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SIMPLIFIED COMPUTATIONAL TOOL FOR PREDICTING FORMATION DAMAGE IN OIL WELLS

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ABSTRACT

The present study underscores the significance of regular well test analysis to ensure the accuracy and consistency of data pertaining to the permeability and skin of exploratory wells. This study advances the development of a novel computer model, ASPIRE, which predicts formation damage in oil wells by analysing well-test data. In this context, identifying blocked pore throats in the formation close to the wellbore by paraffinic deposits (scales) and its influence on permeability necessitates routine well-test analysis. The software employs a modified linear regression model developed in this study to perfectly fit the well-test data's infinitely acting linear flow (IARF) region to a straight line. The cases "CASE 1" and "CASE 2" were considered for constant rate transient drawdown well test analyses. The findings indicate that Case 1, with a high skin factor, requires remedial action, such as stimulation, to increase the formation's permeability close to the wellbore for enhanced productivity. In contrast, Case 2 has higher permeability and lower skin factor than Case 1, so stimulation is not required. In addition, R-squared analyses were conducted to validate the results obtained from the developed tool. The analyses reveal an R-square value of 1 for all cases, indicating a 100% accuracy. Therefore, the study concludes that the developed tool is instrumental in accurately predicting formation damage in oil wells.

Keywords: Well, test, ASPIRE, production, optimization, model.

INTRODUCTION

Well test interpretation is a critical process in reservoir management, involving the analysis of pressure-transient responses that occur due to changes in production rate [1]. This process provides qualitative and quantitative information about the reservoir, essential for decision-making. Per and Carl [2] emphasized that accurate well test interpretation is essential across multiple disciplines, including petroleum engineering, groundwater hydrology, geology, waste disposal, and pollution control.

During exploration, well testing is particularly essential when reservoir data is scarce [3]. The data obtained from well tests contribute to reserve estimation and are used to determine the economic viability of reservoirs and reservoir zones. Additionally, well testing is used in reservoir monitoring to provide essential pressure data that contributes to production optimization and indirectly to reservoir characterisation [4]. In production engineering, well testing provides valuable information on the state of the near-well reservoir volume [5]. It helps answer questions regarding near-well formation damage, the need for well stimulation treatments, and their effects. Figure 1 highligts the well test concept as presented by Per and Carl [2].

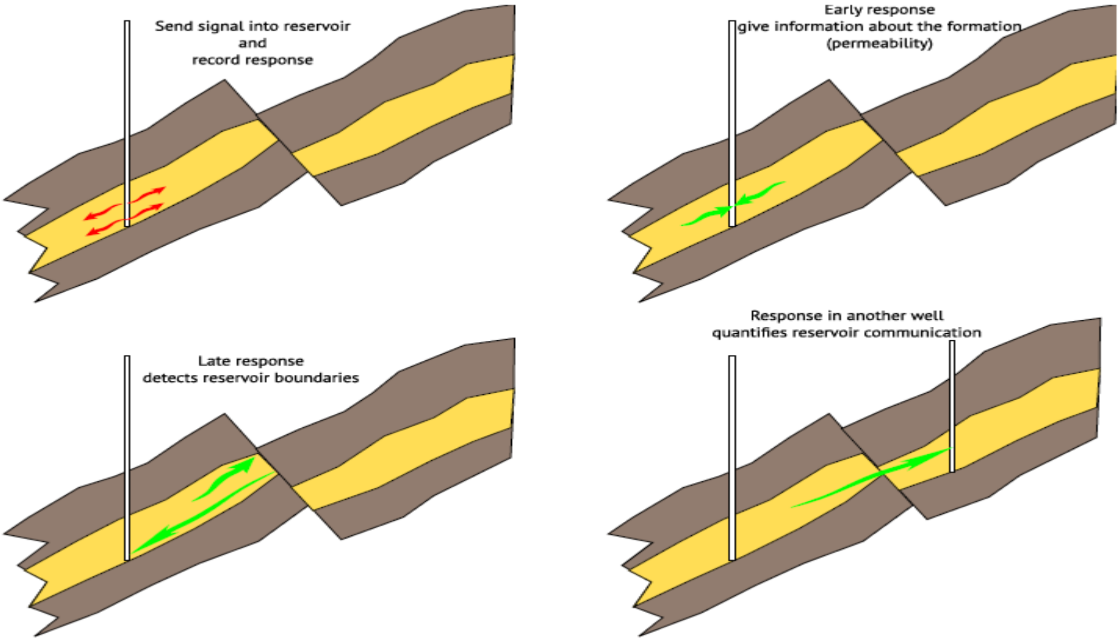


Figure 1*: The well test concept [2]*

The basic concept of well testing involves sending a signal from the well into the reservoir by changing the well production rate or pressure and measuring the pressure/rate change response at the well [6]. The analysis of this response is used to estimate reservoir properties. The early responses are determined by the property in the near-well region, while later responses detect more distant reservoir features. An interference test is conducted by recording the response in another well to investigate reservoir communication. Figure 2 presents a typical well test interpretation procedure. Typical information derived from well tests includes permeability, distance to boundaries and faults, size and shape of sand bodies, near wellbore damage or stimulation (skin), and length of induced fractures [7].

Petroleum engineers face the challenge of deciding whether or not to perform simulations or appropriate remedial actions in the case of formation damage. The petroleum industry is often concerned about determining sensitive parameters for evaluation purposes, such as characterizing the formation near the wellbore to predict formation damage in the pay zones associated with the oil well [9].

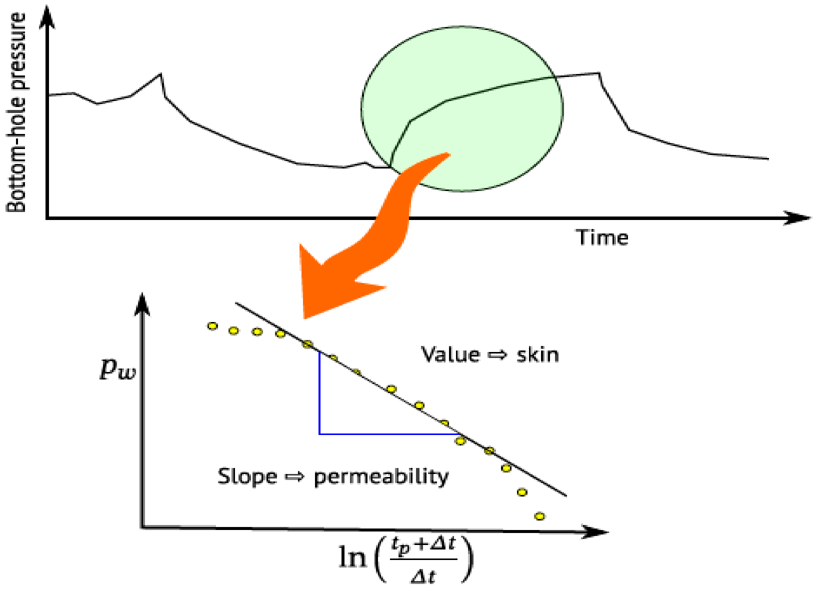


***Figure 2**: Horner Analysis plot – well test interpretation procedure* [2],[8]

Predicting formation damage using well test data is a complex process that requires advanced computations for easy implementation [10]. It has become standard practice in the oil and gas industry to conduct well tests upon completion of any workover operation like reservoir stimulation. This is done to test the stimulated pay zones' integrity and decide whether the stimulation should be re-conducted. With this in view, this study aims to develop a computer model that analyzes well test data, predicts formation damage in oil wells, performs reservoir characterization given some basic geologic data to obtain parameters like permeability and skin, and suggests appropriate remedial actions.

This study reviews available methods of analyzing well test data. A computer model is developed for analyzing well test data for an infinitely acting reservoir flow regime (IARF) under the assumption that the flow rate is constant. Build-up and drawdown analysis is performed for a range of published data to obtain parameters such as permeability, reservoir shape factor, CA, and average reservoir pressure. While analyzing well test data, trends of plots are observed to determine whether remedial actions are necessary to revive the concerned wells, especially in the case of formation damage

METHODOLOGY

Mathematical Modelling

In order to achieve the afore-stated aims and objectives of this research, drawdown tests model was employed. This method or model assumes that the concerned well has been shut for some time and is re-opened again for flow to occur. During the period the well is closed, the wellbore pressure builds up until it reaches the initial reservoir pressure, Pi. But since we are only considering drawdown test and not build-up, well testing procedure starts as soon as the well is opened for flow to occur. Also, it is paramount to note that prior to the drawdown well test analysis, an equipment is often run into the well to measure pressure changes during the drawdown tests. The equipment records the bottom hole pressure and time principally for technical analysis. Invariably, the mathematical models for the interpretation of results from the drawdown testing procedure are briefly discussed herein.

Slope Determination

The data obtained from the drawdown test procedure is usually plotted on a semi-logarithmic chart for technical analysis. More so, it happens that at the early stage of the test procedure, the behaviour of bottom hole pressure is somewhat abnormal and thus yields an abnormal trend. This unconventional behaviour is nonetheless attributed to wellbore storage effect – as discussed in the literature of this research work. It has therefore been established as a norm, not to consider data subject to wellbore storage effect. Hence, in this study, a modified least square regression model was fitted to the data points after one and the half hours for analysis. The straight line equation is represented mathematically as shown in Eq. 1 below;

$$y = m\log_{10}(x) + c \tag{1}$$

Eq. 1 is a straight line equation for a semi-logarithmic chart with *x*-axis on the logarithmic scale.

However, to fit a least square for such equation, the least square model has to be modified to suite the logarithmic scale on the *x*-axis. The conventional least square models as proposed are presented below.

$$y = a_0 + a_1 x + e \tag{2}$$

Were,

$$a_1 = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sum x_i^2 - (\sum x_i)^2} \tag{3}$$

$$a_0 = \overline{y} - a_1\overline{x} \tag{4}$$

Where $\overline{y}$ and $\overline{x}$ are average values of *y* and *x* respectively.

$a_1 = slope$ and a_0 is the intercept. And *n*= number of variables to be considered.

However, Eq. (2) was transformed to envisage the logarithmic scale on the *x*-axis as follows;

$$y(x) = a_0 + a_1\log_{10}(x) \tag{5}$$

Also, Eq. (3) is transformed as follows;

$$a_1 = \frac{n\sum \log_{10}(x_i)\, y_i - \sum \log_{10}(x_i) \sum y_i}{\sum(\log_{10}(x_i))^2 - (\sum \log_{10}(x_i))^2} \tag{6}$$

And Eq. (4) is transformed as;

$$a_0 = \overline{y} - a_1\frac{\sum \log_{10}(x_i)}{n} \tag{7}$$

The slope m, is therefore calculated as follows;

$$m = \frac{y(10) - y(0.001)}{log10 - log0.001} \tag{8}$$

Where $y(10)$ and $y(0.001)$ is the value of y calculated (using Eq. 5) at x of 10 and 0.001 respectively.

Hence, the slope is calculated using Eq. (6.) Once this parameter is specified, other parameters like skin and permeability can be specified.

Calculations of Skin and Permeability

Mathematically, after the slope of the well test data is derived, skin can be computed as follows;

$$s = 1.151\left\{\frac{P_i - P_{1hr}}{|m|} - log\left(\frac{k}{\varphi\mu c_t r_w^2}\right) + 3.23\right\} \tag{9}$$

Where s= skin,

$|m|$ =modulus of the slope.

k =permeability, md

φ =porosity, %.

μ =viscosity of fluid, cp

c_t = total compressibility, psi^{-1}

r_w= wellbore radius, ft.

Moreover, permeability, k, can be calculated as follows;

$$k = \frac{-162.6qB\mu}{mh} \tag{10}$$

Where q= constant flow rate, stb/day

h= reservoir thickness, ft

Model Assumptions

The following assumptions were made in this study:

1) The well is produced at constant rate q, and the flowing bottomhole pressure p_{wf} is measured as a function of time as the pressure draws down.
2) An infinitely acting reservoir was assumed for the drawdown procedure
3) The well is initially shut in, and the reservoir is at uniform pressure

Computer Model

The computer model (ASPIRE) developed in this study is a well test interpretation toolkit for determining important parameters like skin and permeability of the formation near the wellbore. The software incorporates the modified regression model discussed in previous sections of this chapter. It possesses an interface which allows user to import well test data for interpretation. The software can be used to analyse a wide range of data from drawdown well testing procedure. Also, the software is able to present semi-log plots of pressure against time for evaluation purposes. The software was developed using Microsoft Visual C# - a programming language built on Microsoft's dot net framework. The flow chart of the aforementioned developed software – ASPIRE is as shown in Figure 3.

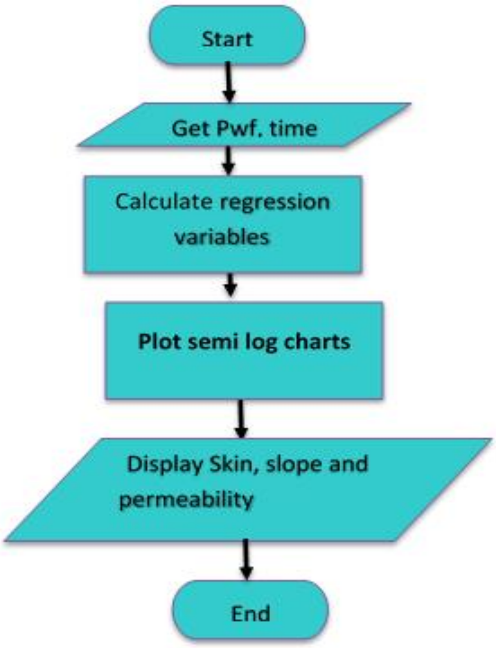


Figure 3*: Flowchart for the developed computer model (ASPIRE)*

Sequential Approach for Well test interpretation using the Computer Model, ASPIRE

In this study, well test analysis was performed using constant rates drawdown tests, the models employed were demonstrated by the computer model (ASPIRE) with the aid of charts for visual representation. However, the sequential process of operating the developed model is described as follows:

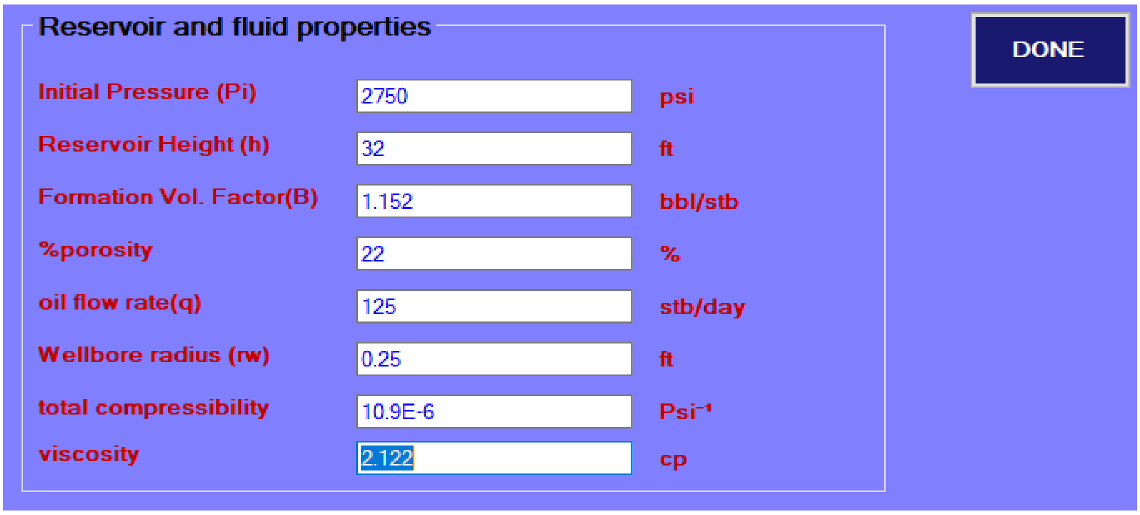
i. Launch the ASPIRE software for well test interpretation and click on "Match reservoir parameters" in the "Data"" tab located at the top left corner of the main window.

ii. Enter the required rock and fluid properties in the dialog box that appears (as illustrated by Figure 4 and 5), then click on "done"

iii. Under the Data tab in the main form window, select "Match Well Test Data"; Specify the type of data to be imported (constant rate or changing rate) – in our case, constant rate – and click on "IMPORT" button to import excel CSV data file into the software.

iv. Click "REGRESS" button to calculate modified regression.

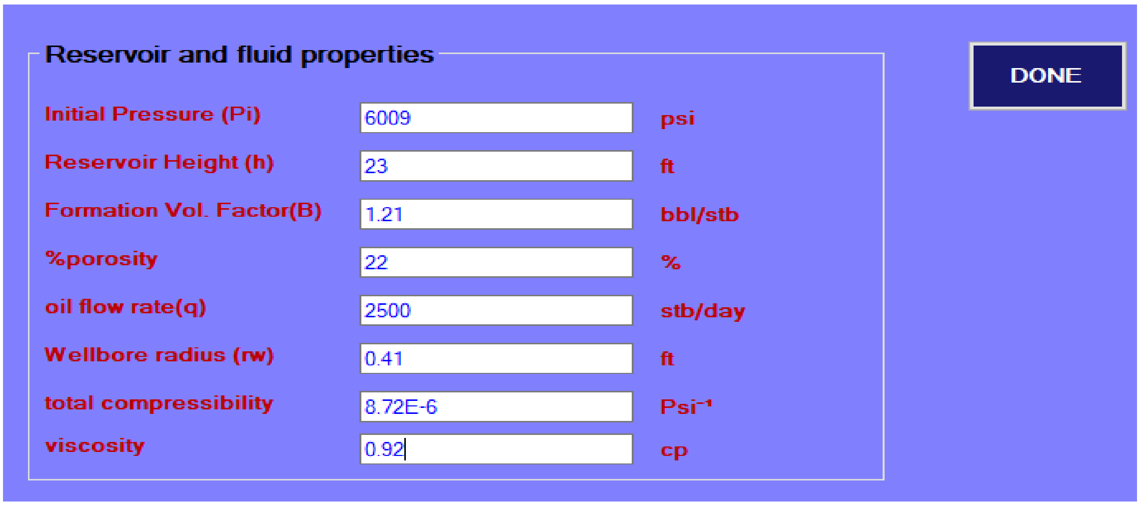
v. Finally, in the "REPORT" tab of the main form, click on "Analyse well-test data" to display well test analysis, charts and calculated slope, permeability and skin.



Reservoir and fluid properties

Initial Pressure (Pi) 2750 psi
Reservoir Height (h) 32 ft
Formation Vol. Factor(B) 1.152 bbl/stb
%porosity 22 %
oil flow rate(q) 125 stb/day
Wellbore radius (rw) 0.25 ft
total compressibility 10.9E-6 Psi⁻¹
viscosity 2.122 cp

Figure 4*: Match rock and fluids property data for CASE 1 on ASPIRE software*



Reservoir and fluid properties

Initial Pressure (Pi) 6009 psi
Reservoir Height (h) 23 ft
Formation Vol. Factor(B) 1.21 bbl/stb
%porosity 22 %
oil flow rate(q) 2500 stb/day
Wellbore radius (rw) 0.41 ft
total compressibility 8.72E-6 Psi⁻¹
viscosity 0.92 cp

Figure 5: *Match rock and fluids property data for CASE 2 on ASPIRE software*

However, it is paramount to note that published data was used in this study for well test analysis. Data obtained from Spivey and Lee [11] are represented in Table 1 and Table 2. Two cases of drawdown test were considered in this study; CASE 1 and CASE 2.

Table 1: *Drawdown data for constant rate –CASE 1* [11]

T (hours)	Pwf (psi)	T (hours)	Pwf (psi)	T (hours)	Pwf (psi)	T (hours)	Pwf (psi)
0.001	2748.95	0.993	0.001	0.0988	2642.29	9.373	2000.53
0.0021	2745.62	1.118	0.0021	0.1121	2627.5	10.545	1995.75
0.0034	2744.63	1.259	0.0034	0.1271	2614.76	11.865	1991.15
0.048	2745.49	1.417	0.048	0.144	2598.79	13.349	1988.67
0.0064	2742	1.595	0.0064	0.163	2582.16	15.018	1984.74
0.0102	2736.69	1.795	0.0102	0.1844	2564.54	16.897	1979.34
0.01225	2737.26	2.021	0.01225	0.208	2545.27	19.01	1981.14

0.0151	2733.72	2.275	0.0151	0.236	2523.21	21.387	1973.78
0.018	2729.13	2.56	0.018	0.266	2501.07	24.061	1970.58
0.0212	2724.23	2.881	0.0212	0.3	2475.93	27.07	1967.59
0.0249	2720.57	3.242	0.0249	0.339	2451.83	30.455	1965.5
0.029	2715.83	3.648	0.029	0.382	2422.8	34.262	1961.64
0.0388	2706.63	4.105	0.0388	0.431	2397.61	38.546	1957.61
0.0447	2698.17	4.619	0.0447	0.468	2367.5	43.366	1955.9
0.0512	2692.75	5.198	0.0512	0.547	2338.18	48.787	1951.21
0.0587	2684.56	5.848	0.0587	0.617	2309.21	54.787	1949.05
0.067	2676.82	6.58	2011.11	0.695	2277.84	60.787	1945.7
0.0764	2665.33	7.404	2007.46	0.783	2251.46	66.787	1942.51
0.0869	2655.67	8.331	2003.24	0.882	2222.09	72	1941.14

***Table 2:** Drawdown data for constant rate –CASE 2* [11]

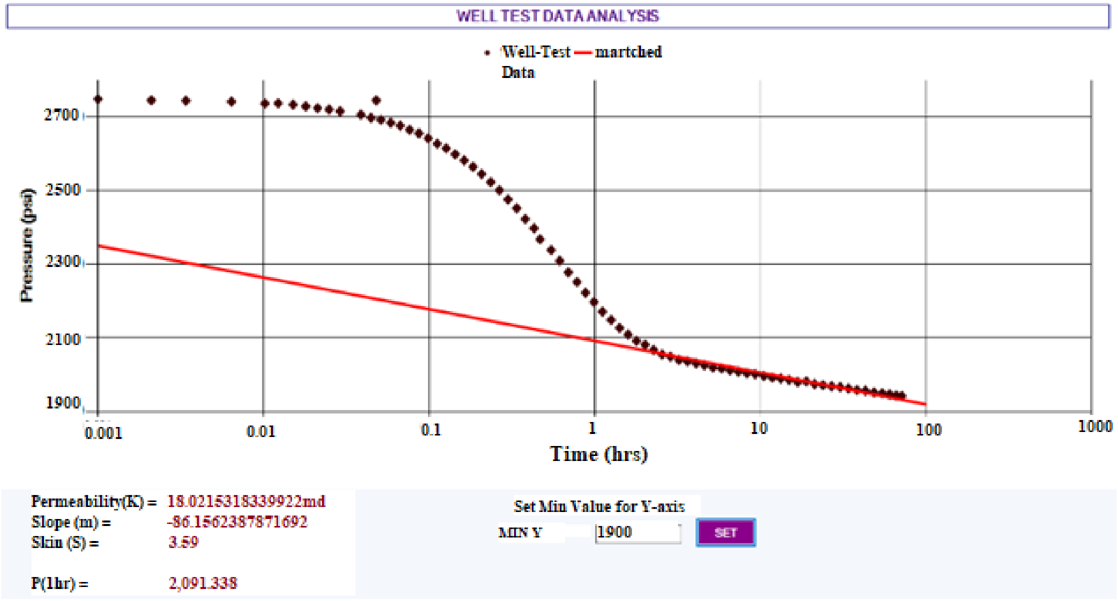
T, (hours)	P, (psi)	dT, (hours)	dP (psi)	T, (hours)	P, (psi)	dT, (hours)	dP (psi)
0.00000	6009.00			0.20058	4769.13	0.20058	1239.87
0.00000	6009.00	0.00000	0.00000	0.23217	4635.16	0.23217	1373.84
0.01670	5867.82	0.01670	141.179	0.26872	4501.08	0.26872	1507.92
0.01933	5845.93	0.01933	163.074	0.31103	4365.85	0.31103	1643.15
0.02237	5819.44	0.02237	189.565	0.36001	4219.70	0.36001	1789.30
0.02590	5792.50	0.02590	216.502	0.41669	4089.84	0.41669	1919.16
0.02997	5765.01	0.02997	243.991	0.48230	3960.16	0.48230	2048.84
0.03469	5720.90	0.03469	288.096	0.55824	3835.59	0.55824	2173.41
0.04016	5688.36	0.04016	320.644	0.64614	3727.20	0.64614	2281.80
0.04648	5642.92	0.04648	366.079	0.74788	3630.08	0.74788	2378.92
0.05380	5587.43	0.05380	421.572	0.86564	3538.77	0.86564	2470.23
0.06227	5521.66	0.06227	487.339	1.00194	3465.23	1.00194	2543.77
0.07207	5459.70	0.07207	549.301	1.15970	3411.56	1.15970	2597.44
0.08342	5389.75	0.08342	619.250	1.34230	3361.60	1.34230	2647.40
0.09655	5306.48	0.09655	702.519	1.55366	3318.80	1.55366	2690.20
0.11176	5211.11	0.11176	797.894	1.79829	3289.38	1.79829	2719.62
0.12935	5117.79	0.12935	891.213	2.08144	3263.02	2.08144	2745.98
0.14972	5009.74	0.14972	999.256	2.40918	3231.28	2.40918	2777.72
0.17330	4886.13	0.17330	1122.88				

RESULTS AND DISCUSSION

This section presents the results of the well test analysis conducted on CASE 1 and CASE 2 drawdown test data. The results are discussed and possible remedial actions recommended for well optimisation purposes.

Results

The results from analysis are shown in the Figures 6 to 8 and Tables 3 to 4.



Permeability(K) = 18.0215318339922md
Slope (m) = -86.1562387871692
Skin (S) = 3.59

P(1hr) = 2,091.338

Figure 6*: Well test analysis for CASE 1 - constant rate drawdown test*

Table 3: *Regression variables for CASE 1*

X **T ,hrs**	**Y** **Regressed P, psi**	**I** **T, hrs**	**J** **Regressed P, psi**
0.001	2091.3	0.001	2349.807
0.0021	2091.259	0.01	2263.65
0.0034	2091.211	0.1	2177.494
0.048	2089.542	1	2091.338
0.0064	2091.098	10	2005.182
0.0102	2090.956	100	1919.025
0.01225	2090.879		
0.0151	2090.773		
0.018	2090.664		
0.0212	2090.545		
0.0249	2090.406		
0.029	2090.253		
0.0388	2089.886		
0.0447	2089.665		
0.0512	2089.422		
0.0587	2089.141		
0.067	2088.831		
0.0764	2088.479		
0.0869	2088.086		
0.0988	2087.641		
0.1121	2087.143		
0.1271	2086.582		
0.144	2085.95		

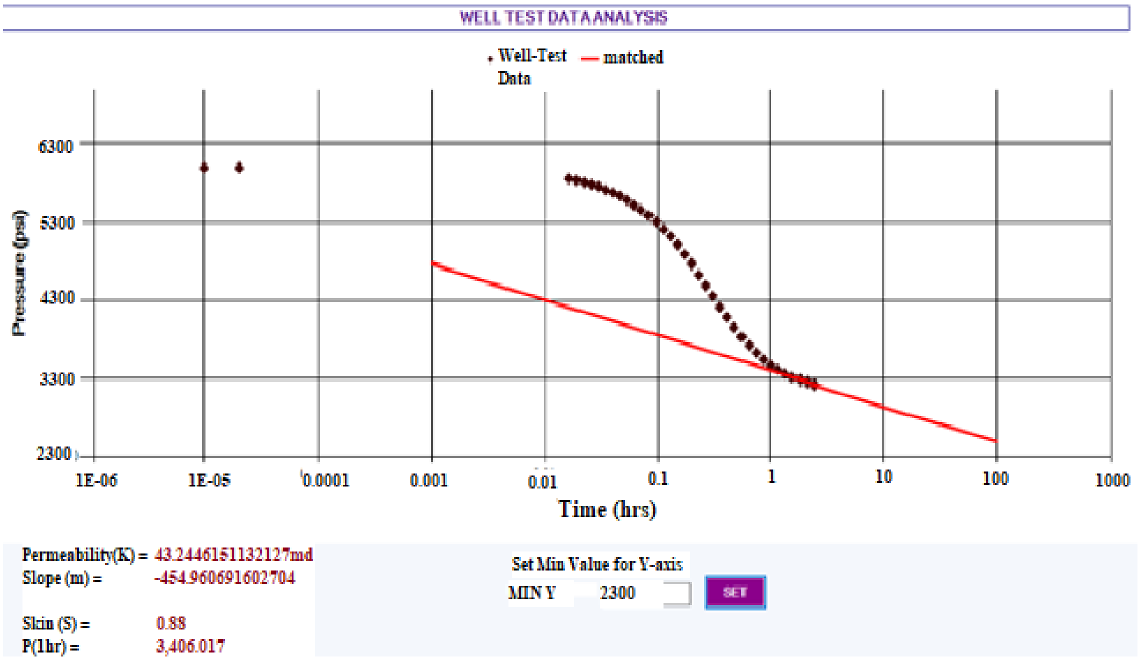
0.163	2085.239
0.1844	2084.438
0.208	2083.555
0.236	2082.507
0.266	2081.385
0.3	2080.113
0.339	2078.653
0.1271	2086.582
0.144	2085.95
0.382	2077.044
0.431	2075.211
0.468	2073.827
0.547	2070.871
0.617	2068.251
0.695	2065.333
0.783	2062.04
0.882	2058.336

Table 4: *Regression variables for CASE 2*

X **T,hrs**	**Y** **Regressed P,psi**	**I** **T,hrs**	**J** **Regressed P,psi**
0.00001	3406.01531562735	0.001	4770.89936630464
0.00002	3406.01333975817	0.01	4315.93867470194
0.0167	3402.7175899685	0.1	3860.97798309924
0.01933	3402.19793637457	1	3406.01729149653
0.02237	3401.59727214432	10	2951.05659989383
0.0259	3400.89979032432	100	2496.09590829112
0.02997	3400.09561156869		
0.03469	3399.16300131646		
0.04016	3398.08220087584		
0.04648	3396.83345155505		
0.0538	3395.38711531642		
0.06227	3393.71355412226		
0.07207	3391.77720232737		
0.08342	3389.53459080982		
0.09655	3386.94027457851		
0.11176	3383.93497755807		
0.12935	3380.45942367316		
0.14972	3376.43457815664		
0.1733	3371.77547863383		
0.20058	3366.38530751499		
0.23217	3360.14353678024		
0.26872	3352.92173493297		
0.31103	3344.56183243891		

0.36001	3334.88402520281		
0.41669	3323.68479869931		
0.4823	3310.72112101943		
0.55824	3295.71637047821		
0.64614	3278.34848039955		
0.74788	3258.24598737791		
0.86564	3234.97815193237		
1.00194	3208.04705502997		
1.1597	3176.87574287059		
1.3423	3140.79637167192		
1.55366	3099.03440071601		
1.79829	3050.69871300335		
2.08144	2994.75197721528		
2.40918	2929.99484076045		
0.00001	3406.01531562735	0.001	4770.89936630464

X in Table 3 and Table 4 represents the time (hrs) from the drawdown well test data in Table 1 and Table 2, respectively. Y in Table 3 and Table 4 represents the regressed variable of the pressures calculated from the ASPIRE model after inputting the well test data in Table 1 and Table 2 in the model. I and J values from the X (T hrs) and Y (regressed pressure variable) are the reason for the perfectly fit straight line of the curve in Figure 6 and Figure 7.



Permeability(K) = 43.2446151132127md
Slope (m) = -454.960691602704

Skin (S) = 0.88
P(1hr) = 3,406.017

MIN Y 2300

Figure 7: *Well test analysis for CASE 2- constant rate drawdown test*

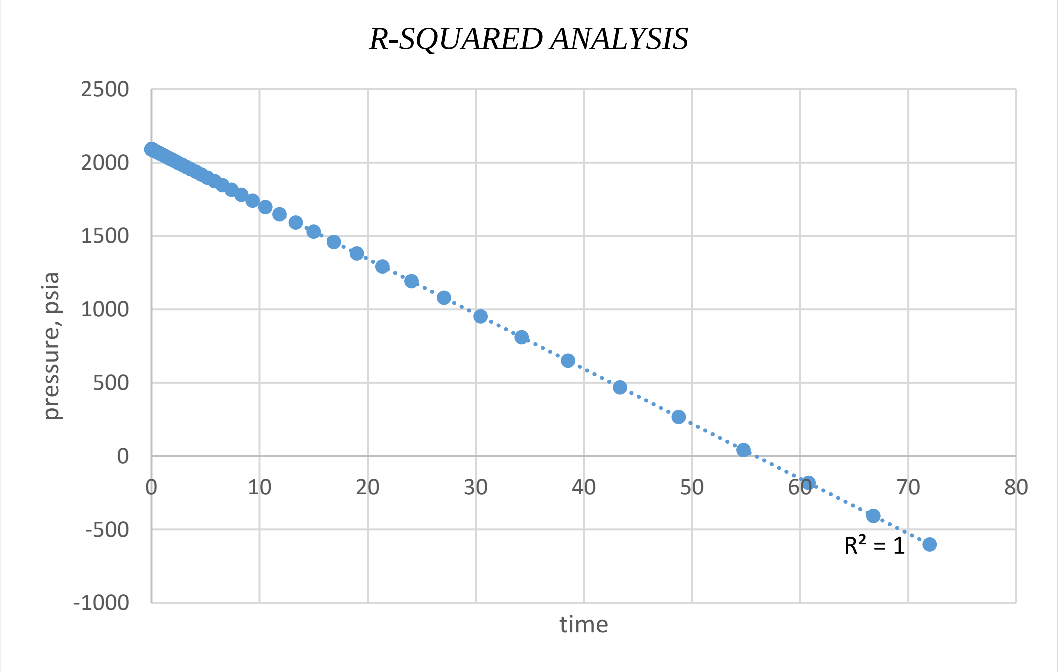


***Figure 8**: R-squared Analysis on regression variables*

Using the formulae in Eq. 11, the Pearson coefficient R of CASE 1 and CASE 2 is estimated to be -1, which shows a perfect negative linear correlation between the pressure and time variables. This means that as Y-variable (pressure) decreases, X-variable (time) increases in a perfectly consistent manner. It represents a strong inverse relationship between the variables, where the data points fall exactly on a straight line with a negative slope. In CASE 2, the situation is the same as CASE 1.

$$R = \frac{\sum(x-\overline{x})\,(y-\overline{y})}{\sqrt{\sum(x-\overline{x})^2\,\sum(y-\overline{y})^2}} \tag{11}$$

Discussion

The calculated variables for a sample well flowing at constant rate for CASE 1 are indicated in Table 3. However, from Figure 6, it can be observed that at time intervals less than one hour, the pressure data was experiencing an abnormal trend. Thus resulting in an S-shape. Conventionally, pressure is meant to decline exponentially as the well is allowed to flow after it has been shut for some time. However, the abnormal behaviour of pressure with time at the early stage of the test can be attributed to wellbore storage effect. Nonetheless, interpretation of well test data is necessary only after the well has recovered from wellbore storage. Consequently, the software – ASPIRE – only fitted a least square regression on the Infinite Acting Radial Flow (IARF) region. This region is not affected by wellbore storage. Well test analysis chart for case 1 is represented in Figure 6. From the analysis, it can be observed that the permeability (k) determined was approximately 18.0215 mD, the skin (s) was 3.59 and the pressure after an hour P(1hr) is 2091.338 psia using the ASPIRE software. These calculations were made using the matched data in Figure 4. More so, the slope of the least square regression fitted to the IARF region, was estimated to be -86. The slope was of course, a negative slope due to the nature of the well test data provided. Moreover, from the analysis, a skin of 3.59 in the formation near the wellbore is tolerable. But remedial actions like matrix acidizing can be performed to further reduce the permeability to a negative value, and to increase the permeability for increased productivity.

Furthermore, the results for a sample well flowing at constant rate for CASE 2 is shown in Table 4 and Figure 7. Table 4 shows the regression variables calculated for the IARF –region. Meanwhile, Figure 7 illustrates well test analysis interpretation for CASE 2. The rock and fluid properties used for this sample well test is represented in Figure 6. Similarly, the permeability (*k*) determined was approximately 43.25 mD, the skin (*s*) was 0.88 and the pressure after an hour P(1hr) was 3,406psi using the ASPIRE software toolkit. The result from Case 2 appears better than Case 1 because of lower skin and higher permeability values which is reflective of higher well deliverability and productivity.

Result Validation

The present study highlights the R-squared analysis based on regression variables, which was conducted to validate a simplified computational tool's efficacy in predicting formation damage in oil wells. Figure 8 contains a graphical representation of the analysis and displays a commendable R-squared value of 1.000, indicating a perfect model fit. This significant finding is a testament to the tool's accuracy and reliability in predicting formation damage, which holds substantial implications for the oil and gas industry. Accurate prediction of formation damage can help operators determine the optimal drilling and stimulation practices, reduce downtime, and improve well productivity. Therefore, this report's findings significantly affect the industry's future operations and success.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The model developed in this study ASPIRE, is a tool that helps predict formation damage in oil wells. It uses well test data and a modified regression model to analyze the condition of the wellbore and the permeability of the formation. The computer model developed is use to analyze different case of drawdown well test data and determine if stimulation is required to improve the well productivity.

The ASPIRE toolkit is user-friendly, with intuitive controls and functions that provide results on a time basis, making it accessible to anyone using the tool. Additionally, the toolkit is portable and easy to install on Windows-based personal computers. The ASPIRE computer model, a well testing toolkit, has demonstrated a high level of competence in analyzing well test data to identify potential remedial actions. The toolkit employs a modified linear regression approach to determine the slope for the drawdown test data. The input data is matched to the calculated values using the incorporated mathematical models. The model then computes vital parameters, such as permeability and skin, for constant rate conditions.

Two drawdown test data sets, CASE 1 and CASE 2, were analyzed. The results indicate that Case 1 requires remedial action, such as stimulation, to increase the formation's permeability near the wellbore and improve productivity. Conversely, Case 2 has a higher permeability and lower skin value than Case 1 and does not require stimulation as a remedial action. Furthermore, this research developed a modified least square regression model on the Infinite Acting Radial Flow (IARF) region of the drawdown test data by ignoring pressure data collected before one hour. This approach enhances accuracy in the well test analysis conducted.

Recommendations

The following recommendations are required to complement this research work:

i. Further work be carried out by accounting for build-up transient test analysis that was not performed in this study,
ii. Real life field data from the Niger Delta region need to be used for future well test analysis,
iii. Type curve drawdown test matching procedure should be employed in future studies.

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