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Improving Sand Control Strategies to Reduce Cost of Oil Well Production

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ABSTRACT

The aim of this research is to improve sand strategies to reduce cost of oil well production at a marginal Oil field. To achieve this, the productivity data was evaluated to determine the application of sand management processes using simple linear regression, evaluation of the effective sand control techniques, improvement of the sand management strategy by adopting the Lewins force model, and cost analysis of selected sand management and control strategies based on the improvement were caried out for four oil wells. The simple linear regression gave a weak positive regression of 0.2502, hence the Lewins force model was applied and gave a percentage error of 0%, 1%, 3%, and 1% for wells A, B, C, and D respectively. The cost of existing and improvement strategies were evaluated and gave an improved result of $55524.04 from $39821.1 for well A, $29834 from $21104.16 for well B, $10991.71 for well C, and $705984.44 from $61176 for well D. It was recommended to incorporate the use of Artificial Neural Network, Random Forest and Support Vector Machine, and also compare the results obtained.

KEYWORDS: Sand Mnagement, Simple Linear Regression, Lewins Force Field Model, Expandable Sand Screen, External Gravel Pack

1. INTRODUCTION

The production of formation sand is a major problem encountered during the production of oil and gas. Over 70 % of the world's oil and gas reserves sit in sand formations where sand production is likely to become an issue during the life of the well (Al-Awad, 2001). Sand production is typical of tertiary formations (with permeability of 0.5 to 8 Darcy) and older formations as they enter their mature stage of production due to poor completion and impact of depletion. Areas where severe sand production problems occur include Nigeria, Trinidad, Indonesia, Egypt, Venezuela, Malaysia, Canada tar sands and Gulf of Mexico. The reservoirs in these formations lie between 3,500 ft and 10,000 ft (subsea) (Al-Awad, 2001).

Generally, the effects of sand production ranges from economics and safety hazards to well productivity and therefore has been an issue of interest to tackle in the petroleum industry. Some of these effects include erosion of downhole and surface equipment, pipeline blockage and leakage, formation collapse, damage to casing/production liner due to formation subsidence, and increased downtime. These devastating effects lead to more frequent well intervention and work over generating additional needs for sand disposal particularly in offshore and swamp locations (Aborisade, 2011).

The effects of sand production are nearly always detrimental to the short and or long-term productivity of the well (Aborisade, 2011). In order to mitigate problems related to sand production new strategies are being continuously investigated, from prediction to control and management. The ability to predict when a reservoir will fail and produce sand is fundamental to deciding whether to use downhole sand control or what type of sand control to use (Appah, 2001).

Sand production occurs normally as a result of drilling and reservoir management activities. Sand grains are disengaged from the rock matrix structure under physical (earth stress) and chemical action. The mechanism of sand production in terms of sand, volumes and sand producing patterns in the reservoir is needed to optimally develop a field. Mechanisms causing sand production are related to the formation strength, flow stability, viscous drag forces and pressure drop into the wellbore (Al-Awad ,2001).

The critical factors leading to accurate prediction of sand production potential and sand production are: formation strength, in-situ stress, and production rate. Other factors are reservoir depth, natural permeability, formation cementation, compressibility, surface exposed to flow, produced fluid types and phases, formation characteristics, pressure drawdown and reservoir pressure. Predicting sand production involves developing empirical and analytical techniques (Appah, 2001).

Preventing the production of sand using passive methods includes techniques to minimize or eradicate sand production to manageable levels. This includes perforation techniques and maximum sand-free drawdown rate. Limiting production rates to avoid sand production in some cases is the most cost-effective method of sand control. In most cases however, low production rates are uneconomical stressing the need for sand control. Sand control tools do not only serve the purpose of preventing the sand grain from entering the wellbore, but also to protect the rock matrix structure, preventing formation damage (Aborisade, 2011).

Controlling formation sand production is costly as it requires huge investment but when successful stabilizes the reservoir and maximizes production and increases recoverable reserves, hence prolong the life of the well. Sand production can lead to reduce recovery rates, equipment rusting and sand settling in the surface vessels. These problems can be overcome through slowing down production rate or using External gravel packing technique or Expandable Sand Screen in controlling sand production in gas wells. Sand production poses a key challenge in field development project in the Niger delta region of Nigeria (Appah, 2001).

Zhang *et al.* (2011) established that the mechanical strength of a formation is crucial information required for predicting sand production and recommending sand control completion. The model presents a method of measuring rock strength such that the restrictions from core testing (as cores are not always available) can be avoided. They conducted tri-axial and hydrostatic test; to construct the failure envelope. The results of the studies showed a single normalized failure envelope used to characterize sandstone formations making it possible to construct the failure envelope for a sandstone formation from the knowledge of critical pressure. A correlation exists between the critical pressure and compression wave velocity (at equivalent depths of burial).

Weingarten and Perkins (1995) conducted a research on the prediction of sand production in gas wells. The method proposed was applied to 13 fields in the US Gulf coast area and has since been used extensively worldwide by the defunct Arco. The rock strength was determined by core testing and log correlations and the results compared. The prediction method differs from commonly used log-based sand prediction model. They modeled pressure gradient in the reservoir, not assuming pressure drop occurs at the perforation face and allows higher drawdowns than those permitted using shear failure criteria. Their model however predicts the onset of sand production and is not designed to apply to situations where some level of sand production is allowable. Water influx was not taken into consideration.

Brar and Aziz (2000) attributed sand production to recent classic sediments and gave practical guidelines for predicting sand production. The most critical factors to sand production were stated as formation strength, changing in-situ stresses and fluid production rate. Sand prediction methods described include production test, well log analysis, laboratory mechanical rock testing, acoustic, intrusive sand monitoring devices and analogy. To support these methods examples and case studies from the Africa, Europe and USA were given. The paper highlighted data required to predict sand production as production test data, formation intrinsic strength, rock dynamics elastic constants, and log data.

According to Vaziri (2002) the factors influencing the tendency of a formation/ well to produce sand can be categorized into rock strength effects and fluid flow effects. These factors include degree of consolidation, production rate, pore pressure reduction, and Increasing water production.

Qui *et al.* (2006) stated that the technique to predict the onset of sanding can be categorized into four basic approaches: Empirical methods using field observations and well data, Laboratory simulation, Numerical methods and Analytical methods.

Nouri *et al.* (2003) stated that the mechanisms responsible for sand production (i.e. sand failure mechanisms) include compressive or shear failure, tensile failure due to pressure drawdown, erosion or cohesive failure due to cementation degradation.

Traditionally, the main classes of sand control techniques are mechanical and chemical. Available sand control techniques in the industry include rate control or exclusion, Non-impairing completion techniques, selective perforation practices, screens (without gravel packs), gravel packs, frac packs, chemical sand consolidation (Nouri *et al*. 2003).

This research is aimed at improving sand control strategies and reduce cost of an oil well production using a marginal oil field. The specific objectives of this study are to examine the productivity data to determine the application of sand management processes using simple linear regression; evaluate effective sand control techniques in oil well production of the marginal oil field; improve sand management strategy by adopting the Lewins Force model; carry out cost analysis of selected sand management and control strategies based on improvement.

2. MATERIALS AND METHODS

The research methodology involved the review of sand production, analysis of sand protection systems to prevent formation sand from moving into the wellbore as sand monitoring techniques to detect when sand production is in excess and, prediction for when to improve upon the sand management technique in place. Also, selection of effective and economical sand control strategies is based on performance, durability and effectiveness of the treatment type used in an oil well. The treatment types that will be evaluated in this project are Expandable Sand Screen (ESS) and External Gravel Pack (EGP). EGP involves complex fluid and gravel pumping operations. ESS were deployed to overcome the shortcomings of existing techniques while also providing some benefits like larger inflow area, operational simplicity and multi-zone capability. A field in Rivers State, Nigeria was used as case study. The marginal field, located 60km southeast Port Harcourt, Rivers State was used as a case study. The materials for this research work will be gotten from field production data in the marginal field, Rivers State in the Niger Delta region of Nigeria. The parameters of interest included real gas pseudo-pressure, flow rate ratio, pseudo-pressure ratio.

2.1 Data Analysis

The data gotten from this research work was analyzed according to:

i. Cumulative sand productivity
ii. Average sand productivity
iii. Oil rate.
iv. performance of the treatment types

Of utmost interest is the oil rate analysis. This involves the flow rate analysis and Pseudo pressure analysis.

2.1.1 Flow Rate

Reservoir gas flow and liquid flow are similar especially after consideration of some assumptions like compressibility, density, viscosity, porosity and saturations which are taken as constants. Thus, a producing well at a constant rate will have pressure (P) as

$$P = K * T_l \qquad (1)$$

where

K= Fluid constant

T_l= Log (time)

Pseudo Pressure

The pseudo-pressure (Ψ) occurs as a result of variation in density, compressibility and viscosity and is called the real gas potential approximated as

$$\Psi = \mathrm{X} \times T_l \qquad (2)$$

where

X = Pseudo-constant

2.2 Lewin Force Field Model

This model was developed by Kurt Lewin (Syed *et al.*, 2016) and finds great application in engineering management. According to Lewins Model, Improvement (∝) is initiated at dis-equilibrium between the drilling force (D_f) and the restraining force (R_f); such that

$$\propto = D_f - R_f \qquad (3)$$

If $D_f > R_f$ then improvement is required.

The Model uses

I – identification of the forces at play (Define the forces and change needed). The change initiated by: Increasing the drilling force sand protection; Weakening the restraining force reducing well activities.

Thus, Well A value is assumed to be the standard value.

Decrements in other wells is indicative of improvement

$\therefore R_f =$ Well -A value

$D_f =$ Other well values

If $D_f > R_f$ then improvement ($\propto$) is required

2.3 `Cost Analysis Method

This will involve economic analysis on the effect of introducing sand management strategy on the four well using (Rawlins, 2010):

Increase in oil produced

$$(PO) PO\ after\ \propto - PO\ before\ \propto \quad (4)$$

Percentage increase in oil produced

$$\%\ \text{increase in OP} = \frac{PO\ after\ \propto - PO\ before\ \propto}{PO\ before\ \propto} \frac{x\ 100}{1} \quad (5)$$

Equivalent profit in dollar

Difference in PO after $\propto$ and before $\propto$ xCBN oil price (dollar) at a given rate.

2.4 Simple Linear Regression

According to William (2020) simple linear regression is used to model the relationship between two continuous variables, with the objective of predicting the value of an output variable based on the value of an input variable. Simple linear regression is used to establish the relationship between several variables. The Simple Linear Regression model is as expressed in Equation (6)

$$\hat{Y} = \alpha + \beta X \quad (6)$$

where

α= Regression constant

β= Regression coefficient

From Equation (6), to determine α Equation (7) is utilized

$$\alpha = M_Y - \beta M_x \quad (7)$$

where β is determined as

$$\beta = \frac{X - M_X}{Y - M_Y} \quad (8)$$

$$Mx = \frac{\sum X}{n} \quad (9)$$

$$M_Y = \frac{\sum Y}{n} \quad (10)$$

where

M_x = Mean of X values
M_Y = Mean of Y values
X = Unit produced
Y = Defective units
n = Number of parameters

Furthermore, the mean squared error can be calculated as

$$MSE = \frac{(Y - \hat{Y})^2}{n} \quad (11)$$

where

MSE = Mean squared error

$(Y - \hat{Y})^2$ = Square of deviate

2.5 JavaScript

The simple linear regression model was applied on JavaScript which a text-based programming language to facilitate the analysis.

3. `RESULTS AND DISCUSSION

3.1 Results for the Analysis of Total and Cumulative Productivity of Sand

Table 1 shows the result for the analysis of total and cumulative productivity of sand of well A to D for four concurrent year.

Table 1: Total and Cumulative Productivity of Sand in Pounds per Thousand Barrel (pptb)

YEARS (x) / WELLS	1 (x_1)	2 (x_2)	3 (x_3)	4 (x_4)	Cumulative $\sum x$=X	Average $\frac{\sum x}{n}$= Y
A	150	245	746	88	1229	307.25
B	555	115	275	1064	2009	502.5
C	190	226	133	238	787	196.75
D	176	208	76	32	492	123

Table 1 was used to generate cumulative and average values of sand produced in pounds per thousand barrel per well. This showed that Well B had more sand production ad Well D had the smallest production. The cumulative and average values were further examined for exiting relationship using simple linear regression as shown in Table 2.

3.1.1 Simple Linear Regression Analysis of the Marginal Oil Field

The result obtained from the simple linear analysis carried out on the defects on the functional relationship between the average sand production and the cumulative sand production of the marginal field oil well using JavaScript in Appendix is presented in Table 2.

Table 2: Simple Linear Regression Analysis of the Marginal Oil Field

X	Y	$X - M_x$	$Y - M_y$	$(X - M_x)^2$	$(Y - M_Y)^2$	$(X - M_x)(Y - M_y)$	$\hat{Y}$	$Y - \hat{Y}$	$(Y - \hat{Y})^2$
1229	307.25	99.75	24.875	9950.06	618.76	2481.28	307.33	-0.08	0.01
2009	502.5	879.75	220.125	773960.06	48455.01	193654.97	502.49	0.01	0.00
787	196.75	-342.25	-85.625	117135.06	7331.64	29305.15	196.74	0.01	0
492	123	-637.25	-159.375	406087.56	25400.39	101561.72	122.94	0.06	0.00
4517	**1129.5**	**0.0000**	**0.0000**	**1307132.75**	**81805.81**	**327003.12**	**1129.50**	**-0.00**	**0.01**

From the simple linear regression analysis carried out using JavaScript, the regression constant (α) was determined as 0.1633 and the regression coefficient (β) as 0.2502 which is a weak positive linear relationship (Patrick *et al.*, 2018).

Hence, using Equation (6) the simple linear regression Equation becomes

$$\hat{Y} = 0.1633 + 0.2502X \quad (11)$$

In order to evaluate the total productivity of sand and oil Table 3 is presented.as follows

Table 3: Total Productivity of Sand and Oil

Well A Oil (BOPD)	Well A Sand (pptb)	Well B Oil	Well B Sand	Well C Oil	Well C Sand	Well D Oil	Well D Sand
420	150	300	155	100	190	850	176
634	245	336	115	175	226	974	208
800	746	410	275	280	133	120	76
884	88	475	1064	322	238	1124	32

Table 3 shows a corresponding oil production alongside sand. And it is further presented in Figure 1, 2, and 3.

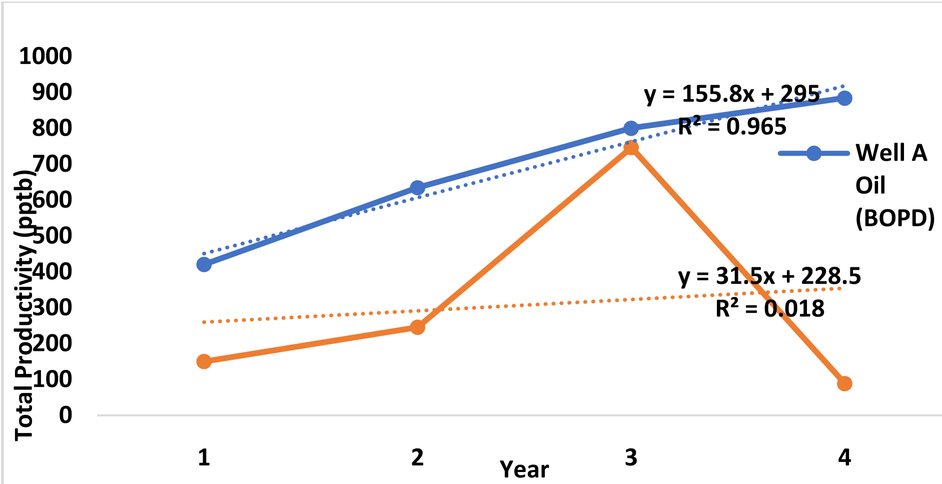

Figure 1: Estimation of Well A Productivity

The coefficient of determination (R^2) shows that the scatter around the regression line is quite small, hence a high R value is obtained. The trend also shows an increment in the oil productivity in well A. This is suggestive of a test for improvement. The sand productivity however, had no defined trend with a poor R^2 value (Patrick *et al.* 2018).

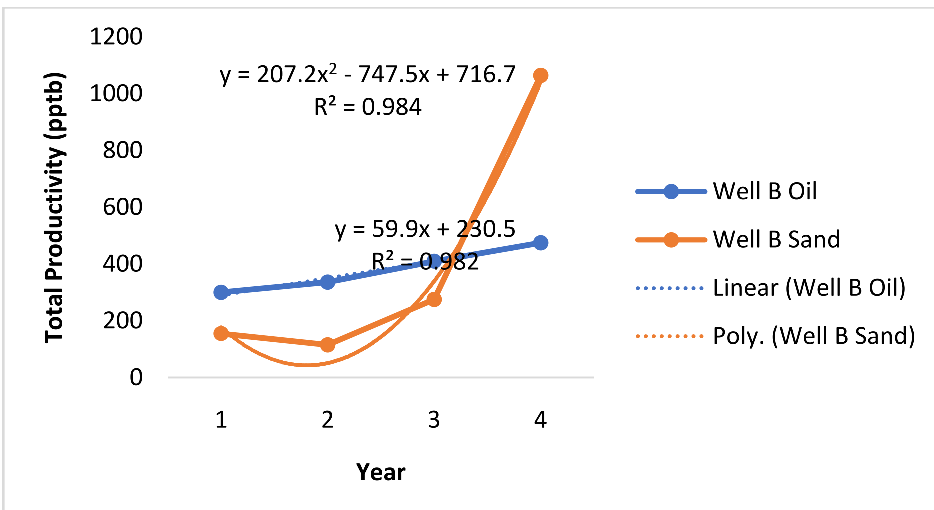

Figure 2: Estimation of Well B Productivity for Oil and Sand

Figur**e** 2 depicts an upshoot in both productivities as the years increased. Though the oil productivity maintained a linear profile, the sand productivity followed a positive polynomial profile. As is expected of a well with few influencing factors, increment in oil rate increases sand production. The R^2 values are also high (Patrick *et al.* 2018).

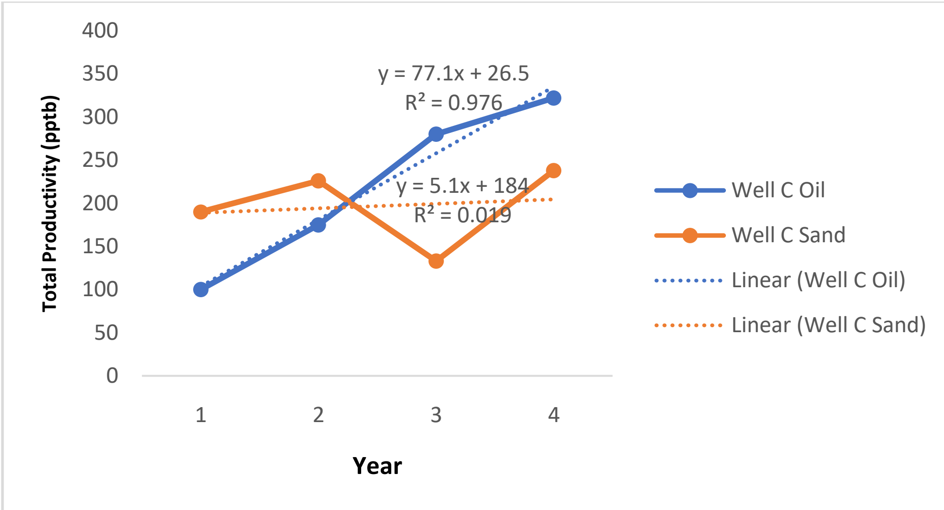

Figure 3: Estimation of Well C Productivity for Oil and Sand

Figure 3 also shows that the trend depicts an increment in the oil productivity in Well C with attendant irregularity in the sand productivity. The R^2 value for the oil productivity shows a good coefficient (Patrick *et al.* 2018).

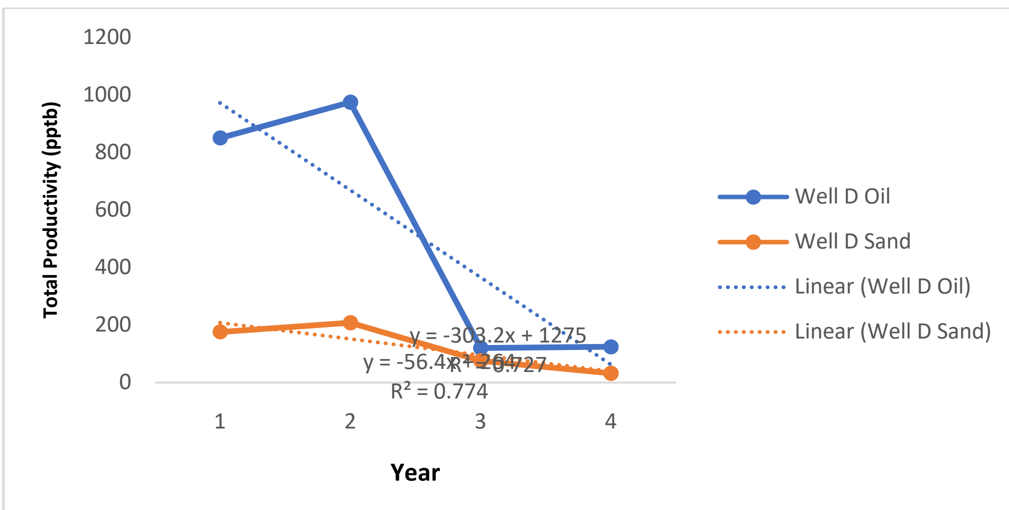

Figure 4: Estimation of Well D Productivity for Oil and Sand

3.1.2 Analysis of Oil Rate

The result for the analysis of oil rate of the wells is presented in Figure 5

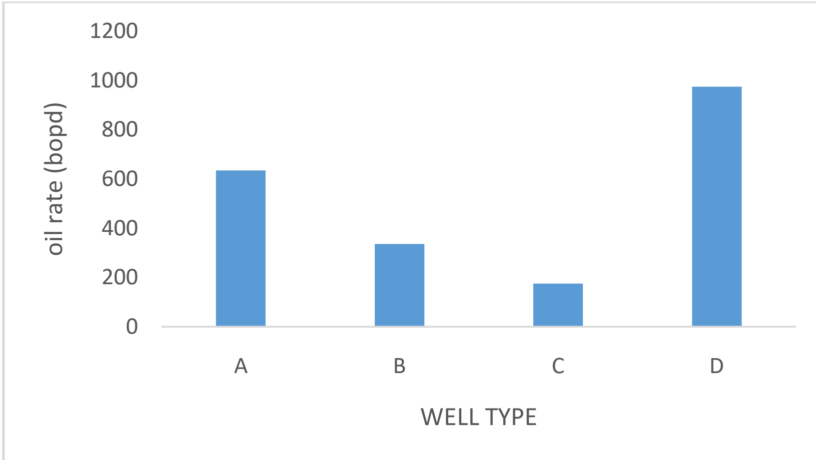

Figure 5: Oil Rate of Various Well

Figure 5 shows the oil rate of various well in the study area. From figure 4.8 well D has the highest oil rate of 974bopd. This is main cause of sand production in this well. There is a critical flow rate for most wells where the frictional drag forces and pressure differential are not higher than the formations compressive strength to cause sand production. This rate can be arrived by gradually increasing the production rate, until sand is been produced. To minimize production of sand operators can choke the flow rate down to critical flow rate where sand production does not occur or where it occurs at an acceptable level.

3.1.3 Analysis of Performance of Well Treatment Type

The analysis of performance of well treatment type using Expandable Sand Screen (ESS) and External Gravel Pack (EGP) is presented in Table 4.

Table 4: Analysis of Performance of Well Treatment Type

WELL	Flow rate ratio of expandable sand screen Y(ESS)	Pseudo-pressure ratio of expandable sand screen X(ESS)	Flow rate ratio of External Gravel Pack Y(EGP)	Pseudo-pressure ratio of External Gravel Pack X(EGP)
A	0.0127	0.9958	0.2032	0.8920
B	0.0132	0.9961	0.1721	0.9169
C	0.0498	0.9688	0.1678	0.9046
D	0.1097	0.9487	0.2012	0.8957

Table 4 shows the analysis of performance of well treatment type using expandable sand screen (ESS) and External Gravel Pack (EGP). It is seen that the gas flow rate ratio(Y) increases from well A (0.0127) to well D (0.0498) when applying ESS whereas the pseudo-pressure (X) ratio increases from well A (0.9958 to well B (0.9961) on ESS. Also, the gas flow rate ratio (Y) reduces from well A (0.2032) to well C (0.1678) when applying EGP and the pseudo-pressure ratio(X) increases from well A (0.8920) to well B (0.9169). The increase in Y value of ESS is an indication of high performance of the wells. The decrease in EGP well performance may be due to debris and loose sand from the formation during production which plugs the pore spaces in the gravel pack. It can also be caused by unclean completion fluid which causes contamination, wrong gravel size selection which can cause sand influx, wrong selection of screen slot to retain the gravel and ineffective placement technique. In other to ascertain whether or not an improvement should be carried out as good management technique, the Lewins force field model is applied as shown in Table 5

Table 5: Lewin's Force Field with %Error

Flow Ratio	**Improvement** $(\propto) = \boldsymbol{D_f - R_f}$	**% Error**
0.8921	0.8921 -	std = 0
0.9169	0.9169-09929 = 0.0248	2.7%
0.9046	09046 – 0.8921 = 0.0125	1.4%
0.8957	0.8957 – 0.8921 = 0.0036	0.4%

The Lewins force model, recognizes that improvement can occur, when the percentage error is ≥ 1.0%. This Well B and Well C are to be improved upon

Usually, one of the wells is usually standardized and used as a basis. In this case, well A is the standard well.

Since pseudo pressure depicts the influence of variation of some gas properties already assumed as constants in liquids, it is also proper to base improvement on pseudo pressure. Table 6 contains information on improvement based on pseudo pressure of ESS.

Table 6: Application of Improvement on Pseudo pressure ratio of Expandable Sand Screen

Flow ratio Ratio of ESS	**Imp$\boldsymbol{rovment}$**$(\propto)$	**% Error**
A 0.0927	Standard	0
B 0.0132	0.0132 -00127 = 0.01	1%
C 0.0498	0.0491 – 0.0127 = 0.0311	3%

D	0.1097	0.1097 – 0.0127 = 0.0917	1%

From the percentage error of 1% for well B and D, improvement is required. Well C clearly shows a higher need for improvement

3.1.4 Result of Sand Management Plan

With the application of sand management, the following results were obtained

i) Increase in production benefits: The increased oil production as a result of using this improved sand management strategy has been very encouraging and satisfying. Table 7 indicates the additional oil produced for each well as a result of sand management

Table 7: Effect of Sand Management and Pressure Variation on Well productivity

Well	Oil Rate Before Sand Management (pptb)	Flowing Tubing Head Pressure (FTHP)	Oil Rate Increment on application of Sand Management (BOPD)
A	634	170	250
B	336	108	139
C	175	150	147
D	974	265	150

3.1.5 Cost Analysis

The result of the cost analysis is presented in Table 8.

Table 8: Cost of Existing Strategy and Improve Strategy

Well	Oil rate	Oil price	Existing Equivalent price in dollars	Improve equivalent price
A	634bopd	$62.81	$39821.54	$55524.04
B	336bopd	$62.81	$21104.16	$29834.75
C	175bopd	$62.81	$10991.71	$20224.78
D	974 bopd	$62.81	$61176.94	$70598.44

4. CONCLUSION

After careful examination of the productivity data for wells A, B, and C gave a high R^2 value depicting an increment in well productivity for both sand and oil. It was however not used to determine whether an intervention was needed for well D. Evaluation of the data obtained from the marginal oil well was carried out to ascertain the effective sand techniques in oil well production of the marginal oil field using simple linear regression, and Lewins forcefield model. The simple linear regression analysis carried out for possible sand management data analysis gave a weak positive regression coefficient of 0.2505. This allowed the application of sand management.

The sand control technique was evaluated using the flow rate ratio and pseudo pressure ratio. The increased flow rate ratio for the ESS screening technique from the standard Wells A to C depict that an action plan was required. Lewins force field model was applied to predict improvement on sand management technique. Decision value according to the force field model showed the application of improvement at ≥1% error.

Application of the sand management technique gave an increment of $15702.5 for Well A, $8730.59 for Well B, $9233.7 for Well C and $9421.5 for Well D. The cost of improvement before and after, established a profit of 39.4% for Well A, 41.3% for Well B, 84% for Well C, 15.4% for Well D. Oil rate also increased with increase in flowing tubing head pressure (FTHP).

From the detailed analysis carried out, it is recommended that should incorporate the use the use of machine learning such as Artificial Neural Network, Random Forest, and Support Vector Machine.

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