Identification of Hydrocarbon Gas and Discriminate CO_2 Using Lame Parameter and Batzle-Wang Model

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Abstract. Drilling activities in 2016 were carried out at 34 points with only achieving a success ratio of 26%. It affects the decreasing in natural gas reserves. In addition, the presence of CO_2 raises problems during production and environmental problems. So, it is necessary to identify hydrocarbon gas and to discriminate CO_2. The method used for gas identification is the Lame parameter where the parameters can distinguish the effects caused by lithology and fluid. The Batzle-Wang model is applied to distinguish between hydrocarbon gases and CO_2 gas by estimating the fluid's properties of CO_2 gas. Based on the analysis of result the parameters Lambda-Rho and Mu-Rho, both parameters can distinguish the lithology and identify the hydrocarbon fluid content. The area around the C4 is indicated hydrocarbon in 9930 - 10000 ft depth with Lambda-Rho 30 – 31.79 GPa*g/cc and Mu-Rho 27 – 43 GPa*g/cc. Based on the Batzle-Wang *Vp* analysis, saturated CO_2 gas is vulnerable at 16000-17000 ft/s where it is still in range *Vp* saturated hydrocarbon gas and distributed around the C4 well based on LMR analysis.

Keywords: **Hydrocarbon gas; CO_2; Lame Parameter; Batzle-Wang Model.**

1 Introduction

Natural gas is a fossil fuel containing mixture hydrocarbons which have the main composition of methane and the rest are ethane, propane, butane, isobutene, and pentane. Besides hydrocarbons, natural gas also contains impurity gases such as helium, nitrogen, carbon dioxide, and other carbon [1]. Natural gas is established by three processes which are Thermogenic, Biogenic, and Abiogenic. Thermogenic is a process caused by high pressure and temperature. Biogenic is caused by the decomposition of organic material and Abiogenic caused by the chemical reaction between H_2 and C [2].

Components of natural gases that can be used to be fuel are methane and propane. Methane can be used as LNG (liquefied natural gas) material and propane is used as LPG material. However, drilling activities in 2016 were carried out at 34 points with only achieving a success ratio of 26%. It affects the decreasing in natural gas reserves in the amount of 7.27 TSCF compares to 2015 [3]. In addition, the presence of CO_2 raises problems during production such as cause's corrosion on pipe production, burning problems at gas burner tower, and decreasing selling value and need more investment. Besides that, it also raises an environmental problem, because CO_2 causes the greenhouse effect [4]. So, it is necessary to identify hydrocarbon gas and discriminate the CO_2.

The method used for gas identification is the Lame parameter where the parameters can distinguish the effects caused by lithology and fluid. The lame parameter consists of Lambda-Rho and Mu-Rho. Lambda-Rho is representation rock incompressibility that sensitive to fluid type and Mu-Rho is representation rigidity of rocks. The Lame parameter can be obtained by simultaneous inversion which is a prestack method that uses reflection attributes from P wave, S wave, and Density [5]. The Batzle-Wang model is applied to distinguish between hydrocarbon gases and CO_2 gas by estimating the fluid's properties of CO_2 gas. The fluid properties are estimated Bulk Modulus of gas (K_g), and gas density (ρ_g) that influenced by temperature, pressure, and specific gravity [6].

The location of this study is in the field "A" located in the North Sumatra Basin. Based on Figure 1, the formation of the basin begins during the Late Eocene by depositing the Tampur Formation with thick clastic sequence and carbonate. The structure temporary period relaxation during the Early Oligocene and re-active during the Late Oligocene. Thick deposits of the Bampo-Burkash sequence were deposited in the lowest position with the development of reef carbonates within the basin margin during this stage.

During Lower Miocene occurs the rifting decelerates and subsequent transgression, submerging the paleo highs and marked the post-rift parts in North Sumatra Basin. The deposition of the Peutu limestone and Belumai sandstone equivalent occurred within the highs.

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Meanwhile, the basinal carbonate and shale were deposited within the lows and submerged platforms. The transgression continues until Lower-Middle Miocene. It is marked by backstepping carbonate deposition towards the Mallaca Platform. The latest tectonic activity occurred since Middle Miocene to present which is characterized by predominant compression, uplift, basin shoaling, and reversal of sedimentation direction [7].

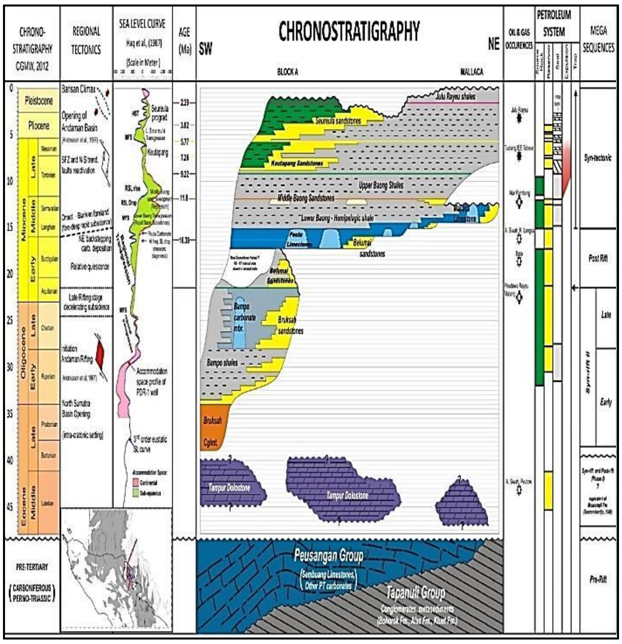

Fig. 1. Chronostratigraphy of North Sumatra Basin [7]

2 Basic Theory

2.1 Simultaneous Inversion

The seismic AVO method is a basic of simultaneous inversion. Simultaneous inversion is a dependence inversion because it works as suspended and simultaneous while estimate P and S impedance. It combines partial seismic angle stack as simultaneous with low-frequency model and convoluted by wavelet that extracts from each angle stack to get P and S Impedance and density. Then, P, S impedance, and density are transformed to *Vp*/*Vs* ratio, Lambda-Rho, and Mu Rho [8].

2.2 Lame Parameter

The Lame parameter is consisting of two parameters, which are rigidity and incompressibility. It is caused by the relation between stress and strain at a medium. Parameter Lambda-Rho and Mu-Rho can be formulated by *Vp* and *Vs* equation [5]

$$V_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} \tag{1}$$

$$(V_p \rho)^2 = \lambda\rho + 2\mu\rho \tag{2}$$

$$V_s = \sqrt{\frac{\mu}{\rho}} \tag{3}$$

Because incompressibility is related to *Vp* and *Vs*, then Lambda-Rho equation is

$$\lambda\rho = (V_p \rho)^2 + 2(V_s \rho)^2 \tag{4}$$

and for Mu-Rho equation is

$$\mu\rho = (V_s \rho)^2 \tag{5}$$

Incompressibility modulus with a density scale (Lambda-Rho) is representation fluid presence. If there is a porous rock with oil or water-saturated getting to press, then the fluid will hold the pressure. It causes the rock being more incompressible. If the rock contains gas, then the rock is easy to compress. It causes the value of incompressibility getting low.

Mu or shear modulus is an ability of the rock to hold a shear pressure and shear strain. If the rock gets shear pressure, so the matrix of the rock will shift and change the shape but not changing the volume, then the rock has a low value of Mu or the rock is ductile. Otherwise, if the matrix of the rock not shifting and not changing the shape, then the rock has a high value of Mu or the rock is rigid.

2.3 Batzle-Wang

Batzle-Wang Model combines the thermodynamic and empirical tendencies of the provided data to predict the effects of pressure, temperature, and composition of the seismic properties on the fluid. The fluid properties include bulk density and modulus as a function of fluid temperature and pressure when the fluid composition is known or estimated. For applications of the Batzle and Wang models, it is assumed that at each point below the bubble point, the resulting gas has the properties or composition as same as the total gas found at the surface conditions. This means that there is no variation in the composition of the gas produced during production. The application of this model also assumes that both oils are left as a fluid after the loosened gas (under bubble point) has the composition as same as Live Oil from its origin, or the fluid is saturated with as much gas as possible for certain conditions [6].

2.3.1 Gas Model

The gas model is influenced by specific Gravity (G), Bulk Modulus of gas (K_g), and gas density (ρ_g). The elastic parameters of gas can be calculated by equation below [9].

$$K_s = \frac{p}{\left(1 \frac{p_{pr}}{z}\frac{\partial z}{\partial p_{pr}}\right)_T}\gamma_0 \tag{6}$$

Where γ_0 is the ratio of heat capacity at constant pressure to heat capacity at constant volume.

$$\gamma_o = 0.85 + \frac{5.6}{(P_{pr}+2)} \frac{27.1}{(P_{pr}+3.5)^2} - 8.7\exp[-0.65(P_{pr}+1)] \quad (7)$$

P_{pr} or pseudo reduced pressure is obtained from the calculation of P_{pc} (pseudocritical pressure)

$$P_{pr} = \frac{P}{P_{pc}} \quad (8)$$

$$P_{pc} = 4.892 - 0.404G \quad (9)$$

$$\rho_g = \frac{28.8GP}{ZRT_a} \quad (10)$$

Where R is a gas constant with values 8.3145 m-^{3}Pa/(mol-K)) and T_a is temperature in Kelvin.

$$T_a = T + 273.15 \quad (11)$$

$$T_{pr} = \frac{T_a}{T_{pc}} \quad (12)$$

$$T_{pc} = 94.72 + 170.75G \quad (13)$$

Where T_{pr} is pseudo reduced temperature and T_{pc} (pseudocritical temperature) is temperature when the phase cannot be distinguished.
z is a compressibility factor given by equation

$$z = \left[0.03 + 0.00527\left(3.5 - T_{pr}\right)^3\right] P_{pr} + \left(0.642T_{pr} - 0.007{T_{pr}}^4 - 0.52\right) + E \quad (14)$$

$$E = 0.109(3.85 - T_{pr})^2 exp\left\{-\left[0.45 + 8\left(0.56 - \frac{1}{T_{pr}}\right)^2\right]\frac{{P_{pr}}^{1.2}}{T_{pr}}\right\} \quad (15)$$

$$\frac{\partial z}{\partial P_{pr}} = A + 0.1308\left(3.85 - T_{pr}\right)^2 \exp\left(B{P_{pr}}^{1.2}\right) B{P_{pr}}^{0.2} \quad (16)$$

$$A = 0.03 + 0.00527\left(3.5T_{pr}\right)^3 \quad (17)$$

$$B = \left(\frac{-1}{T_{pr}}\right)\left[0.45 + 8\left(0.56 - \frac{1}{T_{pr}}\right)^2\right] \quad (18)$$

3 Methodology

The methodology is to determine P, S Impedance, and density using Simultaneous Inversion to transformed into Lame Parameter to the identification distribution of hydrocarbon gas. Then, calculating the bulk modulus and density of CO_2 use Batzle-Wang and transformed into *Vp*. After that, calculating the Lame Parameter of CO_2 to discriminate hydrocarbon gas to CO_2 gas.

4 Result And Discussion

4.1 Well Data Analysis

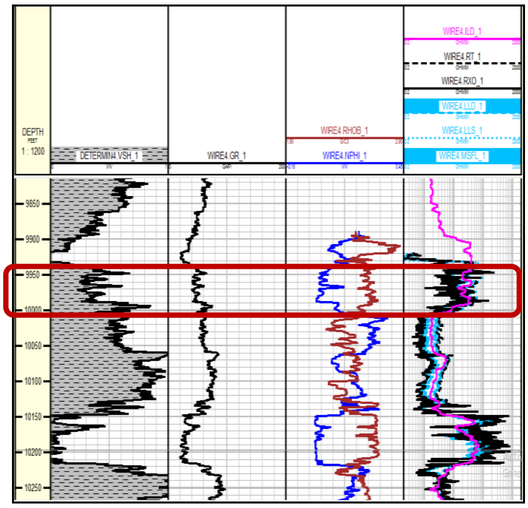

Fig. 2. Target zone based on well data analysis gamma ray and resistivity log in well C4.

Well, data (Fig. 2) from depth 9930 until 10000 ft show that the value of gamma-ray is low approach 40 GAPI. It means the zone is permeable with lithology is Carbonate. The value of the resistivity log shows a high value, which means the zone may contain hydrocarbon. The hydrocarbon cannot drain the electricity, hence the zone may contain hydrocarbon that has high resistivity log values.

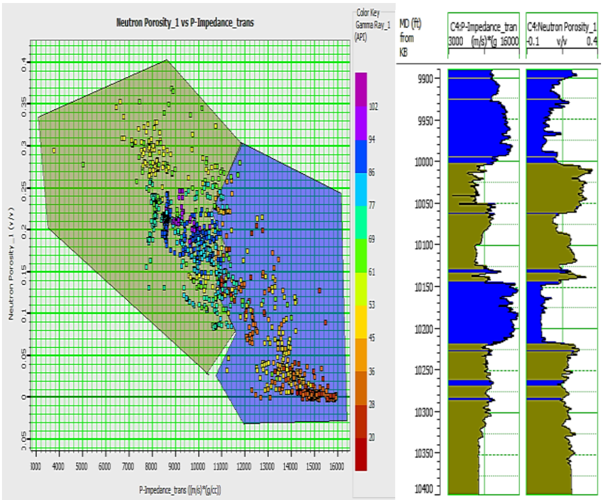

Fig. 3. P Impedance vs NPHI with Gamma Ray as a color key Cross Plot and Cross Section

The zone division considering the content of the shale characterized by gamma-ray. Based on Fig. 3, the green zone is a shale zone with high gamma-ray, higher porosity, and low P-impedance value. It occurs because of the nature of shale is a fairly elastic while P waves propagate in a medium shale. Other zones namely blue represent carbonate with a value of gamma-ray and porosity small but have a large impedance value due to the compact nature of carbonate.

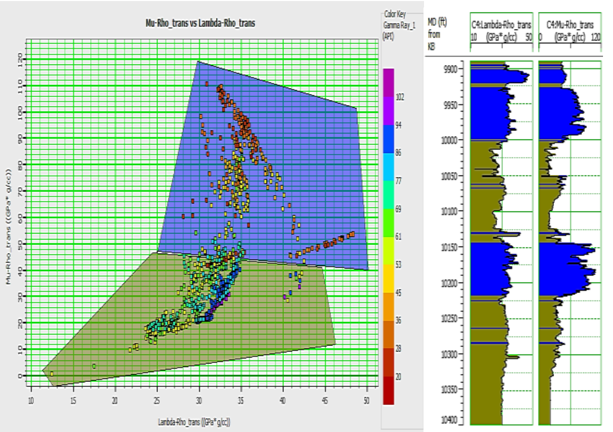

Fig. 4. Lambda-Rho vs Mu-Rho with Gamma Ray as a color key Cross Plot and Cross Section

The parameter Lambda-Rho is sensitive to the effects of fluid contained in rock, while Mu-Rho is sensitive to changes in lithology. Fig. 4 shows the result of a cross plot between Lambda-Rho and Mu-rho with the color key is gamma-ray. The results of the cross plot can be divided into two zones, namely the green zone is the shale zone and the blue zone is the carbonate zone. Same as cross plot Porosity with P impedance, zone division considers the shale content marked by gamma ray log. Shale is zoned in green because it has a small Mu-Rho value which indicates the elastic of the rock while the carbonate is zoned blue because it has a high Mu-Rho value which signifies the compact of the rock.

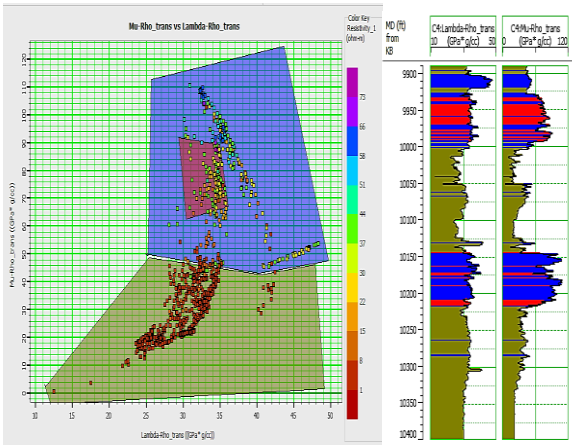

Fig. 5. Lambda-Rho vs Mu-Rho with Resistivity as a Color Key Cross Plot and Cross Section

The determination of the distribution of the hydrocarbon content zone is determined based on the cross plot between Lambda-Rho and Mu-Rho with the color key is Resistivity. Resistivity is used to be a color key because it is a fluid sensitive parameter. Figure 5 shows zones containing hydrocarbons are shown in the red zone, which is a zone with high Resistivity. From the results of the cross plot, it can be seen that around well C4 may contain a lot of hydrocarbons at 9930-10000 ft depth.

4.2 Seismic Analysis

4.2.1 Hydrocarbon Gas Identification

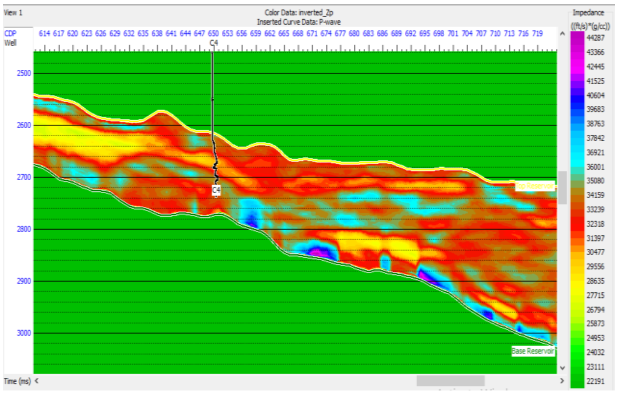

Fig. 6. P Impedance Inversion Cross Section

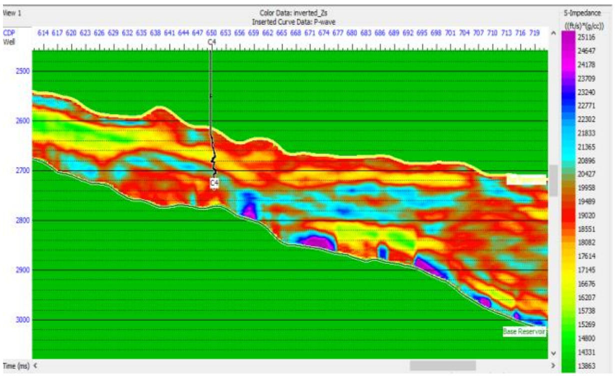

Fig. 7. S Impedance Inversion Cross Section

Fig. 6 and Fig. 7 indicate that the target zone has a high value. P impedance has value around 31000 – 36000 ft/s*g/cc and S impedance in 18000 – 21000 ft/s*g/cc. It indicated that lithology is carbonate because of its compact carbonate characteristics.

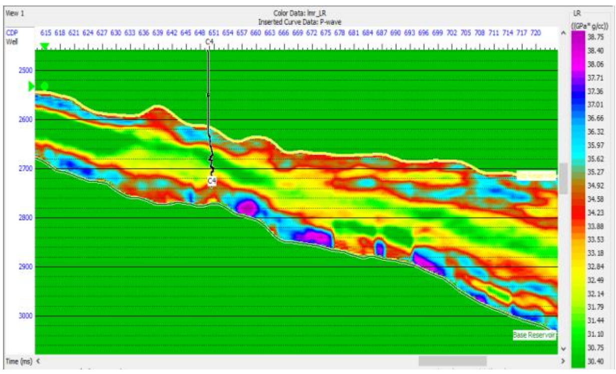

Fig. 8. Lambda-Rho Cross Section

The results of simultaneous inversion which is then transformed to LMR, it will produce a cross-section of Lambda-Rho and Mu-Rho. Mu-Rho parameter is only influenced by S waves and Density so that these parameters are sensitive to lithological changes. Meanwhile, Lambda-Rho is influenced by P waves, S waves, and Density so that the parameters are sensitive to the presence of hydrocarbons especially gas.

Lambda-Rho cross-section (Fig. 8) is known that around well C4 shows a cross-section that has a more dominant green. Areas with green colors show a zone with a carbonate layer which has a fluid content with low water saturation. Because Lambda-Rho in the green zone shows a low value in the range 30 – 31.79 GPa*g/cc. Supported by the results of a cross plot between Lambda-Rho and Mu-Rho on the well, it shows that the C4 well contains a lot of fluid. The reservoir rock around well C4 has a lithology more porous, so that it may contain more fluid.

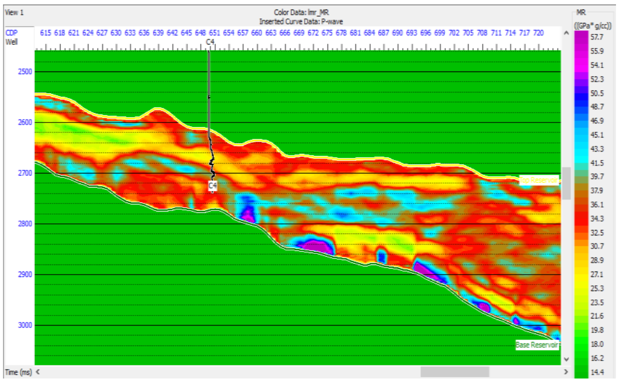

Fig. 9. Mu-Rho Cross Section

Based on the elastic parameters of Mu-Rho which are elastic parameters that are sensitive to lithological changes, it is seen in the Mu-Rho cross section (Figure 9) that the area around wells C4 has high Mu-Rho value with a range of 27 – 43 GPa*g/cc. This shows that the target zone is the reservoir character of carbonate. In addition, supported by the results of cross plot well data between Lambda-Rho and Mu-Rho shows that the target zone is a carbonate.

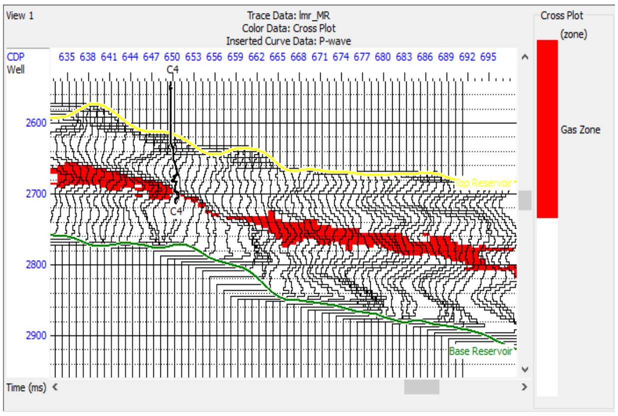

Fig. 10. Gas Zone Cross Section

The cross plot between Lambda-Rho and Mu-Rho gives a clearer picture of the gas zone. The zone has a low lambda-rho value and high Mu-Rho value. It is shown in the red zone in Fig. 10.

4.2.2 CO_2 Identification

The first step to identify CO_2 is calculating bulk modulus and density of CO_2 using Batzle-Wang. It aims to characterize the CO_2.

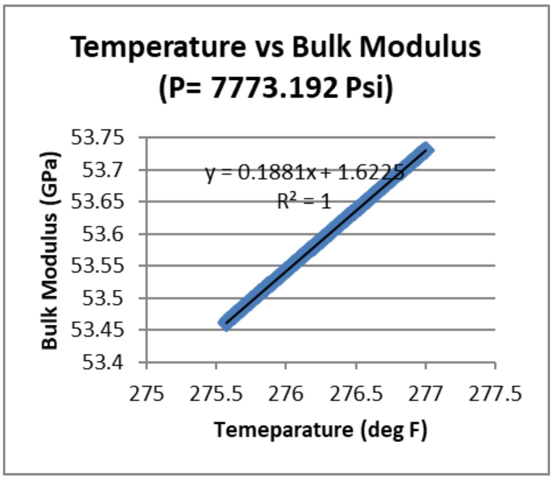

Fig. 11. Bulk Modulus of CO_2

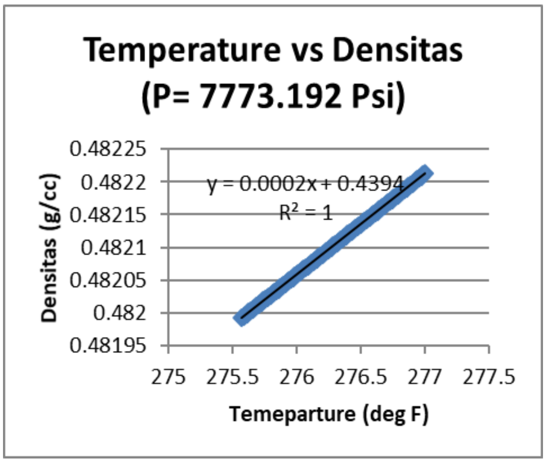

Fig. 12. Density of CO_2

Fig. 11 and Fig. 12 show that bulk modulus and density of CO_2 are increases as temperature increasing as well. The increasing temperature is correlated to depth increasing. It means that the CO_2 is denser when the depth increases. After obtaining the bulk modulus and density of CO_2, the value of *Vp* CO_2 saturated can be calculated.

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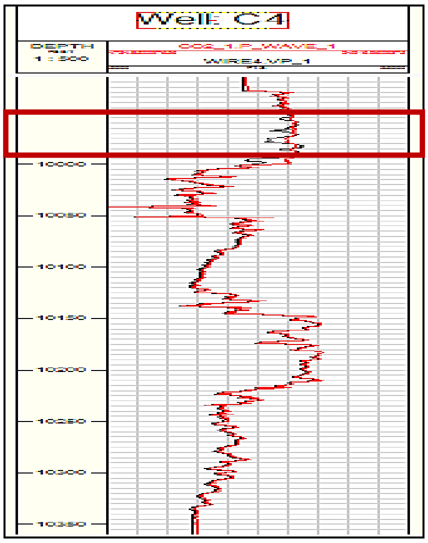

Fig. 13. *Vp* CO_2 saturated Compare to *Vp* Hydrocarbon Gas Saturated

Vp of CO_2 saturated *Vp* of gas fluid-saturated is different (Fig. 13). The differences indicate that the CO_2 gas saturation has a high P wave velocity with a value of 16000 – 17000 ft/s, while *Vp* at the gas zone (9930 – 10000 depth) 14000 – 18000 ft/s. It is caused by a high value of CO_2 Specific Gravity, so it makes CO_2 gas heavier and denser. So it can be concluded that in C4 wells containing CO_2 gas. It is also supported by the results of lab analysis, which shows a CO_2 content of 28% of the overall gas composition.

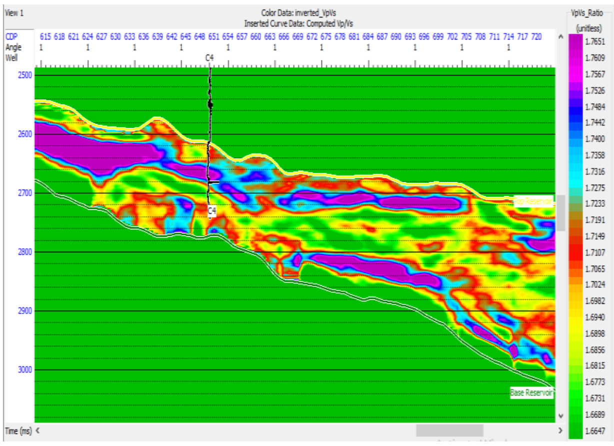

Fig. 14. Lambda-Rho of CO_2 Cross Section

Lambda-Rho cross-section in Figure 14 shows the value in range 31.01 – 31.33 GPa*g/cc. It means that the lambda-rho value of CO_2 is in the range of Lambda-Rho hydrocarbon gas values. But, the value of CO_2 in a higher range, that because CO_2 has a high specific gravity.

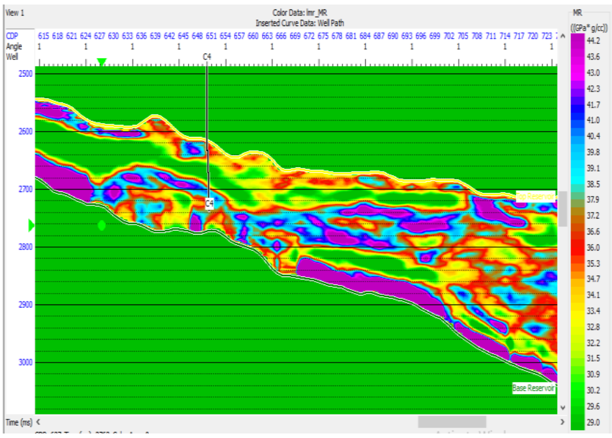

Fig. 15. Mu-Rho of CO_2 Cross Section

On the other hand, the Mu-Rho cross-section (Fig. 15) shows the value in range 29 – 42 GPa*g/cc. Same as Lambda-Rho of CO_2, the Mu-rho value of CO2 is in the range of Mu-Rho hydrocarbon gas values. Because elastic parameters of Mu-Rho are elastic parameters that are sensitive to lithological changes and do not influence by the presence of fluid.

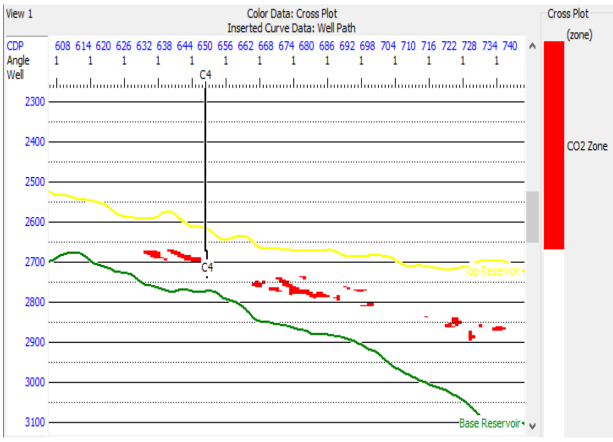

Fig. 16. CO_2 Gas Zone Cross Section

Based on the result of cross plot between Lambda-Rho and Mu-Rho gives a clearer picture of the CO_2 zone. The CO_2 zone has a low Lambda-Rho value and high Mu-Rho value. It is shown in the blue zone. Compared to the gas zone, the CO_2 zone has similarity but thinner as shown in Fig. 16.

5 Conclusion

Based on the results of the parameters Lamda-Rho and Mu-Rho, both parameters can distinguish the lithology and identify the hydrocarbon fluid content. The area around the C4 is hydrocarbon indicated in 9930 - 10000 ft depth with Lambda-Rho 30 – 31.79 GPa*g/cc and Mu-Rho 27 - 43 GPa*g/cc. Based on the Batzle-Wang *Vp* analysis, saturated CO2 gas is vulnerable at 16000 - 17000 ft/s where it is still in the range of *Vp* saturated hydrocarbon gas. CO_2 distribution in the reservoir is around the C4 well based on LMR analysis.

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References

1. V. Chandra, *Fundamentals of Natural Gas*, India: PennWell (2006)
2. S. Purwono, *The Role of Fossil Based Natural Resources for Human Life and How to Overcome the Deficiencies with Enhanced Oil Recovery,* Faculty of Egineering UGM (2008)
3. Anonim, *Oil and Gas Statistics*, Jakarta: Direktorat Jenderal Minyak dan Gas Bumi (2016)
4. Anonim, *The Options for Fiscal Policy and Carbon Storage in the Oil and Gas Industry in* Indonesia, Makalah Diskusi. Jakarta: Kemeterian Keuangan (2015)
5. B. Goodway, *AVO and LAMÉ Constants for Rock Parameterization and Fluid Detection*, CSEG Recorder (2001)
6. M. Batzle, Z. Wang, *Seismic Properties of Pore Fluids*. Geophysic. **57**, 1396–1408 (1992)
7. I.Y. Syarifuddin, P. Ariyanto, *Tectono-Stratigraphy of Block a Area, North Sumatra Basin: The Impact of Local Tectonics and Eustasy to Accomodation Space of the Tertiary Interval*, Indonesian Petroleum Association (2018)
8. S. Sukmono, *Seismic Inversion for Reservoir Characterization*. Institut Teknologi Bandung, Bandung (2002)
9. M.S. Rosid, M. Iksan, R. Wardhana, M.W. Haidar, *Fluid Characterization Based on Intrinsic Properties Analysis of Fluid Using Adaptive Batzel-Wang Method on Field "M"*, 1st International Congress on Earth Sciences (2019)