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RESEARCH ARTICLE

THE EFFECT OF DENSITY-VELOCITY RELATION PARAMETERS ON DENSITY CURVES IN TAU (τ) FIELD, NIGER DELTA BASIN

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ABSTRACT

We considered the constants obtained for tau (τ) Field in the Niger Delta basin from well-log data of three wells (A,B,C) to investigate the effect of inclusion of these constants on density-velocity relation using Hampson Russell Software to generate density curve in tau field. The curves were compared to those generated from Gardner and Lindseth constants and in-situ density curves. Many researchers have worked on constants for density-velocity equations for different Fields; their results always differ from Gardner and Lindseth constants including the constants of Atat *et al.*, 2020 which are considered in this investigation as Tau Field local fit constants. Our findings support the results of these researchers. Results indicate over estimation of density curves when using Gardner and Lindseth constants. The challenge is that in-situ density curves are not accurate due to sand-shale overlap of density values. The most improved and accurate result is given by the density curves obtained using the constants for specific sand and shale lithologies (local fits). This verifies the need for the determination of constants for local fit of the oil field under investigation. The pink curves truly indicate the density estimation for the tau field which is very reliable in the characterisation of reservoir.

KEYWORDS

Density, Velocity, Curves, Effect, Field, Parameters and Well-log data.

1. INTRODUCTION

A density-velocity constant depend on geology when result from a good fit using sonic and density well-log information and is very common in the petroleum study (Gardner *et al.*, 1974). Gardner's (Nwozor, *et al.*, 2017) and Lindseth's constants as confirmed by Quijada and Stewart (2007) and other researches are frequently a source of inaccuracy in some empirical studies that required working with lithology-specific functions. Gardner's constants were provided for density-velocity relation to solve the problem of sand-shale overlap. Density is required in the identification of lithologies, pore fluids, porosity and overburden stress estimations and pore pressure prediction; it is one of the major desires in exploration, reservoir characterization and well planning. These constants are non-unique for most datasets from many sedimentary basins across the world as density-velocity data would not obey the original Gardner (Krasovsky, 1981) and Lindseth curves. Overlap in sands and shales could show variation in petrophysical properties (porosity of fluid saturation) making density not a good indicator of lithology (Atat *et al.*, 2020b). Modelling is necessary to evaluate the effect of these properties on density. Bulk density is an important acoustic indicator of the presence of shale; accuracy in density estimation enables the accurate location of shales in the reservoir.

Local examinations are compulsory to improve the precision of rock properties that were not captured by Gardner or Lindseth during their calibrations. The difference between the local variations and the original

Gardner or Lindseth relationship may be attributed to the differences in composition of the original rock types; perhaps Niger Delta is not naturally connected to the sedimentary basins assessed by them. Constants could be achieved by modifying the coefficients for visual best fitting curves through the dataset.

Density is the property of a matter which specifies an interface among fluids or solids; it is expressed in kgm^{-3} . It can also be expressed in g/cm^3 or g/cc . Density distinguish hydrocarbon from other fluid types (Koughnet *et al.*, 2003). This makes precise density evaluations important for description of reservoir. Analysing petrophysically, bulk density is a better acoustic indicator of shale presence. In order to achieve the aim of modelling of different density-velocity equations and their constraints, compressional wave velocity V_p and shear wave velocity V_s data and Gamma Ray GR and density data from a well are required (Quijada & Stewart, 2007).

The formation density logging tool offers a radioactivity measurement that produces in-situ formation densities. The density log measures the bulk density of a formation by bombarding it with a radioactive material; the resultant gamma ray count after the effects of Compton scattering and photoelectric absorption are recorded. This helps to derive a value for the total porosity of the formation which could be used in the detection of gas-bearing formations and recognition of evaporates. The bulk density tools are induced radiation tools. A formation with a high bulk density has high number density of electrons; it attenuates the gamma rays significantly; low gamma ray count rate is logged at the sensors. A formation with a low

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bulk density has a low density of electrons and it attenuates the gamma rays less than a high density formation; thus, rate of higher gamma ray count is logged at the sensors.

Rate of Gamma ray count depends on the electron number density which is related to the bulk density of a substance (Equation 1).

$$n = \frac{NZ}{A} \rho \quad (1)$$

where n is the electron density number in electron cm^{-3} ; N is the Avogadro's number. Avogadro's constant allows us to connect density to the number of nuclei cm^{-3} and the number of electrons (Tamunobereton-ari *et al.*, 2013). Without the density information, Petrophysicists would be unable to estimate the reserves of hydrocarbon that contained in the reservoir. Density descriptions can aid the determination of the locations and orientations of the formation limits and fault planes; it also helps the operator to know the size and shape of the reservoir and to place the well within it. Bulk density of a rock depends on the solid minerals of which it is composed, its porosity and the density of the fluids occupying that porosity. It also aids in lithological identification.

1.1 Log presentation

The formation density log is documented in tracks 2 and 3 of the standard API log arrangement on a linear scale. The scale is in g/cm^3 and usually within 1.95 to 2.95 g/cm^3 as this is the common range for rocks.

1.2 Identification of Lithology

When used alone, density log is not a good tool for identifying most lithologies because most rocks have an extensive range of densities resulting from their different mineralogical compositions and their variable porosities. Shales have bulk densities within the range of 1.8 to 2.8 g/cm^3 with variable clay minerals densities. Sandstones, limestones and dolomites all have bulk density ranges that overlay each other and that of shales (Kearey *et al.*, 2002; Bosch *et al.*, 2002; Reynolds, 1997; Tamunobereton-ari *et al.*, 2013). The existence of organic matter can also diminish the density of shales by up to 0.5 g/cm^3 . It is easier to compute the total organic carbon (TOC) content of a source rock from the variation in bulk density.

1.3 Density of rocks

Density of rocks (Table 1) is affected by a lot of factors such as concentration of atoms, change in volume due to temperature, change in volume due to pressure and rock type and time. Concentration of Atoms: The mass of a material is necessary for the density determination. Atoms in some solids are closely packed. They could have a low atomic numbers but are heavier than those with high atomic numbers for a given volume. This is the case of Tin (with 50; weight - 118.7 amu) and Manganese (having atomic number of 25 with 54.9 amu, almost half of Tin value). Tin has a lower density of 7.31 gcm^{-3} ; density of Manganese is 7.43 gcm^{-3} .

Change in Volume due to Temperature: High temperature caused the rocks to become ductile and flow; if temperature is low, rocks become brittle and fracture. Change in Volume due to Pressure: Buried rocks are under the influence of a force due to confining pressure. The Earth's crust materials are squeezed; the rocks deeply buried are held together and tend to flow. Rock type and Time: When forces are applied to rocks like shale, rock salt, limestone and schist over a long time, they behave as ductile.

According to Atat *et al.*, 2020, the estimated constants for local fit for tau reservoir is given in Table 2. This table also contains information on Gardner and Lindseth default parameters. If there is no accuracy in the estimation of fluid density, the porosity will not be appreciable. The mud filtrate fluid is noted by the formation density device. The density of fresh water is 1.0 gcm^{-3} and that of salt water is 1.1 gcm^{-3} . Mud fluid density is very useful in the porosity calculations and can be corrected directly for pressure and temperature in some softwares (Glover, 2013; Etu-Efeotor, 1997; Telford *et al.*, 1978).

Table 1: Rock types with their corresponding range of densities.		
S/N	Rock/Mineral types	Density ($\times 10^{-2}\text{gcm}^{-3}$)
1	Alluvium (wet)	196 – 200
2	Shale	206 – 266
3	Sandstone	205 – 255
4	Limestone	260 – 280
5	Chalk	194 – 223

6	Dolomite	228 – 290
7	Anorthosite	261 – 275
8	Halite	210 – 240
9	Granite	252 – 275
10	Granodiorite	267 – 279
11	Basalt	270 – 320
12	Gabbro	285 – 312
13	Gneiss	261 – 299
14	Cassiterite	680 – 710
15	Quartzite	260 – 270
16	Amphibolite	279 – 314
17	Chromite	430 – 460
18	Pyrrhotite	450 – 480
19	Magnetite	490 – 520
20	Galena	740 – 760

Source: Glover (2013); Milsom (1996).

Table 2: Estimated constants for density-velocity relation in tau reservoir				
Constants	Lithology			
	Sand from V_p	Sand from V_s	Shale from V_p	Shale from V_s
b	0.23	0.12	0.52	0.23
n	0.27	0.24	0.45	0.30
Gardner's default: b = 0.31 and n = 0.25				
e	0.320	0.340	0.350	0.350
f	3481	1640	1595	838
Lindseth default: e = 0.308 and f = 1054				

Source: Atat *et al.* (2020).

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The Niger Delta is located (Klett *et al.*, (1997) between latitudes 3°N and 6°N; longitudes 5°E and 8°E (Reijers *et al.*, 1996). The area of study is Tau Field (Figure 1). The sediment capacity is 0.5 $\times 10^6\text{km}^3$ (Hospers, 1965) with deposit width of about 10km (Kaplan *et al.*, 1994). The Akata formation is made up of mostly marine shales; about predictable thickness of up to 0.7 $\times 10^4\text{m}$ (Doust & Omatsola, 1990). The Agbada formation is the core oil reservoir in the Niger Delta. The region experiences both wet and dry seasons.

Figure 1: Map of Africa showing the Tau Field in Niger Delta region (Source: Sam *et al.*, 2017; Atat *et al.*, 2018).

3. METHODOLOGY

Well-log data for three oil wells in the tau field were acquired. The log was conditioned, analyzed and carried out necessary cross plots using Hampson Russell Software (HRS). The HRS crossplot space figures the constants of linear regression lines to march the data. The density versus velocity curves were plotted on a cross-plot interface to determine coefficients using gamma ray as colour key. The regression line to make appropriate march with shales and sand with gamma cuff of greater than 75 API for shale was adjusted. This result was considered to obtain different density curves: first, using Gardner and Lindseth default parameters; second, by replacing Gardner and Lindseth constants with the constants of Atat *et al.*, 2020 for specific rock types in the tau field.

Considering the Gardner and Lindseth default curves (Figures 2 and 3 respectively) for the sands and shales, the coefficient determined falls within 0.31 and 0.35; the sands should be within 0.30 and 0.27. Gardner curve requires density to vary as ($2.0 < \rho_b < 2.5$) gcm^{-3} corresponding to ($1.5 \leq V_p \leq 4.5$) kms^{-1} for shales and ($2.0 < \rho_b < 2.5$) gcm^{-3} corresponding to ($2.0 \leq V_p \leq 5.0$) kms^{-1} for sandstones. Our expected outcome of density curve estimate for the two curves, show for shales, the red curve is fit through purple line; for sands, the green curve is the fit through purple line (Figures 4 and 5).

Figure 2: Gardner's empirical relationship of density versus p-wave velocity. (Source: Sheriff and Geldart, 1995).

Figure 3: Lindseth's empirical relationship of acoustic impedance versus rock velocity (Source: Potter and Stewart, 1998)

Figure 4: Log Density-Log Velocity relationships plot established for single-fit, sand and shale coefficients determination for the study using Gardner approach.

Figure 5: Impedance-Velocity relationships plot established for single-fit, sand and shale coefficients determination for the study using Lindseth's approach.

4. RESULTS

Three wells of tau Field were analyzed in this research and the results are presented in Figures 6 to 11. Density estimated from the well log data is compared to that obtained from local fit constants and Gardner and Lindseth default parameters.

Figure 6: Density estimates for well A using measured density (black curve), using Gardner default values (blue curve) and using specific values for sand and shale (Pink curves) of V_p and V_s .

Figure 7: Density estimates for well B using measured density (black curve), using Gardner default values (blue curve) and using specific values for sand and shale (Pink curves) of V_p and V_s .

Figure 8: Density estimates for well C using measured density (black curve), using Gardner default values (blue curve) and using specific values for sand and shale (Pink curves) of V_p and V_s .

Figure 9: Density estimates for well A using measured density (black curve), using Lindseth default values (blue curve) and using specific values for sand and shale (Pink curves) of V_p and V_s .

Figure 10: Density estimates for well B using measured density (black curve), using Lindseth default values (blue curve) and using specific values for sand and shale (Pink curves) of V_p and V_s .

Figure 11: Density estimates for well B using measured density (black curve), using Lindseth default values (blue curve) and using specific values for sand and shale (Pink curves) of V_p and V_s .

5. DISCUSSION

Density estimated from the well log data is compared to that obtained from local fit constants and Gardner and Lindseth default parameters. The discrepancies above are investigated using a density curves, superimposed with the original density curves (Figures 6 to 8). The plots using Gardner's relation shows that density varies with lithologies. This suggests the correlation of rock property is better when precise rock categories are investigated. Figures 6 to 8 indicate the established density-velocity curves for shales and sands are not as the unique Gardner curve (Density-G). The suitable coefficient decays toward the sand (Density sand-pink) and increases towards the shales (Density shale-pink); for Gardner's curve (Density G-blue), there is a sharp increase in density at the top. Considering shales from (V_s), the appropriate coefficients b and n are 0.23 and 0.30 respectively (Table 2); in the sands (V_s) coefficients are 0.23 and 0.12 respectively (Table 2). This results in the residual standards of 0.05 and 0.0195 for shale and sand correspondingly.

Considering Lindseth's relation, it is observed that the resulting curves (Figures 9 to 11) for shales and sands are changed from the default Lindseth's curve (Density-L). The fitting coefficient slightly drops near sand (Density sand-pink); sharply moves near the shales (Density shale-pink) and Lindseth (Density L- blue) at the top. In shales (V_s), the appropriate constants of e and f are 0.35 and 838 respectively (Table 2); in the sands (V_s), are 0.34 and 1640 respectively (Table 2). This results in the residual standards of 0.2562 and 0.176 for shale and sand correspondingly.

A density-velocity constant depend on geology when result from a good fit using sonic and density well-log information. Density is required in the identification of lithologies, pore fluids and others; it is one of the major desires in exploration, reservoir characterization and well planning. Overlap in sands and shales could show variation in petrophysical properties (porosity of fluid saturation) making density not a good indicator of lithology. These constants are non-unique for most datasets from many sedimentary basins across the world as density-velocity data would not obey the original Gardner and Lindseth curves. Modelling is necessary to evaluate the effect of these properties on density. Local examinations are compulsory to improve the accuracy of rock properties that were not captured by Gardner or Lindseth during their calibration. Moreso, the difference between the local variations and the original Gardner or Lindseth relationship may be attributed to the differences in composition of the original rock types; perhaps Niger Delta is not naturally connected to the sedimentary basins assessed by them. Constants could be achieved by modifying the coefficients for visual best fitting curves through the dataset. Well log data information shows high resistivity, indicating the hydrocarbon reservoir with less water saturation. This encourages the reason for considering these wells.

6. CONCLUSION

We have considered the coefficients for specific rock type (sand and shale) for τ Field in the Niger Delta basin using both P-wave and S-wave information from well log data. The density curves generated from default parameters differ from those of sand and shale lithologies for the field

under investigation. Gardner and Lindseth curves were strongly away from the in-situ; the constants for specific rock type improve the curves. Geology may upset these coefficients meaningfully and could result in loss of evidence if constants for local fits are not estimated before the inclusion in the density-velocity relation for reservoir characterization.

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