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Density Modelling from Well Analysis ofFields [Sand API<75 and Shale API>75], Niger Delta Basin

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Abstract: *Modelling density-velocity relation for Niger Delta basin is very necessary in geological analyses involving rock parameters as density values overlap for sands and shales. Well-Log data were acquired for three wells in a field in the Niger Delta for analysis leading to density modelling. By means of Hampson Russell Software, Gardner's and Lindseth's relations were localized,altered and Atat et al., 2020 constants considered for sand and shale lithologies which helps in the model success. Harmonizing Gardner with those fromLindseth approaches, we obtained the mean; the final models are* $\rho = 0.115V_p^{0.27} - 5439V_p^{-1} + 1.5625$ *and* $\rho = 0.06V_s^{0.24} - 2412V_s^{-1} + 1.4706$ *for sandstones lithology;* $\rho = 0.26V_p^{0.45} - 2278.5V_p^{-1} + 1.42855$ *and* $\rho = 0.115V_s^{0.30} - 11971.5V_s^{-1} + 1.42855$*for shale lithology. With these models, new idea is formulated which will add to universal knowledge. Density information is possible in the absence of density log for accurate characterization of reservoir.*

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I. Introduction

A mathematical model is an explanation of a system using mathematical ideas and language. Mathematics permit relating physical occurrences and physics establish an application field for mathematics. This connection can be categorized in two methods: Mathematicians used physical concepts and arguments; Physicists used mathematical concepts and methods. The statement "physics is a domain of applicationof mathematics; mathematics is the language of physics" may not be true (Tzanakis, 2002). Characterizing the relationship among these disciplines, an essential bulky term than "language and domain of application" is required (Chaachoua&Saglam, 2006). To describe any relation between real word and mathematics, the term "applications and modelling" was recommended (Blum, 2002). These terms perfectly stand for the relation between mathematics and physics. When solving problems the Physicists attempt to achieve a mathematical model that defines some aspect of the real situation (Berry & Houston, 1995). Therefore, it can be said that the model concept is vital for physical sciences. A mathematical concept is called tool when it is used in order to solve a problem (Douady, 1986). A concept is seen as an object when a scientist emphasis is on its definition and properties. Applying this language for the model concept, we can say that modelsare seen as tool andsometimes asobject (Saglam-Arslan&Arslan, 2010).

The density of naturally occurring liquid hydrocarbon mixtures is significant in various petroleum engineering computations. The oil density differs with API gravity and the temperature conditions. Density of oil is the fraction of the mass of oil to its volume. During exploration and production processes it is important to understand that density of water is more than that of oil; thus oil floats on water and gas remains on top of oil and water. The field data from different oil wells drilled is acquired for density estimation.

Well-log data originate from a constant recording obtained in a borehole and documents diverse geological parameters (Rider, 1986). The measurements are derived from three techniques: mechanical, spontaneous or natural and induced (Luthi, 2001; Bigelow, 1992). On a large scale, lithology, bed thickness, compaction, and reserve estimates may also be ascertained through well-log tests (Bigelow, 1992). A collection of well-log data encompassing a geographical area provides material to define reservoir geometry, correlate beds, and map structures (Asquith & Gibson, 1982). Reservoir properties then can be described through combining well-log and core-plug records.

Theory

There are two ways to test wells: open-hole and Logging-While-Drilling (LWD). Open-hole logs cannot take place except when drilling is over; it is usually done in the well when the hole is not cased (Luthi, 2001; Asquith & Gibson, 1982). The instruments attached to a cable are gently lowered into the depths of the well to the data acquisition (Serra, 1984). When the wire-line is pulled upwards from the bottom, the down-hole logger notes the data description while transmitting the information to the surface (Rider, 1986). LWD logs are done while the drilling of the well is on-going to reduce the invasion of fluid and damage to the borehole. This is done by placing the instruments in the bottom-hole of the drill (Luthi, 2001). It enables the acquisition of real-time data. Logs can be expressed in different forms such as a specific curve, group of curves; may also be presented as a logging tool (Asquith & Gibson, 1982).The logging tools achieved the measurements which may not be perfect (Rider, 1986). Watery and mud ran during boring usually enters bedrock surrounding the borehole and influence the log measurements.

The natural phenomena require an appropriate sensor to obtain mechanical and spontaneous measurements (Rider, 1986; Serra, 1984). Natural or spontaneous measurements involve self or spontaneous potential (SP) and gamma-ray; mechanical measurements include temperature and borehole diameter (Rider, 1986). Calipers measure the well diameter; thermometers record the formation temperatures at different depths, which is required when defining porosity and permeability in the formation. Spontaneous potential results in the spontaneous electrical currents and gamma-ray calculates the natural radioactivity in the formation.

Induced measurements need an emitter or transmitter, which creates a specific reaction in the formation, and a detector (Serra, 1984). Induced measurements include resistivity, neutron porosity logs, and sonic or acoustic measurements. Resistivity measures how well electricity flows through the formation since locations containing hydrocarbons act as resistors. Sonic measurements test the travel velocity sound waves through the rock; neutron ray and density tests measure the gamma-ray or neutron density that through processing, determines the amount of pore space or porosity.

Location and Geology

The Niger Delta (Figure 1) is located (Klett*et al*., (1997) between latitudes 3^0N and 6^0N and longitudes 5^0E and 8^0E (Reijers*et al.*, 1996). Niger Delta experiences wet and dry seasons; average rain in a month during wetseason is about 135 mm and this falls to 65 mm during dry season (Atat, et al., 2012; George *et al*., 2010). The oil classification in this basin is Akata-Agbada(Ekweozor&Daukoru, 1994; Tuttle, *et al*., 1999).The Agbadaformation is the main oil reservoir in the Niger Delta.

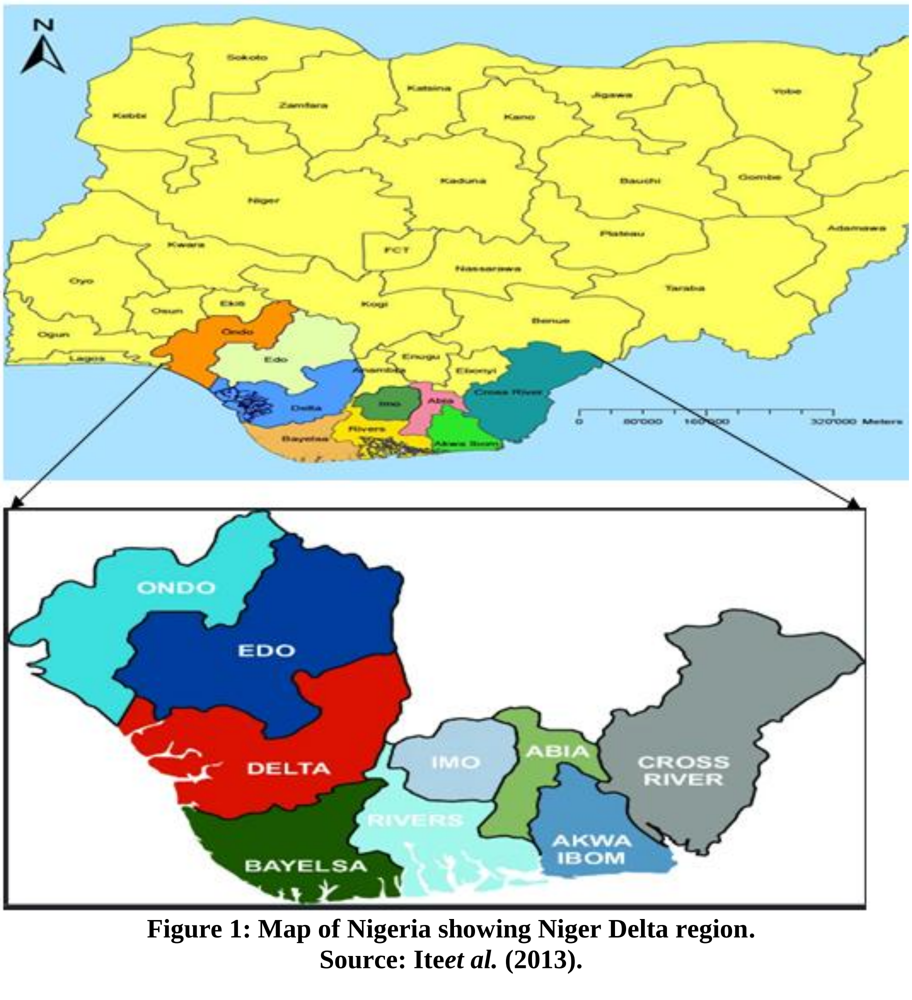

Figure 1: Map of Nigeria showing Niger Delta region.
Source: Ite*et al.* (2013).

II. Materials and Method

Three wells (A, B, C) were available for this study with collection of logs, including caliper, Gamma Ray (GR), resistivity, density and sonic velocity (V_p). S-wave sonic was unavailable but estimated from Castagna curve. Hampson Russell Software(HRS) was the main software used for data loading, processing and necessary cross plots. Data acquired from the onshore Niger Delta oilfield are well history, well Location, suites of logs and marker (Figure 2).

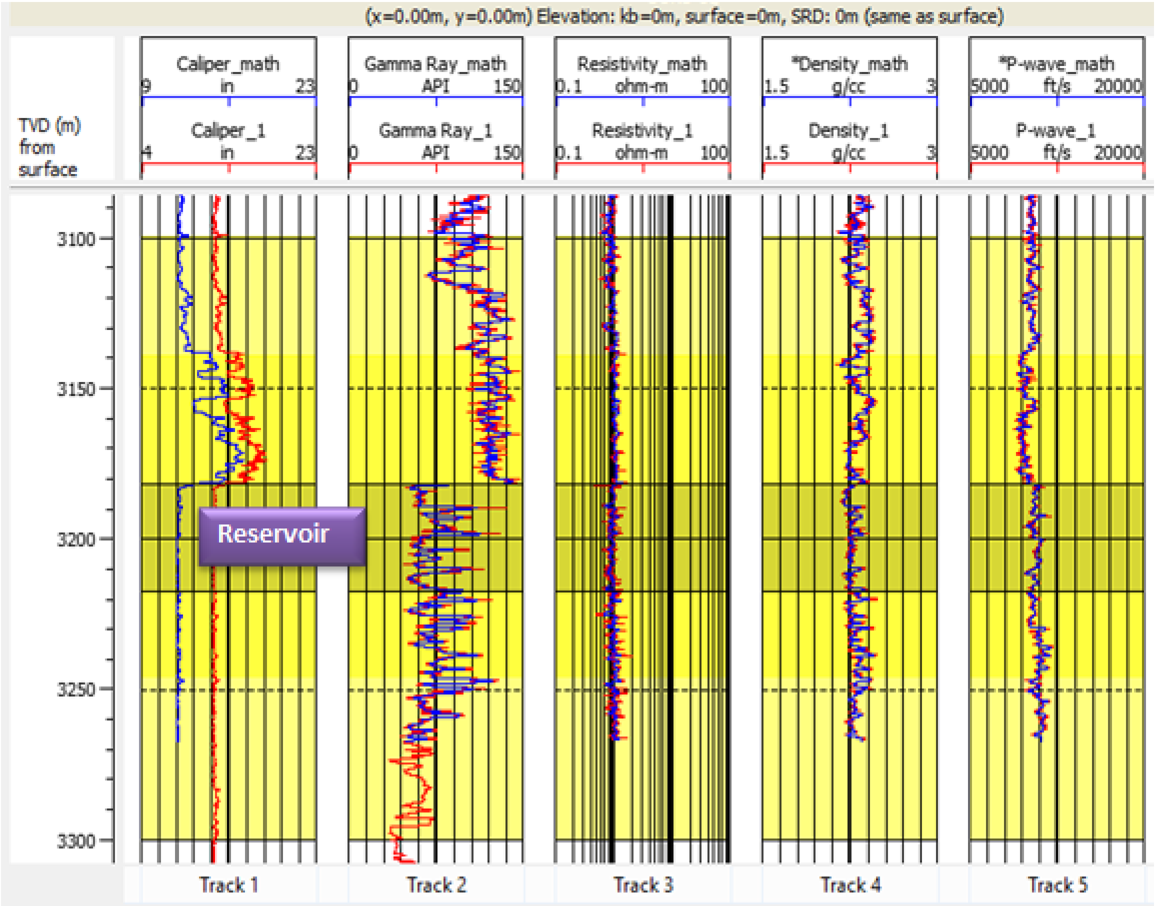

Figure 2: De-spiking of V_p wave, density and other logs using log filtering utility of HRS (filtered logs in blue, unfiltered logs in red).

Atat*et al*, 2020 worked on the constants of density-velocity relation in the Tau Field and came up with the major findings resulting from the local fit for sands and shales differentiated, indicate j and k from compressional wave velocity as 0.23 and 0.27 (from shear wave velocity as 0.12 and 0.24) respectively for sand; 0.52 and 0.45 (from shear wave velocity as 0.23 and 0.30) respectively for shale. Also, the constants r and m from compressional wave velocity as 0.320 and 3481 (from shear wave velocity as 0.340 and 1640) respectively for sand; 0.35 and 1595 (from shear wave velocity as 0.35 and 8380) respectively for shale.

Presenting these information in a localized form of Gardner (Equation 1 and 4) (Gardner *et al.*, 1974; Atat, *et al.*, 2020) and Lindseth (Equation 2, 3, 5 and 6) (Lindseth, 1979; Atat, *et al.*, 2020) respectively, yielded

$$\rho = jV_p^k \tag{1}$$

$$V_p = r\rho V_p + m \tag{2}$$

$$\rho = \frac{V_p - m}{rV_p} \tag{3}$$

where $r$and m are local fit constants from least square fit approach

$$\rho_s = j_s V_s^{k_s} \tag{4}$$

$$V_s = r_s \rho_s V_s + m_s \tag{5}$$

$$\rho_s = \frac{V_s - m_s}{r_s V_s} \tag{6}$$

$\rho = 0.52V_p^{0.45}$ (7)
where V_p is compressional wave velocity; the coefficient and the superscript 0.52 and 0.45 represent j and k respectively, called local fit constants for shale.

$\rho = 0.31V_p^{0.25}$ (8)
where V_p is compressional wave velocity; the coefficient and the superscript 0.31 and 0.25 represent j and k respectively, called local single fit constants.

Gardner (sandstones) from Compressional wave velocity
$\rho = 0.23V_p^{0.27}$ (9)
where V_p is compressional wave velocity; the coefficient and the superscript 0.23 and 0.27 represent j and k respectively, called local fit constants for sand.

Gardner (shale) from Shear wave velocity
$\rho = 0.23V_s^{0.30}$ (10)
where V_s is shear wave velocity; the coefficient and the superscript 0.23 and 0.30 represent j and k respectively, called local fit constants for shale.

$\rho = 0.31V_s^{0.25}$ (11)
where V_s is shear wave velocity; the coefficient and the superscript 0.31 and 0.25 represent j and k respectively, called local single fit constants.

Gardner (sandstones) from Shear wave velocity
$\rho = 0.12V_s^{0.24}$ (12)
where V_s is shear wave velocity; the coefficient and the superscript 0.12 and 0.24 represent j and k respectively, called local fit constants for sand.
These imply that the local fit for sands and shales differentiated, indicate j and k from compressional wave velocity as 0.23 and 0.27 (from shear wave velocity as 0.12 and 0.24) respectively for sand; 0.52 and 0.45 (from shear wave velocity as 0.23 and 0.30) respectively for shale.

The above equations were achieved using Gardner's approach but with specific constants for local fit (Equation 7 from Vp and Equation 10 from Vs both for shale; Equation 8 from Vp and Equation 11 from Vs both for single fit; Equation 9 from Vp and Equation 12 from Vs both for sand).

In order to identify lithologies with Lindseth approach, r and$m$were assessed by re-plotting the graph of velocities versus impedances with GR less than 75. The same cut-off of GR lower than 75 for sands; GR higher than 75 for shales was noted (Atat*et al.*, 2020). This resulted in six relations (Equations 13 to 18).

$V = 0.320\rho V_p + 3481$ (13)
$V = 0.308\rho V_p + 3400$ (14)
$V = 0.350\rho V_p + 1595$ (15)
$V = 0.340\rho V_s + 1640$ (16)
$V = 0.308\rho V_s + 3400$ (17)
$V = 0.350\rho V_s + 8380$ (18)

These also imply, the local fit for sands and shales differentiated, indicate r and m as 0.320 and 3481 resulted in a greater change to 0.340 and 1640 respectively for sand; 0.35 and 1595 from compressional wave velocity to 0.35 and 8380 from shear wave velocity respectively for shale (Equation 13 from Vp and Equation 16 from Vs both for sand; Equation 14 from Vp and Equation 17 from Vs both for single fit; Equation 15 from Vp and Equation 18 from Vs both for shale).

III. Result

In order to achieve our final model, we harmonized our equations obtained by Gardner approach with those obtained by Lindsethapproach from well-log analysis and considered the average. This yields a new idea which will add to global knowledge. This concept is defined below.

SANDSTONES LITHOLOGY (from Compressional wave velocity)

$\rho = 0.115 V_p^{0.27} - 5439 V_p^{-1} + 1.5625$ (19)

$where\ V_p$ is compressional wave velocity, $0.115 = \frac{j}{2}$; $0.27 = k$, $5439 = \frac{m}{2r}$; $1.5625 = \frac{1}{2r}$; $j = 0.23$; $r = 0.320$; $m = 3481$ for sand.

SANDSTONES LITHOLOGY (from shear wave velocity)

$\rho = 0.06 V_s^{0.24} - 2412 V_s^{-1} + 1.4706$ (20)

$where\ V_s$ is shear wave velocity, $0.06 = \frac{j}{2}$; $0.24 = k$, $2412 = \frac{m}{2r}$; $1.4706 = \frac{1}{2r}$; $j = 0.12$; $r = 0.340$; $m = 1640$ for sand.

SHALE LITHOLOGY (from Compressional wave velocity)

$\rho = 0.26 V_p^{0.45} - 2278.5 V_p^{-1} + 1.42855$ (21)

$where\ V_p$ is compressional wave velocity, $0.26 = \frac{j}{2}$; $0.45 = k$, $2278.5 = \frac{m}{2r}$; $1.42855 = \frac{1}{2r}$; $j = 0.52$; $r = 0.350$; $m = 1595$ for shale.

SHALE LITHOLOGY (from shear wave velocity)

$\rho = 0.115 V_s^{0.30} - 11971.5 V_s^{-1} + 1.42855$ (22)

$where\ V_s$ is shear wave velocity, $0.115 = \frac{j}{2}$; $0.30 = k$, $11971.5 = \frac{m}{2r}$; $1.42855 = \frac{1}{2r}$; $j = 0.23$; $r = 0.350$; $m = 8380$ for shale.

IV. Discussion

Our interest is in density for sand and shale; we worked on equations 13, 15, 16 and 18and presentedthe solution in another form (solving using Binomial expansion method) as

LINDSETH (sandstone) from Compressional wave velocity

$\rho = 3.1250 - \frac{10878}{V_p}$ (23)

$where\ V_p$ is compressional wave velocity, $3.1250 = \frac{1}{r}$, $10878 = \frac{m}{r}$, r and m are local fit constants for sand.

LINDSETH (shale) from Compressional wave velocity

$\rho = 2.8571 - \frac{4557}{V_p}$ (24)

$where\ V_p$ is compressional wave velocity, $2.8571 = \frac{1}{r}$, $4557 = \frac{m}{r}$, r and m are local fit constants for shale.

LINDSETH (sandstone) from Shear wave velocity

$\rho = 2.9412 - \frac{4824}{V_s}$ (25)

$where\ V_p$ is shear wave velocity, $2.9412 = \frac{1}{r}$, $4824 = \frac{m}{r}$, r and m are local fit constants for sand.

LINDSETH (shale)from Shear wave velocity

$\rho = 2.8571 - \frac{23943}{V_s}$ (26)

$where\ V_p$ is shear wave velocity, $2.8571 = \frac{1}{r}$, $23943 = \frac{m}{r}$, r and m are local fit constants for shale.

However, relations paired are among Equations 7 to 12 corresponding to Equations 23 to 26 [like Equation 9 with Equation 23].

V. Conclusion

The empirical models of density-velocity relation have been realised due to the specific constants of sand and shale. The American Petroleum Institute (API) considered for linear regression was greater than 75 for shale and less than 75 for sand. The wells assessed were from Niger Delta. The estimation of density from the models (Equations 19 to 22) will accurately satisfy the information needed to characterize reservoir since there will be no loss of evidence that has to do with geology.

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