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RESEARCH ARTICLE OPEN ACCESS

Assessing the Integrity of a Well Stimulation Operation in Niger Delta Using Pressure Transient Analysis

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Abstract:

The wellbore remains the only path through which the subsurface reservoir can be assessed. Well testing and Pressure Transient Analysis (PTA) are effective tools for assessing reservoir and wellbore parameters like permeability (k) and skin factor (s). In this paper, pressure transient analysis as a tool is used to evaluate the integrity of a stimulation job performed on well X in the Niger delta basin. The results of the pressure transient analysis showed that well X after the stimulation operation had a skin value of **-3.77** indicating that the stimulation job was effective. In conclusion, pressure transient analysis is an effective tool for assessing the wellbore and reservoir working conditions.

Keywords **— Pressure Transient Analysis, permeability, skin factor, well testing, stimulation, reservoir, wellbore.**

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I. INTRODUCTION

The construction of a wellbore through drilling remains the only means of assessing these oil and gas accumulations in the reservoir. With the ever increasing demand for energy the reservoir has become the most priced asset of the oil and gas industry [2]. Thus the importance of the reservoir and the wellbore cannot be over emphasized.

Reservoir characterization entails the processes involved in qualifying and quantifying petrophysical properties of the reservoir unit and changes in the orientation throughout the reservoir. Some of such properties includes permeability, porosity and fluid saturation [6]. For the production engineering team, well testing helps to discover if the well drilled into the formation is damaged, how successful was the stimulation treatment and why are these wells not performing as expected [15]. Reference [10] stated that transient well testing is good to be studied using generated data from reservoir simulation model. A successful reservoir characterization depends on a variety of factors such as the quality of core log data, well test data and the interpretation of these data using real time computer aided models.

Since the discovery of oil in Nigeria at Oloibiri in 1956, the Niger Delta basin has been in production ever since then. Geologic and seismic studies have that the Niger Delta basin has maintained a spectacularly thick, sedimentary apron and salient features favorable for petroleum accumulation [12].

Defined into three stratigraphic units, Akata, Agbada and Benin formation. The Niger Delta formation is about 90% sandstones with a few intercalation of shale [3].
Pressure drop due to skin can be expressed mathematically as:

$$s = \frac{kh(\Delta p)skin}{141.2q\mu\beta} \quad \ldots\ldots\ldots\ldots\ldots\ldots.2.1$$

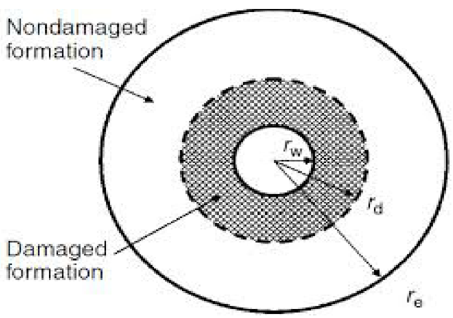

Fig. 1 Damaged formation and nondamaged formation (Source: Bagei, 2000)

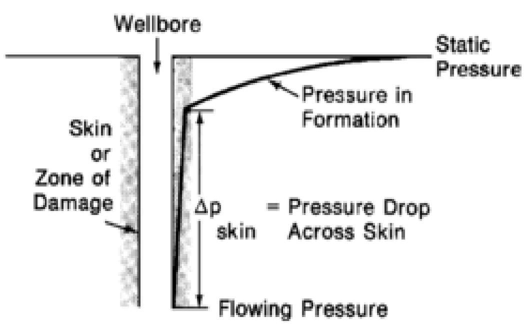

Fig. 2 Near wellbore region pressure profile (Engler and Tiab, 1996)

Formation Damage Causes

Reference [19] summarized the potential reservoir formation damage mechanisms in various well operations involved in hydrocarbon extraction process.

Damage During Drilling Operations

- Pore throat blockage
- Fines migration
- Clay swelling and migration
- Fluid-fluid interaction leading to emulsion/water blockage
- Inorganic scaling
- Alteration of near wellbore pore structure from bit action

Casing and Cementing

- Pore space plugging by cement and mud particles
- Interaction between chemical fluids injected into the wellbore ahead of cement and reservoir mineral fluids
- Cement filtrate invasion leading to clay slacking, silica deposition, scaling and fines migration

Well Completion Operation

- Wettability alteration caused by completion fluids
- Solid/fluid invasion resulting from high hydrostatic pressure
- Rock-fluid incompatibility results to pore throat plugging
- Near wellbore region damage from perforation activity
- Perforations plugging emanating from extraneous debris such as dirt,

Production Operations

- Sand production causing water conning in producing zones of loose formation
- Reservoir permeability reduction resulting from plugging by debris and sand consolidated materials
- Fines migration during DST test caused by excessive drawdown pressure
- Gravel pack screen plugging due to production of silt, clay and debris

Well stimulation

- Perforations, pore space and fracture plugging by solids in well kill fluids
- Acidizing causes release of fines and formation collapse
- Pore and fracture plugging by fracture fluids
- Inorganic and organic scaling resulting to perforation, pore and fracture plugging
- Decline in fracture conductivity caused by propant embedment
- Crushed proppant causing fracture blockage
- In adequate brackets for high viscosity further leading to propped fracture blockage
- Precipitation of iron reaction products

Flooding in secondary recovery process

- Organic scaling resulting from fluid-fluid incompatibility, injected Fluids and formation fluid
- Formation plugging resulting from iron corrosion product
- Surface active contaminants present in injected fluids causing wettability changes
- Injectivity reduction caused by injected corrosion inhibitors
- Wettability changes by compressor lubricant
- Permeability damage caused by suspended particles such as bacteria, clay etc in injected fluid.

Enhanced oil recovery (EOR)

- Fines migration, clay swelling and silica deposition resulting from high pH steam generator effluent
- Organic scaling resulting from thermodynamic changes during heat injection and in situ combustion
- Formation plugging resulting from carbonate deposition during CO2 injection
- Emulsion formation in pore throat caused by CO2 wag processes
- Fines migration resulting from polymer, surfactant and Alkaline during chemical flooding
- Thermal injection causing gravel pack disintegration

Well Stimulation

Well stimulation refers to the range of activities employed in order to increase well productivity by increasing the permeability of the near wellbore region [7]. Well stimulation is employed in a well by two distinct situation; either the reservoir formation is damaged by the various processes involved in the oil recovery process or the undisturbed natural permeability of the reservoir is not economical enough. The term well stimulation is precisely called reservoir stimulation [7].

According to Economides there are three different technologies available for reservoir stimulation. However, this section of this review will only focus on matrix acidizing since by study it is the most used stimulation technology in the Niger Delta basin. The available stimulation technologies includes:

- Hydraulic fracturing
- Acidic fracturing
- Matrix acidizing

Matrix acidizing

Matrix acidization is the oldest method of reservoir stimulation. The first matrix acidization treatment was performed on a carbonate formation in 1895 near Lima, Ohio [11]. Matrix acidizing is different from acid fracturing, in that the acid is injected below the parting pressure of the reservoir formation. Therefore, acid or hydraulic fracture is not created by matrix acidizing.

Pressure Transient Analysis (PTA)

Pressure transient analysis is one of the effective tools used in well productivity prediction and reservoir characterization, through the changes in flow rate and recording the resulting pressure response with respect to time, pressure transient data are acquired. The flow or production rate depends on the effectiveness of certain factors which includes skin effect, permeability of the reservoir, the drainage area (reservoir capacity) and the bottom hole pressure [14].

Pressure transient analysis of a well takes into account the relationship that exists between the flow rate and near wellbore formation pressure. In pressure transient well testing the sandface bottom hole pressure is recorded at the bottom of the well while the flow rate is recorded at the surface of the well over time. In order to properly assess and quantify reservoir parameters, pressure transient well testing alongside computer aided well test interpretation model is required [5].

Information derived from pressure transient well testing

- Flow potential of the reservoir
- Porosity
- Permeability
- Skin (damage extent)
- Reservoir capacity(drainage area)
- And other vital information

Pressure build-up test analysis

The analysis for pressure build-up test is based on the transient state radial flow from the reservoir to the wellbore for a single phase in a porous media. The pressure transient analysis is the theory of unsteady single phase radial flow based on certain assumptions of flow in the near wellbore region [17]. Stewart stated these assumptions as follows

- The reservoir is homogeneous and isotropic with respect to porosity and permeability and are independent of pressure
- The well is completed across the whole reservoir thickness
- The reservoir is uniformly thick

Pressure build-up test involves shutting in a flowing well and recording the resulting pressure response from the closed well as a function of time. The resulting pressure build-up curve is then analyzed for reservoir properties. The most common analysis requires the well to be flowed at constant rate either from the start of test or a long period to establish a pressure distribution that is uniformly stable before shut-in [9]. There are quite a handful of methods used in the analysis of build-up test data. However, the most applicable by frequency of usage is the Horner method. Centered on the supposition that the reservoir is infinite acting. The Horner method forecast a relationship that is linear between the well flowing pressure and test period (time) as a middle transient region (MTR).

In real time application, though the well remains shut-in, there is a after flow effect caused by the wellbore storage which has an influence on the pressure interpreted as the early transient region (ETR). The last is the late transient region (LTR) influence by the reservoir boundary or flow restriction in the vicinity of the wellbore [13]. The figure 3 and 4 summarizes the build-up test period and build-up pressure curve.

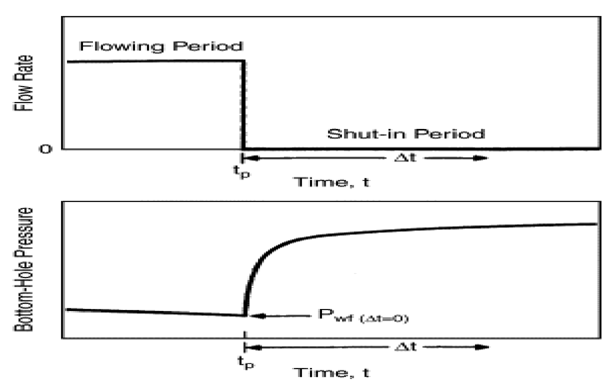

Fig. 3 Pressure buildup curve (Tiab, 1995)

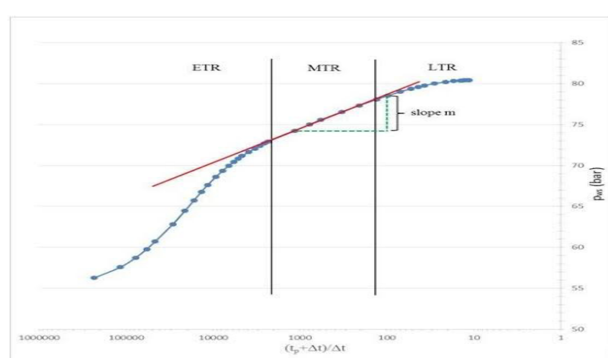

Fig. 4 Period of buildup test on Horner plot (Sonja et al., 2018)

The following are information derived from typical build-up test analysis as stated by [1].

- Reservoir effective permeability
- Skin factor (damage extent)
- Reservoir limit
- Distance to linear no flow barrier
- Porosity
- Reservoir flowing and static pressure

Well Test Interpretation

One of the most important aspect of the method for well test interpretation model is the knowledge gathered from experience, that though all reservoirs are different in their physical description (reservoir rock type, size, pressure, depth and fluid type and content) the possible outcome of the dynamic behavior of these different reservoirs under test condition is limited [9]. This happens because a reservoir acts as a low resolution filter so as to enable only high controls in the reservoir properties that can appear in the output signal. In addition these dynamic behavior are a result of the combination of the period that dominant the different transient times during the test

- The behavior of the reservoir during the middle transient region(practically the same for all wells in a given reservoir)
- The early transient region resulting from well completion
- Boundary effect at the late transient region described by the limit of the reservoir.

II. THE STATEMENT OF PROBLEM/OBJECTIVES

In oil and gas operations, reservoir productivity and performance remains the paramount interest of both the reservoir engineer and the operating company. Oil and gas operations such as drilling, completion, workover, and production can cause damage to the reservoir formation and wellbore. Hence it became necessary to identify the extent of these damages in order to propose possible prevention and remedy to them. This study is basically carried out on Well X in Niger Delta Basin, Nigeria to determine key well and reservoir parameters such as permeability (k) and skin factor (s). This will help to identify if the well is damaged or not thereby assessing the integrity of the stimulation job conducted on the well. Well test analysis software "saphir" will be used to determine the reservoir and wellbore parameters.

III. METHODOLOGY

Well X was assessed and confirmed to be damage as such remedial well stimulation in particular matrix acidizing was carried out on the well. A pressure build-up well test of pressure transient analysis was conducted to ascertain the integrity of the stimulation job.

For a well test to be efficient and successful, the reservoir engineer must be provided with work process, stages, real time update on test data, monitoring and executing of the work process and the validation of the well test to ensure optimum production performance. A workflow designed or tailored to efficiency will enable the reservoir engineer proper decision making in cases where the reservoir is damaged and or stimulated.

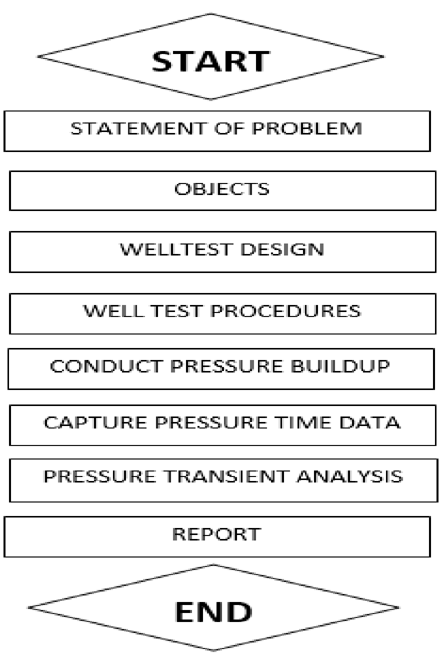

Fig. 5 PTA well test workflow

Well Test Equipment used for Data Capture

- Pressure recorders
- Lubricators (wireline blowout preventer)
- Wireline unit
- Hydraulically operated Christmas tree

Data Required for Pressure Transient Analysis

- Well and reservoir history
- Deviation survey data
- Reservoir datum depth necessary for pressure correction
- PVT parameters such as FVF, μ, C_o C_w C_g or C_t

Where,
FVF = the formation volume factor, B_o and B_g (for oil and gas respectively).
μ = the viscosity of the fluid.
C_o= Oil compressibility.
C_w= Water compressibility.
C_g = Gas compressibility.
Ct = the total compressibility.

- The petrophysical parameters of the formation such as: h, S_w, S_o, S_g, ϕ, the top and bottom of the reservoir.

Where,
h = the reservoir thickness.
S_w = Water saturation.
S_o = Oil saturation.
S_g= Gas saturation.
ϕ = Porosity

- The geological data such as: Top and bottom structural maps, details on the geology of the reservoir formation and well position relative to boundary.
- The Schematics of the well in terms of the perforation details and the well radius (r_w).
- Time, pressure and Temperature data from Bottom hole pressure gauges. At least two gauges per survey needed.
- The Well flowing rates before and during the test period.

Build-Up Test

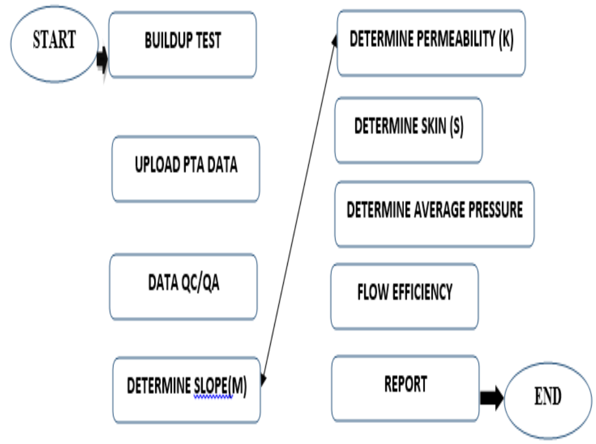

Fig. 6 A build-up test workflow

The Steps and Concept for Analyzing a Buildup Test

Calculating Wellbore Storage Constant (Cs)

Read the coordinates of the point (ΔP, t) selected at the early time line. This can be done

By:

- Making a plot of $\Delta P = (P_{ws}-P_{wf})$ versus t on a log-log graph.
- Examining and selecting the data with strong wellbore storage effect on the log-log unit slope straight line.
- Calculating the wellbore storage constant (C_s) using the equation below:

$$C_s\left({}^{rb}/_{psi}\right) = \frac{qB}{24}\left[\frac{t}{\Delta p}\right]_{unit\ slope} \qquad \text{………......…(1)}$$

- Select the data not strongly affected by wellbore storage effect. Using the gentle slope rule or the 10Δt* (1 cycle) to 50Δt* 1.5 cycle) rule.

The Computer-aided Welltest Design (Diagnostic plots)

The Saphir methodology is adopted in this paper and is based on the Bourdet derivatives which provides a diagnostic tool for type-matching the measured data obtained from WELL X to the interpretation model chosen.

From diagnostic plots i.e the pressure history plot, pressure semilog plot, and pressure log-log plot, the reservoir formation average permeability(K) of the near wellbore zone, the skin factor(S), the wellbore storage constant(C_s), and the permeability thickness product (Kh) are estimated.

TABLE I
THE INTERPRETATION MODEL AND CHOSEN INTERPRETATION MODELS FOR PRESSURE TRANSIENT ANALYSIS

Interpretation model	Chosen Interpretation models
Model option	Numerical
Well	Vertical
Reservoir	Homogeneous
Boundary	Polygonal, no flow
Fluid phase	Oil

IV. RESULT AND DISCUSSION

RESULT

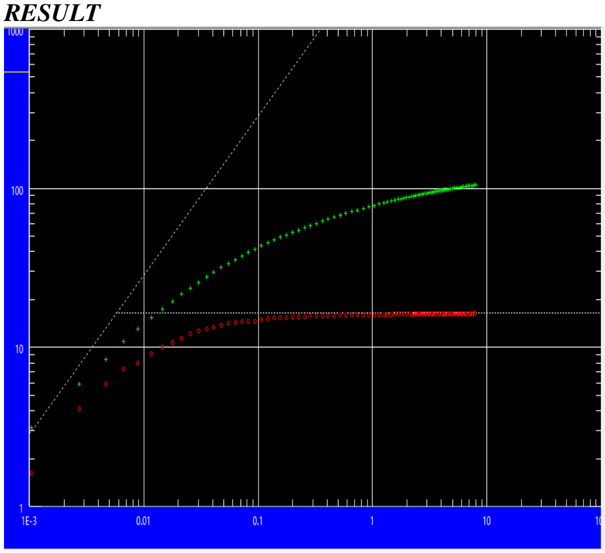

Fig. 7 Derivative (log-log) plot

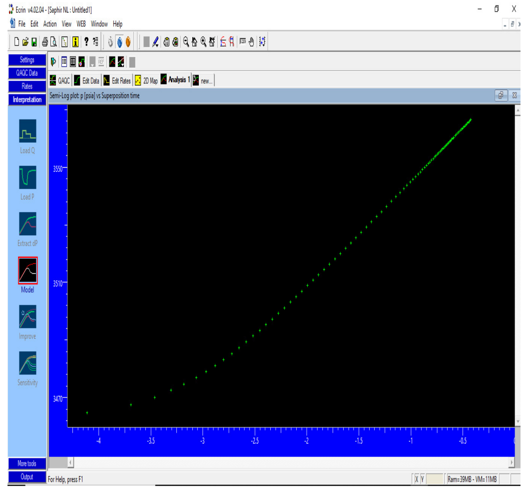
Fig. 8 Semi-log plot of P vs superposition time

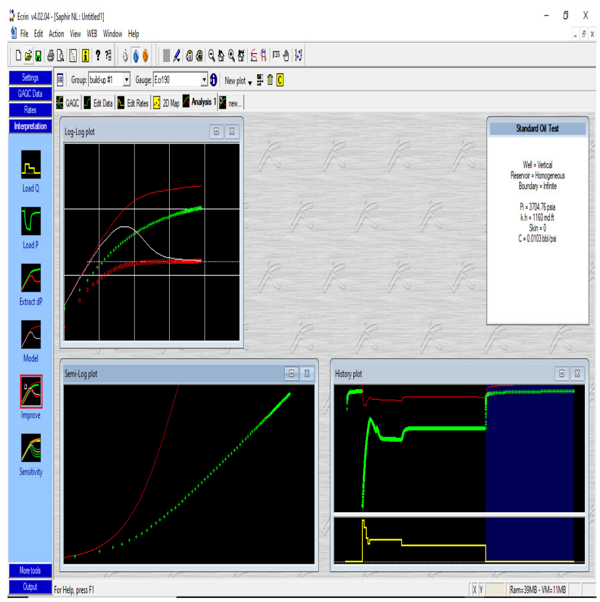
Fig. 9 Model selection with initialize radom parameter

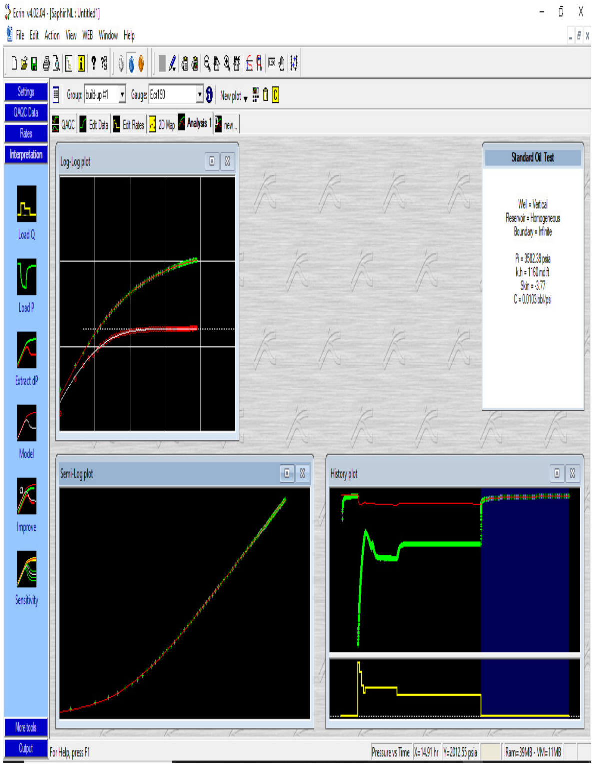

Fig. 10 Regressed model parameters

TABLE II
RESERVOIR AND WELLBORE PARAMETERS AND VALUES

Parameter	**Value**
Initial pressure	3582.39psia
Kh	1160mDft
Skin	-3.77
C	0.0103bbl/psia

DISCUSSIONS

DERIVATIVE PLOT

Derivative plots are used to identify all flow regimes present in pressure transient data and to estimate values for parameters e.g. permeability (k) and skin factor (s') that can be obtained by the analysis of each of these flow regimes. Diagnostic analysis lines are matched to different regions of the derivative response, and various parameters are derived based on the analysis type and line position.

Derivative analysis is a valuable tool for diagnosing a number of distinct *flow regimes*. The flow regimes that one may detect with derivative analysis include infinite-acting radial flow, wellbore storage, linear flow, bilinear flow, inter-porosity flow and boundaries. To help recognize flow regimes, it is convenient to classify them, in a broad sense, according to their time of occurrence (early, intermediate or late time) during a constant-rate pumping test.

Since information can be lost from over smoothing and the derivative is often noisy, it is recommended that the standard analyses are also used to fine tune the parameter values gotten from the derivative analysis. There are several numerical methods available to calculate a derivative. Standard and Bourdet are two methods available within the software and they incorporate a smoothing algorithm to reduce noise in the derivative.

Mechanical skin in its form is a dimensionless factor that indicates the degree of the near wellbore damage of a reservoir well system. Its value ranges from -7 to >100 in reality. Positive skin factor indicate and implies damage near the wellbore that causes restriction to fluid flow into the wellbore. It is the aim of a production engineer to produce a well at its optimum deliverability in a safe and secured process. To achieve this different ways are implemented to reduce the skin factor and increase the deliverability of the well. The well test data analyzed in this study was a well test carried out after a stimulation job was done on the well to access the extent of which the simulation was successful. From the analysis, the mechanical skin factor was evaluated to be **-3.77**. This indicates an improved in flow conditions near the wellbore and the pressure drop is reduced therefore indicating a successful stimulation job.

CONCLUSION

Formation damage is an undesirable operational and economical problem that can take place during the various phases of oil and gas recovery.

Permeability impairment, skin damage, and decrease of well performance, etc. are indicators of formation damage. Formation damage can take place at any time during a well's history from the initial drilling and completion of a wellbore through depletion of a reservoir by production. The negative skin will take place when there is a localized increase in permeability in the vicinity of the wellbore (near wellbore), which can occur as a result of deliberate well stimulation.

RECOMMENDATION

The following under listed recommendations are made;

- Data should be made available in order to have a fully automated well test analysis and interpretation system.
- Additional test should be carried out.
- Smoothing should be used with caution because over smoothing the derivative can completely alter the shape and show flow regimes which may or may not exist. Thus, it is recommended that the least amount of smoothing be applied in order to achieve a recognizable shape of the derivative curve.

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