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A Model for Predicting Choke Performance in Niger Delta

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Abstract

Chokes are very vital components of the producing system used to regulate flow and mitigate undesirable release of hydrocarbons to the environment from downhole. Basically, there are two types of chokes, the surface and subsurface chokes. The surface chokes are designed to operate at critical flow where pressure perturbations downstream are not transmitted upstream whereas the subsurface chokes are designed to operate at subcritical conditions where pressure perturbations downstream are transmitted upstream. This work focused on the development of a model for predicting surface choke performance using an Excel Solver- non-linear gradient reduction technique. With this solver, new sets of constants were developed for an existing choke performance model that was selected amongst several other correlations. Comparison of this model with the selected model and other existing models shows that the model from this study is most accurate in predicting choke performance. Statistical parameters were also used to ascertain the goodness of fit and agreement with existing models and the results show very good agreement.

Keywords*: Multiphase flow; Choke performance; Critical flow; Subcritical; Correlations.*

1. Introduction

Multiphase flow in pipes refers the concurrent flow of liquid, gas and solid together in a pipe. Multi-phase flow is often characterized by liquids and gases occurring simultaneously, howbeit, with some solids in most cases. Virtually all flow phenomena in the petroleum production operations are multi-phase since no fluid is so clean, it does contain at least microscopic particles [1]. Multiphase flow occurs in many industries. Common examples where it occurs are in the nuclear industry, chemical industries, and naval engineering. It is mostly used to investigate phase interactions and hydrocarbon accounting [2]. Multiphase flow through restrictions in the oil and gas industry is of high importance to the production engineer and the two basic restrictions encountered are flow through well head chokes and subsurface safety valves (SSSV) [3].

Well head chokes are used to maintain the well allowable production rate, control sand production by maintaining sufficient back pressure to protect surface equipment [4]. Chokes are also used for protection from other problems such as slugging, restricting flow rate and water coning [5]. Likewise subsurface safety valves (SSSV) are also important as they automatically shut in a well in cases of wellhead and/or surface equipment failure [6].

The use of these restrictions is governed by subcritical and critical flow theory. Well head chokes operate on the principle of critical flow while subsurface valves operate on the principle of subcritical flow. Flow is critical when the velocity of the fluid through the restriction is sonic or attains a Mach number of 1(one). The surface chokes are usually designed and selected so that fluctuations in the pressure downstream of the choke have no effect or transmitted upstream while the subsurface chokes are designed to ensure that downstream perturbations are transmitted upstream [7]. Flow is subcritical when the fluid velocity is subsonic and fluid velocity is less than local velocity of sound [4].

2. Previous works

Analytical and empirical approaches have been proposed to predict the multiphase flow behavior through wellhead chokes. Although, very few works have been done in subcritical flow, Gilbert [8] pioneered the empirical work that predicted critical flow through wellhead chokes, and is given as:

$$q_l = \frac{P_1^E d^D}{AR^B \gamma_0^C} \quad (1)$$

where: q_l= gross liquid rate; BPD, p_1 = wellhead pressure; psia, R = gas liquid rate (GLR) in Mcf/bbl.; d = Choke size in 64th of an inch; γ_o = oil gravity.; *A, B, C, D* and *E* are constants.

This correlation is the most popular choke performance correlation upon which many researchers had benchmarked the development of new correlations. However, one major limitation of the Gilbert's empirical correlations is that it assumes a fixed point for critical flow.

Many researchers have come up with various modified versions of the Gilbert's correlations. These modifications are centered on the values of the constants (A, B, C, D and E) in Equation 1 and the inclusion of additional variables while maintaining the general form of Equation 1. Examples of similar but modified versions of the Gilbert's correlation are those proposed by Different values of the constants for Equation 1 have been proposed by different authors such as Baxendell [9]; Ros [10]; Achong [11]; Pilehvari [12], Al-Attar [13] , Owolabi *et al.* [14], Khorzoughi *et al.* [15] and Okon *et al.* [16] respectively. Al-Attar [13] modified the Gilbert equation by including the API gravity of the crude but recommended the use of more field data to test the correlation. Al-Towailib and Al-Marhoun [17] introduced the effect of gas-oil mixture density into an empirical correlation that describes fluid flowing through chokes.

Ajienka and Ikoku [2] also developed a generalized analytical model. Their model is applicable to both critical and subcritical multiphase flow and can be used for continuous liquid phase and continuous gas phase and is given as:

$$q_{tp} = F_b \beta R_{mp} F_{mp}(X) \quad (2)$$

where: q_{tp} is the two-phase flow rate; F_b is the base factor; β is the multiphase beta factor; R_{mp} is the multiphase specific volume factor; and $F_{mp}(X)$ is the dimensionless pressure factor.

Choubineh *et al.* [18] developed a critical multiphase flow model through chokes. The authors introduced additional useful variables, instead of the normal three variables used by other authors to improve the accuracy in determining critical flow rate. Their analytical model is based on data from south Iran and consists of choke size, wellhead pressure, gas specific gravity, temperature, gas liquid ratio and critical flow rate. Artificial neural network (ANN) with a teaching-learning based optimization (ANN-TLBO) algorithm was used in the development of their model and a non-linear regression approach was adopted to ascertain the values of their empirical constants and is given as:

$$Q_L = \frac{A \times P_{wh} \times D_{64}^B \times \gamma_O^C \times \gamma_g^D \times (\frac{T}{T_{sc}})^E}{GLR^F}, \quad (3)$$

where, P_{wh} is the wellhead pressure (psia); D_{64} is the choke size (1/64); γ_g is the gas specific gravity; γ_o is the oil specific gravity; T is the temperature; T_{sc} is the standard temperature (77^{o}F); GLR is the gas-liquid ratio (SCF/STB), and Q_L is the liquid critical flow rate (STBD).

Joshua *et al.* [19] also developed a new correlation which is empirically based from the works of Choubineh *et al.* [18] method. Using 283 surface production data sets from 7 oilfields in Niger Delta, Joshua *et al.* [1] developed and validated two new models for predicting choke performance. The models are a function of the following variables: choke size, flowing wellhead pressure, oil specific gravity, gas specific gravity, surface temperature and gas liquid ratio. A non-linear multivariate regression was used to derive regression constants and exponents for the two models as shown in Equations 4 and 5.

$$Q_L = \frac{P_{wh} D_{64}^C}{AGLR^B} \quad (4)$$

where A = 49.2531; B = 0.4768 and C = 2.230 and

$$Q_L = \frac{P_{wh}^G D_{64}^C (\gamma_O)^D (\gamma_g)^E (\frac{T}{T_{sc}})^F}{AGLR^B} \quad (5)$$

where A = 0.7486; B = 0.3066; C = 1.6082; D = 4. 3376; E = 0.0021; F = 0.8999; G = 0.6260.

3. Materials and methods

In this work, 2654 raw production data from 100 wells from 7 onshore assets in Niger Delta were obtained to develop a model for choke performance. The raw production data was cleaned to remove outliers using moving averaging technique to obtain a data structure suitable for regression analysis. These data is composed of total liquid rate, net oil flow rate, water flow rate, total gas flow rate, gas-oil ratio (GOR), gas-liquid ratio (GLR), tubing head pressure (psia), well flow line temperature (°F), wellhead choke size (d_{64}), basic sediments and water (BSW), API gravity (@ 60 °F), and the flow line pressure.

A performance evaluation was first conducted on some correlations using these data from Niger Delta with statistical parameters to select the most accurate model that fits these data set. Thereafter, the selected correlation was used as a base for the development of the new correlation. An Excel Solver, a non-linear gradient reduction technique was used to determine the constants for the new correlation. The new correlation was then used to predict the pressure and compared with the base correlation and other correlations by means using error analysis.

4. Results and discussions

As can be seen in Table 1, the most accurate correlation that best predicted the data set is Okon *et al.* [17] with an APE of 39% and standard deviation of 0.9229 compared to other correlations. Hence, it was selected as the base model for the development of the new correlation in this work. The Okon *et al.* [16] correlation is of the form:

$$P_{wh}{}^{E} = \frac{1/A(q_{liq})(GLR)^{B}(API)^{C}}{d_{64}^{D}\left(1-{}^{BSW}/_{100}\right)^{F}\left({}^{T}/_{T_{SC}}\right)^{G}} \quad (5)$$

where A, B, C, D, E, F and G are constants.

Table 1. Statistical evaluation of some selected correlations

Error	Okon *et al.* [16]	Gilbert [8]	Baxendell [9]	Khourzoughi *et al.* [15]
APE (%)	39	95	94	99
Standard deviation	0.9229	1.4581	1.4456	1.5992

Using the non-linear gradient reduction technique, a new sets of constants were developed for Equation 5 as shown in Table 2. Figure 1 shows a cross-plot of predicted and measured wellhead pressure values for Okon *et al.* [16] and this study. Data points on the diagonal implies exact and accurate predictions of the measured pressure, data points above the diagonal implies over-prediction while data points below the diagonal under-prediction of the measured data. As can be seen in Figure 1, model from this study better predicted the wellhead pressures than predictions from Okon *et al.'s* model. To further justify this, a statistical error analysis was performed on both models as shown in Table 3. As can be seen, all the three statistical measures, APE, standard deviation and R^2 values indicates that predictions from the model developed in this study performs better than that of Okon et al. Hence, the constants in the original Equation 5 can be replaced with the new constants developed in this study for evaluating choke performance of wells in Niger Delta.

Table 2. Values of constants for Equation 5 for Okon *et al.* [16] and the model developed in this work

Correlations	A	B	C	D	E	F	G
Okon *et al.* [16]	0.0509	0.6749	0	1.8133	1.321	0.2235	0.000029
This work	1.249	0.517	1.503	-0.421	3.863	0.54	-0.37709

Table 3. Statistical evaluation of base correlations and that in this study

Error	Okon *et al.* [16]	This study
APE (%)	39	16
Standard deviation	0.9229	0.3684
R^2	0.6221	0.822

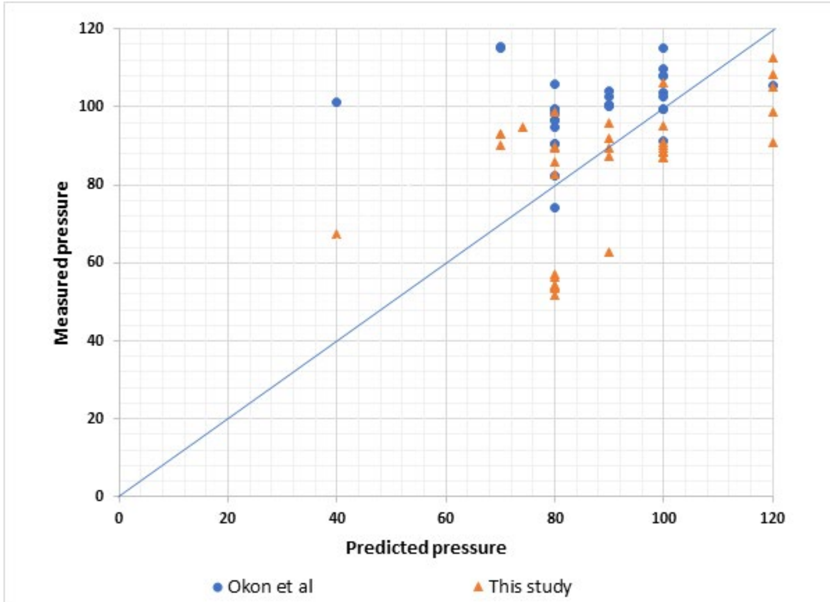

Figure 1. Cross plot of measured and predicted pressures measured for Okon *et al*. [16] and this study. The graph plots values of pressure from field data against values gotten from calculation using model from this study

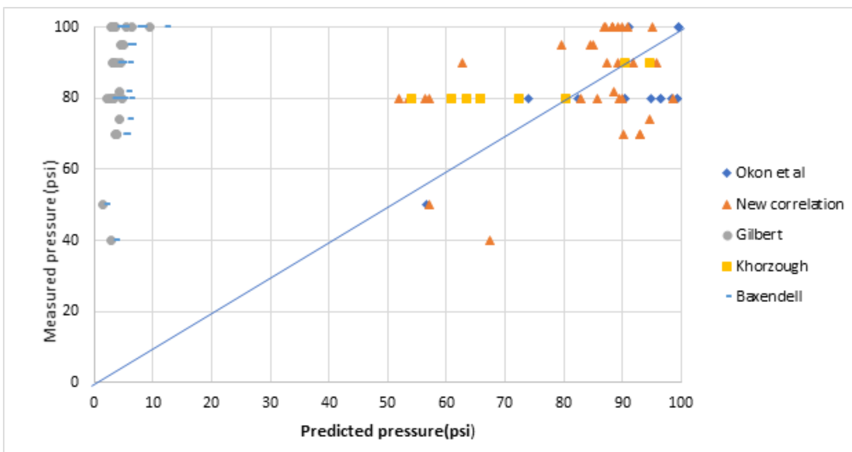

Figure 2. A graph showing a cross plot of measured and predicted pressures for model in this study and other existing correlations

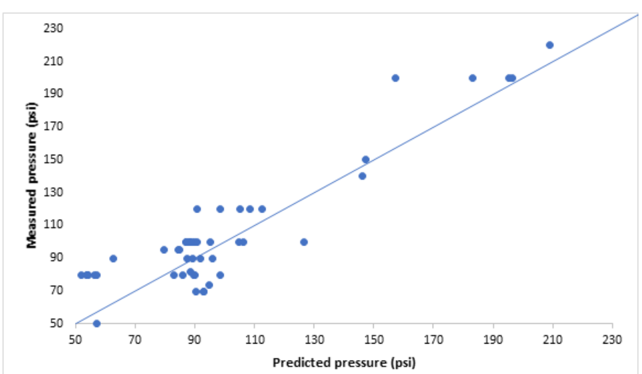

Figure 3. The graph compares results gotten from the model in this study as and field data

More so, the model from this study was compared with other choke performance models as shown in Figure 2. Again, from the cross-plot, the model from this study outperformed the others. In order further validate the accuracy this model, this model was tested with field data on a cross-plot as shown in Figure 3. Obviously, from the cross-plot in Figure 3, there is a strong correlation in the prediction of measured pressure values as the data set cluster around the diagonal.

5. Conclusions

A new model for evaluating choke performance for Niger Delta is developed. This model was developed using Okon et al model as a base model, hence identical except that the values of the constants are different and generated from an Excel Solver- non-linear gradient reduction technique. The model was tested with other models and shown to be more accurate in predicting choke performance compared other models. Also, to ensure it validity, it was tested with a field data and it showed good agreement with field data and other models. This models when is so far tested with Niger Delta and thus should be calibrated when to be deployed in regions outside the Niger Delta.

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