Rock physics modelling based on Voigt-Reuss and cement contact theory method at sand reservoir “FRR” field, Kutai Basin

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Abstract. There has been studied of the rock physics modelling in sand reservoir based on Voigt-Reuss and cement contact theory method case study at FRR field Kutai Basin. The objective of this study to modelling rock physics based on Voigt-Reuss and cement contact theory from geological information. Voigt-Reuss bounds model and cement contact was applied. This method related link between geological information and seismic properties. The data used in FRR field Kutai basin has the sandstone majority marked by 20 % P wave velocity. The results obtained by rock physics modelling shown modulus bulk to porosity has pattern close to lower bounds, that is existence the pore type has soft characterize and decrease bulk modulus with increase clay content and fluid saturation. The results show correlation between bulk modulus estimation and log data have good correlation. This suggests that Voigt-Reuss and cement contact theory model useful for bulk modulus estimation in sand reservoir.

Keywords: Rock physics, cement contact theory, Voigt-Reuss, Gassman model

1. Introduction
Rock physics models are used to estimated seismic properties from the observed petrophysical and reservoir properties [1]. Reservoir parameters such as clay content, sorting, lithology, porosity and water saturation. Seismic properties such as ratio Vp to Vs, density and elastic moduli. Both of parameters connected by rock physics to identify reservoir rock, source rock and caprock [2]. The objective this research to modelling rock physics parameters especially bulk modulus used of Voigt-Reuss bound and cement contact theory method. Gassman fluid substitution has been applied for characterized 100 % fluid in the pore of rock. Therefore, in this paper has been made rock-physics model of modulus bulk and porosity with pure water and gas in the pore from geological information.

2. Method
This research based on rock physics modelling in sand reservoir based on Voigt-Reuss and cement contact theory case study FRR field Kutai Basin by simulation code. Rock physics modelling is done using three following steps.
2.1. Elastic modulus solid rock by Voigt-Reuss
The estimation of the solid rock elastic modulus usually uses the Voigt and Reuss method to model solid rocks to obtain bulk modulus and shear modulus [3] values. Voigt bulk modulus ($M_v$) determined by multiplying the bulk modulus fraction component ($K_i$) and its volume ($V_i$). While, Reuss bulk modulus ($M_r$) determined by dividing the volume fraction ($V_i$) and bulk modulus fraction ($K_i$). Voigt and Reuss equations can be seen in equation 1 and equation 2.

$$K_v = \sum_{i=n}^n V_i.K_i$$  \hspace{1cm} (1)

$$K_r = \sum_{i=n}^n \frac{V_i}{K_i}$$  \hspace{1cm} (2)

2.2. Cement contact theory estimation
Elastic modulus estimation using cement contact theory modelled rocks that decreased their porosity values because they were partially closed by cementation. This estimate developed by Dvorkin [4]. So that it has its own equations and usually combined with the Walpole hashin shriktman equation as the determination of its upper bound [5]. These equations consist of bulk modulus ($K_{CT}$) and shear modulus ($\mu_{CT}$) of contact cement theory. These equations can be seen in equation 3 and equation 4.

$$K_{CT} = \frac{1}{6} (1-0) M_c . S_n$$  \hspace{1cm} (3)

$$\mu_{CT} = \frac{3}{5} K_{CT} + \frac{3 C_o (1 - o)}{20} U_r . S_n$$  \hspace{1cm} (4)

2.3. Gassman estimation
Gassman theory is a theory that often used in approaches to fluid substitution. The Gassman equation relates the saturated bulk modulus of the rock to the porosity, the fluid bulk modulus, the matrix and mineral bulk modulus. Can be mathematically written as equation 5 [6].

$$K_{sat} = k + \frac{1 - K}{K_f + \frac{1 - \frac{K}{K_o} + \frac{K}{K_o}}{K}}$$ \hspace{1cm} (5)

3. Results and discussion
3.1. Log data
Figure 1 show the log data ‘FRR’ field, Kutai Basin. Based on figure 1 target zone in this study at a depth above 2300–2350. This target zone is a formation of a stiff sand (consolidated sand). As mentioned before, in this study using well "FRR" at Kutai Basin. The FRR well used in the study as a modeling validation to be made. If the crossplot results between the elastic modulus of the synthetic data and the field data fit each other than the modeling is sufficiently accurate to estimate the elastic modulus value of each other well.
3.2. Elastic modulus solid rock

Voigt-Reuss modelling is used to estimate solid rock. In this case solid rock used quartz. Model parameter used is bulk modulus value from quartz solid rock 37.9, water 0.08 then in overlay based on value in log. Modeling patterns illustrate the plot of the bulk modulus to the porosity of the well close to the lower bounds. The results of this model can be seen in figure 2.

Based on figure 2 we can see illustrate the plot of the bulk modulus to the porosity with Voigt-Reuss model. This model has patterns well close to the lower bounds. It indicates at pore types tend to have soft cracks properties.

![Figure 1. Log data at FRR field, Kutai Basin. Red rectangle is interest zone](image1)

![Figure 2. Modulus bulk to porosity by Voigt and Reuss model.](image2)
3.3. Elastic modulus based on CCT and Gassman estimation

Further modelling are bulk modulus and shear modulus to porosity-based contact cement theory, this model used content clay variation with addition process from 0–100 % range 20 %. Model parameters used are the bulk modulus of quartz 37.9, shear modulus of quartz 44.3 and clay 9. Modelling is done by matching synthetic data (quartz rock) with log data. The purpose of modelling is to see the estimation of the elastic modulus of a rock in which the rock is filled with a matrix but there is no fluid in its pore. This estimate will be the upper bound while the lower limit uses Walpole Hashin-Shtrikman from the same data. The result of modelling can be seen in figure 3.

Based on figure 3 modelling patterns illustrate the bulk and shear modulus to the porosity plot for matching with field data. The trend between bulk and shear modulus curve with distribution of log data correlated. Major of distributed log data is between cement contact theory curve and only a few are outside or uncorrelated. From elastic modulus curve above. Can be made 3D cube using slice feature with information x axis is porosity, y axis saturation in pore (water until gas), and z axis is clay composition. This is model forward constraint cubes. This is can be info for appropriate rock physics model for reservoir characterization, as seen in figure 4.

![Figure 3](image1.png)

(a) Bulk modulus and (b) Shear modulus to porosity plot.

![Figure 4](image2.png)

(a) 3D cube model of (a) Bulk modulus, (b) Shear modulus, and (c) Density with variation clay composition (0–100 %).
Figure 4 (continued). 3D cube model of (a) Bulk modulus, (b) Shear modulus, and (c) Density with variation clay composition (0–100 %).

Figure 5. Correlation between (a) Vp, (b) Vs, and (c) Density of estimation and log data.

Based on figure 4, we can be analysis from the color, red color are high value of bulk and shear modulus when low porosity and clay content. The higher porosity value and clay content will decrease the bulk and shear modulus. While, based on figure 5 we can determine correlation coefficient between
estimation and log data. The trend show that correlation $V_p(R1) = 0.2545$, $V_s(R2) = 0.6342$, Density 
(R3) = 0.9616.

4. Conclusion
In this study, we can concluded that rock physics model used Voigt-Reuss and cement contact theory 
model can estimate elastic modulus to porosity based on addition clay content variation and fluid 
saturation in the pore also type pore close to upper bound or lower bound. Rock physics modelling can 
be applied with Voigt-Reuss and cement contact theory model in the sand reservoir. Bulk modulus will 
be decrease with increasing clay content and fluid saturation.

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