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Petrophysics and rock physics using VTI model for low permeability and high porosity reservoir in CCS Gundih gas field pilot project, Indonesia

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Abstract. A pilot Carbon Capture and Storage (CCS) project in Indonesia is planned to be implemented in Gundih area, Central Java Province in Indonesia. Prior to conducting CO_2 injection, reservoir characterisations have to study thoroughly to assure that the reservoir is to meet with CCS standard requirements. The Jepon well in the Gundih fied was proposed as a suitable site for CO_2 injection. The decision was made to proceed with a comprehensive site assessment and geological modelling of the Jepon area. This site was selected based on the reason the presence of a potentially suitable reservoir (Ngrayong Sandstone) and primary and secondary seals (Bulu Limestone and Wonocolo claystone). Using logging data, petrophysics and rock physics model are used to evaluate potential of the CO2 injection site. Permeability results from petrophysics calculations and recent injection tests show very small; whilst porosity is relatively high. This can be caused by fractures mostly are not connected. Hence, rock physics for the reservoir is evaluated and modelled as anisotropy or Vertical Tranverse Isotropy (VTI) in which fractures with preferred orientation. Stiffness calculations for VTI medium with different aspect ratio shows consistent with low permeability result.

1. Introduction

Fossil fuel exploitations often cause CO_2 emission in the atmosphere. Carbon Capture and Storage (CCS) is one of methods recently developed to reduce amount of CO_2 emission. The CCS method consists of activities, such as capturing CO_2 molecules, transporting CO_2 and storing CO_2 into subsurface formation. The subsurface formation is one of alternative solutions for the storage of CO_2.

Storage capacity of reservoir must be calculated in order to put CO_2 and also to reduce risk factors. The risk factor is because CO_2 injection process has possibility to leakage to the underground water. This, in turn, can impact environmental hazards. Therefore, properties of reservoir rocks such as porosity and permeability are important factors dealing with injection process. A phenomenon of the CO_2 leakage can occur in both during injection and post-injection processes. Problems arise due to the fact that the injection process can alter reservoir pore pressure and temperature conditions. Increasing pore pressure due to CO_2 injection can induce to a decrease of effective stress for both reservoir rocks

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and surrounding rocks. This can disturb the stress condition of the reservoir. These will affect the hydraulic properties of rocks, such as porosity, permeability capillary pressure.

We attempt to calculate and model petrophysics and rock physics process for "Gundih CCS project" in Indonesia. Gundih CCS project, if successfully run, can be regarded as the first CCS pilot project in Indonesia. The project is devoted for research and development of CCS technologies. In line with that, Indonesian's government has also a plan to reduce CO_2 more than 20% by 2020 [1]. One of many technologies developed to reduce CO_2 emission in the atmosphere is by injecting CO_2 into subsurface formation. Hopefully, it can be successfully implemented in Gundih gas field, Central Java [1,2,3].

Figure 1 shows Java map in which Gundih gas field that is located at the surround of the east Java basin [2]. A fault can be seen in surrounding area which is extended from NE to SW around the Gundih gas field [3]. The fault has a potential impact to CO_2 fluid injection process. Finding from geological studies concludes that Ngrayong Formation is the most possible candidate to be the storage formation. Hence, the CO_2 fluid is planned to put into Ngrayong formation at the depth around 800 m. Based on theoretical calculations, at the depth regarding to the temperature and pressure condition CO_2 fluid should be in supercritical condition [2]. A strong heterogeneity of hydrological and physical properties of the Ngrayong formation is observed between northern and southern region. Wonocolo formation is shallower than Ngrayong formation and the rock samples obtained from this lithology have low permeability [4] (see Figure 2). Hence, this is considered as a seal layer.

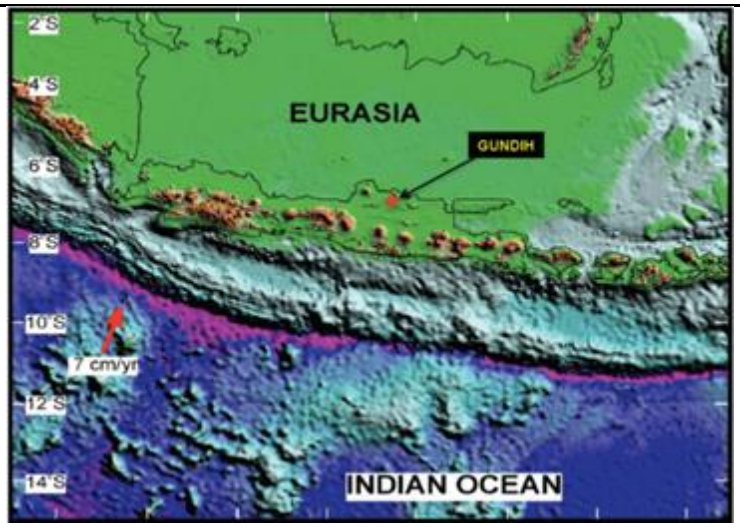


Figure 1. Location map of Gundih Field, Indonesia [4]

Finding preliminary study of GGR (Geology-Geophysics and Reservoir) by ITB-SATREPS-Pertamina shows that the Jepon-1 well is the most reliable candidate for CO_2 injection. The decision was made to proceed with a comprehensive site assessment and geological modelling of Jepon area. This site was selected based on the reason the presence of a potentially suitable reservoir (>800 m; Miocene Ngrayong Sandstone) and primary and secondary seals (Intraformational of Ngrayong, Middle Miocene Bulu Limestone and Late Miocene Wonocolo claystone). The Jepon-1 well was drilled (TD: 1518 m) in order to determine the vertical stratigraphy. The reservoir and seal also investigated based on wireline logs interpretation and the geological and sidewall core sections. One of many reasons is from the sidewall core samples showing that the Ngrayong sandstones intersected by this borehole are well sorted. Then to choose a candidate zone for CO_2 injection in the Jepon-1 well, log data were analyzed to determine petrophysical and rock physics characteristics. At last the result is used to give recommendation the zone for CO_2 injection.

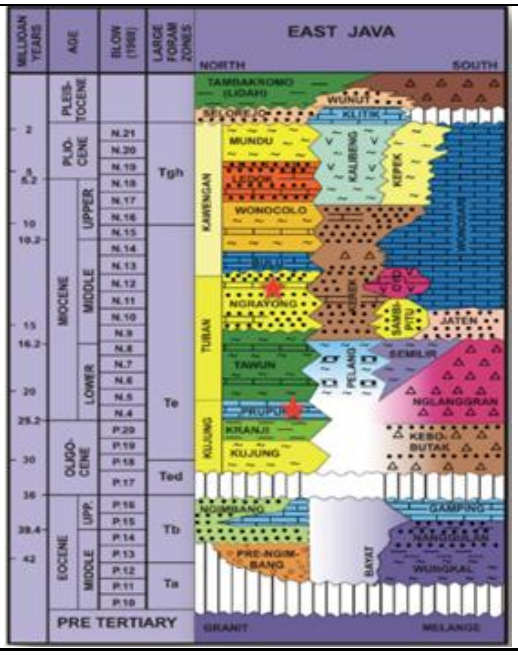


Figure 2. Lithology and Formations East Java Basin [4]

2. Petrophysics

2.1. Core analysis

Core analysis from Ngrayong sandstone member shows a correlation between measured porosity and horizontal permeability. As seen in **Figure 3** log data from the Jepon-1 well show slightly lower porosity-permeability trend-line that are compared to data from Ngrayong sandstone member at Gundih. **Figure 4** shows cross plots between porosity versus permeability. This suggests that for a given porosity, permeability is very low at Jepon.

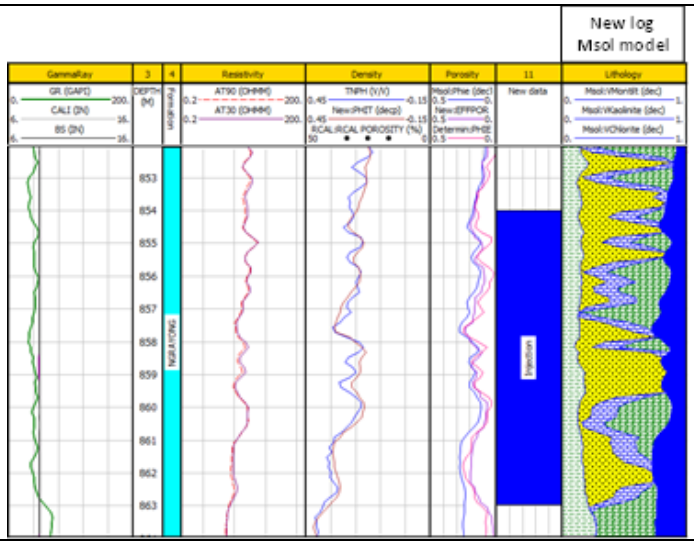


Figure 3. Log data from the Jepon-1 well consists of gamma ray, depth, resistivity, density and porosity.

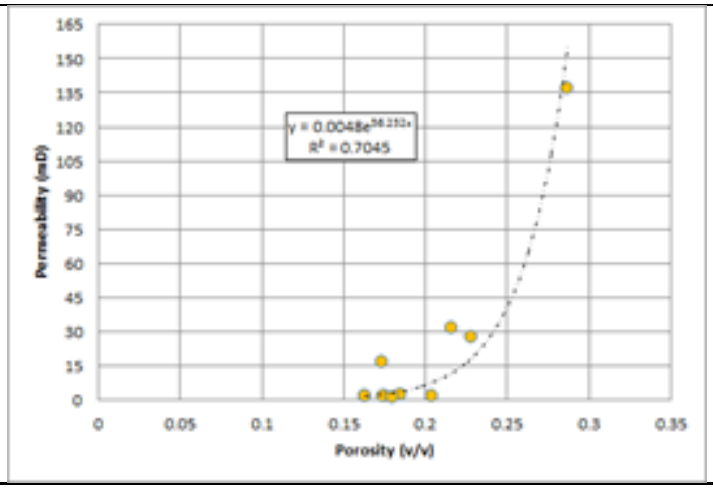


Figure 4. Crossplot porosity versus horizontal permeability from test data in the Jepon-1 well

2.2. Petrophysical analysis

Petrophysical analysis was performed to obtain reservoir properties, such as clay volume, reservoir porosity, and water saturation. The analysis is available for Ngrayong sandstone member in which penetrated in most well completion reports. Interpretations have been independently undertaken using different software and a range of different cut-off values. However, study of the Jepon-1 well is available and these provide much more consistent approaches to determin and multimin petrophysical interpretation. Before the petrophysical analysis was conducted, borehole condition of the Jepon-1well was identified using caliper and bit size logs and no problem was encountered in Ngrayong Formation.

Results of Mineral Solver were validated with XRD and RCAL data. Multimineral method shows that at range of 904-906 m maximum volume of quartz could reach 3% and 6.8% for lime and 73% for dolomite. New log data show quite similar numbers which are 3% for quartz, 19% for lime, and 78% for dolomite. These results are fit to XRD results which shows quartz constitution of 4%, lime of 20%, and dolomite of 70%. Porosity results fit with porosity from RCAL data. Therefore, this study concludes that the multimineral approach is reliable. The new log data comprises of gamma ray and porosity logs and covers only the upper part of Ngrayong Formation which is from the depth of 500-940.6 m.

Petrophysical review of Ngrayong sandstone member undertaken for Gundih CCS project had primary objectives of identifying porosity and permeability trends and investigating hydrocarbon saturations. Petrophysical analysis was undertaken using Paradigm's software, an optimizing petrophysical package. Net sand and net pay were determined in each well over the defined sand intervals using the following cut-offs:

- Porosity – 16%,
- VClay – 40% total,
- Water saturation – 55%.

Porosity derived from the neutron density logs demonstrated the most consistent accuracy with core data and is used to generate net gross value (see Figure 5).

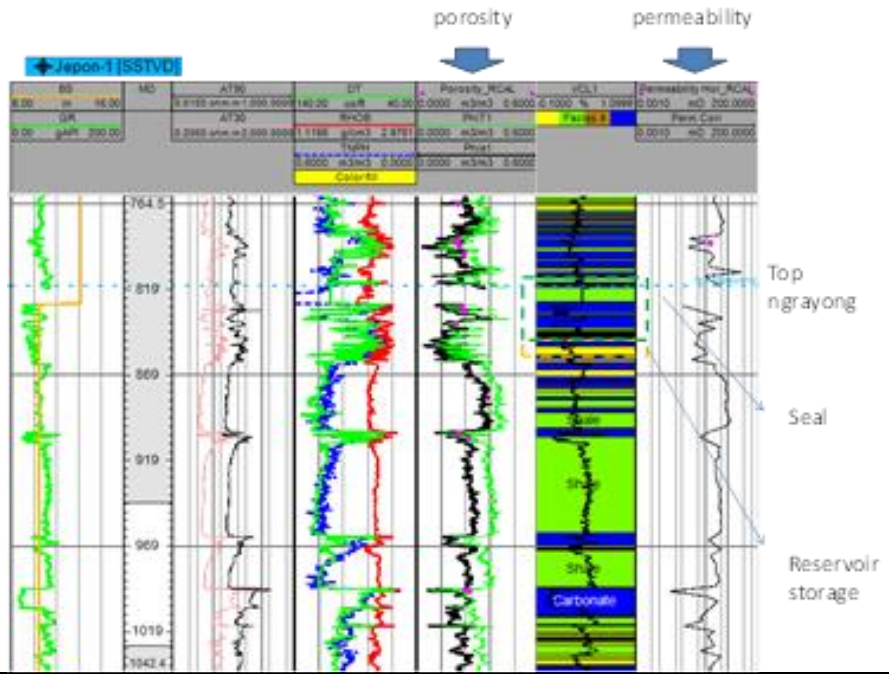


Figure 5. The Jepon-1 well section completion with GR, resistivity, density, lithology, added with result of porosity and permeability log.

3. Modelling of Rock Physics

A medium is called anisotropic if a certain physical parameter, such as permeability, velocity or resistivity, changes with the direction of measurement. In the case of seismic anisotropy, it is assumed that at least wave velocity changes with direction of propagation. There are several assumptions regarding wave propagation in an anisotropy medium containing fractures. For instance, fractures are invariant with respect to rotation about the axis normal to the fracture direction that can be seen as Vertical Tranverse Isotropy (VTI) [5]. Figure 6 shows the anisotropy model of Vertical Tranverse Isotropy.

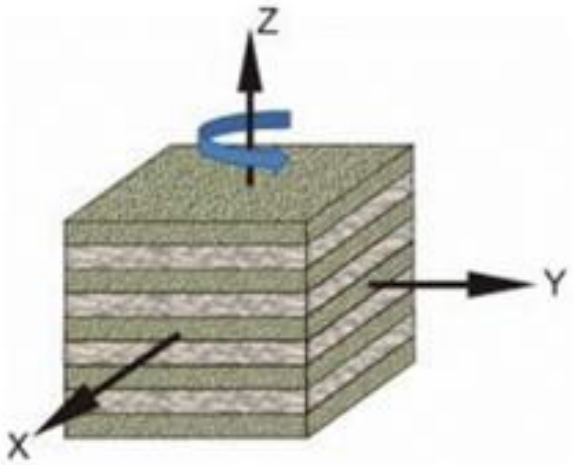


Figure 6. The anisotropy model of Vertical Tranverse Isotropy(VTI)

The first step is to determine effective elastic constants having similar variations of properties as a fractured material. There are several methods to generate equivalent elastic constants for fractured media. The methods, at least, can be divided into two equivalent models: the linear slip model of Schoenberg [6] (1980), and the penny-shaped crack model of Hudson [7].

The first model is proposed by Schoenberg (1980). He modelled fractures as thin infinite parallel planes, highly compliant, non-rigid layers embedded in solid host rock, whilst shape and microstructure are not considered. The linear slip model is valid for the long wavelength limit. However, in small wavelength limit reflections and transmissions can occur at every fracture that can be dispersive. The dispersive effect is not accounted for. Schoenberg and Muir [8] developed a calculus that simplifies the combination of the effects of layering and fracturing.

The second model is Hudson's theory [7] in which fractures are seen as plane distributions of small isolated cracks. It is assumed that the space between two fractures is tiny compared with the wavelength used. In addition, there is almost no interaction between the fractures. We use Hudson's model for fluid or dry ellipsoidal inclusions to calculate elastic anisotropy parameters.

Hudson derives the first order perturbations for penny-shaped cracks orthogonal to the x_1-axis:

$$C^1_{mn} = -\frac{e}{\mu}\begin{bmatrix} (\lambda+2\mu)^2 U_{11} & \lambda(\lambda+2\mu)U_{11} & \lambda(\lambda+2\mu)U_{11} & 0 & 0 & 0 \\ \lambda(\lambda+2\mu)U_{11} & \lambda^2 U_{11} & \lambda^2 U_{11} & 0 & 0 & 0 \\ \lambda(\lambda+2\mu)U_{11} & \lambda^2 U_{11} & \lambda^2 U_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu^2 U_{33} & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu^2 U_{33} \end{bmatrix} \quad ...(3)$$

where: $U_{11} = \frac{16}{3}\left(\frac{\lambda+2\mu}{3\lambda+4\mu}\right)\left(\frac{1}{1+M}\right)$

$$M = \frac{4}{\pi}\left(\frac{a\mu'}{c\mu}\right)\left(\frac{\lambda+2\mu}{3\lambda+4\mu}\right)$$

$$K = \left(\frac{\left(\kappa'+\frac{4}{3}\mu'\right)a}{c\pi\mu}\right)\left(\frac{\lambda+2\mu}{3\lambda+4\mu}\right)$$

where κ' and μ' : the bulk and shear moduli of the inclusion material
κ and μ : the bulk and shear moduli of the uncracked matrix.

The parameters U_{11} and U_{33} are dimensionless quantities, relying upon infill parameters.

Table 1 displays physical properties of formations in Gundih Field used to calculate the model. This table is obtained from petrophysics results that are used as input for rock physics models. Based on Hudson's derivations, the models assume fractures that induce anisotropy. Figure 7 and 8 show cross plot tensor component versus porosity with different aspect ratios. It can be seen from the Figures that anisotropy parameters is high when aspect ratio is low.

Table 1. Physical properties obtained from petrophysics results used to calculate rock physics models.

Lithology	Thickness	Avg Vclay	Effectif Porosity (%)	Total Porosity (%)	Sw	Perm (mD)
Sandstone (reservoir storage)	6.2 m	0.26	16 %	20 %	1	0.8
Sand, Shale & Carbonate (seal)	38 m	0.35	12 %	17 %	0.9	1.74

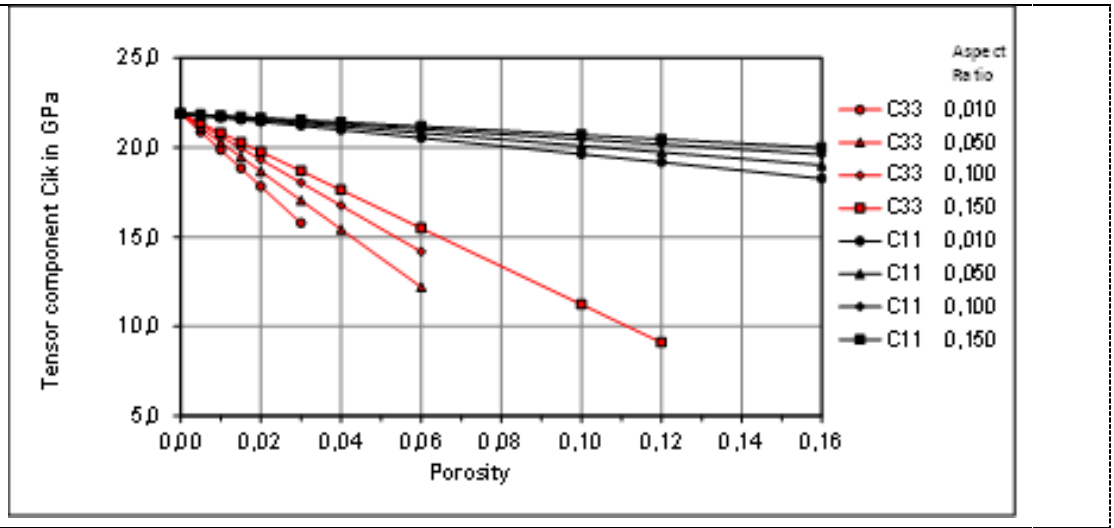


Figure 7. Crossplot tensor component (C11 and C33) versus porosity with different aspect ratios.

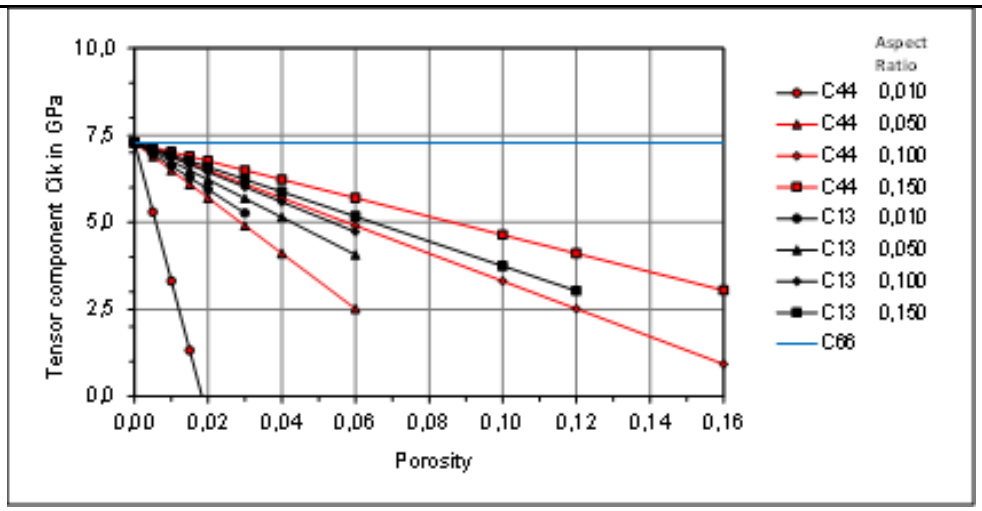


Figure 8. Crossplot tensor component (C44, C66 and C13) versus porosity with different aspect ratios.

4. Discussions

Middle – Late Miocene reservoir of Ngrayong sandstone is one of the successfully explored formations in onshore East Java. In addition, it is considerable potential for storage of CO2 in depleted or near depleted oil/gas fields. According to (Sapiie et.al, 2015), sandstone quality in the Jepon-1 well is characterized with thin, "not to clean" sand, finer grain size, very pervasive carbonate cement and not deep depositional environment with good porosity.

There are several factors that are generally considered favorable for CCS. For instance, CO2 storage is thought to be the best in a reservoir with high porosity (to allow maximum storage), moderate permeability (not high, which would promote rapid CO2 migration), high pressure and low salinity, not to deep burial depths (due to cost implications), structural closure, high vertical heterogeneity (to allow slow CO2 migration and thereby enhance residual, dissolution and mineral trapping) and a thick regional seal. However, very low permeability values in reservoir storage was very big issue for injection. Therefore, creating additional fractures surrounding area need to be done in the terms of well engineering method to make improvement of injectivity. Hence, we consider reservoir rocks as fractures induced anisotropy using Hudson models.

5. Conclusions

Significant findings can be pointed out in this study are:

- Ngrayong sandstone is considered as potential for storage of CO2 since it is depleted or near depleted oil/gas fields. However, carefully our study shows that Ngrayong is not too clean sand with carbonate cement.
- Petrophysical parameters obtained from log data show that reservoir and seal rocks have good porosity and very low permeability. Hence, we model rocks as fractures induced anisotropy that is Vertical Tranverse Isotropy (VTI).
- Rock physics models show that fractures and low aspect ratios can causes anisotropy.
- Since the reservoir is very low permeability, defracturing method is suggested to create additional fractures to make improvement of connectivity.

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