Extraction of pore networks from thin section: 
A case study from deep marine turbidite outcrop

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Abstract. A reservoir should have pores that can accommodate fluid. This capability is supported by the petrophysical properties which reservoirs have. The petrophysical properties depends on how the sediments were deposited. This study is focused on the deep marine turbidite outcrop. Turbidity currents are a sedimentation process which makes the sediments carried randomly at high velocity and low viscosity. The petrophysical properties such as porosity and permeability could be determined using computational fluid dynamics (CFD) analysis and routine core analysis. The approaches of this study are to analyze the petrophysical properties using CFD analysis and compare the results with the routine core analysis. The samples of this study were nine thin sections collected from the outcrops, especially in the middle and the edges of the turbidite channel. These samples then processed in the CFD software called COMSOL Multiphysics thus the porosity and permeability of these samples could be determined. The results show that the porosity values of the CFD analysis are relatively similar with the routine core analysis has and the permeability values of the CFD analysis are higher than the routine core analysis has.

Keywords: Pore network extraction, computational fluid dynamics, permeability, porosity, sandstone reservoir.

1. Introduction
A reservoir should have pores that can accommodate fluid. The fluid should also be able to flow through the pores. Each reservoir has different characteristics. In general, the reservoir has a porosity of around 20–30 %. The porosity value also depends on the characteristics of the pores in the reservoir. Pores could have a small or large space and could be simple or complex. The pore space is defined by a network of pores in the rock [1].

Sandstone is one of the reservoirs that is often found. It is believed that, no matter how old the sandstone reservoir is, the sandstone could be a good reservoir. However, in general, between young and old reservoirs, younger reservoirs are the one with the best characteristics. Sandstone reservoirs could be formed in a variety of depositional environments, such as delta, alluvial fan, submarine fan. Reservoir characteristics such as geometry, texture, and sedimentary structure are affected by this depositional environment [1].

This study is focused on the analogue of a sandstone turbidite outcrop. Turbidity currents or sedimentations are a sedimentation processes which make the fluid transported randomly and carry the
sediment at high velocity and low viscosity resulting poorly sorted sediment deposits [2]. Outcrops of turbidite deposits are also characterized by Bouma Sequences [3].

By using thin sections from several rock samples collected from turbidite outcrops located in Citereup, West Java, precisely at coordinates 6° 31.670’ S, 106° 55.778’ E, the pore network will be discovered in 2D and thus its size and complexity can be identified [4]. If the pore size and complexity can be identified, the petrophysical properties of hydrocarbon reservoirs such as porosity and permeability can be determined by computational fluid dynamics software. The hypothesis of this study was the porosity and permeability values which CFD produces could be similar with the values that routine core analysis produces and could be used to determine the petrophysical properties of the deep marine turbidite outcrop. Routine Core Analysis is a programme which involves fluid saturations, porosity, and permeability measurements on core plugs by using a specific pressure. These measurements can be done by injecting single-phase fluids on dry core plug [5]. The approaches of this study are to analyse the petrophysical properties using CFD analysis and compare the results with the routine core analysis.

2. Data and method

This study used nine sandstones samples whose grain size are very fine. All samples were taken from the same outcrop, which is a turbidite channel outcrop from the part of the Jatiluhur Formation (Tmj), Citereup, West Java. In general, the sandstones at Jatiluhur Formation (Tmj) are very fine to very coarse-grained and interbedded with bioturbated siltstones [3] These samples were taken from the edges and the middle of the channel to find out the different properties of these two parts. In the middle part of the channel, three samples were taken, such as the top, the middle and the bottom (figure 1). These samples were processed into thin sections and also analysed using routine core analysis using helium gas as the single-phase fluid. Blue dyed resin is also added to the thin sections thus the pore networks of the samples could be distinguished. Pores were observed using a microscope which images were then taken from each sample. The images from each sample were then analysed using software called COMSOL Multiphysics.

COMSOL Multiphysics is a software that can be used for modelling, such as the pattern of the structural mechanics, the flow of the fluid, acoustics, chemical engineering, heat transfer, and electromagnetics behaviour [6]. This software is one of the computational fluid dynamics software. Computational fluid dynamics or CFD software is a software which is used to solve and analyse numerical problems in fluid flow. In this study, the software was used to model the fluid flow in samples that could be useful to determine the value of porosity and permeability. Velocity and mass flow of the pores could be modeled by using Navier-Stokes equation 1 and also with setting up the fluid properties, such as density, dynamic viscosity, and the given pressure. Thus the velocity can be used to solve permeability in Darcy’s Law equation 2.

\[ \nabla \cdot \mathbf{u} = 0 \]

In equation 1, the pressure, the dynamic viscosity and the velocity field are represented by \( p \), \( \mu \) and \( \mathbf{u} \) respectively.

Before the analysis, images from thin sections were digitized using the third-party software, such as CorelDRAW and AutoCAD and saved those digitized images as Drawing Exchange Format (DXF) format which were then imported into COMSOL in form of a geometry. All images were scaled down to 2.87 × 1.61 mm thus had their actual scales (figure 2a).
Figure 1. The location and the sketch of the outcrop and the point where the samples were taken.

Figure 2. (a) The example of thin section from sample A2. (b) The example of the computed velocity in sample A2 by using COMSOL Multiphysics.
Boundaries were set on the geometry model into 4 boundaries, such as inlet, outlet, symmetry and wall. The left side of the geometry model is an inlet where the given pressure is 7.15 Pa and the right part of the model is an outlet where the given pressure is 0 Pa. The top and the bottom were set as a symmetry boundary and the rock matrix are defined as wall or a no slip boundary. Then, the geometry which the boundaries were set was processed to produce a mesh. After the mesh was produced, the velocity which pass through the pores could be computed (figure 2b).

To determine permeability, this modelling used an equation known as Darcy’s Law. According to Darcy, permeability can be measured mathematically at the pore fluid flow [7]. Darcy’s equation is very suitable for determining permeability in models with slow fluid flow of the Newtonian fluids such as water with laminar flow [8].

\[
Q = \frac{kA\Delta p}{\mu L}
\]

\[
\kappa = \frac{Q\mu L}{\Delta p A}
\]

\[
\kappa = \frac{Av\mu L}{\Delta p A}
\]

\[
\kappa = \frac{v\mu L}{\Delta p}
\]

In equation 2, the permeability, the dynamic viscosity, the pressure, the volumetric flow rate, the length of the medium, and the cross-sectional area of the flow are represented by \(k\), \(\mu\), \(p\), \(Q\), \(L\) and \(A\) respectively.

Porosity is determined by dividing the area of the pore to the total area. In COMSOL, the area of the pore can also be known easily by using certain expressions and dividing it by the total area (equation 3).

\[
\varphi = \frac{A_p}{A_T}
\]

In equation 3, \(\varphi\) is the porosity, \(A_p\) is the pore area and \(A_T\) is the total area.

3. Results and discussion

As it can be seen, the results of 9 samples for various porosity and permeability values which are produced by COMSOL Multiphysics (CFD analysis) and the routine core analysis were summarized in table 1. Routine core analysis shows that samples A have porosity value much higher than porosity value which samples B have. As it was expected, CFD analysis porosity values show the similar comparison between samples A and B, but samples A and B1 in the CFD analysis have porosity values much higher than the porosity values which routine core analysis produced as shown in figure 3a.

The comparison between permeability values which CFD analysis and routine core analysis produced is also shown in table 1. Both analyses showed that permeability value of samples A is higher than samples B have. However, in the other hand, permeability values which COMSOL produced have many times higher than routine core analysis produced as shown in figure 3b. These were caused by the images taken from the thin sections were captured only in the connected pores to...
find the permeability values thus the other parts which pores are not connected were not analyzed. This thin section is not unrepresentative about calculating permeability. It is just about the scale of the thin section which is small thus not all parts of the rock could be captured.

These thin sections which were taken for CFD analysis are just 2.87 × 1.61 mm in dimension and it was only the connected pores that were used to analyze the permeability. When the upscaling permeability is done to represent one sandstone turbidite outcrop, these values will not represent the outcrop certainly. But, with the thin section cost that is inexpensive, the thin sections sampling could be multiplied and the CFD analysis of each samples could be done more, thus the upscaling could be more certain. Moreover, the time that was consumed to do CFD analysis is just for a moment. Compare with the routine core analysis, the routine core analysis used the core plug to identify the permeability value. The core plug is also a small part of the outcrop thus, same as CFD analyses, does not represent one outcrop certainly. But the core plug is more certain than thin section because the dimension of the core plug is larger than thin section. Other than that, routine core analysis spent a lot of time and costs. Therefore, in the oil and gas industry, doing CFD analysis from drill cutting thin sections could be faster and cheaper than using routine core analysis.

Table 1. Comparison of porosity and permeability in computational fluid dynamics analysis and routine core analysis.

| No. | CFD analysis (COMSOL Multiphysics) | Routine core analysis (@300 psi) |
|-----|-----------------------------------|---------------------------------|
|     | Porosity (%) | Permeability (mD) | Porosity (%) | Permeability (mD) |
| A1  | 61.724       | 6.39×10⁵     | 11.93        | 5.46×10²     |
| A2  | 65.151       | 7.05×10⁴     | 11.90        | 3.43×10¹     |
| A3  | 24.476       | 3.66×10⁴     | 11.11        | 1.79×10¹     |
| A4  | 47.946       | 3.72×10⁶     | 12.97        | 5.05×10²     |
| B1  | 22.44        | 1.13×10³     | 5.43         | 1.92×10²     |
| B2  | 5.7992       | 3.51×10²     | 5.18         | 3.17×10²     |
| B3  | 8.1476       | 7.30×10²     | 5.89         | 5.22×10²     |
| B4  | 3.6465       | 4.01×10²     | 8.37         | 6.95×10²     |
| B5  | 9.2924       | 1.33×10⁴     | 4.96         | 3.04×10²     |

Figure 3. (a) Comparison of porosity value in CFD analysis and routine core analysis. (b) Comparison of permeability value in CFD and routine core analysis.
4. Conclusion
The porosity and permeability value had been studied in both analyses which are computational fluid
dynamics (CFD) analysis and routine core analysis. Porosity and permeability value in which both
analyses produced showed a similar comparison between samples A and samples B. Samples A
showed a higher value of porosity and permeability rather than samples B. The differences between
these analyses are the permeability values which CFD analysis produced are higher than the routine
core analysis produced and the porosity values of samples A which CFD analysis produced have also a
higher value than the routine core analysis produce. It is caused by the scale of the samples of both
analyses which contains uncertainty to represent one large sandstone turbidite outcrop. Therefore,
further studies should be done to make the results more accurate.

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