Digital Rock Physics Applications: Visualisation Complex Pore and Porosity-Permeability Estimations of the Porous Sandstone Reservoir

Handoyo\(^1\), Fatkhan\(^2\), and Fourier DEL\(^3\)

\(^1\)Geophysics Engineering, Faculty Engineering Institut Teknologi Sumatera, Indonesia
\(^2\)Geophysics Engineering, Faculty of Mining and Petroleum Engineering Institut Teknologi Bandung, Indonesia
\(^3\)Earth Science and Complex System, Faculty of Mathematic and Natural Science Institut Teknologi Bandung, Indonesia

handoyo.geoph@tg.itera.ac.id and handoyo_1906@yahoo.com

Abstract. Reservoir rock containing oil and gas generally has high porosity and permeability. High porosity is expected to accommodate hydrocarbon fluid in large quantities and high permeability is associated with the rock’s ability to let hydrocarbon fluid flow optimally. Porosity and permeability measurement of a rock sample is usually performed in the laboratory. We estimate the porosity and permeability of sandstones digitally by using digital images from \(\mu\)CT-Scan. Advantages of the method are non-destructive and can be applied for small rock pieces also easily to construct the model. The porosity values are calculated by comparing the digital image of the pore volume to the total volume of the sandstones; while the permeability values are calculated using the Lattice Boltzmann calculations utilizing the nature of the law of conservation of mass and conservation of momentum of a particle. To determine variations of the porosity and permeability, the main sandstone samples with a dimension of 300 \(\times\) 300 \(\times\) 300 pixels are made into eight sub-cubes with a size of 150 \(\times\) 150 \(\times\) 150 pixels. Results of digital image modeling fluid flow velocity are visualized as normal velocity (streamline). Variations in value sandstone porosity vary between 0.30 to 0.38 and permeability variations in the range of 4000 mD to 6200 mD. The results of calculations show that the sandstone sample in this research is highly porous and permeable. The method combined with rock physics can be powerful tools for determining rock properties from small rock fragments.

Keyword: \(\mu\)CT-scan, sandstone, digital image, permeability, porosity

1. Introduction

Calculations of rock physical parameters can be determined using computer simulation (digital). The digital simulation is performed to model or visualize difference between the pore and the rock matrix and is used to predict the value of porosity, permeability, electrical conductivity, density, and elasticity of the rock. Digital image (3D image) rock can be obtained from scanning using the CT-Scan and combined with digital simulation software. In addition, the digital image has been applied to visualize of rocks and predict physical parameters (e.g., Arns and Knackstedt, 2012; Dvorkin et al, 2009; Handoyo et al, 2014). This paper discusses the digital simulation to visualize complex pore, pore fluid flow and predict value of porosity and permeability of reservoir sandstones that have high porosity values.
2. Theory and Method

A rock (sandstone) generally consists of two main parts: pores and rock solid matrix (Figure 1a). The pore is the space between the rock solid matrix can be filled by a fluid (liquid or gas). Other important physical parameter is permeability that is the ability of a rock to drain the fluid either liquid or gas (Figure 1b).

![Figure 1. A model clean sandstone. Figure (a) Visualization is shown by the pore spaces between rock solid matrix and Figure (b) Models fluid flow in porous rock interconnected.](image)

Quantity of rock pore is expressed by the value of porosity. Porosity ($\phi$) is the ratio between the pore volume ($V_{pore}$) of the total volume of rock ($V_{total}$) which is mathematically written as:

$$\phi = \frac{V_{pore}}{V_{total}} = 1 - \frac{V_{matrix}}{V_{total}}$$

(1)

Where ($V_{matrix}$) is the volume of the solid part of the rock. Furthermore, 3-dimensional model of sandstone samples made a cube with size $300 \times 300 \times 300$ pixels. To find variations, we created a subcube 8 units ($2^n$) with size $150 \times 150 \times 150$ pixels (Figure 2).

![Figure 2. Illustrations of 3-D sandstone model and manufacture of sub-cube variations of the main cube (modified from Dvorkin, 2009).](image)

Absolute permeability appears in Darcy's law as a constant coefficient relating fluid, flow and the porous medium parameters as follows:
\[
\frac{Q}{A} = - \frac{k}{\mu} \frac{dP}{dL}
\]  \hspace{1cm} (2)

Where \( Q \) is the fluid debit, \( A \) is surface area of pore, \( \frac{dP}{dL} \) is the gradient pressure as length function, \( k \) is absolute permeability, and \( \mu \) is the fluid viscosity. In order to calculate permeability, we simulate fluid flow using Lattice Boltzmann method that is as follows (Fourier, 2014):

\[
\frac{Q}{A} = \frac{\mu \langle v \rangle}{dP/dL}
\]  \hspace{1cm} (3)

The process of DRP begins with an image of a large rock sample acquired at a relatively coarse resolution to cover a large field of view (cube). At this stage, rock fabrics larger than the image resolution are resolved while smaller ones are unresolved (sub-cube). Information concerning the unresolved rock fabrics is analyzed from additional images acquired at a finer resolution and smaller field of view. The information from resolved and unresolved rock fabrics are averaged from small-scale image and back into the large-scale image. In general, the stage of the DRP analysis shown in Figure 3.

**Figure 3.** DRP data processing stages on sandstone sample. Stage begins with digital image processing to the calculation porosity and absolute permeability.

### 3. Result and Discussions

Results of scanning using a CT scan are shown in Figure 4. Figure 4 (a) is a natural image of the sample, and Figure 4 (b) is the result of the thresholding process with a view to separate the pores and rock solid matrix.

To determine the variation of the porosity and permeability of the sandstone samples, the main cube made into multiple sub-cube. In this study, made eight major sub-cube from main cube (Figure 5). The cubes shows that scale-factor has influence to value of porosity and permeability of digital sample. The variation shown in Figure 6a.
Figure 4. The scans using CT-Scan with dimensions of 300×300 pixels. Figure (a) shows the difference in density of solid rock matrix, where the highest density indicated by the bright white color. Figure (b) shows the color difference between the pore and solid matrix rock. Pore indicated by black, rock solid matrix is indicated by the white part (after threshold process).

Figure 5. Illustrations of 3-D sandstone model and manufacture of sub-cube variations of the main cube. (a) the sub-cube illustration (Dvorkin, 2009), (b) the main cube with size 300×300×300 pixels, and (c) sub-cubes with size 150×150×150 pixels.

Furthermore, porosity and permeability relationship is shown in Figure 6a. The value of permeability as a function porosity is as an exponential function. The calculations show a high permeability values for higher porosity. Results of digital simulation permeability values are displayed in Figure
6b. Visualization of fluid flow in the pore (streamlined) is expressed in normal velocity (blue) from Latice Boltzman equation.

![Image](image_url)

**Figure 6.** The results of digital simulation calculation of permeability values as a function of porosity (a) and model of fluid flow in porous rock (b).

4. Result and Discussions

- The digital simulations of sandstone samples using CT-Scan are able to separate pores and rock matrix.
- Calculation results show that values of porosity and permeability are relatively high.
- Factor sample size (sub-cube) gives variations of porosity and permeability values are different for each subcube.
- The method combined with rock physics can be powerful tools for determining rock properties from small rock fragments.

References

[1] Andra, H., Combaret N., Dvorkin J., Glatt E., Han J., Krzikalla F., Lee M., Madonna C., Marsh M., Mukerji T., Ricker S., Saenger E.H., Sain R., Saxena N., Wiegmann A. and Zhan X., 2012. Digital Rock Physics Benchmarks-Part I: Imaging and Segmentation. Journal Computers & Geosciences ELSEVIER 50 (2013) 25–32.

[2] Arns, C.H., Knackstedt, M.A., 2002. Computation of Linear Elastic Properties from Microtomographic Images: Methodology and Agreement Between Theory and Experiment Journal of Geophysics, Vol. 67, No. 5, 1396-1405. Australian National University. Canberra.

[3] Dvorkin, J.P., 2009. Releva nce of computational rock physics. Geophysics Journal. Geophysics Department, Stanford University. Stanford. USA.

[4] Fourier, D.E.L., 2014. Analysis of Permeability and Tortuosity of Fontainebleau Sandstone and Its Models Using Digital Rock Physics Approach. Physics of Earth and Complex System, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Indonesia.

[5] Handoyo, 2014. Digital Rock Physics Analysis to Pore Structure Parameters Characterization, Fluid Modeling and Parameter Estimation of Elasticity in Saturated Sandstone Samples. Thesis Magister. FTTM. Bandung Institute of Technology. Indonesia.