Particle Swamp Optimization of Reservoir and Well Parameters Using Drawdown Test

By

Asanimo Racheal* and Okotie Sylvester*

ABSTRACT

Pressure transient testing provides an indirect determination of reservoir and well parameters, it is one of the most essential techniques used to provide details about the reservoir characteristics and well conditions. There are several tests available to properly characterize well and reservoir parameters, in this study, drawdown test is considered with an objective to obtain permeability and skin of a reservoir within the drainage area, from a pressure survey data. Several methods have been developed to obtain skin and permeability from drawdown test, the conventional method uses the graphical technique where the pressure and time data are analyzed with a semi-log plot. The results obtained do not equate the actual parameters of the reservoir, therefore, there is a need to optimize this error. This study is focused on minimizing the error in the mathematical model with particle swarm optimization algorithm. The manual analytical method and the particle swamp algorithm were done in Microsoft Excel. Data was obtained from a well in the Niger Delta region of Nigeria. The results from the algorithm showed a higher level of accuracy, compared to the results obtained from the manual analytical method. The statistical analysis indicates a better result with the particle swamp optimization algorithm, with a relative error of 0.0510 against the 3.9743 from the conventional method. Also, correlation coefficient, R-value of 0.9999 against 0.4733 from the conventional method.

Key words: Particle swamp optimization, well testing, drawdown test, skin, permeability, correlation coefficient, reservoir parameters.

INTRODUCTION

The key to successful development of a field/reservoir is a function of proper characterization of key well and reservoir parameters, which implies that a reliable information about the reservoir conditions is important in many phases of production and development a field (Okotie et at., 2015)[1]. Thus, to characterize a reservoir, we have to describe and adequately quantify the variations in space of the rock and fluid properties associated with the reservoir. The evaluation and interpretation of key well and reservoir parameters to aid decision making in the oil and gas industry are usually carried out with different test and techniques which are synonymous to the test performed by the medical doctors on sick patients to diagnose cause and effect of a particle disease. The activities of the oil and gas industry are often challenging and faced with so many risks and uncertainties. Often times, when some wells are drilled and completed, they are not able to flow naturally to the wellbore, which may be as a result of low permeability or damage to the wellbore due to drilling mud inversion into the reservoir. To ascertain the extent of the damage (skin) or low permeability, requires a well test analysis.

Hence, when the appropriate plan, technology and implementation are in place, well testing can provide vital information related to skin, permeability, average reservoir pressure, drainage volume, distance to boundaries, areal extent, fluid properties, flow rates, drawdown pressures,

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* Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.

[1] S. Okotie, B. Ikporo, O. N. Ogbon, (2015). Well Test and PTA for Reservoir Characterization of Key Properties. American Journal of Engineering and Applied Sciences, 8 (4): 638-647

formation heterogeneities, sand continuity, vertical layering, production capacity, formation damage, productivity index, completion efficiency, a static and flowing gradient for gas lift optimization and more. In the petroleum industry, well test is the execution of a set of planned data acquisition activities to broaden the knowledge and understanding of hydrocarbons properties and characteristics of the reservoir where hydrocarbons are trapped.

There are several tests conducted in oil and gas wells, such as potential test, gas-oil test, productivity test, bottom hole pressure test. The common types of bottom-hole pressure tests include drawdown, injectivity, buildup, falloff, interference/pulse tests and others. Ilfi[2] stated that to obtain the desired test objective, each type of tests has various properties of the reservoir they can obtain while some tests interpret the same properties, but the level of accuracy might be different. He stated that the permeability estimated from buildup test gives a higher level of accuracy than drawdown test; otherwise, skin calculation from buildup test deliver lower accuracy than drawdown test. Hence, transient well testing is good to be studied using generated data from reservoir simulation model. As stated by Onyekonwu[3] that permeability, skin factor, flow efficiency and distance to linear no-flow barrier can be obtained from both buildup and drawdown test but average reservoir pressure can only be determined from buildup test while reservoir drainage volume can be determined from drawdown test. In interference test, permeability, storativity, anisotropic permeability and sand continuity can be obtained.

Concept of Well Testing

The concept of well testing and interpretation is represented in Figure 1. Here the output is the pressure response while the input is the rate. Well test analysis is synonymous with *pressure transient analysis*. In interpretation, we use a mathematical model to relate pressure response (output) to flow rate history (input). When the pressure from the mathematical model equals that of the reservoir, implies that the parameters such as skin factor, permeability, average reservoir pressure etc calculated from the mathematical model are the real parameters of the reservoir.

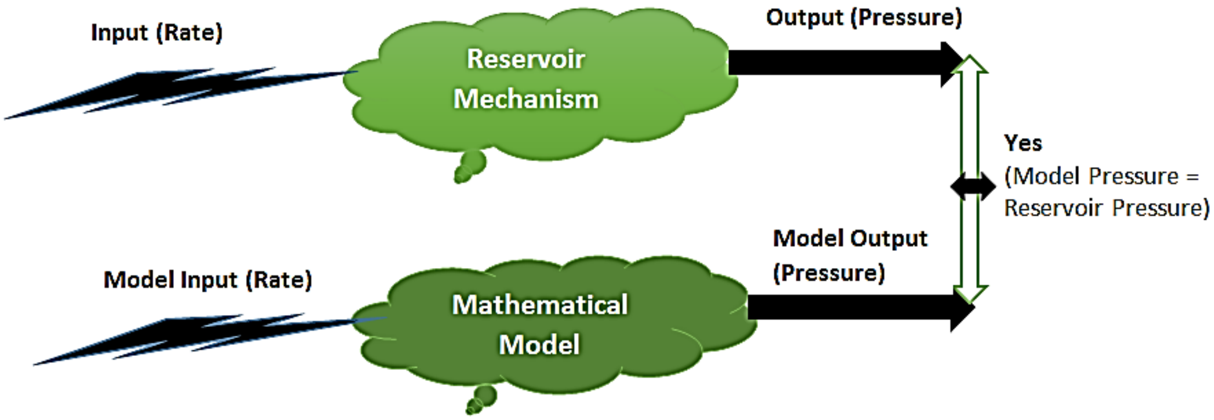

Figure 1: Well test principle

Particle Swamp Optimization

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[2] B. E. Y. Ilfi, 2012. Pressure transient analysis using generated well test data from simulation of selected wells in Norne field. Norwegian University of Science and Technology, Trondheim.

[3] M. O. Onyekonwu, 2013. Well test analysis and design (Lecture note). Laser Petroleum Geosciences Centre, Port Harcourt, Rivers State, Nigeria.

A multi-variable Fitness function for draw down well testing utilized in particle swamp optimization algorithms to be minimized is shown below. These involves obtaining a value of skin and permeability that minimized this function.

$$\sum_{i=1}^{n}\left|p_{wfi}-\left(P_i-\frac{162.6QB_o\mu}{kh}\left(\log\left(\frac{kt_i}{\emptyset\mu c_t{r_w}^2}\right)-3.23+0.87s\right)\right)\right| \tag{1}$$

Particle swarm optimization (PSO) is a global optimization method which was first introduced by Dr. Kennedy and Dr. Eberhart in 1995. Its basic idea was developed from swarm intelligence and is based on the social behavior of animals such as bird flocking, fish schooling and so on. It is based on the natural process of group communication to share individual knowledge when a group of birds or insects search food or migrate and so forth in a searching space, although all birds or insects do not know where the best position is. But from the nature of the social behavior, if any member can find out a desirable path to go, the rest of the members will follow quickly. PSO has been an increasingly hot topic in the area of computational intelligence. It is yet another optimization algorithm that falls under the soft computing umbrella that over genetic and evolutionary computing algorithms as well.

Dorigo[4] have it that in PSO, each particle flies through the multidimensional space and adjusts its position in every step with its own experience and that of peers toward an optimum solution by the entire swarm. Therefore, the PSO algorithm is a member of Swarm Intelligence. Also, the particle velocity is very important, since it is the step size of the swarm. At each step, all particles proceed by adjusting the velocity that each particle moves in every dimension of the search space

Levitan[5] introduced a deconvolution algorithm to pressure transient analysis using the logarithmic plot of pressure and Bourdet derivative which converts variable rate flow periods into a constant rate single drawdown flow period with a duration equal to the sum of the test flow periods' durations. Igbokoyi and Tiab[6] recently developed an elliptical flow to account for permeability anisotropy and provide a range of permeability and a direction of maximum horizontal permeability. Stehfest[7] presented a numerical inversion algorithm used to invert the Laplace space solution to real space. The analytical solution to diffusivity equation led to generation of Bessel equation, this equation makes use of Bessel functions, Abramowitz and Stegum[8] present polynomial approximation to compute the modified Bessel function. Coats et al.[9] developed a similar model that employed least square and linear programming to determine an areal reservoir description from a given performance data. Earlougher and Kersch[10] carried out automatic transient analysis of two field examples. They used the line source solution for an infinite acting reservoir and employed a regression analysis method. The first was an estimation of reservoir parameters from interference test data. In the second a fall-off and interference test was analyzed.

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[4] M. Dorigo, and M. Birattar, 2007. Swarm intelligence. In Scholarpedia, pp. 2(9):1462.
5 M. M. Levitan, 2007. Deconvolution of multiwell test data. SPE-102484-PA Journal paper, 12(4), 420-428.
6 A. Igbokoyi, and D. Tiab, 2010. New method of well test analysis in naturally fractured reservoirs based on elliptical flow. Journal of Canadian petroleum technology publication, 49(06).
7 H. Stehfest, 1970. Numerical inversion of Laplace transforms, Communication of the ACM, 11, No.1, Algorithm 368.
8 Abramowitz & Stegun, 1970. Handbook of Mathematical Functions, with formula graphic and mathematical tables. Dover Publications, Inc., New York.
[9] K. H. Coats, J. R. Dempsey, and J. H. Henderson, 1970. A new technique for determining reservoir description from field performance data. *Soc. Pet. Eng. J.*, 66; Trans., AIME, 249.
[10] R. C. Earlougher, and K. Kersch, 1972. Field examples of automatic transient test analysis. *J. Pet. 24*(19).

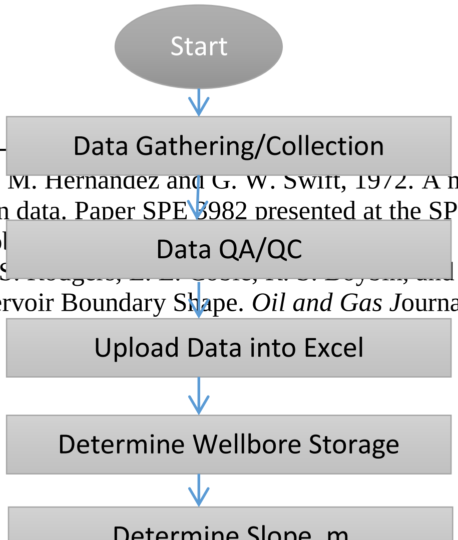
Hernandez and Swift[11] developed a least square differential algorithm for automatically determining description parameters which applied a pseudo-linearization method between performance data and reservoir parameters. Using least square reduction as the criterion for optimizing the description parameters. They claimed this technique eliminated the problems of linearizing the non-linear systems. Rodgers et al.[12] employed a non-linear regression analysis to estimate permeability, diffusivity constant, initial pressure and geometrical distances in bounded reservoirs but with known skin factors and no wellbore storage effects, using data from theoretical and field buildup tests. Since the solution for the pressure at the wellbore was in an analytical form the derivatives necessary to perform the linearization of the nonlinear equations were easily obtained by applying the Leibnitz rule in the most complicated case.

The aim of this research is to minimize the error in the mathematical model adopted to accurately estimate the reservoir and well properties with particle swamp optimization algorithm. The following are the objectives of this study:

- To accurately determine the reservoir's capacity for producing formations
- To accurately determine reservoir and well properties such as permeability and skin for production optimization
- To get the actual productivity of the well

Methodology of This Study

The method adopted for this study is presented in Figure 2.



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[11] V. M. Hernandez and G. W. Swift, 1972. A method for determining reservoir parameters from early draw down data. Paper SPE 3982 presented at the SPE-AIME 47th Annual Fall Meeting, San Antonio, Texas, Octol

[12] J. S [illegible] and J. C. Mokha, 1981. Nonlinear Well Test Analysis Reveals Reservoir Boundary Shape. *Oil and Gas J*ournal, 79, No. 37, 63.

Figure 2: Work flow for this study

Input Data

Table 1 shows the initial reservoir pressure prior to when the drawdown test was conducted and the reservoir rock and fluid properties.

Table 1: Well and Reservoir Data of Well JT_5

Initial Reservoir Pressure (Pi)	3500 psia	µ	1 cp
H	20 ft	Bo	1.2 rb/stb
Q	1500 stb/d	rw	0.33 ft
Ct	0.000015 psia^{-1}	Ø	0.18

Table 2 shows the pressure survey data which were obtained at different time intervals after conducting the draw-down test for about 4days (100 hours = 3days and 4hours).

Table 2: Pressure Survey Data of well JT_5

t (hrs)	P (psia)	t (hrs)	P (psia)
0	3500	20	2762

1	2917	30	2703
2	2900	40	2650
3	2888	50	2597
4	2879	60	2545
5	2869	70	2495
7.5	2848	80	2443
10	2830	90	2392
15	2794	100	2341

This Study Particle Swamp Optimization Two Parameters Update

The algorithm for the Particle Swamp Optimization as presented in Figure 2, is developed for a single variable, and in this study, two variables such as permeability and skin are optimized.

Step 1:

Ten (10) particles with initial positions of K (permeability) and S (skin) were selected as follow:

Permeability = K_1, K_2, K_3, K_4 , K_5, K_6, K_7, K_8, K_9, K_{10}.

Skin = S_1, S_2, S_3, S_4 ,S_5, S_6, S_7, S_8, S_9, S_{10}.

Step 2: choose the number of particles $x_i = (K_i, S_i)$

The initial population (i.e. the iteration number t=0) can be represented as $x_i^o, i = 1,2,3,4,5,6,7,8,9,10$:

$x_1^0(K_1,S_1),\ x_2^0,(K_2,S_2),\ x_3^0(K_3,S_3), x_4^0(K_4,S_4), x_5^0(K_5,S_5), x_6^0(K_6,S_6),$

$x_7^0(K_7,S_7), x_8^0(K_8,S_8), x_9^0(K_9,S_9), x_{10}^0(K_{10},S_{10}).$

Step 3: Evaluate the objective function values for each particle as:

$$f_1^0(K_1,S_1), f_2^0(K_2,S_2), f_3^0(K_3,S_3), f_4^0(K_4,S_4), f_5^0(K_5,S_5), f_6^0(K_6,S_6), f_7^0(K_7,S_7), f_8^0(K_8,S_8),$$

$$f_9^0(K_9,S_9), f_{10}^0(K_{10},S_{10}).$$

Step 4: Initialization

Let C_1=C_2=1.

Set the initial velocities of each particle (K_i,S_i) to zero

Set the iteration number as t=0+1=1 and go to step 5.

Step 5: find the personal best for each particle by

$$P_{best,i}^{t+1} = \begin{cases} P_{best,i}^{t} & if\ f_i^{t+1} > P_{best,i}^{t} \\ x_i^{t+1} & if\ f_i^{t+1} \leq P_{best,i}^{t} \end{cases}$$

For particle K,

$$P_{best,1}^1 = K_{cal} - 5x = K_{cal} - 4x, P_{best,3}^1 = K_{cal} - 3x, P_{best,4}^1 = K_{cal} - 2x, P_{best,5}^1 = K_{cal} - x, P_{best,6}^1 = K_{cal}, P_{best,7}^1 = K_{cal} + x, P_{best,8}^1 = K_{cal} + 2x, P_{best,9}^1 = K_{cal} + 3x, P_{best,10}^1 = K_{cal} + 4x.$$

For particle S,

$$P^1_{best,1} = S_{cal} - 5x = S_{cal} - 4x, P^1_{best,3} = S_{cal} - 3x, P^1_{best,4} = S_{cal} - 2x, P^1_{best,5} = S_{cal} - x, P^1_{best,6} = S_{cal}, P^1_{best,7} = S_{cal} + x, P^1_{best,8} = S_{cal} + 2x, P^1_{best,9} = S_{cal} + 3x, P^1_{best,10} = S_{cal} + 4x.$$

Step 6: find the global best by;

G_{best} =min $\{P^t_{best,i}\}$, where i=1,2,3,4,5,6,7,8,9,10.

Step 7: considering the random numbers in the range (0,1) as r^1_1 =0.2559, r^1_2=0.5294

And find the velocities of each particles by

$$V^{t+1}_i = V^t_i + C_1 r^t_i \left[P^t_{best,i} - x^t_i\right] + C_2 r^t_2 \left[G_{best} - x^t_i\right]; i = 1, \dots \dots 10.$$

For K & S

$$V^1_1\left(P^t_{best,1}, x^t_1, G_{best}\right), V^1_2\left(P^t_{best,2}, x^t_2, G_{best}\right), V^1_3\left(P^t_{best,3}, x^t_3, G_{best}\right), V^1_4\left(P^t_{best,4}, x^t_4, G_{best}\right),$$

$$V^1_5\left(P^t_{best,5}, x^t_5, G_{best}\right), V^1_6\left(P^t_{best,6}, x^t_6, G_{best}\right), V^1_7\left(P^t_{best,7}, x^t_7, G_{best}\right), V^1_8\left(P^t_{best,8}, x^t_8, G_{best}\right),$$

$$V^1_9\ \left(P^t_{best,9}, x^t_9, G_{best}\right), V^1_{10}\left(P^t_{best,10}, x^t_{10}, G_{best}\right).$$

Step 8: find the new values of $x^1_i, i = 1, \dots \dots .10\ by$

$$x^{t+1}_i = x^t_i + V^{t+1}_i$$

Step 9: find the objective function values of $f^1_i, i = 1, \dots \dots .10$

$$f^1_1(K_1, S_1), f^1_2(K_2, S_2), f^1_3(K_3, S_3), f^1_4(K_4, S_4), f^1_5(K_5, S_5), f^1_6(K_6, S_6), f^1_7(K_7, S_7),$$

$$f^1_8(K_8, S_8), f^1_9(K_9, S_9), f^1_{10}(K_{10}, S_{10})$$

Step 8: stopping criterion:
If the terminal rule is satisfied, go to step 2, otherwise stop the iteration and output the results

Results

Result of well JT_5 Analytical Method

Figure 3 represents the semi-log plot of pressure versus time to analytically obtain skin and permeability. The slope of the graph is calculated from the region not polluted by the wellbore storage phase, and thus, we applied the gentle slope or 1.5t*.

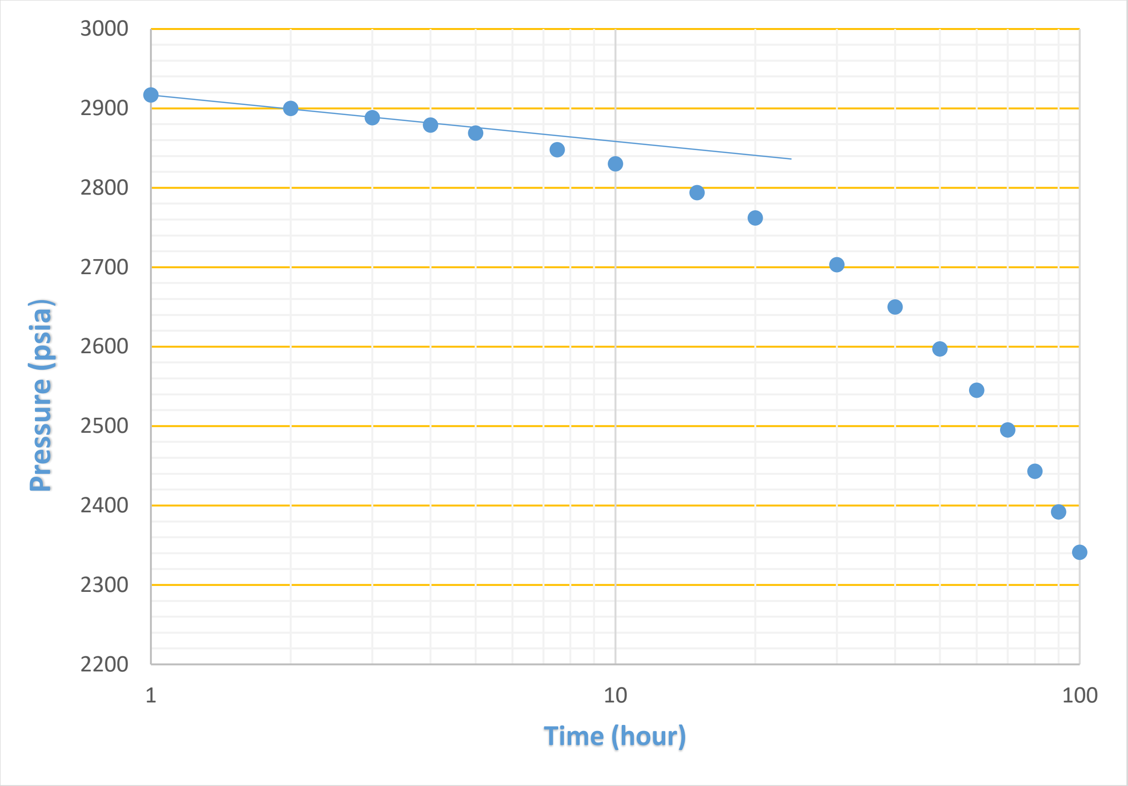

Figure 3: Plot of Pwf against time.

Calculate the permeability and skin are presented as follow: From Figure 3, the slope is calculated as:

$$slope\ (m) = \frac{\Delta P\ (2920 - 2855)}{\log 10 - log\ 1}$$

Thus, slope (m) = 65 psia/cycle

Permeability is given as,

$$k = \frac{162.6q\beta\mu}{mh}$$

$$k = \frac{162.6 * 1500 * 1.2 * 1}{64.7 * 20}$$

$$\therefore k = 226.0875.$$

$$Skin, S = 1.151\left\{\frac{P_{1hr} - P_i}{m_1} - \log\frac{k}{\emptyset\mu C_t {r_w}^2} + 3.232\right\}$$

$$S = 1.151\left\{\frac{3500 - 2917}{64.7} - \log\frac{226.0875}{0.18 * 1 * (15 * 10^{-6}) * (0.33^2)} + 3.232\right\}$$

=3.900886

Comparing Analytical Result with the given Data

The result of the skin and permeability of well JT_5 where inputted into the drawdown pressure equation and the result is presented in Table 3.

Table 3: Calculated versus given bottom hole flowing pressure

t(hr)	P_{wf} (psia)	Calculated P_{wf} (psia)
1	2917	2914.24
2	2900	2894.75
3	2888	2883.36
4	2879	2875.27
5	2869	2869.00
7.5	2848	2857.60
10	2830	2849.51
15	2794	2817.51
20	2762	2800.22
30	2703	2770.51
40	2650	2755.75
50	2597	2745.98
60	2545	2799.14
70	2495	2794.81
80	2443	2780.45
90	2392	2690.57
100	2341	2605.97

Therefore, looking at the plot in Figure 4, you could see the clear disparity in pressure from the pressure data recorded from the gauge during the drawdown test for 100 hours and the calculated pressure from the drawdown pressure equation. The well JT_5 was shut-in for a long period to attain a stabilize pressure before opening to flow at a rate of 1500 stb/d.

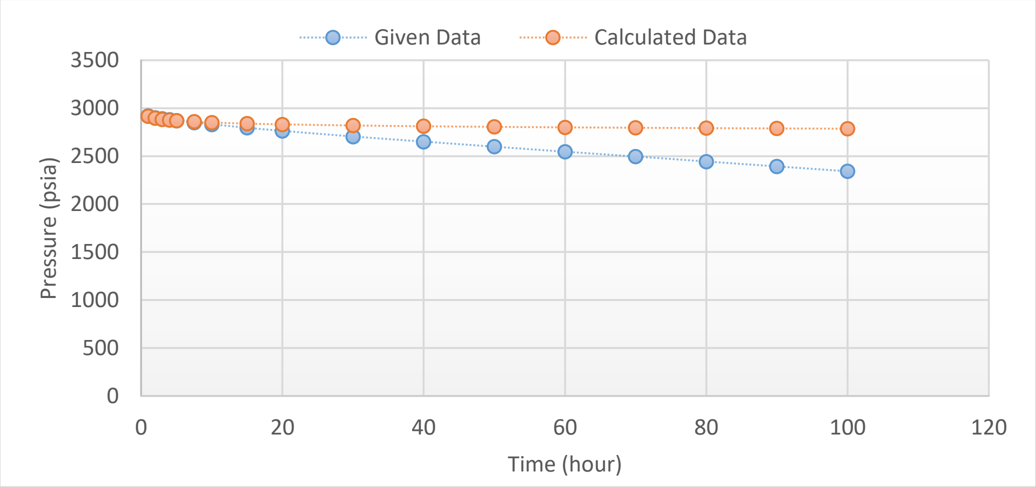

Figure 4: A plot of the experimented and manually calculated bottom hole flowing pressure against time**.**

After conducting 242 iterations, the optimized values for permeability and skin were obtained, which were used with the given initial pressure and reservoir rock and fluid properties to obtain optimized bottom hole flowing pressure with minimal error as seen in Table 4 and plot in Figure 5 for a clearer view. Therefore, the optimized result gave a perfect match with the recorded data. This further confirms the concept in Figure 1. This implies that the optimized skin and permeability are the actual reservoir values.

Table 4: Result of optimized and calculated pressure

S/NO	t(hr)	Pwf (psi)	Calculated Pwf (psia)	Optimized Pwf (psia)
1	1	2917	2914.24	2916.69
2	2	2900	2894.75	2897.73
3	3	2888	2883.36	2886.63
4	4	2879	2875.27	2878.76
5	5	2869	2869.00	2869.94
6	7.5	2848	2857.60	2847.83
7	10	2830	2849.51	2840.03
8	15	2794	2817.51	2795.92
9	20	2762	2800.22	2763.10
10	30	2703	2770.51	2705.16
11	40	2650	2755.75	2651.52
12	50	2597	2745.98	2598.31
13	60	2545	2799.14	2546.74
14	70	2495	2794.81	2496.14
15	80	2443	2780.45	2444.01
16	90	2392	2690.57	2393.44
17	100	2341	2605.97	2343.84

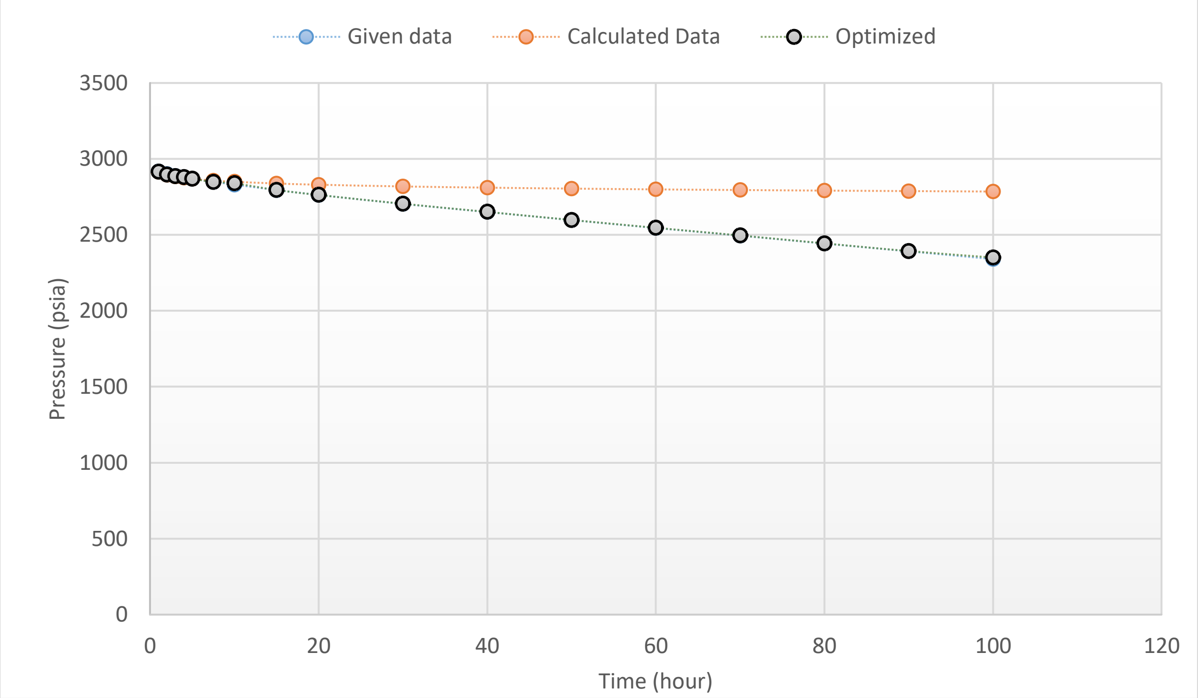

Figure 5: A plot of the experimented pressure, annually obtained pressure and the optimized pressure.

Error Analysis

The summary of the error analysis of the results for the calculated pressure and the optimized pressure is presented in Table 5.

Table 5: Summary of error analysis

Parameter	E_r	E_a	S_x^2		
Calculated Pressure	3.9743	4.0408	22.2598	194.1892	0.4733
Optimized pressure	0.0510	0.0688	0.0085	194.1892	0.9999

CONCLUSION

Based on the result obtained in this study, it can be inferred that the values of skin and permeability obtain from the conventional method of pressure transient analysis are actually initial values and when the skin and permeability are inputted into the drawdown pressure equation, the value obtain is not equal to the measure pressure data.

The result from the analytical method shows a significant disparity in the estimated pressure and if the value of skin and permeability are used as input for reservoir engineering calculations, it will result to wrong evaluation.

The particle swamp optimization algorithm was updated to suit this study objectives and the result shows a better degree of accuracy.

The statistical analysis indicates a better result with the particle swamp optimization algorithm, with a relative error of 0.0510 against the 3.9743 from the conventional method. Also, a correlation coefficient, R-value of 0.9999 against 0.4733 from the conventional method.

RECOMMENDATION

It is recommended that the reservoir parameters be optimized using the modified particle swarm optimization method or any other methods such as gradient descent.

The particle swamp optimization algorithm should be replicated for gas well test analysis and also pressure buildup test.

A computing tool (software) should be developed for optimizing reservoir parameters, using the concept of particle swarm optimization to aid the evaluation and interpretation of well test data.

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