A NEW CHOKE CORRELATION TO PREDICT LIQUID FLOW RATE

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ABSTRACT: *Flow rate prediction is of prime importance for effectively managing and maintaining well productivity. Optimum flow rate prediction can prevent water/gas coning, sand entry, surface equipment problems and avoid formation damage due to imposing of excessive drawdown to reservoir. One of the most common wasy to achieve these goals is by controlling flow rate using wellhead chokes. The aim of this paper is to develop a new empirical Gilbert type correlation which is a function of flowing wellhead pressure, gas-liquid ratio and wellhead choke size. To achieve this, data from 1300 experimental production tests under multi-phase critical flow conditions from 120 Iranian offshore oil wells were used in a non-linear regression analysis. According to our results, predicted oil flow rates from new correlation are in excellent agreement with the observed data. Our results are also more accurate compared to those obtained from conventional methods. Furthermore, the accuracy of the proposed correlation was validated by cross plotting of synthetic and field data. The new correlation has an average relative deviation (ARD) of -0.18% and average absolute deviation (AAD) of 20.73%. The dataset covers a wide range of choke sizes (12/64 to 92/64 inches) and PVT parameters. Therefore, it is applicable in many Middle Eastern offshore oil wells mounted on satellite platforms where difficulties arise while performing productivity tests.*

Keywords: Choke Size, Multi-Phase Flow, Gas-liquid Ratio, Wellhead Pressure

INTRODUCTION

The main objectives for wellhead chokes either fixed or adjustable are about to protect surface facilities from slugging, avoid sand production where drawdown is too high and restricting flow rate and causing back-pressure in flow line to prevent gas channeling and water coning.

In order to achieve these objectives, production engineer needs to calculate reservoir deliverability for optimum exploitation. Estimating reservoir productivity also requires production test and well parameters measurements. This could be reached by flowing the well at several flow rates to measure the bottomhole pressure at stabilized condition before any change in choke size is accrued. Based on the flow regimes and also gas fraction in the fluid, two choke flow models can be detected, sonic (critical) or subsonic (sub-critical) flow. In sonic flow condition which stabilizes the flow rate, fluid is traveling in the opposite direction at the same velocity, so the pressure wave downstream of the choke cannot go upstream through the choke. Therefore, a pressure discontinuity exists at the choke and any change in the downstream pressure cannot be detected from the upstream pressure gauge and vice versa. [1]

Recent studies in fluid mechanics have changed the idea of independence of the flowing rate to the downstream pressure changes in sonic flow. Experimental evidences show if the ratio of downstream to the upstream pressure is about 0.55-0.6, the flow model is sonic and would be subsonic if the value fall above that mentioned value. [2] One can correlate relation between pressure drop across the chokes for each type of production fluids (i.e. Single-Phase Liquid Flow, Single-Phase Gas Flow, and Multiphase Flow). The object of this paper is to generate an equation based on data of an Iranian offshore oil field. The behavior of the wells in this field is Multiphase Flow-sonic.

Previous Works

Tangren et al. [3] in 1949 presented and generalized an expression for a gas-water mixture through chokes in which the liquid is the continuous phase. Gilbert [4] in 1954 derived a correlation with four variables from 268 production tests related to the bean sizes selected between 6/64 to 18/64 inches. It applies for tubing pressures at least 70 percent greater than the line pressure with the assumption of that actual mixture velocities through the bean exceed the speed of sound. Baxendell [5] in 1958 also updated the Gilbert's Correlation with 50 field production tests. Ros [6] in 1960 studied simultaneous flow of gas and liquid through a restriction and correlated a relationship between the mass flows of gas and liquid, restriction size and upstream pressure provided that the flow is a critical one. Achong [7] in 1961 updated Gilbert's relationship on the basis of data from oil wells in the Lake Maracaibo field of Venezuela. Poetmann [8] et al. in 1963 created a graphical model to predict the flow rate through the chokes by using 108 filed production test data; with choke size range of 4/64 to 28/64 inches and flow rates of 10 to 1300 STBD. Omana et al. [9] in 1969 used the results of field experiments with natural gas and water flowing through a choke in a vertical position. Their formula gives the reliable results in an upstream pressure range of 400 to 1000 psig, maximum liquid flow rate of 800 STBD and bean sizes from 4/64 to 14/64 inches. Fortunate [10] in 1972, developed two correlations for critical and subcritical flow regimes. The attribution of Afshord and Pierce's study [11] in 1975 was the subcritical flow regime. Osman and Dokla [12] in 1988 developed four empirical correlations to characterize the behavior of gas condensate flow through chokes. Their data, ranges from 28/64 to 72/64 inches for choke size, with maximum flow rate of 1300 STBD. Their correlation gives better results when using pressure drop data instead of choke upstream pressure in the correlation.

Data

About 1500 production tests, performed during several years in producing life of a Middle Eastern offshore oil field with more than 120 producing wells were utilized to correlate an equation predicting liquid flow rates as a function of choke size, wellhead pressure and gas liquid ratio. Of these, some tests exhibiting subcritical and two phase flow conditions, were removed. Knowing the fact that the wells have approximately the same producing behavior in a formation, gives us the chance of getting more accurate results with this number of test data. Moreover, the data base contains wide range of choke sizes, flow rates and fluid properties, to cover all possible conditions in the future, so the formula was presented in present work can be a good approximation of the reservoir in later literatures.

Table 1 presents a summary of flow parameters for both critical and subcritical flow data and the range of these variables. Moreover, Tables 2 and 3, show the fluid properties of desired reservoir.

Table 1 Production test data ranges

Parameter	Minimum	Maximum
WHP, psig	103	1120
Choke Size, in	12	92
GLR, SCF/STB	12	30782
Flow Rate, STBD	110	11200

Table 2 Range of fluid properties for analytical correlation

Properties	Early Times in Production History	Present Status
Bubble Point, psi	1388	1388
Bg, CF/SCF	0.00957	0.013
Bo, bbl/STB	1.21	1.99
Solution GOR, SCF/STB	374	324
Producing GOR, CF/STB	460	645
API	26.5	25.8
Oil Viscosity, cp	3.2	3.07
Oil Temperature,° F @2800 ftss	126	126

Table 3 Formation water specification

Properties	Present Status
Total Salinity of Formation Water , gr/l	201.3
Water Formation Volume Factor, Bw , bbl/STB	1.0018
Water Compressibility, Cw , 1/psi	3.26E-06
Water Viscosity, cp	0.9538

Presentation of the Model

Our objective is updating the coefficients of Gilbert correlation [4] based on new filed data. So as a general form:

$$q_l = \psi(P, GLR, D_c) \qquad (1)$$

The aim of this study is to find ψ that minimizes the average absolute deviation. To find this, four of P, q_l, GLR and D_c went into regression analysis and finally this function was selected:

$$q_l = \frac{P_{wh}^{a} * D_{choke}^{b}}{c * GLR^{d}} \qquad (2)$$

Where $a = 0.9383$, $b = 1.7137$, $c = 7.8337$ and $d = 0.3636$.

In this equation, P is the upstream well head pressure in psig, q_l the liquid flow rate in bpd, GLR the gas liquid ratio in scf/stb and D_c the choke size in 1/64 of inches.

Results and Discussion

Table 4 illustrates the relative accuracy of different correlations based on statistical error analysis. The accuracy of a correlation can be more adequately evaluated in terms of AAD than by ARD, because the latter may appear small due to the cancellation of positive and negative deviations; whereas with AAD, the negative values of deviation will be converted into absolute values. The lower the AAD value, the higher is the accuracy of the correlation. It is clear that the new empirical model outperforms previous correlations for our samples. The proposed model has an ARD of -0.18%, AAD of 20.73% and RMSE of 26.68%.

Table 4 Statistical analysis of the different correlations

Errors%	Gilb.	Bax.	Ros	Ach.	This Study
AAD	28.02	23.33	23.52	27.69	20.73
ARD	-21.94	-4.32	-9.96	8.24	-0.18
RSME	32.41	29.98	29.36	37.67	26.68

Table 5 Results of flow rates calculated from each correlation

Sample No.	1	2	3	4	5
Measured liquid flow rate, STBD	684	2198	3293	2368	7400
WHP, psig	412	667	412	382	377
Choke Size, 1/64 inches	16	28	32	48	72
GLR, SCF/STB	307	651	677	1389	216
Liquid flow rate from Gilbert, STB	341	1055	821	1106	6484
Liquid flow rate Baxendell, STB	399	1262	987	1351	8055
Liquid flow rate from Ros, STB	346	1177	931	1356	7630
Liquid flow rate Achong, STB	477	1358	1051	1309	9276
Liquid flow rate from this study, STB	523	1633	1287	1850	7200

From the perspective of comparison, five test data were selected randomly and flow rates calculated from each correlation were gathered in Table 5. It shows that the

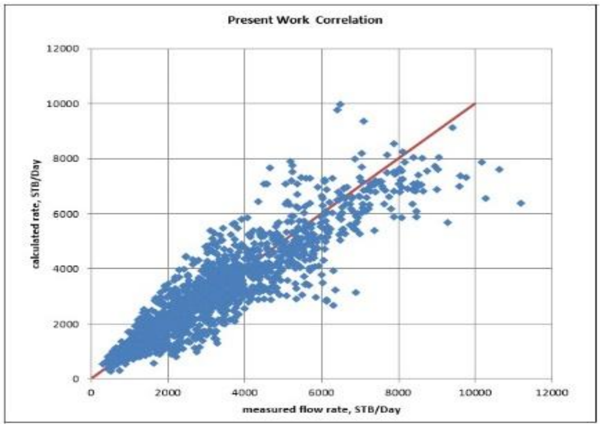


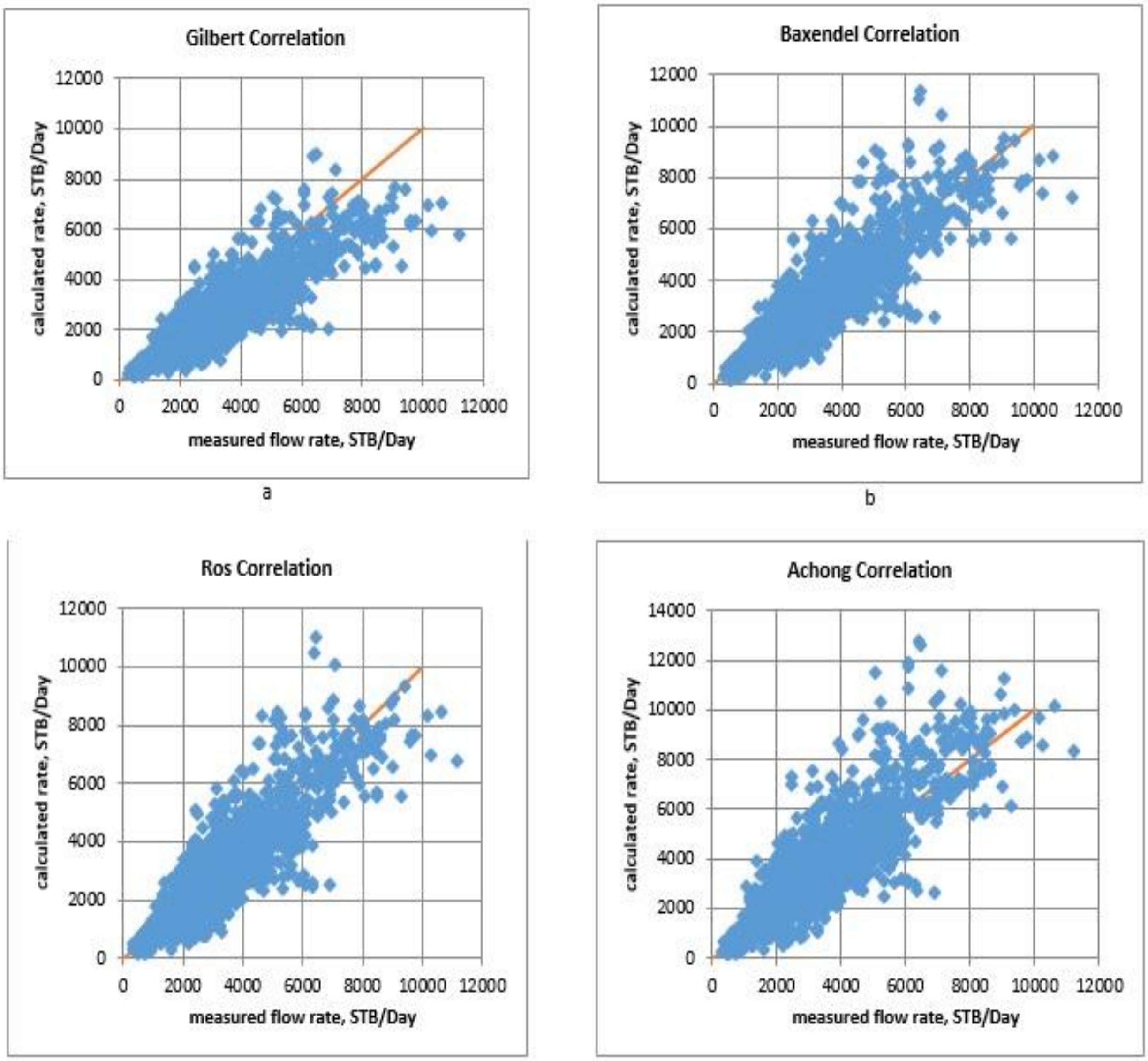
Fig. 1 Calculated vs. measured flow rate and y=x line

empirical correlation derived in present work closely matches the experimental data.

Validation of the New Correlation

For more validation, in Fig. 1 the accuracy of the correlation was determined in a cross plot containing measured flow rates versus calculated flow rates. The closer the plotted data points to the 45° straight line drawn on the cross plot of these values, the more accurate is the correlation.

Also, similar plots related to the four mentioned correlations have been given. As indicated in Fig. 2 at first look, one can easily recognize that data plotted in mentioned figure are scattered (Ros & Baxendell) or under/over-estimated (Gilbert/Achong) rather than that of in present work.



a b

c d

Fig. 2 Flow rate prediction of correlations in literature: a) Gilbert b) Baxendell c) Ros d) Achong

CONCLUSIONS AND RECOMMENDATIONS

1) Due to inaccuracy of results obtained by the existing correlations, attempts were made to propose an empirical correlation to predict multi-phase flow as a function of gas-liquid ratio, wellhead pressure and choke size.
2) Statistical and graphical analyses were used to compare the results arisen by the new correlation with similar existing correlations in the literature. This comparison demonstrated that the least errors in percentage and high precise results have been achieved with the new correlation rather than with Gilbert, Ros, Achong and Baxendell (only 20.63% deviation in AAD, whereas others have more than 23%)
3) This new correlation could be used to wide range of flow conditions and also in the case of offshore oil wells mounted on satellite platforms where the measurement of flow rates is difficult.

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Nomenclature

AAD: Average absolute deviation= $\sum(abs|(q_c - q_o)/q_o|)/N$

ARD: Average relative deviation= $\sum((q_c - q_o)/q_o)/N$

GLR: Gas- liquid ratio (scf/stb)

P: Well head pressure (psig)

q_C: calculated flow rate (STB/Day)

q_l: Liquid flow rate (bpd)

q_0: Observed flow rate (STB/Day)

$RSME$: Relative mean square error= $\sqrt{\frac{1}{N}\sum((q_c - q_o)/q_o)^2}$