Petrophysics Analysis for Determination of Density Porosity and Neutron-Density Porosity on Carbonate Rock in East Java Basin

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Abstract. Indonesia has much potential in energy resources. The exploration and exploitation activities in Indonesia help to fulfill the energy needs in Indonesia. The exploration activities in Indonesia help to find the potential energy resources such oil and gas. Reservoir characterization with petrophysics can be applied to define the lithology, porosity, water saturation, and permeability the rock under the ground. One of the important aspect to define the reservoir is to understand the porosity of the target reservoir. In this paper, the author will calculate the porosity in the reservoir using petrophysics analysis with density and neutron-density. The result is the neutron-density porosity giving better result than the density porosity.

Keywords: density; neutron; petrophysics; porosity

1. Introduction
Indonesia has much potential in energy resources. The exploration and exploitation activities in Indonesia help to fulfill the energy needs in Indonesia. The exploration activities in Indonesia help to find the potential energy resources such oil and gas. Reservoir characterization with petrophysics can be applied to define the lithology, porosity, water saturation, and permeability of the rock under the ground. One of the important aspect to define the reservoir is to understand the porosity of the target reservoir.

Porosity can be determined from density log, neutron log, neutron and density log, and many other methods. The neutron porosity log on formation evaluation used to measure hydrogen index that contain in the formation. Hydrogen index of a material is defined as the partial concentration of hydrogen per unit volume relative to water. A lower number of neutron porosity is caused by a lower number of hydrogen atoms. Density porosity measures the total number of formation electrons, where a lower number of electrons is equivalent to a lower formation density, or a higher formation porosity. In this paper, author will emerge porosity from density log and porosity from neutron-density log and do the comparison for both results to define which one better for defining the porosity of target reservoir.
2. Theory

2.1. Porosity

Porosity is the ratio of void volume to total volume. There are three porosity: porosity sonic, density porosity, and neutron porosity [1]. Below the illustration sketched by author for matrix, wet clay, and pore.

![Figure 1. The Illustration of the assumption of Matrix, Wet Clay, and Pore in the Rock.](image)

Density porosity will measure bulk porosity from the formation. Density porosity ($\phi_D$) can be calculated with equation (1) using parameters: matrix density ($\rho_{ma}$), input bulk density log ($\rho_b$), wet clay volume ($V_{cl}$), wet clay density ($\rho_{cl}$), filtrate density ($\rho_{fl}$), apparent hydrocarbon density ($\rho_{HyAp}$) from hydrocarbon density calculation ($\rho_{Hy}$), flushed zone water saturation ($S_{xo}$) from water saturation ($S_{w}$) and invasion factor calculation, while neutron porosity calculated ($\phi_N$) with equation (4) using parameters: input neutron log ($\phi_{neu}$), neutron wet clay value ($NeuCl$), neutron hydrocarbon-hydrogen index ($NeuHyHI$), neutron matrix correction ($NeuMatrix$), neutron formation salinity correction ($NeuSal$), neutron excavation factor ($Exfact$).

$$\phi_D = \frac{\rho_{ma} - \rho_b - V_{cl}(\rho_{ma} - \rho_{cl})}{\rho_{ma} - (\rho_{fl} + S_{xo}) - (\rho_{HyAp} + (1 - S_{xo}))}$$  \hspace{1cm} (1)

Where,

$$S_{xo} = \frac{S_{w} + Invasion Factor}{1 + Invasion Factor}$$ \hspace{1cm} (2)

$$\rho_{HyAp} = \frac{5.5 \times \rho_{Hy} \times (4 - \rho_{Hy}) - 3}{16 - 2.5 \times \rho_{Hy}}$$ \hspace{1cm} (3)

While $\rho_{Hy}$ is the entered true downhole hydrocarbon density, $\rho_{HyAp}$ is the density tool apparent hydrocarbon density in gm/cc that can calibrate the density tool from electron density to apparent density and will be applied to the outer zone of flushed zone water saturation. Neutron porosity model are shown on the equation below.

$$\phi_N = \frac{\phi_{neu} - V_{cl} + NeuCl + NeuMatrix + Exfact + NeuSal}{S_{xo} + (1 - S_{xo}) \times NeuHyHI}$$  \hspace{1cm} (4)

Where,

$$NeuHyHI = 9 \times \rho_{hden} \frac{(4 - 2.5 \times \rho_{Hy})}{(16 - 2.5 \times \rho_{Hy})}$$ \hspace{1cm} (5)

There are two correction: Neutron formation salinity correction ($NeuSal$) and neutron matrix correction ($NeuMatrix$). The salinity correction calculated from the Neutron Tool look-up table that is defined for a particular neutron logging tool, selected with the Neu Tool Type parameter. The entry into the Look-up table will be formation porosity, flushed zone salinity, and matrix density and the result
will be an interpolation between the values in the Look-up table. The matrix type in the Look-up table will depend on the input matrix density and the Mineral Model parameter. For example, if the mineral model chosen was Sand/Dolomite and the input matrix density was 2.75 g/cc, the correction would be half way in-between Sand and Dolomite correction. The salinity correction will assume the same salinity correction for the special mineral as for the main mineral in special mineral models.

The Neutron matrix correction (NeuMatrix) on the Matrix parameters tab will be calculated from the Neutron tool look-up tables for the defined tool. The result will depend on the actual formation porosity, the input matrix density, and the mineral model. To define the overall neutron mineral response the same mixture will be used if the matrix density indicates a mixture of minerals.

Neutron-density porosity is a combination between neutron log (\(\phi_N\)) and density log (\(\phi_D\)). Neutron-density porosity (\(\phi_{ND}\)) can be calculated with equation below.

\[
\phi_{ND} = \frac{\sqrt{\phi_D^2 + \phi_N^2}}{2}
\]  

(6)

2.2. Volume of Clay
Volume of clay can be determined from single or more indicator. Gamma ray clay indicator calculate using equation (7) using gamma ray (Gr).

\[
V_{cl\text{Gr}} = \frac{Gr - Gr_{clean}}{Gr_{Clay} - Gr_{Clean}}
\]  

(7)

2.3. Water Saturation
Water saturation is the fraction of formation water in the undisturbed zone. Water Saturation can be calculated using Archie Equation below using water saturation, input resistivity (R\(t\)), Formation water resistivity (R\(w\)), cementation factor (m), and saturation exponent (n).

\[
\frac{1}{Rt} = \frac{\phi^m \times Sw^n}{a \times Rw}
\]  

(8)

3. Data and Methodology
Data on this research are log data on well that located in East Java Basin consist of Gamma Ray, Density, Neutron Porosity, Core Data, Resistivity (R\(t\)), and Formation Water Resistivity (R\(w\)).

The workflow of this research shown on the figure below. From the well data with following log used for determining the volume of clay. From the volume of clay, will be defined where the clean zone to be the area of matrix density estimation using log data. After the matrix density estimated, the result then validated with matrix density from core data. Wet clay density and wet clay neutron will determined in shale zone using log data. Water saturation will be defined using Archie Equation. When all paremeter for calculation defined, density porosity and neutron-density porosity could be calculated.
4. Result and Analysis

The formation of target on this research is “Juli” Formation where located offshore in the southwest part of East Java Basin. The “Juli” field is in Pangkah Block. The located of East Java basin is along the southeastern edge of Sundaland (Figure 3).

![Location of Pangkah PSC, Offshore East Java, North East Java basin](image)

**Figure 3.** Location of Pangkah PSC, Offshore East Java, North East Java basin [2].

The regional stratigraphy in the area of study is divided into Paleogene and Neogene sediments as the figure below. Paleogene sediment deposition is related to the rifting or tensional processes during Paleocene to Eocene time where the accommodation space was influenced by the basin configuration at
that time. Where the Neogene sediment deposition related to compressional processes where tectonically influenced by the activity of subduction zone to the south of Java Island [2].

The “Juli” Formation devided into 3 zones. Juli Zone 1 filled with shale, Juli Zone 2 filled with high density Carbonate, and Juli Zone 3 filled with Low density carbonate. In order to determine density porosity and neutron-density porosity we need to determine the parameter such as volume of clay, density matrix, and density wet clay.

4.1. Volume of Clay Calculation
In this study there are shale and carbonate area. The two lithologies can be devided using volume of clay. Volume of Clay is a fraction of the volume of clay in the formation to the total volume of the formation. Volume of clay can be determined from single or more indicator. In this study, will use the single clay indicator gamma ray to calculate the volume of clay.

Gr Clean and Gr Clay shown in Table 1 and the result of volume of clay for the well is on figure 5 below.

| Zone     | Gr Clean | Gr Clay |
|----------|----------|---------|
| Juli Zone 1 | 40       | 118     |
| Juli Zone 2 | 33       | 100     |
| Juli Zone 3 | 33       | 100     |

Figure 4. East Java regional stratigraphy [2].
4.2. Matrix Density Estimation and validation with data core
Matrix density can be estimated using crossplot of RHOB and PHI at the clean zone. The regression line for the point will be the estimate value of matrix density. In figure 6, the estimation of matrix density is 2.71 gr/cc in the clean zone at depth 4670-4671 ft. The crossplot on two other zones that are 4708-4709 ft and 5016-5017 ft and the matrix density estimation is 2.71 gr/cc too. The Matrix density data resulted from the estimation showed the similarity with the grain density from core analysis result. So, the matrix density that will be used to the porosity calculation is 2.71 gr/cc.

4.3. Wet Clay Density and Wet Clay Neutron Estimation
Wet clay density and wet clay neutron can be estimated using crossplot of RHOB and PHI at the shale zone. Wet clay density and wet clay neutron will be estimated from value of the intersection between the line from 100% porosity to the outer point of clustered data with the line from matrix density (2.71 gr/cc) to the outer point of clustered data. In figure 7, the estimation of matrix density is 2.49 gr/cc in the shale zone at depth 4633.77-4697.22 ft. Shale zone found in Juli 1 Zone 1 and two other zones are carbonate area, so wet clay density will be estimated only using this area. The wet clay density that will be used to the porosity calculation is 2.49 gr/cc and wet clay neutron value is 0.373.
4.4. Water Saturation

Water Saturation can be calculated using Archie Equation with parameters $R_w=1.2$ at temperature 180 F, the temperature gradient data applied from other well near the well used in this paper, also parameter $m=1.87$, $n=1.93$, and $n=1$ from company data. Parameters $\rho_{fl}=1.03$ and parameters $\rho_{Hy}=0.793$ from company data. Some of parameter are given by company data, some are being assumption, and some are estimated.

![Figure 7. Crossplot to estimate wet clay density and wet clay neutron at depth 4633.77-4697.22ft.](image)

![Figure 8. Density porosity Log.](image)

![Figure 9. Neutron-Density Porosity Log.](image)
After defining all the parameters for the calculation, both density porosity and neutron-density porosity could be calculated. The result of the density porosity shown in the figure 8 and neutron-density porosity shown in the figure 9. We could see that both results of density porosity and neutron-density porosity are having good correlation with the core data. Core data shown in black square, while density porosity and neutron-density porosity in blue line.

Density porosity and neutron-density porosity have been determined from the research. Almost all the core data fit with the porosity. But we could see at some depth the density porosity and neutron-density porosity have different value with core data. We know that density porosity measures porosity from the number of formation electrons, when it log into gas-filled formation, the result will be a porosity estimate that higher than the true porosity. Meanwhile the neutron porosity mainly calculated the number of hydrogen atoms in formation, that when a gas-filled formation logged, which has a lower number of hydrogen atoms than a water filled formation of the same porosity, the porosity estimate will be lower that the true porosity. These information bring to the conclusion that it is better for using both density and neutron to define the porosity of formation. By properly combining the two reasons above, it is possible to arrive more accurate porosity than would be possible by interpreting each of them separately. We could also see from the figure 8 and figure 9 that the neutron-density porosity bigger than density porosity at the Juli Zone 1 which is in carbonate rock. It may because of the bulk density in the area close to matrix density which interpreted as zone filled with matrix with low porosity. However, this proven to be difficult to have 100% porosity model that fit to data core.

From the result of neutron-density porosity model, shown that some of result have different value with the core data. Below the table showing the error from the porosity log and porosity core data. The average error from 26 core data is 0.03883 and showing the result of neutron-density porosity model having good correlation with core data.

| No | Depth | Porosity from Core Data | Porosity from Log Data | Error |
|----|-------|-------------------------|------------------------|-------|
| 1  | 4636  | 0.157                   | 0.12                   | 0.037 |
| 2  | 4650  | 0.213                   | 0.225                  | 0.012 |
| 3  | 4670  | 0.047                   | 0.0747                 | 0.0277|
| 4  | 4702  | 0.205                   | 0.159                  | 0.046 |
| 5  | 4708  | 0.195                   | 0.202                  | 0.007 |
| 6  | 4715  | 0.23                    | 0.183                  | 0.047 |
| 7  | 4727  | 0.142                   | 0.146                  | 0.004 |
| 8  | 4745  | 0.177                   | 0.163                  | 0.014 |
| 9  | 4758  | 0.148                   | 0.157                  | 0.009 |
| 10 | 4777  | 0.204                   | 0.137                  | 0.067 |
| 11 | 4794  | 0.197                   | 0.185                  | 0.012 |
| 12 | 4797  | 0.054                   | 0.163                  | 0.109 |
| 13 | 4830  | 0.266                   | 0.228                  | 0.038 |
| 14 | 4840  | 0.233                   | 0.232                  | 0.001 |
| 15 | 4848  | 0.298                   | 0.243                  | 0.055 |
| 16 | 4861  | 0.307                   | 0.289                  | 0.018 |
| 17 | 4871  | 0.317                   | 0.283                  | 0.034 |
| 18 | 4900  | 0.305                   | 0.426                  | 0.121 |
| 19 | 4919  | 0.179                   | 0.284                  | 0.105 |
| 20 | 4937  | 0.2                     | 0.217                  | 0.017 |
| 21 | 4943  | 0.321                   | 0.308                  | 0.013 |
| 22 | 4965  | 0.204                   | 0.126                  | 0.078 |
| 23 | 4976  | 0.161                   | 0.258                  | 0.097 |
| 24 | 4995  | 0.047                   | 0.038                  | 0.009 |
| 25 | 5013  | 0.217                   | 0.227                  | 0.01  |
| 26 | 5047  | 0.282                   | 0.304                  | 0.022 |
|    |       |                         |                        | 0.03883 |

Average
5. Conclusion

The results from this study can be summarized as follow,

1. Porosity can be determined from density porosity and neutron-density porosity model using log data which in this paper both density porosity and neutron-density porosity show good correlation with porosity from core data. However, we could still see at some depth, some density porosity and neutron-density porosity show different value with core data.

2. Neutron-density porosity have better result for defining porosity rather than density porosity. It may drive from the neutron log that help to do the correction to the density porosity. In this paper the neutron-density porosity has been validated with core data and has average error of 0.03883.

References

[1] Asquith G B and Gibson CR 1982 Basic Well Log Analysis for Geologists (Tulsa: The American Association of Petroleum Geologists (AAPG))

[2] D Setiawan M N Juliansyah and I W A Darma 2014 Ann. Conv. Proc. on IPA AAPG 2014 – 38th