A SIMPLE ANALYTICAL MODEL FOR PREDICTING SAND PRODUCTION IN A NIGER DELTA OIL FIELD

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ABSTRACT

Sand production, which is predominant in the Niger Delta, is a growing concern in the petroleum industry because of the associated technical, operational and economic challenges. The development of sanding predictive tools and effective management strategies has received much attention in literature. However, most of the published theoretical models have been validated with laboratory or data obtained from petroleum provinces other than the Niger Delta. This work developed a simple analytical model for predicting sand production and validated it using 16 wells in a Niger Delta Field. The results confirmed the well-known impact of flow rate, fluid viscosity and grain size and density of sanding rates. It was also observed that at moderate production rates, sanding in the Niger Delta Field has relatively small arch lengths of below 30 feet.

Keywords: Sand Production, Sand prediction, Niger Delta, arch length, oil production

INTRODUCTION

Sand production is predominant in the Niger Delta because almost all the oil and gas reserves are located within the tertiary agbada sandstones and the upper Akata formation (Adeyanju and Oyekunle, 2010). Production of sand along with reservoir fluids generally varies from few pounds per barrel to catastrophic amounts that could lead to fill-up of production tubings and low well productivity. Sand erodes downhole and surface production facilities and lead to severe economic losses as sand control costs continue to escalate.

Sand production could occur when the induced in-situ stresses exceed the formation in-situ strength. It could also be due to excessive drawdown which causes local failure around the borehole or by depletion which causes local failure of the entire reservoir. Sanding could also result when the drag forces caused by flowing reservoir fluids exceed the natural inherent cohesion in unconsolidated formations.

The economic, operational and safety implications of sand failures require real time efficient sand management (Oluyemi and Oyeneyin, 2010). Sand management techniques have been classified into two broad areas: passive preventive methods and sand control measures (Osisanya, 2010). However, Burton et al (2005) had earlier noted that developing a complete sand management strategy requires formation strength characterization, stress characterization, failure modeling, sand exclusion studies, sand rate and size prediction and use of field sand rate data. Perhaps the biggest challenge in the sand management chain is the reliable estimation of the amount and size of the produced sand. This is important for accurate design of sand control facilities and to ensure that erosion limits for chokes and pipes are not exceeded.

Methods for predicting sanding rates include field observations, laboratory experiments, and theoretical models. Several published theoretical models are based on different sand failure mechanisms. These include Coates and Denoo (1981), Bratli and Risnes (1981) and Weingarten and Perkins (1992). In 1994, Geilikman et al developed an analytical model for predicting onset of sanding from Canadian heavy oil sands. In 1996, van der Hoek et al built on the works of Geilikman et al based on experimental and theoretical studies. Kanj and Abousleima (1999) proposed the use of Neural network technique to sand production modeling. Indeed, there are several other models for predicting onset of sand (Nouri, et al, 2004). However, most of the recent models have utilized the geomechanical principles for predicting sand production beyond the initial onset. These include the works of Addis et al (1998), McLellan et al (2000), Vaziri et al (2002), Palmer et al (2003) and Vardoulakis (2006). However, it is important to use appropriate failure mechanism for sanding prediction modeling (Isehunwa and Farotade, 2010), and Oluyemi and Oyeneyin, 2010). This study developed a simple analytical model to predict sand production in wells in a Niger Delta oil Field.

THEORETICAL FRAMEWORK

A simple analytical model is developed by adapting Vardoulakis method. The basic assumptions were:

1. Sand particles are spherical and submerged in a moving fluid.
2. Drag and buoyancy forces are predominantly acting on the sand particles.
3. During flow, sand production will cause the radius of a cylindrical cavity to grow until equilibrium is attained.
4. Fluid flow can be described by Darcy's law.

Following Vadoulakis (2006), buoyancy force is given by:

$$F_b = \frac{4\pi}{3}\rho_f g R_S^3 \qquad (1)$$

While the surface drag force due to shear stress is:

$$F_{d1} = 4\pi\mu_f R_S U \qquad (2)$$

Drag due to dynamic pressure can be expressed as:

$$F_{d2} = 2\pi\mu_f R_S U \qquad (3)$$

Thus, total drag is the sum of equations (2) and (3):

$$F_D = 6\pi\mu_f R_S U \qquad (4)$$

Number of particles can be expressed as:

$$N = \frac{V_S}{V_g} \qquad (5)$$

$$V_g = \frac{4}{3}\pi R_S^3 \qquad (6)$$

Distributed volume force can be expressed as:

$$f = \frac{NF}{V} \qquad (7)$$

Substituting equation (5) into (7) and simplifying, we obtain:

$$f = (1-\phi)\frac{F}{V_g} \qquad (8)$$

Combining equations (4), (6) and (8) gives the drag body force:

$$F_{DB} = \frac{(1-\phi)6\pi\mu_f R_S U}{\frac{4}{3}\pi R_S^3} \qquad (9a)$$

$$= \frac{(1-\phi)\mu_f U}{\frac{2}{9}R_S^2} \qquad (b)$$

While combining equations (3), (6) and (8) gives the buoyancy body force:

$$F_{BB} = \frac{(1-\phi)\frac{4}{3}\pi\rho_f g R_S^3}{\frac{4}{3}\pi R_S^3} \qquad (10a)$$

$$= (1-\phi)\rho_f g \qquad (b)$$

The fluid velocity is given as:

$$U = \frac{Q_f}{A} \qquad (11)$$

While area of cavity is:

$$A = 2\pi R_a H \qquad (12)$$

At equilibrium, equating (9) and (10) gives:

$$F_{DB} = F_{BB} \qquad (13)$$

Combining equations (11), (12) and (13) and solving for the radius of cavity gives:

$$R_a = \frac{Q_f \mu_f}{\frac{4}{9} R_S^2 \pi H \rho_f g} \qquad (14)$$

Thus, the sand produced can be expressed in volume as:

$$V_{SP} = \pi R_a^2 H \qquad (15)$$

Or, in weight as:

$$S = \rho_S V_{SP} \qquad (16)$$

RESULTS AND DISCUSSION

Equation (14) is a simple analytical model which can be combined with equations (15) and (16) to predict sand production in a well. It is similar to the Bratli-Risnes model given in equation (17), and it shows the effect of flow rate, fluid viscosity, grain size grain density and cavity height on sand production.

$$R_a = \frac{Q_f \mu_f}{T + \frac{1}{T} 16 S_{C0} \pi K_C \tan\alpha} \qquad (17)$$

Table 1 shows the input parameters for model validation, while Figure 1 shows the variation of arch radius during sanding at different flow rates and fluid viscosity.

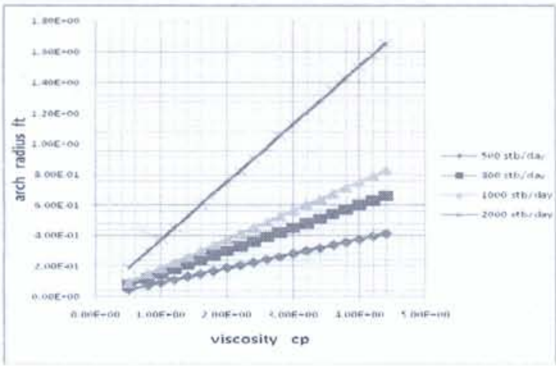

Figure 1: Effect of fluid viscosity on flow rate (H= 10 ft)

NIGER DELTA CASE STUDY

The Field is located South-West of Port Harcourt and has initial oil and free gas in place of about 1200 MMstb and 4730 Bscf respectively. Cumulative oil produced stands at about 200 MMstb from 50 wells completed on 22 reservoirs. Reservoir depths ranged between 7500 and 12800 ft in a stacked series of anticlinal or dip and fault bounded structures. The gravity of the oils varies between 20° and 55° API. Porosity range between 21 and 28 %, and average permeability is about 2000 mD.

For the validation, many wells were screened out of the 50 in the field on the basis of dual or commingled completions, presence of installed sand control devices and history of sand consolidation treatments. A total of 16 wells were finally used for the study. The wells produced between 0.2 and 42.7 pounds per barrel of sand for 5 to 36 years. Water cuts in the wells range between 0 and 63 %.

The results of sand production using equation (14) and compared with Bratli-Risne model are presented in Figures 2–5. Equation (14) models accurately sand production in the Niger Delta wells at low cavity heights of about 10 ft. At such cavity heights, Bratli-Risnes under-estimates sand production in the Niger Delta. This can be attributed to the fact that Bratli-Risnes model was first developed for Canadian heavy oil reservoirs, while the Niger Delta generally has light oil. This study suggests that sanding is a near wellbore phenomenon in the low-viscosity Niger Delta oil reservoirs.

The effect of cavity heights in wells -1 and -2 are shown in Figures 6 and 7 respectively. They confirm the earlier observation and suggest that for accurate prediction of sand production in the Niger Delta, cavity heights of 10 – 30 ft should be maintained.

CONCLUSION

A simple analytical model has been developed for predicting sand production in a Niger Delta oil field. The study suggests that at moderate production rates below 2000 bbls/day, sanding in Niger Delta oil reservoirs is characterized by relatively low cavity heights of between 10 and 30 ft.

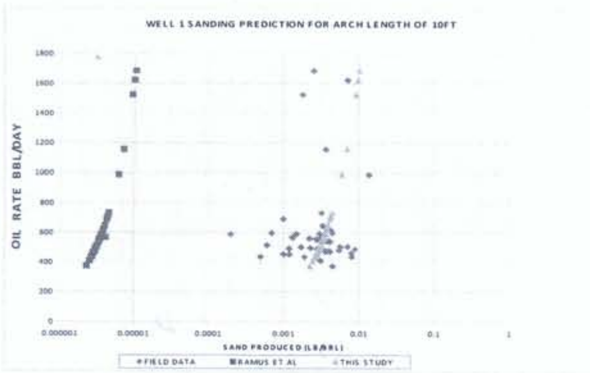

Figure 2: Sand Production Prediction in Well - 1

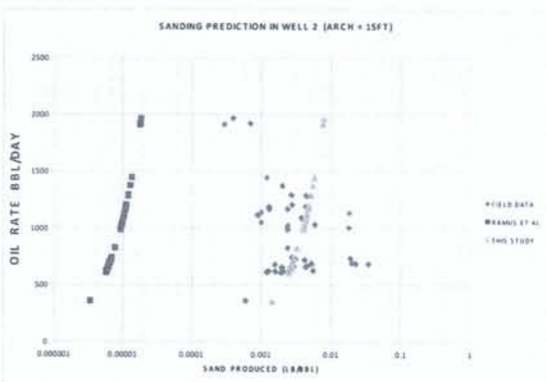

Figure 3: Sand Production Prediction in Well -2

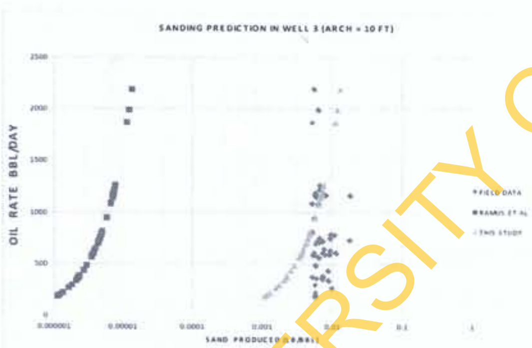

Figure 4: Sand Production Prediction in Well -3

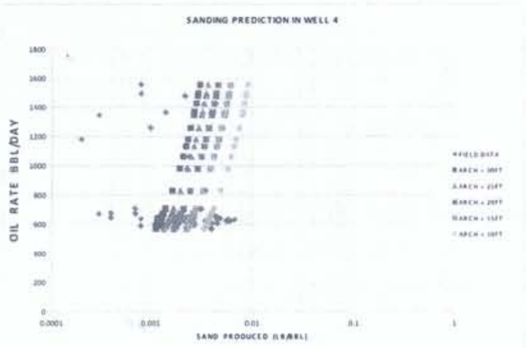

Figure 5: Sand Production Prediction in Well -4

Table 1: Input Parameters for model validation

Input Parameter	This Study	Bratli-Risnes
Fluid Viscosity	1.2 – 5.0 cp	1.2 – 5.0 cp
Arch Cavity	10 – 30 ft	10 – 30 ft
Fluid density	58.28 lb/cuft	58.28 lb/cuft
Sand radius	1000 microns	1000 microns
Sand density	165.34 lb/cu ft.	165.34 lb/cu ft.
Permeability of Partly failed zone	Not Applicable	2000 mD
Failure angle	Not Applicable	60^o
Cohesive Strength in Partly failed zone	Not Applicable	3 Atm

Nomenclature

F_b = buoyancy force
F_{d1} = surface drag force due to shear stress
F_{d2} = form drag due to dynamic pressure
F_D = total drag
N = number of particles
f = distributed volume force
F_{DB} = drag body force
F_{BB} = buoyancy body force
U = fluid velocity
A = area of cylindrical cavity
R_a = radius of cavity
ϕ = porosity
ρ_f = fluid density
ρ_S = sand density

H	=	height of cavity
V_{SP}	=	volume of sand produced
S	=	sand produced
g	=	acceleration due to gravity
μ_f	=	fluid viscosity
K_C	=	permeability in the partly failed zone
α	=	failure angle of the sand
S_{CO}	=	cohesive strength in partly failed zone
T	=	$2(\tan^2\alpha - 1)$
Q	=	flowrate

Subscripts

b	=	buoyancy
d1	=	drag due to shear stress
d2	=	drag due to dynamic pressure
DB	=	drag body
D	=	drag
BB	=	body buoyancy
sp	=	sand produced
a	=	arch
s	=	sand
f	=	fluid
co	=	cohesive

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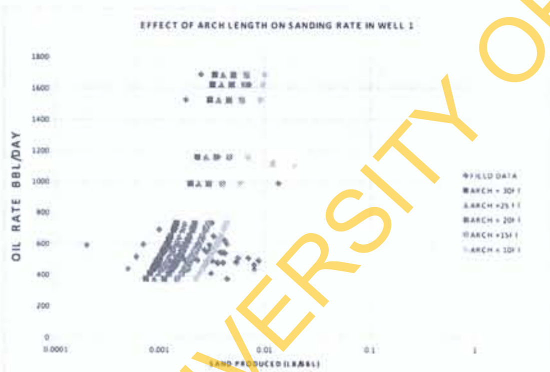

Figure 6: Effect of arch length on sand prediction in well-1

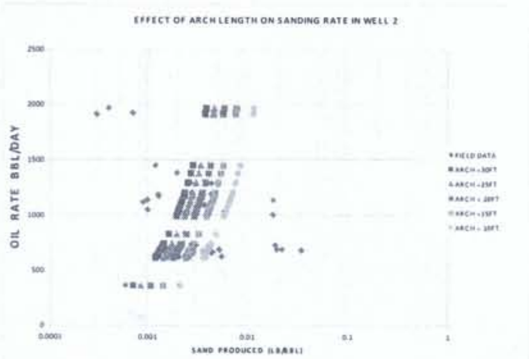

Figure 7: Effect of arch length on sand prediction in well-2