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The Concept of Sand Production in Relation to Frac-Pack and Rock Failure Criteria; A Case Study of Field-"X" Niger Delta

Orubite Joseph Inemi[1]; Acra, E.J[2]; Adiela, U.P[3]
[1, 2]Centre of Petroleum Geosciences, UNIPORT
[2]Department of Geology, University of Port Harcourt, Nigeria
[2]Department of Petroleum Engineering, Nigerian Agip Oil Company, Port Harcourt, Nigeria

Abstract— *This study has been carried out with much consideration on the young modulus, but the research finding has shown that the effective tensile strength of the sand grain can also be a considerable parameter during the design of frac pack propping agent with help of a simple software application for this study.*

I. INTRODUCTION

Geomechanics as a field of study generally investigates deformation of rocks arising from natural and man made processes and its effects on well trajectory. In petroleum engineering, rock mechanics is important in drilling and production because the stability of drilling and perforation affects technical and economic success of drilling, completion and Production operations. Prediction of the mechanical behavior of the subsurface formation of the key in geomechanics to avoid wellbore instabilities which is as a result of the interplay of the in-situ stresses during drilling and hydrocarbon production. The deformation can result in sand production during production stages.

More so, predicting the elastic behavior of unconsolidated sands in important for drilling, well completion and sand control reason. The production of hydrocarbon and water from subsurface formation results in stress and strain freed effects which is mainly as a result of decrease in the reservoir pressure. In order to forecast compaction behavior of petroleum reservoirs, it is important to identify the compressibility and mechanical properties of reservoirs.

Mechanical properties of rocks such as Bulk modulus, Youngs modulus, Shear modulus.

Poisson's ratio etc. can be deduced from two main methods, namely;

1) Measurements of mechanical parameters through laboratory methods, such as strength and static elastic parameters (derived from cores of known depths). (Tiab 2012).
2) Continuous down hole measurements with wire line or other logs, to determine the dynamic elastic constants via measuring compression and shear velocities (Tiab 2012).
3) To evaluate the elastic properties from generated wave semi-velocity logs.
4) To evaluate production condition at which sand causes frac-pack failure.
5) Understanding the concept of sand production in relation to frac-pack and electro mechanisms, linked to rock failure criteria.

Significance of the Study

1. To predict frac-pack design failure over time which can lead to sand production.
2. To determine in order of hierarchy the mechanical properties of unconsolidated sands during production that causes frac-pack failure over time.
3. To offer technical assistance for frac-pack assessment making it is critical to forecast the production state at which frac-pack design fails and sand production occurs.
4. Having a proper knowledge of unconsolidated sand properties so as to maintain the needed draw down pressure and flow rate to avoid frac-pack failure.

II. LITERATURE REVIEW

This section review-s the essential literatures regarding petroleum reservoir, geomechanical rock properties achievable by laboratory measurements or petrophysical logs. In addition the concept of unconsolidated sands, frac pack design tool and related mechanisms linked to rock failure criterion can be explained in this review.

Stress and Related Concepts

Stress is the force acting through a material (rock) of known dimensions (Fl r 2008)

$$0 = \frac{F}{A} \quad (1)$$

The SI unit for stress is Pa (=Pascal' N/m2). The upstream industry uses "oil field" units like psi (pounds per square inch) to represent stress. Past studies have sho4vn that stresses in geomechanics are generally compressive and positive.

Within a rock the magnitude of force AF may differ from one area to another. Consider a portion i of a rock which contains point P. The stress at point P would be the limit value of AFIJAAI when AAi reduces and/or tends to zero, i.e.

$$\sigma = lim \frac{\Delta F_i}{\Delta A_i} \quad (2)$$

Equation 2 shows stress at a point P within a body while Equation I describes the average stress of the whole body that contains point P (Fjr 2008).

Two types of stresses results from equilibrium condition namely normal stress: ci, this is perpendicular to the plane of the object, and shear stress t, this acts at an angle greater or less than 990 along the plane. Compressive and tensile failures are products of normal stress while shear stress results to sheared and torsure failure.

Stress determination is important in determining the original formation structure, position and dimension of features of interest (e.g. faults and unconformities), ground water flows etc. Also it is important to discover the direction of fonnation's weakness (cleavage or joint planes) to determine criteria for wellbore instability analysis (Aadnoy 2011).

For a body under equilibrium, the stress state can be represented with nine components from three (3) sides of a cube. These nine components are usually organized in one matrix (Aadnoy 2011).

$$\sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{bmatrix} \quad (3)$$

Where shear stress as mirrored across the diagonal of the matrix $\sigma il = \sigma ji$ as a result of static equilibrium. The matrix in equation (3) is known as the stresses tensor.

Strain and Related Concepts

Assume a bar with original length L is stretched linearly to a new length L_0. The deformation (strain) is defined as the ratio of elongation with respect to the initial length.

$$\varepsilon = \frac{\Delta 1}{1} \quad (4)$$

Ti-ic deformation at point intervals varies dramatically if the bar's Young's modulus or cross sectional area changes (Angelov 2009). Just like the stress sensor the strain can be organized into a strain sensor (Equation 5) 19 r et al. 2008).

$$\varepsilon = \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & \varepsilon_{zz} \end{bmatrix} \quad (5)$$

The mechanical behavior of real materials is very diverse and complex and it would be impossible to formulate equations which are capable of determining the stress in a body under all circumstances (Spencer 2004). The common effect of different strain histories will be equal to the sum of the effects of the individual strain histories. For a locally reacting material, the internal stress at a certain fixed position can be related entirely to the strain history of that local material (Tigrek 2004). Materials following the same constitutive equations are building one theological class.

Depending on the material properties and stress/strain relation the rheological classes can be elasticity, plasticity and viscosity. The behavior of a material can be elastic or inelastic, Elastic behavior means that applied stress leads to a reversible strain when the stress is removed. Most rock mechanics applications are based on linear elasticity, although it is well established that sedimentary rocks exhibit non-linear behavior, plasticity and even time

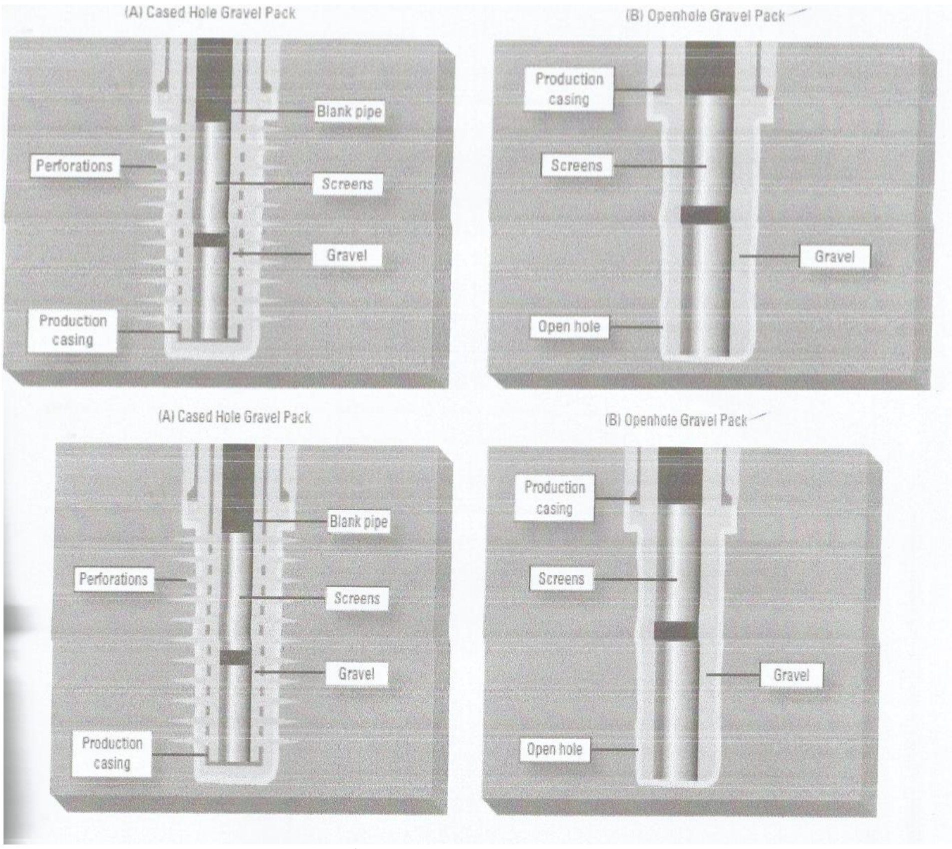

Fig. 1. Schematic for Gravel packing (Sanchez and Tibbles 2007).

III. METHODOLOGY

In view of the geomechanical study and analysis done based on the data from well logs of fieid-X in the Niger Delta, prediction of sanding and frac pack failure within the field was initiated through the acquisition of well logs for the particular field of study.

Source of Data

The data used for the derivation and computation of the rock mechanical properties were gotten mainly from sonic and density logs (compressional travel time). Primary source of geomechanicai parameters is the derivation of shear waves travel time from compressional wave travel using established correlation.

The log data, production data, BHP information, frac pack design parameters and derived rock elastic parameters used for this study wee gotten from field-X in Niger Delta.

Method of Data Collection

Rock mechanical properties such as Young's modulus, shear modulus, bulk modulus, Poisson's ratio and rock compressibility were generated from correlations which contain parameters mainly from density and sonic travel time logs (compressional arid shear wave velocity logs). The sonic log from well logs only contained compressional wave travel time. The shear wave travel time was derived using the following correlations.

$$VP = \frac{304878}{\Delta T_p} \qquad (\frac{km}{s})$$

$$Vs\ (km/s) = (0.846 \ * Vp)\ 1.088 \ldots\ldots(6)\ William\ correlation$$

$$Vs\ (km/s) = (0.844 \ * Vp)\ 0.856 \ldots\ldots(7)\ Castagna\ correlation$$

$$Vs = \frac{304878}{\Delta T_s} \qquad (8)$$

$$\Delta T_s = \frac{304878}{vs} \ldots\ldots\ldots\ldots \qquad (9)\ shear\ sonic\ travel\ time$$

Poisson's ratio

$$\mu = \frac{\frac{1}{2}\left(\frac{\Delta ts}{\Delta tc}\right)2 - 1}{(\frac{\Delta ts}{\Delta tc})^2 - 1}$$

Analytical Model Approach

1. The formation was considered homogenous
2. Isotropic
3. Hooke's law being obeyed under linear elastic behaviour
4. Fracture initiation pressure been equal to the smallest horizontal stress $Pw = \sigma h$

The PKN (Perkins-Kern-Nordgen) and KGD (Kristianovitch-Geertsma-Ie Kierk) models are commonly used analytical models for fracture width computation with their common assumptions of

1. Fracture height being constant and non-dependent of fracture length
2. Net pressure at fracture tip as zero
3. Plain strain condition. The PKN considers it to be vertical, while KRD assumes an horizontal plain strain. PKN model is usually preferred for large length to height ratio greater than I.

$$\frac{w = 2(1-v)P}{G} = \frac{4LPe}{E'} \qquad (10)$$

Where
V= Poisson's ratio
Pe= net pressure
G = Shear modulus
E'= Strain young

Model Approach for Sand Grain Impact on Propping Agent

During sanding the grain particles are known to have erosion and abrasive impact on the proppant over time. The relationship is expressed based on the Hertzian constant surface theory through the effective stress impact of grain is given as:

$$\sigma ra = \frac{-(1-2v)\sigma c)}{3} \qquad (11)$$

Where
σra — maximum tensile stess on proppant
σc= maximum effective stress on proppant

IV. RESULT AND DISCUSSION

Results

The rock mechanical properties derived from input of well logs. BHP Information and production data into the computer programme have been plotted for better understanding.

The plots showing the distribution of rock mechanical parameters, stress and impact of effective stress of sand grains on proppant materials in relation to depth.

Result Analysis for Well 01

The fracture width varies inversely as the Young's modulus of the sand zone of interest, same trend is the changes in the UCS values observed in figure 2 and were likely due to porosity and shaliness variation in the sand zone of interest. Maximum tensile strength was observed where the uniaxial compressive strength gave a corresponding increase with depth. Figure 3 shows intervals where propping agent design consideration should be made as the tensile strength (maximum value) experienced high and low values with depth.

Result Analysis for Well 23

The fracture width design based on krd model used, generated high values in areas where the Young's modulus tend to low values. Trendy UCS and maximum tensile strength characteristics were observed in figure 4. The fracture width plotted with depth showed high values around 5430-5440ft. The propping agent design consideration is highly necessary as high grain effective stress values were obtained.

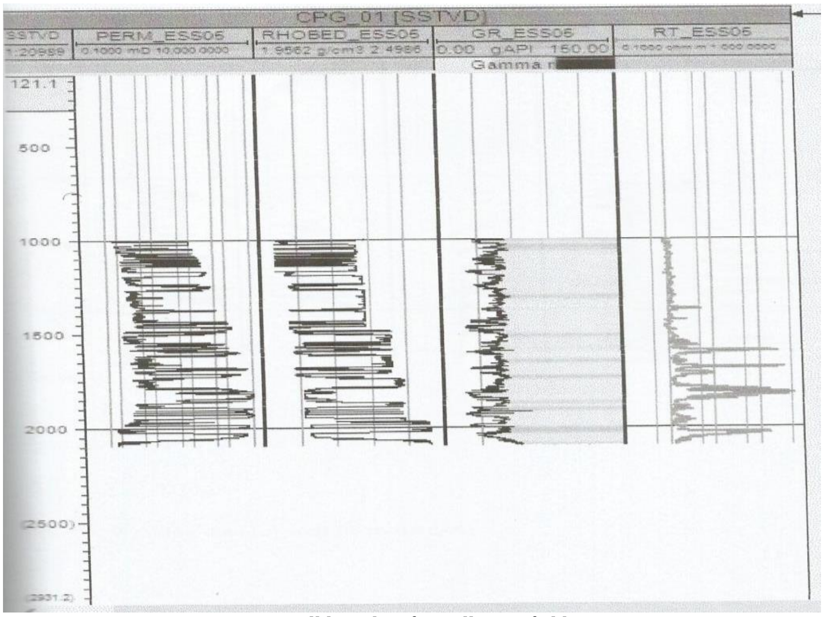

Fig. 2. Well logs data for well 01 in field –X.

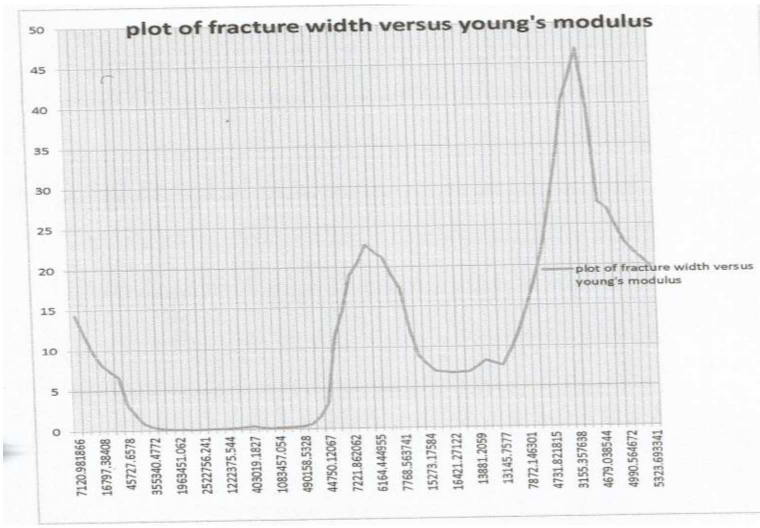

Fig. 3. Plot of fracture width versus Young Modulus for Well 01.

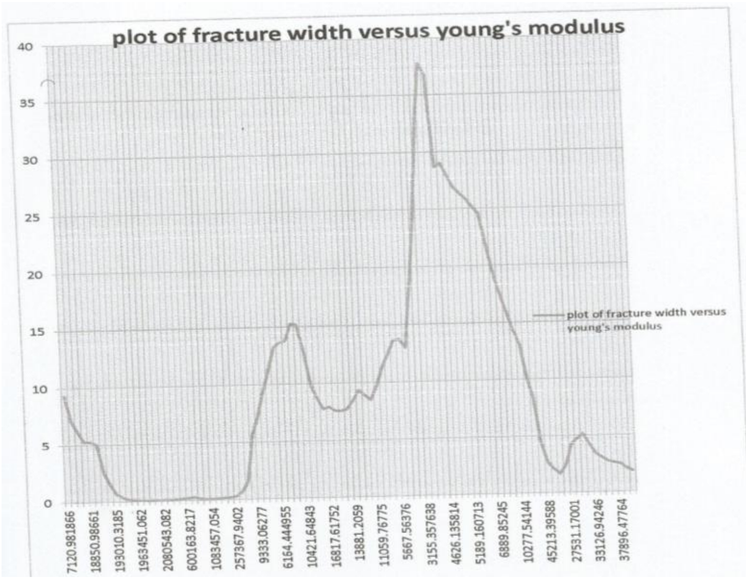

Fig. 4. Plot of Fracture width versus Young’s modulus.

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Following the derivation of the rock mechanical properties for the field of study using the following active wells (01,23). It is therefore necessary to have a quick look into the rock mechanical properties of the formation before designing an effective frac- pack system for the unconsolidated sand which will always have impact on propping agents used and likely propagation channels developed during sand production and stimulation activities for a kno and well defined hydrocarbon bearing sandstone.

Based on our study carried out the following findings were made.

1. The fracture propagation width for stimulation to be effective is a clear function of the Young's modulus of the materials.
2. The impact of sand grains on the propping design consideration should not be left out as its continuous abrasive and erosional effect on the proppant used can affect the efficiency of the propping system over time.
3. The uniaxial compressive strength value was found to be approximately 0.01 times the effective tensile strength for the respective sandstone reservoirs in the field.
4. Unconsolidated sand values were observed with the UCS values less than 15MPa on the average across the wells in the field of study.
5. Having a pre-information of the effective stress and tensile strength of the formation sands will help the lower completion engineers to design an efficient propping agent with high strength capacity towards overcoming the abrasive and erosional effects of the sand grains.

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