AN EMPIRICAL MODEL TO PREDICT SKIN FACTOR OF A LIBYAN OILFIELD

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ABSTRACT

Formation damage management and remediation are both a science and an art (Civan 1996). Currently, there are no proven technologies that are treated for all problems that an oil company may encounter. The issues revolving around formation damage is one of these convoluted issues which many oil companies currently struggle with. This paper has proposed such an innovative approach centered upon three dimensionless groups as well as multiple regression analysis using MINITAB (a statistical computing program) to foster an empirical model to predict skin factor for Field XXX which belongs to a Libyan Oil Company. The first step in this endeavor was employed by the use of data collection consisting of buildup data history and fluid properties from eight oil wells. A total of 39 observations were used in this study. Of these wells, 27 observations were used to develop the empirical model. The remaining 12 observations were chosen randomly to test the capability and validity of the model to validate the empirical model and test predictive competence, predicted skin factor values were compared against skin factor values determined from the buildup test analysis shown in Statistical evidence proved that the model illustrated in this thesis is advantageous and may potentially be utilized in efforts to predict of skin factor. Comparing the developed model predicted results to the observed buildup test results, demonstrations have shown that there is a correlation between the results and well ability of the developed model to estimate skin factor. As a result, this study offers the following conclusions: The size of the data set, used in the development of the empirical model, had significant effects on construction of the model, since the data used for developing the model must be good enough to increase the accuracy of model. In this study, 39 observations were used to form and test the model, which had six variables divided into three groups. These 39 observations represent five years of the production history of eight wells. The developed model presented in this study has the ability to further assist understanding, and evaluating the formation damage by predicting skin factor. The developed model also has the potential use of predicting skin factor instead of conducting a buildup test every year. This will reduce operating unit technical cost (UTC), and save millions of dollars for the Libyan operating company. When the mechanistic or mathematical models correlating certain variables are unknown, statistical tools are shown to be useful in development of models correlating with two or more variables of concern

DATA COLLECTION AND PREPARTION

Skin factor was chosen to be function of the following parameters.

P_{wf} Bottom hole Pressure, psia
q_o Flow Rate, stb/d
k_o Effective Permeability, md
μ_o Oil Viscosity, cp
h_p Perforation Thickness, ft
TDS Total Dissolved Solids, ppm

The form of the model given was:

$$S = f\,(P_{wf}, q_o, k_o, \mu_o, h_p, TDS) \qquad (1)$$

The second step was data preparation. This was used to conduct the multiple linear regression analysis (MLRA). Since skin factor is a dimensionless parameter, this paper applied Buckingham Pi theorem to develop three dimensionless groups (Pi terms $\pi_1, \pi_2, \pi_3, \ldots, \pi_n$). These dimensionless groups were independent variables whereas skin factor was the dependent variable as indicated in equation 2.

$$S = f\,(\pi_1, \pi_2, \pi_3 \ldots \pi_n) \qquad (2)$$

BUCKINGHAM PI-THEOREM

In this section, a method called dimensional analysis along with the Buckingham Pi theorem is introduced to identify important dimensionless parameters governing a particular problem. Dimensionless analysis procedure steps (using Buckingham Pi Theorem) are listed below:

$$\pi_1 = \frac{TDS * L^{-2} * L^3}{p_{wf}} = \left[\frac{TDS\sqrt{k_o}}{P_{wf}} \right] \qquad (3)$$

$$\pi_2 = \frac{q * L^{-3} * P_{wf} * L^2}{\mu L} = \left[\frac{qp_{wf}}{\mu k} \right] \qquad (4)$$

$$\pi_3 = \frac{h_p}{\sqrt{k}} \qquad (5)$$

The third step is preparation. In the buildup model development, three dimensionless groups serve as independent variables while skin factors serve as dependent response variables (Table 4.2). The general form of the model is given as:

$$S = f(\pi_1, \pi_2, \pi_3) \qquad (6)$$

Using the dimensionless groups, the general form of the model has been determined; the next step is to develop the model. The following variables in Table 1 and 2 will be used to develop the multiple regressions model, using the MINITAB software. Multiple Linear regression analysis (MLRA) was then conducted to identify functional relationships by using Minitab.

$$Y(x_1, x_2, x_3) = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \qquad (7)$$

$$S(\pi_1, \pi_2, \pi_3) = \beta_o + \beta_1 \pi_1 + \beta_2 \pi_2 + \beta_3 \pi_3 \qquad (8)$$

$$S = 41.8 + 10.2 \log\left(\frac{TDS\ \sqrt{k}}{P_{wf}} \right) - 12.9 \log\left(\frac{P_{wf}\, q}{k\mu} \right) - 1.69 \log\left(\frac{h_p}{\sqrt{k}} \right) \qquad (9)$$

CHECKING MODEL ADEQUACY

In linear regression, the norm assumption is that model errors ε_i are generally independently distributed with a mean of zero and a variance σ^2. Residuals from the regression model are utilized for checking assumptions of normality and constant variance. The residuals should be graphically analyzed to check the adequacy of a multiple linear regression model. A normal probability plot of the residuals is used to check the normality assumption which the errors are uncorrelated random variables with mean zero and constant variance. The plot of the residuals versus the predicted y values can reveal model inadequacies. The normal probability plot of the residuals for developed empirical model is shown in figure 1. No severe deviations from normality are obviously apparent, the residuals fall extremely close to a straight line. The plot of the residuals versus fitted values, figure 2, indicates that there is no problem with the assumption of constant variance. In general, none of the plots suggests any dramatic problems with the developed model

COEFFICIENT OF DETERMINATION R^2

For the developed model, Minitab reports the quantity of R^2 as 85.3%, implying that the regression model accounts for 85.3% of the observed variability in the data set used to develop the model. In conclusion, a large value of R^2 suggests that the model has been successful in explaining the variability in the response.

TESTING AND VALIDATION

The final step in the model developmental process is the validation of the selected regression model (empirical model). This endeavor involves the comparison of the predicted skin factor with the calculated skin factor from the buildup test for different wells. On these grounds, the 12 observations shown in Table 3 were used for testing capability and validity of the developed empirical model. These observations were chosen randomly, and are not included in the model building process.

MODEL RESULTS

By using Excel, the program used to calculate skin factor by using the developed model from the data, Table 4 was generated. In addition, Table 5 represents skin factor results obtained by using the buildup test.

Comparison of Model Results with Buildup Test Results

The selected model must be tested with similar data sets that are not used in the model building process. This step is necessary to determine the robustness and predictive ability of the model. The developed model was validated by comparing generated results with the buildup test results shown above. The following results are depicted in table (5). From Table 6 and Figure 3, one can conclude that predicted skin factor results are compatible with buildup test results. There are two important classifications of skin factor, either positive skin factor value or negative skin factor value. It is evident that the developed model has the potential to estimate positive and negative values of skin factor. The model may also predict whether damage lingers around the wellbore or not. In Table 6 the comparison among observations 4, 5, and 8, show that there are different values of skin factor with high residuals. In practice, it is inconsequential for petroleum engineers if predicted skin factor value is 9.9 and the buildup test analysis is shown to have a skin factor value of 16.5. This proposition is based on the fact that the predicted skin factor of 9.9 represents enough evidence of the existence of damage and that the company is taking action to improve well productivity. All in all, practicing engineers can conclude that the developed model can be used for predicting purposes.

CONCLUSION

Comparing the developed model predicted results with the observed buildup test results in Table 6, demonstrations have shown that there is a correlation between the results and well ability of the developed model to estimate skin factor. As a result, this study offers the following conclusions:

1. The size of the data set, used in the development of the empirical model, had significant effects on construction of the model, since the data used for developing the model must be good enough to increase the accuracy of model. In this study, 39 observations were used to form and test the model which had six variables divided in three groups. These 39 observations represent five years of the production history of eight wells.
2. The developed model presented in this study has the ability to further assist understanding, and evaluate formation damage by predicting skin factor.
3. The developed model also has the potential to be used to predict skin factor instead of conducting a buildup test every year. This will reduce operating unit technical cost (UTC), and save millions of dollars for operating company.
4. When the mechanistic or mathematical models correlating certain variables are unknown, statistical tools are shown to be useful in development of models correlating with two or more variables of concern.

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Table 1 - Buildup Data and Fluid Properties for Eight Wells

P_{wf}	q_o	k_o	μ_o	h_p	TDS	S
x_1	x_2	x_3	x_4	x_5	x_6	y(x)
2179	4822	165.357	1.07	395.5	220000	10.09
1488	2192	66.121	1.07	395.5	220000	10.43
1141	728	57.45	1.07	395.5	220000	52.37
2604	1447	88.686	1.07	395.5	220000	5.18
1303	180	6.609	1.07	395.5	220000	34.94
1418	4062	7.807	1.07	290	225630	-4.231
1387	1855	5.905	1.07	290	225630	-4.088
857.6	444	2.636	1.07	290	225630	-5.156
1324.3	4066	138.56	0.66	32	208000	20.691
2532.2	756	135.982	0.66	32	208000	12.145
2454	560	101.288	0.66	32	208000	12.888
2730.7	343	0.072	0.66	32	208000	-4.714
659	624	119.275	0.66	110	209200	33.047
2761	142	488.419	0.66	110	209200	29.637
999.21	1528	111.737	0.66	22	215600	36.26
1502	2163	154.893	0.66	22	215600	26.323
1056.25	1018	3.038	0.66	248	214840	-0.383
762.4	909	6.699	0.66	248	214840	8.136
2333	6549	274.15	0.785	160	227000	8.022
755	3807	225.906	0.785	160	227000	24.369
659	3344	26.667	0.785	160	227000	-1.849
721	3855	276.928	0.785	160	227000	19.767
2245	4340	55.29	0.785	80	228000	-3.895
2455	6281	155.809	0.785	80	228000	-1.801
1986	5942	42.527	0.785	80	228000	-4.51
1844	4210	225.225	0.785	80	228000	21.168
1305.47	609	12.52	0.785	80	228000	23.572

Table 2 - Skin Factor and Dimensionless Groups (π_1, π_2, π_3)

No.	S	π_1	π_2	π_3
1	10.07	3.113377	4.773678	1.487935
2	10.5	3.079989	4.66372	1.686977
3	17.22	3.164782	4.130743	1.717501
4	5.18	2.900709	4.598871	1.623219
5	6.4	2.637554	4.520689	2.187079
6	-4.231	2.647963	5.838548	2.016156
7	-4.088	2.59693	5.609817	2.076788
8	-5.156	2.630585	5.130339	2.251925
9	20.691	3.266896	4.769972	0.434331
10	12.145	2.981306	4.328994	0.438409
11	12.888	2.930968	4.312961	0.502371
12	-37.714	2.342323	7.294692	2.076484
13	33.047	3.539951	3.717977	1.003118
14	29.637	3.223892	3.085018	0.696996
15	20.1	3.358090	4.316039	0.318324
16	26.323	3.251995	4.502151	0.247407
17	-0.383	2.549642	5.729383	2.153158
18	8.136	2.862937	5.195193	1.981447
19	8.022	3.207105	4.851232	0.985126
20	24.369	3.655043	4.209732	1.027156
21	-1.849	3.250128	5.022308	1.491133
22	19.767	3.719274	4.106723	0.982937
23	-3.895	2.878042	5.35119	1.031767
24	-1.801	3.064180	5.100618	0.806794
25	-4.51	2.874288	5.548377	1.088758
26	21.168	3.268482	4.642557	0.726782
27	5.448	2.79097	4.90791	1.354288

Table 3 - Data Used to Test the Developed Model

Number of observations	P_{wf}	q_o	k_o	μ_o	hp	TDS
1	1183	2006	10.7	0.62	60	220000
2	677	575	38.88	1.07	33	208000
3	2604	1651	88.7	0.89	191	255000
4	999	1688	111	0.55	45	215600
5	1211	1814	68.6	0.92	190	300000
6	1141	1995	57	0.892	200	255000
7	2179	5610	165.36	1.047	190	255000
8	1488	3000	80	1.07	255	200000
9	2231	640	6.44	1.04	255	300000
10	2761	207	448	0.66	110	200001
11	3087	232	4.76	1.07	190	255000
12	2179	5610	133	1.23	190.5	300000

Table 4 - Predicted Skin Factor Values by Using the Developed Model

#	π_1	π_2	π_3	$S_{(model)}$
1	2.78	5.55	1.26	- 3.58
2	3.28	3.97	0.72	22.83
3	2.96	4.74	1.31	8.74
4	3.08	4.72	1.45	9.90
5	3.31	4.54	1.36	14.70
6	3.23	4.65	1.42	12.31
7	3.18	4.85	1.17	9.68
8	3.36	4.44	.63	17.68
9	2.53	5.33	2.00	- 4.49
10	3.19	3.29	0.72	30.69
11	2.26	5.15	1.94	- 4.88
12	3.20	4.87	1.22	9.52

Table 5 - Includes Skin Factor Values Obtained from Buildup Test Analysis

Number of observations	S (Buildup test results)
1	-0.6
2	20
3	5.4
4	23.41
5	21.5
6	10.21
7	12.5
8	16.5
9	-0.89
10	29.6
11	-4.5
12	11.9

Table 6 - Comparison between the Developed Model and Build up Test Results

Number of observations	Skin factor results from DEM	Skin factor from buildup test	Residual
1	-3.58	-0.6	2.98
2	22.83	20	2.83
3	8.74	5.4	3.34
4	17.68	23.41	5.73
5	14.70	21.5	6.8
6	12.31	10.21	2.1
7	9.68	12.5	2.82
8	9.90	16.5	6.6
9	-4.49	-0.89	3.6
10	30.69	29.6	1.09
11	-4.88	-4.5	0.38
12	9.52	11.9	2.38

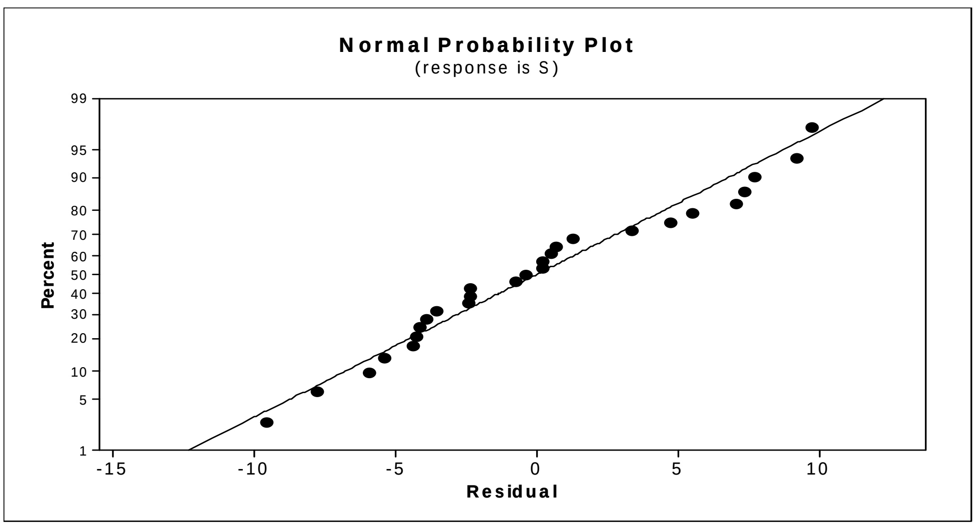

Figure 1- Normal Probability Plot of the Residuals for Developed Empirical Model

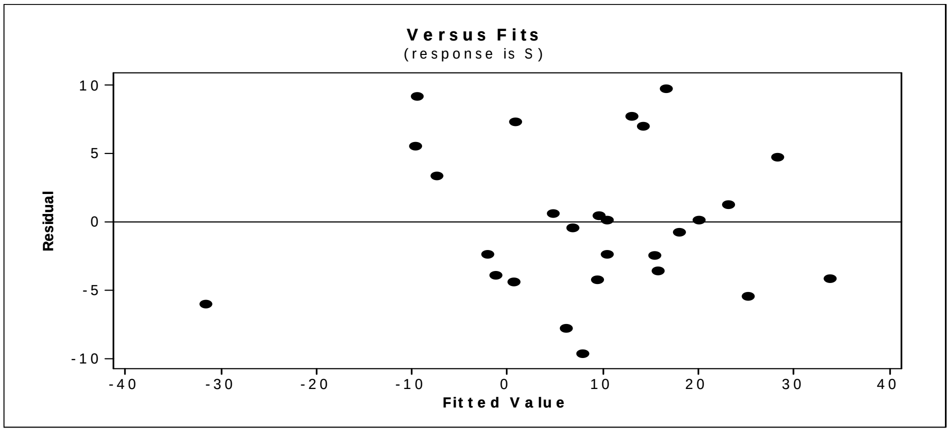

Figure 2 - the Residuals versus Fitted Values

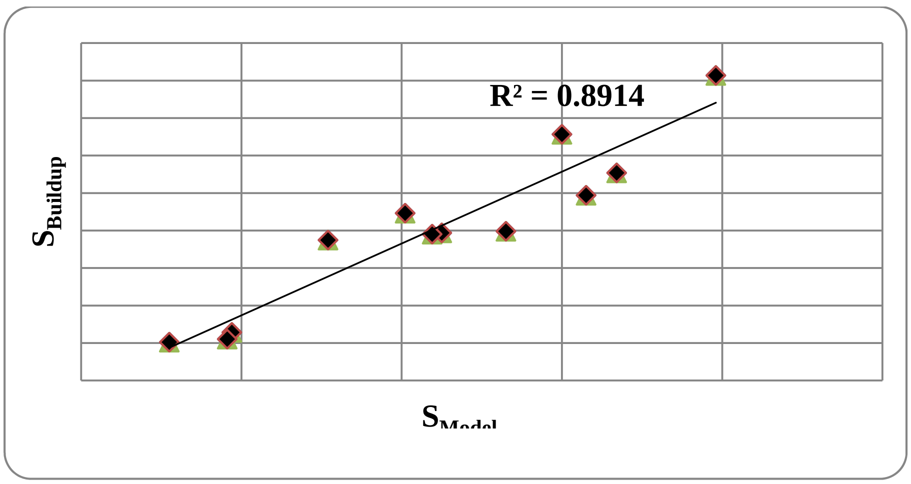

Figure 3 - $S_{buildup}$ vs. S_{model} Shows the R^2 Value