Impact of Reservoir Fluid Saturation on Seismic Parameters: Endrod Gas Field, Hungary

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Abstract. Outlining the reservoir fluid types and saturation is the main object of the present research work. 37 core samples were collected from three different gas bearing zones in the Endrod gas field in Hungary. These samples are belonging to the Miocene and the Upper-Lower Pliocene. These samples were prepared and laboratory measurements were conducted. Compression and shear wave velocity were measured using the Sonic Viewer-170-OYO. The sonic velocities were measured at the frequencies of 63 and 33 kHz for compressional and shear wave respectively. All samples were subjected to complete petrophysical investigations. Sonic velocities and mechanical parameters such as young’s modulus, rigidity, and bulk modulus were measured when samples were saturated by 100%-75%-0% brine water. Several plots have been performed to show the relationship between seismic parameters and saturation percentages. Robust relationships were obtained, showing the impact of fluid saturation on seismic parameters. Seismic velocity, Poisson’s ratio, bulk modulus and rigidity prove to be applicable during hydrocarbon exploration or production stages. Relationships among the measured seismic parameters in gas/water fully and partially saturated samples are useful to outline the fluid type and saturation percentage especially in gas/water transitional zones.

1. Introduction
Endrod gas field has been recently studied by [1]. Sari concluded that porosity and permeability of the analysed sandstones reservoirs have bimodal character, while the reservoir lithology is intercalated with siltstone and claystone. Seismic properties of reservoir fluids are of great importance for reservoir characterization. Seismic velocities of reservoir gases, water and hydrocarbons are discussed by many investigators [2]; [3]; [4]; [5]; [6]; [7]; [8] and [9]. Some of these studies concluded that fluid saturation and porosity influence Poisson’s ratio. It is computed from p-wave velocity (Vp) and S-wave velocity (Vs) by the following relation [10] as;

$$\sigma = \frac{0.5 - (Vs/Vp)^2}{[1 - (Vs/Vp)^2]}$$

(1)

By applying equation (1) in case of water, where Vs = 0.0 km/s, then Poisson's ratio should be equal to 0.5. Poisson's ratio is stress dependent and various over a wide range 0.0 > \sigma < 0.5 for all types of dry and saturated rocks, including negative values [3]; [5]; and [11].

In the present work, our target is to investigate the possible relations among measured and calculating seismic parameters and pore structures.
2. Experimental Procedures
The suite of 37 core samples contained 31 sandstones and only 6 carbonates are ranging in porosity from 0.36 to 0.295. Samples were cut into right cylinders of 2.5 cm diameter and lengths ranging from 4.2 to 5.06 cm. Samples were cleaned in cool Sohxlet apparatus, dried at 100°C for at least 12 hours, and cooled to room temperature. Physical dimensions were measured with a dial caliper to a resolution of 0.001 cm. Compressional (p-wave) and shear (S-wave) velocities were measured at ambient conditions on cylindrical samples using two channels Sonic Viewer OYO – 170 at ultrasonic frequencies of 63 and 33 KHz respectively. P-wave and S-wave velocity measurements were first made with dry samples and then partially saturated with brine water (Sw = 75 %) and fully saturated with brine water (Sw = 100%). Concentrations of the used brines were 90 g / l for all samples of the Great Hungarian Plain. The Poisson’s ratio was calculated at each step while samples were partially and/or fully saturated with either gas or water phase.

3. Results and Discussions
The sample pore fluids and their saturation percentages affect the overall rock compressibility, density, p-wave and s-wave velocity. The following part is focused on discussing the obtained laboratory measurements in order to display the most effective combination, which can be implemented for enhancing reservoir geophysical interpretation.

3.1. Porosity – Permeability Relations
Porosity and permeability data of the studied samples have been plotted as shown in figure 1. The Upper Pliocene samples obtained from the Algyo Formation reveal the highest values of porosity and permeability, while each of them is closely related to the other. This indicated by high correlation coefficient (R² = 0.94) and controlled by the following regression line equation;

\[ K = 0.026\varepsilon^{31.15} \]  

where: \( K \) = Permeability, MD and \( \varepsilon \) = porosity, fr.

![Figure 1. Permeability vs. porosity for all studied samples](image)
The Lower Pliocene samples obtained from the Szolnok Formation has been studied in some details by [12 and 13]. In the present work, it is characterized by a reliable correlation coefficient ($R^2 = 0.91$) and the following equation:

$$K = 0.0025e^{8.79\phi}$$  \hspace{1cm} (3)

The Miocene limestone samples have the lowest permeability, while its relation to porosity is controlled by a robust equation ($R^2 = 0.85$) as;

$$K = 0.0155e^{2.47\phi}$$  \hspace{1cm} (4)

The above-mentioned relationships indicate that permeability is a function of porosity and pore space framework. Therefore, the permeability of these types of sedimentary rocks could be outlined and predicted using the above listed equations.

3.2. Permeability – Acoustic Velocity Relations

The permeability has been related to P-wave and S-wave velocities, where samples were 0%, 75% and 100% brine water saturated. These plots show great variations especially when samples were 75% brine saturated (figures 2, 3, 4). Figure 2 shows the relation between both P-wave and S-wave velocities and permeability when samples were 100% gas saturated (dry). The S-wave velocity – permeability relation seems to be less significant ($R^2 = 0.33$), than that existed between permeability and P-wave velocity ($R^2 = 0.75$). The sample points of both trends are close to each other’s especially at permeability more than 100 mD. It means that at high permeability values, the P-wave and S-wave velocities may be coinciding and then Poisson’s ratio will appear as negative value. Figure 3 displays the same relationship but the samples were 75% brine saturated. The calculated trend lines in this case are completely separated and far away from each other.

![Figure 2. Permeability vs. acoustic velocity at 100% gas saturation](image-url)
The correlation coefficient between acoustic velocities and permeability are greatly enhanced ($R^2 = 0.43$ and 0.82) with only compressional wave. The calculated regression line equations controlling these relations are:

\[ V_p = 3.56 K^{-0.084} \]  
\[ V_s = 1.16 K^{-0.061} \]

Porosity – velocity relation when samples were 100% water saturated is shown in figure 4. It reveals high correlation coefficient ($R^2 = 0.76$ and 0.83) for S-wave and P-wave respectively. The calculated regression line equations are:

\[ V_p = 3.68 K^{-0.086} \]  
\[ V_s = 2.63 K^{-0.085} \]

The equations (5, 7 and 8) can be used in practice to estimate permeability from velocities in water bearing reservoirs.

![Figure 3. Permeability vs. acoustic velocity at 75% gas saturation](image)

3.3. Effect of saturation on acoustic velocity
The laboratory measurements support the belief that lower P-wave velocities and higher reflection coefficients are obtained in sedimentary reservoirs that contain gas, while the higher velocities are obtained for them at 100% brine saturation (Figure 5). This figure shows the behaviour of the average compressional and shears wave velocities with different gas/water saturations for the studied samples. Figure 6 exhibits the decrease of S-wave velocity with brine saturation until it reaches 75%, and then it grows with increasing brine saturation. Similar laboratory results were reported by [7] for the cretaceous oil bearing reservoirs.
3.4. Poisson’s ratio and Gas/Water Saturation
The effect of fluid saturation on the Poisson’s ratio is studied in some details ($S_w = 0\%, 25\%, 50\%, 75\%$ and $100\%$) by [8] and they concluded that, in case of gas/water saturation, the relation displays the saddle shape and in case of oil/water saturation the monoplane with flat top shape is obtained.

Figure 4. Permeability vs. acoustic velocity at 100% water saturation

Figure 5: Acoustic velocity vs. water saturation

The present laboratory results can serve as a guide to the interpretation of monopole as well as dipole acoustic logs.
Figure 6. Poisson’s ratio and acoustic impedance vs. water saturation

Figure 6 shows the effect of water saturation on both the average acoustic impedance (AI) and Poisson’s ratio. An uncompleted saddle shape of Poisson’s distribution is presented due to the gas/water partial saturation in the present work, was only one run (at $S_w = 75\%$). This relation indicates that the Poisson’s ratio grows with increasing water saturation until it reaches 75% and then it starts to decrease drastically to be of negative value or around to the value of zero by increasing of the water saturation. The concepts outlined in figure 6 can be employed for detecting the lower part of the gas / water transitional zone in sedimentary reservoirs. The acoustic impedance is increased by a gradual increasing of water saturation until it reaches 75% and starts to increase very slowly up to 100%.

3.5. Geomechanical Properties for Dry and Saturated Rocks
Young’s modulus (E), rigidity (G) and bulk modulus (k) were calculated for dry and fully saturated samples and plotted against porosity (figures 7 and 8).

Figure 7. Dynamic-mechanical parameters (Young modulus, bulk modulus, Rigidity) for dry samples (100% gas saturated) vs. porosity
These figures show that the bulk modulus for all samples is highly increased by water saturation, while the rigidity decreases and young’s modulus is not affected by water saturation.

Figure 8. Dynamic-mechanical parameters for saturated samples (100% water saturation) vs. porosity

4. Conclusions
The present investigation introduces an attempt for highlighting the effect of brine saturation on the seismic parameters and their relevant reservoir properties. In fact, the compressional velocity grows with increasing water saturation and that is well-known in early literature sources. The new information in this subject is the behaviour of the shear wave velocity with fluid saturation. The shear wave velocity decreases as the water saturation increases until it reaches 70% - 75% and then starts to increase again which confirming conclusions that have been achieved by [7, 8]. Poisson’s ratio can be integrated with acoustic impedance to outline the gas/water transitional zone in the gas bearing reservoirs. Moreover, the behaviour of the shear wave velocity side by side with geomechanical parameters can be useful in this case as well. Several reliable and robust relations have been calculated which can be employed for prediction of some gas/water bearing zones.

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