ACCURACY OF SACHDEVA'S CHOKE MODEL FOR PREDICTION GAS AND LIQUID RATE OF IRANIAN GAS CONDENSATE WELLS.

Mojtaba Golshadi[1]*,Abbas Shahrabadi[2], Vahid Mobedifar[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

Flow through a surface choke can be either critical or subcritical. Most of the correlations available to petroleum engineers are for critical flow but in lots of high rate gas/condensate wells subcritical flow occurs in large choke sizes. Sachdeva's multiphase choke flow model has capabilities of predicting critical-subcritical boundary and liquid and gas flow rates for given upstream and downstream pressures. Accurate modeling of choke is vitally important for a petroleum engineer in production from reservoirs.In this study, the accuracy of the Sachdeva's choke model was evaluated using data from gas condensate wells in Iran.

Comparisons of the results from the model and field measurements indicate that Sachdeva's choke model generally under-estimates gas and condensate flow rates. Based on measurements from 101 gas condensate wells .it was found that the model under-estimates gas rate and liquid rate by as much as 35% and 65%, respectively. The investigation further went on to improve the performance of Sachdeva's choke model. It was found that the error of the model could be minimized using of choke discharge coefficient (CD). For gas condensate wells, the error in gas flow rate calculations can be minimized using CD = 1.048 However, the error in liquid flow rate calculations for condensate wells is minimum when CD = 1.62.

NOMENCLATURE

Ac = choke cross-sectional area, ft2
CD = discharge coefficient
Cp = specific heat at constant pressure, BTU/^{o}R
Cv = specific heat at constant volume, BTU/^{o}R
G2 = mass flux at downstream, lbm/ft2/sec
gc = gravitational constant
$k = C_p/C_v$, specific heat ratio
M_2 = mass flow rate at down stream, lbm/sec.
n = polytropic exponent for gas
V_{G1} = gas specific volume at upstream, ft3/lbm
V_{G2} = gas specific volume at downstream, ft3/lbm.
V_L = liquid specific volume at upstream, ft3/lbm
p_1 = upstream pressure, psia
p_2 = downstream pressure, psia
x_1 = free gas quality at upstream, mass fraction
y_a = actual pressure ratio
y_c = critical pressure ratio

INTRODUCTION

Wellhead chokes are widely used in the petroleum industry to control flow rate from wells, to maintain stable pressure downstream from the choke, and to provide the necessary backpressure to a reservoir to avoid formation damage from excessive drawdown. Consequently, it is extremely important for petroleum engineers to be able to select the correct choke size for a given application. This is only possible through accurate modeling of choke performance. Two types of gas–liquid flow can exist in a choke; critical and sub-critical flow. During critical flow, the velocity of the flowing fluids through the choke reaches the sonic velocity for the two-phase fluid and the flow rate becomes independent of the downstream pressure. Conversely, in sub-critical flow the flow rate depends on the pressure differential and changes in the downstream pressure affect the upstream pressure. Fortunati [1] reported that a majority of wells in the field operates under sub-critical conditions. However, most of the correlations available to petroleum engineers are for critical flow. Theoretical approaches and empirical methods are available in the literature for predicting choke behavior. Tangeren et al. [2] did the first theoretical study on two-phase flow through restrictions. He assumed polytropic expansion of gas that is dispersed uniformly in the mixture having liquid as the continuous phase. He studied only critical flow, and showed that when gas bubbles are added to an incompressible fluid above a critical flow velocity, the medium becomes incapable of transmitting pressure change upstream against the flow. Several empirical choke flow models have been developed in the past half-century. They generally take the following form for sonic flow:

$$Pu = CR^{b}Q/S^{a}$$

This equation was originally proposed by Gilbert[3], and based on production data from the Ten Section Field in California, he found the values for C, b, and a to be 435, 0.546, and 1.89, respectively. Note that the critical flow rate is independent of the downstream pressure which, therefore, does not appear in the Gilbert-type equations. Other values of these empirical constants were reported by various investigators including Baxendell [4], Ros [5], and Achong [6]. Poettmann and Beck [7] extended the work of Ros[5] to develop charts for different API crude oils. Omana et al. [8] derived dimensionless choke correlations for water–gas systems. Al-Attar and Abdul-Majeed [9] made a comparison of existing choke flow models using 155 well tests from the East Baghdad 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%. Osman and Dokla [10] applied the Least Square Method to field data and developed empirical correlations for gas condensate choke flow.

In addition to these empirical methods, numerous theoretical approaches exist to predict choke performance. Fortunati [1] developed the first correlations for both critical and sub-critical flow and the boundary between these regimes. Ashford [11] presented a model for two-phase critical choke flow based on the work of Ros[5]. He assumed conditions and a critical–subcritical boundary definition similar to Tangeren's. Gould [12] plotted the Ashford boundary, showing that different values of the polytropic exponent yield different boundaries. Ashford and Pierce [13] derived an equation to predict the critical pressure ratio.

Their model assumes that the derivative of flow rate with respect to the downstream pressure is zero at critical conditions. One set of equations was recommended for both critical and sub-critical flow conditions. Pilehvari [14,15] also studied choke performance under subcritical conditions. Sachdeva et al. [16] presented a model developed to solve the mass flow rate through a choke for both sub-critical and critical conditions. He also derived an expression in order to find the boundary between critical and subcritical flow. This model has also been verified against multiphase experiments. Approach for finding the critical pressure ratio and the mass flow rate in much the same way as the model by Sachdeva et al. [16]. Perkins[17] included the threephase effects for the polytropic expansion exponent, n, and also found the mixture average velocity at the throat.

Guo et al. [18] evaluated the accuracy of the Sachdeva's model using data from oil and gas condensate wells in Southwest Louisiana.

ANALYSIS AND SACHDEVA'S MODEL

Sachdeva's multiphase choke flow model is reviewed in this section for clarity. This model uses the following equation to calculate critical-subcritical boundary:

$$y_{c}= \left\{\frac{\frac{k}{k-1}+\frac{(1-x)V_{l}(1-y_{c})}{x_{1}V_{G1}}}{\frac{k}{k-1}+\frac{n}{2}+\frac{n(1-x_{1})V_{l}}{x_{1}V_{G1}}+\frac{n}{2}\left[\frac{(1-x_{1})V_{l}}{x_{1}V_{G1}}\right]^{2}}\right\} \quad (1)$$

where
yc = critical pressure ratio
k = Cp/Cv, specific heat ratio
n = polytropic exponent for gas
x1 = free gas quality at upstream, mass fraction
VL = liquid specific volume at upstream, ft3/lbm
VG1 = gas specific volume at upstream, ft3/lbm
VG2 = gas specific volume at downstream, ft3/lbm.

The polytropic exponent for gas is calculated using

$$n = 1 + \frac{x_{1}(c_{p}-c_{v})}{x_{1}c_{v}+(1-x_{1})c_{l}} \quad (2)$$

The gas specific volume at upstream (VG1) can be determined using the gas law based on upstream pressure and temperature. The gas specific volume at downstream (VG2) is expressed as:

$$V_{G2} = V_{G1}y_{c}^{-(1/k)} \quad (3)$$

The critical pressure ratio yc can be solved from Eq. (2) numerically. The actual pressure ratio can be calculated by:

$$y_{a}=p_{2}/p_{1} \quad (4)$$

Where : ya = actual pressure ratio
p1 = upstream pressure, psia
p2 = downstream pressure, psia.

If ya < yc , critical flow exists, and the yc should be used (y = yc). Otherwise, subcritical flow exists, and ya should be used (y = ya).

The total mass flux can be calculated using the following equation:

$$G_2=C_D\{288g_cp_1\rho_{m2}^2[(1-x)(1-y)/\rho_L+(kx_1/(k-1))(V_{G1}-V_{G2})]\}^{0.5} \quad (5)$$

Where:
G2 = mass flux at downstream, lbm/ft2/sec
CD = discharge coefficient
gc = gravitational constant
ρm2 = mixture density at downstream, lbm/ft3
ρL = liquid density, lbm/ft3.

The mixture density at downstream (ρm2) can be calculated using the following equation:

$$1/\rho_{m2}=x_1V_{G1}y^{-(1/k)}+(1-x_1)\ V_1 \quad (6)$$

Once the mass flux is determined from Eq. (6), mass flow rate can be calculated using the following equation:

$$M_2=G_2A_c \quad (7)$$

Where:
Ac = choke cross-sectional area, ft2
M2 = mass flow rate at dow stream, lbm/sec.
Liquid mass flow rate is determined by:

$$M_{L2}=(1-x_2)M_2 \quad (8)$$

At typical velocities of mixtures of 50-150 ft/s flowing through chokes, there is virtually no time for mass transfer between phases at the throat. Thus $x_1=x_2$ can be assumed. Liquid volumetric flow rate can then be determined based on liquid density. Gas mass flow rate is determined by

$$M_{G2}=x_2M_2 \quad (9)$$

The major drawback of Sachdeva's multiphase choke flow model is that it requires free gas quality as an input parameter to determine flow regime and flow rates, and this parameter is usually not known before flow rates are known. A trial-anderror approach is therefore needed in flow rate computations.

RESULTS AND DISCUSSION

The applicability of Sachdeva's choke flow model to Iran gas condensate wells was evaluated .Using101data points from wells. The input parameters consist of gas and liquid rates, chock size, upstream and downstream pressures, oil density and discharge coefficient factor (CD). Other parameters needed in the calculation were assumed to be constant throughout the calculations. Different values of discharge coefficient CD were utilized in order to improve the model performance.

Gas Rate. The data points from gas condensate wells are plotted in Figure 1, which clearly shows inaccuracy of the model.

Different values of CD were used in order to investigate the possibility of accuracy improvement of the model. The results are shown in Figs. 2 -9, which display the shifting of the calculated gas flow rates and the errors generated. They indicate the improvement to the model when the value of CD is increased. Apparently when the discharge coefficient factor CD=1.048 is used the model predicts the gas rate within an acceptable error for most data points Figure 8.

Figure 11 indicates that a CD value of 1.048 generates a relative average error of around 0.5% as compared to 5.5%, -2.5%, -4.7%,-9.9%,-14.8%, -24% and -33.5% generated by CD=1.1, CD=1.02, , CD=1, CD=0.95, CD=0.9, CD=0.8 and CD=0.7,respectively.

Liquid Rate. Figure 11 portrays the difference between the measured and model-calculated (with CD=0.75) liquid rate values for all the 101 data points. This figure shows poor accuracy of the model for all the points. Different values of CD were used in order to investigate the possibility of accuracy improvement of the model. The results are shown in Figs. 12-19, which display the shifting of the calculated liquid flow rates and the errors generated. They indicate the improvement to the model when the value of CD is increased. Apparently when the discharge coefficient factor CD=1.62 is used the model predicts the liquid rate with lower error for most data points Figure 20. Figure 21indicates that a CD value of 1.62 generates a relative average error of around –0.5% as compared to +2%, -10%, -23%, -42%, -47% and -54%,generated by CD=1.65, CD=1.5, CD=1.25, CD=0.95, CD=0.85 and CD=0.75,respectively.

CONCLUSIONS

Based on the case studies conducted using 101 data points from Iranian gas condensate fields, the following conclusions are drawn:

1. Comparisons of the results from model and field measurements indicated that Sachdeva's choke model generally under-estimates gas and condensate flow rates. The Sachdeva's choke model is accurate

for predicting liquid and gas rates of gas condensate wells .Error of the model could be minimized using different values of choke discharge coefficient (CD).

2. A discharge coefficient CD=1.048 should be used for predicting gas rates of gas condensate wells using the Sachdeva's choke model.

3. A discharge coefficient CD=1.62 should be used for predicting liquid rates of gas condensate wells using the Sachdeva's choke model also less error of the model exists for the data points with lower gas liquid ratio.

KEYWORDS
Sachedeva choke flow model, sub-critical flow, discharge coefficient, gas rate, liquid rate.

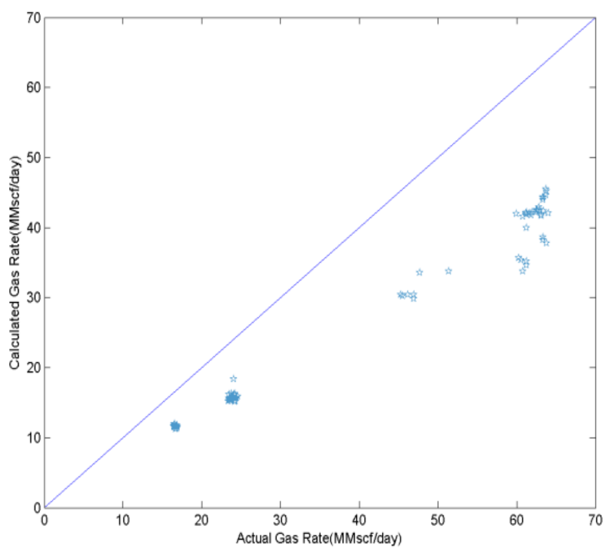

Fig.1-
Comparison between Measured and Calculated Gas Rates Using CD=0.7

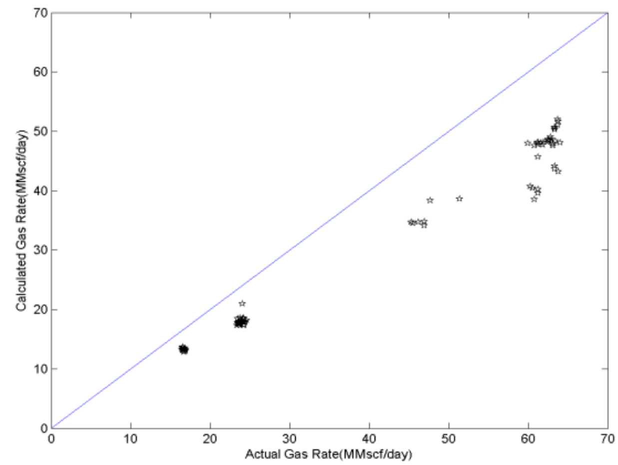

Fig.2-
Comparison between Measured and Calculated Gas Rates Using CD=0.8

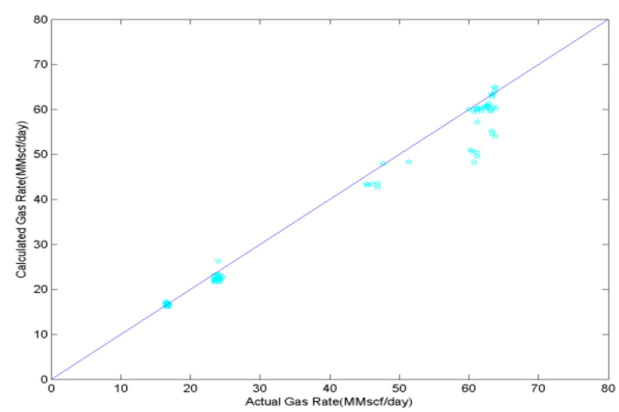

Fig.3-
Comparison between Measured and Calculated Gas Rates Using CD=0.9

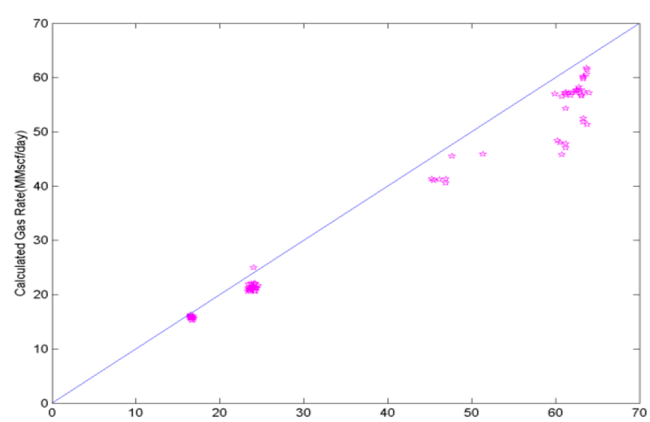

Fig.4-
Comparison between Measured and Calculated Gas Rates Using CD=0.95

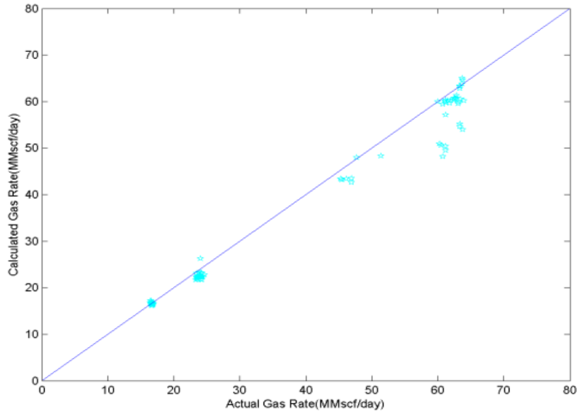

Fig.5-
Comparison between Measured and Calculated Gas Rates Using CD=1

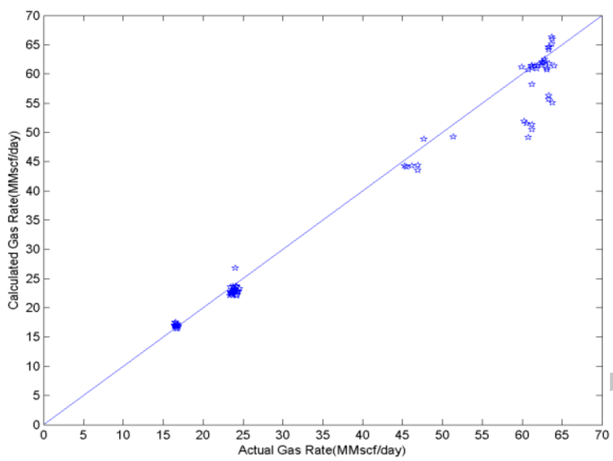

Fig.6-
Comparison between Measured and Calculated Gas Rates Using CD=1.02

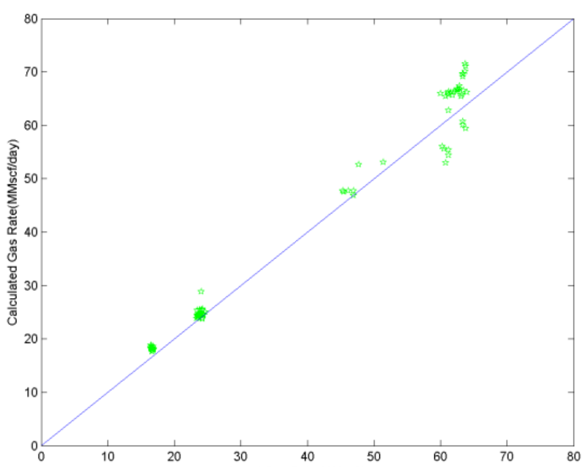

Fig.7-
Comparison between Measured and Calculated Gas Rates Using CD=1.1

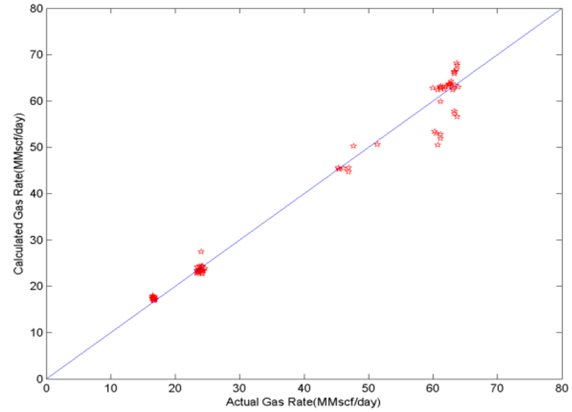

Fig.8-
Comparison between Measured and Calculated Gas Rates Using CD=1.048

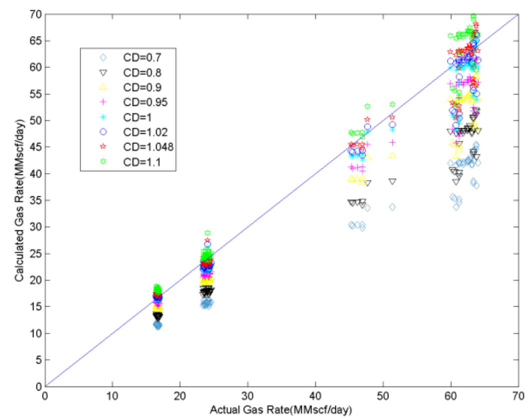

Fig.9-
Comparison between Measured and Calculated Gas Rates Using various CD values.

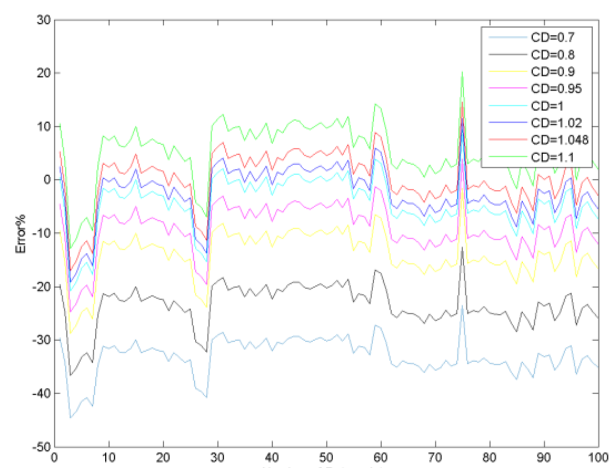

Fig.10-
Error in Gas Rate Prediction Using Various CD Values

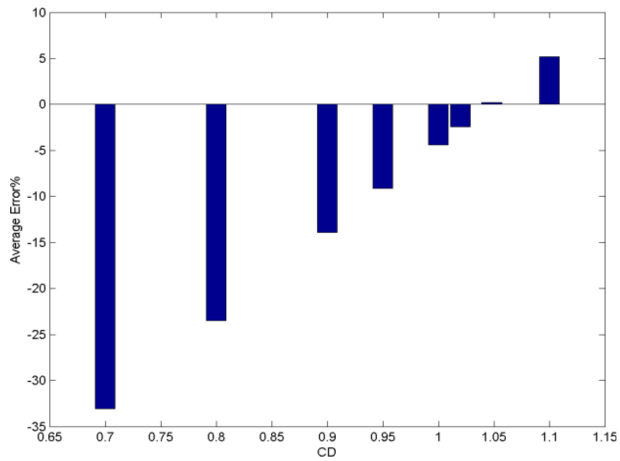

Fig.11-
The Average Error in Gas Rate Prediction Using Various CD Values

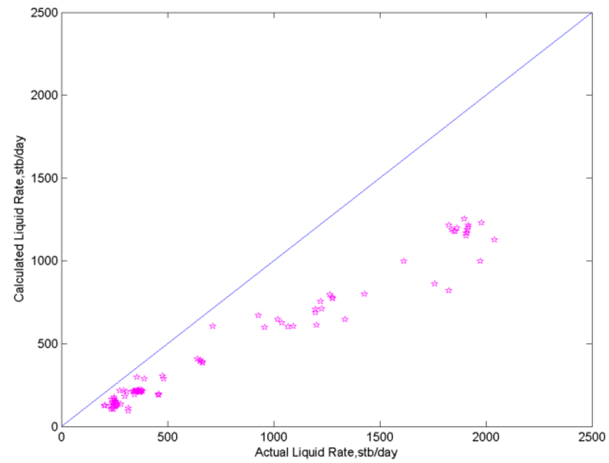

Fig.14-
Comparison between Measured and Calculated Liquid Rates Using CD=0.95

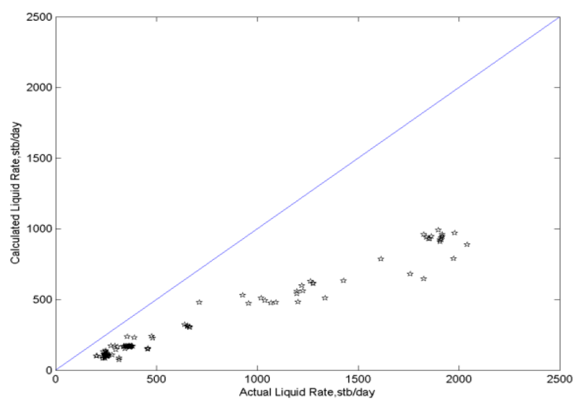

Fig.12-
Comparison between Measured and Calculated Liquid Rates Using CD=0.75

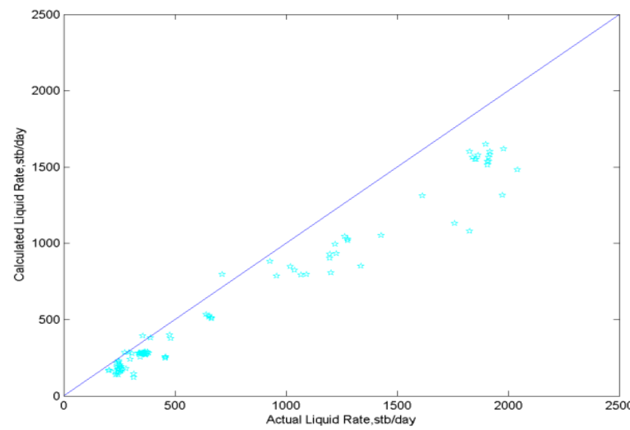

Fig.15-
Comparison between Measured and Calculated Liquid Rates Using CD=1.25

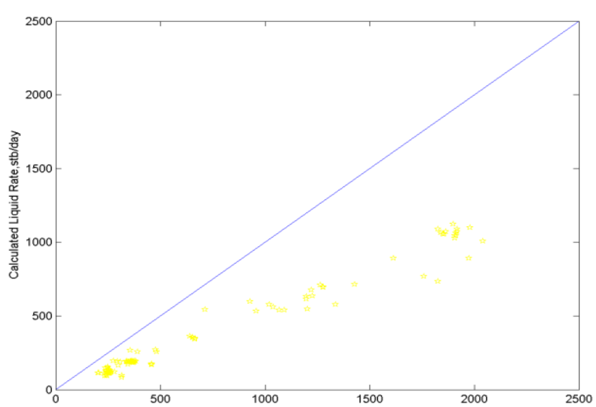

Fig.13-
Comparison between Measured and Calculated Liquid Rates Using CD=0.85

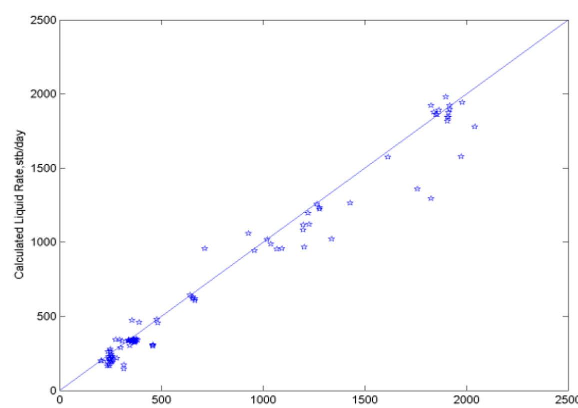

Fig.16-
Comparison between Measured and Calculated Liquid Rates Using CD=1.5

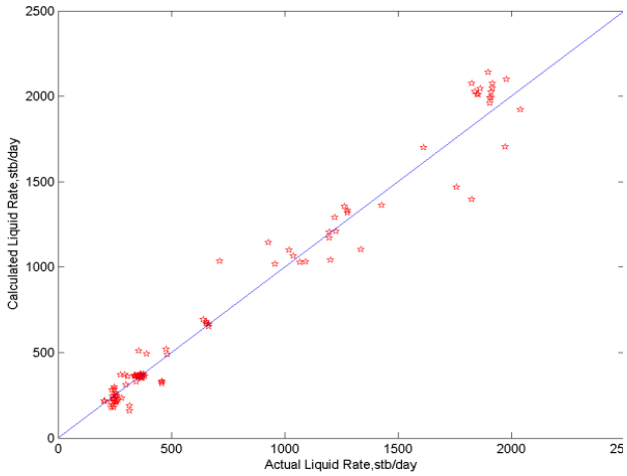

Fig.17-
Comparison between Measured and Calculated Liquid Rates Using CD=1.62

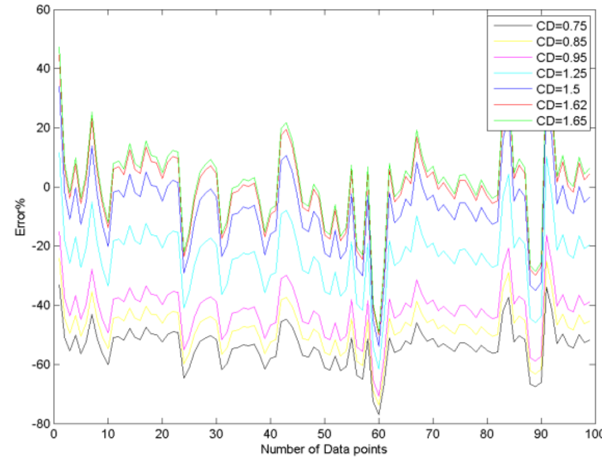

Fig.20-
Error in Liquid Rate Prediction Using Various CD Values

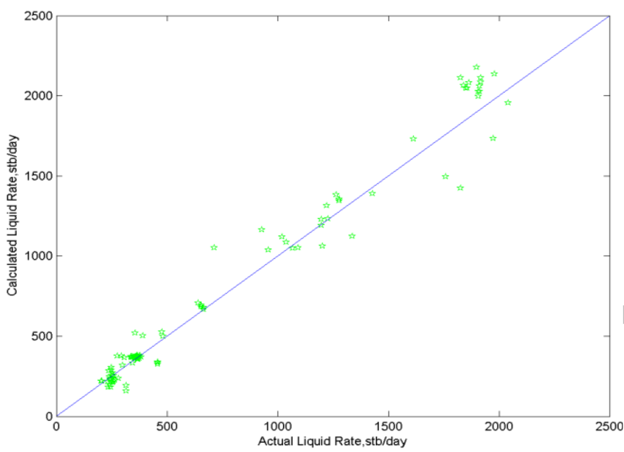

Fig.18-
Comparison between Measured and Calculated Liquid Rates Using CD=1.65

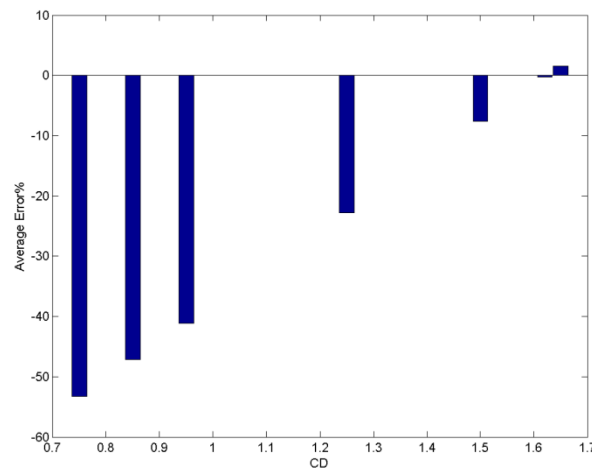

Fig.21-
The Average Error in Liquid Rate Prediction Using Various CD Values

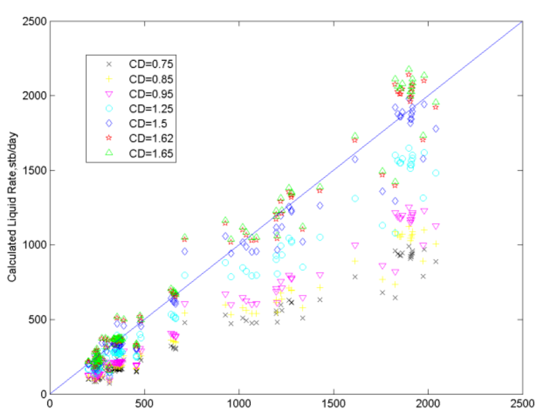

Fig.19-
Comparison between Measured and Calculated Liquid Rates Using various CD values

REFERENCES

1.Fortunati, F., 1972. Two-phase flow through wellhead chokes. SPE 3742, presented at SPE European Meeting.
2.Tangeren, R.E., Dodge, C.H., Seifert, H.S., 1949. Compressibility effects of two-phase flow. J. App. Phys. 20, 637–645.
3.Gilbert, W.E., 1954. Flowing and gas-lift well performance. API Dril.Prod. Prac. 20, 126–157.4.Baxendell, P.B., 1957. Bean performance-lake wells. Shell Internal Report.
5.Ros, N.C.J., 1960. An analysis of critical simultaneous gas–liquid flow through a restriction and its application to flow metering. Appl. Sci. Res. 2, 374.

6.Achong, I.B., 1961. Revised bean and performance formula for Lake Maracaibo Wells. Shell Internal Report.

7.Poettmann, F.H., Beck, R.L., 1963. New charts developed to predict gas–liquid flow through chokes. World Oil, pp. 95–101.

8. Omana, R., Houssiere Jr., C., Brown, K.E., Brill, J.P., Thompson, R.E., 1969. Multiphase flow through chokes. SPE 44th Annual Meeting, Denver, Colorado, SPE paper 2682.

9.Al-Attar, H.H., Abdul-Majeed, G., 1988. Revised bean performance equation for East Baghdad oil wells. SPE Production Engineering, pp. 127–131.

10. Osman, M.E., Dokla, M.E., 1990. Gas condensate flow through chokes. SPE paper 20988.

11. Ashford, F.E., 1974. An evaluation of critical multiphase flow performance through ellhead chokes. J. Pet. Tech. 850–863.

12. Gould, T.L., 1976. Discussion of paper: an evaluation of critical multiphase flow erformance through wellhead chokes, by Ashford, P.E. J. Pet. Tech. 843.

13. Ashford, P.E., Pierce, P.E., 1975. Determining multiphase pressure drop and flow capabilities in down hole safety valves. J. Pet.Tech. 27, 1145–1152.

14. Pilehvari, A.A., 1980. Experimental study of subcritical two-phase flow through wellhead chokes. University of Tulsa Fluid Flow Projects Report, Tulsa.

15.Pilehvari, A.A., 1981. Experimental study of subcritical two-phase flow through wellhead chokes. University of Tulsa Fluid Flow Projects Report, Tulsa.

16.Sachdeva, R., Schmidt, Z., Brill, J.P., Blais, R.M., 1986. Two-phase flow through chokes. SPE Annual Technical Conference and Exhibition, New Orleans, SPE 15657.

17.Perkins, T.K., 1993. Critical and subcritical flow of multiphase mixtures through chokes. SPEDC 271.

18.Guo, B., Al-Bemani, A.S., Ghalambor, A., 2002. Applicability of Sachdeva's choke flow model in Southwest Louisiana gas condensate wells. SPE Gas Technology Symposium, Calgary, Alberta, Canada, SPE 75507.