'Fizz Water' and Low Gas Saturated Reservoirs

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Summary

Numerous dry holes have been drilled based on false hydrocarbon indicators (DHI) and have been attributed to 'fizz water' effects. However, this 'fizz water' concept is ill-defined and misunderstood. Newly measured data show that dissolved gas has negligible effect on water velocity. In addition, gas bubbles exsolving from either water or oil have only a small effect on fluid properties at pressures higher than about 20 Mpa (about 3000 Psi). Gas at high in situ pressure and temperature conditions has similar properties to light oil. Realistic gas properties must be used to estimate the properties of gas-liquid mixtures. Trapped original gas distribution in situ may be patchy (in layers or packets), while the exsolved or leaked gas distribution is likely to be relatively homogenous. Although fluid properties and gas distributions are complicated in deep-water reservoirs, seismic evaluation of gas saturation is possible. Developing seismic techniques to quantitatively calibrate hydrocarbon indicators in addition seismic evaluation of rock density and attenuation should lead to new integrated techniques for better evaluation of hydrocarbon saturation.

Introduction

Uneconomic gas or hydrocarbon saturation and the complexities of deep-water turbidite systems combine to produce tempting but false prospects. With dry hole costs in the range of $ 20 to 30 million, and with the vast expense of completion and production facilities, we must have a thorough understanding of the potential reservoirs. Low gas-saturated reservoirs have been recognized as a common failure in hydrocarbon exploration. Post-mortem evaluations of dry wells are often incomplete. 'Fizz water' is often blamed for the false hydrocarbon indicators. It has been believed that gas dissolved in water or few percent of a separate gas phase in water can reduce the pore fluid modulus significantly, and in turn the rock impedance. Thus, 'fizz water' is a common scapegoat for dry holes. Unfortunately, the ill-defined 'fizz-water' concept looks so logical it may actually prevent efforts to search and develop new techniques for seismic evaluation of hydrocarbon saturation. A much better analysis of rock and fluid properties is needed to reduce our exploration risks.

Velocity and Modulus of 'Fizz Water '

One definition of 'fizz water' is brine with dissolved gas. A relation for this dissolved gas effects on brine compressibility had been published (Dodson and Standing, 1945) and adopted later by Batzle and Wang, (1992) and

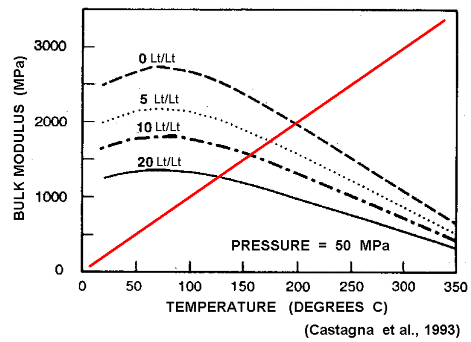

Figure 1: Incorrect calculate effect of gas in solution on water bulk modulus

Castagna et al. (1993) as shown in Figure 1. The model suggests that the modulus of water with 5L/L gas in solution is significantly lower than that of gas-free water. As a consequence, rocks saturated with this 'fizz water' were expected to have low compressional velocity and impedance. However, recently measured data demonstrates that dissolved gas has a negligible effect on water velocity. Typical data is shown in Figure 2.

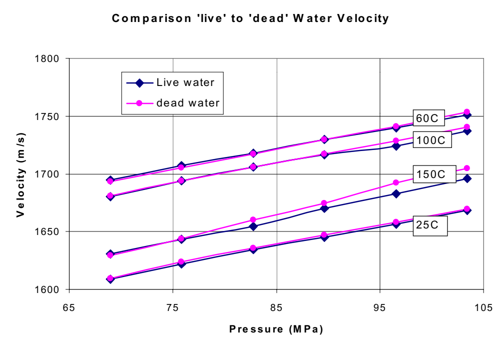

Figure.2. Measured 'live 'and 'dead' water velocity at different conditions

Both gas-free (dead) water and water with dissolved gas (live) of about 6.5 L/L methane (bubble point of 69 Mpa at 22 °C) were measured as functions of pressure up to 103.5 MPa and temperatures up to 150 °C. Data show that dissolved gas has negligible effect on water velocity. This result is consistent with static compressibility measurements (Osif, 1988). In fact, the amount of gas that can actually go in solution in water is also overestimated in Figure 1 due to the restricted bubble point.

As an alternative explanation, when pressure is lowered below the bubble point, gas bubbles come out of solution within the water to form a gas-water mixture. This free gas phase was expected to dramatically lower the mixture modulus. Data show that these exsolved gas bubbles at elevated pressures are only a tiny fraction of the total mixture volume, and also have a negligible effect on volume and density (Figure 3) until pressure is lower than about 20 Mpa (3000 psi).

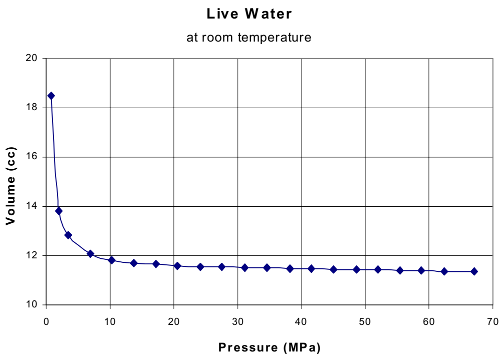

Figure 3. Measure Volume-Pressure for 'live' water under the bubble point.

Modulus of Gas

Another incorrect concept is that gas is so compressible, it has an almost negligible modulus. However, the data shown in Figure 4 (Han and Batzle, 2000a) demonstrate that with increasing pressure, gas can behave much like an oil. At the relatively low pressure of 15 MPa, velocity increases with increasing temperature, which is a behavior similar to an idea gas. At a higher pressure of 41 MPa,

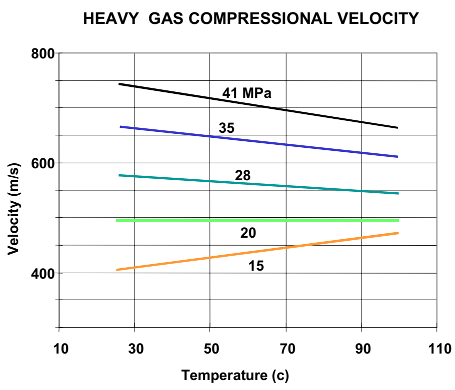

Figure 4. Measured velocity on gas show gas behave at low pressure but liquid behave at high pressure.

velocity decreases with increasing temperature, which is similar to liquid oil behavior. In fact, we are in the super-critical pressure-temperature region where the distinction between gas and liquid is meaningless.

The impact that this realistic gas behavior has on rocks can be calculated using Gassmann's equations (Gassmann, 1951). For a shallow reservoir with a pore pressure of 13.8 MPa and temperature of 30 °C, gas with gravity of 0.63 has modulus of 0.02 GPa. Based on such an assumption, a few percent free gas phase in a water-gas mixture can dominate the fluid mixture properties (Wood, 1955), and thus the properties of a saturated rock. Thus, compressional-wave impedance is not vary sensitive to gas saturation ranging from Sg = 10 to 100% (water saturation, Sw > 90%), as shown in Figure 5a. Unfortunately, this concept has been widely accepted as a cause for many false shows and dry holes.

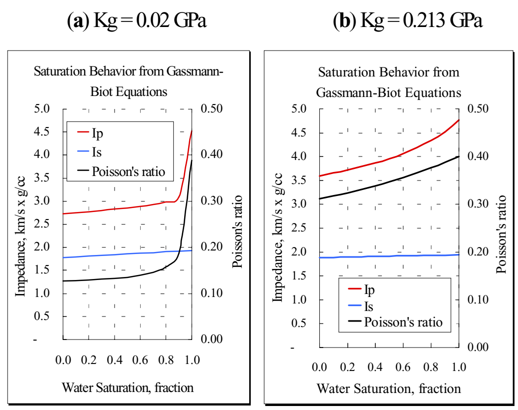

Figure 5. Calculated rock response with gas saturation for 'fizz water' low modulus gas (a), and more realalistic gas modulus (b) on impedance and Poisson's ratio.

Recently, we have also measured many hydrocarbon fluid samples at in situ conditions (Han and Batzle, 2000b). At typical deep-water conditions, such as with a pore pressure of 48.3 MPa and temperature of 58 °C, gas with of gravity 0.7 has a modulus of about 0.2 GPa. Heavy gas or gas condensate at high pressures (such as 69 MPa) may have modulus more than 0.5 GPa. In that case, compressional-wave impedance shows a more or less linear relation to gas saturation (Figure 5b). We may have a chance under these realistic conditions to evaluate gas saturation seismically.

At high pressure and temperature conditions, a gas phase is similar to an oil (Han and Batzle, 2000a). Although much more gas can be dissolved into oil than water, exsolved gas at pressures higher than 20 Mpa still hlittle effect on properties of a gas-oil mixture as shown in Figure 6. Realistic values for the gas properties must be used to evaluate gas saturation effects.

Clearly, dissolved gas in water or gas coming out of solution from either water or oil at pressures higher than 20 Mpa are not likely be measured seismically. Seismic

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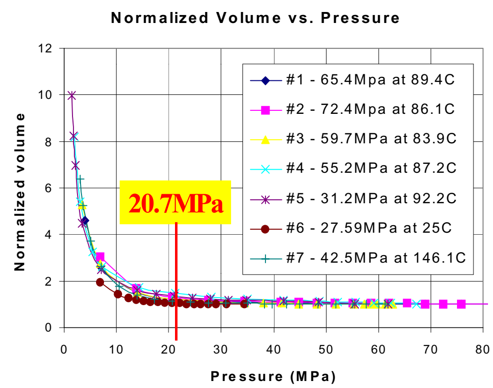

Figure 6. Normalized volume as function of pressure for live oil under the bubble point.

anomalies at such high pressures is not related to the standard concepts of 'fizz water'.

Patchy Saturation Effects

In the Gassmann's equation, it was assumed that pore fluids are in pressure equilibrium in all the pores. For the gas-water mixture, homogeneous gas distribution on a pore scale is the easiest case for pressure equilibrium. This can occur when fluid pressure drops lower than the bubble point (Cadoret et al., 1993). Homogeneously distributed low-pressure gas causes low fluid modulus and low rock compressional velocity at seismic frequencies. However, it may not be the case for the original gas distribution in situ. This distribution could be very complicated and related to pore connectivity, capillarity forces, buoyancy, and many large-scale factors such as the gas source, stratigraphy, structure, lithology, seal, and leakage. Thus gas distribution could be very complex. Trapped original gas may be distributed in a patchy way, such as in layers or gas pockets. The patchy saturation effect is more or less linearly related to velocity and impedance (Mavko et al., 1998). However, exsolved and leaked gas may be distributed moere homogeneously. One question is how to identify gas distributions and their effects on seismic attributes.

Density and Attenuation Estimate

Deep-water reservoirs often associated with high porosity, high permeability, and overpressure. If we believe that at deep water the 'fizz water' concept is wrong, seismic attributes should be correlated to gas saturation more or less linearly. We still need to be careful to verify our evaluation with other seismic attributes. Because high porosity is typical for deep-water reservoirs, different gas saturation should cause a strong linear change of rock density. Density of a low gas saturated reservoir can be 10% higher than that of a high gas saturated reservoir. Techniques to evaluate reservoir density (e.g. Wu, 2000, Zhu, et. al, 2000) should help in gas saturation analysis. Attenuation may be another key attribute for gas saturation evaluation. Low gas saturation causes higher attenuation than highly gas saturated rock (Murphy, 1982, Yin et al., 1991). Wavelet analysis (amplitude and frequencies) (Wu, 1998) may help to distinguish low gas saturated reservoirs from those with high gas saturation.

Conclusion

'Fizz water' is an ill-defined and miss-applied concept. Dissolved gas or gas exsolving out of water or oil at high pressure (>20 MPa) has little effect on pore fluid mixture properties. Realistic gas properties must be used to evaluate fluid mixture effects on rocks. Low gas saturation effects on seismic impedance may occur only in shallow formations with low pressures. Gas distribution affects seismic attributes significantly. Trapped original gas distribution seems to be patchy (layers or pockets). Patchy saturation is more linearly correlated to seismic velocity. For deep-water reservoirs, we have a chance to evaluate gas saturation by accurately calibrating seismic attributes. We also need to develop other techniques such as density and attenuation indicators to help distinguish low gas zones from high gas reservoirs.

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