

P005

Determination of the Acoustic Properties of Hydrocarbon Rich Gases Using PVT Relations

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SUMMARY

Published approaches for determining the seismic properties of pore fluids are investigated to examine the effect of gas quality at constant pressure and temperature. For this purpose, a range of fluids from natural gas to rich gas condensate is prepared and tested to determine pertinent acoustic properties of the fluid at single-phase conditions. The results show that the ratio of heat capacities of fluids in currently used models do not vary with the change in gas quality, consequently the calculated gas bulk modulus may not appropriately reflect the fluid composition dependency. Therefore a new approach is suggested in this work to calculate the ratio of heat capacities of gases where the effect of gas quality is taken into consideration. This leads to an increase in accuracy of predicted seismic property changes for gas condensate and other gas reservoirs.

Introduction

An accurate understanding of pore fluid properties is required for quantitative dynamic and static evaluation of the reservoir using seismic data. Fluid properties are critical in seismic studies with applications such as amplitude versus offset analysis (AVO), time-lapse feasibility studies and modelling, simulation to seismic calculations, evaluation of amplitude anomalies, and locating hydrate zones. Petroelastic modelling transforms fluid bulk modulus and density to effective saturated rock properties. At the core of this modelling is the Gassmann (1951) formula, for which fluid bulk modulus is required. Fluid bulk modulus is a function of saturation and the bulk modulus of gas, oil and brine, which also depends on temperature, fluid pressure and composition. Here, we concentrate on the gas bulk modulus κ_{fl} that is given by

$$\kappa_{fl} = f(S_g, S_o, S_b, \kappa_g, \kappa_o, \kappa_b; T, \rho_f, C) \quad (1)$$

where S_g , S_o and S_b stand for the saturation of gas, oil and brine, respectively, κ_g , κ_o and κ_b are the bulk moduli of gas, oil and brine, respectively, T is the temperature, ρ_f is the density of fluid and C represents the generic compositional content. The seismic properties of pore fluid have been studied by many authors such as Biot (1956); Thomas et al., (1970). Batzle and Wang (1992)(B&W) used a combination of thermodynamic relations and empirical correlations to examine the effect of pressure, temperature and composition on the seismic properties of hydrocarbon gases, oil and brine in typical exploration conditions. They provided simplified semi-empirical equations to approximate the bulk modulus of gas, oil and brine. Their proposed methodology could reliably predict pertinent properties of black oil systems, however, their capability in determining seismic properties of gas condensates, in particular the effect of composition variation is less reliable. The gas bulk modulus of pore fluids is related to the pressure (P), the compressibility factor (Z), and the ratio of heat capacity (γ) using the following equation (B&W)

$$\kappa_g = \frac{1}{\beta_g} = \frac{P}{\left(1 - \frac{P}{Z} \frac{\partial Z}{\partial P}\right)_T} \gamma. \quad (2)$$

Based on this equation, if the pressure variation is negligible, the bulk modulus is mainly affected by the compressibility factor and the ratio of heat capacity. In this study we examine the sensitivity of these two parameters on gas quality, considering whether seismic techniques can distinguish fluids with different compositions but with similar pressure?

Compositional model preparation

Our gas reservoir is composed of two components, methane (C_1) and decane (nC_{10}). Five different types of two-component fluids exhibiting lean to rich gas condensate behaviour are prepared (see Table 1). The reservoir temperature and pressure are kept constant at 212°F and 5720 psia, respectively. The Eclipse compositional phase behaviour model (PVT_i) is used to determine the PVT and phase behaviour of the gases including the dew point pressure and the gas density at reservoir conditions.

	GAS 1	GAS 2	GAS 3	GAS 4	GAS 5
C_1 mole %	99	97	95	92	90
nC_{10} mole %	1	3	5	8	10
Molecular Weight – MW (amu)	17.22	19.58	21.94	25.48	27.84
Dew Point (psia)	1872	3875	4752	5391	5578

Table 1: Compositional simulation (PVT_i , Eclipse 300) model. FIVE different Fluid compositions are considered for a mixture of C_1 and nC_{10} .

Compressibility factor

B&W (1992) used the following equation to estimate the compressibility factor of gas

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

where

$$E = 0.109(3.85 - T_{pr})^2 \exp\left\{-\left[0.45 + 8\left(0.56 - \frac{1}{T_{pr}}\right)^2\right] \frac{P_{pr}^{1.2}}{T_{pr}}\right\} \quad (4)$$

P_{pr} stands for pseudo reduced pressure which is the pressure divided by the critical pressure. T_{pr} represents pseudo reduced temperature that is the (absolute) temperature divided by the (absolute) critical temperature. As an alternative approach we used the calculated gas phase density by the Peng-Robinson equation of state in the phase behaviour model of Eclipse (PVTi) to determine the gas compressibility factor which is given by

$$Z = \frac{MW \cdot P}{\rho_g RT_a} \quad (5)$$

where MW is the molecular weight, ρ_g represents the gas density, R is the universal gas constant and T_a stands for the absolute temperature. The gas compressibility factor of the prepared fluids (Gas 1 to Gas 5) is calculated using the two approaches and the results are plotted in Figure 1.

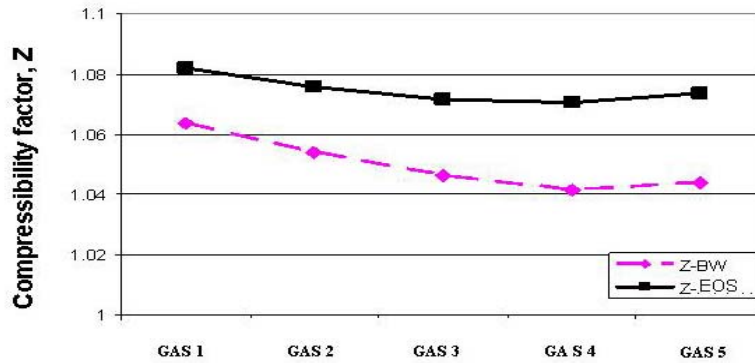


Figure 1: Compressibility factor comparison between B&W approximation versus equation of state (EOS). Pink dashed curve represents B&W and black curve represents EOS.

Both approaches show a similar trend with the change in the quality of gas, but the variation of compressibility factor with gas quality is higher for the B&W model in comparison to the EOS. Both approaches have reasonably predicted the required gas compressibility factor.

Ratio of heat capacity

The second parameter that strongly affects the gas bulk modulus with little pressure variation is the ratio of heat capacities known as gamma (γ). The original form of the adiabatic gas bulk modulus equation uses gamma but under typical exploration conditions B&W used gamma₀ (γ_0) to approximate gas bulk modulus.

$$\kappa_g \cong \frac{P}{\left[1 - \frac{P_{pr}}{Z} \frac{\partial Z}{\partial P_{pr}}\right]} \gamma_0 \quad (6)$$

where

$$\gamma_0 = 0.85 + \frac{5.6}{(P_{pr} + 2)} + \frac{27.1}{(P_{pr} + 3.5)^2} - 8.7 \exp[-0.65(P_{pr} + 1)] \quad (7)$$

The proposed equation by the B&W for calculating (γ_0) seems to be weakly composition-dependent. For gases the ratio of heat capacities can be calculated by knowing the heat capacity at constant pressure (C_p) and the heat capacity at constant volume (C_v).

$$\gamma = \frac{C_p}{C_v} \quad (8)$$

For ideal gases (gases at low pressure), the above equation would reduce to

$$\gamma_0 = \frac{C_p^0}{C_v^0} = 1 + \frac{R}{C_v^0} \quad (9)$$

In our approach the ratio of heat capacities for the real gases at reservoir condition is calculated using Eq (8). The heat capacity at constant volume (C_v) at high pressures is determined using an empirical low pressure heat capacity, corrected for non-ideality at higher pressure (Thomas et al., 1970). The heat capacity at constant pressure (C_p) is then calculated using the following thermodynamic relation:

$$C_p - C_v = -T \left(\frac{\partial p}{\partial T} \right)_v^2 / \left(\frac{\partial p}{\partial V} \right)_T \quad (10)$$

The required derivations in the above equation are determined using an equation of state.

Figure 2 presents a cross plot of the γ_0 of the prepared fluids (Gas 1 to Gas 5) using the B&W approximation in dashed pink and the ratio of heat capacity at low pressure (ideal gas) in dark blue (Eq. 8). Both curves exhibit a similar trend with a negligible difference. The B&W approximation estimates higher values for γ_0 in comparison to the ideal gas approach, however, the difference between the two values are constant, independent of gas quality. It should also be noted that both models (i.e. B&W and ideal gas approach) are almost insensitive to gas quality as the difference between γ_0 of Gas 1 and Gas 5 is very small.

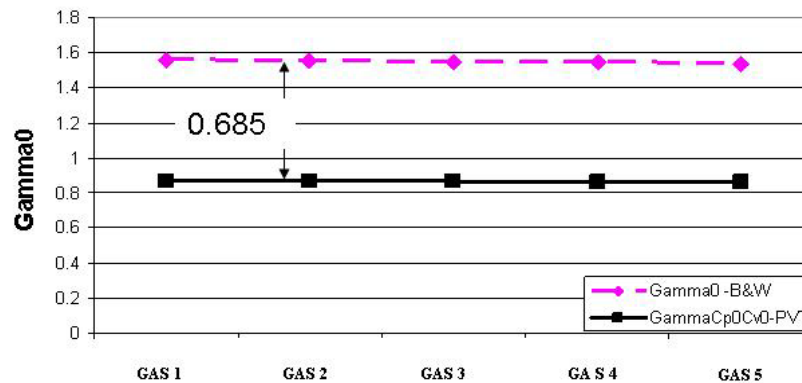


Figure 2: A cross-plot of two equations for γ_0 , B&W approximation in dashed pink and the ratio of heat capacity at low pressure in black.

The calculated ratios of heat capacities (γ) for the five gases using the suggested approach in this study are plotted in Figure 3 and they are compared with those of B&W results. While the B&W approach is almost insensitive to gas quality, the proposed approach is a strong function of gas composition/quality.

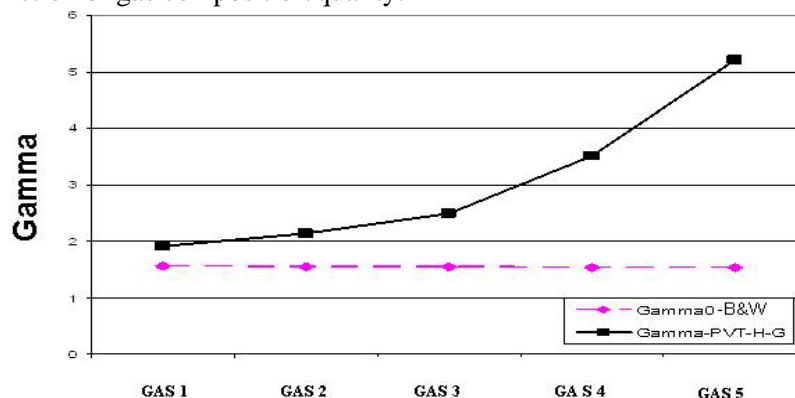


Figure 3: Dashed pink curve represents the B&W results for different PVT data. Black curve represents low pressure γ_0 .

Using the determined gamma values, the calculated gas bulk moduli for the five gases are given in Figure 4. The results demonstrate that for lean gas condensate systems, the predicted gas bulk moduli by the two approaches are similar, whereas for richer gases deviations up to 50% could be expected.

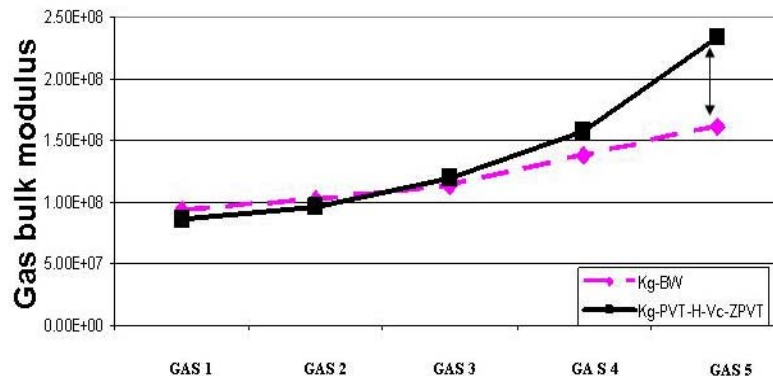


Figure 4: Comparison between B&W approximation of adiabatic gas bulk modulus and the other approach. Dashed pink curve B&W results, black curve the new approach results.

Conclusions

Determination of gas compressibility factor, the ratio of heat capacities and the adiabatic gas bulk modulus of some single-phase gases of various qualities at constant (reservoir) temperature and pressure is investigated using the B&W approach and the methodology proposed in this study. Both approaches seem to calculate the compressibility factor adequately, presenting similar trends for the variation of the Z-factor against gas quality. The suggested correlation by B&W to calculate the ratio of heat capacities (γ) is mostly insensitive to gas quality (hence composition). This is similar to γ at low pressure. However, the proposed function in this study showed a strong dependency of the ratio of heat capacities to the gas quality. Using the B&W and the developed methodology in this study to determine gamma (γ), the calculated gas bulk moduli for lean gas condensate systems are similar, whereas for richer gases deviations up to 50% is observed. From the above, the suggested methodology in this study should be used in gas reservoirs, in particular rich gas condensate reservoirs, where it is capable of distinguishing gases with different qualities.

Acknowledgments

The authors would like to thank the Edinburgh Time-Lapse Project, Phase III, sponsors for their support (BG, BP, Chevron, ConocoPhillips, ExxonMobil, IkonScience, Landmark, Maersk, Norsar, Norsk-Hydro, Petrobras, Shell, Statoil, Total, and Woodside) as well as Schlumberger for the use of Eclipse. We also acknowledge support from reservoir fluid studies research group. The authors also acknowledge Khamis Al-Subhi for his help in reservoir modelling.

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