Tuning effect on fluid properties estimated from AVO inversion.

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Summary

AVO seismic signatures present in seismic data could be affected by several factors; one of those is the tuning or thin-bed effect. We propose a methodology to infer from seismic amplitudes and fluid properties, the presence of thin bed effect. This methodology includes: forward modeling, normal incidence amplitude and gradient estimation using Zoeppritz's equations, a method to obtain P-S zero-offset reflectivities from acoustic impedances and AVO inversion techniques based on Biot-Gassmann theory.

We tested the methodology for 25 rock property models from different environments under two situations: with and without thin-bed effect. For almost 96% of the rock models with tuning effect, the fluid bulk modulus (K_f) was negative and 80% of the models without tuning effect, K_f was positive. On the other hand, rock models without tuning effect and K_f negative, showed saturated bulk modulus (K_{sat}) approximating Reuss bound and K_{dry}/μ_{dry} ratio lower than 0.6.

Introduction

In seismic exploration, reservoir fluid characterization represents the primary objective, hence numerous technologies have been developed to extract from seismic data the fluid and rock properties; one of the most used technologies is known as AVO inversion.

Recently, several methods have been proposed in order to extract the fluid properties of the reservoir based on AVO inversion:

Hilterman (2001) and Russell (2001) illustrated a technique based on Biot-Gassmann theory to extract the fluid term (ρ_f) from the P (I_P) and S (I_S) acoustic impedances.

$$rf = I_P^2 - CI_S^2 \qquad (1)$$

where I_P and I_S are the P-wave and S-wave impedance contrast respectively and C is the constant used to differentiate fluid term which depends on the available well-log data.

Goodway (2001) proposed the lambda-mu-rho technique based on two attributes Lambda-rho ($\lambda\rho$) and Mu-Rho ($\mu\rho$) (Lamé impedances), which are obtained from AVO by using C = 2. In this method the fluid term is lambda-rho ($\lambda\rho$). Batzle et al., (2001) proposed to use the saturated bulk modulus to identify fluid properties, assuming $K_{dry} = \lambda_{dry}$ which leads constant C (Vp^2_{dry}/Vs^2_{dry}) equal to 2.33.

Unfortunately, seismic amplitudes not only come from different pore-fluids or contrast in impedance but also come from diverse problems and pitfalls, such as the effect of thin bed, which is going to be addressed in this work.

Tuning effect can be defined in a simple way as the interference of the energy from the top and base reflections of a bed. Since every day discovery of a blocky reservoir, thick enough to avoid tuning effect is a challenging task, we want to define one of the many and important unknowns pertaining to this issue, as follows:

Is it possible to infer a possible tuning indicator if the seismic amplitudes and the fluid properties are substantially different from those that we will expect without tuning condition?

In order to answer that question, we are going to test the sensitivity and response of different AVO inversion techniques under non-tuning condition and then under tuning condition in order to search for proper indicators. To accomplish that task, several tools are going to be used: forward modeling, Zoeppritz's equations, AVO inversion and Gassmann's equations.

Dataset

Twenty-five (25) rock-property models (Table 1) represent the input data from different environments (Class I, II, III and IV). The rock-property models include P-wave, S-wave velocities and densities for shale and sands. The objective is to test the methodology for reservoirs with different shales/sands impedances ratio.

Some of the rock-property models were taken from Castagna (1994) and from measurements in deep-water environments.

Technical approach

In order to carry out the AVO inversion to extract the fluid properties of the reservoir, several tasks are included in our technical approach:

Tuning effect on fluid properties

#	Vp (shale)	Vs (shale)	ρ (shale)	Vp (sand)	Vs (sand)	ρ (sand)
1	2770	1520	2290	3080	2340	2140
2	4060	2180	2580	3620	2580	2300
3	3050	1690	2340	2910	1850	2010
4	3210	1600	2390	3960	2800	2410
5	2770	1270	2450	2690	1590	2250
6	2750	1260	2430	3190	1980	2450
7	3600	1850	2630	4910	3300	2590
8	1940	770	2100	1540	980	2050
9	2670	1130	2290	2070	1290	2020
10	2100	1030	2100	1680	1150	2100
11	2590	1390	2300	1860	1160	2090
12	2380	940	2270	2250	1300	2060
13	2740	1390	2060	2840	1760	2080
14	2310	940	1900	3040	1920	2090
15	2870	1300	2270	2930	1790	1960
16	2770	1520	2300	4050	2380	2320
17	2900	1330	2290	2540	1620	2090
18	2476	963	2230	1861	1105	1990
19	2593	1052	2250	2084	1221	2000
20	2706	1138	2290	2295	1347	2040
21	2825	1228	2310	2457	1445	2070
22	2926	1305	2340	2606	1543	2100
23	3062	1408	2350	2841	1678	2100
24	3225	1532	2360	2936	1764	2180
25	3332	1613	2370	3118	1876	2200

Table 1. Rock property models. Velocities are given in m/s and densities in Kg/m^3.

1. Forward Modeling

To form synthetic CMP gathers rock-property models are assumed to generate reflectivity series, which is to be convolved with a 30Hz Ricker wavelet. The layer model to be used is a two-layer model over a half space (Figure 1). Setting offset equal to depth, I restrict the incidence angle to be lower than 30 degrees (Table 2).

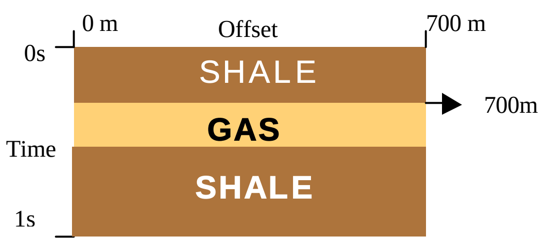

Figure 1. Layer model used to generate synthetic gather. A gas sand layer is encased in two shale sequences. (Vertical and horizontal scales are not the same).

Parameter	Value
Thickness of layer 1	700 m
Thickness of layer 2	Variable
Offset max.	700 m
Sampling interval	20 m
Time interval	0.001 s

Table 2. Parameters used in forward modeling.

Examples of a synthetic gather with and without tuning effect are shown in Figure 2.

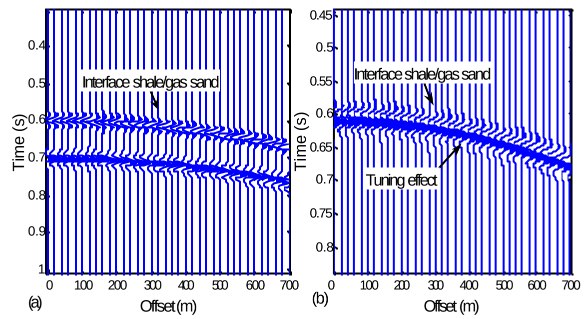

Figure 2. Synthetic CDP gather for a model with two layers over a half-space. a) No tuning effect, b) With tuning effect.

2. Estimation of Intercept and Gradient

Estimates of normal incidence amplitude (A) and gradient (B) are going to be made from a linear fit. However, amplitudes were calculated based on the Zoeppritz's equations.

$$RC(q) = A + B\sin^2 q \qquad (2)$$

3. AVO Inversion

To find the fluid term or pore-fluid discriminant from seismic data, we will use a method based on a linear approximation of the Zoeppritz's equations to invert from intercept and gradient estimations, P and S zero offset reflectivities.

This method assumes (Mavko et al. 1998):

- Small contrasts in material properties across the boundaries.
- Angles of incidence less than 30° approx.
- Vp/Vs ratio is equal to 2.

To obtain the impedances, we invert knowing that zero offset P-S reflectivities could be approximated as,

$$R_{P0} = A$$
$$R_{S0} = \frac{A - B}{2} \qquad (3)$$

Knowing the relationship of P-reflectivity (R_{P0}) and S-reflectivity (R_{S0}) with acoustic impedances, we get:

Tuning effect on fluid properties

$$I_{P(i+1)} = I_{P(i)}\left(\frac{1+R_{P0}}{1-R_{P0}}\right)$$
$$I_{S(i+1)} = I_{S(i)}\left(\frac{1+R_{S0}}{1-R_{S0}}\right) \tag{4}$$

Once impedances are calculated, the next step is calculating the fluid indicator based on the approach proposed by Batzle and Han (2001). For this technique ρΔK is the fluid indicator, which could be found from P-wave and S-wave velocities.

$$I_P^2 = r\,(K_{dry} + {}^4\!/\!_3\, m + \Delta K)$$
$$I_S^2 = rm \tag{5}$$

Then, to obtain the fluid term, we subtract the above equations, and we look for a constant C such that ρ (K_{dry} + (4/3)μ) = ρμ. Constant C is defined as following:

$$C = \frac{K_{dry}}{m} + \frac{4}{3} = \frac{l_{dry}}{m} + 2 = \left(\frac{V_P}{V_S}\right)^2_{dry} \tag{6}$$

Finally, if K_{dry} = μ, then C = 2.33.

$$I_P^2 - (2.33)I_S^2 = r\Delta K \tag{7}$$

Using the approximation proposed by Batzle and Han (2001) of the Gassmann equations, we substitute ΔK for G (ϕ) K_f, to calculate the fluid bulk modulus.

$$rK_f = \frac{I_P^2 - (2.33)I_S^2}{G(f)} \tag{8}$$

where G (ϕ) is the gain function and represent the dry frame properties of the rock.

Applying tuning condition

The layer thickness of the gas sand is decreased to analyze the effect on seismic amplitudes and fluid properties from 100m to 1 m. Applying the above methodology to 25 rock models is shown in Table 1. We calculate A (intercept) and B (gradient) with and without tuning effect.

As we expected, tuning effect magnify the seismic amplitude, therefore we could expect a significant change in the fluid properties of the rock under tuning condition. Applying the methodology proposed, fluid bulk modulus is calculated for both situations.

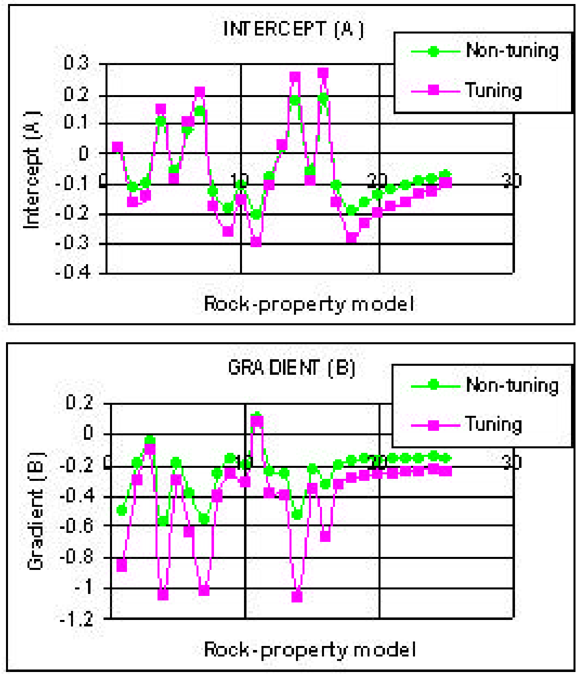

Figure 4. Intercept and gradient values calculated for gas sands under tuning and non-tuning condition.

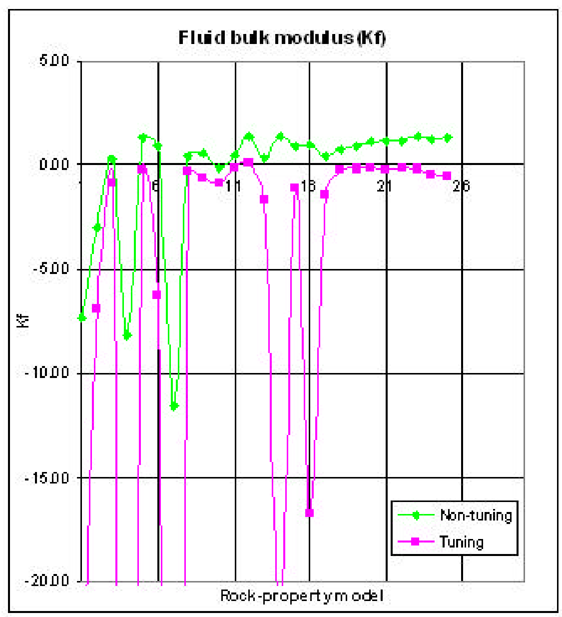

Figure 5. Calculated fluid bulk modulus for both situations. Note that most of the rock models show negative values for tuning condition and positive values for non-tuning condition.

Tuning effect on fluid properties

Five models without tuning effect showed negative fluid bulk modulus and only one model with tuning effect showed a positive fluid bulk modulus.

For an exhaustive study of models without tuning effect but $K_f<0$, we use Gassmann equations in order to calculate K_{dry} and μ_{dry}. The results for those models were K_{dry}/μ ratio lower than 0.6 (Table 3). However, according to Murphy (1993) and Wang (2000), an average K_{dry}/μ ratio for sandstones is 0.9 and a usual approximation is $K_{dry} = \mu_{dry}$.

#	K_{dry}/μ
1	0.229
2	0.399
4	0.430
7	0.654
10	0.432

Table 3. K_{dry}/μ ratio for the rock-property models showing fluid bulk modulus negative for non-tuning condition.

Conclusions

Tuning effect is an important factor that must be considered for seismic amplitude interpretation since it affects significantly, not only the seismic amplitudes but also the fluid properties of the rock reservoir, which is the ultimate goal for exploration geophysics. On the other hand, rock physics constraints allow us to offer more quantitative description of this effect.

We proposed a simple methodology to show the impact of rock physics constraints in order to search for proper indicators of tuning effect, in this case, we found $K_f < 0$ for models under tuning condition and $K_f > 0$ for models without tuning effect. Also, we found that most of the models without tuning effect but $K_f < 0$ are anomalies (mostly Class I reservoirs) since their bulk moduli lie on or below Reuss bound and present considerably low K_{dry}/μ ratio for sandstones.

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