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Analyzing Wellhead Choke Sizes for Liquid Flowrate Performance Optimization

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ABSTRACT

The life of a well is dependent on the rate at which it is produced and the total cumulative recovery obtainable or the volume of hydrocarbon produced per day and is a function of the size of the choke irrespective of the flow regime. While unregulated production can pose high risk as reservoir damage or production problems such as water or gas coning and early water break-through, a regulated production can optimize and maximize fluid flow rate as well as facilitate reservoir management by way of production allocation for various wells, and also protect surface equipment and limit problems such as slugging, restricting flow rate and causing back-pressure in flow-line to prevent channeling. Thus, choosing the right choke size and type is of utmost importance during production. Gilbert equation was used as the base model for the selection of optimal choke size for this work, well head choke sizes were analyzed for liquid flow rate during production. Field data such as tubing head pressure, flow line pressure, separator sizes, Gas oil Ratio (GOR), Pipe and Tubing diameter, Liquid Production per day, Oil production per day, Water Production per day, Basic Sediment and Water (BS &W) were obtained from producing well in the Niger Delta. The effect of seven (7) different choke sizes of 26” 28” 30” 32” 34” 36” and 38” on the production performance of the well were analyzed with Microsoft Excel. Liquid Flow Rate logarithm form model of Gilbert was generated as a function of Gas Oil Ratio, Basic Sediment and Water, well head Pressure and Choke Size. Results from the analysis shows that highest production rate of 1932STB/day was obtained at a large choke size of 30’’ with lower operating pressure. The large choke size enhances well stability and reduces sand production problems and stopping early water break through. The model developed which shows the relationship between flowrate Q_L and other variables such as GOR, BSW, ΔP and choke size (CD) was validated with the base Gilbert model and the Owolabi *et al* and Okon *et al* models and the results showed good agreement. Further validation with two field test points confirmed that the new model proposed in this study, works excellently well at choke sizes of 30/64-in and 32/64-in. This study therefore encourages the wider application of this new model that could account for the presence of BSWs components to enhance accuracy of predicted choke performance.

Keywords: Wellhead, Optimization, Choke Sizes, GOR, BSW, Liquid Flowrate, Well head pressure Production and performance.

1 INTRODUCTION

The two basic restrictions encountered through the well head during production are the Chokes and the sub-surface safety valve (SSSVs). The main function of Chokes is to control fluid flow rate to allowable limits in other to avoid risks such as; reservoir damage, preventing of water coning and early water break through as well to facilitate reservoir management.

Wellhead chokes are an integral part of the wellhead assembly (WHA), whose main function is to control fluid oil and/or gas flow rates to allowable limits in order to; avoid such risks as reservoir damage – such as sand production problems (Joseph and Ajienka,2019). It also prevents water-coning and early water break through, as well as to facilitate reservoir management by way of production allocation for various wells, protect surface equipment and protection from other problems such as slugging, restricting flow rate and causing back-pressure in flow line to prevent gas channelling. The subsurface safety valves (SSSV) are very important because subsurface safety valve automatically shut in a well when the wellhead equipment and/or surface production equipment fails (Schaefer, 1970).

The flow regimes associated with well production could either be single-phase (the production of just one fluid type such as; oil or gas) or multiphase. 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. Although, in most cases, there are also solids present in the mixture. Virtually all flow phenomena in the petroleum production operations are multiphase since no fluid is so clean and does not contain at least microscopic particles (Bratland 2010). Multiphase flow occurs in many industries and commonly found in nuclear industries, chemical industries, in naval engineering. It is mostly used in to investigate phase interaction and hydrocarbon accounting.

There are two (2) basic types of chokes, which are; adjustable and positive. The adjustable chokes are often used during completion operations to allow the operator to clean and flow test the well. Once the optimum flow rate is determined, the adjustable choke is usually replaced with a positive choke for production - commonly calibrated in 64ths of an inch, from zero to full bore opening.

The ability to accurately estimate multiphase flow rate is important for quick evaluation of well performance and is possible by the application of correlations. Although, Nodal analysis is usually utilized for well performance evaluation on a general scale, it does not accurately model the flow behaviour in chokes, due to the fact that the method assumes for chokes that the flow is always critical (which is not always the case), but empirical correlations on the other hand have been utilized for all well conditions (both critical and sub-critical).

Various researchers have investigated the phenomenon of multiphase flow through wellhead chokes. There is an existing relationship between the flowrate and other wellhead parameters in the literature. These theories and correlations describe two phase flow through restrictions and are used to determine the most optimum size of the choke or to predict flow rate using wellhead parameters. These empirical correlations were based on certain range of parameters involved in the correlation and the data set from the region where the test wells are located. This work will analyse wellhead choke for optimal fluid flowrate. To determine the strength and weakness of these correlations, statistical analyses are usually utilized

1.2 Statement of the Problem

At the production stage if the well is not controlled or regulated using the appropriate choke size the challenges that are likely to occur are sand production, water or gas coning (Joseph and Ajienka, 2019). High production rate can result to the damage of the reservoir formation which result in lower cumulative recovery rates. High production rate can result to the damage of the reservoir formation, resulting in lower recovery. All these challenges and much more can be prevented by the use of chokes at the well head.

Although, as a production engineer, it's not just about using chokes at the well head but knowing the right size and or type of chokes to use, when and how to use the chokes at the well head.

1.3 Aim of the Study

The aim of this study is to analyze well head choke sizes and types for liquid flowrate performance optimization.

1.4 Objectives of the Study

To achieve the above aim, the following objectives were addressed:

i. Evaluate data from wellhead chokes to better understand and ascertain the effects of choke sizes and or types on wellhead during production.
ii. Examine the relationship that exist between change in pressure and gas oil ratio (GOR) for liquid flowrate performance optimization.
iii. Develop a model which will show the relationship between flowrate Q_L and other variables such as Gas Oil Ratio, Basic Sediments and Water and Well head pressure (ΔP), choke size (CD).
iv. Compare Liquid flow rate results from the empirical with the actual measured liquid flow rate from the wellhead to ascertain the volume of hydrocarbon produced per day.

1.5 Significance of Study

The importance of this work to the oil and gas industry is as follows:

i. It will guide in selection of the best choke size to optimize production
ii. It will aid, promotes and encourages the drive to go into fluid production by oil and gas industries, and guides the Production Engineer while producing irrespective of whatever

fluid flow rate performance that is been encountered at the wellhead during production, reducing cost, man-hour and eradication of rigorous calculations.

1.6 Scope of Study

This work is not experimental, Production field data was collected from Niger Delta field to evaluate wellhead chokes performance to better understand and ascertain the effects of choke sizes and or types on wellhead during production.

2. MATERIALS AND METHODS

2.1 Materials

The materials and data used in this work are Production Data (Flow rates, Basic Sediment and Water, Well head Pressure) from oil producing well being produced using different choke sizes and types, data on chokes, Microsoft Excel, literature data of previous studies done.

2.1.1 Data Gathering from a Producing Well Head with Different Choke Sizes

Based on the production well test experiment conducted with the five (5) different choke sizes on a well flowing from a particular reservoir, with different production facilities such as separators, casing, inlet manifolds operating at different pressures for eight (8) days, as stated above, the following data were obtained:

Field = XYZ

RMP = RMP 22

Well = W1

Reservoir = R1

Status = FL

Chokes (1/64th) = 26, 28, 30, 32, 34, 36 and 38

Pressures Measurements of Production facilities:

FTHP = 840 -1,200 Psig

FLP =75-110 Psig

Separator = 47-48 Psig

BLPD=1412-1800 STB/d

BWPD=2-36 STB/d

BOPD=1410-1764 STB/d

Total gas 632 -2100MScf/d

Gas Oil Ratio (GOR) =448-1190 Scf/STB

BS&W =0.15 – 2.0 (%) given in (Table 3.1 and 3.2)

Table 2.1: Production Well Test Data for the Pressures Measurements of Production Facilities Using Different Choke Sizes

Choke (/64th)	GL CHOKE	FTHP (Psig)	Casing (Psig)	FLP (Psig)	Separator (Psig)
26	Nil	840	0	75	47
28	Nil	840	0	85	47
30	Nil	840	0	84	46
32	Nil	1,030	0	98	45
34	Nil	1,080	0	100	48
36	Nil	1100	0	105	48
38	Nil	1200	0	110	48

Table 2.2: Production Well Test Data of the Production Performance Using Different Choke Sizes

Choke (/64th)	FTHP (Psig)	BLPD	BWPD	BOPD	Total Gas MCFD	GOR	BS&W %	SAND Lbs
26	840	1,412	2	1,410	632	448	0.15	<0.5
28	840	1,892	4	1,888	1,036	549	0.20	<0.5

30	840	1,936	4	1,932	1,046	541	0.23	<0.5
32	1,030	1,924	10	1,914	2,002	1,041	0.50	<0.5
34	1,080	1,770	15	1,755	1,596	909	0.83	<0.5
36	1,100	1,770	18	1752	1643	938	1.00	1.3
38	1,200	1,800	36	1764	2100	1,190	2.00	2.0

2.1 .2 Analytical (Modeling) Approach

The field data from different case study wells were obtained and using the Gilbert correlations to analyze wellhead choke sizes for liquid flow rate performance optimization at different flowing tubing head pressure

2.2 Basic Assumptions for Model Development

i. Flow through the surface choke is at critical condition
ii. The liquid rate equals the oil rate for two-phase flow.
iii. The performance of the well is considered at the wellhead/surface conditions.

2.2.1 Base Model (Gilbert, 1954)

For critical flow conditions, based on daily production data of a California oil field, Gilbert established an empirical relation for the tubing head pressure which related the liquid flow rate, the gas-liquid ratio and the choke size by

$$P_{wh} K Q_L \tag{2.1}$$

Where:

$$K = \frac{AR^B}{d^c} \tag{2.2}$$

P_{wh}= wellhead flowing pressure (Psi)

Q = gross liquid flowrate (STB/D)

R = gas-liquid ratio (Mscf/STB)

D = surface choke diameter $\frac{1}{64}$

2.3 Model Developed

$$LogQ_L = aLogGOR + bLog\Delta P + cLogCD + dLogBSW \quad (2.3)$$

The Equation (3.2) above was resolved using statistical multilinear regression with EXCEL to establish the model constants, a, b, c and d.

Making choke size (logCD) the subject of formula, we have

$clogCD = logQ_L - (alogGOR + blog\Delta P + dlogBS\&W)$

At constant pressure and plotting Q_L vs CD

$$K = (GOR)^a (\Delta P)^b (BSW)^d \quad (2.4)$$

At constant choke size and plotting Q_L vs GOR

$$K' = (CD)^c (\Delta P)^b (BSW)^d \quad (2.5)$$

At constant choke size and plotting Q_L vs ΔP

$$K'' = (GOR)^a (CD)^c (BSW)^d \quad (2.6)$$

$At\ contant\ choke\ size\ ploting\ Q_L vs\ BSW$

$$K''' = (GOR)^a (\Delta P)^b (CD)^c \quad (2.7)$$

Where;

Q_L= liquid flowrate

GOR= gas oil ratio

ΔP= wellhead pressure

CD= choke diameter

BSW= basic sediment and water

2.4 Empirical Model Development

The model that will be generated from production well test data which relates the fluid flow rate as a function of GOR, pressure, choke size and BSW is presented as follows;

$$Q_L = f(GOR^a \Delta P^b CD^c BSW^d) \quad (2.8)$$

$$Q_L = [(GOR)^a\ (\Delta\rho)^b\ \ (CD)^c\ \ (BSW)^d] \quad (2.9)$$

The power dependance of the various variables can be determined mathematically through graphical representation in form of equation (3.5)

Recall the general form of the choke performance equation with the %BSW term accounted;

$$P_{wh} = \frac{A\,(GOR)^B\,Q_L^D\,(BSW)^E}{D_{64}^C} \qquad (2.10)$$

If we linearize by taking the log of both sides, the resulting linear approximation is written as follows:

$$LogP_{wh} = LogA + BLogGOR - CLogD_{64} + DLogQ_L + ELogBSW \qquad (2.11)$$

The coefficients A, B, C, D and E in this study were determined statistically using multilinear regression of the linearized form in logarithmic equation format. The coefficients are numerically defined as follows:

A = antilog of intercept on Pwh – axis (dependent variable)

B = partial slope of GOR (independent variable)

C = partial slope of the D64 (independent variable)

D = partial slope of QL (independent variable)

E = partial slope of %BSW (independent variable)

The summary of the regression is a linearized version of Equation (2.9).

3. RESULTS AND DISCUSSION

3.1 Pressure Measurement / Gauges of the Production and Surface Facilities

Figure 3.1 presents' pressure measurements of the production and surface facilities for Flowing Tubing Head Pressure (FTHP), the casing, the Flow Line Pressure (FLP), the inlet manifold, and the separator for seven choke sizes

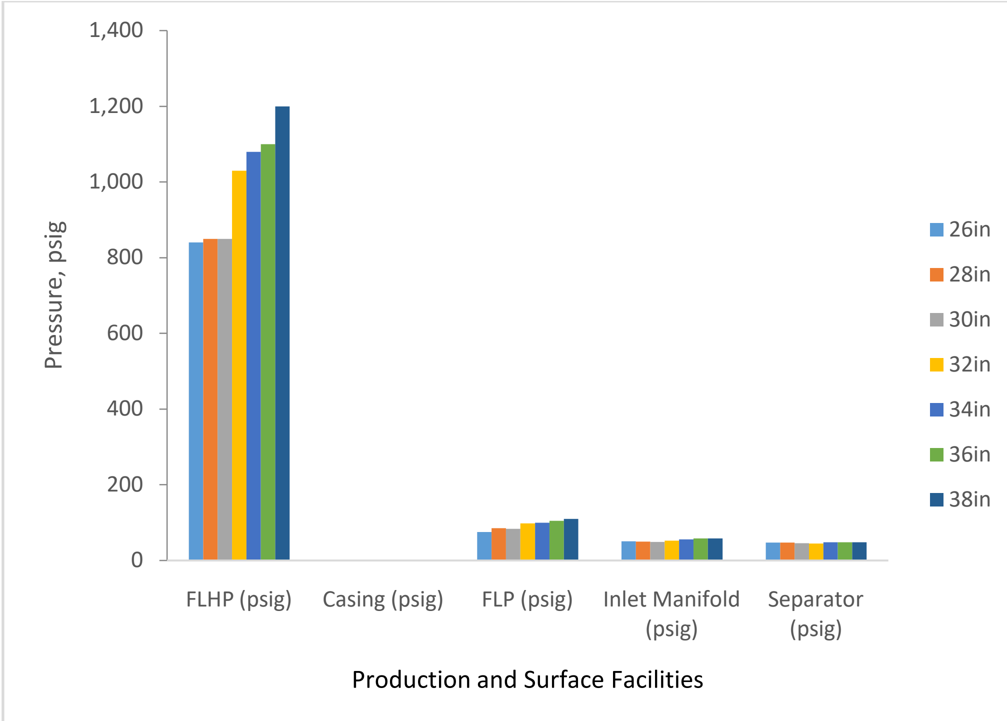

Figure 3.1: Pressure Measurements of Production and Surface Facilities for the Seven Different Choke Sizes

Figure 3.1, it was observed that no gas lift (GL) choke was used; the production and surface facilities were set at different pressure measurement even with the same choke type and choke sizes for different days. These pressure changes were made to observe and validate the effect that pressure has on chokes during production or well test analysis. The casing used was set at zero pressure (i.e., no pressure exertion in the casing).

3.2 Effect of GOR on the Liquid Flow Rate

The result of the impact of GOR on the flow rate is presented in Figure 3.2

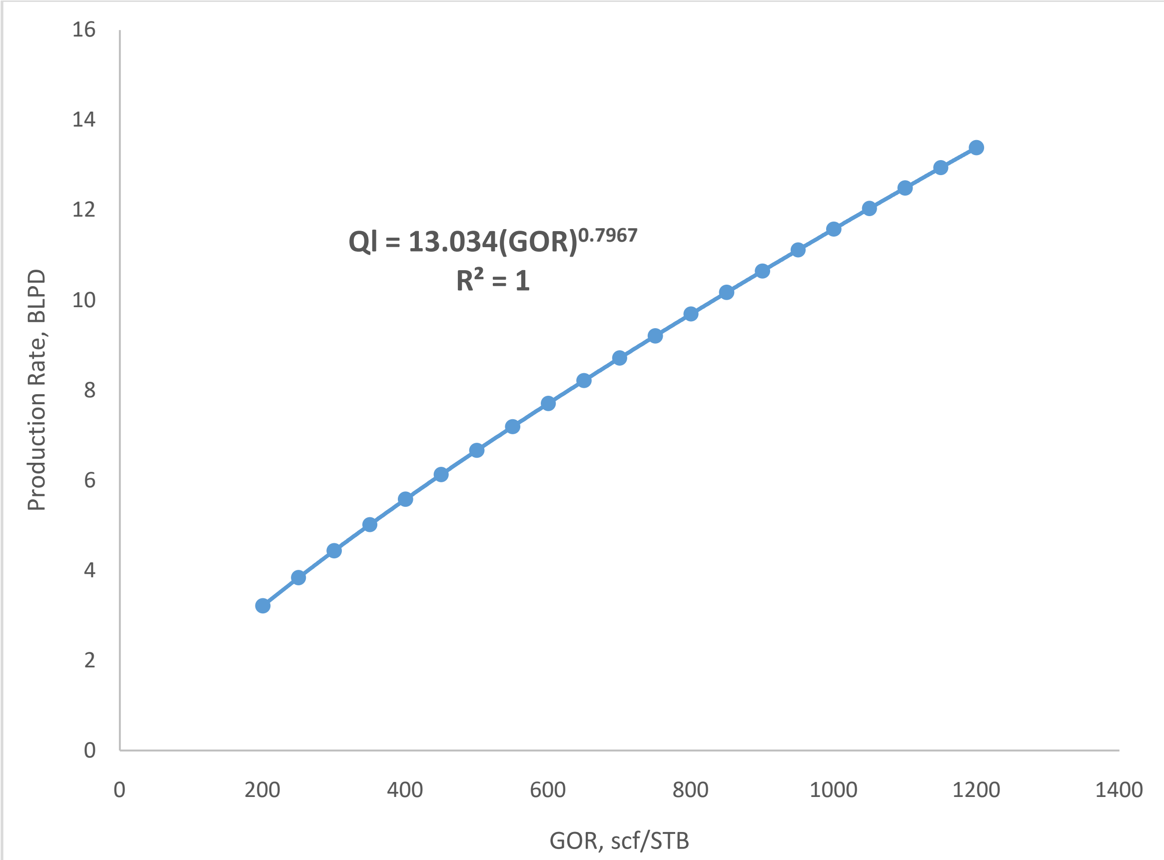

Figure 3.2: Effect of GOR on the Liquid Flowrate

A proportionate graph showing the relationship between Q (liquid flowrate) and GOR at optimized conditions of choke size (30-in), Pwh and %BSW shown in Figure 3.2 above showed resulted in a power law fit with R^2 of 1 (perfect fit). As the flow rate increases there is a corresponding increase in GOR. This prediction from our new model provides a preliminary insight on the validity of the new model proposed and this is a good indication that the proposed model is performing well and closely represents actual field observation as shall be seen later.

3.3 Effect of Choke size on the Liquid Flowrate

Figure 3.3 presents effect of Choke Size on flow rate

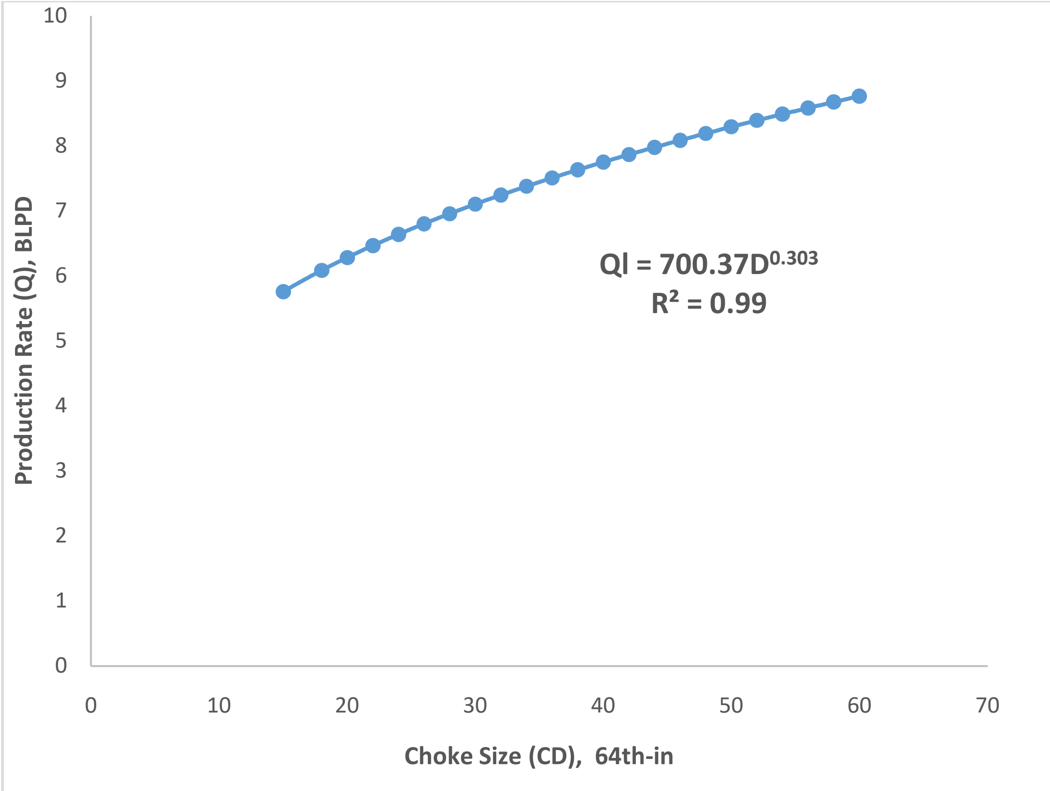

Figure 3.3: Q (Flow Rate) against CD (Choke Size)

Choke size against liquid flowrate is a proportional graph showing that increase in wellhead choke size gives a corresponding increase in the liquid flow rate.

3.4 Effect of BW&S on the liquid flowrate

The effect of BS &W on the liquid flow rate is presented in Figure 3.4

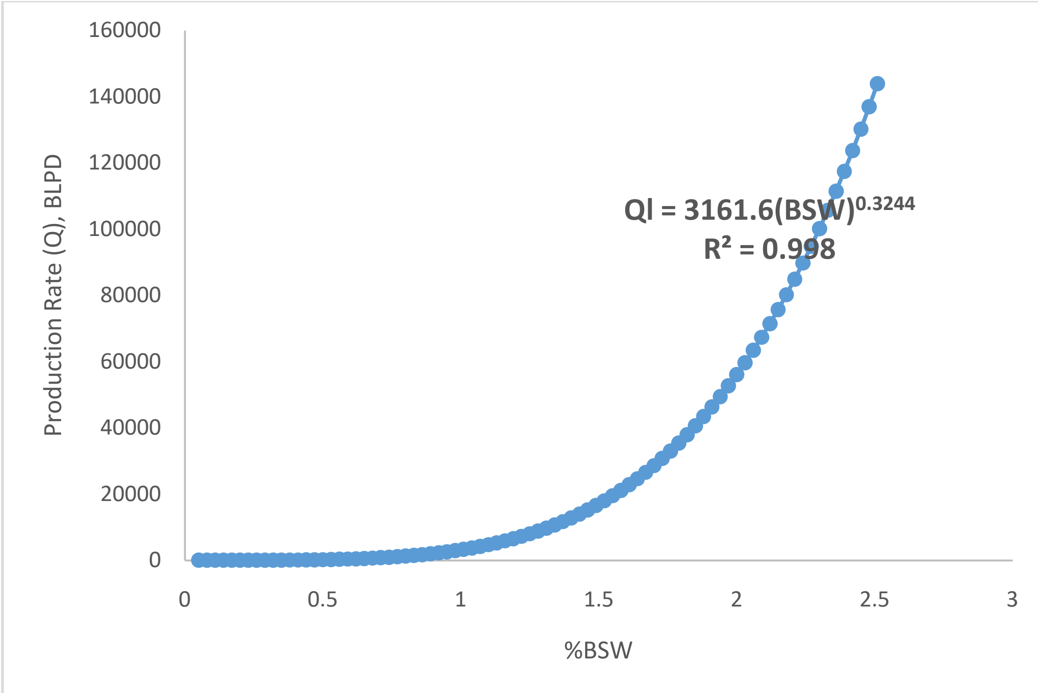

Figure 3.4: Q (flow rate) against BS&W (Basic sediment and water)

The above graph shows that the BS&W is proportional to the liquid flow rate, meaning as flow rate increases there is a corresponding increase in BS&W

3.5 Predicted QL and Measured QL

Results of the predicted liquid flow rate with the measured (observed field data) is presented in Figure 3.5. The trend showed a good agreement with minimal discrepancies. For this study, the optimal choke size from Figure 3.5 it was noted that 30-in/64-in choke size and this value was used as a benchmark for future predictions. A more detailed analysis of model validation is discussed in the subsequent Figures.

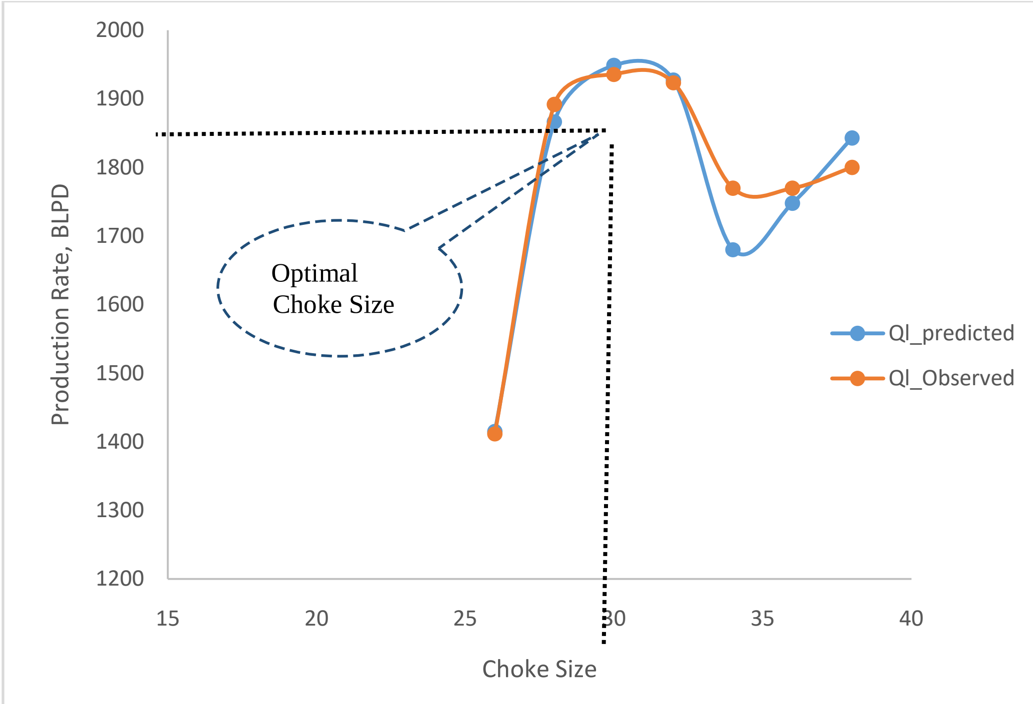

Figure 3.5: Predicted QL against Field Observed QL

3.6 Comparison of Developed Model with Existing Models for Niger Delta Field

Equation (3.1) below presents the general form of choke performance equation in which A, B, C, D and E are standard model constants. Re-writing the equation in terms of well flow rates will result to Equation (3.2). In order to validate the model developed in this work, the resulting model parameters from Excel regression analysis was adapted to the general form described in the Equation (3.1) and correlation coefficients are extracted as presented in Table (3.1) below.

$$P_{wh} = \frac{A\,(GOR)^B\, Q_L^D\, (BSW)^E}{D_{64}^C}, \text{psig} \tag{3.1}$$

$$Q_L = \left[\frac{P_{wh} D_{64}^C}{A\,(GOR)^B\,(BSW)^E}\right]^{\frac{1}{D}} \tag{3.2}$$

Table 3.1: Comparison of Model Constants with Existing Models in Standard Form

Models	Correlation Constants

	A	B	C	D	E
Gilbert, W. (1954)	10	0.546	1.89	1	0
Owolabi *et al*, (1991)	35.72	0.289	1.83	1	0
Okon *et al*, (2015)	5.1474	0.5048	1.7093	1	0
New Model	1244.5	0.192	-0.07302	-0.241	0.07817

In the general form of choke performance equation, the following resulting equations can be written using the model constants in Table 3.1 above.

For Gilbert Model; (1954)

$$P_{wh} = \frac{10\ (GOR)^{0.546}\ Q_l}{D_{64}^{1.89}}\ \text{, psig} \tag{3.3}$$

For Owolabi et al; (1991)

$$P_{wh} = \frac{35.75(GOR)^{0.289}\ Q_l}{D_{64}^{1.83}}\ \text{, psig} \tag{3.4}$$

For Okon et al; (2015)

$$P_{wh} = \frac{5.147\ (GOR)^{0.5048}\ Q_l}{D_{64}^{1.7093}}\ \text{, psig} \tag{3.5}$$

Proposed New Model;

$$P_{wh} = \frac{1244.5\ (GOR)^{0.192}\ Q_L^{-0.241}\ (BSW)^{0.07817}}{D_{64}^{-0.07302}}\ \text{, psig} \tag{3.6}$$

In Figure 3.7 below, the plot of flow rate versus choke size is plotted for each of the model. The results show that the new model is within acceptable range. Throughout the tested choke size, the new model showed better agreement with those of the previous Niger Delta correlations which are the (Owolabi *et al*, 1991) & (Okon *et al*, 2015) Despite the fact that the new model does not follow the conservative form of the Gilbert base model, it has clearly demonstrated an acceptable performance to the other models when validated with actual field data.

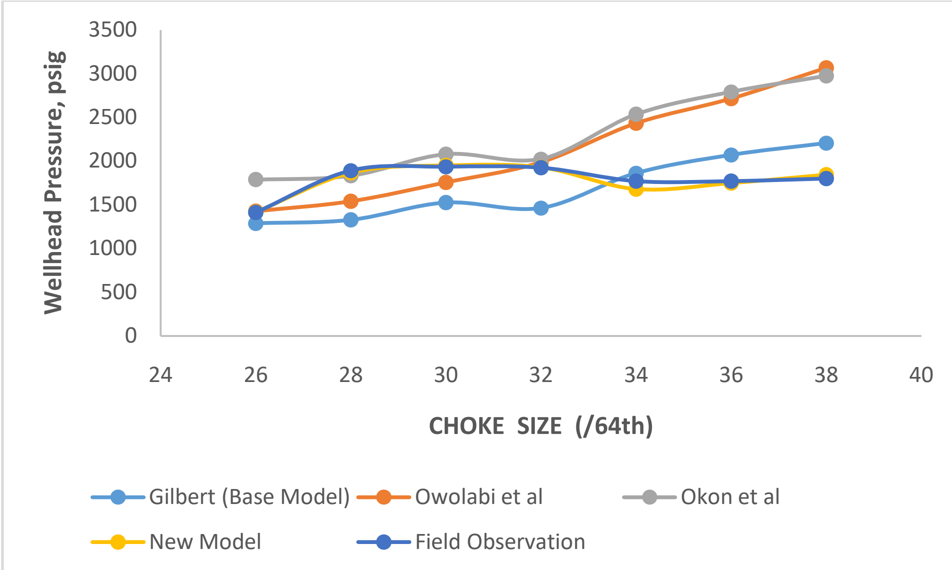

Figure 3.6: Model Validation using Flow Rate versus Choke Size

Figure 3.6 shows a similar trend in terms of the accuracy of our new model. Besides the new model developed, it can be seen that the models showed remarkable deviation from the data collected from Field X. As has been noted previous, the remarkable difference between the proposed new model and the existing models is based on the fact that the new model incorporated the effect of basic sediments and water as a percentage of total production from the well.

At lower pressures, the BSW components are not readily transported through the tubing system and may result to accumulation in the wellbore. However, as pressure increases, the lifting capacity of the total well system also increases and BSW are produced along the well fluids. In severe situations, this can remarkably impair the overall production capacity of the well as shown by relatively smaller flow rates at higher pressures of the new model. This observation is supported by Figure 3.6. Above Pwh = 932psig, there was a larger deviation of previous models from the actual field test. Another possible reason for this is the fact that this model introduced in this study is specifically directed to a particular field in the Niger Delta with remarkable %BSW produced along the well fluids.

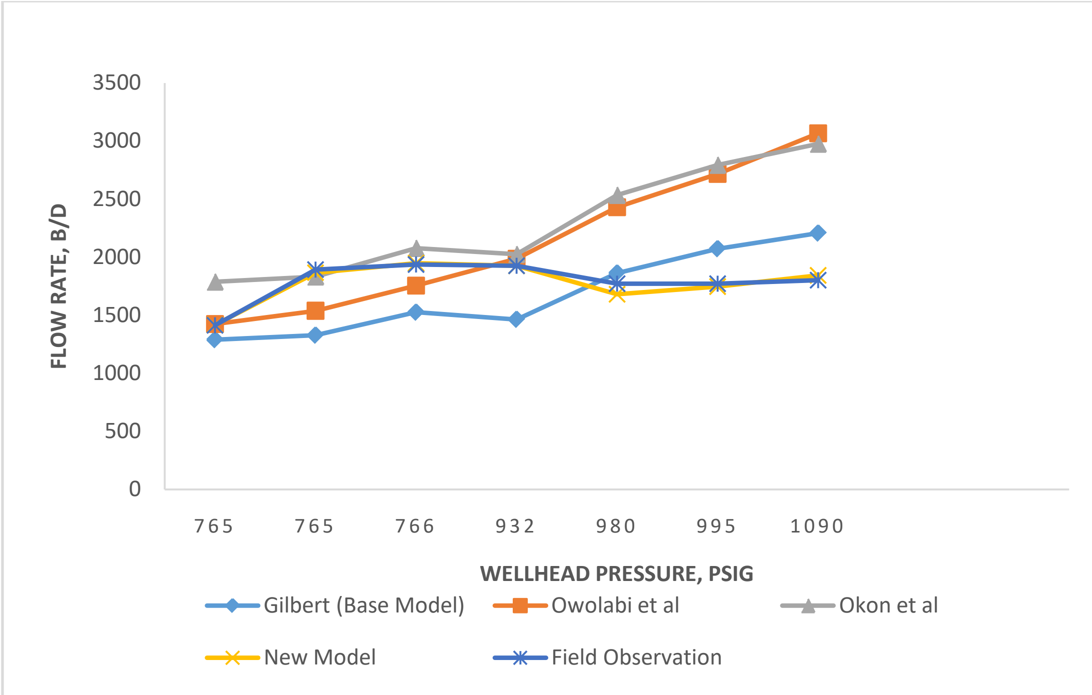

Figure 3.7: Model Validation using Flow Rate versus Wellhead Pressure

From the ongoing analysis, it has been shown that besides the basic structure of the new model, the major difference is in its ability to account for the presence of BSWs. The Figure 3.8 below raises some concern for further investigation on the impact of BSWs components on choke performance. However, the results clearly show that the presence of sediments will be most remarkable in the choice of choke size. The previous models showed that at choke sizes less than or equal to 32/64-in, there be high pressure at the wellhead which could be overestimated by the existing models if applied to this same field. However, at higher choke sizes, the reverse is the case.

Despite some deviations in the trend pattern, we can easily establish that at choke sizes less than 32/64-in, the models are sufficiently close enough. This has further validated the new model proposed in this work and the associated previous assumptions stated in chapter 3. This observation is clearly due to the fact that at smaller choke sizes beyond the optimal diameter, the BSW components are not readily transport and co-produced or at least its co-production is remarkably impeded.

It is worth noting that the new model introduced in this work (Equation 3.6) is an adapted form of the generally choke performance equation. The introduction of the new term, “BSW” in the equation remarkably alters the basic structure of the model. However, the regression results show it is accurate and could be trusted for further predictions.

Figure 3.8: Model Validation using Wellhead Pressure versus Choke Size.

4 Conclusion and Recommendations

4.1 Conclusion

Based on the research carried out in this study the following conclusions were drawn;

i. The liquid flow rate is directly proportional to the four independent variables (Gas oil Ratio, Well head Pressure, Choke size and Basic Sediment and Water)

ii. The optimal choke size of 30-in yielded the optimal production rates that resulted to Ql = 1936STB, GOR = 541.5scf/STB, Pwh = 766psig and BSW of 0.23%. Beyond this choke size, Ql gradually declines with increasing GOR, Pwh and BSW respectively.

iii. The choke size has a significant effect on Oil production rate and the pressure at which the other production facilities installed alongside the choke during production performance test analysis is operating at, also has effect on the Oil production rate (production performance rate).

iv. The model developed which shows the relationship between flowrate Q_L and other variables such as GOR, BSW, ΔP and choke size (CD) was validated with the base Gilbert model and the (Owolabi *et al*, 1991) & (Okon *et al*, 2015) models and the results showed good agreement with field observation but deviated remarkably from the earlier models. This does not outrightly mean that the existing models are not adequate. It only implies that they are inadequate for this particular field or those other fields with similar features. This study therefore encourages the wider application of this new model that could account for the presence of BSWs components to enhance accuracy of predicted choke performance.

4.2 Recommendations

i. This research involved the analysis of 7 chokes, so further studies should cover wider range of choke sizes to establish a more standardize study.

ii. The pressures of the other production facilities were altered for each choke size. Further studies can be done with pressures maintained and results obtain to further validate the study.

iii. The new model proposed in this study were based on data from a particular field. It is therefore recommended to try it out with other fields to see understand better the limitations of its wider application.

4.3 Contributions to Knowledge

This study which aims at analyzing the effects of well head choke sizes for liquid flowrate performance has contributed to knowledge in the following ways:

i. Promotes and encourages the drive to go into fluid production in the Oil and Gas sector regardless of the flow regime by enabling the production engineer know the right choke size to select at safe operating pressure.

ii. This study enables us understand that unregulated production can pose high risk as reservoir damage or production problems such as water or gas coning and early water break-through, while selecting the right choke size will regulate production and optimize fluid flow rate as well as protect surface equipment.

iii. Eradication of rigorous calculations, knowledge of correlations and models, and tedious procedures while operating in the activities of Oil and Gas industry to meet the world's energy demands.

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