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A Comprehensive Study on the Current Pressure Drop Calculation in Multiphase Vertical Wells; Current Trends and Future Prospective

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Abstract: A reliable estimation of the pressure drop in well tubing is essential for the solution of a number of important production engineering and reservoir analysis problems. Many empirical correlation and mechanistic models have been proposed to estimate the pressure drop in vertical wells that produce a mixture of oil, water and gas. Although, many correlations and models are available to calculate the pressure loss, these models developed based on certain assumption and for particular range of data where it may not be applicable to be used in different sets of data. This study presents an investigation on the predictive performance evaluation for the reliable methods used to calculate the pressure drop in multiphase vertical wells taking into consideration the dimensions of each model. Most correlations and models created to calculate pressure drop were developed based on accurately and reliably measured flow parameters. However, it can only work best on the proposed data range. Statistical error analysis and graphical error analysis are used to analyze the variation between predicted values and actual ones. Hence, it showed most reliable methods that can perform well in different well conditions. Based on the analysis of this study, the artificial neural network models had showed better prediction accuracy and minimum number of variables even if other data beyond the range of data is used.

Key words: Model, multiphase flow, oil and gas industry

INTRODUCTION

Multiphase flow in pipes is the process of simultaneous flow of two phases or more. In oil or gas production wells the multiphase flow usually consist of oil, gas and water. The estimation of the pressure drop in vertical wells is quite important for cost effective design of well completions, production optimization and surface facilities. However, due to the complexity of multiphase flow several approaches have been used to understand and analysis the multiphase flow.

Oil and gas industry is needed to have a general method for forecasting and evaluating the multiphase flow in vertical pipes (Poettman and Carpenter, 1952). Multiphase flow correlations are used to determine the pressure drop in the pipes. Although, many correlation and models have been proposed to calculate pressure drop in vertical well, yet it's still arguing about the effectiveness of these proposed models.

Numerous correlations and equations have been proposed for multiphase flow in vertical, inclined and horizontal wells in the literature. Early methods treated the

multiphase flow problem as the flow of a homogeneous mixture of liquid and gas. This approach completely disregarded the well-known observation that the gas phase, due to its lower density, overtakes the liquid phase resulting in "slippage" between the phases. Slippage increases the flowing density of the mixture as compared to the homogeneous flow of the two phases at equal velocities. Because of the poor physical model adopted, calculation accuracy was low for those early correlations. Another reason behind that is the complexity in multiphase flow in the vertical pipes. Where water and oil may have nearly equal velocity, gas have much greater one. As a results, the difference in the velocity will definitely affect the pressure drop.

Many methods have been proposed to estimate the pressure drop in vertical wells that produce a mixture of oil and gas. The study conducted by Pucknell *et al.* (1993) concludes that none of the traditional multiphase flow correlations works well across the full range of conditions encountered in oil and gas fields. Besides, most of the vertical pressure drop calculation models were developed for average oilfield fluids and this is why special

conditions such as: Emulsions, non-Newtonian flow behavior, excessive scale or wax deposition on the tubing wall, etc., can pose severe problems. Accordingly, predictions in such cases could be doubtful (Takacs, 2001).

The early approaches used the empirical correlation methods such as (Hagedorn and Brown, 1965; Duns and Ros, 1963; Orkiszewski, 1967). Then the trend shift into mechanistic modelling methods (Ansari *et al.*, 1994; Aziz and Govier, 1972) and lately the researchers have introduced the use of artificial intelligence into the oil and gas industry by using artificial neural networks such as (Ayoub, 2004; Mohammadpoor *et al.*, 2010).

The main purpose of this study is to evaluate and assess the current empirical correlations, mechanistic model and artificial neural networks for pressure drop estimation in multiphase flow in vertical wells by comparing the most common methods in this area. The parameters affecting the pressure drop are very important for the pressure calculation. Therefore, it will also be taken into account in the evaluation.

EMPIRICAL CORRELATIONS

The empirical correlation was created by using mathematical equations based on experimental data. Most of the early pressure drop calculation was based on this correlations because of its direct applicability and fair accuracy to the data range used in the model generation. In this study, the empirical correlations for pressure drop estimation in multiphase flow in vertical wells are reviewed and evaluated with consideration of its required dimensions, performance, limitation and range of applicability.

This empirical correlation is resulted from laboratory experiments with some modification and adjustments in the correlation by using actual field data. Duns and Ros (1963) correlation is in terms of a dimensionless gas velocity number, diameter number, liquid velocity number and a dimensionless mathematical expression. The acceleration gradient is neglected in the methods. Although, this method is developed to calculate the pressure drop with dry oil/gas mixtures, it can also be used with wet oil/gas mixtures in some cases.

Correlation is one of the most common correlations used in the industry. Hagedorn and Brown (1965) developed a correlation using an experimental study of pressure gradients occurring during continuous two-phase flow in small diameter vertical conduits, a 1500 ft vertical wellbore and considering 5 different fluids types in the experiment which is water and four types of

oil. This correlation involves only dimensionless groups of variables and it can be applied over a much wider range of conditions compared to other correlations.

This correlation had developed an equation for two-phase pressure drops in flowing and gas-lift production wells over a wide range of well conditions with range of precision about 10%. The method is an extension of the study by Griffith and Wallis (1961). The correlation is valid for several flow regimes such as; bubble flow, slug flow, transition flow and annular-mist flow. Orkiszewski (1967) proved his assumptions by comparing the measured pressure drop results of 184 wells to the calculated ones. The parameters considered in his equation for the pressure drop are the effect by the energy lost by friction, the change in potential energy and the change in kinetic energy. The results obtained by these methods are still applicable for wide range of well conditions (e.g., heavy oil). But, there are some well conditions that have not been evaluated (e.g., flow in the casing annulus and in the mist flow regime).

Beggs and Brill (1973), developed a method to predict the pressure drop for horizontal, inclined and vertical flow. It also takes into account the several flow regimes in the multiphase flow. Therefore, Beggs and Brill (1973) correlation is the most widely used and reliable one by the industry. In their experiment, they used 90 ft long acrylic pipes data. Fluids used were air and water and 584 tests were conducted. Gas rate, liquid rate and average system pressure was varied. Pipes of 1 and 1.5 inch diameter were used. The parameters used are gas flow rate, Liquid flow rate, pipe diameter, inclination angle, liquid holdup, pressure gradient and horizontal flow regime. This correlation has been developed so it can be used to predict the liquid holdup and pressure drop.

API (1978) stated that the Gray correlation was developed by Gray (1978), specifically for wet gas wells. Although, this correlation was developed for wet gas vertical flow but it can also be used in multiphase vertical and inclined flow. In his correlation flow is treated as single phase and dropped out water or condensate is assumed to adhere to the pipe wall. The parameters considered in this method are the phase velocity, tube size gas condensate ratio and water ratio. The pressure difference due to friction is calculated using the Fanning friction pressure loss equation.

Mukherjee and Brill (1985) proposed a correlation for Pressure loss, Holdup and flow map. Their correlation was developed following a study of pressure drop behaviour in two-phase inclined flow. However, it can also be applied to vertical flow. Prior knowledge of the liquid

holdup is needed to compute the pressure drop using Mukherjee and Brill (1985) correlation. The results obtained from their experiments were verified with Prudhoe Bay and North Sea data.

MECHANISTIC MODELS

Mechanistic models or known also as semi-empirical correlations deal with the physical phenomena of the multiphase flow. These kinds of models are developed by using mathematical modelling approach. A fundamental hypothesis in this type of models is the existence of various flow configurations or flow patterns, including stratified flow, slug flow, annular flow, bubble flow, churn flow and dispersed bubble flow. The first objective of this approach is thus, to predict the existing flow pattern for a given system. Although, most of the current presented mechanistic models have been developed under certain conditions which limit their ability to be used in different range of data, these models are expected to be more reliable and general because they incorporate the mechanisms and the flow important parameters (Gomez *et al.*, 2000).

Aziz and Govier (1972), have proposed a simple mechanistically based scheme for pressure drop calculation in wells producing oil and gas. The scheme was based on the identification of the flow pattern map. The mechanical energy equation was presented in the relationship between the pressure gradient, the flow rate, the fluid properties and the geometry of the flow duct. While the model proposed new equations for bubble and slug flow patterns, it recommended the old Dun and Ros equations for annular mist pattern. The new prediction method incorporates an empirical estimation of the distribution of the liquid phase between that flowing as a film on the wall and that entrained in the gas core. It employs separate momentum equations for the gas-liquid mixture in the core and for the total contents of the pipe. The model has presented 44 values of predicted pressure drop with absolute error almost equal to that for Orkiszewski (1967) correlation. However, the uncertainties and lack of some field data made it difficult to develop a fully mechanistically, reliable based computation method.

Mechanistic model is developed by Ansari *et al.* (1994), for upward two-phase flow in wellbores. This model was developed as part of the Tulsa University Fluid Flow Projects (TUFFP) research program. The model predicted the existence of four flow patterns which are; bubble flow, slug flow, churn flow and annular flow. The model was evaluated by using the TUFFP well databank

that is composed of 1775 well cases, with 371 of them from Prudhoe Bay data. Ansari *et al.* (1994) claimed that the overall performance of the comprehensive model is superior to all other methods considered with an exception of Hagedorn and Brown (1965) empirical correlation due to extensive data used in its development and modifications made to the correlation.

ARTIFICIAL NEURAL NETWORKS

An artificial neural networks model is a structure (network) composed of a number of interconnected units (artificial neurons). Each unit has an Input/Output (I/O) characteristic and implements a local computation or function (Jahanandish *et al.*, 2011). It has been only a few years since neural networks first gained popularity. In the past two to three years banks, credit card companies, manufacturing companies, high tech companies and many more institutions have adopted neural nets to help in their day-to-day operation. Most researchers believe that artificial neural networks may be able to produce what rule based artificial intelligence (expert systems) have promised for so long but failed to deliver.

The use of Artificial Neural Networks (ANNs) in petroleum industry can be tracked back several years ago. The literature has many industry problems solved by several authors using ANNs models. ANNs have been used in several area of oil and gas industry such as; permeability prediction, well testing, enhanced oil recovery, PVT properties prediction, improvement of gas well production, prediction and optimization of well performance and integrated reservoir characterization and portfolio management (Ayoub, 2004).

Experience showed that empirical correlations and mechanistic models failed to provide a satisfactory and reliable tool for estimating pressure drop in multiphase flowing wells. Large errors are usually associated with these models and correlations (Takacs, 2001). Artificial neural networks gained wide popularity in solving difficult and complex problems, especially in petroleum engineering (Mohaghegh and Ameri, 1995).

Ayoub (2004) model, presented an Artificial Neural Networks (ANNs) model for prediction bottom-hole flowing pressure and consequently the pressure drop in vertical multiphase flow. The model was developed and tested using field data covering a wide range of variables. A total of 206 field data sets collected from Middle East fields; were used to develop the ANN model. These data sets were divided into training, cross validation and testing sets in the ratio of 3:1:1. The testing subset of data

which was not seen by the ANN model during the training phase, was used to test the prediction accuracy of the model. Trend analysis of the model showed that the model correctly predicted the expected effects of the independent variables on bottomhole flowing pressure. This indicated that the model simulates the actual physical process. Although, the results showed that his model significantly outperformed all existing methods and provided predictions with higher accuracy. The author claimed that his model can be used only within the range of used data. Consequently, caution should be taken beyond the range of used input variables. Ayoub (2004) model demonstrates the power of artificial neural networks model in solving complicated engineering problems.

SOURCE OF DATA

A total of 260 data sets were collected from different Middle East fields and believed to be quite reliable. The data used for comparing the different pressure predicting methods covers an oil rate from 45-19618 BPD, water cut upto 91.8%, oil gravity from 13.60-37.00 API and wellhead pressure from 5-640 psi. All data sets which consistently resulted in poor predictions by all correlations and mechanistic models were considered to be invalid; hence, it has been removed. Table 1 shows the statistical analysis of the used data.

Selected methods for evaluation: Based on the extensive literature study carried out by the authors, six empirical correlations, from which two mechanistic models and one artificial neural networks model were selected for evaluation. These are:

- Ansari *et al.* (1994) model
- Ayoub (2004) model
- Aziz and Govier (1972) model
- Beggs and Brill (1973) correlation
- Duns and Ros (1963) correlation
- Gray (1978) correlation
- Hagedorn and Brown (1965) correlation

- Mukherjee and Brill (1985) correlation
- Orkiszewski (1967) correlation

EVALUATION PROCESS

The common obstacle for using a pressure drop method whether it's an empirical correlation, a mechanistic model or an artificial neural network model that most of these models are applicable for specific range of data and conditions in order to predict the pressured drop accurately. However, in some cases, it can work well also in some actual filed data with acceptable perdition error.

To analyse and compare the effectiveness of each correlation or model, the values of both measured and predicted pressure drop are recorded. All the selected correlations and models are evaluated using actual filed data where the predicted pressure drop is compared to the measured one. The analysis is conducted via statistical and graphical error analysis.

Statistical error analysis has been used to check the accuracy of the model. The statistical parameters used in this study are average absolute percent relative error, average percent relative error, maximum absolute percentage error, minimum absolute percentage error, root mean square error, coefficient of determination and the standard deviation of error. Equations for those parameters are given in the appendix. To confirm the obtained results only one graphical error analysis used which is cross plot. Cross plots were used to compare the performance of all the selected models. A 45° straight line between the calculated pressure drop values versus measured pressure drop values is plotted which represents a perfect correlation line. When the values go closer to the line, it indicates better agreement between the measured and the estimated values.

MODEL EVALUATION

The evaluation for each methods will be based on the bottom hole pressure prediction and then and the estimated pressure drop. Table 2 shows the average absolute percentage relative error, average percentage relative error, maximum absolute relative error, minimum absolute relative error, root mean square error, coefficient of determination and the Standard deviation of all the selected methods (Appendix 1). Aziz and Govier (1972) model has achieved the highest average absolute percentage relative error with 12.1% while Ayoub (2004) model achieved the lowest value with 4.8%. Figure 1 shows the absolute and relative error of each empirical correlation, mechanistic model and artificial neural networks.

Table 1: Statistical analysis of the used data

Flow parameter	Min	Max	Average	STD
Bottomhole pressure (psi)	1019.79	3105.00	2205.30	486.66
Oil rate (bbl/D)	45.20	19618.00	4552.16	4598.26
Water rate (bbl/D)	0.00	7900.00	1784.68	2368.18
Gas rate (Mscf/D)	0.00	12495.00	2203.67	2755.98
Depth (ft)	2726.38	8070.87	5810.17	1049.09
Tubing diameter (in)	2.00	4.00	3.75	0.33
Surface temperature (°F)	70.00	160.00	113.55	27.44
Wellhead pressure (psi)	5.00	640.00	240.81	148.88
Oil gravity (API)	13.60	37.00	30.77	5.85

Table 2: Statistical analysis results of the selected methods

Method	AAPE	APE	MaxAPE	MinAPE	RMSE	R ²	STD
Aziz and Govier (1972)	12.0968	5.8956	46.6863	0.1688	15.8240	0.5158	14.6847
Hagedorn and Brown (1965)	11.9864	10.3126	31.3833	0.2806	13.7535	0.8065	9.0999
Gray (1978)	11.8941	9.9174	50.6174	0.4964	14.3411	0.7875	10.3591
Orkiszewski (1967)	11.0000	8.7381	26.7816	0.0611	13.0893	0.7692	9.7455
Mukherjee and Brill (1985)	9.1695	4.0663	39.3635	0.0004	11.4425	0.7981	10.6956
Ansari <i>et al.</i> (1994)	7.6344	4.9474	24.2722	0.0475	9.5011	0.8442	8.1114
Duns and Ros (1963)	7.5593	8.5755	30.0916	0.0851	9.3525	0.8537	8.6421
Beggs and Brill (1973)	6.4278	2.1967	24.9539	0.0851	8.2240	0.8667	7.9252
Ayoub (2004)	4.8010	1.3000	20.1594	0.0150	6.6274	0.9095	6.4987

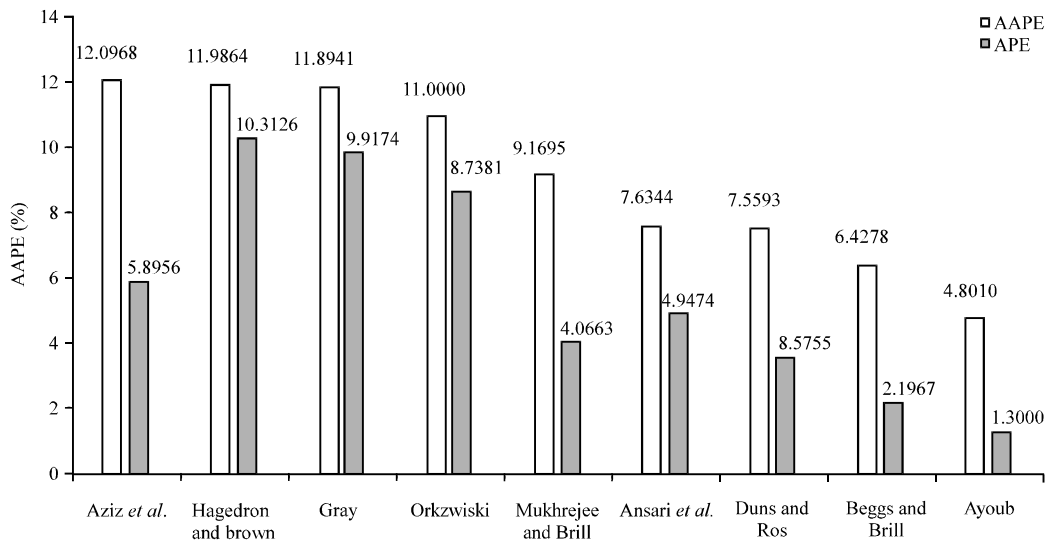


Fig. 1: Absolute (AAPE) and relative (APE) percentage error of all models

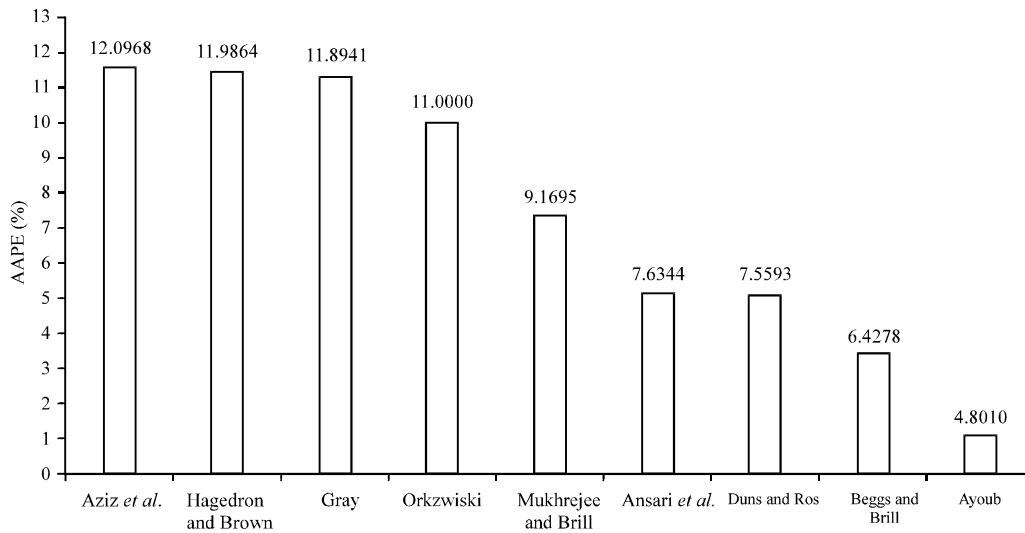


Fig. 2: Average absolute percentage relative error for all models

Figure 2-4 indicate the performance of all investigated models. Aziz and Govier (1972) mechanistic model achieved the worst average absolute relative error (AAPE), Root Mean Square Error (RMSE) and coefficient

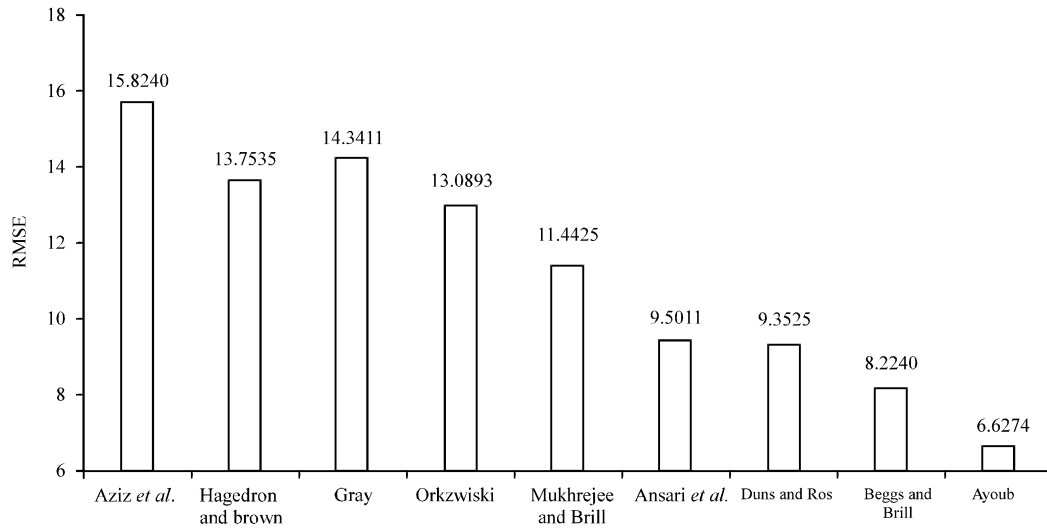


Fig. 3: Root mean square error for all models

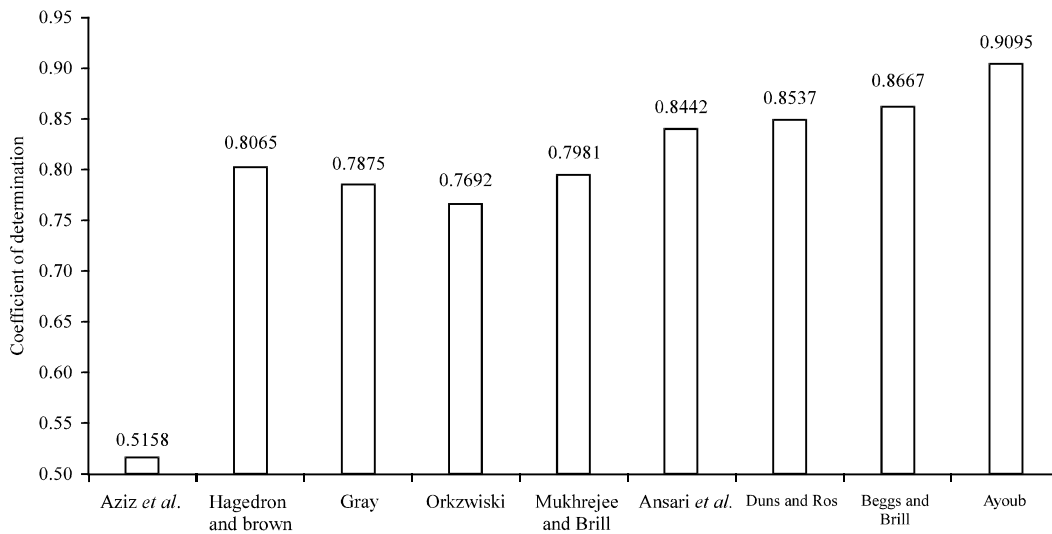


Fig. 4: Coefficient of determination for all models

of determination (R^2) among all investigated models while Ayoub (2004) model achieves the best results.

A close result can be extracted when Root Mean Square Error (RMSE) of each model has been plotted against the standard deviation (STD) of errors, as presented in Fig. 5. The best model will be located at the lower left corner which is indicated by the intersection of both lower values of RMSE and STD. As in this case, Ayoub (2004) model performed the best, followed by Beggs and Brill (1973) correlation, Duns and Ros (1963) correlation and Ansari *et al.* (1994) model.

Also, average absolute relative error (AAPE) of each model has been plotted against the confident of determination (R^2), as presented in Fig. 6. However, this time the best model will be located at the upper left corner which is indicated by the intersection of both low AAPE value with High R^2 . As in this case, Ayoub (2004) model performed the best, followed by Beggs and Brill (1973) correlation, Duns and Ros (1963) correlation and Ansari *et al.* (1994) model.

Figure 7-15 present cross-plots of estimated pressure drop versus measured pressure drop for each of the

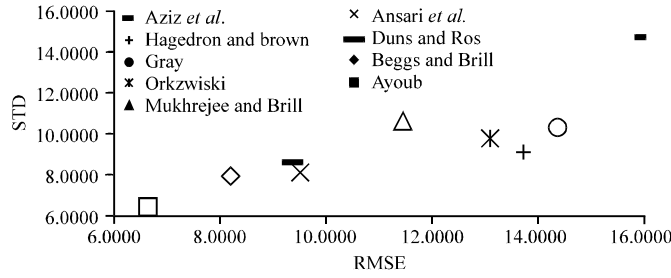


Fig. 5: Root mean square error against standard deviation for all models

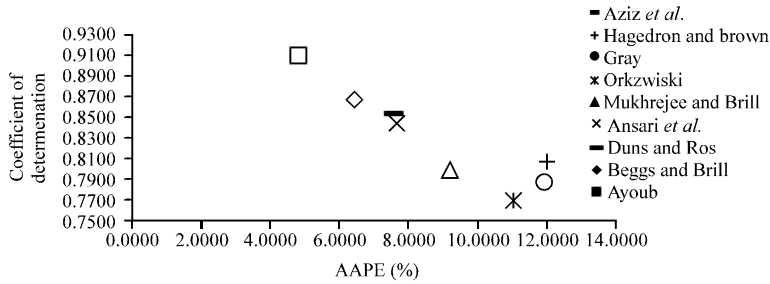


Fig. 6: Average absolute relative error against the coefficient of determination for all models

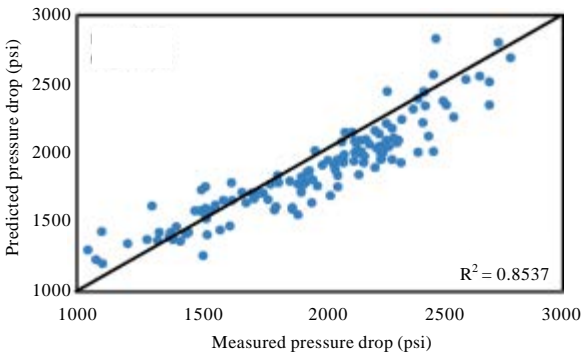


Fig. 7: Cross plot of pressure drop for Duns and Ros (1963) correlation

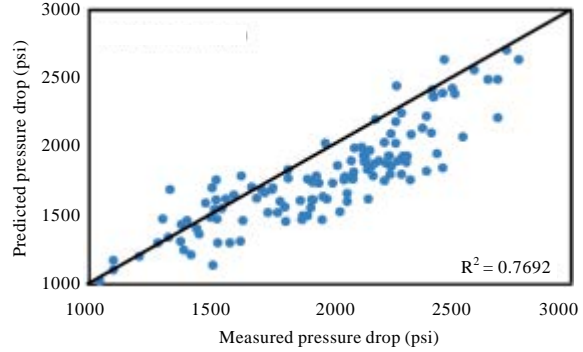


Fig. 9: Cross plot of pressure drop for Beggs and Brill (1973) correlation

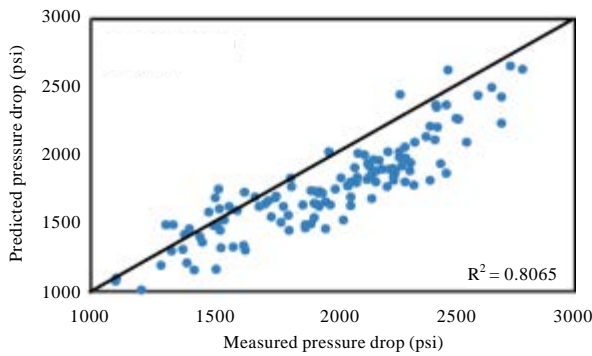


Fig. 8: Cross plot of pressure drop for Hagedorn and Brown (1965) correlation

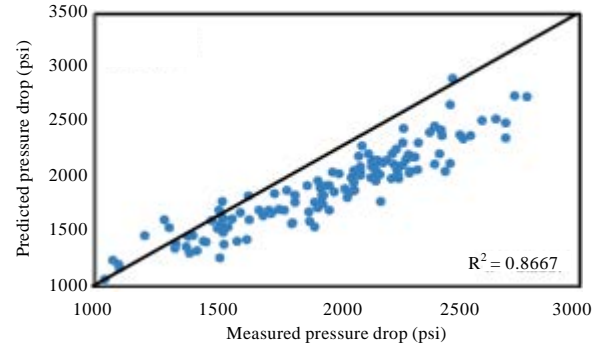


Fig. 10: Cross plot of pressure drop for Orkiszewski (1967) correlation

Appendix 1: Statistical parameters

Average absolute percentage relative error:

$$E_a = \frac{1}{n} \sum_{i=1}^n |E_i|$$

Average percentage relative error:

$$E_e = \frac{1}{n} \sum_{i=1}^n E_i$$

Maximum absolute relative error:

$$E_{max} = i +^n \max |E_i|$$

Minimum absolute relative error:

$$E_{min} = i +^n \min |E_i|$$

Root mean square error:

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^n E_i^2 \right]^{0.5}$$

Coefficient of determination:

$$R^2 = \frac{\sum_{i=1}^n [(\Delta P)_m - (\Delta P)_c]^2}{\sum_{i=1}^n [(\Delta P)_m - \overline{\Delta \Delta P}]^2}$$

Standard deviation:

$$STD = \sqrt{\left[\left(\frac{1}{m-n-1} \right) \sum_{i=1}^n \left\{ \left[\frac{(\Delta P)_m - (\Delta P)_c}{(\Delta P)_m} \right] \times 100 \right\}^2 \right]}$$

where, E_i is the relative deviation of a calculated value from the measured value:

$$E_i (\%) = \left[\frac{(\Delta P)_m - (\Delta P)_c}{\Delta P_m} \right] \times 100 \quad i = 1, 2, 3, \dots, n$$

Where:

$(\Delta P)_m$ = Measured value pressure drop

$(\Delta P)_c$ = Calculated value pressure drop

$$\overline{\Delta \Delta P} = \frac{1}{n} \sum_{i=1}^n [(\Delta P)_m]_i$$

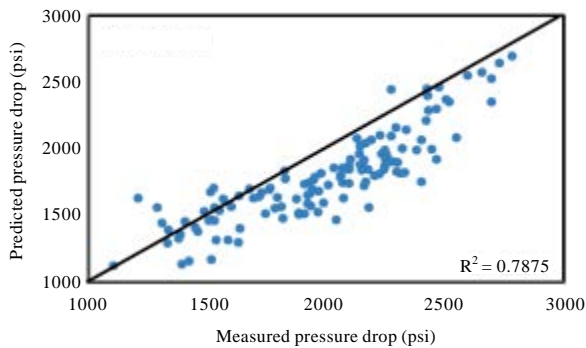


Fig. 11: Cross plot of pressure drop for Gray (1978) correlation

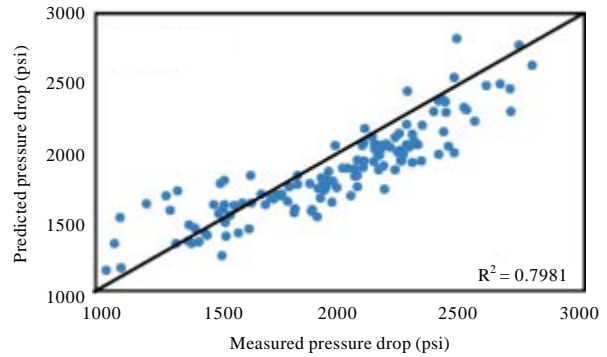


Fig. 12: Cross plot of pressure drop for Mukherjee and Brill (1985) correlation

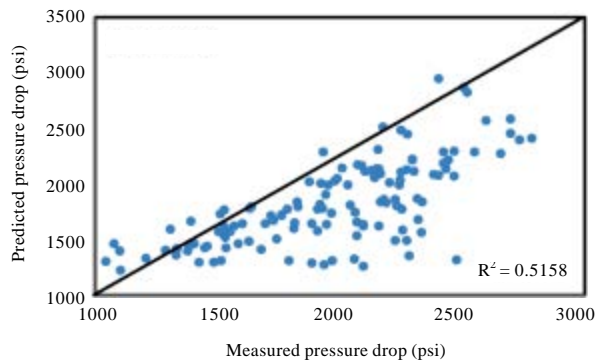


Fig. 13: Cross plot of pressure drop for Aziz and Govier (1972) model

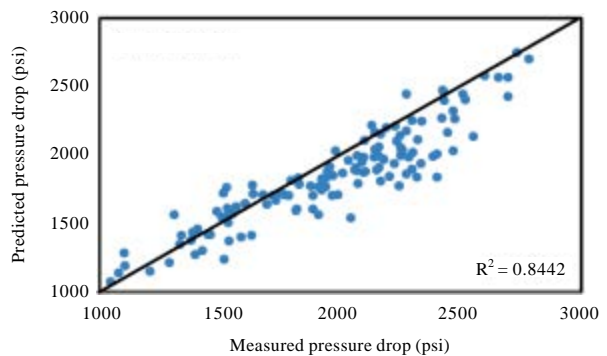


Fig. 14: Cross plot of pressure drop for Ansari *et al.* (1994) model

investigated methods. These figures show the difficulty and instability of estimating the pressure drop. It has been noticed that most of investigated methods, Duns and Ros (1963), Hagedorn and Brown (1965), Orkiszewski (1967), Beggs and Brill (1973), API (1978),

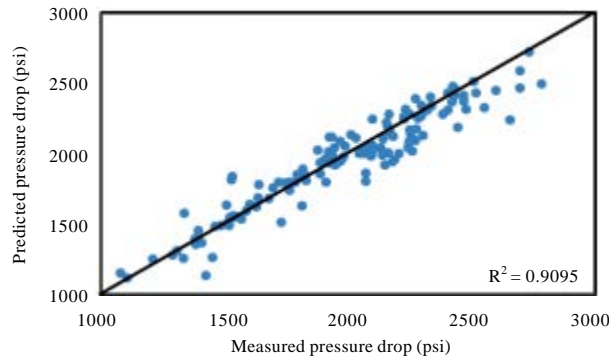


Fig. 15: Cross plot of pressure drop for Ayoub (2004) model

Mukherjee and Brill (1985) and Aziz and Govier (1972) tend to underestimate the pressure drop value. On the other hand, Ansari *et al.* (1994) and Ayoub (2004) have showed a quite good correlation around the actual values.

CONCLUSION

The main aim of this study is to compare the current available methods of predicting pressure drop in multiphase vertical wells, their accuracy, performance and applicability. However, there is no rule of thumb when it comes to choosing the best general method that can satisfy all conditions. Therefore, based on the previous results. Authors have reached the following conclusions:

- For very accurate prediction, the correlation that gives better result will vary depending on the data investigated and the physical situation
- For easy and fast prediction, the artificial neural networks model has shown superiority to the empirical correlations and mechanistic models
- Ayoub (2004) model and Beggs and Brill (1973) correlations showed good estimation while Aziz and Govier (1972) model showed severe underestimation of the pressure drop

RECOMMENDATIONS

Based on the above conclusions, the authors would like to suggest the following recommendation:

- Ayoub (2004) artificial neural networks model is highly recommended for predicting pressure drop in vertical well in multiphase flow especially for the data range recommended by the model

- Beggs and Brill (1973) is a good correlation and also recommended to be used when Ayoub (2004) model is not available
- More improvements and developments in the artificial neural networks models for predicting pressure drop in the multiphase vertical flowing wells will definitely lead to better and accurate prediction in the future. Hence, all focuses and researches are highly recommended to go through that direction

Not to be forgotten, there are still many empirical correlations, mechanistic models and artificial neural networks in the literature which have not been evaluated in this study and may have more or less accurate results when predicting pressure drop in vertical wells. However, the methods were selected based on the authors' perspective. Therefore, all the conclusions and recommendations were based on the selected methods.

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REFERENCES

- API, 1978. API User's Manual for API 14B Subsurface Controlled Subsurface Safety Valve Sizing Computer Program. 2nd Edn., American Petroleum Institute (API), USA., Pages: 48.
- Ansari, A.M., N.D. Sylvester, C. Sarica, O. Shoham and J.P. Brill, 1994. A comprehensive mechanistic model for upward two-phase flow in wellbores. SPE Prod. Facilities, 9: 143-151.
- Ayoub, M.A., 2004. Development and testing of an artificial neural network model for predicting bottomhole pressure in vertical multiphase flow. M.Sc. Thesis, King Fahd University of Petroleum and Minerals, Dahrhan, Saudi Arabia.
- Aziz, K. and G.W. Govier, 1972. Pressure drop in wells producing oil and gas. J. Can. Petroleum Technol., Vol. 11. 10.2118/72-03-04
- Beggs, D.H. and J.P. Brill, 1973. A study of two-phase flow in inclined pipes. J. Pet. Technol., 25: 607-617.
- Duns, H.J. and J.C.J. Ros, 1963. Vertical Flow of Gas and Liquid Mixtures in Wells. Proceedings of the 6th World Petroleum Congress, June 19-26, 1963, Frankfurt, pp: 451-465.
- Gomez, L.E., O. Shoham, Z. Schmidt, R.N. Chokshi and T. Northug, 2000. Unified mechanistic model for steady-state two-phase flow: Horizontal to vertical upward flow. SPE J., 5: 339-350.

- Gray, H.E., 1978. Vertical flow correlation-gas wells. In User Manual for API 14B Subsurface Controlled Safety Valve Sizing Computer Program, Second Edition, Appendix B. API., Washington, DC.
- Griffith, P. and G.B. Wallis, 1961. Two-phase slug flow ASME. *J. Heat Transfer*, 83: 307-320.
- Hagedorn, A.R. and K.E. Brown, 1965. Experimental study of pressure gradients occurring during continuous two-phase flow in small-diameter vertical conduits. *J. Petroleum Technol.*, 17: 475-484.
- Jahanandish, I., B. Salimifard and H. Jalalifar, 2011. Predicting bottomhole pressure in vertical multiphase flowing wells using artificial neural networks. *J. Petroleum Sci. Eng.*, 75: 336-342.
- Mohaghegh, S. and S. Ameri, 1995. Artificial neural network as a valuable tool for petroleum engineers. SPE 29220, Society of Petroleum Engineers (SPE), West Virginia University, USA.
- Mohammadpoor, M., K. Shahbazi, F. Torabi, Q. Firouz and A. Reza, 2010. A new methodology for prediction of bottomhole flowing pressure in vertical multiphase flow in Iranian oil fields using Artificial Neural Networks (ANNs). Proceedings of the SPE Latin American and Caribbean Petroleum Engineering Conference, December 1-3, 2010, Lima, Peru.
- Mukherjee, H. and J.P. Brill, 1985. Pressure drop correlations for inclined two-phase flow. *J. Energy Resour. Technol.*, 107: 549-554.
- Orkiszewski, J., 1967. Predicting two-phase pressure drops in vertical pipe. *J. Petroleum Technol.*, 19: 829-838.
- Poettman, F.H. and P.G. Carpenter, 1952. The multiphase flow of gas oil and water through vertical flow strings with application to the design of gas-lift installations. *Drilling Prod. Pract.*,
- Pucknell, J.K., J.N.E. Mason and E.G. Vervest, 1993. An evaluation of recent mechanistic models of multiphase flow for predicting pressure drops in oil and gas wells. Proceedings of the Offshore European Conference, September 7-10, 1993, Aberdeen, UK.
- Takacs, G., 2001. Considerations on the selection of an optimum vertical multiphase pressure drop prediction model for oil wells. Proceedings of the SPE/ICoTA Coiled Tubing Roundtable Conference, March 7-8, 2001, Houston, Texas, USA.