Reservoir characterization of gas saturated sandstone using Extended Elastic Impedance (EEI), Poisson Impedance (PI) and Curved Pseudo Elastic Impedance (CPEI)

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Abstract. The WR field in this study is a gas hydrocarbon proven field with high saturation rate and reservoir character in tight sandstone. There are prestack 3D seismic data and three well data that have P-wave velocity (Vp) and S-wave velocity (Vs). In its development there are three kind of methods using Vp, Vs, and angle function constants that is Extended Elastic Impedance (EEI), Poisson Impedance (PI), and Curved Pseudo Elastic Impedance (CPEI). By using correlation coefficient concept between two kinds of variable, we can look for the angle function constants which used in those three methods. The results obtained from those three methods correlated with lithology log data (Gamma ray (GR)) at the range of angle (-90° to 90°) is EEI = 30°, PI = 59° and CPEI = -69°, whereas with fluid log target (Water Saturation (SW)) obtained angle values correlated with EEI = 20°, PI = 51° and CPEI = -60°. The highest correlation to the target lithology (GR) and fluid (SW) log data of the three methods is CPEI with correlation 0.881 for lithology and 0.604 for fluid. The vertical of the three methods shows a good reservoir character with high saturation rate of gas. The result of the lateral distribution of the three methods shows the character of the depositional environment in the target reservoir located in the estuarine environment in upper shoreface facies for Reservoir A and transition facies for Reservoir B. The direction trend of the source of the sedimentary sediment is the south-east direction, and this result fits with the regional geological concept in the WR field.

Keywords: EEI, PI, CPEI, reservoir, P-wave, S-wave

1. Introduction
The WR field in this study is a gas hydrocarbon proven field with high saturation rate and reservoir character in tight sandstone. Having a complete P-wave velocity (Vp) and S-wave velocity (Vs) data in the well log data and having a 3D seismic in the form of prestack time migration that covers the entire area. Acoustic impedance seismic inversion method using P-wave velocity (Vp) has long been used for reservoir characterization. However, the acoustic impedance inversion method does not provide more information about elastic and fluid parameters. For this reason, the utilization of S-wave velocity (Vs)
is needed especially in gas saturated sandstone reservoirs. Seismic impedance method at the non-normal incidence angle by utilizing Vp and Vs and the angle function constant answers the problem. In its development there are three impedance methods by utilizing Vp and Vs as well as the angular function constants proposed by the researchers and able to characterize gas-saturated sandstone reservoirs. Whitcombe et al. proposed the Extended Elastic Impedance (EEI) method by utilizing Optimized Vp and Vs so that it could better connect seismic data with elastic parameters [1]. The basis of the EEI method is the improvement of the Elastic Impedance (EI) method which is an impedance method in non-normal incidence angle. Then Quekenbush et al. provide a new impedance terminology, Poisson Impedance (PI), which is based on the concept of axis rotation in crossplot analysis [2]. This PI method can be related to the equation of Poisson ratio, and is able to provide better lithological information for the interpretation of geological facies on seismic data [3]. Whereas according to Avseth the fluid trend towards Vp and Vs is not linearly related but in the form of curves, the method is named Curved Pseudo Elastic Impedance (CPEI). The concept of the CPEI method proposed by Avseth was inspired by the EEI method and the Rock Physics Template method (RPT) [4]. This CPEI method is mathematically simplified by Palgunadi et al. and successfully separates the gas fluid in the sandstone reservoir [5]. The geological concept in the WR field is Estuarine depositional in reservoir A and B which are tight enough due to the possibility of having been deeply buried cause geological analysis with an acoustic impedance method that is not informative. It is very interesting to see the comparison of three methods to characterize the reservoir in WR field data. So that the expected result can provide better geological information compared to the acoustic impedance inversion method.

2. Data and method

The data consists of 3D seismic data with final processing in the form of prestack time migration, and there are three well data with complete Vp and Vs data and also other log data. Reservoir target at WR Field is divided into two, namely, A Reservoir that is younger and Reservoir B that is older. Reservoir A is restricted to Top A markers while reservoir B is limited by Top marker B (figure 1). Regional geological concepts of Reservoir A and Reservoir B are deposited on the estuarine environment, with the position of Reservoir A being in transition and Reservoir B being in shallow sea.

![Figure 1. Correlation of the three wells found on the WR field.](image)
The Elastic Impedance (EI) method proposed by Connolly is the basis of the impedance based on the linearization of the Zoeppritz equation for waves at non-normal incidence angle [6]. This equation connects between P-wave velocity (Vp), S-wave velocity (Vs) and density to produce elastic impedance. There are also angular function constants which can be used to find compatibility with the elastic parameters sought. However, the angular function of the EI equation is only limited to sin² \( \theta \), whereas based on observations Whitcombe et al. the reflectivity values that correlate with the physical properties of a rock can exceed sin² \( \theta \). For this reason, Whitcombe et al. [1] proposed the expansion of angles to reach infinity at an angle of -90° to 90° by acting on sin² \( \theta \) with tan \( \theta \), so that the terminology of Extended Elastic Impedance (EEI) is obtained. EEI method application using angle function constants can predict the physical parameter value of a rock (figure 2).

Avseth et al. [4] introduced the Curved Pseudo Elastic Impedance (CPEI) method which is a development of the proposed EEI method [1, 4]. CPEI introduced by Avseth et al. [4] is a rotation method of non-linear axis functions [4]. The basic principle of this CPEI method is the EEI method which is combined with Rock Physics Template (RPT). Mathematically EEI is correlated with water saturation data (Sw), which is then maximized by rotating on the gas saturated sandstone Rock Physics Template (RPT) model curve. The concept of the RPT curve is built by incorporating rock physics parameters such as; pressure, mineral character, porosity, and fluid properties in the crossplot between acoustic impedance (AI) and Vp / Vs ratio so that the boundary trend is seen between saturated reservoirs and not saturated reservoirs [4] (See figure 3).

Unlike the EEI method which is a reflectivity function derived from the Zoeppritz equation, Poisson Impedance (PI) terminology is born from the concept of axis rotation on acoustic impedance (AI) and shear impedance (SI) crossplots. The PI concept proposed by Quakenbush et al. [2] mathematically follows the rotation function on a cartesian coordinate axis figure 4. The equation of the function resembles the second term of the poisson ratio equation, which is the physical parameter of a rock. PI method is widely used to increase sensitivity on crossplots to identify geological trends in an oil and gas field.

Of the three methods, it is necessary to know the value of the angular function constants that correlate with the physical properties of a rock. The method used to find the angle function constant value is the Target Coefficient Correlation Analysis (TCCA). The principle of this TCCA method is to

Figure 2. The EEI method results are correlated with elastic rock parameters such as Lambda-Rho (LR) at an angle of 20° and Mu-Rho (MR) at an angle of -31°.
Figure 3. CPEI method combined with the RPT concept on well data.

Figure 4. Concept of PI method on crossplots between AI and SI.

correlate each method (EEI, PI, and CPEI) with the selected property target (e.g. log GR represents the lithology property) in the range of -90º to 90º in the well data figure 5. Then the angle that has been obtained from the TCCA method is applied to the seismic cross section data, which is then carried out vertically or laterally.

3. Results and discussion
The results of the TCCA analysis for the three methods from the average of the three wells showed that the CPEI method had a higher correlation value for the lithology log target (Gammaray (GR)) and fluid (Water Saturation (SW)). The correlation value reached 0.881 in CPEI with an angle of -69º for the target lithology log (GR) and a correlation value of 0.604 on CPEI with an angle of -60º for the
fluid log target (SW). However, for the Lambda-Rho (LR) and Mu-Rho (MR) log targets of the three methods, EEI, PI and CPEI have almost the same level of correlation and are quite high, that is, the correlation is around 0.99 (more clearly can be seen in table 1).

Qualitatively the three methods (EEI, PI and CPEI) by using the input angle chi (χ) based on TCCA analysis (table 1) show a less significant difference. This can be seen from the results in figure 6, of the three methods in the three well data which show similar appearance trends. But at certain points there are differences that can still be seen from the three methods.

![Figure 5.](image)

**Figure 5.** Concept of PI method on crossplots between AI and SI.

**Table 1.** TCCA analysis results from the average of the three-well data.

|       | LR     | Corr | MR     | Corr | GR     | Corr | SW     | Corr |
|-------|--------|------|--------|------|--------|------|--------|------|
| EEI   | 20     | 0.9962 | -31    | 0.9924 | 33     | 0.8701 | 20     | 0.5870 |
| PI    | 51     | 0.9948 | -90    | 0.9972 | 59     | 0.8765 | 51     | 0.5785 |
| CPEI  | -53    | 0.9912 | 90     | 0.9971 | -69    | 0.8818 | -60    | 0.6042 |

![Figure 6.](image)

**Figure 6.** Comparison of EEI, PI and CPEI methods from well data.
Figure 7. Crossplot analysis for lithology log targets for (a) AI, (b) EEI, (c) PI and (d) CPEI methods.

Overall, all three methods can predict lithological parameter values from GR and fluid log data from SW log data. Where the success of the three methods cannot be separated from the value of P-wave velocity (Vp) and S-wave velocity (Vs) data sensitivity. Where a good separation between Vp and Vs data to see lithology and fluid is the main key. The more sensitive Vp and Vs data that is used, the maximum EEI, PI and CPEI will be generated.

Among the three methods (EEI, PI, and CPEI) when compared with acoustic impedance (AI) crossplot shows a fairly good lithological separation trend between sand and shale, and also the separation between saturated zones and unsaturated zones (figure 7 and figure 8). The results of crossplot analysis between Reservoir A and Reservoir B zones have different sensitivity between Vp and Vs, where Reservoir A tends to have better sensitivity compared to Reservoir B. Low sensitivity in B Reservoir zone is affected, one of them is heavy minerals such as pyrite and siderite which is quite a lot in the zone. The number of heavy minerals also causes the reservoir quality to be tight enough so that the reservoir is at a fairly high acoustic impedance value.

Lateral distribution of seismic data (figure 9) for the three methods (EEI, PI and CPEI) shows a better geological trend compared to the acoustic impedance method (AI). Seen the environmental pattern of deposition in Reservoir A and Reservoir B is in the estuarine environment. The A reservoir shows more specifically the pattern of channel development and alluvial fan and shows Reservoir A is in the Upper Shoreface position. Whereas in Reservoir B, the body pattern of the sand bar indicates the Reservoir B position is in transition. This is evidenced by the results of the data core analysis found in each well that shows the same depositional environment based on the lateral distribution of EEI, PI and CPEI.
Figure 8. Crossplot analysis for fluid log targets (bottom) for (a) AI, (b) EEI, (c) PI and (d) CPEI methods.

Figure 9. Comparison of lateral AI distribution results of, (a) EEI, PI, CPEI lithology log target and fluid log target, and (b) reservoir geological facies of Reservoir A and Reservoir B.
4. Conclusion
The EEI, PI, and CPEI methods have a similar trend to the trend of P-wave velocity (Vp), and S-wave velocity (Vs) data. Trends in good Vp and Vs separation (not overlapping / irregular) such as the WR-Y well will give results for the EEI, PI, and CPEI methods to be more optimal. The results of the EEI, PI, and CPEI methods when compared to each other (curves), generally do not have significant differences, but the angular constant values for each target log in each method have differences. In the target log GR, the angular values of chi (\(\chi\)) for EEI (30), PI (59) and CPEI (-69) are obtained, while for the target log SW, the chi value (\(\chi\)) is correlated with EEI (20), PI (51) and CPEI (-60). The highest correlation to the lithology log target is GR and fluid log in the form of SW log from the three methods is the CPEI method with a correlation of 0.881 for log GR and 0.604 for log SW. Lateral distribution of seismic data for the three methods (EEI, PI and CPEI) shows a better geological trend in estuarine depositional system compared to the acoustic impedance (AI) method.

References
[1] Whitcombe N, Connolly P A, Reagan R L and Redshaw T C 2002 Geophysics 67 63-7
[2] Quakenbush M, Shang B and Tuttle C 2006 The Leading Edge 25 128-38
[3] Direzza A, Andika I K and Permana A 2012 AAPG Int. Convention and Exhibition (Singapore) available at http://www.searchanddiscovery.com/abstracts/html/2012/90155ice/abstracts/dir.htm
[4] Avseth P, Veggeland T and Horn F 2014 The Leading Edge 33 266-74
[5] Palgunadi K H, Viantini I, Yogi I B S and Winardhi S 2016 SEG Int. Exposition and 87th Ann. Meeting, (Dallas) pp 3448-52
[6] Connolly P 1999 The Leading Edge 18 438-52