Global Journal of Researches in Engineering: J
General Engineering
Volume 23 Issue 3 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Stocastic Modelling of Scaling Index, Fracturing and Parameters Performance of Produced Water Re-Injection in a Hydrocarbon Acquifer Field

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GJRE-J Classification: FOR Code: 091599

STOCASTICMODELLINGOFSCALINGINDEXFRACTURINGANDPARAMETERSPERFORMANCEOFPRODUCEDWATERREINJECTIONINAHYDROCARBONACQUIFERFIELD

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Stocastic Modelling of Scaling Index, Fracturing and Parameters Performance of Produced Water Re-Injection in a Hydrocarbon Acquifer Field

Kingsley E. Abhulimen [α], Fashanu T. A. [σ] & Odiachi J. C. [ρ]

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Keywords: reservoir performance, stochastic, monte carlo simulations, produced water reinjection and bayesian model.

I. Introduction

Produced water Re-injection (PWRI) into spent hydrocarbon aquifer offers economic and environmental friendly way to maximize disposal of produced water into the offshore and deep offshore field environments *[1].* However gradual shut down of aquifers due to injectivity decline, formation damage, cake formation and fracturing of the internal walls of the aquifer limits its use as a sustainable water resource for secondary oil recovery production *[2].* Maintaining injectivity requires minimizing formation damage near injection wells [3, 4, 5]. Recent studies by *[Ibidapo Obe et.al 2016] [6] and [Abhulimen et.al. 2018] [7]* demonstrated the significance of Internal filtration, Geochemical reaction-scaling, adsorption of particles to surface grain, hydrodynamic molecular transport in formation damage (permeability decline),and an injector decline performance. Their work however only covered numerical methods to solve the resulting physical models and did not cover assessments realized stochastically to predict performance of injection produced water, formation damage progress and scaling index, which is the objective of this study. Reinjection offers solutions to management of produced water reinjection and ensures compliance to stricter regulatory requirements for operators of offshore fields, their re several risks associated with its use which out weights its benefits. Numerical prediction of formation damage, fracturing, injectivity, petroleum production performance and pressure distribution for produced water re-injection in depleted reservoirs for most reservoir fields is limited because applicable data for input in the numerical deterministic model is only available for only a small number of data for spatial locations [8]. Thus problems associated with prediction of reservoir performance based on numerical approaches required prediction to be inaccurate in some instances making the case to use stochastical approaches with multiple random simulations trials implemented to estimate the uncertainty associated with stochastic probabilistic distribution of the input parameter. In recent studies, [9, 10] a methodology for modeling injectivity impairment during produced water disposal into low-permeability is reported [11, 12]. Recent approaches in history matching recognized that quantifying uncertainty requires multiple realizations of produced water reinjection performance data integration, risk assessment, quantification of uncertainty being a key issue in formation damage evaluation, reservoir characterization and development. Several models have been used to predict water reinjection [13, 14, 15, 16, and 17]. High rates of oil production are the direct result of pressure maintenance enabled by water reinjection. Early injection ensures that the reservoir pressure remains above the bubble point pressure to prevent expansion of gas.

II. Model Development

Field data obtained from an operator and approved by the regulator was used to derive and model a statistical strategy for evaluation performance of produced reinjection related to scaling index, fracturing progression and parameter performance in an oil field which is in contrast to numerical approaches

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previously reported in literature [18,19,20,21,22,23,24, 25]. The chi-square test was used to evaluate how well a set of observed data fits a corresponding expected set. The Monte Carlo Simulation robust model strategy for the prediction of fracturing and cake formation in a multi faulted reservoir faulted is expressed in a linear regression model of the form

$$y_i = \beta_1 + \beta_2 x_{2i} + \beta_3 x_{3i} + \varepsilon_i \qquad (1)$$

Where y_i is the dependent variable and x_{2i}, x_{3i} are independent variables. In the Monte Carlo model, the coefficients of the model - $\beta_1, \beta_2, \beta_3$ are fixed parameters. In practice, their true values are not known and the purpose is to estimate these values. The random error term, ε makes the model a statistical one to solve and not a deterministic model. The Monte Carlo Simulation is ran based on the regression equation such that random numbers are predicted based on the probability and cumulative distribution functions of the dependent variables. For each run, the dependent variable is predicted based on the regression equation. This simulation predicts the dependent variables at multiple scenarios and inference is drawn from the results. In F-testing of regression coefficients, in the full model as the equation above the error terms assumed are normally distributed as $e_i \sim N(0, \sigma^2)$ where 0 is the mean and σ is the variance. In the reduced model, to test a null hypothesis of linear restrictions on the coefficients, the model under H_o can be expressed as a regression model (called the "reduced model") with p regressor variables – some of which may be different from the *X's* and *p+1* regression parameters where $p < k$.

The F-test help in comparing SS_{full} and SS_{red} to test the reduced model against the full model. SS_{full}, SS_{red} denote the residual sum of squares for the full model and the reduced model respectively and the corresponding degrees of freedom. In the case that a constant occurs in both the reduced and full model, $df_{fall}=n-k-1$ and $df_{red}=n-p-1$.

The rv's SS_{full} and SS_{red} - SS_{full} are independent and if H_o (the reduced model) is true, then $(SS_{red} - SS_{full}) / \sigma^2$ is chi-square distributed with degree of freedom equal to $s = df_{red} - df_{fall}$. The F test statistic, F is calculated as $F = \frac{(SSred - SSfull)/s}{SSfull\ /dffall} = \frac{(SSred - SSfull)/\sigma^2 s}{SSfull\ /(\sigma^2 dffall)}$.

It is important to note that the T-test and F-test are types of statistical test used for hypothesis testing and decides whether or not the null hypothesis is to be accepted or rejected. This hypothesis tests do not take decisions rather they assist the researcher in decision making.

Procedure for F-test.

- Two regressions were run, one for the full regression and one for the residual.
- The sum of squares is picked out from source tables.
- The degree of freedom in both cases were determined.
- The F statistic was calculated as $F = \frac{SSR/K}{SSE/(n-k-1)}$; and H_o is rejected if F is larger than the upper 1-α percentile in the *F(s,df $_{fall}$)* distribution (corresponding to the level of significance, α).
- Also, written as $F = \frac{MSR}{MSE}$, where $MSR = \frac{SSR}{K}$ $and\ MSE = \frac{SSE}{n-k-1}$
- MSE is "Mean Square for Residuals that is, the ratio of SSE (sum of squares residual) to the degrees of freedom, n-k-1; MSR Mean Square for Regression that is, the ratio of SSR (sum of squares regression) to the degrees of freedom, k.

The T- statistic for each independent variable is evaluated as:

$$T = \frac{Estimated\ coefficient}{Standard\ Error\ of\ the\ coefficient}$$

The T- value helps in determining if a predictor is significant. The bigger the absolute value of the T value, the more likely the predictor is significant.

a) P – Value

The P – value shows how statistically significant an independent variable is. It is the probability of obtaining a test statistic which is at least as extreme as the calculated value. Excel software was used in computing this value. Modelling involves using previously developed data to arrive at a model that can be enumerated stochastically.

III. Field Data Description Results

The field under study is located within the central part of the onshore fields of the Niger Delta. Historically the field consists of two parts (29) and Campos Basin bloc BC-4 in Gulf of Guinea. The field is divided in two parts. Based on report by Idialu, 2014 [23] and published article by Abhulimen et.al 2017 [7], and following reference (Castellini et.al 2000, Frade CPDEP report, Meyer, R.B et.al (2003)) [28,29,30].

a) Development of Water Reinjection Project

According to reference (29, 30) studied field is a multi-reservoir, faulted anticline, heavy oil accumulation at a depth ranging from approximately 2200-2600 m subsea, in Campos Basin block BC-4. Water depth within the areal extent of the field ranges from 1050-1300 m. Studied Field will be developed as an all subsea well peripheral water flood project, with all injection below the various oil water contacts. The project use vertical or deviated water injection wells and long, horizontal open-hole gravel pack production wells. Dummy Variables were used to develop this linear

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regression equation. In this case, case1 the independent variables were not divided by a base value.

IV. Results and Discusssions

a) Field Data and Fractured Injection Simulation

Figure 2 shows that PWRI does result in a significant change in injectivity due to the assumed damage to the external filter cake. Figure 3 shows fracture growth will occur at the rate necessary to rate of water reinjection. A higher injection rate increases injectivity. Figure 2 shows there is little impact on injectivity. Lower permeability results in steeper fracturing. Figure 3 shows there is almost no difference in injectivity between four, 6m perforated intervals across the whole N570 vs. one, 6m interval within the lower portion of the zone.

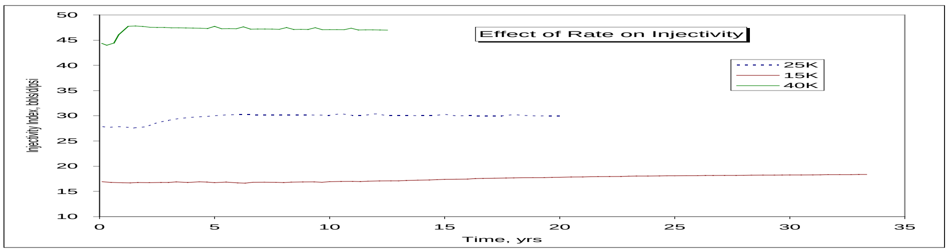

Figure 2: Effect of Rate on Injectivity

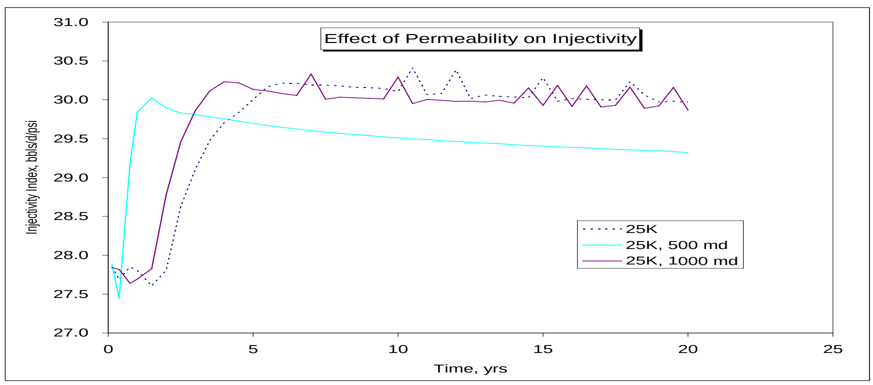

Figure 3: Effect of Permeability on Injectivity

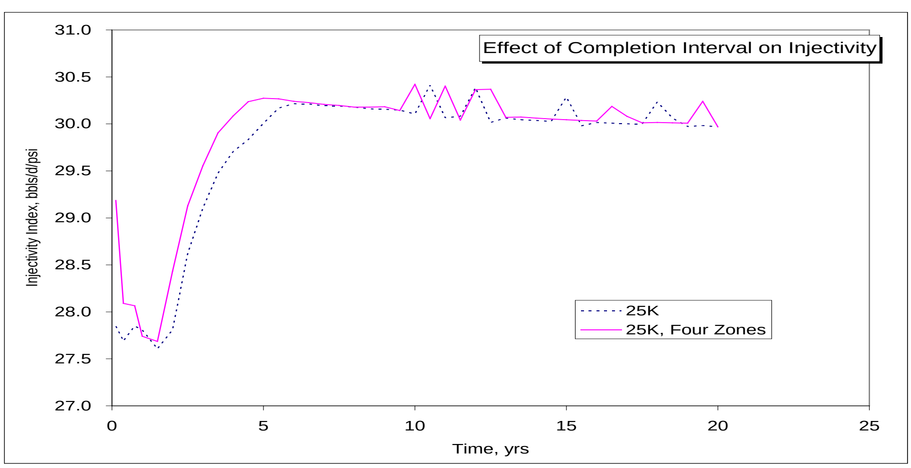

Figure 4: Effect of Completion Interval on Injectivity

In these section results of modeling analysis based on field data parameters is discussed. Table 1 is regression statistics based on data of scaling index and the other fracturing parameters were obtained from a petroleum regulator in Nigeria and as presented and reported by Idialu 2014. The MATLAB regression model Simulink provides the regression statistics results in Table 3.0. Table 4.0 is the CHI-SQUARE values of variables of Injectivity with fracturing scale production and formation damage. The regression equation is given by for scaling Index SI to predict scaling tendencies in the field studied as a function of Temperature, pressure, pH and Injection rate.

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$$SI = 1 + A_1 TEMPERATURE + A_2 PRESSURE + A_3 PH\ after + A_4 pH + A_5 INJECTION\ RATE$$

Where $A_{1=}$ 0.005210855

$A_{2=}$ -9.91E-05
$A_{3=}$ 0.456150678
$A_{4=}$ -0.021847425
$A_{5=}$3.02E-07

Figure 5 shows the effect of each input on the scaling Index (output). The marker on the top right of Figure 6 show that increase the temperature from 80 to 189 make the SID increase by say 0.1 while the next marker show that increase in the pressure make the output to decrease by 0.1. Figure 5 show adjusted SI for Temperature and pH while fig 6 shows adjusted SI for temperature and pressure for any value of pH after. The SI increases as temperature increase. Figure 7 shows Adjusted SI at any temperature reading and chart indicates the SI decreases as the pressure increases. Figure 8 show interaction of the entire inputs on the output on SI and pH after. It was observed that Injection rate does not really have much effect on the scaling index.

Table 1.0: Regression Statistics

Multiple R	0.9724
R Square	0.946
Adjusted R Square	0.944
RMSE	0.00724
Error degree of Freedom	244
Observations	250

	Coefficients	Standard Error	t Stat	P-value
Intercept	-1.458805352	0.186270479	-7.83165	1.47E-13
Temp	0.005210855	0.000144843	35.97596	1.54E-99
Pressure	-9.91E-05	5.15E-06	-19.2332	8.49E-51
pH	0.456150678	0.021363995	21.35138	9.30E-58
pH after	-0.021847425	0.004520292	-4.83319	2.38E-06
Injection Rate	3.02E-07	9.03E-08	3.339175	0.000972

Table 2.0: Chi-Square Values for the Variables

	P-value
Intercept	1.47E-13
Temp	1.54E-99
Pressure	8.49E-51
pH	9.30E-58
PH after	2.38E-06
Injection Rate	0.000972

Table 3.0: T- Stat for the Variables

	T Stat
Intercept	-7.83165
Temp	35.97596
Pressure	-19.2332
pH	21.35138
pH after	-4.83319
Injection Rate	3.339175

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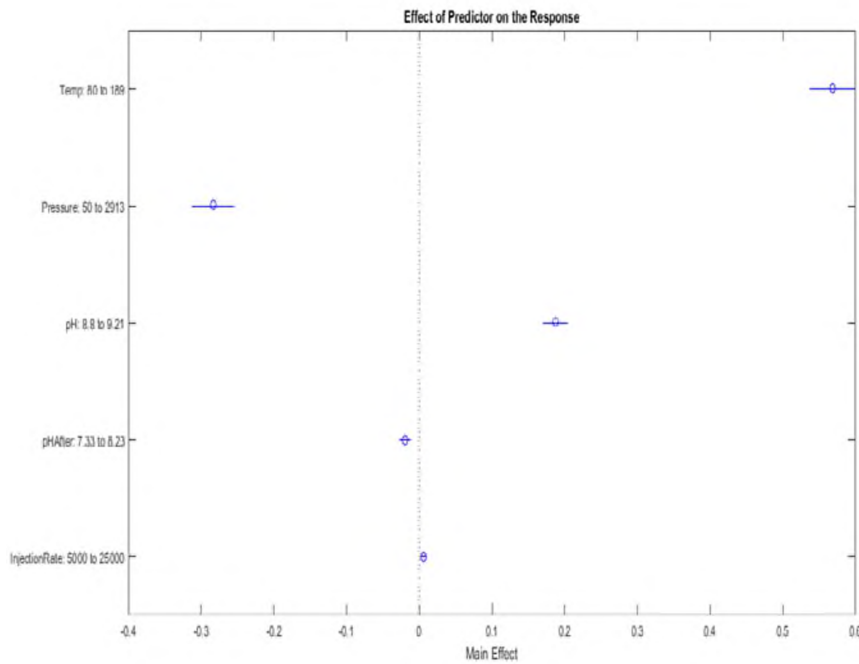

Figure 5: Effect of Predictor on Response

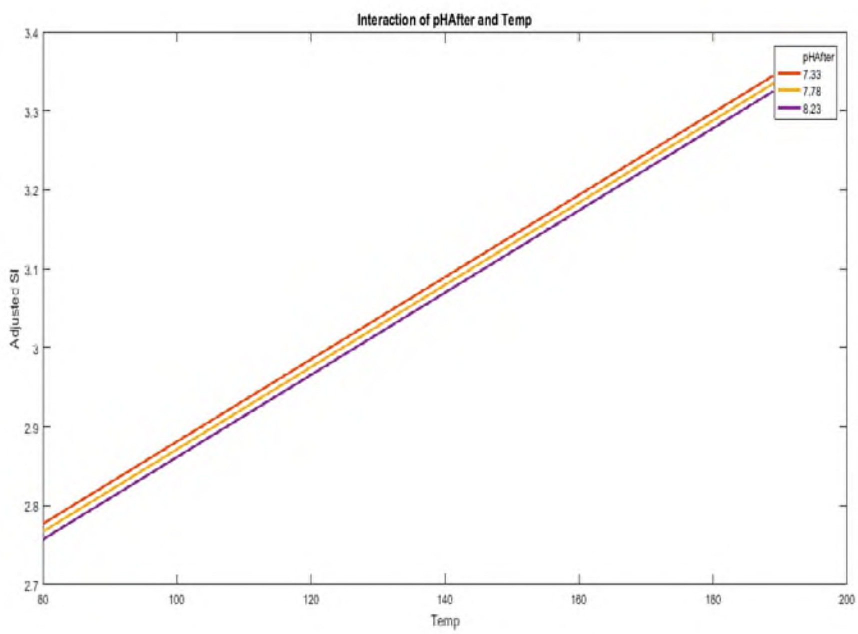

Figure 6: Adjusted SI with Temperature and pH

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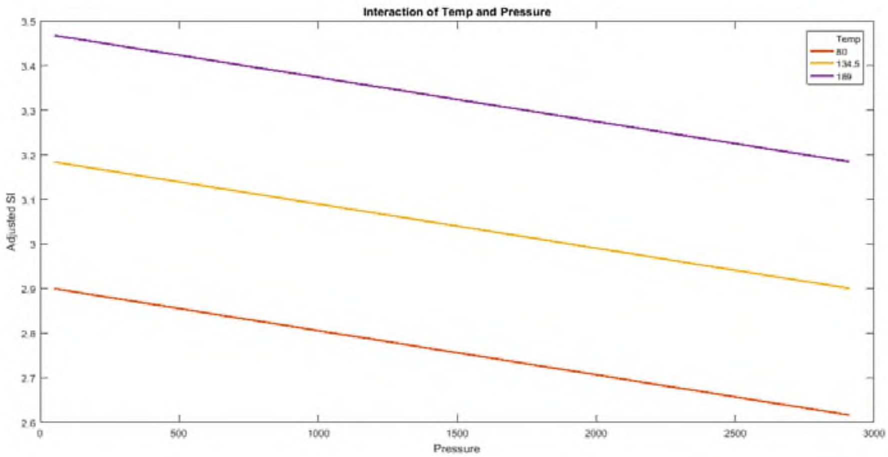

Figure 7: Adjusted SI with Pressure and Temperature

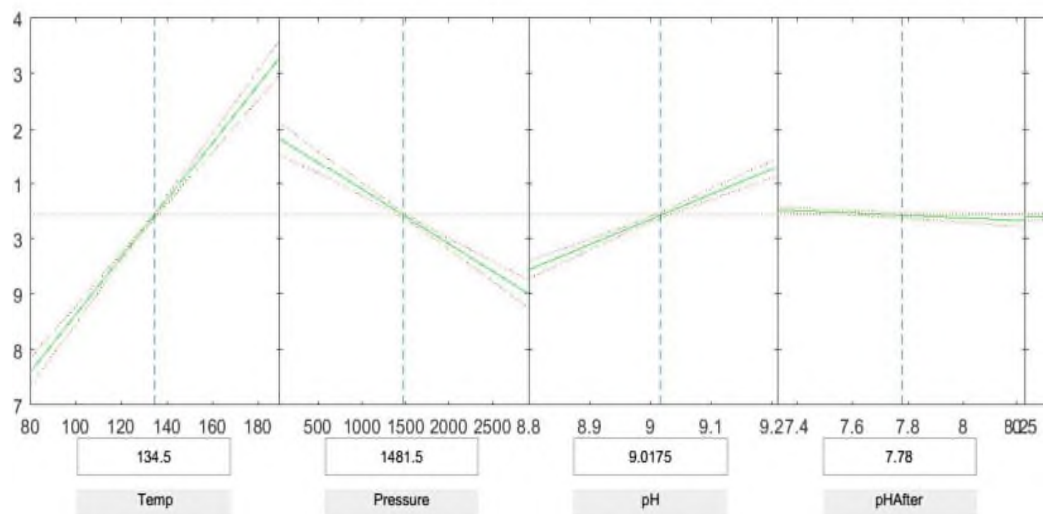

Figure 8: SI with Temperature, Pressure, pH and pH After

Table 6.0 shows the regression statistics based on field data after simulating on MATLAB to generate the regression model or equation with an R square of 97%. Table 7.0 is ANOVAs parameters. Table 8.0 shows Chi-Square test based on data on fracturing phenomenon.

Table 6.0: Regression Statistics

R Square	0.997
Adjusted R Square	0.9965
RMSE	0.00347
Observations	60

Table 7.0: Anova Paramters

	SS	DF	MS	F	Significance F
Regression	0.205440621	59	0.003482		
Residual	0.204815196	7	0.029259	2432.721	4.51E-63
Total	0.000625425	52	1.20E-05	0	

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	Coefficients	Standard Error	t Stat	P-value
Intercept	0	0	NaN	NaN
Young's modulus, psi	1.68E-10	1.36E-09	0.124152	0.901713
Poisson's Ratio	2.287796099	0.025236959	90.65261	2.48E-55
Toughness, psi-in1/2	0.00141057	0.000910887	1.548567	0.128054
Pressure, psi	-7.59E-05	0.000266942	-0.28421	0.777471
Compressibility, psi-1	-294.8436887	279.1197758	-1.05633	0.296103
Permeability, md	-9.20E-08	1.46E-06	-0.06309	0.949956
Porosity	-0.021072465	0.013422726	-1.56991	0.123006
Formation Fluid Viscosity, cp	0	0	NaN	NaN
Coeff of ThermExp (1/R)	0	0	NaN	NaN
Temp(F)	0.00567176	0.004939851	1.148164	0.256591
Biots Constant	0	0	NaN	NaN

Table 8 are chi square values for variables used to generate P values for intercept, young modulus, psi, Poisson's ratio, toughness, pressure, compressibility, porosity, formation fluid based on data provided in Appendix A Table A3

Table 8.0: Chi-Square Values for Variables

	P VALUES
Intercept	0
Young's modulus, psi	0.901713
Poisson's Ratio	2.48E-55
Toughness, psi-in1/2	0.128054
Pressure, psi	0.777471
Compressibility, psi-1	0.296103
Permeability, md	0.949956
Porosity	0.123006
Formation Fluid Viscosity, cp	0
Coeff of Therm Exp (1/R)	0
Temp(F)	0.256591
Biots Constant	0

Table 9.0: T Stat for the Variables

	T-STAT
Intercept	0
Young's modulus, psi	0.124152
Poisson's Ratio	90.65261
Toughness, psi-in1/2	1.548567
Pressure, psi	-0.28421
Compressibility, psi-1	-1.05633
Permeability, md	-0.06309
Porosity	-1.56991
Formation Fluid Viscosity, cp	0
Coeff of ThermExp (1/R)	0
Temp(F)	1.148164
Biots Constant	0

The regression equation to described fracturing phenomenon based on field data is given by

Y=1+B1YOUNG'SMODULUS+B2POISON\RATIO+B3TOUGHNESS+B4PRESSURE+B5COMPRESSIBILITY+B6PERMEABILITY+B7POROSITY+B8FORMATION FLUID VISCOSITY+B9COEFF OF THERM EXP+B10TEMP+B11BIOT'S CONSTANT.

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Where Y= σ/TVD

B1=1.68E-10
B2=2.287796099
B3=0.00141057
B4=-7.59E-05
B5=-294.8436887
B6=-9.20E-08
B7=-0.021072465
B8=0
B9=0
B10=0.00567176
B11=0

Table 10: Regression Output

Residual=Output-Predicted(Fitted)

Observation	Predicted σHmin/TVD	Residuals
1	1.755176515	0.002383335
2	1.754210421	0.003282703
3	1.754196673	0.003649684
4	1.755563744	0.002167322
5	1.745017372	0.001815937
6	1.707914432	0.004508949
7	1.777649715	-0.003188842
8	1.776929853	-0.002976813
9	1.739535586	0.001000309
10	1.830843069	-0.007807289
11	1.820752739	-0.005421826
12	1.712883501	0.00694037
13	1.760415293	0.001803846
14	1.80893194	-0.000982362
15	1.806798456	-0.009183584
16	1.738907353	0.004243237
17	1.73288535	0.002451627
18	1.77603357	-0.001781725
19	1.77773054	0.000433982
20	1.788037258	-0.002962604
21	1.787112245	0.00014607
22	1.866485352	-0.001191938
23	1.898519512	-0.000441118
24	1.855876948	-0.001025834
25	1.825406668	-0.003844158

Figure 8 shows a match of predicted reservoir production rate and actual production rate and fits into trend analysis for each injectivity run and Fig 9 shows a similar trend for pressure difference is observed. The production rate is marked by peak maxima and minima for each injection run. The tables for both the production index and fracturing phenomenon simulated on MATLAB generated an appropriate model that can be used to analyses the data given. The model generated shows a good fit because the value for the Multiple R (correlation coefficient that tells us how strong the linear relationship is; value of 1 is a perfect positive

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relationship while a value of 0 shows no relationship at all), R Squared (statistical measure of how close the data are to the fitted regression line)and the Adjusted R Squared (a modified version of R Squared that has been adjusted for the number of predictors in the model) tends towards 1.0 while the value for the Standard error or the Root Mean Square Error (RMSE) which measures how much error there is between two datasets, compares a predicted value and an observed or known value and the Mean Square Error that measures the average of the squares of the errors or deviation i.e difference between the estimator and what is estimated. Figure 9 shows the effect of each input on the output (Scaling Index). Increase in temperature will directly lead to an increase in the value of the Scaling Index but reverse is the case for pressure. Figure 9 also shows the interaction between all the inputs on the output. pH after and Injection rate does not really have much effect on the output (Scaling Index).

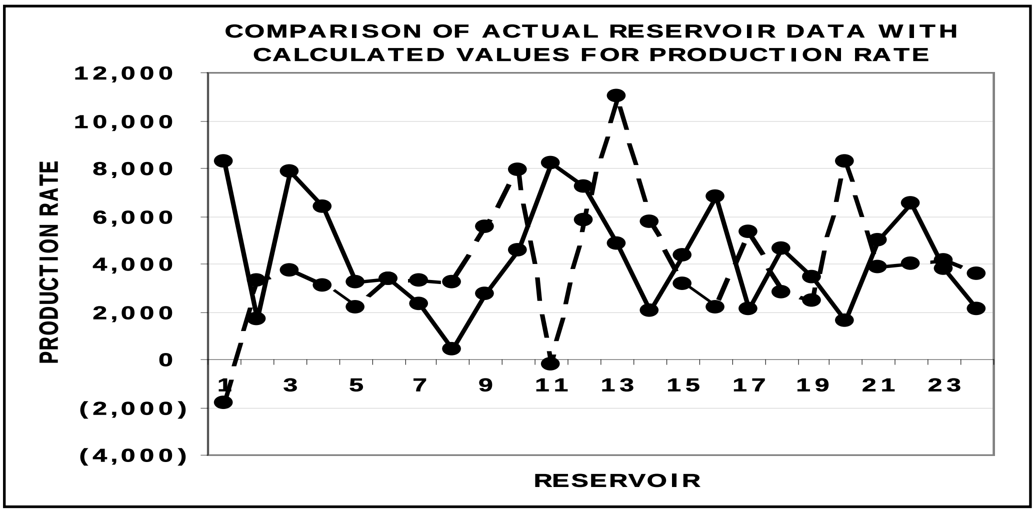

Figure 9: Comparison of Actual Reservoir Data with Simulated Values for Production Rate

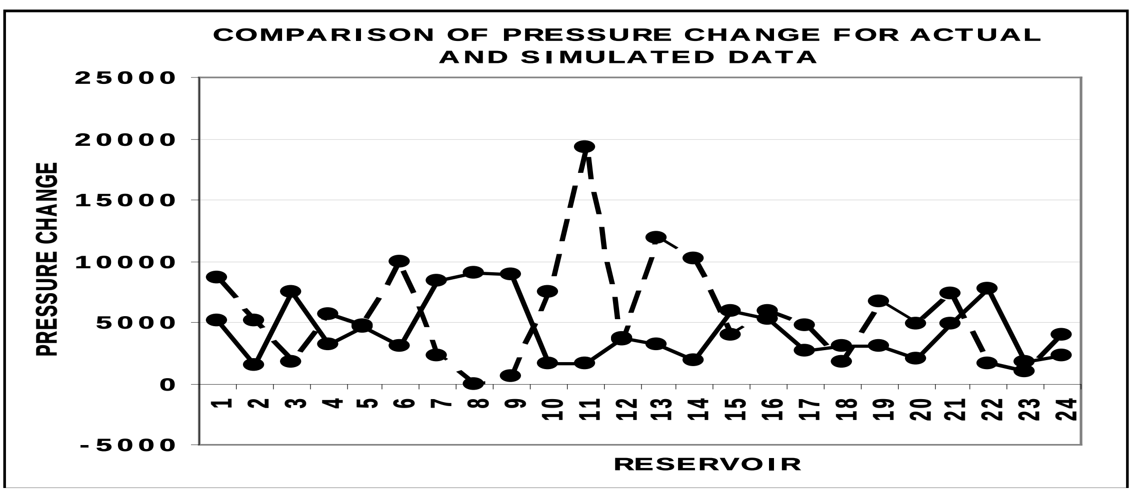

Figure 10: Actual Reservoir Data with Simulated Values for Pressure Change

Figure 10 and Fig 11 show the frequency distribution statistics for the multiple injection runs with particular classes of production and pressure for multiples simulation injection run. Figure 10 pressure change is shown by peak maxima and minima for injection group 1-24 considered for the reservoir system. A profile of Figure 11that closely resembles frac pressure data and the peak maxima and minima per injection run

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Figure 11: Frequency Distribution of Production Rate for Each Injectivity Group

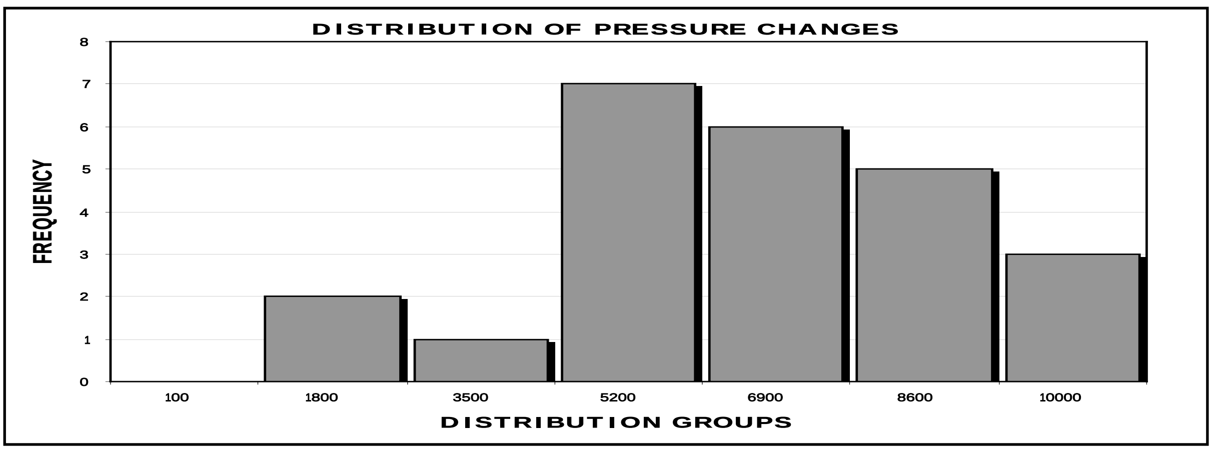

Figure 12: Frequency Distributions of Pressure Changes for Each Injectivity Group

Excel Sheets show the data categorization of variables in Table 5.0. The Monte Carlo model is applied to available reservoir data to study stochastically the pressure performance for several water injection rates for reservoir performance. The pressure changes normalized within a normal distribution thresholds is use to represent different probability scenarios for different injection rate schemes. This calculation also achieved with MS Excel functions required the calculation of the mean and standard deviation of the set of pressure changes for the different reservoirs. The data are represented using simulation random numbers generated to replicate the probability calculated for each of the above pressure change. The results show probabilities is a normal distribution are between 0 and 1, random numbers were generated to lie between 0 and 1 also. MS Excel functions were then written to achieve an inversion of the simulated probability values to pressure changes. To ensure that the simulated values keep dimensions with the actual reservoir data, the mean and standard deviation calculated for the actual data were employed for the inversion. The regression analysis for the field data below is presented in Fig 13 .The regression statistics show multiple of R is 0.998476685, R Square is 0.99695569 and Adjusted R square is 0.919622802 and Standard error of 0.003468055 for the 60 observations shows a strong agreement with the Monte Carlo Simulation model and Field data.

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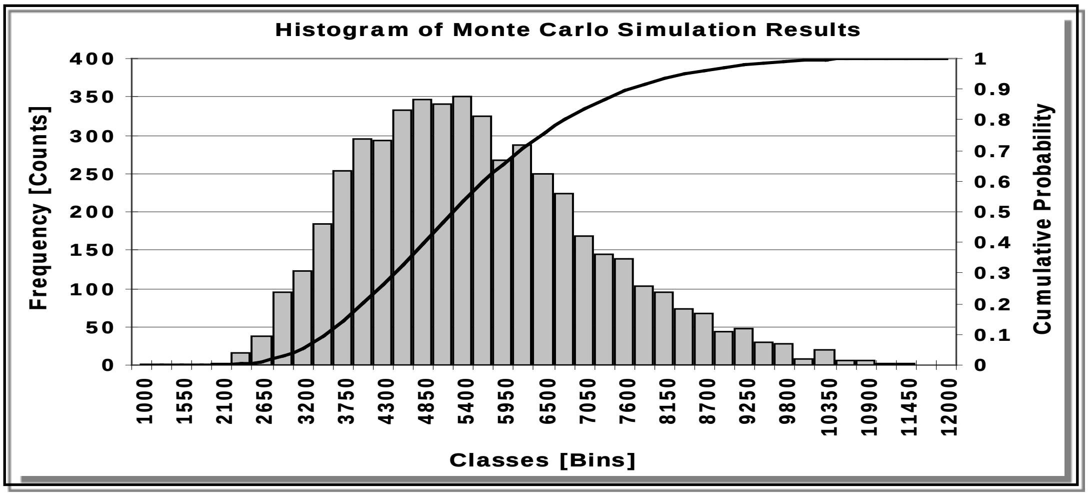

Figure 13: Histogram and Probability Distribution of the Monte Carlo Simulation

This results of simulation of field and production data obtained from the operator such as reservoir data of the study area, produced water parameters quality, factors which are responsible for cake formation and fracture formation is presented in Figure 13. Figure 13 is the data obtained from water reinjection indicates that calcite (calcium carbonate) forms the cake during the water reinjection process. From the graph showing the distribution of water reinjected parameters, it is observed that the amount of calcium and carbonate contained in the produced water is small relative to the other constituents and contributed majorly to cake formation.

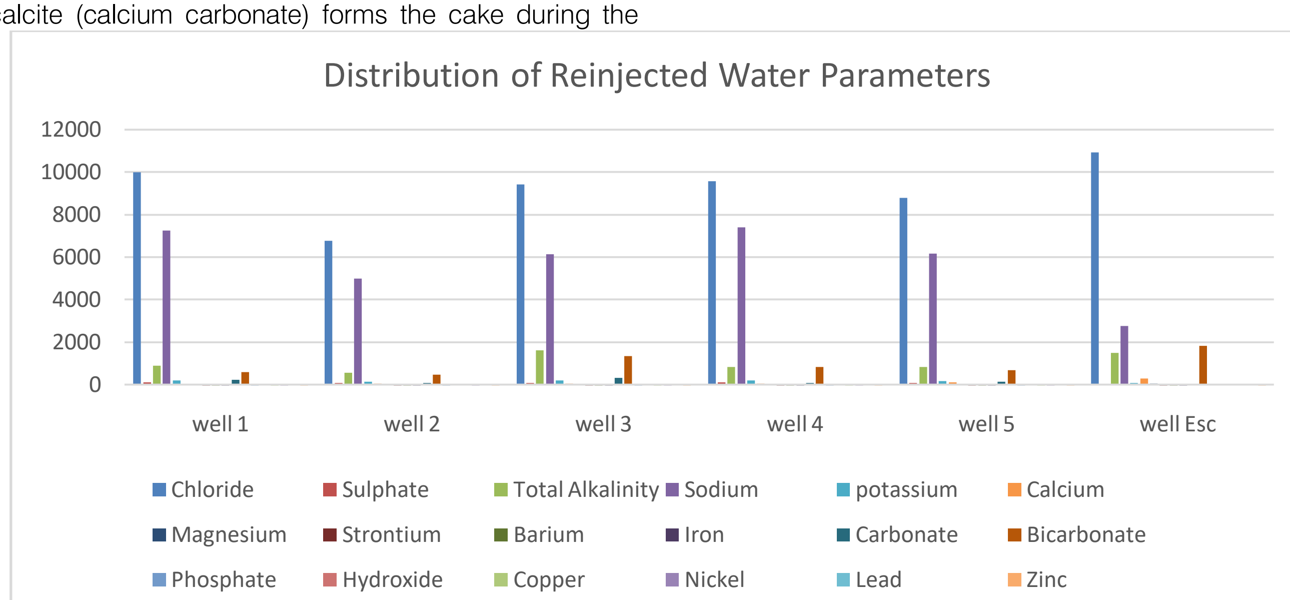

Figure 13: Chart for Distribution of Produced Water Parameters Quality in the Wells

b) Regression Analysis Output

Under the null hypothesis, the regression function does not depend on explanatory variables. The individual T statistic is used in calculating the P value which shows the statistical significance of the individual variables. An alpha level of 0.30 was used in this study. A P value less than the alpha level indicate a high statistical significance of the variable. A re-run regression analysis was performed to eliminate variables with high P values and insignificant regression coefficients. In this report, the Scaling Index (SI) which is used as an index of scaling in the formation resulting from produced water reinjection is the dependent variable prediction is based on temperature, pressure, pH, pH after precipitation and Injection rate. A high Multiple R value indicates a strong linear relationship existence. The Adjusted R squared value used in the regression analysis of this study is a multi linear regression. The regression analysis output from the field data is presented in Table 11

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Table 11: Regression Analysis Output from Field Data for Well 10 Field X-10ST (Scenario1)

Regression Output Scenario 1

Regression Statistics	
Multiple R	0.991167
R Square	0.982411
Adjusted R Square	0.980412
Standard Error	0.003463
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.02948	0.005896	491.5183	2.04E-37
Residual	44	0.000528	1.2E-05		
Total	49	0.030008			

	Coefficients	*Standard Error*	*T Stat*	*P-Value*
Intercept	-2.16204	0.351959	-6.14286	2.08E-07
Temp	0.00116	0.001933	0.600312	0.551378
Pressure	5.76E-05	6.76E-05	0.851287	0.399219
pH	0.55999	0.037971	14.74792	1.22E-18
pH after	-0.01215	0.005895	-2.06095	0.045248
Injection rate	5.4E-09	1.6E-07	0.033702	0.973267

*SI = -2.16204 + 0.00116 * Temperature + 0.0000576 * Pressure + 0.55999 * pH – 0.01215 * pH after precipitation + 5.4E-09 * Injection Rate. Table 4.0 OS Re-Run regression output scenario 1*

Table 12: Re-Run Regression Output Scenario 1

Regression Statistics	
Multiple R	0.991166
R Square	0.982411
Adjusted R Square	0.980847
Standard Error	0.003425
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.02948	0.00737	628.3449	7.62E-39
Residual	45	0.000528	1.17E-05		
Total	49	0.030008			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-2.17122	0.220229	-9.85893	8.1E-13

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Temp	0.001162	0.001911	0.607929	0.546291
Pressure	5.76E-05	6.68E-05	0.862559	0.392954
pH	0.561117	0.017791	31.54021	2.5E-32
pH after	-0.0123	0.003793	-3.24242	0.002235

*SI = -2.17122 + 0.001162 * Temperature + 0.0000576 * Pressure + 0.561117 * pH – 0.0123 * pH after precipitation*

c) *Regression Analysis Output from Field Data for Well 12 Field X-12HST (Scenario 2)*

Table 13: Regression Output Scenario 2

Regression Statistics	
Multiple R	0.988244
R Square	0.976626
Adjusted R Square	0.97397
Standard Error	0.003595
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.023759	0.004752	367.6826	1.06E-34
Residual	44	0.000569	1.29E-05		
Total	49	0.024328			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-2.08432	0.347215	-6.00297	3.34E-07
Temp	0.002274	0.002004	1.13481	0.262599
Pressure	9.93E-06	6.6E-05	0.150273	0.881236
pH	0.54543	0.035752	15.25596	3.5E-19
pH after	-0.01598	0.005797	-2.75678	0.008465
Injection rate	1.79E-08	1.67E-07	0.107264	0.915067

*SI = -2.08432 + 0.002274 * Temperature + 9.93E-06 * Pressure + 0.54543 *pH – 0.01598 * pH after precipitation + 1.79E-08 * Injection Rate*

Table 14: Rerun Regression Output Scenario 2

Regression Statistics	
Multiple R	0.988235186
R Square	0.976608784
Adjusted R Square	0.97508327
Standard Error	0.003517229
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.023758938	0.00791965	640.183386	1.67336E-37

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Residual	46	0.000569062	1.2371E-05
Total	49	0.024328	

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-2.134068821	0.15778	-13.525597	1.2145E-17
Temp	0.002584819	6.86134E-05	37.6722122	3.1818E-36
pH	0.548701518	0.016598371	33.057553	1.0517E-33
pH after	-0.016524371	0.003773413	-4.3791581	6.8162E-05

*SI = -2.13407 + 0.002585 * Temperature + 0.548702 * pH – 0.01652 * pH after precipitation*

d) Regression Analysis Output from Field Data for Well 13 Field X-13HST (Scenario 3)

Table 15 is the regression output for scenario 3

Table 15: Regression Output Scenario 3

Regression Statistics	
Multiple R	0.975719
R Square	0.952028
Adjusted R Square	0.946577
Standard Error	0.005013
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.021944	0.004389	174.6405	7.53E-28
Residual	44	0.001106	2.51E-05		
Total	49	0.02305			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-3.44031	0.667229	-5.15611	5.75E-06	-4.78502
Temp	0.006318	0.003042	2.077188	0.043654	0.000188
Pressure	-0.00011	9.94E-05	-1.09295	0.280366	-0.00031
pH	0.693906	0.070894	9.788002	1.29E-12	0.551029
pH after	-0.06126	0.012195	-5.0229	8.94E-06	-0.08583
Injection rate	5.18E-07	2.13E-07	2.430296	0.019233	8.85E-08

*SI = -3.44031 + 0.006318 * Temperature – 0.00011 * Pressure + 0.693906 * pH – 0.06126 * pH after precipitation + 5.18E-07 * Injection Rate*

Table 16: Rerun Regression Output Scenario 3

Regression Statistics	
Multiple R	0.972414
R Square	0.945589
Adjusted R Square	0.940752
Standard Error	0.005279
Observations	50

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ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.021796	0.005449	195.5079	7.96E-28
Residual	45	0.001254	2.79E-05		
Total	49	0.02305			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-4.60358	0.489533	-9.40402	3.44E-12	-5.58955
Temp	0.008126	0.003106	2.616268	0.012059	0.00187
Pressure	-0.00015	0.000103	-1.50154	0.1402	-0.00036
pH	0.827179	0.047315	17.48224	1.1E-21	0.731881
pH after	-0.08656	0.006688	-12.9415	9.01E-17	-0.10003

*SI = -4.60358 + 0.008126 * Temperature – 0.00015 * Pressure + 0.827179 * pH – 0.08656 * pH after precipitation*

e) *Regression Analysis Output from Field Data for Well 18 Field X-18ST (Scenario 4)*

Table 17: Regression Output Scenario 4

Regression Statistics	
Multiple R	0.997422
R Square	0.99485
Adjusted R Square	0.994265
Standard Error	0.003114
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.082423	0.016485	1699.89	3.83E-49
Residual	44	0.000427	9.7E-06		
Total	49	0.08285			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1.15459	0.32674	-3.53367	0.000977
Temp	-0.00441	0.001934	-2.28196	0.027384
Pressure	0.000274	7.36E-05	3.71952	0.000562
pH	0.491024	0.034478	14.24165	4.38E-18
pH after	-0.00445	0.006946	-0.64022	0.525348
Injection rate	2.42E-08	1.18E-07	0.204374	0.839004

*SI = -1.15459 – 0.00441 * Temperature + 0.000274 * Pressure + 0.491024 * pH – 0.00445 *pH after precipitation + 2.42E-08 * Injection Rate*

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Table 18: Rerun Regression Output Scenario 4

Regression Statistics	
Multiple R	0.997314
R Square	0.994636
Adjusted R Square	0.994286
Standard Error	0.003108
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.082406	0.027469	2843.115	3.29E-52
Residual	46	0.000444	9.66E-06		
Total	49	0.08285			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1.10102	0.20865	-5.27688	3.45E-06
Temperature	-0.00485	0.001865	-2.59896	0.012524
Pressure	0.00029	7.15E-05	4.056664	0.000191
pH	0.485192	0.01795	27.0295	7.08E-30

*SI = -1.10102 – 0.00485 * Temperature + 0.00029 * Pressure + 0.485192 * pH*

f) *Regression Analysis Output from Field Data for Well 26 Field X-26 (Scenario 5)*

Table 19: Regression Output Scenario 5

Regression Statistics	
Multiple R	0.986538
R Square	0.973258
Adjusted R Square	0.970219
Standard Error	0.00287
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.01319	0.002638	320.2661	2.03E-33
Residual	44	0.000362	8.24E-06		
Total	49	0.013552			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.00585	0.425917	-0.01373	0.989111
Temp	-0.00014	0.001721	-0.08203	0.934997
Pressure	6.6E-05	5.65E-05	1.167831	0.249164
pH	0.32345	0.047651	6.787871	2.34E-08
pH after	0.003212	0.009405	0.341508	0.734347
Injection rate	7.46E-08	9.11E-08	0.818697	0.417372

*SI = -0.00585 – 0.00014 * Temperature + 6.6E-05 * Pressure + 0.32345 *pH + 0.003212 * pH after precipitation + 7.46E-08 * Injection Rate*

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Table 20: Rerun Regression Output Scenario 5

Regression Statistics	
Multiple R	0.986282
R Square	0.972753
Adjusted R Square	0.971594
Standard Error	0.002803
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.013183	0.006591	838.9829	1.7E-37
Residual	47	0.000369	7.86E-06		
Total	49	0.013552			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-0.18532	0.252548	-0.73382	0.466704	-0.69339
Pressure	6.37E-05	3.56E-06	17.89608	1.29E-22	5.65E-05
pH	0.344549	0.027479	12.5384	1.33E-16	0.289267

*SI = -0.18532 + 6.37E-05 * Pressure + 0.344549 * pH*

g) Regression Analysis Output from Field Data for Field X (Scenario 6)

FIELD X

This scenario considers altogether the previous scenarios.

Table 21: Regression Output Scenario 6

Regression Statistics	
Multiple R	0.972378
R Square	0.945518
Adjusted R Square	0.944402
Standard Error	0.007245
Observations	250

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.222256	0.044451	846.9089	6.3E-152
Residual	244	0.012807	5.25E-05		
Total	249	0.235062			

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	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1.45881	0.18627	-7.83165	1.47E-13
Temp	0.005211	0.000145	35.97596	1.5E-99
Pressure	-9.9E-05	5.15E-06	-19.2332	8.49E-51
pH	0.456151	0.021364	21.35138	9.3E-58
pH after	-0.02185	0.00452	-4.83319	2.38E-06
Injection rate	3.02E-07	9.03E-08	3.339175	0.000972

*SI = -1.4588 + 0.00521 * Temperature – 9.905E-05 * Pressure + 0.456 * pH – 0.02185 * pH after precipitation + 3.01545E-07 * Injection Rate*

h) Regression Analysis Output from Field Data for Field Y

Table 22: Regression Analysis on Rock Properties

Regression Statistics	
Multiple R	0.999199
R Square	0.998399
Adjusted R Square	0.998218
Standard Error	8.593554
Observations	60

ANOVA

	df	*SS*	*MS*	*F*
Regression	6	2440890	406814.94	5508.727
Residual	53	3914.006	73.849176	
Total	59	2444804		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-4151.74	79.70977	-52.08573	3.36E-47
Young's modulus, psi	-5.4E-07	3.29E-06	-0.163835	0.870484
Poisson's Ratio	5077.193	62.49606	81.240204	2.65E-57
Pressure, psi	1.892506	0.024376	77.637016	2.87E-56
Compressibility, psi-1	-576349	690414.7	-0.834786	0.407585
Permeability, md	0.006449	0.002004	3.2186398	0.0022
Porosity	-38.5441	33.04645	-1.166361	0.24869

*Shear Stress = - 4151.74 – 5.4E-07 * Young's Modulus + 5077.193 * Poisson's Ratio + 1.89 * Pressure – 576349 * Compressibility + 0.006449 * Permeability – 38.5441 * Porosity*

Table 23: Re-Run Regression Analysis on Rock Properties

Regression Statistics	
Multiple R	0.999199
R Square	0.998398
Adjusted R Square	0.99825
Standard Error	8.515768
Observations	60

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ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	2440887.7	488177.5	6731.783	3.77E-74
Residual	54	3915.9886	72.51831		
Total	59	2444803.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-4157.12	71.976823	-57.7564	3.14E-50
Poisson's Ratio	5074.787	60.197479	84.30232	5.32E-59
Pressure, psi	1.893951	0.0225194	84.10327	6.04E-59
Compressibility, psi-1	-541275	650444.08	-0.83216	0.408983
Permeability, md	0.006473	0.0019803	3.268503	0.001884
Porosity	-34.6017	22.444932	-1.54162	0.129005

*Shear Stress = - 4157.12 + 5074.787 * Poisson's Ratio + 1.89 * Pressure – 541275 * Compressibility + 0.006473 * Permeability – 34.6017 * Porosity*

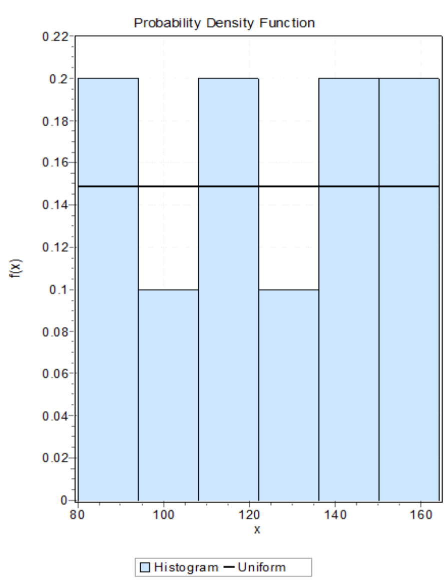
i) Monte Carlo Simulation

The Monte Carlo Simulation which are the probability distribution defines the best fit of the independent variables where each scenario was described.

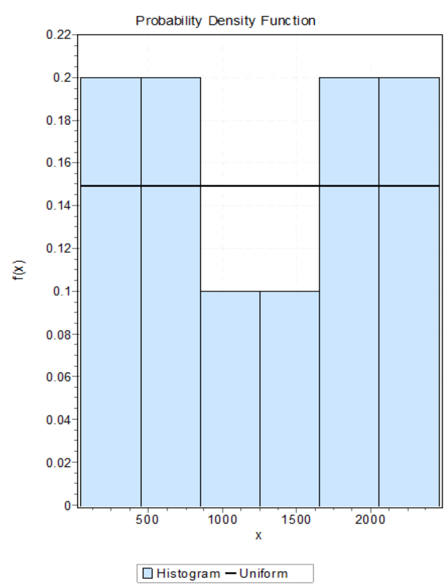
i. *Monte Carlo Probability Distributions*

Scenario 1 – WELL 10

Temperature (Uniform)



Pressure (Uniform)



Global Journal of Researches in Engineering (J) Volume XXIII Issue III Version I Year 2023

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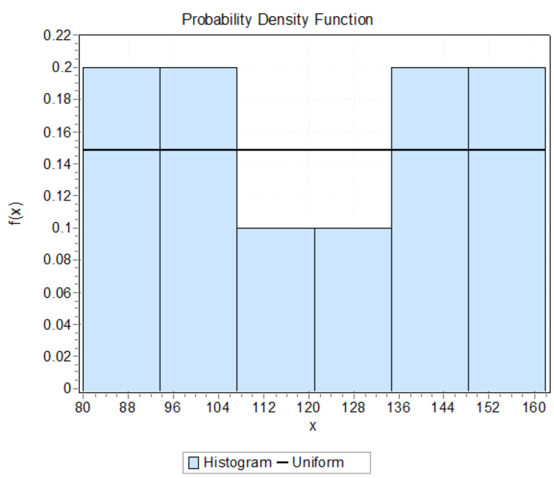
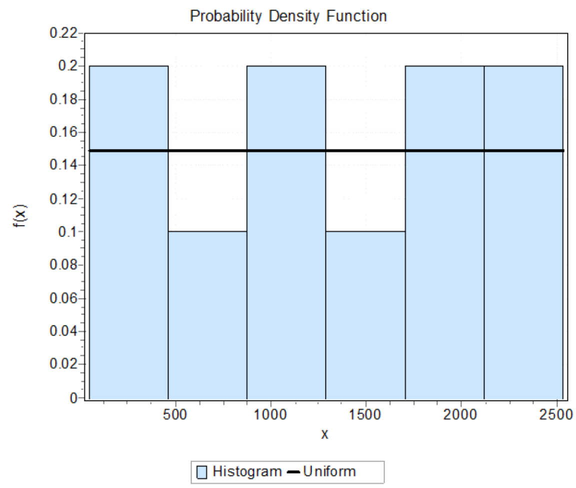
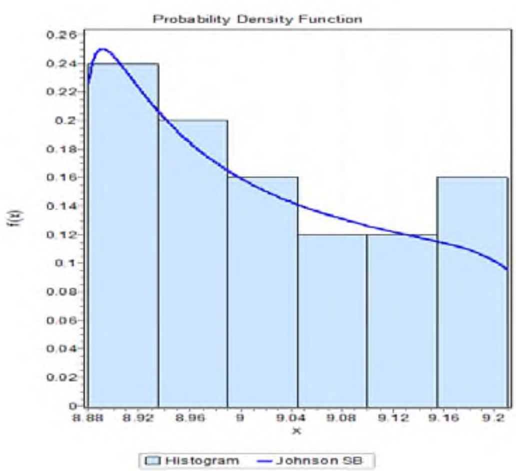
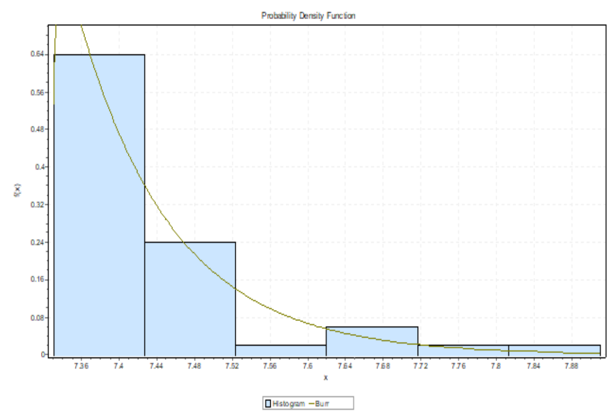


pH (Johnson SB)



pH after (Burr)





Injection Rate (uniform)

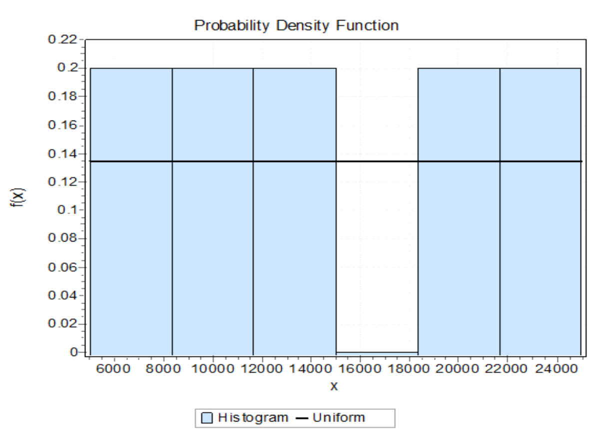


Figure 19: Probability Distribution Functions for Variables in Predicting SI in Well 18

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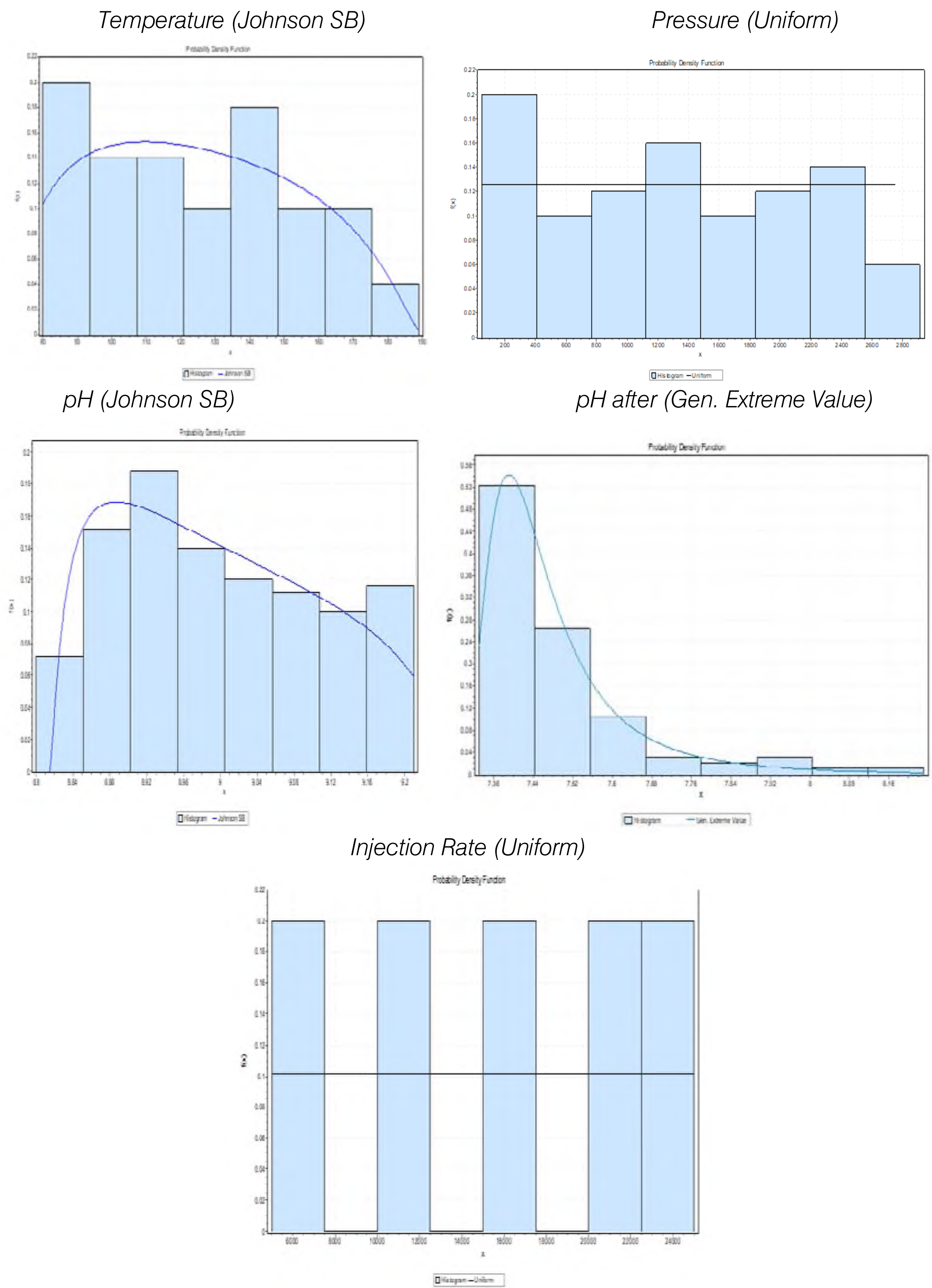

Figure 20: Probability distribution functions for variables in predicting SI in Field X

j) Simulations of Effects of Cake formation, fracturing on Injection Well Performance

The injector well performance was evaluated based on the injectivity index. An average value of 15,000 bbl/d was used as injection rate in calculating injectivity index based on average injection rates in the various wells of the Nigerian oil field. Based on the estimated values of Scaling Index (SI) from the Monte Carlo Simulation, Injectivity Index was then determined and various plots created.

In a number of thirty (30) simulation plots to model the effects of cake formation on injector well performance, it was observed in Scenario 1, that twenty-five (25) simulation plots indicated a decreasing trend in well performance, four (4) indicated a constant trend in the injection well performance and one (1) indicated an increasing trend in well performance based on

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increasing cake formation. In Scenario 2, it was observed that twenty-eight (28) simulation plots indicated a decreasing trend in well performance, zero (0) indicated a constant trend in the injection well performance and two (2) indicated and increasing trend in well performance based on increasing cake formation. In Scenario 3, it was observed that twenty-seven (27) simulation plots indicated a decreasing trend in well performance, and three (3) indicated a constant trend in the injection well performance based on increasing cake formation. In Scenario 4, it was observed that twenty-six (26) simulation plots indicated a decreasing trend in well performance, two (2) indicated a constant trend in the injection well performance and two (2) indicated an increasing trend in well performance based on increasing cake formation. In Scenario 5, it was observed that twenty-five (25) simulation plots indicated a decreasing trend in well performance, and five (5) indicated an increasing trend in well performance based on increasing cake formation. In Scenario 6, it was observed that all thirty (30) simulation plots indicated a decreasing trend in well performance, based on increasing cake formation. A tabulated expression is seen in *Appendix B1.* Appendix B1show the simulations that there were occasions when Injectivity index was very high which indicated high well performance before a decline. This could be likened to a result of computer generated low values of flowing wellbore pressure.

k) Simulations of Effect of Fracturing on Injector Well Performance

The table below shows the simulation data for evaluating the effect of fracturing on the Injector Well Performance for a Field Y in the Gulf of Mexico.

Table 24: Simulation Data for Fracturing Effect on Injector Well Performance in Field Y Gulf of Mexico

Parameter	Values
Reservoir Pressure, Pe	5000 psia
Maximum Shear Stress	2500 psi
Fluid Shear Stress	1671.315 psi
Wellbore Flowing Pressure, P_{wf}	Simulated
Injection Rate	15,000 bbl/d

A K_{fs} value of 0 indicates rock fracture propagation while a K_{fs} value of 1 indicates least fracture propagation. A simulation plot of Injectivity Index against rock fracture production Rate is illustrated below.

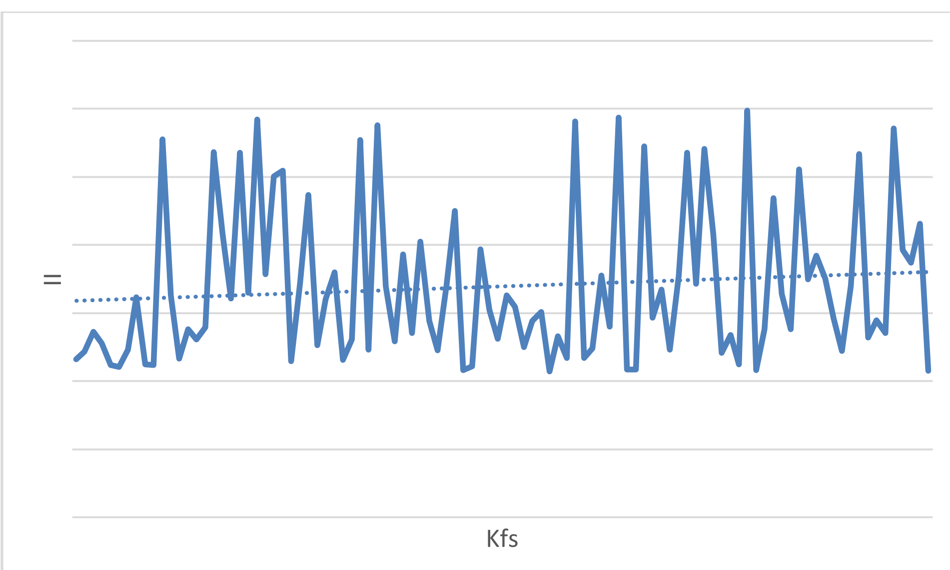

Figure 21: Simulation Plot (10) for Field Y in Gulf of Mexico

To model the effect of rock fracture propagation rate on Injector Well Performance, fifty (50) simulation plots were run. It was observed that seven plots (7) indicated a decline, seven (7) indicated a constant and thirty-six (36) indicated an increase in Injector Well Performance with increasing value of Kfs i.e. decreasing rock fracture propagation rate which implies more fluid flow.

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V. Conclusion

In the formation of the hypothesis, five explanatory variables: Temperature, Pressure, pH, pH after precipitation and Injection rate were used to create a statistical regression analysis model for the prediction of Scaling Index (SI). Hence, it is suggested that all the five explanatory variables be used in creating a model. The Monte Carlo simulations ran all indicated SI values greater than 0 in all scenarios indicating potential for scale formation. SI = < 0 indicates no potential for scaling and SI = > 0 indicates scaling potential. In predicting fracturing, the rock shear stress and maximum shear stress were evaluated and fracturing can occur when the fluid shear stress is greater than the residual stress from the maximum rock stress and rock shear stresses at a depth. Based on the Simulation Plots obtained from the Program, a range of 83.3% - 100% indicated that formation of cake leads to decline in Injection Well Performance and 72% indicated that decrease in the rock fracture propagation rate corresponds to an increase in Injector Well Performance. Furthermore for each temperature, the SI decreases as the pressure increases and based on field data the regression statistics show R to be 0.998476685, R Square to be 0.99695569 and Adjusted R square is 0.919622802 and standard error of 0.003468055 for the observations shows a strong agreement with field data.

Nomenclature

q = Production Rate	bbls/day
k = Permeability	Darcy
A = Cross section area	m^2
μ = Fluid viscosity	Kg/m.s
$\frac{\Delta P}{L}$ = Pressure gradient (Pressure change per unit length).	Pascal/m

Acknowledgements

The data was supplied by Department of Petroleum Resources (DPR) and CNL/Energy Technology Company in Houston Texas under the University Technology Partnership programme and this well appreciated. Substantial data analysis was carried out by a simulation software supplied by Systems Engineering and Chemical and Petroleum Engineering faculty and this well appreciated as well.

Declaration of Interest

"The authors have nothing to declare"

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A5: Field Data for Well 26 Field X-26

SI	Temp	Pressure	pH	pH after	Injection rate
2.99	80	50	9.2	7.91	5000
2.99	89	326	9.14	7.58	5000
2.99	98	602	9.1	7.51	5000
2.99	107	878	9.06	7.47	5000
2.99	116	1154	9.02	7.44	5000
3.00	126	1430	8.98	7.42	5000
3.01	135	1706	8.95	7.41	5000
3.01	144	1982	8.92	7.41	5000
3.02	153	2258	8.9	7.41	5000
3.03	162	2534	8.88	7.41	5000
2.99	80	50	9.21	7.77	10000
2.99	89	326	9.15	7.52	10000
2.99	98	602	9.11	7.46	10000
2.99	107	878	9.06	7.43	10000
3.00	116	1154	9.03	7.4	10000
3.00	126	1430	8.99	7.38	10000
3.01	135	1706	8.96	7.37	10000
3.02	144	1982	8.93	7.36	10000
3.03	153	2258	8.91	7.36	10000
3.04	162	2534	8.88	7.36	10000
2.99	80	50	9.21	7.7	15000
2.99	89	326	9.16	7.5	15000
2.99	98	602	9.11	7.44	15000
3.00	107	878	9.07	7.41	15000
3.00	116	1154	9.03	7.38	15000
3.01	126	1430	9	7.37	15000
3.01	135	1706	8.96	7.36	15000
3.02	144	1982	8.94	7.35	15000
3.03	153	2258	8.91	7.34	15000
3.04	162	2534	8.89	7.34	15000
2.99	80	50	9.21	7.66	20000
2.99	89	326	9.16	7.48	20000
2.99	98	602	9.11	7.43	20000
3.00	107	878	9.07	7.4	20000
3.00	116	1154	9.03	7.38	20000
3.01	126	1430	9	7.36	20000
3.01	135	1706	8.97	7.35	20000
3.02	144	1982	8.94	7.34	20000
3.03	153	2258	8.91	7.34	20000
3.04	162	2534	8.89	7.33	20000
2.99	80	50	9.21	7.63	25000
2.99	89	326	9.16	7.47	25000
2.99	98	602	9.11	7.43	25000
3.00	107	878	9.07	7.4	25000
3.00	116	1154	9.03	7.38	25000
3.01	126	1430	9	7.36	25000
3.01	135	1706	8.97	7.34	25000

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3.02	144	1982	8.94	7.34	25000
3.03	153	2258	8.91	7.33	25000
3.04	162	2534	8.89	7.33	25000

A6: Field Data For Well In Gulf Of Mexico

TVD	σHmin	σHmin/TVD	Young's modulus, psi	Poisson's Ratio	Toughness, psi-in1/2	Pressure, psi	Compressibility, psi-1	Permeaility, md	Porosity	Formation Fluid	Coeff of Therm Exp (1/R)	Temp(F)	Biots Constant
2133.64	3750	1.75756	92000	0.392	400	3134	1.05E-05	100	0.343	0.7	3.50E-06	95.6	1
2134.29	3751	1.757493	86000	0.392	400	3134	1.07E-05	100	0.386	0.7	3.50E-06	95.6	1
2134.43	3752	1.757846	180000	0.392	400	3134	1.03E-05	100	0.393	0.7	3.50E-06	95.6	1
2134.57	3752	1.757731	350000	0.392	400	3135	1.05E-05	100	0.35	0.7	3.50E-06	95.7	1
2134.72	3729	1.746833	7.70E+05	0.386	400	3135	9.53E-06	100	0.216	0.7	3.50E-06	95.7	1
2135.57	3657	1.712423	2.30E+06	0.368	400	3135	3.65E-06	100	0.117	0.7	3.50E-06	95.7	1
2135.86	3790	1.774461	1.10E+06	0.4	400	3136	3.27E-06	100	0.274	0.7	3.50E-06	95.7	1
2139.29	3795	1.773953	4.60E+05	0.4	400	3138	5.82E-06	100	0.314	0.7	3.50E-06	95.9	1
2140.72	3726	1.740536	1.00E+06	0.383	400	3141	5.48E-06	100	0.295	0.7	3.50E-06	96.1	1
2142.58	3906	1.823036	2.60E+06	0.421	400	3143	3.34E-06	100	0.15	0.7	3.50E-06	96.2	1
2142.86	3890	1.815331	1.10E+06	0.418	400	3145	4.76E-06	100	0.291	0.7	3.50E-06	96.3	1
2146.15	3691	1.719824	3.70E+05	0.371	400	3147	5.70E-06	100	0.308	0.7	3.50E-06	96.4	1
2147.86	3785	1.762219	7.20E+05	0.391	400	3150	4.31E-06	100	0.289	0.7	3.50E-06	96.6	1
2148.29	3884	1.80795	2.70E+05	0.413	400	3151	5.52E-06	100	0.351	0.7	3.50E-06	96.6	1
2166.76	3895	1.797615	1.20E+05	0.411	400	3163	6.10E-06	100	0.371	0.7	3.50E-06	97.3	1
2167.34	3778	1.743151	2.90E+05	0.379	400	3174	6.37E-06	100	0.265	0.7	3.50E-06	98	1
2175.37	3775	1.735337	4.70E+05	0.376	400	3180	4.63E-06	100	0.31	0.7	3.50E-06	98.3	1
2185.71	3878	1.774252	1.90E+05	0.394	400	3191	6.93E-06	100	0.331	0.7	3.50E-06	99	1
2194.96	3903	1.778165	9.20E+04	0.394	400	3203	9.13E-06	1500	0.358	0.7	3.50E-06	99.7	1
2205.51	3937	1.785075	1.00E+05	0.397	400	3215	8.62E-06	1500	0.347	0.7	3.50E-06	100.4	1
2208.97	3948	1.787258	4.20E+05	0.395	400	3224	6.09E-06	100	0.32	0.7	3.50E-06	100.9	1
2209.84	4122	1.865293	8.70E+05	0.429	400	3226	3.72E-06	1500	0.295	0.7	3.50E-06	101	1
2210.13	4195	1.898078	3.90E+05	0.443	400	3227	5.81E-06	1500	0.285	0.7	3.50E-06	101.1	1
2210.42	4100	1.854851	1.50E+05	0.425	400	3227	9.06E-06	1500	0.307	0.7	3.50E-06	101.1	1
2221.17	4046	1.821563	8.90E+04	0.411	400	3234	9.56E-06	1500	0.308	0.7	3.50E-06	101.5	1
2221.32	4003	1.802082	1.90E+05	0.4	400	3241	9.24E-06	1500	0.29	0.7	3.50E-06	101.9	1
2221.46	4020	1.809621	3.50E+05	0.403	400	3241	8.56E-06	1500	0.278	0.7	3.50E-06	101.9	1
2221.75	4023	1.810735	8.80E+05	0.404	400	3241	5.68E-06	1500	0.212	0.7	3.50E-06	101.9	1
2222.33	4025	1.811162	1.50E+06	0.404	400	3242	4.00E-06	1500	0.186	0.7	3.50E-06	101.9	1
2222.48	4026	1.81149	5.20E+05	0.404	400	3242	7.16E-06	1500	0.246	0.7	3.50E-06	102	1
2222.63	4039	1.817217	2.70E+05	0.406	400	3242	6.99E-06	1500	0.254	0.7	3.50E-06	102	1
2233.68	4078	1.825687	8.70E+05	0.411	400	3249	9.14E-06	1500	0.311	0.7	3.50E-06	102.4	1
2234.7	3933	1.759968	2.60E+05	0.378	400	3257	4.33E-06	1500	0.293	0.7	3.50E-06	102.8	1
2236.3	4070	1.81997	5.30E+05	0.405	400	3259	3.67E-06	1500	0.213	0.7	3.50E-06	102.9	1
2238.63	4338	1.937792	8.20E+05	0.454	400	3262	5.11E-06	1500	0.284	0.7	3.50E-06	103.1	1
2239.51	4038	1.803073	2.50E+05	0.397	400	3264	4.17E-06	1500	0.329	0.7	3.50E-06	103.2	1
2239.95	3942	1.759861	6.10E+05	0.377	400	3265	3.43E-06	1500	0.32	0.7	3.50E-06	103.2	1
2241.71	4119	1.837437	2.50E+06	0.411	400	3267	3.81E-06	1500	0.175	0.7	3.50E-06	103.3	1
2242.15	4320	1.926722	1.10E+06	0.449	400	3268	3.23E-06	1500	0.283	0.7	3.50E-06	103.4	1
2245.38	4224	1.881196	5.30E+05	0.431	400	3271	3.56E-06	1500	0.258	0.7	3.50E-06	103.5	1
2251.54	4281	1.901365	2.40E+05	0.439	400	3278	3.94E-06	1500	0.318	0.7	3.50E-06	103.8	1
2251.98	4333	1.924085	6.80E+05	0.446	400	3283	3.33E-06	1500	0.261	0.7	3.50E-06	104.1	1
2252.86	4366	1.937981	2.30E+06	0.451	400	3284	3.33E-06	1500	0.143	0.7	3.50E-06	104.1	1
2253.01	4312	1.913884	1.30E+06	0.442	400	3285	3.25E-06	1500	0.156	0.7	3.50E-06	104.2	1
2253.15	4313	1.914209	7.50E+05	0.442	400	3285	3.46E-06	1500	0.2	0.7	3.50E-06	104.2	1
2255.94	4123	1.82762	3.20E+05	0.406	400	3287	3.70E-06	1500	0.311	0.7	3.50E-06	104.3	1
2256.38	4235	1.8769	9.90E+05	0.427	400	3290	5.31E-06	1500	0.21	0.7	3.50E-06	104.4	1
2257.99	4411	1.953507	2.20E+06	0.457	400	3291	3.14E-06	1500	0.206	0.7	3.50E-06	104.5	1
2259.02	4134	1.829997	1.10E+06	0.407	400	3293	3.28E-06	1500	0.206	0.7	3.50E-06	104.6	1
2259.76	4149	1.836036	1.80E+06	0.409	400	3295	3.19E-06	1500	0.251	0.7	3.50E-06	104.6	1
2261.81	4104	1.814476	7.60E+05	0.4	400	3297	3.73E-06	1500	0.266	0.7	3.50E-06	104.7	1
2264.89	4025	1.777128	5.20E+05	0.382	400	3300	3.86E-06	1500	0.258	0.7	3.50E-06	104.9	1
2272.81	4197	1.846613	3.40E+05	0.413	400	3309	3.78E-06	100	0.3	0.7	3.50E-06	105.3	1
2273.7	4159	1.829177	2.10E+05	0.404	400	3315	5.63E-06	100	0.307	0.7	3.50E-06	105.6	1
2275.6	4207	1.848743	3.90E+05	0.412	400	3317	3.48E-06	100	0.334	0.7	3.50E-06	105.7	1
2288.77	4205	1.837231	2.70E+05	0.408	400	3329	3.73E-06	100	0.316	0.7	3.50E-06	106.3	1
2289.51	4313	1.883809	4.40E+05	0.425	400	3339	3.41E-06	100	0.277	0.7	3.50E-06	106.8	1
2291.88	4266	1.861354	1.80E+05	0.416	400	3342	3.88E-06	100	0.353	0.7	3.50E-06	106.9	1
2295.44	4281	1.865002	4.50E+05	0.417	400	3346	3.84E-06	100	0.293	0.7	3.50E-06	107.1	1
2316.41	4182	1.80538	3.80E+05	0.392	400	3364	3.56E-06	100	0.312	0.7	3.50E-06	108	1

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