Computing seismic properties of natural gases and evaluating AVO responses

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Abstract

We investigate the performance of original and modified DASH formulations for predicting acoustic velocity in natural gases as compared to the Batzel and Wang equations. Our results demonstrate that the alternative formulations are capable of predicting acoustic velocity with better accuracy for the Starvodgass and Gulf Coast gas mixtures. It is also observed that modified DASH formulation is capable of capturing a temperature bias that the original DASH formulation is not. Furthermore, we evaluate the differences in AVO modeling observed when fluid properties are calculated with DASH and BW equations in a synthetic interface of reservoir and overlaying sealing.

Introduction

Batzle and Wang (1992) (BW) developed an important formulation of equations that allow for the determination of seismic properties in pore fluids. Carvalho and Moraes (2018) compile an alternative formulation for computing these seismic properties in natural gases, designating it as the DASH formulation, after Dranchuk and Abou-Kassem (1975) and Sutton and Hamman (2009). Carvalho and Moraes (2019) provide their own input into DASH formulation, developing a new equation for heat capacity ratio. This rearranged set of equations is called the modified DASH formulation, and in the same manner as BW and DASH formulations, it is implemented to estimate acoustic velocity in natural gases. In the present work, we apply the studied formulations to the Starvodgass and Gulf Coast gas mixtures in order to verify their performance for predicting acoustic velocity in the fluids. AVO modeling is also implemented in order to verify the reflectivity differences when fluid properties are calculated with BW and DASH formulations.

Method

We apply and analyze three different sets of equations for predicting acoustic velocity in natural gas mixtures: BW equations, which were developed and compiled by Batzel and Wang (1992); DASH equations, which were compiled by Carvalho and Moraes (2018) after the formulations proposed by Dranchuk and Abou-Kassem (1975) and Sutton and Hamman (2009); and finally Modified DASH equations, which use the expression for heat capacity ratio presented by Carvalho and Moraes (2019).

The main goal of these formulations is to compute bulk modulus and acoustic velocities in natural gases. To perform such estimations, various equations are used within the formulation in order to calculate variables in the intermediate steps. These variables comprise mainly pseudo-critical temperature and pressure, z-factor, density, isothermal heat capacity, heat capacity ratio, adiabatic compressibility, and ideal heat capacity.

To test the accuracy of the formulations, we model acoustic velocity in two natural gas mixtures described by Younglove et al. (1993): Equinor (formerly Statoil) Starvodgass and Gulf Coast gas mixtures, in a total of 127 experimental data points of measured acoustic velocity at several pressure and temperature conditions. The compositions of the gas mixtures are informed on Tables 1 and 2.

Table 1 – *Composition of the Gulf Coast gas mixture*

Component	Mol. Fraction
C1	0.74348
C2	0.12005
C3	0.08251
n-C4	0.03026
n-C5	0.00575
n-C6	0.0023
CO2	0.01028
N2	0.00537

Table 2 – *Composition of the Stavordgass gas mixture*

Component	Mol. Fraction
C1	0.96561
C2	0.01829
C3	0.0041
n-C4	0.00098
i-C4	0.00098
n-C5	0.00032
i-C5	0.00046
n-C6	0.00067
CO2	0.00597
N2	0.00262

Finally, we perform an AVO analysis simulating the interface of a Boise sandstone reservoir as described by Gregory (1976), with an overlaying sealing with properties as per Table 3. The reservoir is saturated with the Starvordgass gas mixture. Seismic properties of the medium saturated with the fluid are calculated using Gassman (1951). AVO responses are modeled using Zoeppritz equations (Zoeppritz, 1919) at a high-pressure (14000 psia) and high-temperature (126.85 DEG C) scenario.

Table 3 – *Characteristics of the upper layer. Source: modified from Carvalho and Moraes (2018b)*

Characteristics of the sealing rock	
Vp	1850 m/s
Vs	1100 m/s
Density	2.28 g/cc

Results

Figures 1 – 5 correspond to the modeled acoustic velocity for the Gulf Coast gas mixture, at temperatures from 450 DEG R to 630 DEG R. Pressures and temperatures are expressed in their estimated reduced form.

It can be observed that DASH formulation largely outperforms the traditional BW equations in all isotherms studied. In fact, as pressure and temperature increase, DASH and modified DASH formulations tend to outperform BW formulation even more.

Furthermore, modified DASH shows relevant increase in accuracy when temperature approaches criticality (pseudo-reduced temperature near unity).

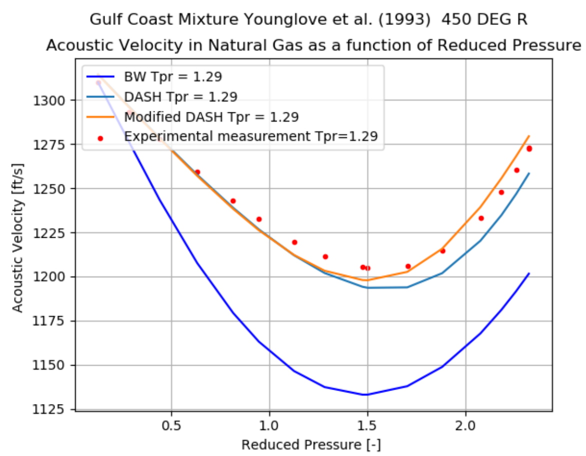

Figure 1 – *Modeled and experimental acoustic velocities in the Gulf Coast natural gas mixture at 450 DEG R.*

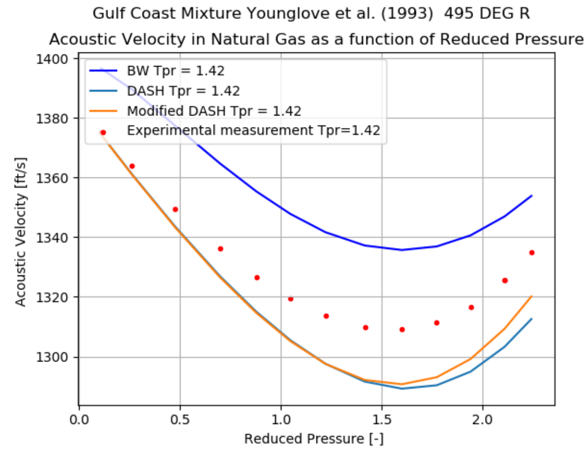

Figure 2 – *Modeled and experimental acoustic velocities in the Gulf Coast natural gas mixture at 495 DEG R.*

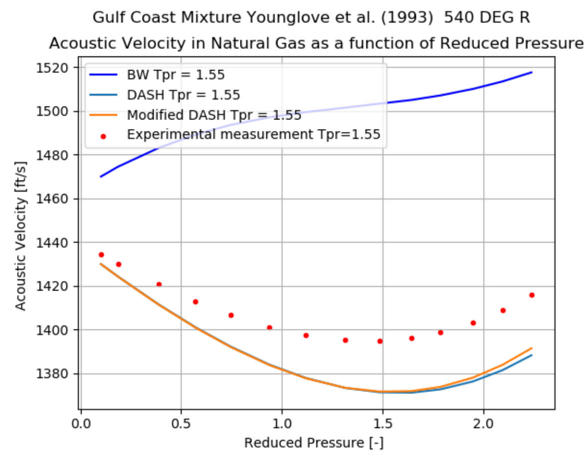

Figure 3 – *Modeled and experimental acoustic velocities in the Gulf Coast natural gas mixture at 540 DEG R.*

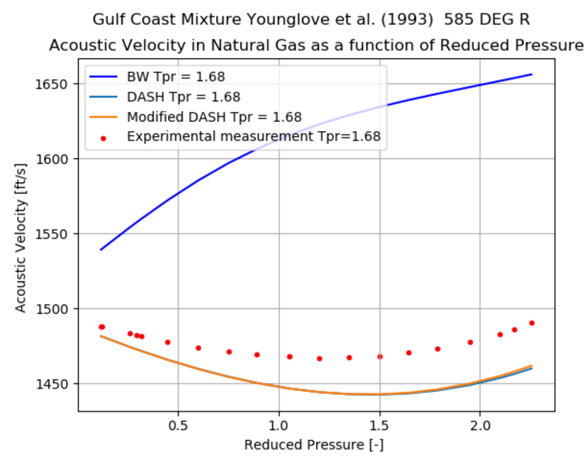

Figure 4 – *Modeled and experimental acoustic velocities in the Gulf Coast natural gas mixture at 585 DEG R.*

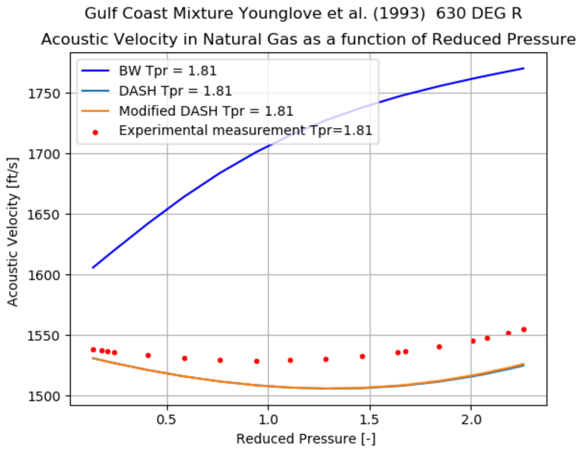

Figure 5 – *Modeled and experimental acoustic velocities in the Gulf Coast natural gas mixture at 630 DEG R.*

Figures 6 – 9 correspond to the modeled acoustic velocity for the Equinor (formerly Statoil) Starvodgass natural gas mixture, at temperatures from 540 DEG R to 630 DEG R. In this heavier mixture, DASH formulation also outperforms BW formulation.

A feature similarly observed for the Stavordgass mixture is that BW formulation tends to yield a higher misfit as pressure and temperature increase. This is an indicator that the BW equations might not be the best approach for modeling seismic velocities of natural gases in scenarios of high pressure and high temperature, once DASH and modified DASH equations provide more accurate modeled results in those cases.

Moreover, the same pattern is observed for modified DASH formulation when compared to the results for the Gulf Coast gas mixture: modified DASH is able to better predict acoustic velocity at lower temperatures, near the critical conditions. This indicates that the modified DASH formulation is capable of capturing a specific temperature dependency.

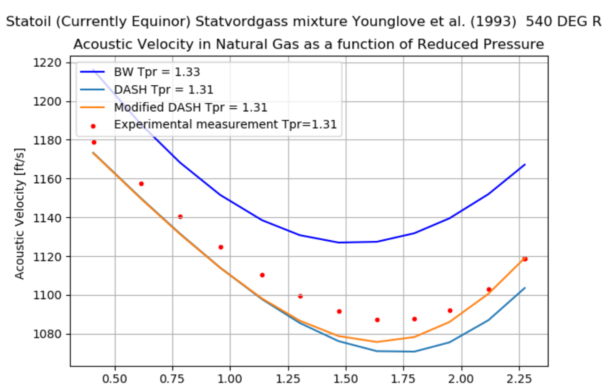

Figure 6 – *Modeled and experimental acoustic velocities in the Equinor Starvodgass natural gas mixture at 540 DEG R.*

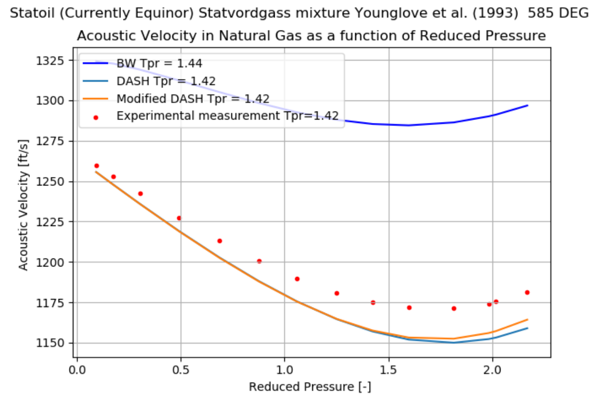

Figure 7 – *Modeled and experimental acoustic velocities in the Equinor Starvodgass natural gas mixture at 585 DEG R.*

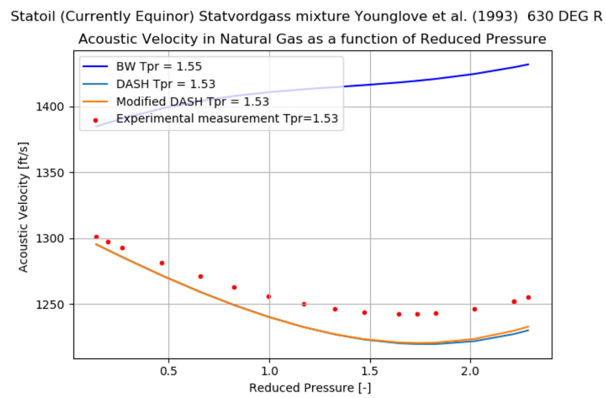

Figure 8 – *Modeled and experimental acoustic velocities in the Equinor Starvodgass natural gas mixture at 630 DEG R.*

Figures 9 and 10 demonstrate the difference in AVO response in a modeled case in which fluid properties are calculated with BW and DASH formulations. A larger difference in reflectivity can be observed at the longer offsets.

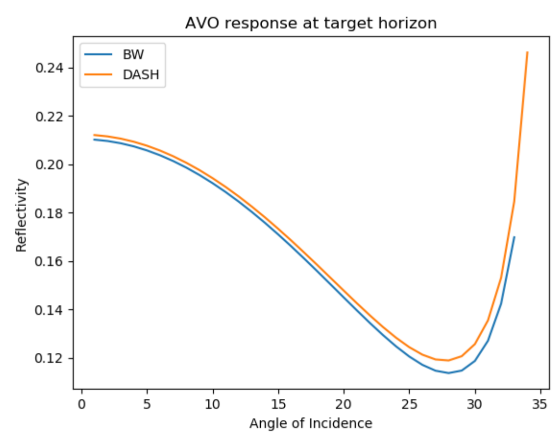

Figure 9 – *AVO response for fluid properties calculated with BW and DASH formulations for the the Equinor Starvodgass natural gas mixture at a temperature of 126.85 DEG C*

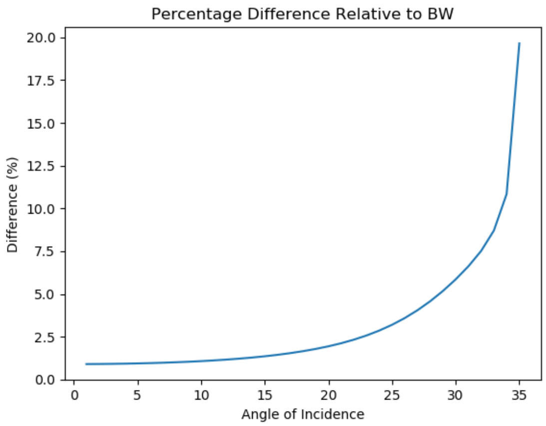

Figure 10 – *Variation in reflectivity in the case from Figure 9.*

Conclusions

The results presented indicate that both DASH and modified DASH formulations provide much higher accuracy for modeling the experimental data from the Gulf Coast and the Stavordgass natural gas mixtures. The BW formulation, however, yields the larger misfit in its prediction of acoustic velocity for the fluids studied.

Specifically, the BW equations seem to provide higher misfit as pressure and temperature increase, which could become a point of concern for its applicability in high pressure and high temperature scenarios, such as those found in the Brazilian pre-salt.

Moreover, modified DASH formulation demonstrates to be capable of capturing a temperature bias that the original DASH formulation is not. Therefore, modified DASH appears to provide the best fitting to the experimental data of the two mixtures studied.

Finally, the AVO modeling demonstrates that the use of DASH formulation for computing fluid properties does impact the estimated reflectivity, causing the greater differences at the longer offsets.

Further developments of current work include a sensibility analysis of DASH and modified DASH formulations in order to verify their performance in AVO modeling.

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