Elastic Property Modeling, Extended Elastic Impedance (EEI) and Curve-Pseudo Elastic Impedance (CPEI) Inversion for Pore Type Analysis and Hydrocarbon Distribution in Carbonate Reservoir, Kujung I Formation, "Humaira" Field, North East Java Basin

I N Kumalasari* and I S Winardhi

1Sumatera Institute of Technology, Lampung, Indonesia
2Exploration and Engineering Seismology Research Group, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology, Bandung, Indonesia

*Corresponding author’s email: istinrulkumalasari@gmail.com

Abstract. The complexity of the pore shape in carbonate rocks causes the need for a special strategy to characterize carbonate reservoir. The more information used, the more accurate the reservoir characterization will be. Pore type analysis is the important study because it relates to the fluid flow properties. The elastic property modeling show a good match to the actual data. The results of the well log and petrophysical data analysis show that the gas zone is located at the upper side of Kujung I Formation. Based on rock physics modeling result, the possible pore type developing in the Kujung I Formation is reference pore with the dominance of the aspect ratio value of about 0.17-0.19. The carbonate layer containing hydrocarbons is characterized by low Lamda-Rho, Lamda/Mu values and a low Poisson ratio. Porous carbonate layer, characterized by a low Mu-Rho value. The slice results show that the gaseous area is located on the anticline. The zone that has good porosity indicated by low Mu-Rho. In the IN-3 well there are no hydrocarbons, this analysis is in accordance with the geological condition of the IN-3 well which is in a low area on the time structure map. The inversion results show a good match between CPEI against water saturation log and CPEI against porosity log.

1. Introduction
Apart from sandstone reservoirs, oil and gas production in the world is also largely produced from carbonate reservoirs. The complexity of the pore shape in carbonate rocks causes the need for a special strategy to characterize this reservoir. The accuracy in characterizing the reservoir depends on how much information or data we use. The integration of available data will increase the accuracy of obtaining reservoir characterization [1]. The diagenesis process causes heterogeneity in the pores of carbonate rocks. Based on laboratory measurements, variations in pore shape in carbonate rocks cause the relationship between velocity and porosity to become scatter [2]. Pore type analysis is important for well production studies (fluid flow). The aspect ratio is a parameter that represents the pore shape of the rock. The intensive cementation and diagenesis processes cause carbonate rocks to have more complex pore shape variations. In rock physics, the pore types of carbonate rocks are divided into three, namely soft pore (i.e., microporosity and crack), reference pore (i.e., interparticle), and stiff pore (i.e., vuggy and moldic porosity). The rounder the pore shape in the rock, the greater the Vp value in the rock when compared to the flattened pore shape or soft pore [3]. In this study, a modification of the [4] method was
used to predict the aspect ratio and the Kuster-Toksöz equation [5] to calculate the effective modulus of rocks. Analysis of rock physics is a step that needs to be continued before carrying out the seismic inversion process. The Extended Elastic Impedance (EEI) method is the development of the concept of Elastic Impedance (EI) proposed by Connolly with a wider angle range (-90° to 90°) [6]. To further improve the results of reservoir character analysis, the Curved Pseudo Elastic Impedance (CPEI) can be used. The CPEI method is the development of the EEI method based on the Rock Physics Template (RPT) with the concept of connecting rock elastic parameter variations with reservoir parameters so that the CPEI approach can improve the results of reservoir characterization in describing fluid distribution [7]. Avseth and Veggeland found that the CPEI attribute correlates well with saturation and resistivity. In this study area, CPEI inversion is necessary, considering this method has never been applied in the research area. The purpose of this study was to determine the pore shape in the study area and to determine the distribution of gas hydrocarbons. By integrating the results of log data analysis, petrophysical data, pore type analysis, EEI and CPEI inversion analysis, will be able to maximize reservoir characterization (pore type and gas distribution) in the research area that reflects the true geological state for further field development analysis.

2. Data and Methodology

2.1. Data
The data used in this study are marker data, check shot data, 3 well log data (IN-1, IN-2, IN-3), horizon data, petrophysical data and partial angle stack seismic data (near, mid, and far).

2.2. Method
In this study, there are 3 main steps, namely elastic property modeling, extended elastic impedance (EEI) inversion, and curve pseudo elastic impedance (CPEI) inversion.

2.2.1. Elastic property modeling
First, data with Vcl more than 0.2 need to be eliminated before data processing is performed. We need to minimize the effect of claystone, so that the modeling focus on carbonate rocks only. In this study, there was no XRD (X-Ray Diffraction Data). So, the mineral modulus for each depth predicted by using Dvorkin and Krief equations. A modified Kumar and Han method, the aspect ratio of soft pore, reference pore, and stiff pore are 0.09, 0.177, and 0.506, respectively. Modulus effective of inclusion rock calculate by using Kuster-Toksöz (Ksat and μsat). The Pmi and Qmi used in this study is penny crack pore geometry. The comparison between the original log data and the predicted result (P-wave and S-wave velocity) need to be done to test the accuracy of the predicted elastic property values used in the modeling are correct. Furthermore, rock physics processing is continued to obtain rock physics template (RPT) to obtain the relative CPEI (wet saturated line in figure 2) equation from the poisson ratio and Lamda-Rho curves. In addition, the trigonometric CPEI equation is used to find the optimum angle which has high correlation with porosity (figure 1).

![Figure 1. Comparison between CPEI (-23°) against porosity](image)
2.2.2. Hydrocarbon prospect zone and sensitivity analysis

Hydrocarbon prospect zone analysis is done by integrating well and perophysical data. The most sensitive parameter for separating reservoir zones containing hydrocarbons is \( \lambda - \rho \) (8-26 GPa) and Poisson Ratio less than 0.3 (unitless). The \( \mu - \rho \) parameter is good for separating the lithology of shale, porous carbonate, and tight carbonate.

![Figure 2. Cross plot Lamda-Rho against Poisson Ratio and wet saturated line.](image)

2.2.3. S-wave velocity prediction

The prediction of the S-wave velocity is done using the neutron porosity log. In the IN-2 well, a cross plot was carried out between the neutron porosity as the x-axis and \( \mu \) as the y-axis in the wet zone (because the presence of hydrocarbon makes the NPHI log smaller and does not reflect the actual state of porosity). From the cross plot, the \( \mu \) equation is obtained as an NPHI function to predict \( \mu \) parameters in IN-1 wells to calculate S-wave.

2.2.4. EEI and CPEI inversion

Based on the cross plot analysis, it was found that the elastic parameters needed in this study were \( \lambda - \rho \) and \( \mu - \rho \). The best correlation angle for EEI with \( \mu - \rho \), \( \lambda - \rho \), and Poisson Ratio are 77°, -24°, -45° and -46° respectively. Initial model was carried out using IN-2 and IN-3 wells because both wells had P-wave and S-wave data. Meanwhile, other well data with S-wave obtained from the prediction results is used as a blind test inversion results. The next step is pre-inversion analysis as QC parameters that will be used in the inversion process. After obtaining the \( \lambda - \rho \), \( \mu - \rho \), \( \lambda / \mu \), and Poisson Ratio Inversion Volume from the EEI inversion using model based and sparse spike method and combine the result using frequency domain merge. The next process is to obtain the relative CPEI volume using the wet saturated line and CPEI equations which correlate with porosity. The results of this CPEI volume need to be scaled so that a range of values is equivalent to the value range with saturation and porosity.

3. Result and Discussion

3.1. Well log and petrophysical data analysis

The results of the well log and petrophysical data analysis show that the gas zone is located at the upper side of Kujung I Formation (Figure 3). This result is in accordance with the well report data that there is a gas show of IN-1 and IN-2 wells at the top of the Kujung I Formation. Meanwhile, in the IN-1 well there is no gas zone found. This is supported by the location of the IN-3 well which is in the low area on the time structure map. Table I is the result of gas zone analysis from log and petrophysical data.

| Well no | Gas zone depth | GR | \( V_{clay} \) | NPHI and RHOB curves | Mean total porosity | Water saturation |
|---------|----------------|----|--------------|----------------------|---------------------|------------------|
| IN-1    | 4635-4714 (ft) | Low | 0.22         | Crossover            | 0.27                | 0.52-0.90        |
| IN-2    | 4617-4684 (ft) | Low | 0.25         | Crossover            | 0.28                | 0.24-0.86        |
3.2. Pore type analysis

Figure 5 shows the result of elastic property modeling. Modeling results show a good match against the original data. The elastic property modeling results indicate that the possible pore type developing in the Kujung I Formation is reference pore with the dominance of the aspect ratio value of about 0.17-0.19 (figure 4). Carbonate rocks with reference and soft pore types have effective porosity and good permeability [8]. However, if it has a lot of clay content, the effective porosity decreases because the clay blocks the pores. Meanwhile, carbonate rocks with stiff and reference pore types have lower effective and permeability, because the vuggy or moldic porosity types are not connected to each other.

Figure 4. The result of property elastic modelling (Kumar and Han (2005) for predicting aspect ratio and Kuster-Toksöz for effective modulus calculation).

Figure 5 shows that the gas-saturated prospect zone is located at a depth of 4617-4684 ft has a higher aspect ratio (in some location has a moderate aspect ratio). The bigger the aspect ratio, the rounder the pore shape. This means that, perhaps at the upper side of formation has a more rounded pore shape or stiff pore such as vuggy or moldic porosity.
3.3. Porous carbonate and gas distribution analysis

The best correlation angle EEI log against Mu-Rho, Lamda-Rho, and Lamda/Mu are 77°, -24°, and -45° respectively. The results of the EEI inversion show a match to the well log data. In Figure 6, it can be seen that the hydrocarbon zone is located at the top of Top Kujung 1 which is marked by low Lamda-Rho inversion results (20-28 GPa), low Lamda/Mu (1.19-2.5) and low poisson ratio (less than 0.3). The carbonate layer contains gas with good porosity located in the high area on the time structure map (Figure 7).

![Figure 6. Result of EEI inversion (a) Lamda,Rho, (b) Mu-Rho, (c) Lamda/Mu, and (d) Poisson Ratio](image)

Based on the trigonometric CPEI equation, the best correlation angle to porosity is -23° with a correlation value of 0.85. Meanwhile, the gas availability is searched by the CPEI relative equation (wet saturated line). The results of the CPEI scaling process can be seen in Figure 8 which shows a good match to the saturation and porosity log data. The gaseous layer is located below the Top Kujung 1 horizon with a thickness of 10-15 ms at the IN-2 well. In the IN-3 well there are no hydrocarbons with high CPEI results, this analysis is in accordance with the geological condition of the IN-3 well which is in a low area on the time structure map.

![Figure 7. Distribution of gas and porous carbonate from EEI inversion result](image)
4. Conclusion
Fluid flow properties control by pore type in carbonate, so it is important to do a study on pore type analysis. In this study, the elastic properties modeling show a good match to the actual data. The possible pore type developing in the Kujung I Formation is reference pore. The gas-saturated prospect zone has a higher aspect ratio (in some points it has a moderate aspect ratio). The bigger the aspect ratio, the rounder the pore shape. This means that, perhaps at the upper side of formation has a more rounded pore shape or stiff pore such as vuggy or moldic porosity. The carbonate layer containing hydrocarbons is characterized by low Lamda-Rho, Lamda / Mu values and a low Poisson ratio. Porous carbonate layer, characterized by a low Mu-Rho value. The slice results show that the gaseous area is located on the anticline (on the time structure map). The zone has good porosity, which is indicated by low Mu-Rho. The inversion results show a good match between CPEI against Sw and CPEI on porosity.

Acknowledgments
The author would like to thank all those who have helped towards the entire process of drafting and publishing this paper.

References
[1] Fanchi J R 2002 Shared Earth Modelling Butterworth-Heinemann Oxford, England 170-181
[2] Eberli G P Baechle G T Anselmetti F S, and Incze M L 2003 Factors controlling elastic properties in carbonate sediments and rocks The Leading Edge 22 654-660
[3] Xu S and Payne MA 2009 Modelling Elastic Properties in Carbonate Rocks The Leading Edge 28 66-74
[4] Kumar M and Han D 2005 Pore shape effect on elastic properties of carbonate rock Society of Exploration Geophysicists Expanded Abstracts 1477-1480
[5] Kuster G T and Toksoz M N 1974 Velocity and attenuation of seismic waves in two-phase media Geophysics 39 587–618
[6] Whitecombe D A Connolly P A Reagan R and Redshaw T C 2002 Extended elastic impedance for fluid and lithology prediction Geophysics 67 63–67
[7] Avseth P Veggeland T and Horn F 2014 Seismic screening for hydrocarbon prospects using rock-physics attributes The Leading Edge 33 266–274
[8] Prananda A Rosid M S and Widodo R W 2020 Pore type characterization of Kais Carbonate Reservoir using differential effective medium IOP Conference Series Earth and Environmental Science 538 1–8