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Modeling Critical Flow through Choke for a Gas-condensate Reservoir Based on Drill Stem Test Data

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Abstract

Gas-condensate reservoirs contain hydrocarbon fluids with characteristics between oil and gas reservoirs and a high gas-liquid ratio. Due to the large gas-liquid ratio, wellhead choke calculations using the empirical equations such as Gilbert may contain considerable error. In this study, using drill stem test (DST) data of a gas-condensate reservoir, coefficients of Gilbert equation was modified; 26.7% of DST data has uncertainty. In these data, due to a problem of flow transmitter, the water flow rate is recorded equal to zero. This makes the mean absolute error of 5% in the measuring of total liquid phase flow rate. Because of uncertainty in the water flow rate in some DST data, the coefficients were optimized for two sets of data to investigate the effect of water flow rate on the calculations. The first dataset was the complete set of DST data, and, in the second, data were filtered with the elimination of uncertain data. The regression results showed that the whole data have a mean absolute error of 5.1%. For this regression, the uncertain data had a mean absolute error of 8.6%, while the error of the remaining data was 3.9%. In this case, for 38% of uncertain data, the mean absolute error was more than 10% indicating that these data are the major factor of the error. Mean absolute error for the filtered dataset was 3.0%. Error reduction was due to the elimination of data with uncertainty. In this case, 3% of the total data had a mean absolute error of more than 10%. In other words, 5% error of the liquid phase flow measurement that includes 26.7% of data caused an increase of 2.1% in the error of calculations. This showed that the elimination of uncertain data causes a remarkable reduction in error. To study the effect of temperature on choke calculations, wellhead temperature was considered as a variable in the Gilbert equation form. The regression results showed that the mean absolute error of 3.0% does not change, and the wellhead temperature has no considerable effect on the choke calculation accuracy.

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1. Introduction

Gas-condensate reservoirs are important sources of hydrocarbon considered as an intermediate of oil and gas reservoirs. As the hydrocarbon production starts, these reservoirs behave as a single phase gas reservoir. Initial fluid pressure is above the dew point curve, and as a result of reservoir production and pressure decrease, the condensate will form as a separate phase within the reservoir. Gas-liquid ratio in gas-condensate reservoirs changes between 3200 to 150000 SCF/STB (Danesh, 1998).

Wellhead choke is a type of valves installed to control the well flow and to protect surface facilities from damage due to pressure variation. Positive and adjustable chokes are the main types used on wellheads. Positive chokes has a fixed cross section, but the cross section of adjustable chokes can be controlled instrumentally. Fluid flow through chokes may be either critical or subcritical.

There are theoretical and empirical methods for choke modeling. In 1949, Tangren et al. (1949) presented the first theoretical investigation on two-phase flow across the restrictions like chokes. Ashford and Pierce (Ashford et al., 1975) also presented a theoretical model for calculating pressure drop for multiphase flow through chokes and Sachdeva et al. (1986) extended the investigation of Ashford and Pierce. In 1954, Gilbert (1954) proposed a simple empirical correlation for critical flow through chokes and this correlation became a base for some other researchers such as Ros (1960), Baxendell (1957), Achong (1961) and Pilehvari (1981). Al-Attar and Abdul-Majeed (Al-Attar et al., 1988) compared some choke flow correlations such as Gilbert and Ashford model with production data from 155 well tests. They showed that the Gilbert model had the minimum average error within the studied model for flow calculations through chokes. Osman and Dokla (Osman et al., 1990) analyzed field data to present empirical correlations for chokes in gas-condensate wells. Perkins (1993) generated equations from general energy equation that described isentropic flow of multiphase mixtures through chokes. Al-Towailib and Al-Marhoun (Al-Towailib et al., 1994) employed more than 3500 production test data from ten fields in the Middle East to present an empirical correlation for two-phase critical flow through chokes. Elgibaly and Nashawi (Elgibaly et al., 1998) proposed empirical correlations for two-phase flow through wellhead chokes based on data from the Middle East oil wells. Esmaeilzadeh et al. (Esmaeilzadeh et al., 2006) proposed different empirical forms of choke equation considering various parameters such as pressure drop and upstream temperature and verified them with data from five gas-condensate reservoirs in Iran. Lak et al. (2014) made a comparison between some of experimental and theoretical models for well flow splitting calculations in a gas-condensate field and showed that the theoretical mechanistic model has more accuracy in flow calculation.

In this paper, the Gilbert equation form is adjusted for a gas-condensate reservoir fluid. The experimental data for this study is taken from DST data conducted for several production wells of this reservoir. Also, the effect of wellhead temperature on choke calculation is investigated for Gilbert form of choke equation.

2. The field and drill stem test data

The studied gas-condensate field is located at the Persian Gulf offshore. It includes 11 operating platforms in the studied block. Each platform contains several wells. Well production streams pass through a flexible choke valve to reduce pressure, and then they are mixed together at the surface and sent to refinery.

A set of drill stem test (DST) data were collected from different wells of this gas-condensate field in the time period from 1992 to 2013. This set of data contains wellhead pressure and temperature, choke diameter, separator pressure and temperature, and flow rates of gas, condensate, and water. A schematic of surface process is shown in Figure 1.

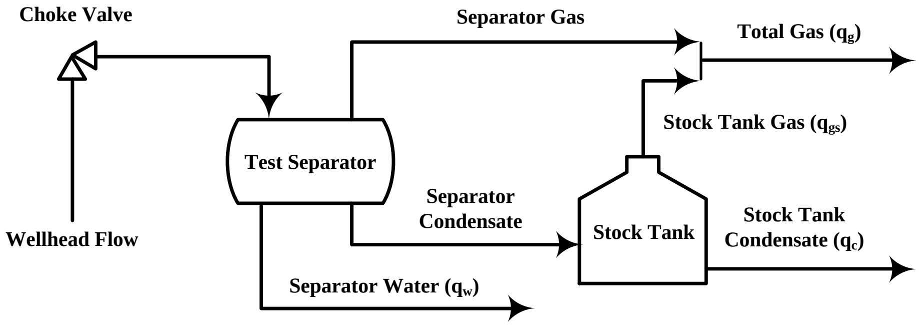

Figure 1
A schematic of surface process.

According to this figure, wellhead flow production enters a test separator after passing across a choke valve with a specific opening diameter. Gas, condensate, and water separation is performed in the test separator. Then, separator condensate enters a stock tank in standard conditions (60 °F and 1 atm), and condensate and gas leave the stock tank. Total gas flow rate (q_g) is the sum of separator gas and stock tank gas flow rates. Gas-liquid ratio (GLR) is calculated by dividing total gas flow rate by total liquid (water and condensate) flow rate (q_c+q_w) as shown in Equation 1:

$$R = \left(\frac{q_g}{q_c + q_w} \right) \tag{1}$$

A sample of surface DST data is given in Table 1. Totally, 864 DST datasets are collected and studied in this work. Plot of GLR versus wellhead pressure is shown in Figure 2. As seen in this figure, wellhead pressure range is 1580 to 4180 psi, and GLR changes between 13900 and 43300 SCF/STB. In average, water content is 5% of total liquid flow rate. Ranges of operational variables are presented in Table 2.

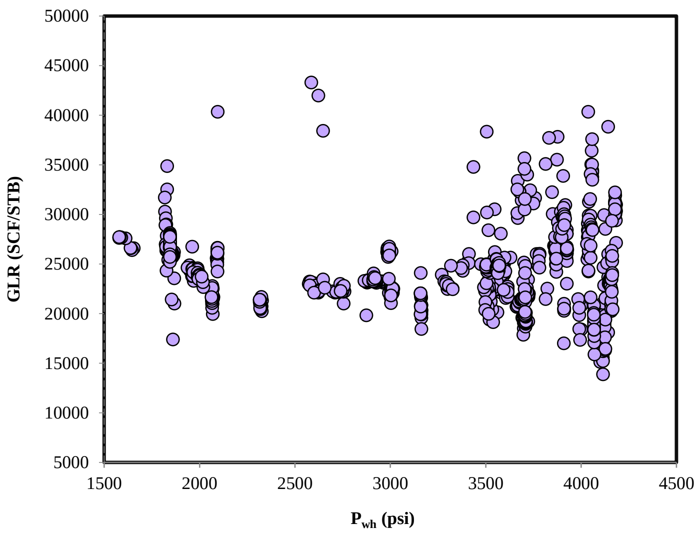

Figure 2
Values of GLR versus wellhead pressure of DST data.

The data presented in Tables 1 and 2 show that the water flow rate is recorded as zero in 231 data entries or 26.7% of all the data. It is due to the uncertainty of water flowmeter because sometimes the flow transmitter does not operate properly and results in a water flow rate of zero in recording DST data. This makes the mean absolute error of 5% in the measuring of total liquid phase flow rate.

Table 1
A sample of surface DST data.

P_{wh} (psi)	T_{wh} (°F)	s ($^1/_{64}$ in)	$P_{sep.}$ (psi)	$T_{sep.}$ (°F)	q_g (MMSCFD)	q_c (STBD)	q_w (STBD)	R (SCF/STB)
3906.0	111.0	24	554.0	92.0	11.622	426.0	18.0	26176
3921.0	115.0	24	551.0	91.0	11.507	427.0	9.0	26392
3923.0	115.0	24	543.0	31.0	11.324	440.0	2.0	25620
3927.0	118.0	24	543.0	90.0	11.348	412.0	17.0	26452
3542.0	125.0	32	532.0	70.0	17.848	754.0	8.0	23423
3544.0	128.0	32	525.0	73.0	17.666	680.0	12.0	25529
3548.0	128.0	32	526.0	75.0	17.803	665.0	14.0	26219
3547.0	131.0	32	521.0	75.0	17.761	547.0	35.0	30517
3001.0	139.0	40	535.0	80.0	24.097	917.0	5.0	26136
3006.0	141.0	40	536.0	80.0	24.075	916.0	0.0	26283
2993.0	141.0	40	543.0	80.0	24.265	914.0	0.0	26548

Table 2
Ranges of operational variables in DST data.

Variable	Range
P_{wh} (psi)	1580-4180
T_{wh} (°F)	95-151
s ($^1/_{64}$ in)	24-64
$P_{sep.}$ (psi)	265-1095
$T_{sep.}$ (°F)	31-126
q_g (MMSCFD)	10.7-47.3
q_c (STBD)	281-2520
q_w (STBD)	0-195
R (SCF/STB)	13900-43300

3. Choke modeling

As mentioned before, the wellhead chokes are installed to control the well flow or downstream pressure. If flow velocity through the choke is less than the sound speed, it is called subcritical flow. Otherwise, flow in the choke is critical when flowing velocity is greater than the sound speed. In a critical flow, the flow rate is not dependent on downstream conditions. For a compressible fluid, the flow rate increases when pressure ratio decreases. Once critical pressure ratio has been reached at the sonic velocity, the flow becomes choked and the flow rate remains constant (Holland et al., 1995).

Several empirical models have been developed for critical choke flow modeling. The general form of these models is presented in Equation 2 that is based on Gilbert investigations on chokes (Guo et al., 2007).

$$P_{wh} = \frac{CR^m q_L}{s^n} \tag{2}$$

where, C, m, and n are empirical constants related to fluid properties in this equation. Gilbert calculated the values of 10, 0.546, and 1.89 for C, m, and n respectively on the basis of production data from the ten section field in California (Gilbert, 1954).

Other values for the constants were proposed by other researchers such as Ros (1960), Baxendell (1957), Achong (1961), and Pilehvari (1981). These values are presented in Table 3. The optimized values of the constants are not unique, and there is rather a large variation in the constants, mostly for C, and to a less extent for m and n.

Table 3
Empirical parameters of Equation 2.

Model	***C***	***m***	***n***
Gilbert (Gilbert, 1954)	10.00	0.546	1.89
Ros (Ros, 1960)	17.40	0.500	2.00
Baxendell (Baxendell, 1957)	9.56	0.546	1.93
Achong (Achong, 1961)	3.82	0.650	1.88
Pilehvari (Pilehvari, 1981)	46.67	0.313	2.11

Because of different ranges of operational parameters such as flow rate, pressure, and GLR, the optimized constants of a certain dataset cannot be used to make predictions from another dataset, and this can lead to a considerable error. For example, if the original Gilbert equation (Gilbert, 1954) is used to predict wellhead pressure for sample surface DST data of Table 1, a mean absolute error (ME%) of 28.2% will be resulted, as shown in Table 4. The relative error and mean absolute error percent are calculated from Equations 3 and 4.

$$RE(\%) = \left| \frac{P_{wh,cal} - P_{wh,rep}}{P_{wh,rep}} \right| \times 100 \tag{3}$$

$$ME(\%) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{P_{wh,cal} - P_{wh,rep}}{P_{wh,rep}}\right|_i \times 100 \tag{4}$$

Table 4

Wellhead pressure calculations with original Gilbert (Gilbert, 1954) equation (C=10.00, m=0.546, and n=1.89).

$P_{wh,rep}$ (psi)	s ($^1/_{64}$ in)	q_L (STBD)	*GLR* (SCF/STB)	$P_{wh,cal}$ (psi)	*RE* (%)
3906	24	444	26176	2825	27.7
3921	24	436	26392	2786	28.9
3923	24	442	25620	2779	29.2
3927	24	429	26452	2745	30.1
3542	32	762	23423	2649	25.2
3544	32	692	25529	2521	28.9
3548	32	679	26219	2510	29.3
3547	32	582	30517	2337	34.1
3001	40	922	26136	2232	25.6
3006	40	916	26283	2224	26.0
2993	40	914	26548	2231	25.4
	***ME* (%)**			**28.2**	

Standard deviation from the mean absolute error is defined by Equation 5. This parameter shows the dispersion of error values around the mean error.

$$SD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(RE(\%)_i - ME(\%)\right)^2} \tag{5}$$

Mean absolute error is calculated for the entire DST data with the mentioned models. The calculation results are presented in Table 5.

Table 5

The mean absolute error of models for the entire DST data.

Model	*ME* (%)
Gilbert (Gilbert, 1954)	27.7
Ros (Ros, 1960)	46.3
Baxendell (Baxendell, 1957)	40.0
Achong (Achong, 1961)	18.5
Pilehvari (Pilehvari, 1981)	85.1

As these calculations show, the error of the studied models is between 18.5 to 85.1%. Respectively, Achong and Pilehvari have the minimum and maximum errors between these models. Also, the parameter *C* of the choke Equation 2 is minimum and maximum for these two models (respectively 3.82 and 46.67). Generally, it appears that high *C* values cause a higher error in choke calculations for this gas-condensate fluid. In other words, lower values of *C* should be used for the modeling of wellhead chokes in this gas-condensate reservoir.

4. Method of DST data regression

In Gilbert equation and similar equations, parameters such as gas-liquid ratio and choke size appear in power form. Therefore, after taking logarithm, equation converts to a linear equation to obtain constants with the minimization of the calculation error.

Taking logarithm from both sides of Equation 2 results in Equation 6:

$$\ln P_{wh} = \ln C + m \ln R + \ln q_L - n \ln s \tag{6}$$

The error of pressure calculation for a given point (e_i) and the sum of square of errors (S) are defined as Equations 7 and 8:

$$e_i = \ln P_{wh,cal} - \ln P_{wh,i} \tag{7}$$

Then, S is defined as the summation of error squares:

$$S = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} \left(\ln C + m \ln R_i + \ln q_{L,i} - n \ln s_i - \ln P_{wh,i} \right)^2 \tag{8}$$

Parameter S will be minimized provided that all partial derivatives are equal to zero. In other words:

$$\frac{\partial S}{\partial C} = \frac{\partial S}{\partial m} = \frac{\partial S}{\partial n} = 0 \tag{9}$$

Writing the equations for three derivatives leads to a set of equations with C, m, and n as unknowns. These equations are shown with Equations 10 to 12.

$$N \ln C + m \sum_{i=1}^{N} \ln R_i + \sum_{i=1}^{N} \ln q_{L,i} - n \sum_{i=1}^{N} \ln s_i - \sum_{i=1}^{N} \ln P_{wh,i} = 0 \tag{10}$$

$$\ln C \sum_{i=1}^{N} \ln R_i + m \sum_{i=1}^{N} (\ln R_i)^2 + \sum_{i=1}^{N} \ln q_{L,i} \ln R_i - n \sum_{i=1}^{N} \ln s_i \ln R_i - \sum_{i=1}^{N} \ln P_{wh,i} \ln R_i = 0 \tag{11}$$

$$\ln C \sum_{i=1}^{N} \ln s_i + m \sum_{i=1}^{N} \ln R_i \ln s_i + \sum_{i=1}^{N} \ln q_{L,i} \ln s_i - n \sum_{i=1}^{N} (\ln s_i)^2 - \sum_{i=1}^{N} \ln P_{wh,i} \ln s_i = 0 \tag{12}$$

By solving this set of equations, the optimum values for parameters C, m, and n are calculated.

In order to investigate the effect of temperature on choke calculations, Gilbert equation was changed and wellhead temperature was considered in the equation, as follows:

$$P_{wh} = \frac{C T_{wh}^k R^m q_L}{s^n} \tag{13}$$

For this case, S is defined with Equation 14.

$$S=\sum_{i=1}^{N}e_i^2=\sum_{i=1}^{N}\left(\ln C+k\ln T_{wh,i}+m\ln R_i+\ln q_{L,i}-n\ln s_i-\ln P_{wh,i}\right)^2 \quad (14)$$

Taking derivatives of Equation 14 with respect to constants *n*, *m*, *C*, and *k* results in set of Equations 15 to 18:

$$N\ln C+k\sum_{i=1}^{N}\ln T_{wh,i}+m\sum_{i=1}^{N}\ln R_i+\sum_{i=1}^{N}\ln q_{L,i}-n\sum_{i=1}^{N}\ln s_i-\sum_{i=1}^{N}\ln P_{wh,i}=0 \quad (15)$$

$$\ln C\sum_{i=1}^{N}\ln T_{wh,i}+k\sum_{i=1}^{N}(\ln T_{wh,i})^2+m\sum_{i=1}^{N}\ln R_i\ln T_{wh,i}+\sum_{i=1}^{N}\ln q_{L,i}\ln T_{wh,i}-n\sum_{i=1}^{N}\ln s_i\ln T_{wh,i}-\sum_{i=1}^{N}\ln P_{wh,i}\ln T_{wh,i}=0 \quad (16)$$

$$\ln C\sum_{i=1}^{N}\ln R_i+k\sum_{i=1}^{N}\ln T_{wh,i}\ln R_i+m\sum_{i=1}^{N}(\ln R_i)^2+\sum_{i=1}^{N}\ln q_{L,i}\ln R_i-n\sum_{i=1}^{N}\ln s_i\ln R_i-\sum_{i=1}^{N}\ln P_{wh,i}\ln R_i=0 \quad (17)$$

$$\ln C\sum_{i=1}^{N}\ln s_i+k\sum_{i=1}^{N}\ln T_{wh,i}\ln s_i+m\sum_{i=1}^{N}\ln R_i\ln s_i+\sum_{i=1}^{N}\ln q_{L,i}\ln s_i-n\sum_{i=1}^{N}(\ln s_i)^2-\sum_{i=1}^{N}\ln P_{wh,i}\ln s_i=0 \quad (18)$$

5. Results and discussion

In this study, the calculations are performed for two sets of DST data. The first dataset includes all 864 data points. The second dataset involves those points for which water flow rate is available; this set includes 633 data points. The results are presented in Table 6.

Table 6

Regression results.

Dataset	*N*	*C*	*m*	*N*	*ME* (%)	*SD*
All Data	864	0.25	0.899	1.76	5.1	5.1
Data with specified water flow rate	633	0.72	0.811	1.80	3.0	3.0

Figure 3 compares the calculated versus reported wellhead pressure for all the data. The 45° line is also shown for better comparison. The reported wellhead pressure versus the calculated wellhead pressure for data with a specified water flow rate is shown in Figure 4.

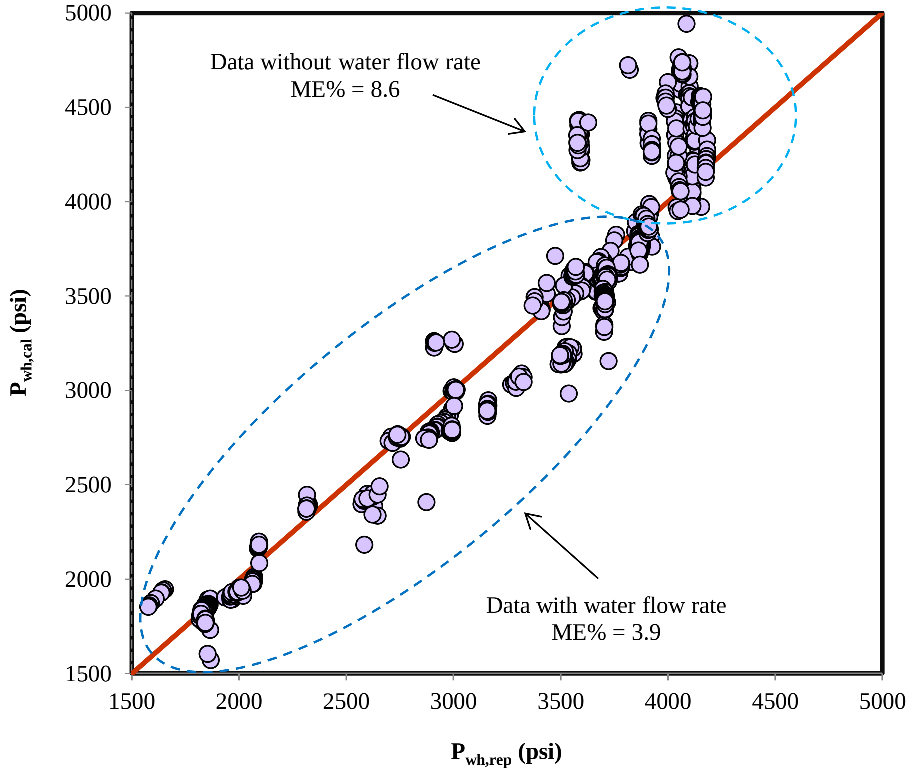

Figure 3
The reported wellhead pressure versus the calculated wellhead pressure for all the data.

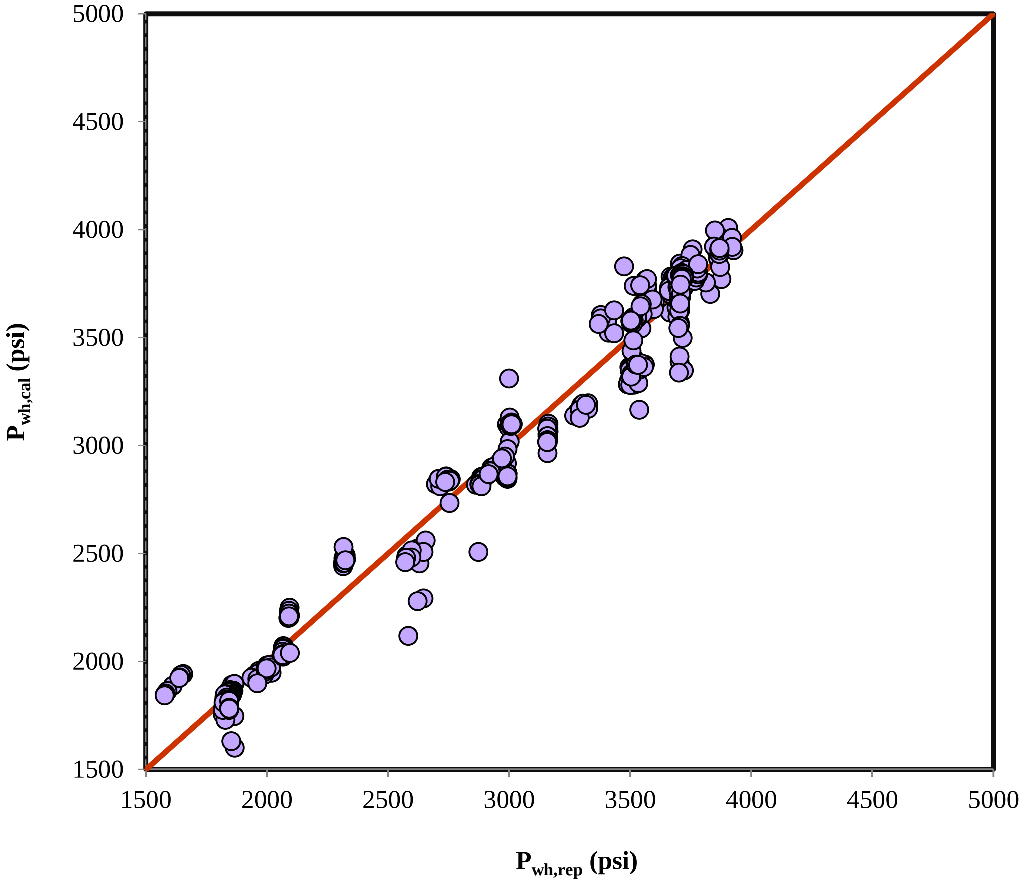

Figure 4
The reported wellhead pressure versus the calculated wellhead pressure for the data with a specified water flow rate.

According to the results, data without a water flow rate are scattered at the top of the graph. Uncertain data have a mean absolute error of 8.6%, while the error of the remained data is 3.9%; the mean absolute error is 5.1% for all the data. It is between two mentioned errors. In this case, for 38% of the uncertain data, the mean absolute error is more than 10%, which indicates that these data are the major factor of the error. In other words, uncertain data increase the regression error of all the data.

The results show that the regression for the data containing water flow rates is more accurate with a mean absolute error of 3.0%. In this case, 3% of the total data has more than 10% error. Better regression is due to the elimination of the uncertain data. In other words, 5% error of the liquid phase flow measurement, which includes 26.7% of all the data, cause an increase of 2.1% in the error of calculations. This implies that the elimination of uncertain data causes a considerable reduction of error in calculations, and removing uncertain data in data filtering will result in more accurate calculations. The parameters obtained from this regression can be used for the choke calculation of gas-condensate fluid with proper accuracy.

Therefore, although the water-condensate ratio is not high, and in average water forms 5% of the total liquid phase, choke calculation accuracy decreases due to neglecting water flow rate.

The results of the regression of Equation 13 for data with a specified water flow rate are shown in Table 7. Also, the wellhead pressure calculated by Equation 2 versus the wellhead pressure calculated by Equation 13 for this regression is shown in Figure 5.

Table 7
Regression results for Equation 13.

Dataset	*N*	*C*	*m*	*n*	*k*	*ME* (%)	*SD*
Data with specified water flow rate	633	0.40	0.821	1.82	0.115	3.0	2.9

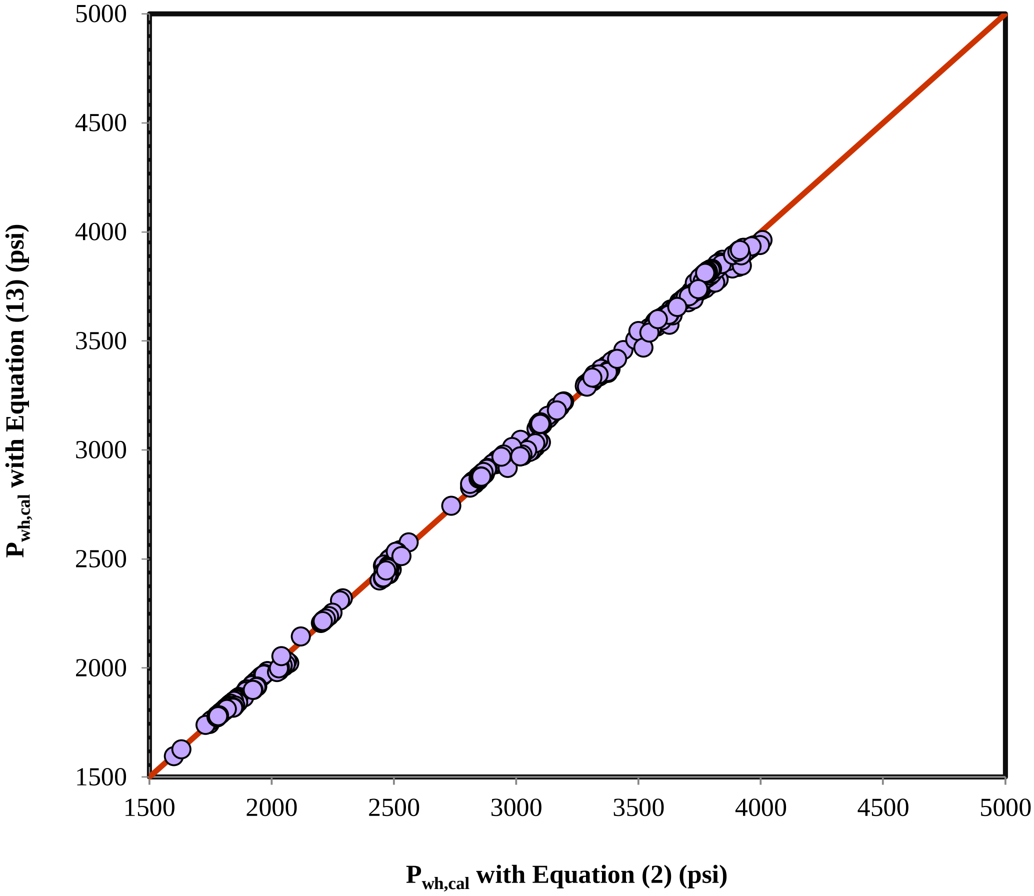

Figure 5
The wellhead pressure calculated by Equation 2 versus the wellhead pressure calculated by with Equation 13.

The regression results for Equation 13 show that the mean absolute error of 3.0% does not change, and there is not a considerable difference between the wellhead pressures calculated by Equations 2 and 13. Therefore, considering the wellhead temperature in the Gilbert equation form has no tangible effect on choke calculation accuracy.

6. Conclusions

In this work, critical flow calculations through chokes were studied based on DST data from a gas-condensate reservoir. The water flow rate of 26.7% of these data was zero because of uncertainty in water flowmeter. Therefore, DST data was divided into two sets; the first dataset contained all the data, and, in the second, the uncertain data was eliminated. The base form for choke calculation was Gilbert model. Using DST data, the equation parameters was modified.

The results showed that uncertainty in water flow rate decreases the accuracy of regression. Uncertain data had a mean absolute error of 8.6%. The mean absolute error was 5.1% for all the data and 3.0% for data with a specified water flow rate. This shows that the elimination of uncertain data causes a remarkable reduction in error.

For studying the effect of wellhead temperature on calculations, temperature was considered in the calculation equation, and specified data and parameters were modified again. The results showed that the mean absolute error is 3.0%, and there is no significant difference between the wellhead pressure values calculated by the new equation and those calculated by Gilbert form equation. Therefore, wellhead temperature has no considerable effect on choke calculation.

Nomenclature

C	: Choke equation constant
e	: Pressure calculation error [psi]
GLR	: Gas-liquid ratio [--]
k	: Choke equation constant [--]
m	: Choke equation constant [--]
ME (%)	: Mean absolute error percent [--]
n	: Choke equation constant [--]
N	: Number of data [--]
$P_{sep.}$	: Separator pressure [psi]
P_{wh}	: Wellhead pressure [psi]
$P_{wh,cal}$	: Calculated wellhead pressure [psi]
$P_{wh,rep}$	: Reported wellhead pressure [psi]
q_c	: Condensate flow rate [STBD]
q_g	: Total gas flow rate [MMSCFD]
q_{gs}	: Stock tank gas flow rate [MMSCFD]
q_L	: Liquid flow rate; summation of water and condensate flow rates [STBD]
q_w	: Water flow rate [STBD]
R	: Gas-liquid ratio [SCF/STB]
$RE\%$	: Relative error percent [--]
s	: Choke diameter [$^1/_{64}$ in]
S	: Summation of error squares [--]
SD	: Standard Deviation [--]
$T_{sep.}$	: Separator temperature [°F]
T_{wh}	: Wellhead temperature [°F]

References

Achong, I., Revised Bean Performance Formula for Lake Maracaibo Wells, Shell Internal Report, 1961.

Al-Attar, H.H. and Abdul-Majeed, G., Revised Bean Performance Equation for East Baghdad Oil Wells, SPE Production Engineering, Vol. 3, No. 1, p. 127-131, 1988.

Al-Towailib, A.L. and Al-Marhoun, M.A., A New Correlation for Two-phase Flow through Chokes, Journal of Canadian Petroleum Technology, Vol. 33, No. 5, p. 40-43, 1994.

Ashford, F.E. and Pierce, P.E., Determining Multiphase Pressure Drop and Flow Capabilities in Down-hole Safety Valves, Journal of Petroleum Technology, Vol. 27, No. 9, p. 1145-1152, 1975.

Baxandell, P., Bean Performance-Lake Wells, Shell Internal Report, 1957.

Danesh, A., PVT and Phase Behavior of Petroleum Reservoir Fluids, 400 p. Elsevier, 1998.

Elgibaly, A.A.M. and Nashawi, I.S., New Correlations for Critical and Subcritical Two-phase Flow through Wellhead Chokes, Journal of Canadian Petroleum Technology, Vol. 37, No .6, p. 36-43, 1998.

Esmaeilzadeh, F., Bimkar, F. and Pirakeh, J., Correlation Determines Gas-condensate Flow through Chokes, Oil and Gas Journal, Vol. 104, No .6, p. 48-51, 2006.

Gilbert, W.E., Flowing and Gas Lift Performance, Drilling and Production Practice Conference, New York, January 1954.

Guo, B., Lyons, C., and Ghalambor, A., Petroleum Production Engineering, 312 p. Elsevier Science and Technology Books, 2007.

Holland, F. and Bragg, R., Fluid Flow for Chemical and Process Engineers, 2nd Edition, 384 p. Butterworth-Heinemann, 1995

Lak, A., Azin, R., Osfouri, Sh., Gerami, Sh., and Chahshoori, R., Choke Modeling and Flow Splitting in a Gas-Condensate Offshore Platform, Journal of Natural Gas Science and Engineering, Vol. 21, p. 1163-1170, 2014.

Osman, M.E. and Dokla, M.E., Gas Condensate Flow through Chokes, SPE Paper 20988, 1990.

Perkins, T.K., Critical and Subcritical Flow of Multiphase Mixtures through Chokes, SPE Drilling and Completion Journal, Vol. 8, No. 4, p. 271-276, 1993.

Pilehvari, A.A., Experimental Study of Critical Two-phase Flow through Wellhead Chokes, Tulsa University Fluid Flow Projects Report, 1981.

Ros, N.C.J., An Analysis of Critical Simultaneous Gas/Liquid Flow through a Restriction and its Application to Flow Metering, Journal of Applied Sciences Research, Vol. 9, p. 374-389, 1960.

Sachdeva, R., Schmidt, Z., Brill, J.P., and Blais, R.M., Two-phase Flow through Chokes, 61st SPE Annual Technical Conference and Exhibition, New Orleans, October 1986.

Tangren, R.E., Dodge, C.H., and Seifert, H.S., Compressibility Effect of Two-phase Flow, Journal of Applied Physics, Vol. 20, No. 7, p. 637–645, 1949.