Predication of Oil Flow Rate through Choke at Critical Flow for Iraqi Oil Wells

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Abstract

Before the production leaves the well head, it passes through a choke which serves to stabilize the optimum or desired flow rate against variations in flow line pressure.

In this paper, the aim is to develop new correlation to predict oil flow rate through chokes with critical flow for Iraqi oil wells. This study shows that there is a strict quantitative connection between three factors: upstream pressure, gas-oil ratio and choke size with oil flow rate at critical flow for one hundred production tests of Iraqi oil wells.

Many forms have been tried using nonlinear regression analysis to obtain the optimum form of correlation that gives minimum differences between the calculated and field data. Here, based on Iraqi oil wells data; new correlation has been developed for predicting oil flow rate through chokes at critical flow.

The proposed correlation exhibits more accuracy (only 4.523% average absolute error) than the existent correlations. The correlation coefficient of the new correlation is determined as 0.997. The cross plots of calculated and field data gives strong index of priority of new correlation for applying with Iraqi oil wells. The graphical

presentation of the results of the new correlation for Iraqi oil wells states more matching with the field data that are not used in formulating the new correlation than Gilbert (1954), Baxendall (1957), Ros (1959), Achong (1961), Secen (1976), Pilehvari (1981), Osman and Dokla (1990), Owolabi, Dune and Ajienka (1991), Elgibaly and Nashawi (1996), Mesallati, Bizanti and Mansouri (2000) and Alrumah and Bizanti (2007) correlations.

Introduction

Multiphase flow of gas and liquid comes to mind commonly in the petroleum, chemical and related industries. In the petroleum industry gas-liquid mixture are transported through vertical, inclined and horizontal wells from the reservoir to the wellhead, from the wellhead to the gas-liquid separator and to stock tank. The refinery receives the mixture which undergoes further traveling from distillation and separating units to final storage (Omana, Brown, Houssiere, Brill and Thompson (1969)).

The flow of fluids through restrictions such as chokes or orifices is commonly used in the oil and gas industry for flow metering and estimation of pressures. Practically all flowing wells utilize some surface restriction in order to regulate the flowing rate. Only very few wells are produced with absolutely no restrictions for getting maximum production rate (Ajienka and Ikoku (1987)). Wellhead chokes are used in the petroleum industry to control flow rate, to maintain well allowable, to protect surface equipments, to prevent

water and gas coning and to provide the necessary backpressure to reservoir to avoid formation damage from excessive drawdown (Nasriani and Kalantariasl (2011)).

A wellhead choke controls the surface pressure and production rate from a well. Chokes usually are selected so that fluctuations in the line pressure downstream of the choke have no effect on the production rate. This requires that flow through the choke be at critical flow conditions.

Under critical flow conditions, the flow rate is a function of the upstream pressure. For this condition to occur, the downstream pressure must be approximately 0.55 or less of the upstream pressure (Clegg (2007)). The difficulty of multiphase flow through chokes has not been adequately solved for all cases (Osman and Dokla (1990)). Tangren,

Dodge and Seifert (1949) performed the first analysis on gas-liquid two-phase flow through restrictions. They presented an analysis of the behavior of an expanding gas-liquid system. They demonstrated 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. Many empirical equations have been developed to estimate the relationship between production rate and wellhead pressure for two-phase critical flow. Gilbert (1954) suggested empirical correlation for critical flow through choke that predicts liquid flow rates as a function of flowing wellhead pressure,

gas-liquid ratio, and surface wellhead choke size. The author used production data from ten section field in California. Baxendall (1957) revised Gilbert's equation to update the coefficients based on incremental data. Ros (1959) published revised forms of the correlation proposed by Gilbert (1954) using updated regression parameters based on other data from different oil fields. Ros (1960) performed a theoretical analysis is presented of the mechanism of simultaneous flow of gas and liquid through a restriction at critical speed. This analysis led to develop an equation relating mass flow of gas and liquid, upstream pressure and choke size. To make Ros' correlation available to oil field workers, Poetmann and Beck (1963) converted the correlation to oil field units and reduced it to a graphical form. Poetmann and Beck concluded that variations in gas gravity on final results are very little and could be neglected. Their charts are not suitable if there is water production with oil. Omana, Brown, Houssiere, Brill and Thompson (1969) conducted experimental field tests at the facilities of Union Company of California's Tiger Lagoon Field in Louisiana to study the multiphase flow of gas and liquid (gas-water system) through a small-sized choke in a vertical position and used dimensional analysis to obtain their empirical equation. Although their correlation gave good matching with field tests that were used data which were employed to formulate correlation, this correlation is not widely accepted because of limitation of choke size, limitation in flow rate, limitation in pressure and using of water

instead of oil in the field experiments. Achong (1961) modified the Gilbert's equation to match the performance of wells in the Lake Maracaibo Field of Venezuela. Ashford and Peirce (1975) developed a mathematical model relating dynamic orifice performance in both critical and subcritical flow regimes. Orifice pressure losses and capacities were related to relevant fluid properties and choke dimensions. Graphical correlations were also presented to foresee the maximum capacity of an orifice for any known set of dynamic conditions. Their correlation involved three phase flow and was essentially an extension of Ros' correlation eliminating some of hypotheses made by Ros. Sachdeva, Schmidt, Brill, and Blais (1986) make theoretical model to calculate flow rate of choke through investigation of two-phase flow through wellhead chokes, including both critical and subcritical flow. Data were gathered for air-water and air-kerosene flows through five choke diameters from 0.25 in. (6.35 mm) to 0.5 in. (12.7 mm). They used Kerosene and water to cover the approximate range of liquid densities encountered in the field. Secen (1976), Pilehvari (1981), Osman and Dokla (1990) and Owolabi, Dune and Ajienka (1991) revised Gilbert's correlation and developed similar correlations with different constant and exponents. Elgibaly and Nashawi (1996) developed correlation to describe the choke performance of the Middle-East oil wells. Their correlation was formulated with well test data from fields in Kuwait, Libya, Egypt and other Middle-East countries. Mesallati, Bizanti and Mansouri (2000)

make evaluation to determine a generalized correlation which best fits and describes the multiphase fluid flow through well head chokes for offshore Bouri oil field in north of the Libyan coast in the Mediterranean Sea, based on actual production tests from vertical wells and horizontal wells in the same field. Ghareeb and Shedid (2007) attempted to overcome the limitations of the existing correlations for artificially flowing wells by development of a new correlation capable to calculate precisely the wellhead flow production. Their correlation was developed using a set of production test from wells in Egypt. This developed correlation includes several parameters of tubing size, wellhead and bottom-hole temperatures, producing gas-oil ratio, pay zone depth, and water cut. Alrumah and Bizanti (2007) used actual data production tests from vertical wells from Sabriyah Fields in Kuwait to establish a new generalized multiphase flow choke correlation that predicts liquid flow rates as a function of flowing wellhead pressure, surface choke size and gas-liquid ratio.

Data Acquisition

In this paper data from different oil wells in Iraqi oil fields were gathered to form a correlation that covers ranges of flow rates, gas-oil ratio and choke sizes. The reports of production test involve oil flow rates, choke sizes, downstream and upstream pressures and gas-oil ratios.

Chokes usually are selected so that fluctuations in the line pressure downstream of the choke have no effect on the production rate (Clegg (2007)). This requires that flow through the choke be at critical flow conditions. Under critical flow conditions, the flow rate is a function of the upstream pressure only. For this condition to occur, the downstream pressure must be approximately 0.55 or less of the upstream pressure (Clegg (2007)).

Figs. (1-3) show the distribution of production data that has been employed to introduce new correlation for calculating oil flow rate through choke.

Formulation of the Proposed Correlation

The formulation of new empirical equation for calculating the flow rate through choke of the critical flow is very complex because of :

1- Many variables affect the flow rate.

2- Detection the type of flow through choke.

3- Difficulty of gathering field tests.

4- No linear relationship between the affecting variables and the flow rate through choke.

The basic conception of regression analysis is to produce a linear or nonlinear combination of independent variables that will correlate as closely as possible with the dependent variable. Therefore the best manner to find the suitable form of the correlation is by using the

nonlinear regression analysis that searches the minimum difference between the observed and calculated oil flow rates. The nonlinear regression process for finding the best values of constants for the proposed correlation is nonlinear function, multivariable and constrained.

The formulation of nonlinear regression analysis has been taken as the difference between measured field oil flow rate and calculated oil flow rate from the proposed correlation as objective function that nonlinear regression technique searches its minimum value while the choke size, gas-oil ratio and upstream pressure were been taken as variables.

In this paper, many mathematical forms have been suggested to find the optimum one. All of them have been tested through comparison with measured data and the error analysis has applied for all of the suggested forms as shown in Table (1).

The following form has been selected because it gives the best statistical criteria among other suggested correlation forms.

$$Q = a_1 P^{a_2} D^{a_3} GOR^{a_4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table (2) includes the values of constant (a_1, a_2 , a_3 and a_4) of equation (1). The selection of constants (a_1, a_2 , a_3 and a_4) has been achieved using nonlinear estimation where the initial values of constants are assumed and are changed continuously until the minimum difference between the values of measured and calculated

oil flow rate is achieved. The statistical criteria in Table (1) give the comparison between the suggested correlation forms only but the selected form has to be subjected to other tests with published correlations as shown in the next section of the paper.

The suggestion of many forms has given depiction about the effect of each variable on the calculation of flow rate through chokes.

The choke size and upstream pressure are classified as major effective variables as shown in equation (5) in Table (1) where this equation includes only choke size and upstream pressure with average absolute percent relative error that is close to average absolute percent relative error of equation (1). The gas – oil ratio is categorized as minor effective variable because the equation (7) in Table (1) which its dependent variables are gas-oil ratio and upstream pressure and equation (12) in Table (1) that includes gas-oil ratio and choke size only have average absolute percent relative error (37.936 and 13.102 respectively) greater than equation (5) in Table (1). The statistical criteria of the equations (7) and (12) in table (1) are poor because of absences of choke size in equation (7) and upstream pressure in equation (12) while statistical criteria of equation (5) is good and near to the best statistical index of equation (1). Although equation (5) is not included gas – oil ratio as independent variable but the suggestion of suitable mathematical combination that includes the three variables gives the best criteria among other suggested forms which neglect one of three variables with considering the effective of each variable to

detect the feasibility of apply each of the equations (5), (7) or (12) depending on available field data.

Testing of Proposed Correlation

Five statistical criteria of deviations and graphical representations were used for evaluating the efficiency of the new correlation with the measured field data and with the calculated oil flow rates of the published correlations. The criteria involve the average percent relative error, the average absolute percent relative error, the standard deviation, the root mean square error and the correlation coefficient. The mathematical terminologies for these criteria are given as follow:

- Average percent relative error $= \frac{1}{N} \sum_{i=1}^{N} \left[\frac{(q_{measured} - q_{calculated})}{q_{measured}} \right]_i \times 100$

- Average absolute percent relative error
$$= \frac{1}{N} \sum_{i=1}^{N} \left| \left[\frac{(q_{measured} - q_{calculated})}{q_{measured}} \right]_i \right| \times 100$$

- Standard deviation $= \frac{1}{N} \left[N \sum_{i=1}^{N} \left(\left[\frac{(q_{measured} - q_{calculated})}{q_{measured}} \right]_i \times 100 \right)^2 - \right.$

$\left. \left(\sum_{i=1}^{N} \left[\frac{(q_{measured} - q_{calculated})}{q_{measured}} \right]_i \times 100 \right)^2 \right]^{0.5}$ The root mean square error

$$= \sqrt[2]{\frac{1}{N} \sum_{i=1}^{N} \left(\left[\frac{(q_{measured} - q_{calculated})}{q_{measured}} \right]_i \times 100 \right)^2}$$

- Correlation coefficient =

$$\frac{\sum_{i=1}^{N}(q_{measured} \times q_{calculated}) - \left(\frac{\sum_{1=1}^{N} q_{measured} \quad \sum_{1=1}^{N} q_{calculated}}{N}\right)}{\sqrt[2]{\left(\sum_{i=1}^{N} q_{measured}^2 - \frac{\left(\sum_{i=1}^{N} q_{measured}\right)^2}{N}\right)\left(\sum_{i=1}^{N} q_{calculated}^2 - \frac{\left(\sum_{i=1}^{N} q_{calculated}\right)^2}{N}\right)}}$$

A- Testing Using the Constructed Field Data

The two following processes of evaluation of the new correlation have been completed using the field data that were employed to find the optimum form of the new correlation.

1- Comparison with the Measured Data

Ninety – five percent of measured actual wellhead production rates from Iraqi producing wells are plotted versus predicted ones using the newly-developed correlation, equation 1, and graphically depicted in Figure 4. This graphical presentation reveals accurate prediction results with good matching between the calculated and measured oil flow rates. This comparison gives the first index of feasibility of the proposed correlation.

2- Comparison with the Published Correlations

The comparison has been achieved with eleven previous published correlations as shown in Table (3). This comparison states that the new correlation is more accurate than published correlations and gives the second index of practicability of the proposed correlation.

B- <u>Testing Using Non- Constructed Field Data</u>

In this section, the measured field data that are not used to formulate the new correlation are plotted versus the calculated oil flow rate using the new correlation and many published correlation as shown in Fig. (5) through (16). Fig. (5) presents good agreement between the field dad and the results of the new correlation while fig. (6) through (16) show very poor matching of the results for all used published correlations with the field data therefore these cross plots grant the third index of viability of the proposed correlation.

<u>Conclusions</u>

1. New correlation (equation (1)) is suggested for predicting oil flow rate through choke at critical flow for Iraqi oil wells. It includes gas-oil ratio, choke size and upstream pressure as independent variables.

2. The validity of the proposed correlation was tested against the data of Iraqi oil well that have been illustrated in Fig. (1), (2) and (3). The obtained results confirm the validity of the new correlation.

3. The accuracy of the new correlation has been evaluated in comparison with numerous correlations available in the literature for critical flow. Results of the statistical analysis demonstrated that the highest precision has been achieved with the new correlation.

Nomenclature

a_1, a_2, a_3 and a_4 : Constants of equation (1)

D: Choke size, (1/64) inch

GOR: Gas-Oil ratio, scf/STB

P: Upstream pressure, psi.

Q: Oil flow rate, STB/day

N: Number of field data.

References

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

2. Ajienka, J.A. and Ikoku, C.U., " A Generalized Model for Multiphase Flow Metering", SPE 17174, August 1987.

3. Alrumah M. and Bizanti M., "New Multiphase Choke Correlations for Kuwait Fields", presented at SPE Middle East Oil and Gas Show and Conference, Kingdom of Bahrain, , 11-14 March 2007.

4. Ashford, F.E. and Pierce, P.E., "Determining of multiphase pressure drops and flow capacities in down-hole safety valves" , Journal of Petroleum Technology, Vol. 27, Sept. 1975..

5. Baxendall, P. B., and Thomas, R.: "The Calculation of Pressure Gradients in High-Rate Flowing Wells,", Journal of Petroleum Technology, Vol. 13, Oct. 1961.

6. Clegg, J. D., "Petroleum Engineering Handbook, Volume IV-Production Operations Engineering" Copyright by Society of Petroleum Engineers, Richardson, TX , 2007.

7. Elgibaly, A. A. M. and Nashawi, I. S., "Prediction of Two-Phase Through Chokes for Middle – East Oil Wells" SPE 36274, October 1996.

8. Ghareeb M. and Shedid A. S., " A New Correlation for Calculating Wellhead Production Considering Influences of Temperature, GOR, and Water-Cut for Artificially Lifted Wells", prepared for presentation

at the International Petroleum Technology Conference held in Dubai, U.A.E., 4–6 December 2007.

9. Gilbert, W.E.: "Flowing and Gas-Lift Well Performance," Drill. & Prod. Prac., API, Dallas (1954) 126–57.

10. Mesallati, A., Bizanti, M, and Mansouri, N., " Multiphase-Flow choke correlations for Offshore Bouri Oil field," International Gas Union 21st World Gas Conference, Nice, France, June 6-9, 2000.

11. Nasriani, H. R. and Kalantariasl A., "Two Phase Flow Choke Performance in High Rate Gas Condensate Wells", presented at SPE Asia Pacific Oil and Gas Conference and Exhibition, Jakarta, Indonesia, 20-22 September 2011.

12. Owolabi, O. O., Dune, K. K. and Ajienka, J. A. , "Producing the Multiphase Flow Performance Through Wellhead Chokes for the Niger Delta Oil Wells", International Conference of the SPE Nigeria Section Annual Proceedings, August 1991.

13. Omana, R., Houssiere, C., Jr., Brown, K. E., Brill, J. P., and Thompson, R. E., " Multiphase flow through chokes", Presented at the SPE 44th Annual Meeting held 28–31 September 1969 in Denver, Colorado. SPE paper 2682.

14. Osman, M. E. and Dokla, M. E., "Gas condensate flow through chokes". SPE 20988, April 1990.

15. Pilehvari, A. A., "Experimental study of critical two-phase flow through wellhead chokes", Tulsa, OK: University of Tulsa Fluid Flow Projects Report, June 1981.

16. Poettmann, F. H., and Beck, R. L., "New Charts Developed to Predict Gas-Liquid Flow Through Chokes," World Oil, March 1963 .

17. Ros, N. C. J., "An Analysis of Critical Simultaneous Gas/Liquid Flow Through a Restriction and Its Application to Flow metering," Applied Science Research, (1960), Vol. 9, PP. 374–389.

18. Sachdeva, R., Schmidt, Z., Brill, J.P., Blais, R.M., "Two-Phase Flow Through Chokes", presented at SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 5-8 October 1986.

19. Secen, J. A., "Surface-choke measurement equation improved by field testing and analysis", Oil and Gas Journal , Vol. 30, August 1976.

20. Tangren, R. F., Dodge, C. H., and Seifert, H. S., "Compressibility effects in two-phase flow", J. Applied Physics, Vol. 20, 1949.

Tables and Figures

Table (1)

No. of Eq.	Suggested Form	Average Percent Relative Error	Average Absolute Percent Relative Error	Standard Deviation	The Root Mean Square Error	The Correlation Coefficient
1.		0.273	4.523	7.225	7.23	0.997
2.	$a_1\, P^{a_2} +\, a_3\, D^{a_4} +\, a_5\, GOR^{a_6}$	-0.405	7.777	11.236	11.243	0.996
3.	$a_1\, P^{a_2} +\, a_3\, D^{a_4} +\, a_5\, GOR^{a_6} +\, a_7$	-0.378	7.687	11.105	11.112	0.996
4.		-0.711	4.747	7.469	7.502	0.997
5.		0.306	5.203	7.996	8.002	0.996
6.		-0.865	5.472	8.425	8.469	0.997
7.		-19.035	37.936	45.104	48.956	0.938
8.		-17.484	37.725	45.611	48.847	0.938
9.	$a_1\, P^{a_2} +\, a_3\, P^{a_4} +\, a_5\, P^{a_6} +\, a_7$	-14.251	34.638	45.252	47.443	0.943
10.		-7.345	19.789	26.433	27.435	0.971
11.		-7.207	19.757	26.351	27.318	0.971

12.		-0.306	13.102	17.129	17.13219	0.988
13.		-1.582	12.712	16.864	16.938	0.989
14.	$a_1 GOR^{a_2} D^{a_3} P^{GOR^{a_4} D^{a_5}} + a_6$	-2.568	12.359	16.795	16.99	0.99
15.	$a_1 e^{(a_2 P)} + a_3 e^{(a_4 GOR)} + a_5 e^{(a_6 D)}$	-2.493	8.946	13.558	13.786	0.995
16.	$a_1 e^{(a_2 P)} + a_3 e^{(a_4 GOR)} + a_5 e^{(a_6 D)} + a_7$	-0.639	8.126	12.187	12.203	0.995
17.	$a_1 P^{a_2} + a_3 e^{(a_4 GOR)} + a_5 D^{a_6}$	-1.831	7.439	10.686	10.842	0.996
18.	$a_1 P^{a_2} + a_3 e^{(a_4 GOR)} + a_5 D^{a_6} + a_7$	-2.566	12.507	16.828	17.022	0.99

Table (2)

Constant	a_1	a_2	a_3	a_4
The value	19049.65	-0.69	0.704	0.101

Table (3)

Suggested Form	Average Percent Relative Error	Average Absolute Percent Relative Error	Standard Deviation	The Root Mean Square Error	The Correlation Coefficient
The New Correlation	0.273	4.523	52.731	7.23	0.981
Gilbert	57.709	58.858	29.047	64.607	0.903
Baxendell	48.928	53.313	35.793	60.623	0.901
Ros	51.247	54.808	35.087	62.108	0.898
Achong	45.806	51.979	37.771	59.37	0.9
Secen	42.826	51.873	41.148	59.39	0.898
Pilehvari	8.18	58.022	67.785	68.276	0.898
Osman-Dokla	81.731	81.731	12.041	82.613	0.909
Owolabi , Dune and Ajienka	48.621	51.751	32.840	58.673	0.913
Elgibaly and Nashawi	57.926	58.528	25.664	63.357	0.912
Mesallati, Bizanti and Mansouri	64.841	65.256	22.938	68.779	0.88
Alrumah and Bizanti	48.230	52.193	34.327	59.199	0.912
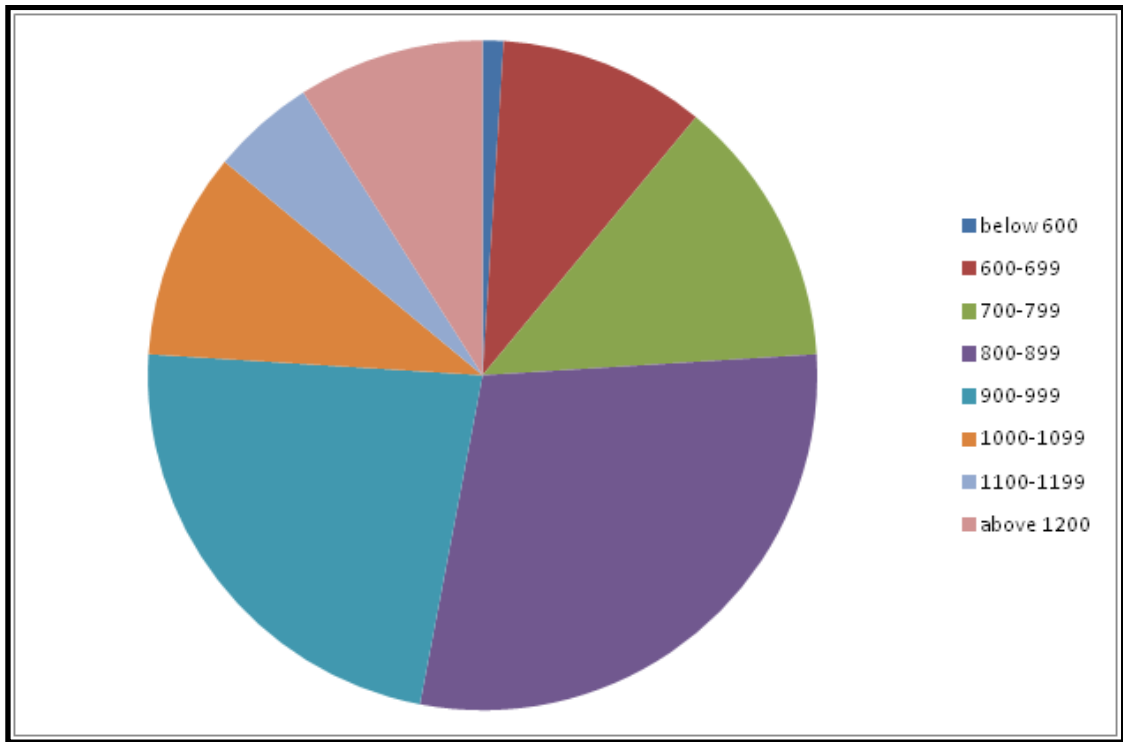
Fig. (1) The distribution of upstream pressure (psi) for overall data
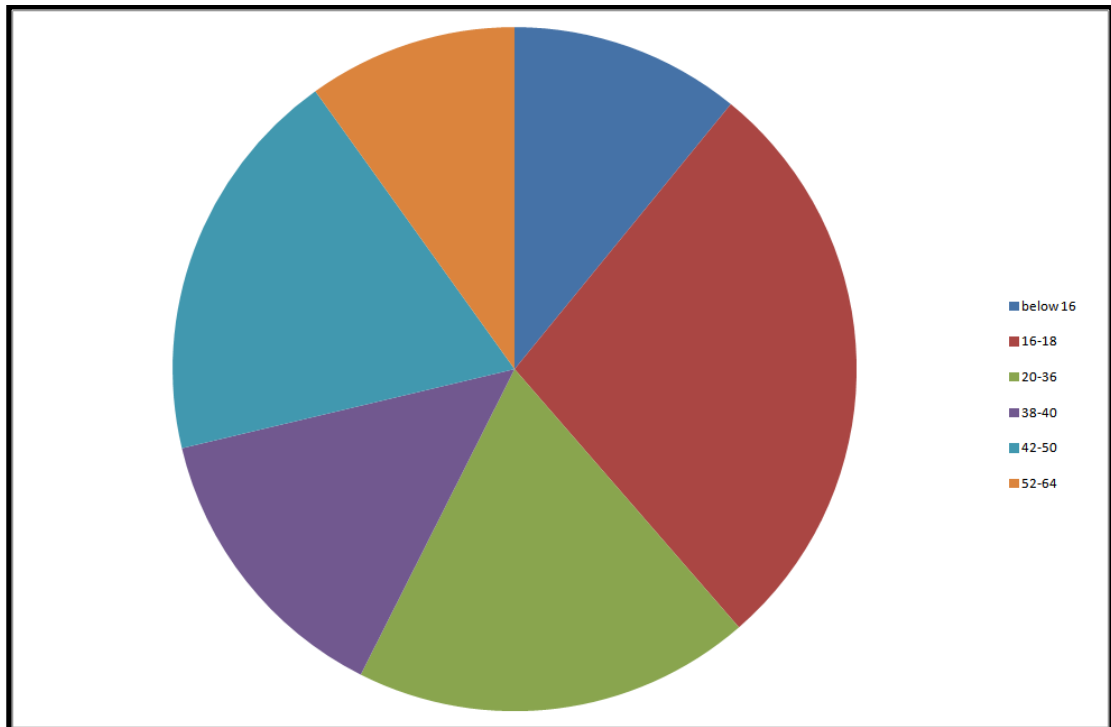
Fig. (2) The distribution of choke size (1/64'') for overall data
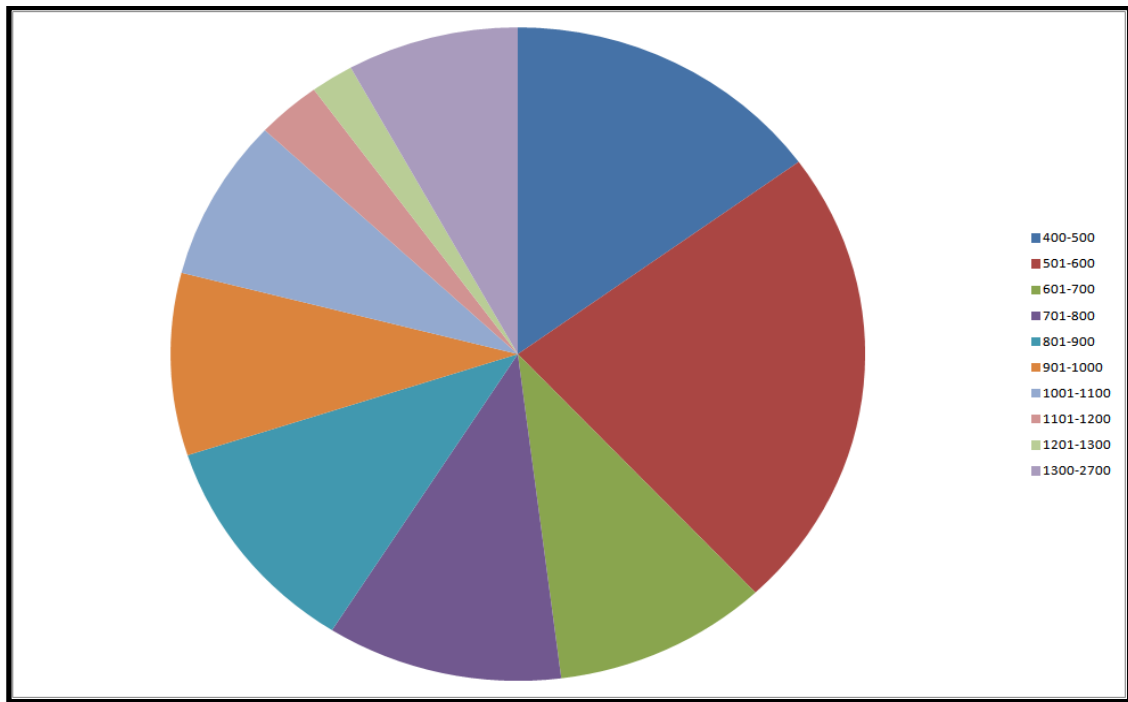
Fig. (3) The distribution of gas-oil ratio (scf/STB) for overall data
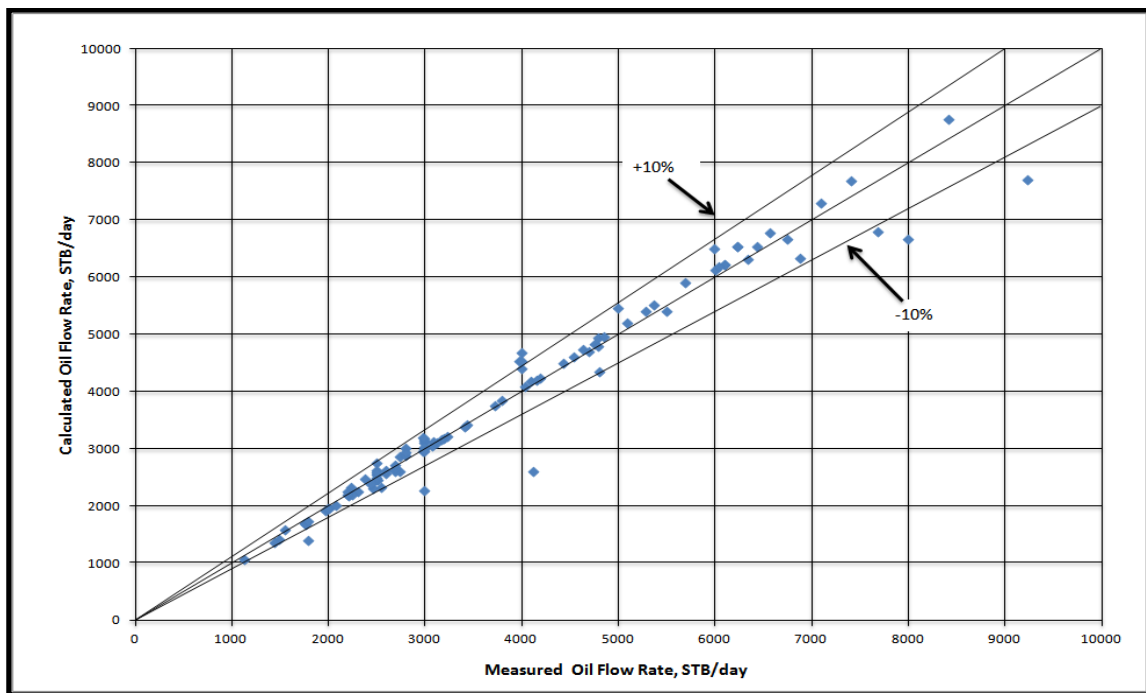
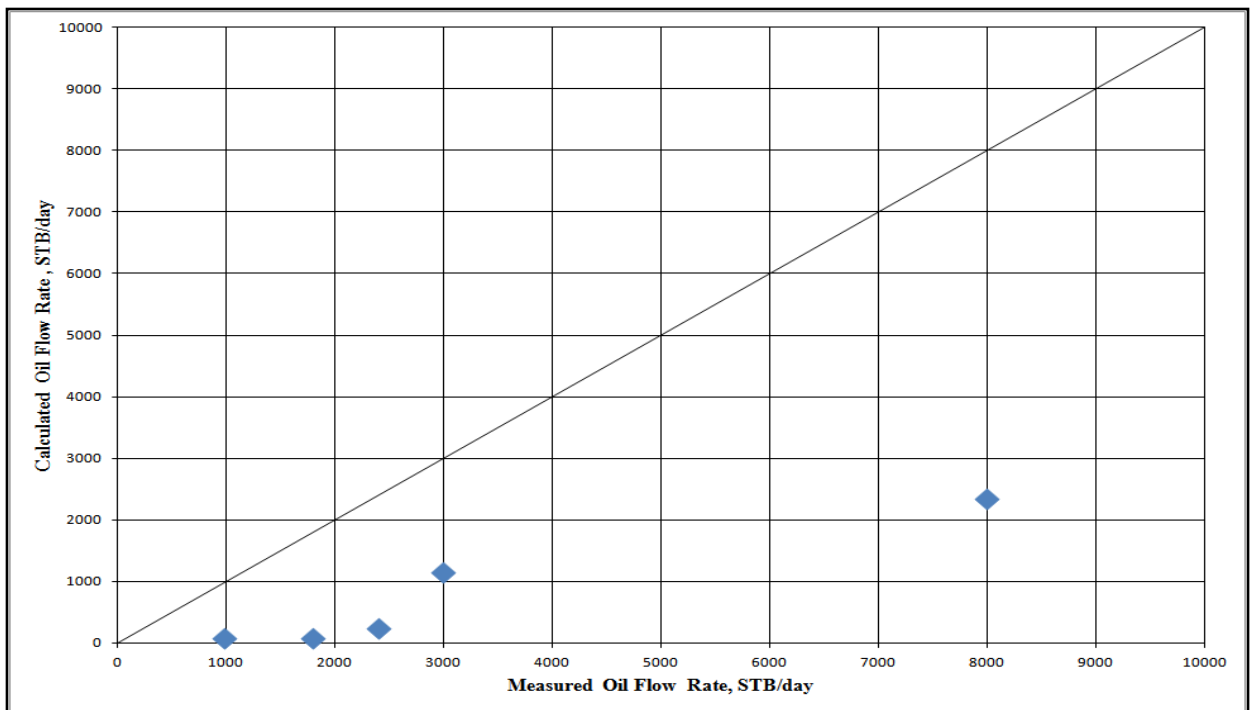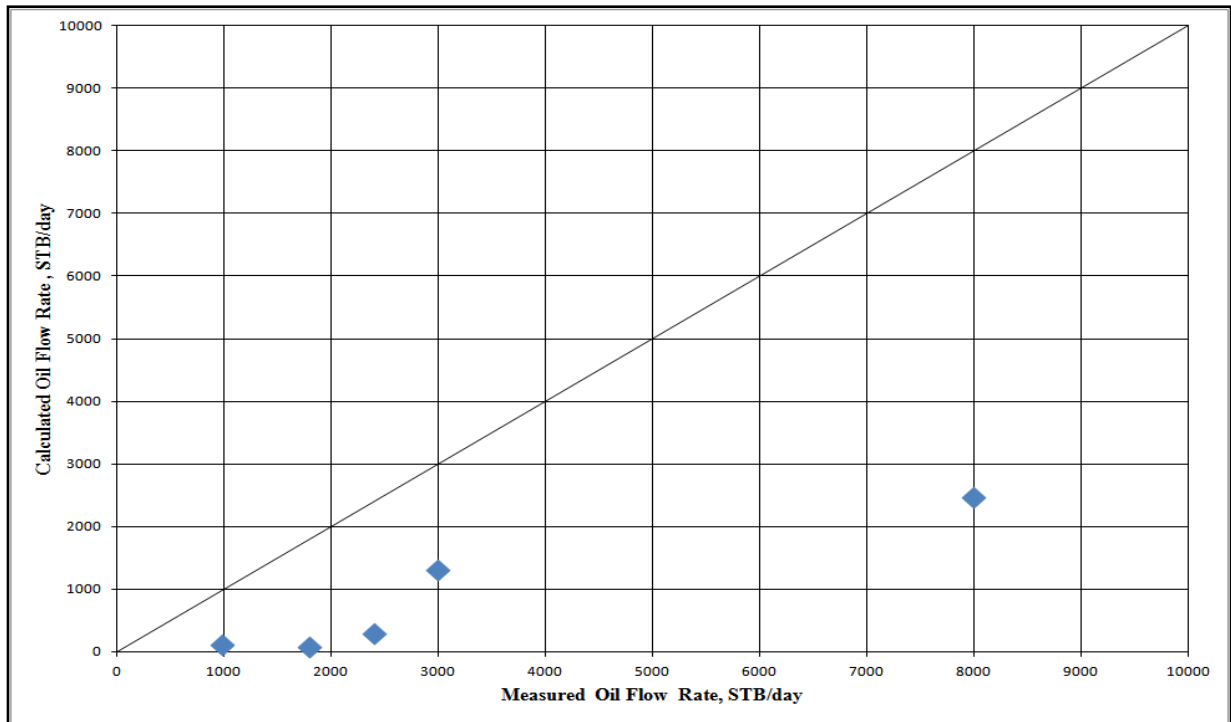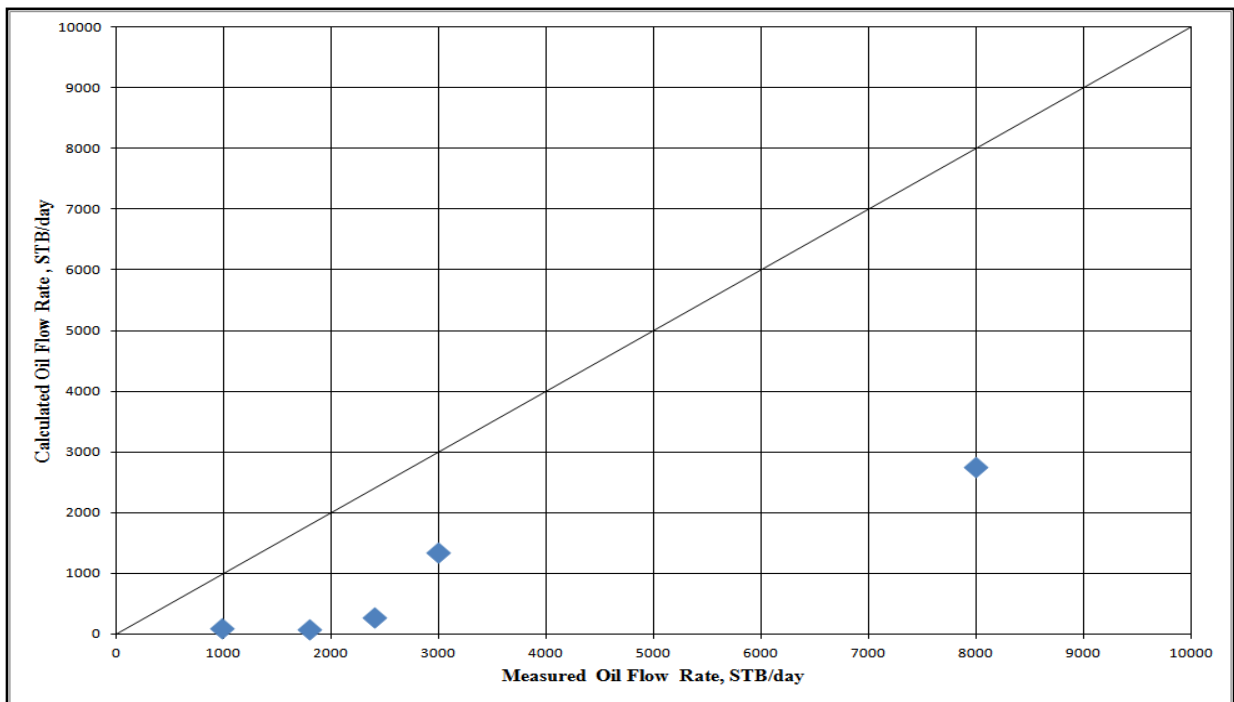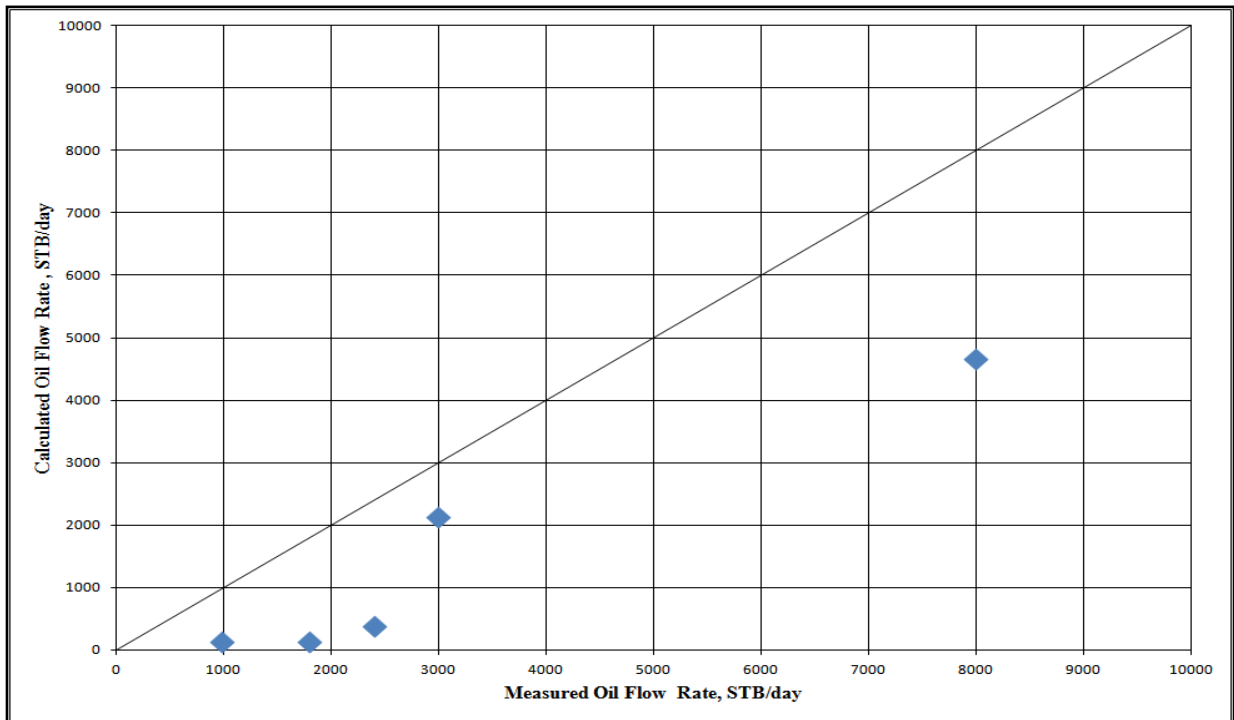**Fig. (4) Calculated oil flow rate versus actual measured oil flow rate**
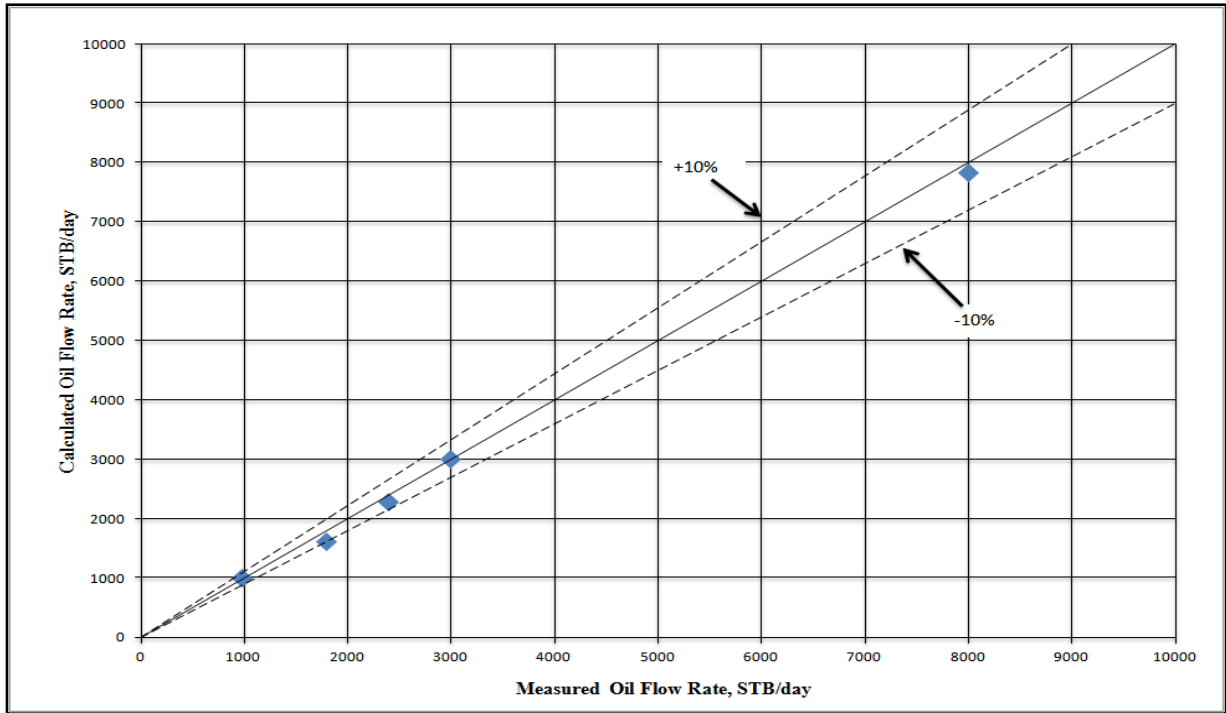
Fig. (5) Comparison of measured data and calculated oil flow rate by new correlation
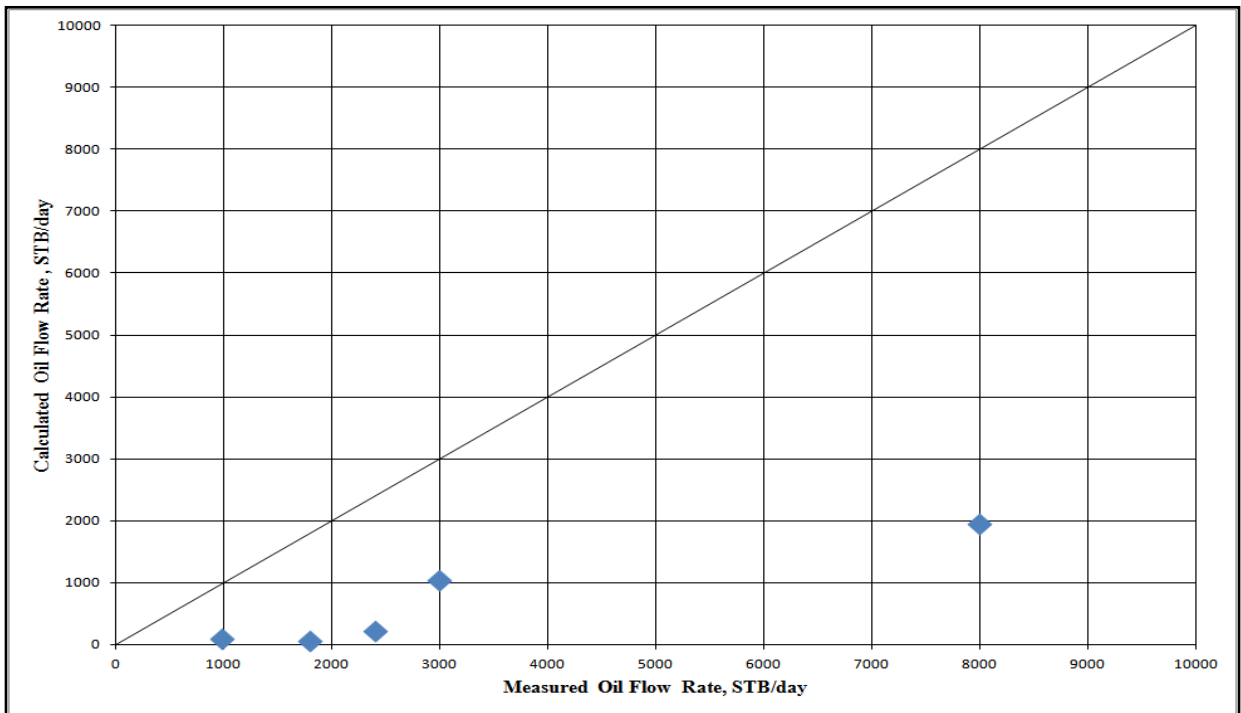
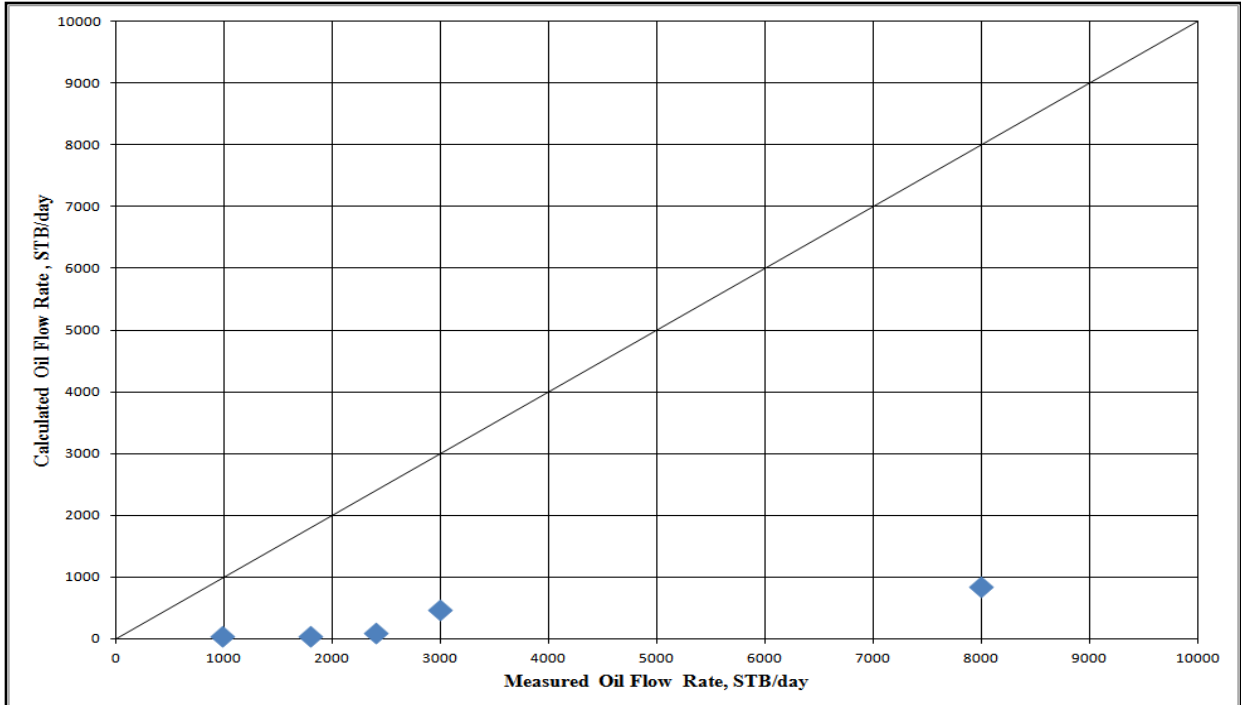**Fig. (6) Comparison of measured data and calculated oil flow rate by Gilbert's correlation**
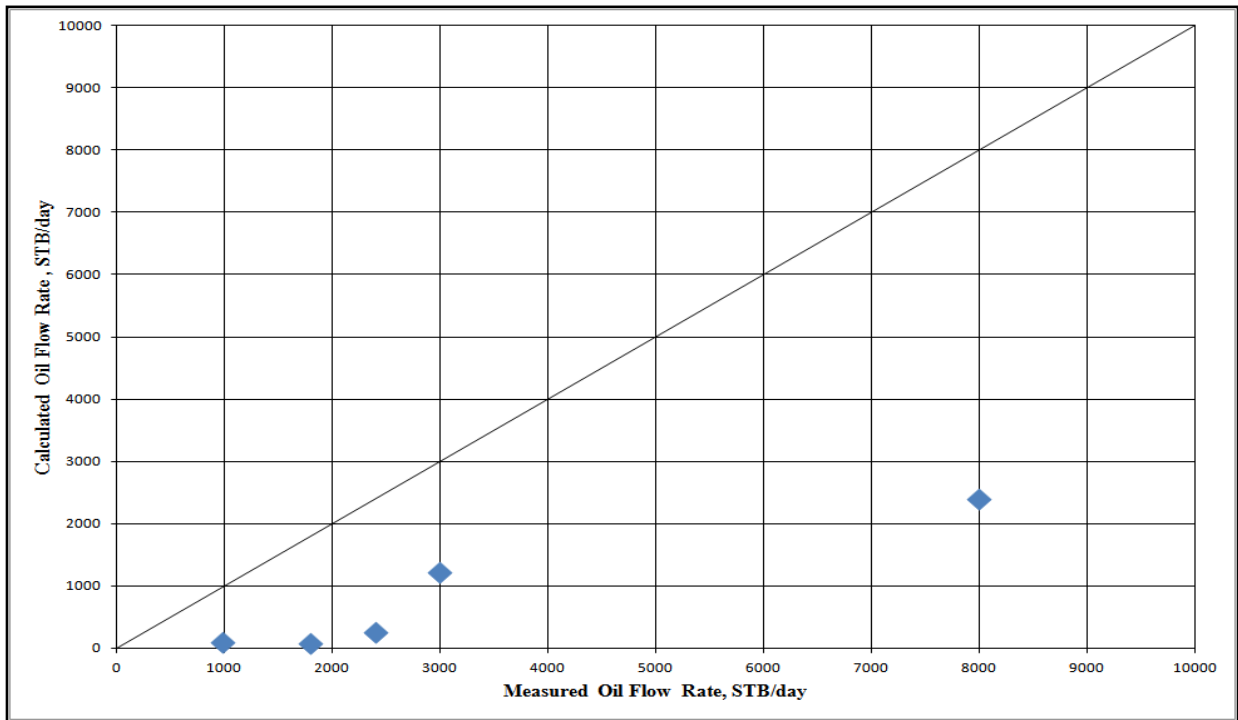
Fig. (7) Comparison of measured data and calculated oil flow rate by Baxendall's correlation

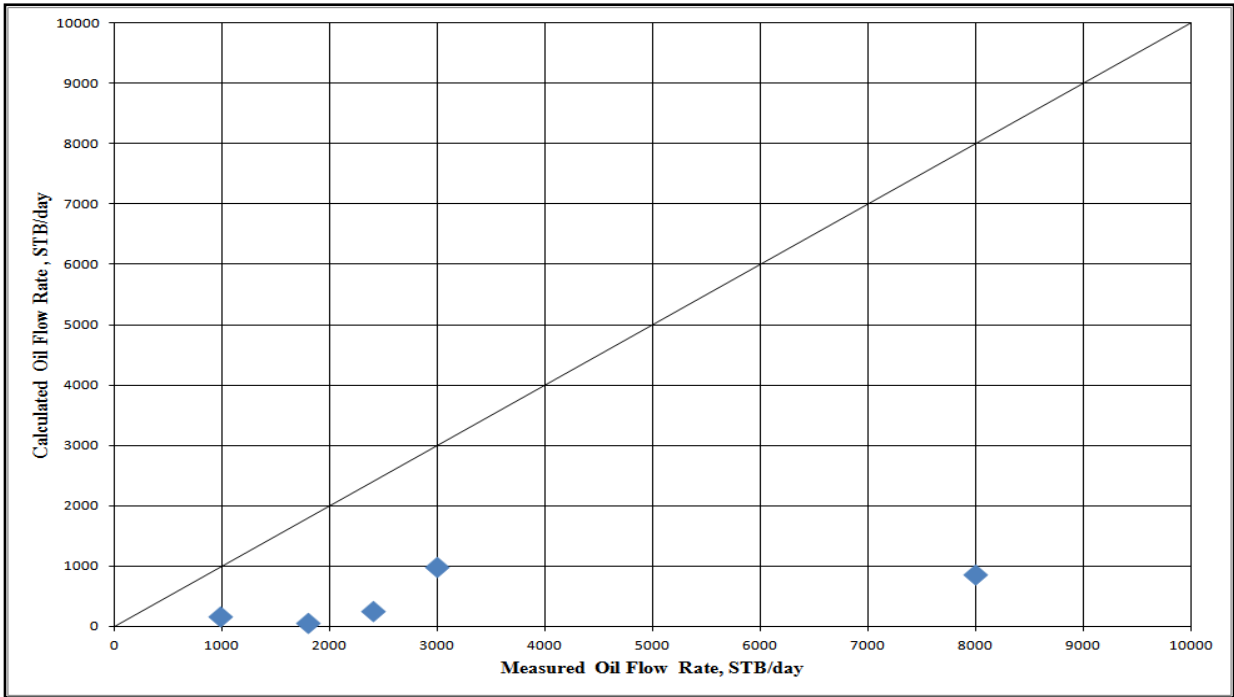**Fig. (8) Comparison of measured data and calculated oil flow rate by Ros' correlation**

Fig. (9) Comparison of measured data and calculated oil flow rate by

Achong's correlation

Figure (10) Comparison of measured data and calculated oil flow rate by

Secen's correlation

Fig. (11) Comparison of measured data and calculated oil flow rate by Pilehvari's correlation

Figure (12) Comparison of measured data and calculated oil flow rate by Osman and Dokla's correlation

Fig. (13) Comparison of measured data and calculated oil flow rate by Owolabi, Dune and Ajienka's correlation
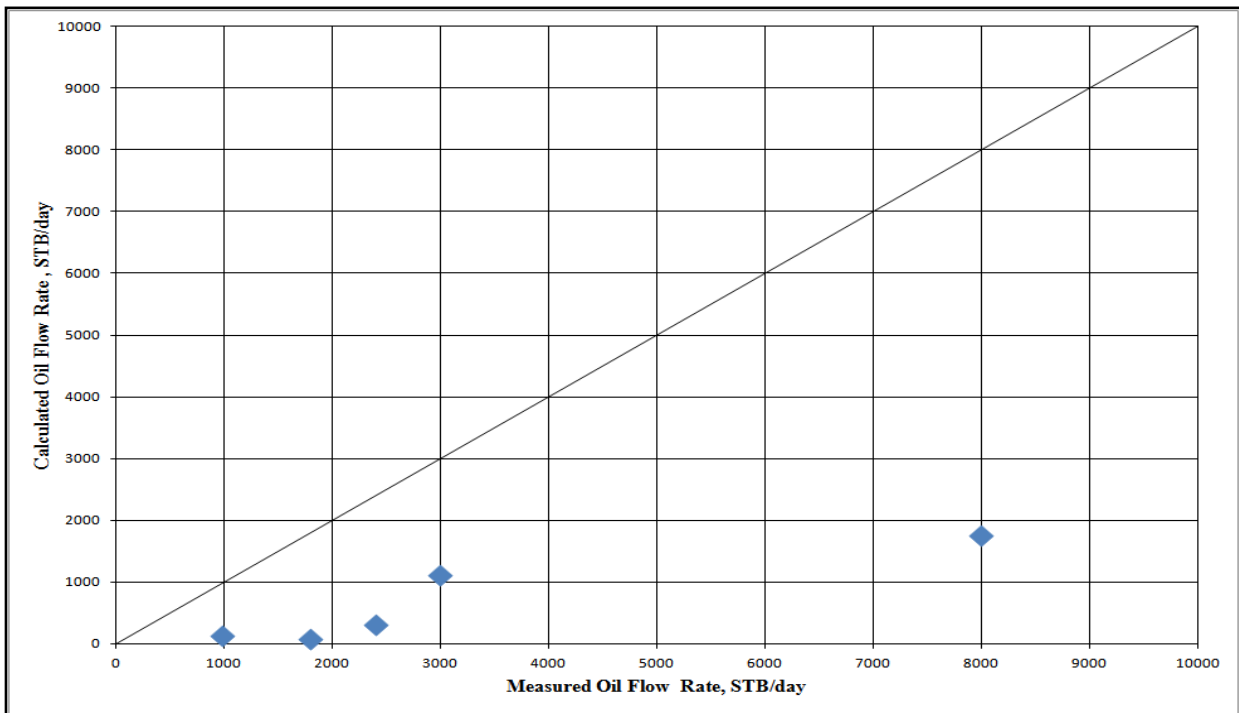

Fig. (14) Comparison of measured data and calculated oil flow rate by Elgibaly and Nashawi's correlation
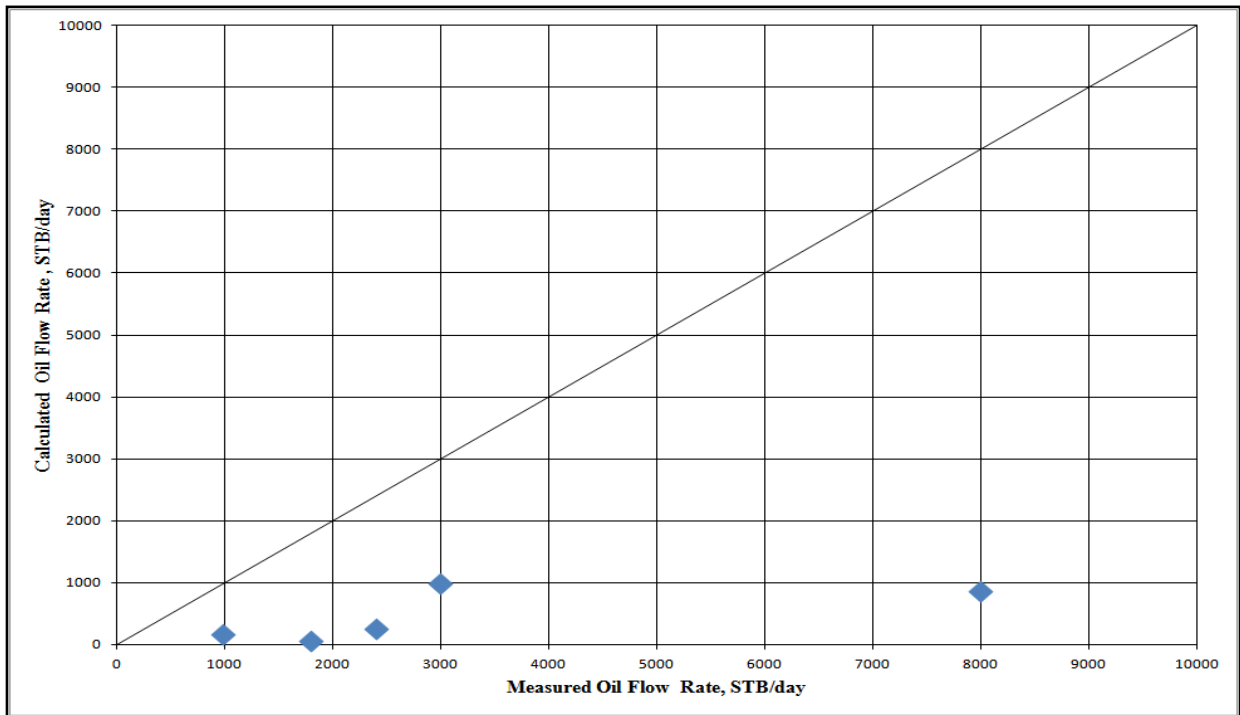
Fig. (15) Comparison of measured data and calculated oil flow rate by Mesallati, Bizanti and Mansouri's correlation
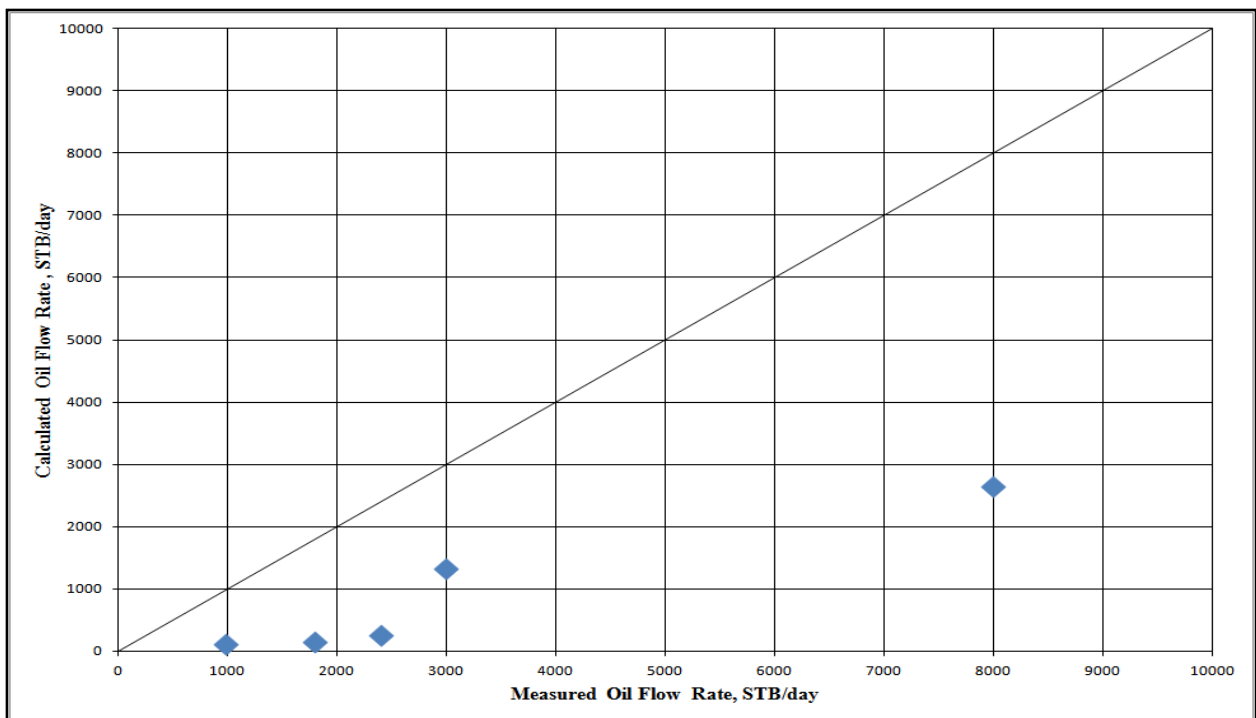

Fig. (16) Comparison of measured data and calculated oil flow rate by Alrumah and Bizanti's correlation