Pore Pressure Prediction using Anfis Method on Well and Seismic Data Field "Ayah"

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Abstract. Nowadays oil and gas industries are focusing in production and development where well drilling is common and often done. One among many aspects need to be considered for drilling safety is pore pressure prediction. There are so many methods used in prediction the pressure including machine learning ANN but no one has ever done this with ANFIS which is combination of ANN and FIS machine learning. This study wants to use ANFIS for making a pore pressure distribution in 2D seismic data with 70% accuracy. Both pre-stack and post-stack seismic data are used here with well and RFT measurement. The modified Eaton-Azadpour and Eaton are two methods that applied to predict pore pressure. The methods are considered to be good in prediction pore pressure as they accommodate the rocks condition during drilling. The well parameters models are then distributed with ANFIS to find its correlation with P-impedance, S-impedance and density so we may find its distribution in 2D seismic data. The result shows that pore pressures are distributed very well but still need another study to give information regarding drilling safety.

Keywords: ANFIS; Azadpour; Eaton; Pore Pressure

1. Introduction

Indonesia is one of the big oil producer in the world and nowadays Indonesia is more focus on production and development steps where drilling will be more intensive. In drilling, the pore pressure prediction is usually done in advance to prevent any borehole breakout, kick, mud loss and any drilling hazard due to high pressure information. Pore pressure prediction usually done by many methods like Eaton [1] and Bowers [2] to predict pore pressure by using well and prestack velocity of seismic as its data but those methods and other methods also only use well data for predicting pore pressure but there is no method to combine both well and seismic data to predict pore pressure.

Nowadays, since the industry 4.0 era, machine learning is applied here to combine both seismic and well data to predict pore pressure in 2D seismic data. Recently, it is done by using PNN or Probabilistic Neural Network [3,4] and ANN or Artificial Neural Network [3] but there is almost no publication that apply ANFIS machine learning for predicting pore pressure. ANFIS has a greater accuracy than PNN and ANN because ANFIS is a combination of two machine learnings and they are ANN and FIS so it is hoped that ANFIS can give a better accuracy in pore pressure prediction [6]. In this study we want to discuss the accuracy of ANFIS, generating mechanism of overpressure in our study field are(Ayah field) and the pore pressure distribution in 2D seismic section in study area as the result of ANFIS pore pressure distribution.
2. Geological Data and Methodology

The geology of study area can be explained by stratigraphy in the area as shown in Figure 1. There is Sembakung Formation that consist of sandstone and shale or claystone as this formation is made up from the subsidence (due to rifting process) during the basin formation and that is why it seem shale as the bottom of formation and shale again as the top of formation [4]. The Sujau Formation is made up of the cyclic sedimentation as the sea-level is very low so that the sand of Sujau Formation is deposited. As the sea-level rising and no sediment supply from land the Seilor Formation is formed where this formation is consisted of open marine shale and carbonate formation. No information regarding of what is the depositional environment of Sujau Formation but it could be suggested that this is shallow marine most probably continental shelf or lagoon. Next is Tempilan Formation that consist of shale and sandstone and the formation is formed due to sea-level fall so the coarsening upward is happened. Again no information regarding of how does there is an unconformity between Seilor and Tempilan but there might be an uplifted process combined with sea-level fall. Sea level again slowly rising and with a very calm, passive margin area where the Tabalar carbonate build-up is formed and during the formation of this build-up carbonate it could be possible the lagoon depositional environment. There is shale of Mesalai Formation and Naintupo Formation that is formed behind the carbonate platform that might be deposited from any sea life-form in that lagoon. The cessation of Tabalar carbonate build-up is shale on the Tabalar Formation which is formed due to slowly rising of the sea-level. Meliat Formation consist of sandstone and shale with an unconformity where at this time there is an uplifted happened from early of middle-miocene until late ploocene and pleistocene and all of the formation formed from this range of age is deposited as deltaic deposits due to uplift during the range of ages.

There are so many prediction methods in hands where each method has own limitation of its usage. Methods which is commonly used in industry are Bowers [1] and Eaton [2] methods (to be more precise it is called as modified Eaton method). Both methods are common due to its ability in distribute the

![Figure 1: Stratigraphy of study area [7].](image-url)
value of pore pressure in 2D seismic section by using the prestack velocity data that is fitted with well velocity. The methods can be effectively used in pore pressure prediction of well section. However, the methods cannot combine two data of well and seismic data to predict pore pressure so machine learning is implemented here to combine two data to get accurate pore pressure prediction. First of all, the well tie seismic in order to do the seismic interpretation. Seismic picking is then done to pick the top of formation. Physically the overpressure could be occurred at shale formation because the water cannot be easily dewatered due to its low permeability and this might occur at shale formation of Santul, Meliat, Mesalah or Naintupo. According to well report, the overpressure occurs at Santul Formation so the picking is focused to the Santul top and Meliat top at seismic section.

Seismic interpretation clearly shows a deltaic progradation which the thickening horizon seaward and it is usually happened in deltaic formation. The formation is prone to disequilibrium compaction mechanism or clay diagenesis mechanism of overpressure so that why the Santul and Meliat is picked as top formations. The line chosen for pore pressure prediction is line A because the line has a well data as the validator of our ANFIS pore pressure model. The seismic picking is then verified by seismic QC and pre-inversion analysis. After the seismic simultaneous inversion is done, the ANFIS is then processed in Matlab. Before doing the ANFIS processing, the data pre-processing like combining training and validation data as one data and randomly choose the data for training is done. The result of testing modelled is then distributed the pore pressure using seismic data inversion. Modelling of ANFIS is done by taking the trace of inverted seismic data ($Z_p$, $Z_s$, and density) as a training data with pore pressure derived from well as output data. The data training is done by using Gaussian membership function and the result of training is then proven to be matched the field data. The model is then tested to real data and the result is also matched so that the model then may use to distribute pore pressure through the seismic data.

Before doing the simultaneous inversion, the pre-analysis must be done in order to see whether the inversion derived from software is matched with well data. This is necessary because if it does not match then the result of inversion is questionable. Software will compare the $Z_p$, $Z_s$ and density generated from building model with inversion calculated from seismic directly. This inversion calculation is done by deconvolution of seismic seismogram to separate wavelet from acoustic impedance. The $Z_s$ then calculated via equation that relates density and $Z_p$. This calculation should be matched with the actually measured (well log data).

3. Results and Discussion
From well data section of Figure 2 it can be seen the mechanism of overpressure tends to unloading mechanism. The sonic data is in reversal condition and the cause of this unloading mechanism is reducing clay content. The reducing of clay looks likely due to some processes like diagenesis, erosional, or hydrocarbon generation as the RHOB and Sonic crossplot data are confirmed that clay diagenesis occurs at this overpressure zone from depth 1360-1500 meter. Below this zone the lithology is dominated by carbonate rock and sandstone making it impossible to predict the pore pressure because the pore pressure prediction can only be done in shale or mud rock.
Figure 2: Well logs section at well A.

Figure 3 clearly shows that the diagenesis of clay may occur due to many points shows a higher content of illite near overpressure zone. This process might generate a certain amount of water and due to reaction of diagenesis, the smectite content in the shale might be reduced and will decrease the value of effective stress. However, according to the Figure 3 the process of clay diagenesis is still on progress because the data is slowly rising from smectite zone (under the red line in Figure 3) to illite zone (upper the red line in Figure 3) but comparing with Figure 3 at depth around 1400-1500 meter encounter very slow sonic velocity accompanied with low density but slowly decreasing resistivity. We suggest that the slow sonic velocity and low density is not only caused by water produced by clay diagenesis but also a gas is also reacting with the water produced by this diagenesis and the gas may come from the carbonaceous shale which might contain lignite. The reaction between gas and water combined with decreasing effective stress might create overpressure.
Figure 3: Clay diagenesis from well logs

In this study, Eaton pore pressure prediction method is modified to predict pore pressure in deltaic formation bounded by red squares and Azadpour is applied for carbonate rock bounded by blue square (see Figure 4). The Azadpour is considered a great method for predicting pore pressure in carbonate formation [5]. From the result in Figure 4 it can be seen the pore pressure prediction is strongly associated with RFT reading so the pore pressure prediction is, more or less, accurate. Overpressure happened at depth around 1360-1500 meter shown by pore pressure graph that is higher than hydrostatic pressure and caused by clay diagenesis.
In well B of Figure 5 it can be seen that the overpressure happens at depth near to 2000 meter (around 1900 meter). It is also confirmed by well report that suggest the overpressure occur at around 1900 meter. This is too thin to be predicted by seismic data so it may not see this overpressure phenomenon at seismic section. In this section the overpressure zone is indicated from constant sonic, density and resistivity value with increasing depth and the cause of this overpressure is might be fast sedimentation in deltaic environment because according to stratigraphy in regional geology the overpressure formation is deltaic and fast sedimentation in deltaic environment may inhibit the dewatering process. The
overpressure zone might be thick but due to decision to stop drilling process the overpressure zone is thin.

Figure 6: Pore pressure prediction using modified Eaton at well B.

Figure 6 of density and Zp picture shows the pore pressure is low around overpressure zone highlighted in the picture. The Zp value of overpressure zone is around 5000-8000 kg.s/m² and density around 2.1-2.2 g/cm³ but it cannot be seen clearly because the overpressure zone is thin.

Figure 7: Zp of Line 704 shown a little value around 5000-8000 kg.s/m³.
Figure 8: Density section of Line 704 shown low density around 2.11-2.16 g/cm³.

Figure 7 and Figure 8 show the density and Zp values is low at depth below overpressure zone and it might be the reason why the overpressure zone might be thick. The low density and Zp suggest that rocks are not compacted normally and this might be caused by highly pressured water that hold the rock pore opened. The high water saturation might cause the density is low because water might dominate rock pores, thus, dominating the rock density. High water saturation might also cause the Vp decreasing due to fluid domination in the rock and with decreasing Vp and density the Zp will also decrease. The zone of overpressure below overpressure zone indicated by well is shown by green color in Figure 8 below the well zone and yellow zone in Figure 7.

Figure 9: ANFIS training result.
Figure 10: ANFIS testing result.

Figure 9 and 10 show us the modelling result of ANFIS using Gaussian membership function. It can be seen that the result is matched both in training and testing so the model is valid to be used in any kind of data.

Figure 11: Two dimensional pore pressure model.
ANFIS pore pressure model shows a high value of pore pressure at the bottom of the well with value around 3000 Psi. This is matched to what is found at well report and this also supported by the fact that the Zp and density data is very low below the well bottom. According to ANFIS model, the pore pressure near the well is not high but at bit further there is the high pore pressure. At the middle depth and top, the pressure is not too high so it is not prone to overpressure.

Figure 12: Comparison between real pore pressure value and ANFIS model.

Figure 12 shows that the accuracy of model is very high (correlation coefficient of $r^2 = 0.9536$) so we may conclude that the pore pressure model is accurate.

4. Conclusion
From explanation above we can see that ANFIS may be used to predict pore pressure as well as to make a pore pressure model with a high accuracy. So, it is very recommended to use this machine learning for future study. However, there are still many things to be corrected like anisotropy analysis, and comparison to other machine learning. The research also ignoring the mechanism of overpressure and still need to be considered for next study.

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References
[1] Eaton, B. A. 1975. The equation for geopressure prediction from well logs. SPE, Paper No. 5544, 11p.
[2] Bowers, G. L. 2001. Determining an appropriate pore-pressure estimation strategy. Offshore Technology Conference, paper OTC 13042.
[3] Singha, Dip & Chatterjee, Rima & Sen, Mrinal & Sain, Kalachand. (2014). Pore pressure prediction in gas-hydrate bearing sediments of Krishna–Godavari basin, India. Marine Geology. 357. 1-11. 10.1016/j.margeo.2014.07.003.
[4] Haris, A., Sitorus, R. J., & Riyanto, A. (2017). Pore pressure prediction using probabilistic neural network: Case study of South Sumatra Basin. IOP Conference Series: Earth and Environmental Science, 62(1), [012021]. https://doi.org/10.1088/1755-1315/62/1/012021.
[5] Darman, Herman. (2000). An outline of the geology of Indonesia. IAGI.
[6] Rahmanifard, H. and Plaksina, T. *Artif. Intell. Rev.* (2018). https://doi.org/10.1007/s10462-018-9612-8.
[7] Noon, S., Harrington, J., Darman, H., 2003, The Tarakan Basin, East Kalimantan: Proven Neogene Fluvio-Deltaic, prospective Deep-Water and Paleogene Plays in a Regional Stratigraphic Context, *Proceeding of the Indonesia Petroleum Association.*