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Reflectivity of P-Wave Analysis for Fractured Reservoir Characterization in HTI Medium

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Abstract: Nowadays, fracture is crucial issues for reservoir characterization because it is a main factor to control the fluid flow and has a correlation with permeability of the rock in the reservoir. Reflectivity of P-wave or known by, AVO analysis is a popular method that is used in industry to characterize the reservoir. However, for reservoir with fractures (fractured reservoir), AVO analysis for isotropy medium will give the inaccuracy result because fractures induce anisotropy so anisotropy parameter should be considered to characterize the fractures. AVOZ analysis was applied for fractures characterization including its parameter (orientation, intensity and fluid-filling) to know the behavior of fracture in HTI medium. In this study, we get that AVOZ analysis is more accurate than AVO for isotropy medium to characterize the fracture in HTI medium. In addition, by using AVOZ analysis fractures, its parameters could be characterized. Fractures that have same orientation with symmetry axis of plane will have lower anisotropy reflectivity and it will increase until the azimuth angle is perpendicular with symmetry axis.

Key words: Thomsen's parameters, anisotropy, isotropy, fractures

INTRODUCTION

The existence of fractures in reservoir will influence the physical properties of the reservoir. Since, the fractures induce the anisotropy, its mean, the existence of fractures in reservoir will cause the reservoir to become anisotropic medium. Isotropic medium has different characteristics with anisotropic medium. One of them is Thomsen's parameters that influence the characteristic of anisotropic medium and we can't find Thomsen's parameters in isotropic medium (Thomsen, 1986). Thus, reflectivity of P-wave, that propagates in anisotropic, will be different with reflectivity of P-wave from isotropic medium. Therefore, to characterize the reservoir with fractures (fractured reservoir) there is need of different method so that fractures and its parameters (orientation, intensity and fluid filling) in the reservoir could be appropriately characterized.

Amplitude versus offset or angle is a popular method to characterize hydrocarbon. Many researchers have published their study about AVO for reservoir characterization. However, it is just effective if applied for isotropic medium. To characterize fractures within reservoir with its parameters, Thomsen's parameter should be considered. Thus, AVO calculation should be modified for fractures characterization (Ruger, 1997). Besides Vp, Vs, density (ρ) or Poisson ratio (σ), other parameters should be included for AVO calculation to characterize the fractures are epsilon (ε), delta (δ) and gamma (γ). In this study, we will study the effect and behavior of fractures against reflectivity in anisotropy environment with vertical aligned or known by HTI medium. HTI medium is a kind of transversely isotropic medium in which the fractures within this medium is vertically aligned.

From this study, we expect that we can see, learn and comprehend the character and behavior of reflectivity of P-wave that propagating in HTI medium (azimuthal anisotropy reflectivity). Later on, the character and behavior of P-wave reflectivity will be used to characterize the fractures inside the reservoir with its parameter (orientation, intensity and type of fluid-filling the fractures) especially for HTI medium.

BASIC THEORY OF FRACTURES

Anisotropy: Anisotropy is a condition of a medium in which the character of the medium is influenced by mineral configuration, pores, fractures or cracks, etc. Thereby, the wave that propagating in the medium will be varied and dependent against angle. It is known as seismic anisotropy (Thomsen, 2002). There is several kind

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of anisotropy medium and in this study, we just discuss an anisotropic medium that is transversely isotropic medium with vertically aligned and horizontal symmetry axis or known by Horizontal Transversely Isotropic medium (HTI). Simply, in HTI medium, we assume the fractures is vertically aligned.

Hudson's penny-shaped model: Hudson's penny-shaped Model is a fractures theory that assumes the fractures inside the medium caused by crack inwhich the shaped of cracks is penny-shaped with vertically constructed (Hudson, 1980). Hudson's describe the structure of fractures by using crack density and aspect ratio of sphereroidal cracks (Hudson, 1990, 1994). Crack density is total of fractures or crack inside the medium. By knowing the value of the crack density, we will know the intensity of cracks or fractures in a reservoir. In addition, aspect ratio of the cracks will help us to know the dimension of crack and fractures and it will help us to do interpretation and characterization of fractures.

Schoenberg's linear-slip model: Schoenberg's linear-slip model is other fractures theory defined by Schoenberg and Douma (1988). Schoenberg assumes that fractures in medium are infinitely thin and highly compliant layers or planes weakness with linear-slip. From this model, Hsu and Schoenberg (1993) defined 2 kind of dimensionless constant to know the physical properties of fractures that are N and T. N will bring out the information about type of fluid that filling the cracks or fractures while, T brings the information about crack intensity or intensity of fractures in a reservoir.

FORWARD MODELING OF AVOZ (AMPLITUDE VERSUS OFFSET AND AZIMUTH) IN HTI MEDIUM

A workflow had designed and carried out in this study. We started study by analyze the elastic stiffness tensor in HTI medium and correlate with Hudson's penny-shaped crack model and Schoenberg's linear-slip model. The analysis of the stiffness elastic tensor, Hudson's penny-shaped crack model and Schoenberg's linear-slip model was purposed to obtain the anisotropic level of this medium, the physical properties of fractures and Thomsen's parameter were later used to calculate and analyze the azimuthal anisotropic reflectivity of the medium or known by AVOZ.

Ruger's approximation for HTI medium is used for calculating the azimuthal anisotropic reflectivity in this study (Ruger, 1997). P-wave reflectivity of HTI medium is a total of reflectivity in isotropic environment with reflectivity in anisotropic environment as mentioned in Eq. 1:

$$Rp(\varphi,\theta) = Rp_{isotropic}(\theta) + Rp_{anisotropic}(\varphi,\theta) \quad (1)$$

Here, azimuthal anisotropic reflectivity is function of azimuth (φ) and incident angle (θ). Reflectivity in isotropic is depended on P-wave velocity (Vp), s-wave velocity (Vs) and density (ρ) whereas, the reflectivity in anisotropic besides depend on to Vp, Vs and ρ also influenced by Thomsen's parameter that is epsilon (ε), delta (δ), gamma (γ). Thomsen's parameter will influence second and third term in amplitude calculation.

AVOZ forward modeling was carried out to several simple model of fractured reservoir with physical properties of each model as shown in Table 1-6.

Table 1: Physical properties of model 1

Parameters	Values
Vp of layer 1 (m sec^{-1})	4561
Vs of layer 1 (m sec^{-1})	2988
ρ of layer 1 (kg m^{-3})	2670
Vp of layer 2 (m sec^{-1})	4860
Vs of layer 2 (m sec^{-1})	3210
ρ of layer 2 (kg m^{-3})	2320
crack density (e)	0.1
Aspect ratio of cracks	0.01
Bulk modulus of fluid (Pa)	0.93×109
Shear modulus of fluid (Pa)	0
Incident angle	0:50
Azimuth	0, 30, 45, 60, 90

Table 2: Physical properties of model 2

Parameters	Values
Vp of layer 1 (m sec^{-1})	4561
Vs of layer 1 (m sec^{-1})	2988
ρ of layer 1 (kg m^{-3})	2670
Vp of layer 2 (m sec^{-1})	4860
Vs of layer 2 (m sec^{-1})	3210
ρ of layer 2 (kg m^{-3})	2320
crack density (e)	0.1
Aspect ratio of cracks	0.01
Bulk modulus of fluid (Pa)	2.2×109
Shear modulus of fluid (Pa)	0
Incident angle	0:50
Azimuth	0, 30, 45, 60, 90

Table 3: Physical properties of model 3

Parameters	Values
Vp of layer 1 (m sec^{-1})	4561
Vs of layer 1 (m sec^{-1})	2988
ρ of layer 1 (kg m^{-3})	2670
Vp of layer 2 (m sec^{-1})	4860
Vs of layer 2 (m sec^{-1})	3210
ρ of layer 2 (kg m^{-3})	2320
crack density (e)	0.2
Aspect ratio of cracks	0.01
Bulk modulus of fluid (Pa)	0.93×109
Shear modulus of fluid (Pa)	0
Incident angle	0:50
Azimuth	0, 30, 45, 60, 90

Table 4: Physical properties of model 4

Parameters	Values
Vp of layer 1 (m sec^{-1})	4561
Vs of layer 1 (m sec^{-1})	2988
ρ of layer 1 (kg m^{-3})	2670
Vp of layer 2 (m sec^{-1})	4860
Vs of layer 2 (m sec^{-1})	3210
ρ of layer 2 (kg m^{-3})	2320
crack density (e)	0.2
Aspect ratio of cracks	0.01
Bulk modulus of fluid (Pa)	2.2×109
Shear modulus of fluid (Pa)	0
Incident angle	0:50
Azimuth	0, 30, 45, 60, 90

Table 5: Physical properties of model 5

Parameters	Values
Vp of layer 1 (m sec^{-1})	4561
Vs of layer 1 (m sec^{-1})	2988
ρ of layer 1 (kg m^{-3})	2670
Vp of layer 2 (m sec^{-1})	4860
Vs of layer 2 (m sec^{-1})	3210
ρ of layer 2 (kg m^{-3})	2320
crack density (e)	0.1
Aspect ratio of cracks	0.1
Bulk modulus of fluid (Pa)	0.93×109
Shear modulus of fluid (Pa)	0
Incident angle	0:50
Azimuth	0, 30, 45, 60, 90

Table 6: Physical properties of model 6

Parameters	Values
Vp of layer 1 (m sec^{-1})	4561
Vs of layer 1 (m sec^{-1})	2988
ρ of layer 1 (kg m^{-3})	2670
Vp of layer 2 (m sec^{-1})	4860
Vs of layer 2 (m sec^{-1})	3210
ρ of layer 2 (kg m^{-3})	2320
crack density (e)	0.1
Aspect ratio of cracks	0.1
Bulk modulus of fluid (Pa)	2.2×109
Shear modulus of fluid (Pa)	0 Pa
Incident angle	0:50
Azimuth	0, 30, 45, 60, 90

Here, model 1 and model 2, model 3 and model 4 and model 5 and model 6 are two differences model that different on kind of fluid-filling cracks or fractures respectively which model 1, model 3 and model 5 are filled by gas and model 2, model 4 and model 6 are filled by water.

Although, model 1, model 3 and model 5 are same models in type fluid-filling the cracks and fractures however, the physical properties of the fractures are different in crack density and aspect ratio of cracks. Here, the crack density and aspect ratio of model 1, model 3 and model 5 are 0.1 and 0.01, 0.2 and 0.01 and 0.1 and 0.1, respectively. It is same with model 2, model 4 and model 6 in which the differences of these models are the physical properties of the cracks.

We calculated the stiffness tensor and Thomsen's parameters of each model before we calculated the AVOZ response. We try to analysis the variation of amplitude from the result 0° until 50° of incidence angle and the azimuth are 0°, 30°, 45°, 60° and 90°.

RESULTS AND DISCUSSION

The reflectivity (AVO) in isotropic environment is so different with the reflectivity (azimuthal anisotropic reflectivity) in anisotropic medium. In isotropic environment, the reflectivity will bring out kind of fluid information in the reservoir. In anisotropic environment, besides the information of fluid filling, the azimuthal anisotropic reflectivity also brings out the information about the orientation of fractures and intensity of the fractures in the reservoir to the interpreter. Here, we will discuss the relationship among reflectivity, fracture orientation, fracture intensity and fracture fluid-filling.

Fractures orientation: Fractures orientation is one parameter that is discussed in this study. Orientation of fractures will give the different response of reflectivity. Besides the effect of Thomsen's parameters, azimuthal anisotropy reflectivity is influenced by azimuth in which azimuth is a parameter to determine the orientation of the fractures in a reservoir. Figure 1 and 2 show the difference of reflectivity response of each azimuth.

The azimuthal anisotropy reflectivity response will be different compared by isotropy response. In addition, every azimuth will give the difference response to each other. Figure 1 and 2 show the azimuthal anisotropy reflectivity caused by the azimuth with the high value (90° from the symmetry axis) that will display the higher response than other azimuth value and it will decreases properly until the value of azimuth is 0°. The 0° of the azimuth mean the direction of seismic line is same with the symmetry axis while the 90° of the azimuth mean the direction of seismic line is perpendicular with the symmetry axis. By analyzing the direction of the seismic line (azimuth parameter), we could determine the orientation of the fracture. Once, the azimuthal anisotropy reflectivity response of the an azimuth is same with the reflectivity response in isotropy environment, then we could interpret that the orientation of the fractures or the crack is same with the azimuth value. In other words, the azimuthal anisotropy reflectivity will increase properly with azimuth value. By analyze the azimuth of seismic line, we could be able to obtaine the orientation of the fractures or cracks in the reservoir.

Fractures fluid-filling: To know the fluid content in the reservoir is a main purpose of reservoir characterization. AVO method is a popular method in industry to know the

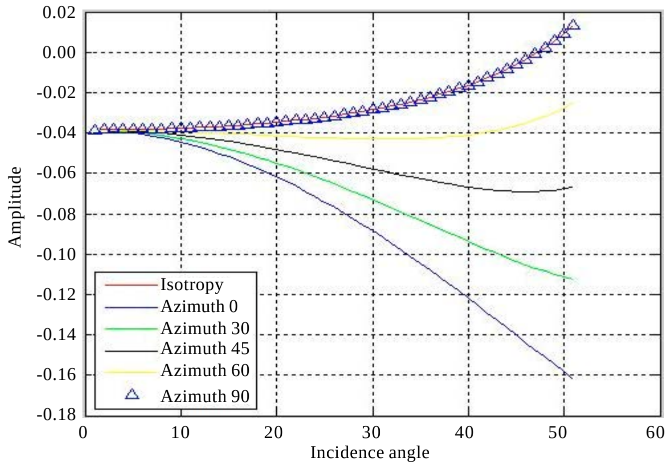

Fig. 1: Azimuthal anisotropy reflectivity of model 1

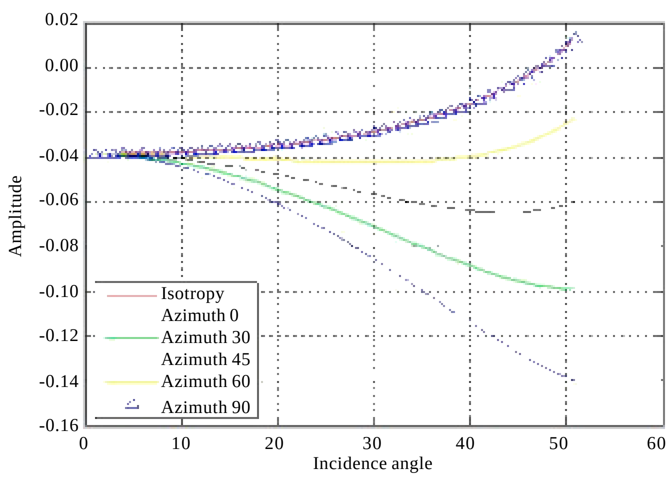

Fig. 2: Azimuthal anisotropy reflectivity of model 2

fluid information of the reservoir. However, in anisotropic medium, the analysis to know fluid content in the reservoir is different with AVO analysis in isotropic environment. For HTI medium, Hsu and Schoenberg (1993) had defined two dimensionless of physical properties of fractures. One of them is the normal weaknesses (Δ_N). Normal weaknesses parameter is physical parameters of fractures to know the fluid-filling the fractures.

Table 7-12 are the value of fractures weaknesses parameter and Thomsen's parameter of each model that can be obtained from forward modeling.

Here, we can see that the existence of the fluid in the fractures or cracks in the reservoir will influence the normal weaknesses of the fractures. Model 1 until model 4 show the value of normal weaknesses (Δ_N) of the water condition is one-half of the gas condition whereas, for model 5 and 6 the value of normal weaknesses (Δ_N) of the water condition is lower than the gas condition. In addition, azimuthal anisotropy reflectivity value of both fluid is different each other. The reflectivity in water condition is higher than gas condition (Fig. 1 and 2). Therefore, to characterize the kind of fluid-filling the fracture in HTI medium besides the azimuthal anisotropy reflectivity, also we can use the normal weaknesses parameter to determine it. Once the fractures or cracks in the reservoir is filling by fluid so the value of N parameter will be lower or closer to zero. Water-filling will have the lower value of N parameter than gas-filling.

Fractures intensity: Besides the orientation and fluid-filling the fractures, other parameter that should be characterized is the intensity of the fractures in the reservoir. By knowing the intensity of the the fractures in the reservoir we will know and comprehend the complexity of the reservoir. Complexity of reservoir is related to anisotropy level of its medium. Intensity of the fractures related to geometry of the fractures and on this study it's related to crack density and aspect ratio. Tangential weaknesses parameter (Δ_T) is a parameter to represent the intensity the fractures or cracks in the reservoir. Let's see model 1 and model 3 also Table 7 and 9 in which the crack density of these model are 0.1 and 0.2, respectively.

By comparing the result of model 1 and model 3, we can see the azimuthal anisotropy reflectivity of model 1 is higher than azimuthal anisotropy reflectity of model 3 (Fig. 3). In addition, Thomsen's parameter of model 1 is higher too than model 3. However, tangential weaknesses parameter (T) of model 1 is lower than model 3. From this case, we know that crack density is properly with fractures intensity and tangential weaknesses but inversely with azimuthal anisotropy reflectivity. In addition, by comparing model 1 and model 5 in which model is different in aspect ratio value and aspect ratio value of these model are 0.01 and 0.1. We obtained that the Thomsen's parameters value of these model is

Table 7: Fractures weaknesses and Thomsen's parameter value model 1 gas condition

Parameters	Values
Epsilon (ε)	-0.0836
Delta (δ)	-0.0186
Gamma (γ)	-0.1253
N	0.1696
T	0.2507

Table 8: Fractures weaknesses and Thomsen's parameter value and model 2 water condition

Parameters	Values
Epsilon (ε)	-0.0431
Delta (δ)	-0.0096
Gamma (γ)	-0.1253
N	0.0875
T	0.2507

Table 9: Fractures weaknesses and Thomsen's parameter value model 3 gas condition

Parameters	Values
Epsilon (ε)	-0.1677
Delta (δ)	-0.0366
Gamma (γ)	-0.2506
N	0.3392
T	0.5013

Table 10: Fractures weaknesses and Thomsen's parameter value model 4 water condition

Parameters	Values
Epsilon (ε)	-0.0864
Delta (δ)	-0.0191
Gamma (γ)	-0.2506
N	0.1749
T	0.5013

Table 11: Fractures weaknesses and Thomsen's parameter value model 5 gas condition

Parameters	Values
Epsilon (ε)	-0.2202
Delta (δ)	-0.0476
Gamma (γ)	-0.1253
N	0.4445
T	0.2507

Table 12: Fractures weaknesses and Thomsen's parameter value model 6 water condition

Parameters	Values
Epsilon (ε)	-0.1765
Delta (δ)	-0.0385
Gamma (γ)	-0.1253
N	0.3568
T	0.2507

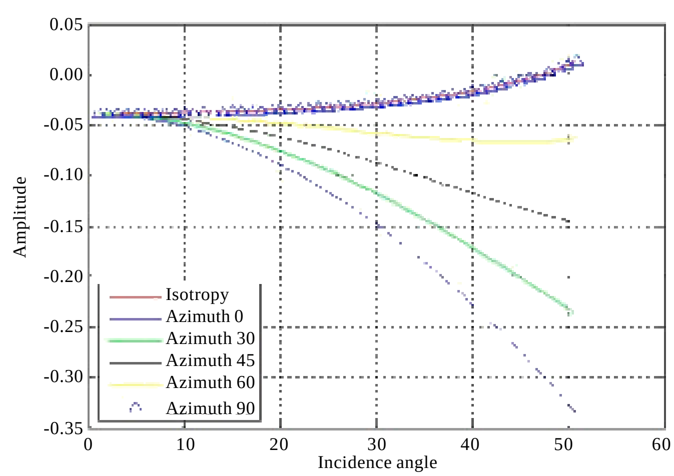

Fig. 3: Azimuthal anisotropy reflectivity of model 3

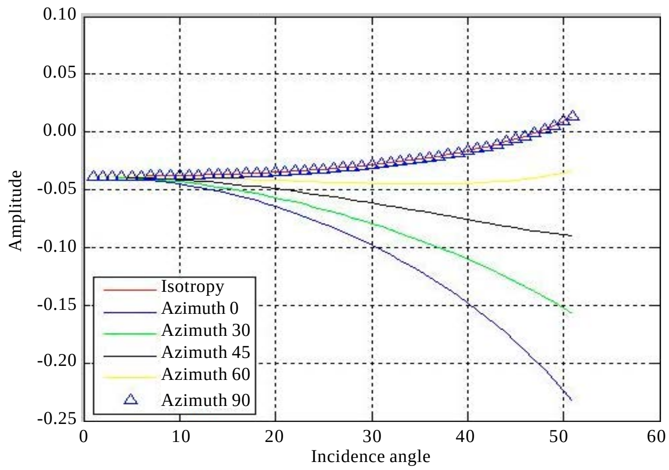

Fig. 4: Azimuthal anisotropy reflectivity of model 5

different which Thomsen's parameters value of model 5 is lower than the model 1. Azimuthal anisotropy reflectivity of model 5 (Fig. 4) is also lower than model 1. From this comparison, we know that fractures intensity in the reservoir is close with level of anisotropy a medium. Once the medium is very anisotropic so we can say the medium will have high intensity of fractures. Fractures intensity of a reservoir is influenced by geometry of the fractures (aspect ratio) and it's related to crack density. Once the aspect ratio of the fractures or crack is small so the anisotropic level of the medium is also low but it will be higher once the aspect ratio of the fractures is high.

CONCLUSION

P-wave reflectivity or known by AVAZ is a powerful method to characterize the fractured reservoir with its parameters if we compared with S-wave.

Fractures orientation is related with the azimuth of the seismic line by analyzing the azimuthal anisotropy reflectivity with the azimuth the orientation of the fractures could be obtained.

To determine the fractures fluid-filling, besides using azimuthal anisotropy reflectivity, we can also use value of normal weaknesses. From this study, we obtained that water effect is higher than gas effect in azimuthal anisotropy reflectivity however, it's closer to zero than gas effect.

Fractures intensity is closer to anisotropic level of a reservoir and related to crack density. In addition, its parameter is related to geometry of the fractures or cracks that is aspect ratio.

REFERENCES

Hsu, C.J. and M. Schoenberg, 1993. Elastic waves through a simulated fractured medium. Geophysics, 58: 964-977.

Hudson, J.A., 1980. Overall properties of a cracked solid. Math. Proc. Cambridge Phil. Soc., 88: 371-384.

Hudson, J.A., 1990. Overall elastic properties of isotropic materials with arbitrary distribution of circular cracks. Geophys. J. Int., 102: 465-469.

Hudson, J.A., 1994. Overall properties of anisotropic materials containing cracks. Geophys. J. Int., 116: 279-282.

Ruger, A., 1997. P-wave reflection coefficient for transversely isotropic models with vertical and horizontal axis of symmetry. Geophysics, 62: 713-722.

Schoenberg, M. and J. Douma, 1988. Elastic wave propagation in media with parallel fractures and aligned cracks. Geophys. Prosp., 36: 571-590.

Thomsen, L., 1986. Weak elastic anisotropy. Geophysics, 51: 1954-1966.

Thomsen, L., 2002. Understanding seismic anisotropy in exploration and exploitation. SEG-EAGE Distinguished Instructor Series No. 5. Society of Exploration Geophysicists.