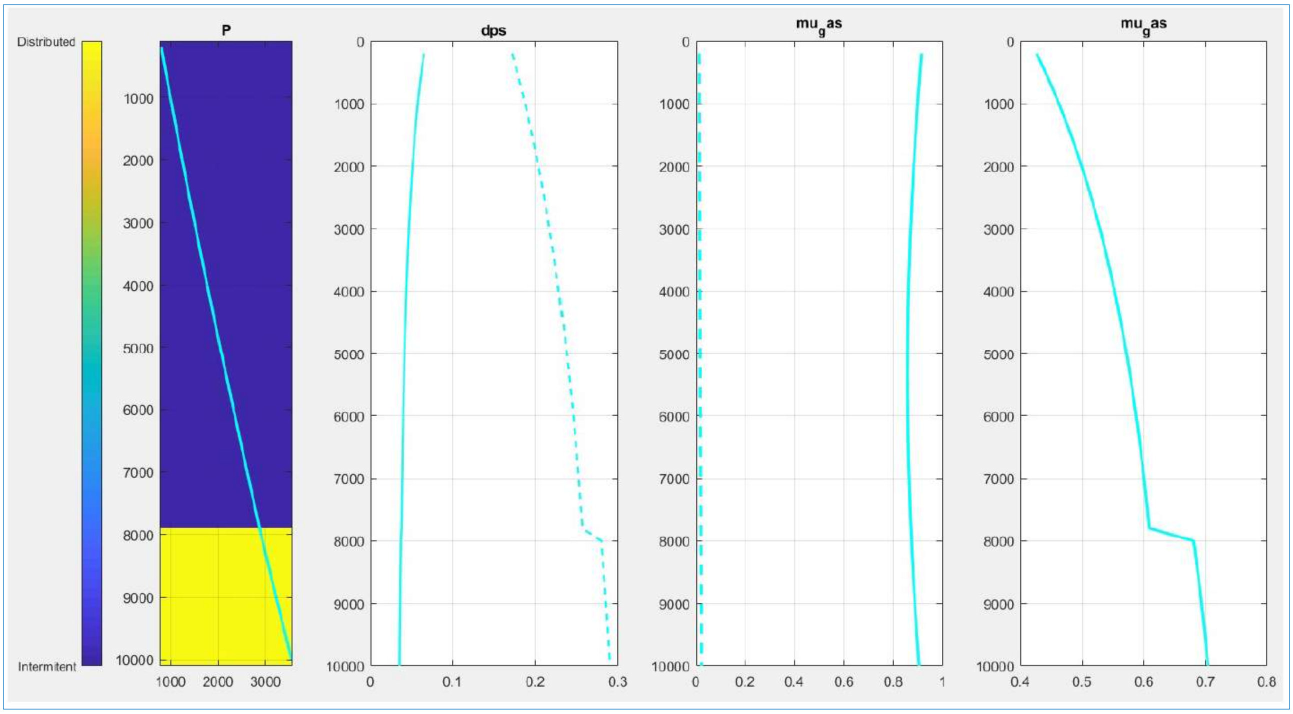

Fig. 1. Sample graph (Column 1: Color Code shows flow regime, Log shows Pressure gradient; Column 2: Continuous line is Frictional Pressure drop, Dotted Line is Potential Energy drop; Column 3: Continuous line is Viscosity, Dotted Line is Gas Compressibility; Column 4 shows Liquid Hold up)

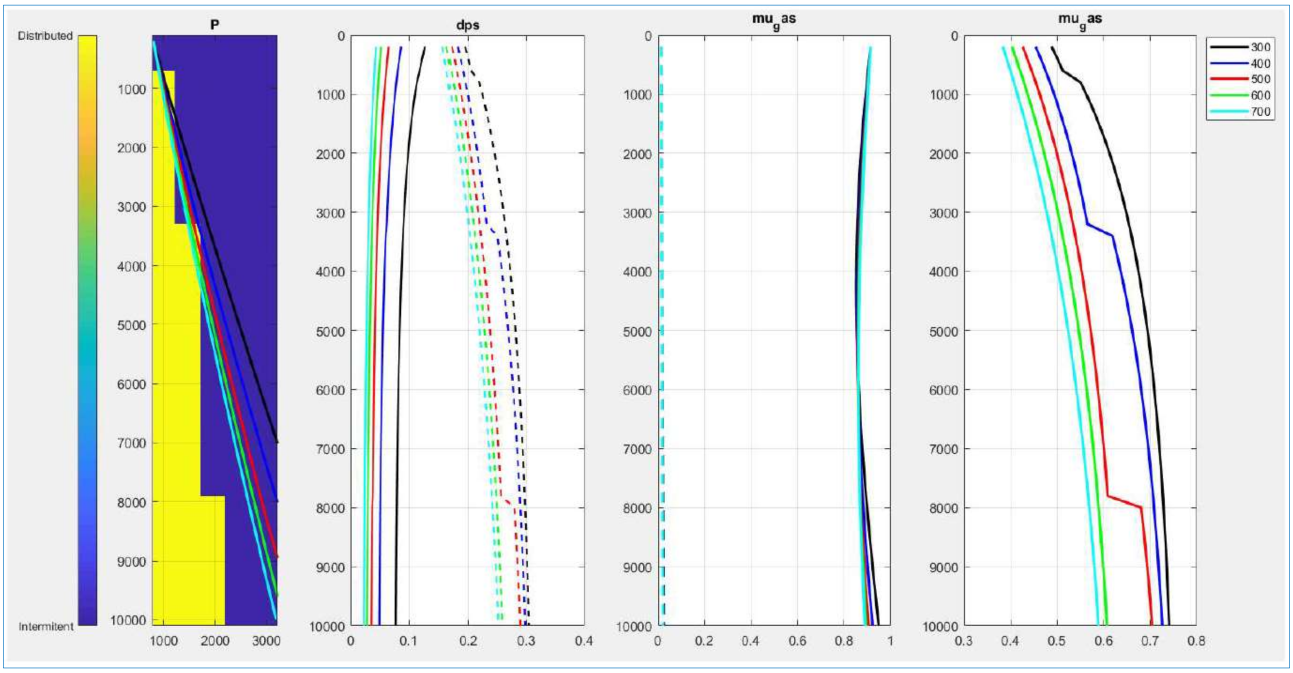

Fig. 2. Sensitivity Analysis on GOR

6.2. Structural Elements

Field observations show folds, foliations, fractures and micas parting discontinuities in the quartzite formation (Figs. 5a, b, c). Thin soil layers with gravelly sandy-clay composition, are found in the quartzite beds separating each quartzite bench from the other thus, forming a micas parting discontinuity (Figs. 5a, b, c).

The cloud of points obtained from the crests of the different folds shows an axial plane inclined by 30° with respect to the horizontal (Fig. 5c). It is also possible to observe some folds whose layers do not show any discontinuity visible at the macroscopic scale, but instead a foliation made up of an alternation of dark and light bands (Fig. 5c).

6.3. Direction and Dips

The mode of outcrop of the quartzite formation (in benches) facilitated the measurement of the different parameters in the field (directions and dips). The direction and dip data collected in the field (Table 1), were used to produce the rose diagram (Fig. 6a), with the relative points density from the 1% Area contouring methodology (Fig. 6b).

Table 1. Directions and dips

No	Directions (°E)	Dip	Transformed direction	Transformed dip	Dip orientation	Latitude	Longitude	Elevation (m)
1	29	25,0	119	65	WNW	3°51'31,72"	10°32'59,26"	2 07
2	25	20,0	115	70	WNW	3°51'31,55"	10°32'59,33"	207
3	20	25,0	110	65	WNW	3°51'335,007"	10°32'57,606"	179
4	70	22,0	160	68	NNW	3°51'34,57"	10°32'58,05"	193
5	26	30,0	116	60	WNW	3°51'34,52"	10°32'58,17"	192
6	51	18,0	141	72	NW	3°51'34,6"	10°32'57,93"	191
7	160	30,0	70	60	WSW	3°51'33,87"	10°32'59,76"	200
8	158	20,0	68	70	WSW	3°51'33,86"	10°32'59,74"	192
9	10	22,0	100	68	WNW	3°51'33,78"	10°32'59,76"	194
10	185	28,0	275	62	WNW	3°52'3,37"	10°33'25,22"	278
11	190	44,0	280	46	WNW	3°52'3,37"	10°33'25,12"	280
12	192	40,0	282	50	WNW	3°52'3,28"	10°33'25,14"	279

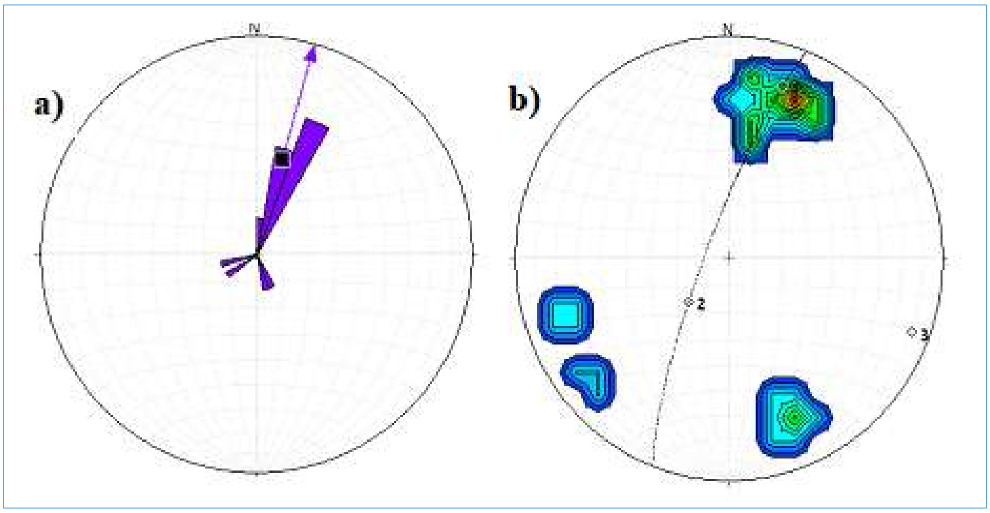

Fig. 6. Stereographic projection. a) Rose diagram; b) Stereogram densities (1% Area contouring)

The rose diagram has two major directions, one primary from N 21° to N 30° E and the other secondary from N 10° to N 21° E; the vector mean is N 15° E. The rose diagrams obtained from the lineaments (Fig. 4) suggest that, the lineaments are distributed in different directions, indicating that the study area has complex geological structures. Such lineaments are often formed due to tectonic stresses in the Earth's crust, and are commonly associated with faults or fractures such as the recumbent fold (Fig. 5c) (according to the folds grouping presented by Fluety (1964)) present in the study area. According to the stratigraphic principle of cross-cutting, the fractures observed at the quarry (Fig. 5) are post-metamorphic, since they cut the limbs of the inclined folds (which result from ductile deformation). The presence of recumbent folds (Fig. 5) in the study area, confirms the work of Jean-Lavenir et al. (2023) concerning the Cameroon Pan-African fold belt context of the Pouma Area.

4. Conclusion

In conclusion, the investigation of tectonic features in the Pan-African mobile belt of Pouma, Littoral-Cameroon, through a combination of remote sensing and fieldwork, has provided valuable insights into the geological history and structural complexity of the area. The presence of diverse lineament directions indicates the existence of complex geological structures within the study area. The predominant NE-SW orientation of the lineaments corroborates previous studies, suggesting the presence of a significant tectonic corridor running from Pouma in the Northeast to Campo in the Southwest, known as the Kribi-Campo Fault. Additionally, the identification of post-metamorphic fractures cutting through inclined folds confirms the presence of a Pan-African fold belt in the Pouma Area, aligning with previous research. These findings contribute to our understanding of the Neoproterozoic era and the tectonic processes that shaped the region. The results obtained from this study have important implications for both regional and global tectonic studies. They offer valuable insights into the geological evolution of the Pan-African mobile belt in Cameroon and provide a basis for further investigations in the area. The combination of remote sensing and fieldwork techniques has proven to be effective in characterizing tectonic features, enhancing our understanding of geological complexities and allowing for more accurate interpretations. It is evident that the tectonic history of the Pouma Region is complex and warrants further research and exploration. By continuing to investigate the geological structures and tectonic features of the area, we can gain a deeper understanding of the dynamic processes that have shaped the landscape over time. Overall, this study contributes to the broader field of tectonic studies, particularly in the context of the Pan-African mobile belt and its Neoproterozoic history. The findings emphasize the significance of integrating different methodologies and approaches to unravel the complex geological features of a given region. By building upon these findings, we can continue to expand our knowledge of the geological evolution and tectonic processes that have shaped our planet.

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Appendix

Python code for sensitivity analysis made in this paper.

```
import numpy as np
import matplotlib.pyplot as plt

def Z_g(T,tpc,P,ppc):
    pr = P / ppc
    tr = T / tpc
    A = 1.39 * ((tr - 0.92) ** 2) + (0.36 * tr) - 0.101
    B = (0.62 - 0.23 * tr) + (0.016 / (0.056 + (tr ** 2)))
    C = 0.132 - (0.32 * np.log10(tr))
    D = 10 ** (-0.45)
    Z = 1 + ((A * pr) / (tr ** B)) + (C * (pr ** D))
    return Z

def mu_g(gamma_g,T,P,Z_gas):
    ppc = 677 + 15 * gamma_g - 35.7 * gamma_g ** 2
    tpc = 168 + 325 * gamma_g - 12.5 * gamma_g ** 2
    Tr = T / tpc
    Pr = P / ppc
    A = (9.4 + 0.02 * gamma_g) * (Tr ** 1.5) / (T + 273.15)
    B = 3.0 + 0.02 * gamma_g - 0.0001 * gamma_g ** 2
    mu_g = 2.6693e-6 * ((T + 273.15) ** 0.68) * ((1 + A * Pr ** B) /
(Z_gas ** 0.75))
    return mu_g

def dpfunction(q_o, q_g, ang, rw, rough, T, T_gsc, P, p_gsc,
gamma_g, rho_l, Z_gas, mu_gas, mu_l, sigma_og):
    grav = 32.17  # acceleration due to gravity, ft/s^2
    rho_g = gamma_g * 62.43  # gas density, lb/ft^3
    rho_m = (1 - GOR / (GOR + 1)) * rho_l + (GOR / (GOR + 1))
* rho_g  # mixture density, lb/ft^3
    Q = q_o + q_g  # total flow rate, STB/d
    vel_m = Q / (86400 * 0.19635 * ((rw ** 2) * np.pi))  # average
mixture velocity, ft/s
    vel_g = q_g / (86400 * 0.19635 * ((rw ** 2) * np.pi) * rho_g)  #
gas superficial velocity, ft/s
    Re_m = (rho_m * vel_m * rw) / mu_l  # Reynolds number for
the mixture
    f_l = ((1 / ((1.82 * np.log10((rw / rough) + 1.1) ** 2)) - 2 *
np.log10(rough / (3.7 * rw) + (2.51 * (Re_m ** (-0.25))))) ** (-2))  #
friction factor for liquid
    f_t = ((1 / ((1.82 * np.log10((rw / rough) + 1.1) ** 2)) - 2 *
     np.log10(rough / (3.7 * rw) + (2.51 * (Re_m ** (-0.25))))) ** (-
     2)) * ((1 - sigma_og)
```