Integrated Pore Pressure Model Estimation – Case Study of Jambi Sub-basin, South Sumatera, Indonesia

Ahmad Farhan Farabi1*, Ignatius Sonny Winardhie2, Noor Cahyo Wibowo3

1Geophysical Engineering Study Program, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology, Bandung, Indonesia
2Geophysical Engineering Study Program, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology, Bandung, Indonesia
3Geophysics Division, Pertamina Upstream Technical Center, Jakarta, Indonesia.

*Corresponding author’s email: farhan.farabi@students.itb.ac.id

Abstract. Pore pressure estimation is crucial in drilling wells for safety purposes also a very effective method for dealing with drilling accidents. Determination of overpressure is the main foundation in the evaluation to minimize the non-productive time (NPT). Here we present several models to generate pore pressure analysis of well from Jambi Sub-basin, South Sumatera, Indonesia. The model for estimation pore pressure is carried out by 3 methods: Eaton, Yan & Han, and Kan & Swan. Those methods will be compared to gain a more accurate model estimation within the study area. Kan and Swan’s model show the best fit for estimation because this method is suitable for the formation of tester like MDT/DST on higher frequency with parameter of C1 = 0.001 and C2 = 0.0003 for Jambi Sub-basin. The velocity data to construct the 3D pore pressure model was also validated with well data using multi-attribute analysis. The multi-attribute analysis used 2 algorithms, namely step-wise regression and probabilistic neural network (PNN). The analysis show that PNN has a better correlation compared to step-wise regression. The analysis shows the overpressure zone depth is ranges from 1700 – 2000m on Gumai Formation with maximum pressure around 6500 psi. The peak of overpressure dominated by Gumai and Talang Akar formation is caused by the loading mechanism because the rate of sedimentation on thick shale sequence is higher than the rate of dewatering on those formations.

Keywords: Pore Pressure, Kan & Swan Model, Eaton Model, Yan & Han Model.

1. Introduction
As E&P activities focus more on complex environments and reduction of drilling costs, pore pressure analysis becomes part of the well planning and drilling process to generate safety drilling accidents. Overpressure, one of the drilling accidents seen globally is the main foundation in the evaluation to minimize the non-productive time (NPT). An accurate model for estimation pore pressure is required to generate suitable information future production. We already did analysis 1D modeling pore pressure of onshore well from South Sumatera Basin especially Jambi Sub-basin with integrated data of formation pressure, well log and drilling event. We applied Eaton, Yan & Han, and Kan & Swan method to compute pore pressure from the sonic log and compared each other to generate an accurate model within the study area. Integration of multiattribute analysis to generate velocity is used to construct 3D pore pressure model. 2 methods step wise regression and probabilistic neural network are compared to generate a better velocity model.
1.1. Geological Setting
Jambi sub-basin is located in the South Sumatera Basin and was on the east of Barisan Mountain. South Sumatera Basin is divided into two sub-basin, Palembang, and Jambi, which is separated each other [1]. The basin was formed due to extensional tectonic during rifting from Eosen-early Oligosen which generates half-graben[3]. It also generates two different basins between Barisan Mountain that is fore-arc basin and back-arc basin. This study area is categorized as back-arc basin. Several large oil and gas fields have been discovered in this basin, which is on Talang Akar Sandstone formation and Batu Raja Limestone formation have been established in the multiple pay zone of various reservoirs.

1.2. Pore Pressure Estimation Method
Pore pressure estimation is well defined by the Terzaghi equation which means pore pressure on formation is vertical stress minus effective stress from the rock. Physically, effective stress is the stress that is borne by grain-to-grain contacts.

\[ p = (\sigma_v - \sigma_v') \]  \hspace{1cm} (1)

Where \( p \) is pore pressure, \( \sigma_v \) overburden pressure, \( \sigma_v' \) effective stress.

1.2.1 Eaton Method
Eaton [2] proposed an empirical equation for calculating pore pressure from the sonic log and resistivity. This method using the assumption of Terzaghi equation where overburden pressure formed by pore pressure and effective stress itself. This method was applied by Eaton in 1975 for well that have overpressure zone on the Gulf of Mexico. An empirical equation for the sonic log is

\[ p = \sigma_v - (\sigma_v - P_n)\left( \frac{\Delta I}{\Delta n} \right)^n \]  \hspace{1cm} (2)

1.2.2 Yan & Han Method
This method shows that velocity model (Figure 1.a) is best property to implicated stress effect on velocity where the value of differential pressure is not high or less than 60 MPa[6]. It also using three parameters fitting from formation tester which can be generated from this equation

\[ V_p = V_{pa} (1 - C \exp \left( -\frac{P_d}{b} \right)) \]  \hspace{1cm} (3)

Where, \( V_p \) is the velocity of P-wave, \( P_d \) is differential pressure and \( V_{pa} \),C and b is constant.

Differential pressure of this basin can be obtained from formation tester (MDT/DST) data within 3 well (Figure 1.b)

Figure 1. (a) Pore pressure effect on P-wave velocity from laboratory measurement on Gulf of Mexico. (b) Pore pressure effect on P-wave velocity from analysis on Jambi Sub-basin.
1.2.3 Kan & Swan Method

In 2001 Swan proposed a new scheme for calculated pore pressure using velocity data. This method using a polynomial empirical equation between gradient pore pressure and transit time deviation. This deviation is between normal compaction trend and sonic transit time[4]. We can conclude that a higher deviation generates a higher pore pressure gradient (Figure2). This also needs formation tester to be fitting precisely to generate constant. Gradient relationship can be modeled empirically which can be written

$$ P(z) = R_w z + C_1 \Delta t + C_2 (\Delta t)^2 $$

$$ \Delta t = t(z) - t_n(z) $$

Where $R_w$ is hydrostatic gradient, $t(z)$ is sonic transit time, $t_n(z)$ is normal compaction trend and $C_1$ $C_2$ is constant.

![Figure 2](image2.png)

**Figure 2.** fitting trend between transit time deviation and pressure gradient within 3 well on Jambi sub-basin.

2. Data and Methodology

This study area located on onshore of South Sumatera Basin (Figure3.a). Data of this study include 5 well with MDT data (modular tester), DST data (Drill stem test), marker formation and wireline log which can be shown on (Figure3.b).

![Figure 3](image3.png)

**Figure 3.** (a) Basemap study area. (b) availability of data.
Methodology to generate pore pressure could be breakdown into several workflows which can be elaborate below. First, Normal compaction trend (NCT) is determined before calculated pore pressure because of the rock compaction that causes pressure. Determining the volume of shale is necessary because shale rock has the consistency of compaction rather than sandstone or limestone. So we determine pore pressure in shale sequence. (Figure 4.a) Shows that data already cut-off on 0.29 Vshale and 85 gamma-ray value which means below that value cannot be used on further analysis. (Figure 4.b) is sonic log data that already cut-off by shale and from that we can be implied there was deviation between sonic log and normal compaction trend which can generate overpressure zone. A pattern of sonic log on FA-1 shows that the value from 1900m is constant that indicates overpressure which caused by loading mechanism[5]. On formation pressure, we could mapping gradient of hydrostatic and overburden to simplify the calculation and should be fitting due to evaluating a characteristic of fluid density and rock density within the study area (Figure 4.c).

![Figure 4.](image)

(a) V-shale FA-1 (b) Sonic data and NCT well FA-1 and (c) Hydrostatic Pressure curve

3. Results and Discussion

1D model using 3 methods are applied to all well within the study area and indicated penetrate through the overpressure zone. On (Figure 5) shows FA-2 well’s top overpressure is from 1900m on Gumai formation. Based on those models, we can conclude that Kan & Swan model is the best fit between pore pressure calculation and formation tester rather than two other methods on higher frequency or adjacent sample with parameter of C1 = 0.001 and C2 = 0.0003 for Jambi Sub-basin particularly. The main reason Yan & Han model is not good enough is because in this model using an exponential empirical equation and did not present of hydrostatic gradient/pressure on that model so the result could be good at overpressure but, can not be good enough to fit hydrostatic line. Eaton also not fit enough than model Kan & Swan because parameter Eaton constant could be different every basin and could be "cheating" with Eaton. We can conclude that model Kan & Swan is the best fit and use on well correlation. Pressure excess shows that overpressure has approximately 6500 psi on maximum overpressure zone on Gumai or Talang Akar formation. Well correlation from 5 well (Figure 6) show that top overpressure is between 1700 – 2000m on Gumai formation, it is not too much different between well caused by a post-rift mega sequence that basin height is assumed to equal along the basin. This matches the geological condition
on Gumai formation which on the transgression phase so the rate of sedimentation is higher rather than the rate of dewatering.

On (Figure 7) we used 10 attribute to compute the algorithm with 3 iteration of each calculation to reduce error every attribute. PNN algorithm show much higher frequency rather than step wise regression or interval velocity for instead and also have the best correlation 0.966 and then PNN velocity would be our initial velocity for 3D pore pressure model.

![Figure 5. Estimation Model Pore Pressure on well FA-2](image)

![Figure 6. Well correlation model estimation of pore pressure Jambi Sub-basin, South Sumatra.](image)
From 3D pore pressure model and slicing (Figure 8) overpressure zone is present on 1700m and keep increasing until 2250m. Talang akar and Lahat formation dominated by highly overpressure equivalent to 0.8 psi/ft. That issue could happen on shale sequence which overburden by thick shale above it for this case is Gumai formation.

4. Conclusions
Based on our study, we can summarize that model Kan & Swan has the best fit on higher frequency with parameter of C1 = 0.001 and C2 = 0.0003 for Jambi Sub-basin. Velocity from multiattribute analysis show PNN has the best correlation rather than step wise regression or interval velocity. From well analysis, we can conclude that the top overpressure zone is present between 1700-2000m on Gumai formation that can consist of 6500psi on the overpressure zone. 3D pore pressure model indicate top overpressure zone along the seismic area was present on 1700m and increasing until 2250m. The pattern on the sonic log and pressure model shows that it has constant velocity on the overpressure zone that can be categorized by loading mechanism or disequilibrium compaction. It is matched with the geological condition on Gumai formation which on the transgression phase which dominated by shale sequence so the rate of sedimentation is higher rather than the rate of dewatering of fluid.
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