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Sand Failure Mechanism and Sanding Parameters in Niger Delta Oil Reservoirs

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ABSTRACT

Sand production is a major issue during oil and gas production from unconsolidated reservoirs. In predicting the onset of sand production, it is important to accurately determine the failure mechanism and the contributing parameters. The aim of this study was to determine sand failure mechanism in the Niger-Delta, identify the major contributing parameters and evaluate their effects on sanding.

Completion and production data from 78 strings completed on 22 reservoirs in a Niger Delta oil Field were evaluated. Sand failure mechanisms and contributing parameters were identified and compared with published profiles. The results showed that cohesive stress is the predominant sand failure mechanism. Water cut, bean size and gas oil ratio (GOR) impact sand production in the Niger Delta.

Keywords: Sand failure, Sanding, Niger Delta, oil production, cohesive stresses

INTRODUCTION

Sand production (or sanding), which is the disaggregation of formation due to in-situ stress and fluid flow, is widespread during production of hydrocarbons from unconsolidated sandstone reservoirs (Tronvoll et al. 2004). It is a process that develops progressively in three stages: failure of rocks surrounding an open hole or perforation from which free sand grains are generated, detachment of sand grains from failed materials, and, transport of those free grains by the effluents into the wellbore and up to surface. Sand failures are caused by shear, compressive, tensile, and cohesive stresses. Understanding the causes of sand production in a field helps to accurately predict sanding and rates. It also helps to overcome the difficulty of determining whether or not sand control is required in areas where there is little or no production experience and where reservoir factors or operating conditions are different from previous experiences.

The effects of sanding are two-sided. On one hand, there could be loss of oil production and hence revenue due to formation sand and fines plugging or reduced well productivity. In addition to damaging pumps and downhole equipment, erosion of casing and surface facilities may also occur. Sand failure can cause wellbore-stability problems, reduced production, and in extreme cases, loss of wells. Disposal of produced sands is costly because of strict regulations due to concerns on safety and the environment.

On the other hand, sanding could contribute to improved well productivity and recovery in heavy oil reservoirs with the use of the Cold Heavy Oil Production with Sand (CHOPS) technique, which allows higher production rates than conventional methods.

Sand may be produced under transient, continuous, or catastrophic conditions depending on rock strength properties, depth and pressure, depletion and drawdown, sand particle shape and size, bean-up size, shutdown/start-up frequency, water cut, reservoir fluid type, and perforations size, frequency and orientation.

There have been extensive studies on sand failure mechanisms using laboratory experiments, theoretical modelling and field observations. In 1996, van den Hoek et al. conducted laboratory experiments in which sand failure was observed for near-cavity effective stresses above a certain threshold, independent of applied drawdown. The results led to the conclusion that cavity failure under compression or tension stress in most cases depends only on cavity size, and not on near-wellbore stress or drawdown. Sand prediction tools based on theoretical modeling include the works of Yi et al (2003), Risnes et al. (1981) and Papamichos et al. (1999). Studies based on field observations include those of Ghalambor et al (1994).

Field observations technique was used in this paper to study sanding in a Niger Delta oil Field.

MATERIALS AND METHODS

THEORETICAL FRAMEWORK

Drilling a well through a rock formation introduces a stress field at the wellbore proximity that may be great enough to cause failure. Additionally, when a wellbore is actively or passively loaded, the stress effect could cause formation failure. For a homogeneous, isotropic, linearly elastic rock mass, if we include the effect of the pore fluid pressure, the displacement u of an elastic material can be described by the equation:

$$(\lambda + 2G)\frac{d}{dr}\left(\frac{du}{dr} + \frac{u}{r}\right) + \ell R + \alpha\frac{dp}{dr} = 0 \qquad (1)$$

Where,
λ, G = Lame's parameters
ℓR = radial volume force per unit volume
α = 1-C_r/C_b
C_r = rock matrix compressibility and
C_b = rock bulk compressibility.

The pressure gradient is given by Darcy's law in radial form.

$$\frac{dp}{dr} = \frac{\mu q}{2\pi hkr} \qquad (2)$$

Where,
μ = fluid viscosity
q = fluid flow rate
h = height of flowing zone
k = rock permeability

Equation 1 can be simplified by setting ℓR to zero, to give:

$$(\lambda + 2G)\frac{d}{dr}\left(\frac{du}{dr} + \frac{u}{r}\right) + \alpha\frac{dp}{dr} = 0 \qquad (3)$$

The stresses are given by:

$$\sigma_r = \lambda\Delta^e + 2G \in^e{}_r + \alpha p \qquad (4)$$

$$\sigma_\theta = \lambda\Delta^e + 2G \in^e{}_\theta + \alpha p \qquad (5)$$

and,

$$\sigma_z = \lambda\Delta^e + 2G \in^e{}_z + \alpha p \qquad (6)$$

Where,
$\in^e{}_r$, $\in^e{}_\theta$ and $\in^e{}_z$ are elastic strain components and

$$\Delta^e = \in^e{}_r + \in^e{}_\theta + \in^e{}_z \qquad (7)$$

The solutions of these equations require an understanding of the load history of the material and the imposition of appropriate failure criteria.

Three criteria commonly used in wellbore proximity failures are the Mohr-Coulomb failure criterion which relates the shearing resistance to the contact forces and friction and the physical bonds (cohesion) that exist among the grains[1], the Hoek-Brown criterion which is empirical and applies more to fractured reservoirs, and the

Drucker-Prager criterion which is based on the assumption that the octahedral shearing stress reaches a critical value and fits high stress levels.

NIGER DELTA CASE STUDY

The Field is located South-West of Port Harcourt with an aerial extent of approximately 30 km^2. It has initial oil and gas in place of about 1200 million barrels and 4730 Bscf respectively, while cumulative oil production stands at about 200 MMstb. There are 50 wells in the field, with 78 strings, penetrating 22 reservoirs at depths between 7500 ft and 12800 ft in a stacked series of anticlinal or dip and fault bounded structures. The gravity of the oils varies between 20° API in the shallow reservoirs to 55° API in the deeper zones. Porosity range between 21 and 28 %, while permeability varies from 100 mD – 5000 mD. Initial reservoir pressures range between 3600 and 5800 psia.

The field reports were studied to obtain information on well strings, completion dates and types, drilling, casing and completion records, pressure, production and work-over history, perforation summary, top structure map, log data and completion diagrams. Re-completion operations and sand control devices were also investigated to provide a fair understanding of the wells and completions in the field.

WELL SELECTION PROCESS

Only oil wells were considered for this study. Completions where sand control devices were installed were screened out. A total of 78 strings were first selected and screened. These reduced to 54 on the basis of dual or commingled completions. Out of the 54 strings considered, 22 were found to have sand control devices installed or had sand consolidation treatments and were screened out leaving 32 wells. A total of 16 wells were finally used for the study after screening out gas wells. The selected wells have produced for periods ranging from 5-37 years.

Information extracted from the finally selected candidates included completion trajectory, depth and thickness of completion, perforation frequency, bean size and operations, water cut, production period, GOR, shut-in frequency, depletion and sand quantity produced. Sand production rates and trends were observed over production life and compared with observed trends in literature to determine failure type. Critical sanding events were noted while an average critical sanding value of 6 ppt was used in the field based on experience and previous studies. Production parameters were also observed over periods of sand production to determine their contributions to sanding. The impact of some of the identified parameters on sanding was evaluated not only for each of them, but for combinations of the parameters.

RESULTS AND DISCUSSION

Sand production was found to begin at the onset of production in most of the wells considered (Figure 1). The production of sand at the onset of oil production indicated that depletion of reservoir pressure did not play any direct impact on the commencement of sand production in the reservoirs. Observed trends of sand production also showed that sand production was not influenced by the depletion of the reservoir pressure (Figure 2). Increased depletion in many of the wells did not give corresponding increase in sand production. This failure at onset of production is attributed to loss in cohesion strength in the reservoirs due to fluid losses during drilling, completions and work-overs.

Production start-up of wells was done on high bean sizes after initial gradual increment (Figure 3). On re-opening of shut-in wells, the bean size was kept at the sizes in which they were at shut-in and were not increased gradually with time at re-opening of the wells. Sanding may result from formation weakening, perhaps from fatigue effects related to repeated well shut-ins. Transient pressure gradient effects during well shut-in and bean-up are known to cause sanding.

Changes in choke sizes affected sand production, though there were few cases in which such changes did not affect the quantity of sand produced. The effect of high water-cut on sanding was observed in some of the selected wells. This agrees with the well-known fact that high water cut causes capillary-bonding reduction between originally water-wet sand grains, promotes chemical interaction between rock matrix and water because of increased water saturation and results in increase in drag force for mobilizing sand grains from failed sand materials.

High GOR was found to have effect on quantity of sand produced in some of the selected wells observed. Although this phenomenon has not been extensively discussed in literature, there were wells in which high GOR was the only parameter which could validly explain the cause of the sanding observed. The effects of some production practices were observed to have affected sanding. The ramping-up of the choke during well start-ups instead of gradual increments was found to have negative consequences on sanding. This practice is known to cause early water breakthroughs which in turn affects sanding.

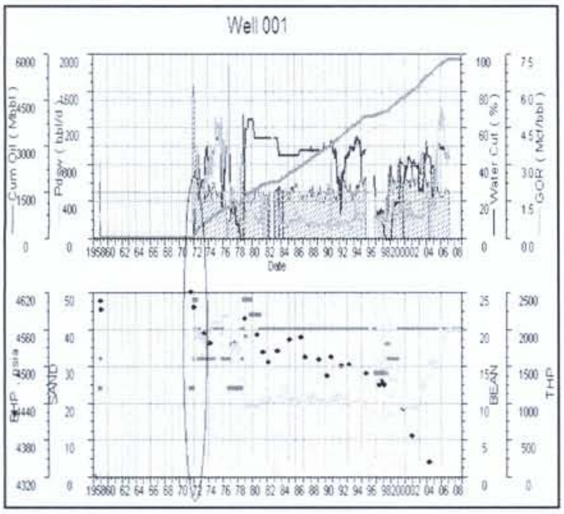

Figure 1: An example showing the onset of sanding at the start of production

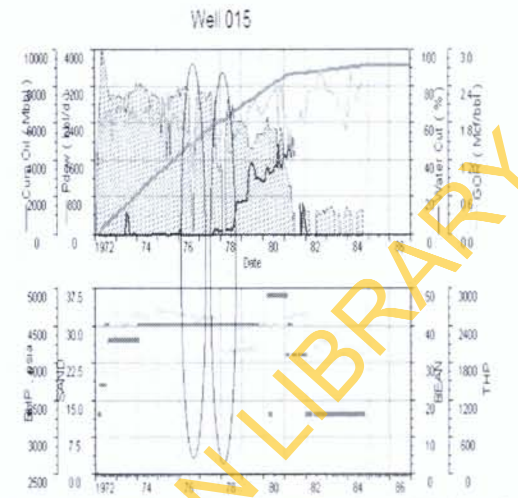

Figure 3: The effect of re-opening of well on high bean size

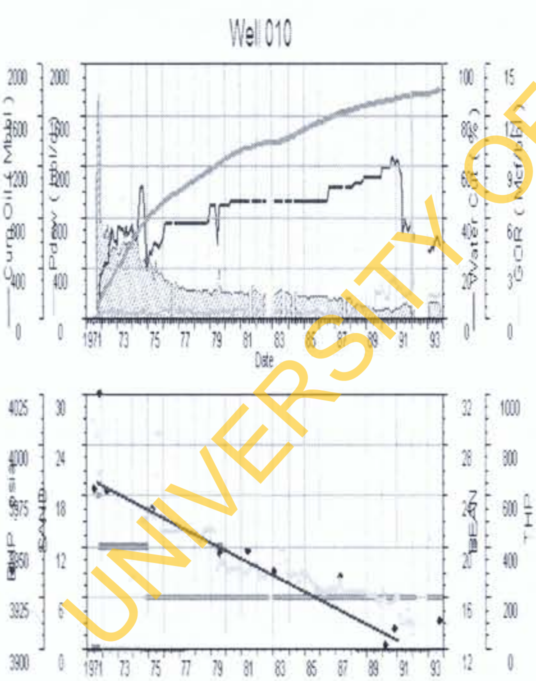

Figure 2: Example showing non-correspondence of increase in sand produced with depletion

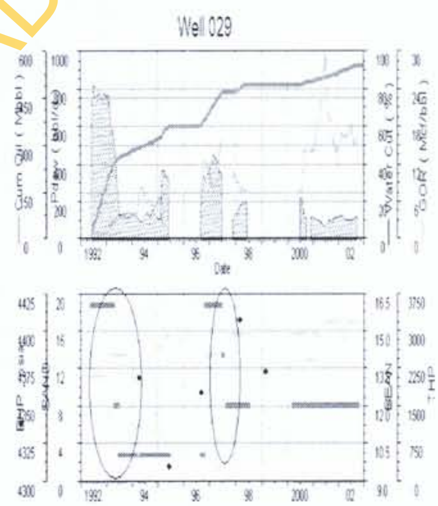

Figure 4: Effect of bean size decrease on sanding

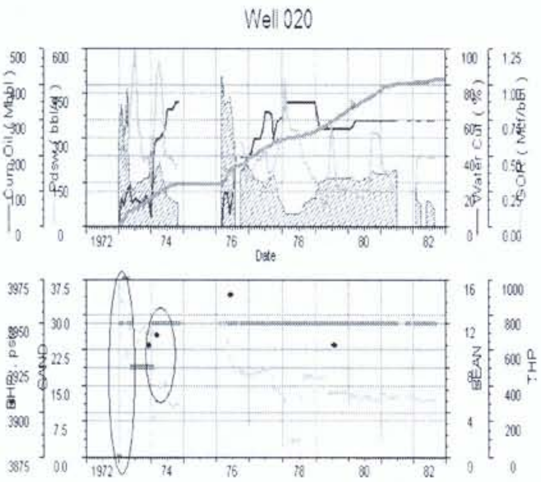

Figure 5 showing the effect of bean size increase on sanding

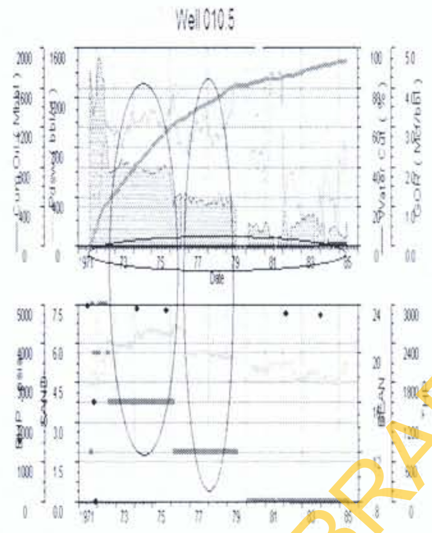

Figure 7: Effect of high GOR on sanding

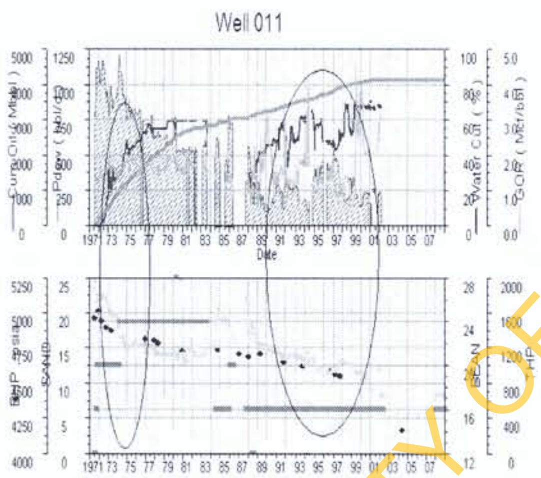

Figure 6: Effect of high water cut on sanding

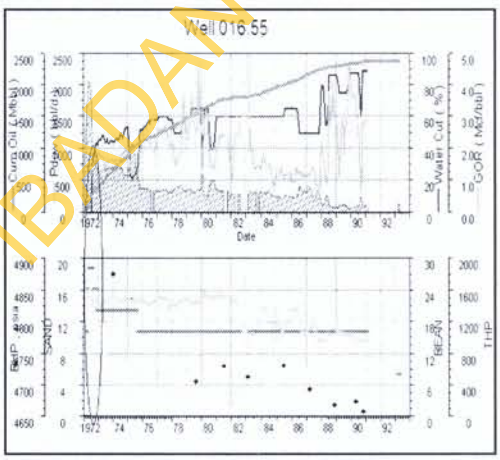

Figure 8: Effect of ramping-up of bean size on early water

CONCLUSION

From the study conducted on selected oil wells in the Niger-Delta, the following conclusions have been made:

- The predominant failure mechanism is cohesive. This is evident from the steady quantity of sand produced over the life of most of the wells from inception of production.
- The Compressive failure mechanism is found but not predominant. There was no strong correlation between depletion of reservoir pressure and sand quantity produced.
- Drilling, completion and some production practices prepared the basis for sand failures in the Niger Delta Field.
- Bean size, water cut and GOR contribute to sanding in the Niger Delta either individually or combination.

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