Evaluation of shale hydrocarbon potential in upper Talang Akar formation based on laboratory geochemical data analysis and Total Organic Carbon (TOC) modelling

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Abstract. In shale hydrocarbon exploration, shale acts as the source rock and reservoir rock. This study aims to evaluate the potential of shale hydrocarbons based on the laboratory geochemical data and TOC (Total Organic Carbon) modelling. Evaluation of shale hydrocarbons in the study field was carried out on two wells, X-1 and X-3 wells with a target in the upper part of Talang Akar formation as a source rock. Geochemical data is needed for evaluating the quality of the source rock by looking at the total organic carbon content, the maturity, and the hydrocarbon produced by the source rock. Analysis of the laboratory geochemical data resulted that the shale of upper Talang Akar formation had enough potential and mature organic material and also will generate the hydrocarbon in oil form. One of the main parameters for the success of shale hydrocarbons exploration is to know the amount of organic material of the source rock. TOC obtained from laboratory geochemical data is discrete data. Therefore, TOC modelling is carried out to obtain prediction of continuous TOC in upper Talang Akar formation in both wells. This prediction uses three different methods, those are Passey, multiple linear regression, and neural network. Based on those three methods, neural network produces the best data. The correlation obtained from X-1 well and X-3 well using neural network method are 0.96 and 0.84 respectively.

Keywords: Shale hydrocarbon, total organic carbon, Talang Akar formation

1. Introduction
Shale hydrocarbons are oil or gas produced directly from its source rock. In shale hydrocarbon petroleum system, shale acts as the source rock and the reservoir rock. Nowadays, an observation of shale hydrocarbon could be an alternative way for finding a new energy resources of fossil fuel that might be useful to overcome the declining of oil and gas production which is in line with the increasing in the oil and gas consumption. In 2013, the Ministry of Energy and Mineral Resources (ESDM) of Indonesia provided data showing the potential for shale gas resources in Indonesia reach to 574 TCF. This shows that shale gas in Indonesia has greater potential than conventional natural gas potential which is only
worth 334.5 TCF. While Indonesia's potential for shale oil resources is estimated to reach 11.24 million tons in 2007. The study field is located in the southeastern part of the South Sumatra Basin. The South Sumatra Basin had been known to have a productive petroleum system in producing conventional hydrocarbons in Indonesia. In this basin, the Talang Akar formation acts as a mature source rock and porous rock reservoir and contributes the largest conventional hydrocarbons [1]. The upper part of Talang Akar formation could be potential as a source rock due to it has a little sandstone compared to the lower part, therefore the possibility of thick and clean shale penetration is higher at the upper part of Talang Akar formation [2].

Understanding the characteristics of the potential source rock is very important in shale hydrocarbon observation. The organic richness (presented by TOC) and maturity are some of the main parameters to determine the potential of shale hydrocarbon resources. The potential shale gas and shale oil commonly indicated by TOC > 2 wt% and TOC > 1 wt% respectively [3]. This paper presents the geochemical data and total organic carbon (TOC) analysis to evaluate shale hydrocarbon potential with target is the shale hydrocarbon reservoirs of upper part of Talang Akar formation.

2. Method

2.1. Geochemical analysis

Geochemical analysis is the first step and the key for identifying the shale hydrocarbon potential. From this analysis we could know whether the shale is potential to be a source rock or no. Geochemical data provides us the characteristics of the shale. The purpose of this analysis is to obtain the quality, the quantity and the maturity of organic richness contained in the shale based on the laboratory geochemical data.

The amount of organic material contained in a source rock is defined as Total Organic Carbon. A rock could become a source rock when the organic material that contained in the rock meets the minimum standard amount of organic material which could form hydrocarbons. Peters and Cassa [4] classified that a rock with TOC range 0–0.5 wt% to poor, 0.5–1 wt% to fair, 1–2 wt% to good, 2–4 wt% to very good, and more than 4 wt% to excellent for becoming a source rock. The maturity level of source rock is controlled by time and temperature. High temperature and short time will have the same effect with low temperature and long time on rock maturity [5]. The maturity level of source rock can be determined using analysis of vitrinite reflectance (Ro) and maximum temperature (Tmax). Based on Peters and Cassa [4], the maturity level of the source rock classified by vitrinite reflectance 0.2–0.6 %Ro and Tmax less than 435 °C as immature phase, 0.6–0.65 %Ro and 435–445 °C as early mature phase, 0.65–0.9 %Ro and 445–450 °C as peak phase, 0.9–1.35 %Ro and 450–470 °C as late phase and more than 1.35 %Ro and more than 470 °C as overmature phase.

The hydrocarbon generated from the source rock is known by integrating the combination of hydrogen index (HI), maximum temperature, and vitrinite reflectance. Based on Peters and Cassa [4], rock with hydrogen index more than 600 mgHC/gTOC generates oil, 300–600 mgHC/gTOC also generates oil, 200–300 mgHC/gTOC generates both oil and gas, 50–200 mgHC/gTOC generates gas, and less than 50 mgHC/gTOC generates no hydrocarbon.

The TOC, Tmax and vitrinite reflectance values obtained from each laboratory geochemical data will be plotted against the depth to determine whether the source rock of the study area has good organic material or not. The hydrogen index will be plotted against the maximum temperature based on vitrinite reflectance to determine the generated hydrocarbon form.

2.2. Total organic carbon (TOC) modeling

TOC is one of the main parameters to determine the potential of shale hydrocarbon resources. TOC that obtained from the laboratory geochemical data is discrete. Therefore, calculating the continuous TOC
is an important step that must be taken in evaluating shale hydrocarbons. This study used 3 methods for calculating TOC, those methods are Passey’s method, Multiple Linear Regression, and Neural Network.

2.2.1. Passey’s method (1990). One of the most popular methods for calculating TOC is Passey’s method. Passey’s method, known by $\Delta \log R$ equation, predicts the TOC value by using the relation between deep resistivity and DT (sonic transit time) log and also Level of Maturity (LOM) data. The relationship is shown in equation 1 and equation 2. The baseline data is obtained when DT log overlaid on deep resistivity log with the scaling is 1 logarithmic value of the deep resistivity is same as the 50 value of sonic DT. If there is a crossover between high deep resistivity log and high sonic DT log in the shale lithology, then the area in the crossover is a potential shale gas area [6]. The determination of the baseline i LOM is determined using $\Delta \log R$ and TOC curve (figure 1).

$$\Delta \log R = \log 10 \left( \frac{R}{R_{\text{baseline}}} \right) + 0.02(DT - DT_{\text{baseline}})$$  \hspace{1cm} (1)

$$TOC = (\Delta \log R) 10^{(2.297-0.168\text{BLOM})}$$  \hspace{1cm} (2)

2.2.2. Multiple linear regression. Verma and Marfurt conducted a comparison between the Passey’s method and multiple linear regression to predict TOC logs. The results obtained are the two methods show the same TOC trend but the absolute value of TOC is different [7]. Furthermore Verma and Marfurt stated that the multiple linear regression method gave better results than the Passey’s method. This method uses a direct relationship between well log data and TOC geochemical analysis. Therefore the TOC log model produced is only specific to the study area. While the Passey’s method does not use geochemical TOC data directly in its formulation, but only through the level of maturity.

Figure 1. (a) Determining of DT and deep resistivity baseline, and (b) determining LOM.
The multiple linear regression equation in this study used gamma ray, density, resistivity, DT, and neutron porosity logs as independent variables. The selection of these logs is based on the fact that shale which contains a lot of organic material will have a high gamma ray (GR) value, low density value [8], high resistivity and sonic DT value [6] and high neutron-porosity value relative to neutron-porosity shale [9]. The obtained multiple linear regression equation is shown below:

\[
TOC_{MLR} = -8.18758008 - 0.01230093 \text{GR} + 0.43122104 \text{Resist} + 0.03437825 \text{DT} + 7.51207797 \text{NPHI} + 2.08416727 \text{RHOB}
\]

(3)

2.2.3. Neural network. Neural network (furthermore called Artificial Neural Network) is a mathematical model that is inspired by the workings of the brain's nervous system in processing information by extracting patterns from historical data technology [10]. The neural network is developed under the category of artificial intelligence. The neural network could do an estimation, an identification, a classification or making a decision by a machine program in various conditions [11]. This model consists of a number of processing elements (called neurons) that are interconnected and work together to solve the problem in processing information. Neural networks work based on a model (example) called a training network [12]. The model involves adjusting the connection between input data, hidden layer and output data (prediction). The neural network carried out an iterative process that is not carried out by multiple linear regression. Due to the iterations, therefore, the data generated by the neural network will show the actual conditions in the real world. The optimum iterations number was selected based on training and validation errors. The optimum iterations number is the one which will give the lowest training error [11].

In this study, neural network modelling used interactive petrophysics software. This study model used five input data layers, 1 hidden layer and 1 output layer. The input data are the five logs data which same as that used in multiple linear regression method. Those data were selected based on their relative effect to the laboratory TOC data. Those input data are gamma-ray, density, resistivity, sonic DT and neutron porosity. The output data is data which we want to do an estimation, in this study is TOC [11]. The training process is carried out by determining zones that will be used as models in calculating neural networks. Determination of zones for the model based on which regions represent the good data. In this study, the training zone was chosen based on the depth containing TOC from the laboratory, also based on gamma-ray values that showed shale lithology. Figure 2 shows the process of the training network. The developed TOC was trained in upper Talang Akar formation of X-1 well and was tested in upper Talang Akar formation of X-3 well. Moreover, the correlation for predicting TOC for X-1 and X-3 well should be compared with the laboratory TOC data.

3. Results and discussion

3.1. Geochemical analysis

Figure 3 shows that the upper part of Talang Akar formation in both well can potentially become source rock. The shale containing organic material with fair to good quality. It is ranged from 0.82–2.21 wt% in X-1 well and 0.95–4.85 wt% in X-3 well.

Based on the classification of Peters and Cassa, the early mature phase of the rock is categorized by Tmax value in range 435–445 °C and vitrinite reflectance (Ro) value starts from 0.6 [4]. Based on the curve of Tmax vs depth (shown in figure 3) in the X-1 well, it is shown that the upper Talang Akar shale formation is in the early mature phase. However, there is an anomaly at a depth of 2068 m which shows shale in the immature phase with a Tmax value of 433 °C. But based on the study of Sarjono and Sardjito [5], the South Palembang sub-basin has entered the early mature phase with vitrinite reflectance (Ro) ranged from 0.3–0.4 %Ro and Tmax 422–433 °C. Therefore, based on X-1 well and X-3 well, it can be said that the Talang Akar formation in the study area is mature and begins to enter the early mature phase with Tmax values ranging from 433–441 °C.
Figure 2. Process of the training network

Figure 3. Geochemical analysis of the upper part of Talang Akar formation. Blue oval represents X-1 well, red oval represents X-3 well. (a) TOC as a function of depth, (b) Tmax as a function of depth, and (c) Vitrinite reflectance (Ro) as a function of depth.
Based on the laboratory geochemical data, the X-1 well has a hydrogen index value in the range of 159 to 371 mgHC/gTOC and X-3 well has a hydrogen index value in the range of 191 to 269 mgHC/gTOC. Based on Peters and Cassa classification, the hydrogen index value of 50–200 mgHC/gTOC will generate hydrocarbons in the gas form, while the hydrogen index value of 200–300 mgHC/gTOC will generate hydrocarbons in the oil or gas form. Therefore, the shale of Talang Akar formation for the study area can produce oil or gas in X-1 well and X-3 well. However, based on the Tmax vs. HI curve with reference to vitrinite reflectance (Ro) shown in figure 4, although the Talang Akar formation of the study area contains HI values that can generate gas, the Talang Akar formation of the study area is still included in the oil window phase which will generate hydrocarbons in the oil form.

Based on the crossplot of the geochemical analysis parameters shown in figure 3 and figure 4, it is known that the shale in the upper part of Talang Akar formation in X-1 and X-3 well contain organic material with fair to good quality, mature and will generate the hydrocarbon in oil form.

3.2. Total organic carbon modeling

Figure 5 shows the comparison of TOC from the Passey, multiple linear regression, and Neural Network methods applied to X-1 well and X-3 well. The result shows that the TOC trend of these three methods are almost similar, even though the resulting TOC value is not the same. The Passey’s method gives a good result in X-1 well shown by the correlation is 0.78, but in X-3 well the correlation is not as good as in X-1 well, shown by the correlation is only 0.329. Passey’s method depends on the determination of the baseline and the chosen of the LOM value. Passey’s method will give a good result if the determination of the baseline is correct.

Multiple linear regression method gives a good result in both wells. It is shown by the correlation value between TOC from geochemical data and TOC from multiple linear regression is equal to 0.73 for X-1 well and 0.75 for X-3 well. Although the results obtained are quite good, but basically not all equations in the real world conditions are in the form of linear equations. Therefore, although the trends and correlations obtained from multiple linear regression in this study field are quite good, the value obtained is not necessarily in accordance with the actual conditions in this study field.

![Tmax vs HI](image)

**Figure 4.** Geochemical analysis of the upper part of Talang Akar formation. The relationship between Tmax and hydrogen index of (a) X-1 well, and (b) X-3 well.
Figure 5. Comparison of TOC passey, TOC multiple linear regression and TOC neural network of (a) X-1 well, and (b) X-3 well.
Basically, the work process of neural networks is better than multiple linear regression even though it uses the same input data. This is because multiple linear regression assumes all input data have a linear relationship. Even though the facts in the real world conditions are not all data related linearly. Multiple linear regression involves binding between data, calculating the dependent variable based on the independent variable (well log data). While the neural network is a non-linear regression and works based on the model from the field and the calculation is iterative.

The correlation generated from the TOC neural network vs. TOC lab for X-1 well and X-3 well are 0.96 and 0.84 respectively. It is believed that the TOC prediction using the Neural network method produces better data than the Passey’s and multiple linear regression methods.

4. Conclusion
Geochemical analysis shows that the shale in the upper Talang Akar formation on the X-1 Well contains quite potential organic material and in X-3 well has the potential to become source rock, organic material is mature and generates hydrocarbon in the oil form. The TOC ranged from 0.82–2.21 wt% in X-1 well and 0.95–4.85 wt% in X-3 well. TOC modeling using 3 methods shows that TOC modeling with neural network method is the best method for calculating TOC log models in the upper Talang Akar formation of the study area. The correlation obtained in X-1 well is 0.96 while the correlation in X-3 well is 0.84.

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References
[1] Ginger D and Fielding K 2005 Proceedings of the Annual Convention - Indonesian Petroleum Association in Annual convention; 30th, Indonesian Petroleum Association (Jakarta: IPA)
[2] Perbawa A Kusuma B and Winardhi S 2012 Integration of Seismic Inversion, Pore Pressure Prediction, and TOC Prediction in Preliminary Study of Shale Gas Exploration in PROCEEDINGS PIT HAGI 2012, 37th HAGI Annual Convention & Exhibition (Palembang: Proceedings PIT HAGI)
[3] Haris A et al. 2018 Unconventional resources of hydrocarbon in Sumatra Basin, Indonesia in Shale Gas-New Aspects and Technologies (Web Science: IntechOpen)
[4] Peters K E and Cassa M R 1994 Applied Source Rock Geochemistry, Chapter 5 in The Petroleum System (USA: AAPG Memoir 60)
[5] Sarjono S and Sardjito 1989 18th Ann. Conv. Proc. 1 427-67
[6] Passey Q R Moretti F J Kulla J B Creany S and Stroud J D 1990 American Assoc. Petrol. Geol. Geol. 74 ISSN 0149-1423
[7] Verma S and Marfurt K 2014 A Way of TOC Characterization on Barnett and Woodford Shale (Pittsburgh : AAPG Annual Convention and Exhibition) Article #80429
[8] Schmoker J W 1979 Am. Assoc. Petrol. Geol. Bull. 63 1504-37
[9] Heslop K A 2010 Generalized Method for the Estimation of TOC from GR and Rt available at http://www.searchanddiscovery.com/documents/2010/80117heslopndx_heslop.pdf
[10] NeuroSolutions 2015 The Premier Neural Network Software available at http://www.neurosolutions.com/
[11] Mahmud A A A et al. 2017 Int. J. Coal Geol. 197 72-80
[12] Senergy Software Ltd 2013 Interactive Petrophysics User Manual (Scotland: Senergy Ltd)