APPLICABILITY OF GENERAL GILBERT TYPE CORRELATION FOR IRANIAN GAS CONDENSATE WELLS

Mojtaba Golshadi[1]*, Abbas Shahrabadi[2], Mohamad Mallahi[3], Mohammad Golshadi[4]
1,2-Islamic Azad University, mahshahr Branch , IRAN.
3-South Zagros Oil and Gas Production Company, Iranian Central Oil Fields Co. (ICOFC), National Iranian Oil Co. (NIOC), Shiraz, IRAN..
4- Petroleum university of technology (PUT) , Ahwaz , IRAN.
Corresponding Author's E-Mail: golshadi.m@gmail.com

ABSTRACT

Wellhead chokes are special equipment that widely used in the petroleum industry to control flow rate from wells. Two types of gas–liquid flow can exist in a choke; critical and sub-critical flow. Field data of 29 wells producing from 3 gas condensate reservoir located in Iran were used to develop a general Gilbert type formula obtained by non-linear regression of data points for gas condensate wells. The present study develop a general Gilbert type formula for gas condensate wells, flowing through different choke sizes between 30/64 in. and 192/64 in. under subcritical flow conditions in order to develop empirical correlations to be applied to predict gas flow rates under wide range of flow conditions usually encountered during the flow of gas condensates through wellhead chokes in wells.

A comparison between the measured data and observed data is done with five different errors parameters.

The results of this study could be considered in the design and implementation of deliverability tests, pressure transient tests, well control, and long-term well production of high rate gas condensates wells.

NOMENCLATURE

a	Choke size exponent
b	Gas–liquid ratio exponent, Eq. (1)
b'	Gas–liquid ratio exponent, Eq. (2)
C	Empirical constant, Eq. (1)
C'	Empirical constant, Eq. (2)
Pu	Upstream (wellhead) pressure, psia
Pd	Downstream pressure from choke, psia
ΔP	Pressure differential across choke, psia
Q	Gross liquid rate, Stb/D
Qg	Gas flow rate, MMScf/D
R	Gas–liquid ratio, MScf/Stb
S	Choke size, 1/64 in

INTRODUCTION:

Almost all flowing wells include some form of surface restriction to regulate the flow rate. Typically, a well has a surface choke placed immediately following the wellhead. On offshore wells, a storm choke is upstream of the wellhead beneath the mud line.

Positive and adjustable chokes are the two general types of chokes used on wells.

Reasons for installing chokes in the production system include to:

• Protect the reservoir and surface equipment from pressure fluctuation.
• Maintain stable pressure downstream of the choke for processing equipment.
• Provide the necessary backpressure on a reservoir to avoid formation damage and prevent sand from entering the wellbore.
• Prevent gas or water coning.
• Control flow rates and maintain well allowable.
• Produce the reservoir at the most effective rate.

Flow through a surface choke can be either critical or subcritical.

Critical flow occurs when the velocity through the choke is greater than the sonic velocity of the fluid. This results in a mach number for the fluid that is greater than or equal to one.

For fluids with a velocity greater than sonic velocity, any downstream perturbation is unable to propagate upstream and the mass flow rate through the choke is solely a function of the upstream parameters.

Choke correlations

Critical Flow Correlations. Tangren et.al.[1] developed an equation of state and one of motion for gas-water mixture flowing through a “de Laval” nozzle, assuming an incompressible liquid, an ideal gas, a homogeneous mixture, no mass transfer between phases, isothermal, adiabatic, and one- dimensional laminar flow. A few gas-water experiments at critical flow conditions were run. The significance of the Tangren approach was to show that when gas bubbles are added to an incompressible liquid, the mixture becomes compressible and above the critical flow velocity, the medium becomes incapable of transmitting pressure changes against the flow. Gilbert[2] presented an approximated solution for critical flow through chokes based on regularly reported well production data. He also gave a detailed description of the role of chokes in wells and the interactive use of flowing gradient curves with choke performance curves based on his equation.

Gilbert made no attempt to study cases where the upstream pressure was less than “1.7” times the downstream pressure. He stated that below this level, well performance is sensitive to line pressure (subcritical flow). He also cautioned that small errors in bean size can cause up to a 20% error in the desired upstream pressure. Baxendell [3], Ros [4] and Achong [5], published revised forms of the equation proposed by Gilbert [2] using updated coefficients based on additional data from different oil fields. Ros [6] extended the work of Tangren et.al. [1] to higher gas liquid ratios where gas was the continuous phase. Basically, Ros also considered a uniform throat velocity but objected Tangren’s assumption of the homogeneous model. The main assumptions in Ros development are; polytropic gas expansion, negligible potential energy and irreversible losses, except those due to slippage. He stated that “when mist flow occurs in the restriction, any liquid film on the wall would be negligibly small, liquid dispersion occurs at the entry of the restriction, liquid droplets are accelerated by the higher gas velocity, slippage at the end of the throat can be neglected and the wall friction can be ignored if the restriction is short”. Poettmann and Beck [7] presented a more usable form of the original Ros [6] equation. They converted Ros’ equation to oil field units and presented a series of working curves for a gas gravity of “0.6” and for three different API gravities. They compared their charts to “108” field tests and predicted production rates to an average error of +6.5% and SD of “26.4”. Omana et.al. [8] obtained critical and subcritical flow data through wellhead chokes in an experimental facility of Union Oil Company of California’s Tiger Lagon Field. The field experiments were conducted with water and natural gas. The tests included “35” liquid, “24” gas and “47” two-phase flow tests and covered wide ranges of flow rate, choke size and pressure. A dimensional analysis was performed that yielded eight dimensionless groups. A regression analysis was performed on the critical flow data that yielded an empirical correlation involving five dimensionless groups. Using his critical flow data, Omana [8] compared his correlation with those of Ros [6] and Gilbert [2],then he claimed that his correlation gives better results than others. Ashford [9] presented a study which was strictly for critical flow through chokes. Assuming polytropic expansion of the gas phase, critical flow occurs at a pressure ratio of “0.544” and a specific heat ratio of “1.04” prevails. He developed an equation for predicting the oil flow rate through a choke. Using field data from “14” flowing well tests, he calculated discharge coefficients necessary to reproduce the field data. Calculated discharge coefficients ranged from “0.642” to “1.218” for choke sizes ranging from 16/64thto 40/64th of an inch. Ashford [9] claimed that his discharge coefficients were approximately equal to “1.0”. Al-Attar and Abdul-Majeed [10] made a comparison of existing choke flow models using “155” well tests from the East Baghdad Oil Field. They concluded that the best overall comparison was obtained with the Gilbert correlation which predicted measured production rate within an average error of 6.19%.

Subcritical Flow Correlations. Very little work has been done on subcritical two-phase through restrictions. Fortunati [11] presented a correlation for subcritical flow that drew heavily from the work of Guzhov and Medviediev [12]. No experimental work was included. Fortunati stated that while critical flow for gas occurs when $p_2/p_1 = 0.5$, the critical pressure ratio for two-phase systems can be as low as “0.225” and is highly dependent on λg , the no-slip gas hold-up. He agreed with earlier investigators that no-slippage occurs at the throat of a choke. Fortunati’s analysis is based completely on adownstream pressure of approximately “20” psia. However, Guzhov and Medviediev presented a way to extrapolate the results to higher pressures. Fortunati’s study was applied to “250” field cases. The calculated discharge coefficients agreed well with the range of 1.06 ± 0.12 of those predicted by Ros[6]. Ashford and Pierce [13] extended the theory of Ros [6] and developed an equation for subcritical flow through restrictions. Experiments were run on a flowing well 12,000 ft deep with an Otis J type “22J037” subsurface valve located at 3500 ft to act

as an orifice. Three bean sizes were considered:14/64th, 16/64th , and 20/64thof an inch. Pressure bombs were located as close above and below the valve as possible.
Considerable difficulties were reported in obtaining reliable data, and discharge coefficients necessary to match measured and theoretical rates showed considerable scatter. The subcritical flow equation was used to prepare several plots of p 2 /p 1 vs.
Q o with p 1 as a correlating parameter. Sachdeva et. al. [14] presented a model developed to solve the mass flow rate through a choke for both subcritical and critical conditions. This model has also been verified against multiphase experiments. Perkins [15] presented an approach for finding the critical pressure ratio and the mass flow rate in much the same way as the model by Sachdeva et. al. [14]. Perkins [15] included the three-phase effects for the polytropic expansion exponent and also found the mixture average velocity at the throat. Guo et. al. [16] evaluated the accuracy of the Sachdeva's model using data from oil and gas condensate wells in Southwest Louisiana. Comparisons of the results from model and field measurements indicated that Sachdeva's choke model generally under-estimates gas and condensate flow rates. Guo et. al. [16] found that the error of the model could be minimized using different values of choke discharge coefficient. Al-Attar [17] developed a new empirical method to predict choke performance under sub-critical flow conditions of gas condensates. Nasriani[18] apply this method and presented 3 experimental constant for 15 gas condensate wells in Iran.
Al-Attar [17] used production data of three wells producing from a gas condensate reservoir located in the Middle East. The ranges covered by the all various flow parameters such as gas flow rate and choke size were up to 43.7 MMSCFD and 128 of 64th in. respectively.
Flowing data indicated sub-critical flow conditions through choke in all tests. All data points were subdivided into eight sets representing eight different choke sizes; 30/64 in., 45/64 in., 48/64 in., 56/64 in., 69/64 in., 96/64 in., 112/64 in., and 192/64 in.
For each choke size, a plot of (Pu-Pd) /Qg versus R on log–log scale graph paper was prepared and, irrespective of the choke size, the data points constantly lined up on a straight line with a negative slope.
The clear trend of these plots is thus a characteristic of sub-critical flow conditions for the test data points considered in that study, and mathematically takes the following form.

$$Q_g = (1/C')\Delta P\ R^{b'} \qquad (1)$$

Where C 'and b' are empirical constants and function of the choke size.
The approach has been found superior to the application of non-linear regression analysis on a modified version of the Gilbert-type formula. He recommended to verify the accuracy of his new approach with more field data representing subcritical flow of gas condensate in chokes.
The present study determines a new Gilbert type correlation for Iranian gas condensate reservoirs using non-linear regression. A comparison between the measured data and observed data is done with five different errors parameters.

RESULTS AND DISCUSSION

The ratio between the upstream pressure and downstream from choke (P_u /P_d) of each test is found to be less than 2.0, indicating sub-critical flow conditions through choke in all tests. Consequently, and in an attempt to correlate the flow parameters, the data points were subdivided into seven sets representing eight different choke sizes; 30/64 in., 45/64 in., 48/64 in., 56/64 in., 69/64 in., 96/64 in., and 192/64 in.
The number of data points for each set is listed in Table 1.

Table 1
Number of field tests per choke size

Choke size (1/64 in.)	No. of field tests
30	25
45	6
48	35
56	5
69	8
96	23
192	42
Total	144

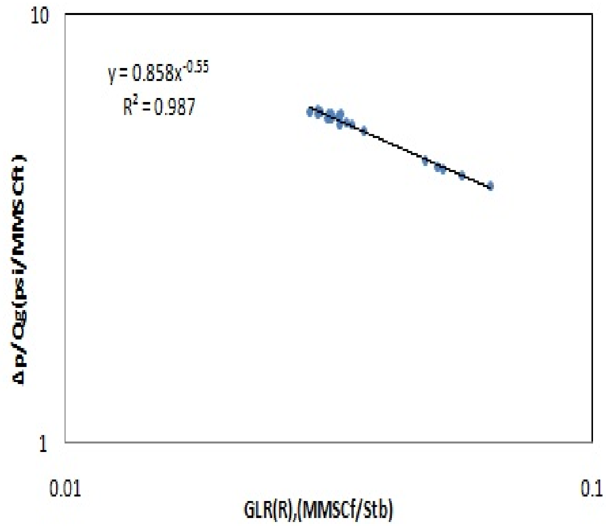

Fig. 1.
Data plot for S=96/64 in.

For each choke size, plot of (P_u -P_d)/ Q_g versus R on log–log scale graph paper was prepared and, irrespective of the choke size, the data points constantly lined up on a straight line with a negative slope. The results of these plots are shown in Figs. 1–4. For choke size 96/64in. 56/64in. 192/64in. and 69/64, respectively.

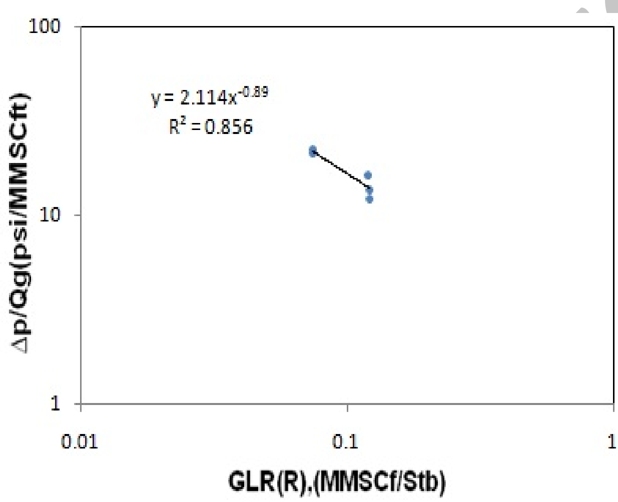

Fig. 2.
Data plot for S=56/64 in.

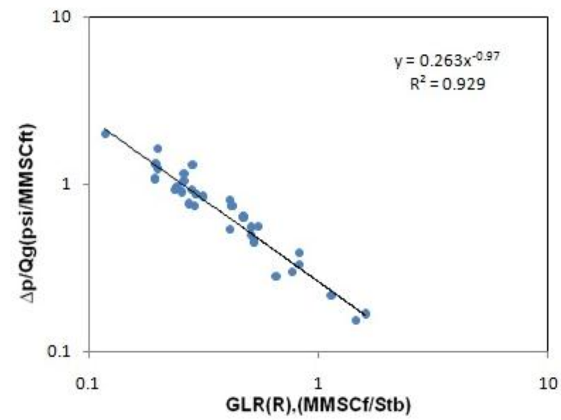

Fig. 3.
Data plot for S=192/64 in.

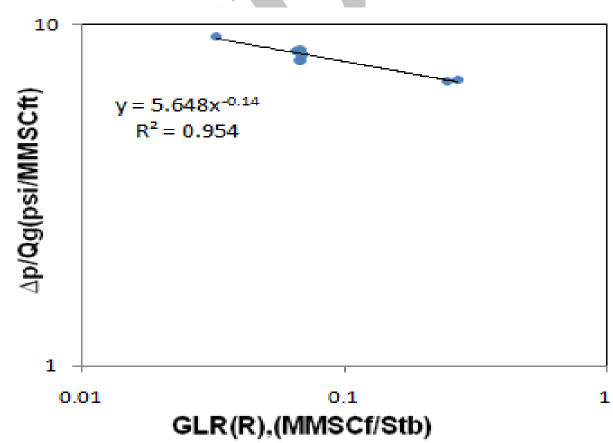

Fig.4.
Data plot for S=69/64 in.

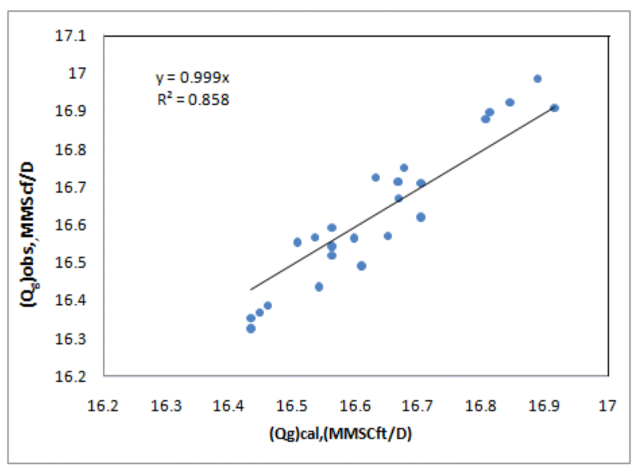

Fig.5.
Comparison between measured and predicted gas flow rates; S= 30/64 in.

The applicability of Non-Linear Regression Analysis technique to 3Iranian gas condensate reservoirs was evaluated using 144 data points from 29 wells. Typical samples of the collected data are shown in Table 2, and the ranges covered by the various flow parameters of these tests are listed in Table 3.

Table 2.
Typical Sample of field tests

Choke Size (S) 1/64 in.	Pressure Drop (Pu-Pd) , Psi	Gas Flow Rate (Qg) MMScf/D	Gas Liquid Ratio (R) MScf/Stb
30	787.9	19.9	68.2
45	279.3	16.3	78
48	580.6	23.6	64.8
56	558.6	45.9	121
69	367.5	46.9	68.5
96	364.5	62.6	31.7
192	102.9	100.1	213.4

Table 3 .
Ranges of flow parameters covered in this study

Flow Parameter	Minimum Value	Maximum Value
Choke size (S)	30	192
Pressure drop (Pu-Pd)	14.69	1470
Upstream pressure (Pu)	1087	3256
Downstream pressure (Pd)	961	1881
Gas Liquid Ratio (R)	29	825
Gas flow rate (Qg)	16.43	109.00
Wellhead flowing temperature(T)	106	176

The General form of multiphase flow through chokes can be written as:

$$Q_g = (1/CR^b)\Delta P\ S^a \qquad (2)$$

Where C is constant and a and b are exponents to be determined from field data using non-linear regression analysis technique, ΔP, Pressure differential across choke, psia ,Qg Gas flow rate, MMScf/D, R, Gas–liquid ratio, MScf/Stb and S Choke size, 1/64 in.
Non-linear regression analysis was applied to each choke size and all test data points and using Excel sheets solver determining the values of the empirical constants in Eq. (2). The values of the empirical constants for each choke size are listed in Table4.

Table 4 .
The values of the empirical constants for various choke size.

Choke Size (S) 1/64 in.	a	b	C
30	2.042074	-0.45563	331209.5
45	2.052824	-0.47107	331209.5
48	2.013019	-0.40766	331209.5
56	1.396749	-0.93214	331209.5
69	2.35573	-0.15101	331209.5
96	1.97098	-0.56674	331209.5
192	1.385368	-0.97821	331209.5
All data points	2.054573988	-0.35602	331208.9

The obtained empirical constant and exponents for all test data points were 331208.9, 2.054573988, and -0.35602for C,a, and b, respectively, and Eq. (3) can be written as follows.

$$Q_g = (1/331208.94R^{-0.35602})\Delta P\ S^{2.054573988} \qquad (3)$$

Comparisons between observed and calculated gas flow rates of the various choke sizes using non-linear regression analysis are presented in Figs. 5–11. The overall comparison of all test data points is presented in Fig. 12

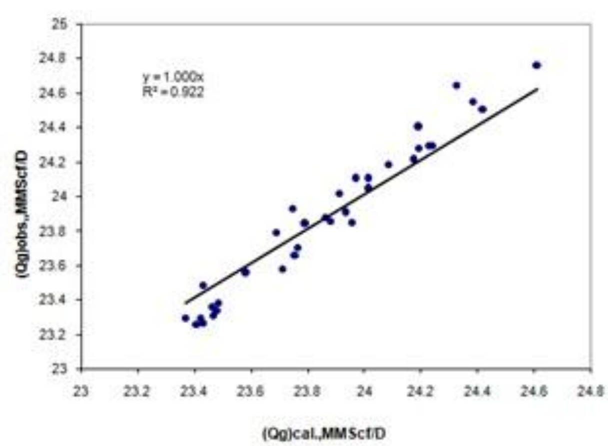

Fig.6.
Comparison between measured and predicted gas flow rates; S=45/64 in.

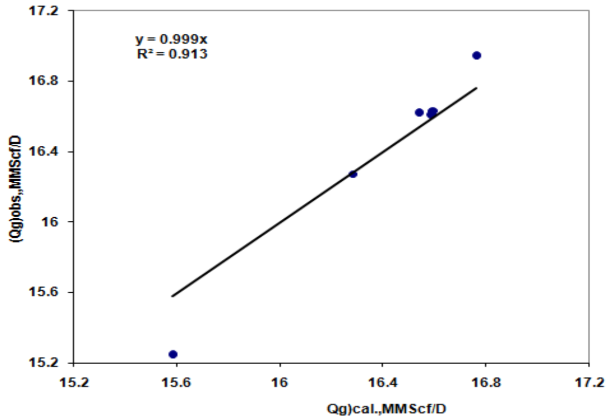

Fig.7.
Comparison between measured and predicted gas flow rates; S=48/64 in.

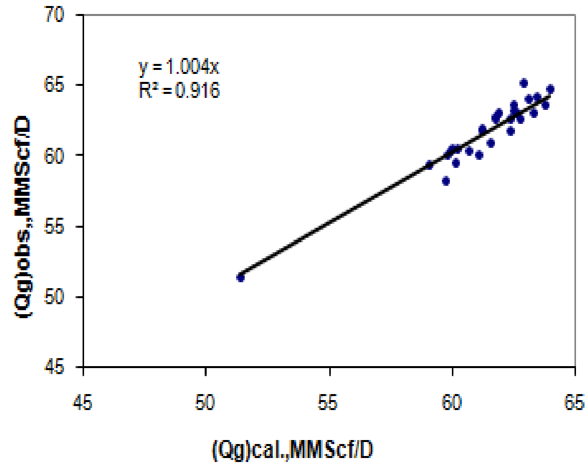

Fig. 10.
Comparison between measured and predicted gas flow rates; S= 96/64 in.

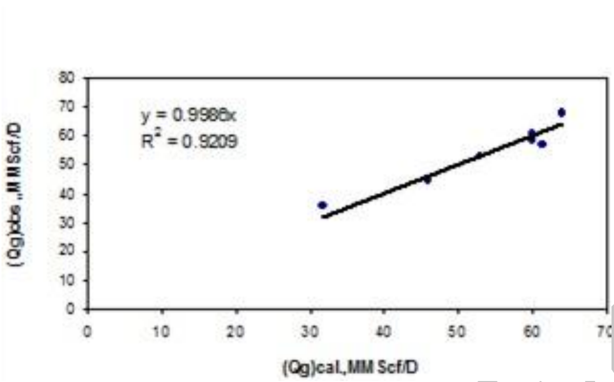

Fig.8.
Comparison between measured and predicted gas flow rates; S=56/64 in.

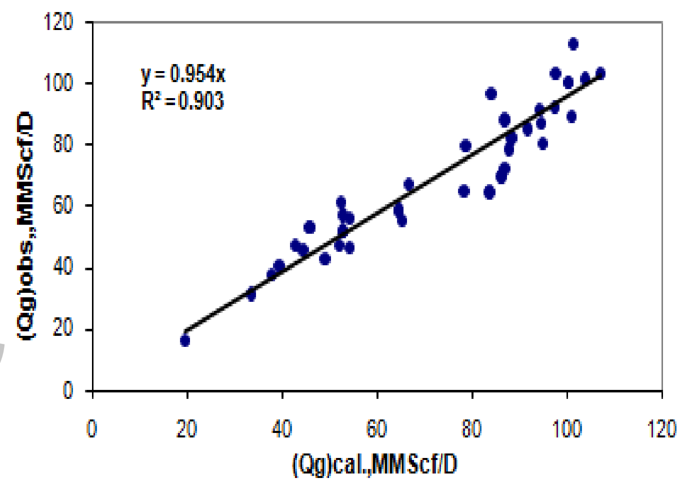

Fig. 11.
Comparison between measured and predicted gas flow rates; S= 192/64 in.

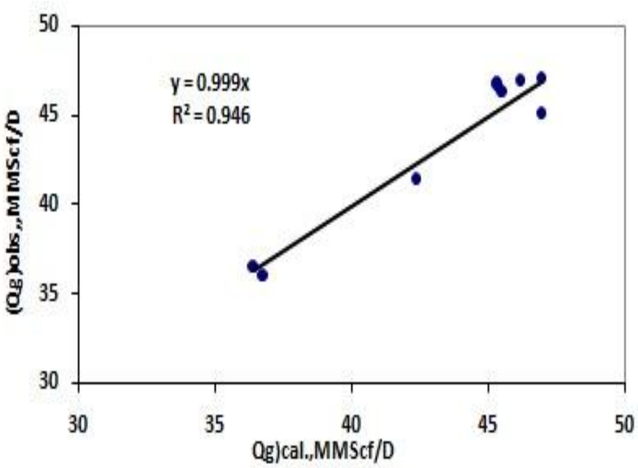

Fig. 9.
Comparison between measured and predicted gas flow rates; S= 69/64.

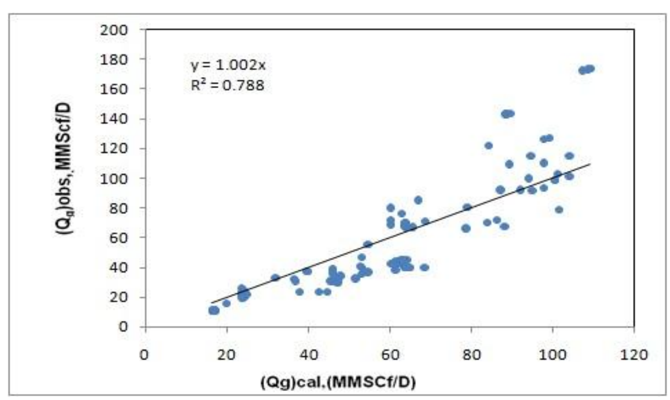

Fig. 12.
Comparison between measured and predicted gas flow ratesfor all data; based on non-linear regression analysis (Eq. (3)).

Accuracy of each technique is evaluated for gas condensate wells with five different error parameters. Using five statistical measures, namely, root mean square error, mean absolute error, simple mean error, mean percent absolute error, and mean percent error, the gas flow rates predicted by Eq. (3), and the results are listed in Table 5.

Table5.
Comparison between results of present approach and Non Linear Regression Analysis approach for all data points.

Statistical measure	Non-linear regression analysis (Eq. (3))
Root mean square error	8.882285
Mean absolute error	8.523591
Simple mean error	8.523591
Mean percent absolute error	0.419444045
mean percentage error	0.356677901

CONCLUSIONS

Based on the case studies conducted using 151 data points from Iranian gas condensate fields, Non-Linear Regression Analysis technique is accurate for predicting behavior of the subcritical flow of gas condensates in wellhead chokes.

A new empirical correlation can help engineers for controlling gas-condensate production and predicting the performance of flowing wells under different conditions.

The correlations was verified with151 data points from3 gas-condensate reservoirs in Iran. The data covered a wide range of flow rates and choke sizes.

Five error parameters verified the accuracy of the Non-Linear Regression Analysis technique. The accuracy of the approach has been found to be significantly increased when applied to individual choke sizes.

While the formula is of a general nature, one should limit its application to the range of data presented in this study and the production engineer should be careful in using correlations because all apply only to the ranges of flow rates, upstream pressure, gas-liquid ratios, and choke sizes of the field data used in this development.

KEYWORDS

Sub-critical flow, Gilbert correlation , Gas Condensate Wells. Choke performance , non-linear regression.

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