Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/pc
Petroleum & Coal 51 (2) 91-99, 2009

EFFECTS OF OIL FIELD SCALE DEPOSITION ON OIL PRODUCTION FROM HORIZONTAL WELLS

Olufemi A. Bamidele*, Olugbenga A. Falode and Olusegun Omole

*Department of Petroleum Engineering, University of Ibadan, Ibadan, Nigeria, *corresponding author: Email: ofemidele@yahoo.com*

Received March 30, 2009, accepted April 15, 2009

Abstract

Flow assurance is a major concern to the petroleum industry, characterised by the numerous technical problems related to the dynamic nature of the produced effluents or by-products. These problems change gradually throughout the field's life, periodically requiring adjustment of the solution. To mismanage is not only costly but can be devastating to the economics of a field. Flow assurance has been an emerging multi-disciplinary subject addressing the hydrocarbon production from offshore fields. The problem of plugging of production lines by hydrates, asphaltenes, paraffin or scales is considered, by operating companies, as one of the major problems in the development of oil/gas fields.
This paper systematically presents an analytical model developed for predicting productivity of reservoir with incidence of scale deposition in the vicinity of horizontal wellbore.

Key Words: *productivity; scale; skin; horizontal well, permeability.*

1. Introduction

The benefits of utilizing horizontal wells to exploit hydrocarbon reservoirs are well known and have been disclosed in the literature through many field applications. These developments and applications include: recovery by waterflooding, gas reservoirs, reduction of water coning, mature and depleted fields, unconsolidated sands, thin reservoirs, heavy oil and ultra deep water scenarios [1-8]. More recently, the advances in the well engineering with new drilling and completion techniques have brought to industry new possibilities of some additional benefits, especially in tight gas formations, reservoirs with naturally vertical fractures and carbonate reservoirs, by inducing multiple fractures along the horizontal wells[8]. If the well is oriented to intersect these fractures the productivity index can be substantially increased even when the fracture density is low. The placement of hydraulic fractures along the wellbore can significantly enhance and stimulate the well productivity by increasing the contact area with the formation, reducing drawdown, bypassing the damaged zone, and eventually, connecting new areas and draining new volumes from these areas not connected before.

Scaling is the precipitation of dense, adherent material on metal surfaces and other materials. Scale formation at oil producing well screens eventually results in lower oil yields and well failure. In addition, the problem of scale in water flooding occurs all the way from the water injection facilities to the producing well[10-14]. In general, there are six important regions where scaling can occur during and after injection operations:

- in the injector wellbore;
- near the injection-well bottom-hole;
- in the reservoir between the injector and the producer;
- at the skin of the producer well;
- in the producer wellbore; and
- at the surface facilities.

Calcium sulfate ($CaSO_4$), calcium carbonate ($CaCO_3$), barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$), iron carbonate ($FeCO_3$) and iron hydroxides are the most common scales in oilfield environments[15]. In addition, there are some scale deposits in oilfield environments that are called pseudoscale; that is, the deposit of a reaction product between two or more anthropogenic-introduced chemicals.

The magnitude of flow impairment induced by oilfield sulphates scale deposition around the well bore require description and classification of sulphate scales precipitation, scale build up (saturation), and their corresponding formation damage scenario at different operational and reservoir/brine parameters[10-12]. Major factors that influence the mixing and scale formation have been described in the literature. The details of how sulphate scales are deposited in different locations in the reservoir near the well bore region and the consequent formation damage has also been presented[12]. The amount of scale precipitated at any point in the reservoir during such movement does not cause significant reduction in formation permeability[9-10].

Studies[10-13] have shown that formation damage caused by sulphate precipitation can be better described as an exponential function of the depositional rate constant, salt concentration and production time rather than by a hyperbolic function of these variables as proposed[9]. Hence, there is the need to develop an expression for estimating the productivity index in horizontal wells producing from water-flooded reservoirs with possible incidence of sulphate scale formation based on the exponential function model. The purpose of this paper is to present the mathematical expression for achieving this.

The main goal of this work is to develop necessary mathematical equations for the evaluation of horizontal well scale deposition. This involves modifying existing scale models to properly model scale deposition around horizontal wells, determination of the influence of scale deposition on reservoir thickness and reservoir anisotropy on scale deposition and comparison of scale deposition effects in vertical and horizontal well productivity.

2. Model Development

The model assumed steady state flow of oil and water, average scale concentration in the reservoir and exponential shape for formation damage function in water flooded reservoirs with incidence of scale deposition in the vicinity of the well bore caused by mixing of incompatible waters.

Besides, in calculating the required vertical well-bore diameter to produce oil as the same rate as that from the horizontal well, equal drainage volumes were assumed that is, $r_{eH} = r_{eV}$, and equal productivity indices were assumed, that is, $\left(q/\Delta p\right)_H = \left(q/\Delta p\right)_V$.

Finally, scale saturation is constant and scale causes one hundred percent damage. Fadairo et al.[12] expressed the pressure gradient due to the presence of scale in the flow path as follows

$$\frac{dP}{dr} = \frac{q\mu B e^{(3k_{dep}Ct)}}{2\pi K h r_s} \tag{1}$$

In which $\xi_\phi = 3k_{dep}C.t$ and $\Psi_\phi = 3k_{dep}C$ is defined as formation damage coefficient.

However, the formation damage coefficient is a function of time.

Instantaneous local porosity is defined as the difference between the initial porosity and the damaged fraction of the pore spaces i.e. the fraction of the mineral scale that occupied the total volume of the porous media.

That is,

$$\phi_s = \phi_0 - \phi_m \tag{2}$$

$$\frac{\phi_s}{\phi_0} = 1 - \frac{\phi_m}{\phi_0} \tag{3}$$

The volume of scale ∂V which drops out and get deposited in the volume element over the time interval, ∂t, is given as follows[10]:

$$dV = q\left[\frac{dC}{\rho dP}\right]_T dP.dt \qquad (4)$$

Where $\left(\frac{dC}{dP}\right)_T$ is defined as the change in saturated solid scale content per unit change in pressure at constant temperature.

Hence, the change in porosity due to scale deposition over time interval is given as:

$$d\phi_m = \frac{q\left[\frac{dC}{dP}\right]_T \frac{q\mu Be\left(3k_{dep}Ct\right)}{2\pi khr_s}.dr.dt}{2\pi r_s drh\rho}$$

$$d\phi_m = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu Be^{\left(3k_{dep}Ct\right)}dt}{4\pi^2 r^2{}_s h^2\rho} \qquad (5)$$

Integrating equation …….

$$\phi_m = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu Be^{\left(3k_{dep}C.t\right)}}{4\pi^2 r^2{}_s h^2\rho.3k_{dep}C} \qquad (6)$$

Where $\psi_\phi = 3k_{dep}C$

$$\phi_m = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu B\xi_\phi}{4\pi^2 r^2{}_s h^2\rho.3k_{dep}C}$$

$$\phi_m = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu B\xi_\phi}{4\pi^2 r^2{}_s h^2\rho.\Psi_\phi} \qquad (7)$$

By substituting (7) into (2)

$$\frac{\phi_m}{\phi_0} = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu B\xi_\phi}{4\pi^2 r^2{}_s h^2\phi_0\rho.\Psi_\phi}$$

Where $S_{sc} = \frac{\phi_m}{\phi_0}$, which is the volume occupied by scale. Expressing this volume as a fraction of the total pore volume occupied by oil, we then have:

$$S_{sc} = \frac{\phi_m}{\phi_0} = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu B\xi_\phi}{4\pi^2 r^2{}_s h^2\phi_o\rho.\Psi_\phi(1-S_{wc})} \qquad (8)$$

$$S_{sc}\Psi_\phi\phi_o\left(1-S_{wc}\right) = \frac{q^2\left[\frac{dC}{dP}\right]_T \mu B\xi_\phi}{4\pi^2 r^2{}_s h^2\rho} = \frac{\phi_m}{\phi_0}.$$

$$\frac{\phi_s}{\phi_0} = 1 - \frac{\phi_m}{\phi_0} = 1 - S_{sc}\Psi_\phi\phi_{oil}\left(1-S_{wc}\right)$$

By expressing the initial and instantaneous permeabilities as a function of altered porosity (Frank et al.[13]; Civan et al.[10]we have:

$$\frac{k_s}{k_0} = \left(\frac{\phi}{\phi_0}\right)^{3.0}$$

$$k_s = k_0\left[\frac{\phi}{\phi_0}\right]^{3.0}$$

By substituting the scale formula we have

$$k_s = k_0\left[1 - S_{sc}\phi_o\Psi_\phi\left(1-S_{wc}\right)\right]^{3.0} \qquad (9)$$

At the initial time $t=0$, prior to production, the scale saturation $S_{sc}=0$, and the damaged permeability is equal to the initial permeability, $k_s=k_0$

Bringing this convetional skin factor equation, which is generally expressed as:

$$s_{vertical}=\left(\frac{k}{k_s}-1\right)\ln{r_s}/{r_w} \tag{10}$$

And adopting Renard and Dupuy[16] proportionality, we can express the relationship between horizontal and vertical well damage as:

$$s_{horizontal}=\left(\beta h/L\left[\left(k/k_s\right)-1\right]\ln\left(r_s/r_w\right)\right)$$

$$s_{horizontal}=\left(\beta h/L\right)s_{vertical}$$

By substituting (9) into (10), we have:

$$s_{vertical}=\left[\frac{k}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi\left(1-S_{wc}\right)\right]^{-3.0}-1\right]\ln{r_s}/{r_w}$$

We also have for the horizontal skin due to scale as:

$$s_{horizontal}=\frac{\beta h}{L}\left[\frac{k}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi\left(1-S_{wc}\right)\right]^{-3.0}-1\right]\ln{r_s}/{r_w}$$

The above equation is substituted into Joshi's[1] horizontal scale model as follows:

$$q_H=\frac{2\pi k_H h\Delta p/\left(\mu/\beta\right)}{\ln\left[\frac{a+\sqrt{a^2-\left(L/2\right)^2}}{L/2}\right]+\frac{\beta^2 h}{L}\ln\left(\frac{h}{2r_w}\right)+s_{horizontal}} \tag{11}$$

Where, $a=\frac{L}{2}\left[\frac{1}{2}+\sqrt{{1}/{4}+\frac{1}{\left({0.5L}/{r_{eH}}\right)^4}}\right]^{0.5}$ and $\ln\left[\frac{a^2+\sqrt{a^2-\left(L/2\right)^2}}{L/2}\right]+{\beta^2 h}/{L}\ln\left(\frac{h}{2r_w}\right)$ is a dimentional factor that converts the conventional Darcy equation of fluid flow in porous media to a horizontal form.

The horizontal well scale model then becomes,

$$q_h=\left[\frac{2\pi kh\Delta p}{\mu\beta}\right]/\left\{\ln\left[\frac{a+\sqrt{a^2-\left(L/2\right)^2}}{L/2}\right]+{h}/{L}\ln\left(\frac{h}{2r_w}\right)+s_{horizontal}\right\}$$

$$q_h=\left[\frac{2\pi kh\Delta p}{\mu\beta}\right]/\left\{\ln\left[\frac{a+\sqrt{a^2-\left(L/2\right)^2}}{L}\right]+{h}/{L}\ln\left(\frac{h}{2r_w}\right)+\frac{h}{L}\left[\frac{k_H}{k_0}\left[[1-S_{sc}\phi_o\Psi_\phi\left(1-S_{wc}\right)]^{-3.0}-1\right]\right]\ln{r_s}/{r_w}\right\} \tag{12}$$

For $L\succ h$ and $\left({L}/{2}\right)\prec 0.9r_{eH}$

q_h gives the flow rate into a horizontal well with incidence of scale deposition

The productivity index J is expressed as ${q_h}/{\Delta p}$

$$J_h=\frac{q_h}{\Delta p}=\left[\frac{2\pi kh}{\mu\beta}\right]/\left\{\ln\left[\frac{a+\sqrt{a^2-\left(L/2\right)^2}}{L/2}\right]+{h}/{L}\ln\left(\frac{h}{2r_w}\right)+\frac{h}{L}\left[\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi\left(1-S_{wc}\right)^{-3.0}-1\right]\right]\ln{r_s}/{r_w}\right\} \tag{13}$$

Therefore, J_h is the horizontal well productivity index due to the presence of scale.

2. 1 Influence of Anisotropy

Of particular importance in the production of the horizontal well is the horizontal-to-vertical permeability anisotropy. The larger the vertical permeability, the higher the productivity index from horizontal well will be. Low vertical permeability may render horizontal wells unattractive.

Joshi[3] presented a horizontal well deliverability relationship. The relationship (mixed steady state in the horizontal plane and pseudo-steady state in vertical plane) as

$$q_H = \frac{k_H h \Delta p}{141.2\left(\ln\left\{\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right\}+\left(\frac{\beta h}{L}\right)\ln\left[\frac{\beta h}{r_w(\beta+1)}\right]\right)}$$

Where $\beta = \sqrt{k_H/k_v}$ and $a = \frac{L}{2}\left\{0.5+\left[0.25\left(\frac{r_{eH}}{L/2}\right)^4\right]^{0.5}\right\}^{0.5}$ for $\frac{L}{2} \prec 0.9 r_{eH}$

This model is modified for horizontal well with scale deposition as:

$$q_H = \frac{k_H h \Delta p}{141.2\left(\ln\left\{\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right\}+\left(\frac{\beta h}{L}\right)\ln\left[\frac{\beta h}{r_w(\beta+1)}\right]+s_{horizontal}\right)}$$

$$q_H = \frac{k_H h \Delta p}{141.2\left(\ln\left\{\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right\}+\left(\frac{\beta h}{L}\right)\ln\left[\frac{\beta h}{r_w(\beta+1)}\right]+\left(\frac{\beta h}{L}\right)\left\{\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})\right]^{-3.0}-1\right\}\ln {r_s}/{r_w}\right)}$$

Where $s_{horizontal} = \frac{\beta h}{L}\left[\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})\right]^{-3.0}-1\right]\ln {r_s}/{r_w}$ (14)

2. 2 Effective Wellbore Radius and Scale Factor

Effective wellbore radius of horizontal well can be calculated by converting productivity of a horizontal well into that of equivalent vertical well. The effective wellbore radius is defined by $r_w^{'} = r_w \exp(-s)$. To calculate the required vertical wellbore diameter to produce oil at the same rate as that of the horizontal well, equal drainage volumes, $r_{eh} = r_{ev}$, and equal productivity indices, $(q/\Delta p)_h = (q/\Delta p)_v$ were assumed. This gives

$$\left[\frac{2\pi k_h h(\mu B)}{\ln\left(r_e/r_w^{'}\right)}\right]_v = \left[\frac{2\pi k_h h(\mu B)}{\ln\left[\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right]+\left(\frac{h}{L}\right)\ln\left[\frac{h}{2r_w}\right]+\frac{h}{L}\left[\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})^{-3.0}-1\right]\right]\ln {r_s}/{r_w}}\right]_h$$

Simplifying and rearranging, we obtain:

$$r_w^{'} = \frac{r_{eh}(L/2)}{a\left[1+\sqrt{1-[L/(2a)]^2}\right]\left[{h}/{2r_w}\right]^{h/L}\left[{r_s}/{r_w}\right]^{h/L\left[\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})^{-3.0}-1\right]\right]}}$$

If the reservoir is anisotropic, the effective wellbore radius is,

$$r_w^{'} = \frac{r_{eh}(L/2)}{a\left[1+\sqrt{1-[L/(2a)]^2}\right]\left[{\beta h}/{2r_w}\right]^{\beta h/L}\left[{r_s}/{r_w}\right]^{\beta h/L\left[\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})^{-3.0}-1\right]\right]}}$$

Further adopting Renard and Dupuy[16] proportionality between horizontal and vertical well damage

$$q_H = \frac{k_H h \Delta p}{141.2\left(\ln\left\{\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right\}+\left(\frac{\beta h}{L}\right)\ln\left[\frac{\beta h}{r_w(\beta+1)}\right]+\left(\frac{\beta h}{L}\right)\left\{\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})\right]^{-3.0}-1\right\}\ln {r_s}/{r_w}\right)}$$

The effective wellbore radius for a horizontal well with scale deposition can then be expressed as:

$$r_w^{'} = \frac{r_{eh}(L/2)}{a\left[1+\sqrt{1-[L/(2a)]^2}\right]\left[\frac{\beta h}{r_w(\beta+1)}\right]^{\beta h/L}\left[{r_s}/{r_w}\right]^{\beta h/L\left[\frac{k_H}{k_0}\left[1-S_{sc}\phi_o\Psi_\phi(1-S_{wc})^{-3.0}-1\right]\right]}} \quad (15)$$

3. Results and Discussion

The model assumed that scale alone caused the formation damage and showed that productivity decline due to scale formation around the horizontal well bore is better described when the formation damage function was assumed to be an exponential function of the scale depositional rate constant, salt concentration and time than when hyperbolic shape was assumed as opined by Bedrikovetsky et al.[9]. Besides, Table 1 showed the fluid and rock parameters used in the prediction model and some of the parameters are from Joshi's3 paper.

Table 1: Fluid and Reservoir Parameters used as Inputs in the Scale Prediction Model

Ψ_Φ	4	a	1114ft
Φ_o	0.04	L	varies
r_w	0.365 ft	Formation volume factor ,B	1.05
S_{wc}	0.25	Viscosity	1cp

3. 1 Effect of Scale on Productivity

The productivity index of a formation due to sulphate scale deposition was compared with that of the formation without scale deposition(Joshi's Model) as shown in Figure 1.

The ratio of productivity index of horizontal well with scale and without scale is shown in figure 2. It is observed that the ratio reduces as the horizontal well length increases from 0 to 1000ft. Indicating that scale deposition has a greater effect on the horizontal well productivity and the effect could be devastating if not controlled. This verifies the fact that skin

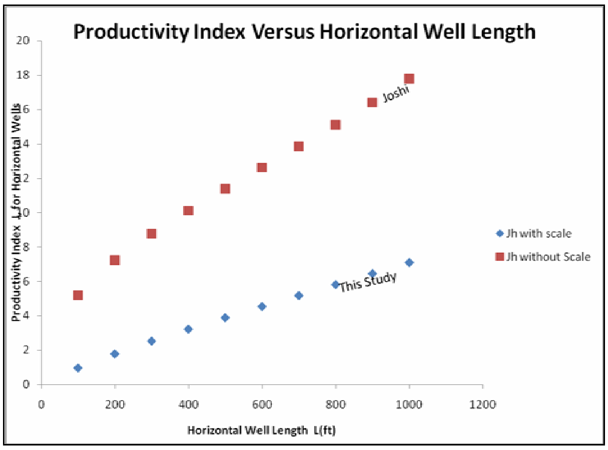

Figure 1 Productivity Index Versus Horizontal Well Length

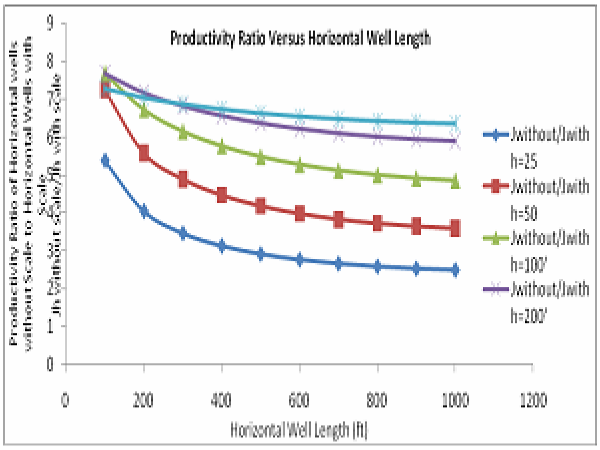

Figure 2 Productivity Ratio Versus Horizontal Well Length

3.2 Effect of Scale on Well Length

A careful observation was made in that horizontal well length has a quite sigificant effect on productivity if not long enough. As the scale saturation 10%, the productivity of a horizontal well with 1000ft horizontal well length is forty times that of 100ft horizontal well length. Besides, at the scale saturation of 95%, the productivity of a horizontal well length 1000ft could be as high as five times its 100ft counterpart figure 3.

3.3 Effect of Scale on Reservoir Anisotropy

Influence of reservoir anisotropy on the productivity augmentation through horizontal wells with scale deposition is shown in figure 4. The low vertical permeability significantly reduces horizontal well productivity with scale deposition. Conversely the higher vertical permeability, the higher the horizontal well productivity even with the presence of scale deposition. This confirms the result of Joshi[1,3] that horizontal well technology is best applied in reservoirs with high vertical permeability.

3.4 Effect of Scale on Reservoir Thickness

The influence of sscale on reservoir reservoir thickness is quite significant; the incremental gain in reservoir contact area in a thin reservoir is much more than that in a thick reservoir. However, it is carefully observed that at horizontal well length of 100ft and below, there is no significant difference in the productivity of thin and thick reservoirs. However, as the horizontal well length increases, the productivity of thin and thick reservoirs with the presence of scale and at 1000ft, the productivity of thin reservoir is 1.7 times that of thick reservoirs figure 5.

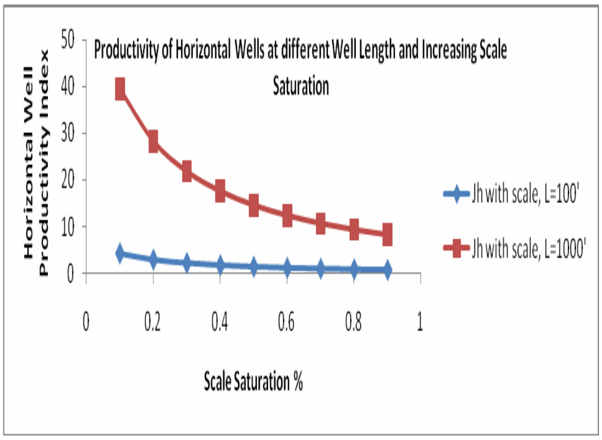

Figure 3 Productivity of Horizontal Well with Increasing Scale Saturation

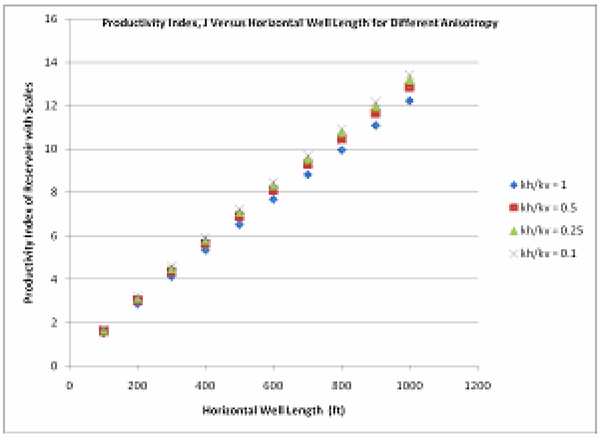

Figure 4 Productivity Index at Different Anisotropic Ratios

3.5 Effect of Scale on Water Saturation

At 25% water saturation, and with increasing scale saturation, vertical wells have greater skin factors than the horizontal wells. This implies that, damaged caused by scale are better experienced in vertical wells than the horizontal wells. And horizontal wells are good candidates for managing scale deposition.

3.6 Vertical Well and Horizontal Well Skin Factors

Figure 6 compares vertical and horizontal wells skin factors, it showed that at 25% water saturation, and with increasing scale saturation, vertical wells have greater skin factors than the horizontal wells. This implies that, damaged caused by scale are better experienced in vertical wells than the horizontal wells. And horizontal wells are good candidates for managing scale deposition.

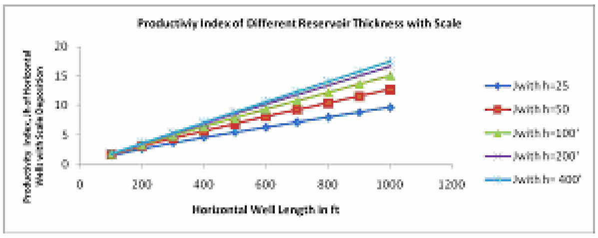

Figure 5 Productivity Index Versus Reservoir Thickness

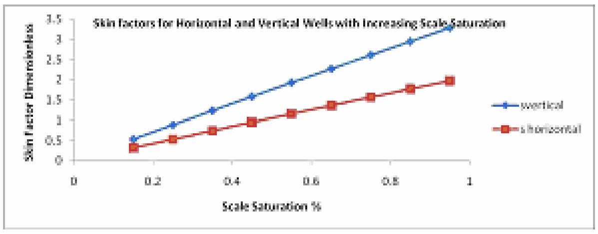

Figure 6 Comparison of Skin Factor for Horizontal and Vertical Wells

4. Conclusion

The following conclusions were drawn from the result of this study:

- At every given pore volume of sea water injected, the decline in productivity index for oil wells in water flooded reservoirs due to sulphate scale deposition depends upon oilfield solid scale saturation in the porous media.
- The rate of decline in productivity index due to sulphate scale deposition is the function of operational and reservoir/brine parameters such as scale concentration in the brine, viscosity of brine, formation volume factor of the brine, solid scale density, injection rate, pressure drawdown, reservoir temperature, reservoir thickness, brine velocity and decrease in horizontal well length of the wellbore .

- The low vertical permeability significantly reduces horizontal well productivity with scale deposition. Conversely, higher vertical permeability enhances horizontal well productivity.
- Water injection is better carried out when the horizontal well length is appreciably long to allow greater productivity and reduction in scale deposition.
- Finally, the effect of scale deposition is greater in vertical wells compared to horizontal wells counterpart.Showing that horizontal wells are better candidates for managing scales.

The developed model is presented in form of an analytical expression that can be easily programmed without any advanced computational skill to predict productivity decline due to scale.

NOMENCLATURES

Symbol

C	Concentration
K	Permeability
r	Radius
S_w	Water saturation, dimensionless
S_{w_c}	Connate water saturation, dimensionless
T	Temperature
B	Formation Volume Factor
t	Production time
ϕ_o	Initial Porosity, dimensionless
ϕ_s	Instantaneous porosity, dimensionless
ϕ_m	Damaged fraction porosity
k_o	Initial permeability
ρ	Density
C	Salt Concentration at the well bore pressure
K_{dep}	Deposition rate constant
P	Pressure
q	Flow rate
r_w	Well bore radius
S_{sc}	Saturation of sulfate (Scale), dimensionless
S_{wc}	Connate water saturation, dimensionless
$s_{horizontal}$	Horizontal Skin factor, dimensionless
V	Volume of scale
μ	Viscosity
δ	Activity coefficient
Ψ_{ϕ}	Formation damage coefficient
a	half the major axis of drainage ellipse
h	reservoir height
J	productivity index
k	permeability in Darcy
L	horizontal well length
Δp	Pressure drop
β	Square root of permeability ratio, $\sqrt{k_H / k_v}$

Subscripts

H	horizontal well	eH	horizontal well
h	horizontal	eV	vertical well
V	Vertical well	s	skin
w	well		

Acknowledgment:

The financial support of Esso Exploration & Production Nigeria Limited, an ExxonMobil Subsidiary and Petroleum Technology Development Fund Chair in Petroleum Engineering, University of Ibadan, for the sucessful completion of this work is gratefully acknowledged.

References

[1] Joshi Sada, D.: Horizontal Well Technology, Joshi Technologies International, Inc. Tulsa, Ok, U.S.A, Penn Well Books, 1991, p. 1-91.

[2] Gust D.: Horizontal Drilling Evolving from Art to Science", Oil & Gas Journal, 1989 p. 43-52

[3] Joshi, S.D.: Augmentation of Well Productivity With Slant and Horizontal Wells, Journal of Petroleum Technology, 1988, p. 729-943.

[4] Ezeddin E.S.: How New Horizontal Wells affect the performance of Existing Vertical Wells, paper SPE, presented at 2001 SPE/AAPG Western Region Meeting held in Long Beach, California.

[5] Babu, D.K., and Odeh, A.S.: Productivity of a Horizontal Well, paper SPE 18334 1988 SPE Richardson, TX.

[6] Dashti Q., Ma, E.D., Kabir C.S.: A Case Study Challenges the Myths of Horizontal wells in High Productivity Reservoir, paper SPE 71637, presented at 2001 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana.

[7] Erdal Ozkan, : Analysis of Horizontal-Well Responses: Contemporary vs. Conventional, 2001, (SPE 72494) was revised for publication from paper SPE 52199, first presented at the 1999 SPE Mid-Continent Operations Symposium, Oklahoma City, Oklahoma.

[8] Oberkrcher, Jim, Smith, Ray, Thackwray, Ian .: Boon or Bane? A Survey of the First 10 Years of Modern Multilaterals, paper SPE 84025 presented at SPE Annual Technical Conference and Exhibition held in Denver, Colorado, U.S.A. 5-8.

[9] Bedrikovetsky, P.G., Gladstone, P.M., Lope, Jr., Rosario, F.F., Silva, M.F., Bezerra, M.C. and Lima, E.A.: Oilfield scaling part II: Productivity Index Theory, SPE 81128, SPE Latin American and Caribbean Petroleum Engineering Conference, Port-of-Spain, Trinidad and Tobago, 2003.

[10] Civan, F.: Modeling Well Performance under Non Equilibrium Deposition Condition, SPE 67234, presented at SPE production and Operations Symposium Oklahoma, USA, 2001.

[11] Fadairo, A.S, Omole, O., and Falode, O.: Effect Of Oilfield Scale Deposition On Mobility Ratio, SPE 114488 presented at the CIPC/SPE Gas Technology Symposium 2008 Joint conference held in Calgary, Alberta, Canada, 2008a.

[12] Fadairo, A.S., Omole O., and Falode, O.: Modelling Formation Damage Induced by Oilfield Scale, Accepted for publication in the J. Pet. Sci. and Technology, 2008b

[13] Frank, F., Chang, and Civan, F.: Modelling of Formation Damage Due to Physical and Chemical Interaction between Fluid and Reservoir Rock", SPE 22856, SPE Annual Technical Conference and Exhibition, Dallas, Texas, 1991.

[14] Haarberg, T., Selm, I., Granbakken, D.B., Østvold, T., Read, P., and Schmidt, T.: Scale Formation in Reservoir and Production Equipment during Oil Recovery II, equilibrium Model, SPE Journal Production Engineering, 1992,Volume 7, Number 1

[15] Moghadasi, J., Sharif, A., Kalantari, A.M. and Motaie, E.: A New Model to Describe Particle Movement and Deposition in Porous Media, SPE 99391, presented at 15th SPE Europe Conference and Exhibition, Vienna, Austria. 2006a.

[16] Renard, G.I. and Dupuy, J.M.:Inluence of Formation Damage on the Flow Efficiency of Horizontal Wells, paper SPE 19414, presented at the Formation Damage Control Symposium, Lafayette, Louisiana, Feb. 22-2.