Reservoir Characterization by Investigating the Reservoir Fluid Properties and their Effect on Seismic Response of Fenchuganj Gas Field, Bangladesh

SM Ariful Islam1, Md. Shofigul Islam1* and Mohammad Moinul Hossain2, Md Aminul Islam3

1Department of Petroleum and Mining Engineering, Shahjalal University of Science and Technology, Sylhet 3114 Bangladesh
2Geophysical Division, Bangladesh Petroleum Exploration and Production Company (BAPEX), Dhaka, Bangladesh
3Department of Petroleum Geoscience, Faculty of Science Universiti Brunei Darussalam Jalan Tunghk Link Gadong BE1410, Negara Brunei Darussalam

Abstract

Fenchuganj Gas Field is located in the Surma Basin of Bangladesh and characterized by water-drive gas field. In the reservoir condition, water saturation increases as gas production rise. The fluid properties of the four individual gas zones of this reservoir at the present condition and at the gas depleted condition should be addressed with proper prediction. In this paper, we characterize the total reservoir with special emphasis on Upper Gas Zone and New Gas Zone I which are compared with other two gas zones (New Gas Zone III and New Gas Zone II) representing some modeling results (has done before by these authors) which evidences that the pore fluids have a significant effect on the acoustic impedance and the Poisson’s ratio of the reservoir rock which is directly correlated with seismic amplitudes at constant pressure with Batzle-Wang model and Gassmann-Biot models. These models with varying pressure and water saturation conditions show the reasonable predicted fluid modulus against pressure for all four gas sands. The reservoir modeling from irreducible water saturation condition (90% gas saturation) to residual gas condition (10% gas saturation) provides a way to estimate values at reservoir conditions from logging conditions. Fluid bulk density increases when water saturation increases with constant pressure and stay around constant when water saturation increases with pressure drop. But overall it increases through the production path that we assumed. Amplitude versus Offset (AVO) analysis is also compared with other study models which will give an understanding of pressure and water saturation of the reservoir rock layers. This study is also showing that all four gas zones of the Fenchuganj are under gas sand category 3. We propose the modeling of fluid property in determining the convenience of time lapse seismic, predicting AVO and amplitude response, and forecasting in the study field and making production and reservoir engineering decisions.

Keywords: Fluid; Reservoir characterization; Gas sand; Saturation; AVO

Introduction

Reservoir characterization incorporates all the characteristics of the reservoir that are relevant to its ability to store hydrocarbons and also to produce them. Models for reservoir characterization are used to suggest the behavior of the fluids within the reservoir under different sets of situation and to find the best possible production techniques that will maximize the production.

However, for the interpretation and evaluation of structural or stratigraphic features in the subsurface, the seismic data are commonly used. The physical properties of pore fluids have a vital effect on the seismic response of a porous rock containing it. It is essential to have an understanding of the changes in p-wave (compressional) velocity, s-wave (shear) velocity, and density as fluid or rock properties change to know or predict the effect of changes in seismic amplitudes and travel times.

For determination of the fluid properties from well log and seismic data, different methods are used (e.g., [1-10]). In this study, we have used Batzle and Wang [8] model, Gassmann [2] –Biot [3] model and AVO (Zoeppritz equation) model. The Batzle and Wang [8] model determines fluid properties, whereas, the Gassmann-Biot model predicts the saturated rock properties in reservoir rock matrix and gives a forecast of future effects of saturated rock properties on seismic response. Moreover, the AVO (amplitude variation with offset) model predicts the seismic response from the layered rock properties [11].

The amplitude versus offset (AVO) is a general term in reflection seismology for referring to the dependency of the seismic attribute, amplitude, with the distance between the source and receiver (the offset). AVO analysis is a method that geophysicists can accomplish on seismic data to determine a rock’s fluid content, porosity, density or seismic velocity, shear wave information, fluid indicators (hydrocarbon indications [12]). The P-wave and S-wave velocity, bulk density, acoustic impedance, Poisson’s ratio (PR), and bulk modulus are determined from Batzle and Wang [8] without considering the rock matrix and from Gassmann-Biot models as a function of the saturating fluid rocks.

Fenchuganj Gas Field is one of major gas producing fields in the Surma basin with estimated reserves of 553 Bcf. These authors already have worked on first two zones (New gas Zone [13] III and New gas Zone II) of Fenchuganj Gas Field. However, it is required to work with all four layers for better reservoir characterization [31]. Here we aimed i) to predict the velocity, density and modulus of fluid/fluid saturated rock matrix samples for both varying saturation with constant/varying pressure using Batzle and Wang model and Gassmann-Biot model, and ii) to predict seismic response from the layered rock properties using

*Corresponding author: Md. Shofigul Islam, Department of Petroleum and Mining Engineering, Shahjalal University of Science and Technology, Sylhet 3114 Bangladesh, Tel. 880821711945; E-mail: sho_fiq@yahoo.com

Received September 27, 2014; Accepted November 15, 2014; Published November 22, 2014

Citation: Islam SMA, Islam MS, Hossain MM, Islam MA (2014) Reservoir Characterization by Investigating the Reservoir Fluid Properties and their Effect on Seismic Response of Fenchuganj Gas Field, Bangladesh. J Fundam Renewable Energy Appl 4: 144. doi: 10.4172/20904541.1000144

Copyright: © 2014 Islam SMA, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
AVO (Zoeppritz equation) for all four layers with special emphasis on Upper Gas Zone (most targeted zone) and New Gas Zone I of Fenchuganj Gas Field.

**Geological Setting and Stratigraphy of the Study Area**

Fenchuganj structure of Surma basin lies under Fenchuganj Upazila of Sylhet district. It is about forty kilometers southeast of Sylhet town. Geographically, it is bounded by longitude 90°53’-92° east and latitude 24°30’-24°37’ north and it is tectonically located in the transition zone between the central Surma basin and the Folded Belt in the east (Figure 1).

The Surma Basin of Bangladesh experienced a variety of sediment facies, indicating a range of depositional environments during the Neogene time [15]. Furthermore, during the Miocene time, the Sylhet Basin has a noticeable subsidence and marine transgression. The transgression of the Miocene certainly affected the coastline. It is believed that the Surma Basin has undergone two successive phases of evolution; the marine transgressive phase, followed by a regressive phase resulting in a series of continental fluvo-deltaic to marginal marine sedimentation during the Neogene. The thickness of the late Mesozoic and Cenozoic strata in the Surma Basin range is from about 13 to 17 km [15,16], and much of this group is Neogene in age. The Great Himalayan Orogeny and related tectonics subject the Surma Basin during the Miocene-Pliocene times. However, major changes in sea level for Neogene are transgressive-regressive phenomena suggested by [15].

Fenchuganj structure is an elongated structure and about 30 km long and 8 km wide. It is a reversibly faulted asymmetrical anticline with NNE-SSW trending axis [16]. The eastern flank has sharp dip than the western flank. The amount of dip in the eastern flank varies from 30°-35°, whereas in the western flank dip varies from 20° to 25°.

Fenchuganj anticline is structurally higher in comparison to Jalalabad, Kailash Tila, and Beanibazar anticline with reference to Upper Marine Shale of Miocene age, but it is lower than Atgram anticline according to prominent horizon like Upper Marine Shale (UMS). The exposed rock is Dupi Tila of Plio-Pleistocene age. The formation of our targeted layers is Bokabil and Bluban [17].

**Methodology**

In this paper, we have used Batzle and Wang [8], and Gassmann–Biot [2,3] model for varying/constant saturation with varying/constant pressure condition. We used the input values from well test analysis. The detailed methodology is reported our previous paper [16]. The AVO calculation of Zoeppritz equation was also performed to predict the layer rock property and to compare with aforesaid two methods for better confidence are also described by Islam et al [16].

**Result and Discussion**

Four gas bearing zones are present and identified in the Fenchuganj gas field. They are New Gas Zone III, New Gas Zone II, Upper Gas Zone and New Gas Zone I. Analysis of all four gas zones is presented in this paper while analysis of the first two gas zones has already published [17]. We emphasized on the mainly Upper Gas Zone and new gas Zone I, and compared the results with other two zones. The results of all zones are tabled of course.

New Gas Zone III was found at a depth of 1656-1680m, with pressure 16.3888 MPa (2377 psi), temperature 46.67°C (116°F), porosity 27.3%, gas saturation 54%, water saturation 46% and salinity 8500 ppm. The New Gas Zone II with depth 1992-2017 m, pressure 19.7328 MPa (2862 psi), temperature 51.11°C (124°F), porosity 14.5%, gas saturation 36%, water saturation 64% and salinity 9500 ppm. The Upper Gas Zone with depth 2030-2086 m, pressure 20.1121 MPa (2917 psi), temperature 51.67°C (125°F), porosity 25%, gas saturation 60%, water saturation 40% and salinity 10000 ppm. And the New Gas Zone I with depth 2148-2154 m, pressure 21.2841 MPa (3087 psi), temperature 55.56°C (132°F), porosity 24.8%, gas saturation 57%, water saturation 43% and salinity 10500 ppm. For all gas zones, density of airs 0.00122 g/cc, the API gravity of condensate is 31.86°, gas-condensate ratio is 142260, gas constant(R) is 8.3145, and specific gravity of gas is 0.5624. These are the initial condition of gas layers Table 2. Fluid properties for gas zones were analyzed using the aforementioned methods of the previous paper by these authors [17]. Our main aim was to investigate and forecast the behavior of reservoir fluid properties during production which are discussed below.

**Fluid models for Varying Saturation under Constant Pressure**

**Batzle and Wang Model:** Using Batzle and Wang model for varying saturation with constant pressure for initial conditions, i.e. parameters, we have calculated density (ρ), acoustic velocity (Vp) and modulus (k) of gas, brine and mixture phase (Table 3).

The calculated result shows that the density(ρ), acoustic velocity (Vp) and bulk modulus (k) are 0.1367 g/cm3, 3,549.46 m/s, and 41.25 MPa for Upper Gas Zone, whereas New gas Zone I shows these values are 0.1412 g/cm3, 559.70 m/s, and 44.24 MPa, respectively for gas phase (Table 3). For brine and mixture phase, all the parameters (density, acoustic velocity and bulk modulus) have changed significantly (Table 3).

The cross-plot between bulk modulus and density for changing the saturation of gas zones have been formulated which are given in Figure 2. The values of modulus and density for changing saturation are listed in Table 4.
density (ρw), bulk modulus (Kw), hydrocarbon density (ρhyd) and bulk modulus (Khyd). The important output values are the bulk density (ρd), P-wave velocity (Vp), S-wave velocity (Vs), acoustic impedance (AI), and Poisson’s ratio (σ) as they vary due to changes in saturation. The dry frame modulus is held constant.

Using the Gassmann-Biot model at the reservoir condition, we found that the values of dry frame rigidity (G) are 6.58438 and 3.83328 GPA, bulk density (ρ) are 2.19998 and 2.1947707 g/cm3, fluid bulk modulus (Kf) are 0.068027 and 0.076594 GPA, saturated bulk modulus (KB) are 34.610512 and 16.74993 GPA, compressional wave velocity (Vp) are 4441.031 and 3118.338 m/s, shear wave velocity (Vs) are 1730.0079 and 1321.572 for Upper Gas Zone and New Gas Zone I, respectively (Table 6). Some other values of output parameters for different saturation are listed in Table 6.

Saturations of gas zones change from the initial condition with production. In Figure 2, the red marked position is the initial condition, whereas the green line indicates the production direction. These Figures show that for saturation changes with constant pressure, both the bulk modulus and density increases as the water saturation increases. However, the density increases very rapidly and bulk modulus increases slowly at the initial stage of production, whereas reverse situation (density increases slowly and bulk modulus increases very rapidly) exists at the later stage.

Gassmann-Biot model: In this section, Table 5 and Table 6 demonstrate the use of the Gassmann-Biot equations with fluid and rock properties to determine the overall reservoir rock seismic properties such as velocity and density. The input values include porosity (ρ), solid material bulk modulus (Ks) and density (ρs), brine density (ρb), bulk modulus (Kb), hydrocarbon density (ρhyd) and bulk modulus (Khyd). The important output values are the bulk density (ρ), P-wave velocity (Vp), S-wave velocity (Vs), acoustic impedance (A), and Poisson’s ratio (σ) as they vary due to changes in saturation. The dry frame modulus is held constant.

Using the Gassmann-Biot model at the reservoir condition, we found that the values of dry frame rigidity (G) are 6.58438 and 3.83328 GPA, bulk density (ρ) are 2.19998 and 2.1947707 g/cm3, fluid bulk modulus (Kf) are 0.068027 and 0.076594 GPA, saturated bulk modulus (KB) are 34.610512 and 16.74993 GPA, compressional wave velocity (Vp) are 4441.031 and 3118.338 m/s, shear wave velocity (Vs) are 1730.0079 and 1321.572 for Upper Gas Zone and New Gas Zone I, respectively (Table 6). Some other values of output parameters for different saturation are listed in Table 6.
Table 4: Modulus and density for different saturation condition.

| Gas% | Brine% | Density, g/cc | Modulus, Gpa | Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|------|--------|---------------|--------------|
| 5    | 95     | 0.956         | 0.5125       | 5    | 95     | 0.959         | 0.618        |
| 10   | 90     | 0.913         | 0.2857       | 10   | 90     | 0.915         | 0.3521       |
| 20   | 80     | 0.825         | 0.1516       | 20   | 80     | 0.829         | 0.1893       |
| 30   | 70     | 0.736         | 0.1032       | 30   | 70     | 0.742         | 0.1294       |
| 40   | 60     | 0.647         | 0.0782       | 40   | 60     | 0.655         | 0.0983       |
| 50   | 50     | 0.558         | 0.0629       | 50   | 50     | 0.568         | 0.0793       |
| 60   | 40     | 0.469         | 0.0527       | 60   | 40     | 0.482         | 0.0864       |
| 70   | 30     | 0.381         | 0.0453       | 70   | 30     | 0.393         | 0.0571       |
| 80   | 20     | 0.292         | 0.0397       | 80   | 20     | 0.308         | 0.0501       |
| 90   | 10     | 0.204         | 0.0354       | 90   | 10     | 0.221         | 0.0447       |

...}

Figure 2: Cross-plot of fluid modulus and density as saturation values change (gas%, brine%) for a) New Gas Zone III, b) New Gas Zone II, c) Upper Gas Zone and d) New Gas Zone I.
In this paper, we have assumed full water (wet) and gas saturation is 95% water and 90% gas, respectively. We also considered the irreducible gas saturation or depleted reservoir condition at 20% gas or 80% water (Figure 6 and Figure 7).

Based on the theory on pore fluid distribution in pore space, it is resolved that pore fluid should rise compressional velocity and decline slightly shear velocity of the rocks [2,3]. Moreover, experimental results also demonstrate that compressional and shear velocity are related to saturation [18,19]. According to Gregory [21], the saturation has larger effect on rock velocities in low porosity rocks than that of rock with high porosity. VP in fully water-saturated rocks is apparently larger than those in partially water-saturated rocks. Vp do not always fall with the rise of saturation. Instead Vp is related with pressure, porosity and the chemical interactions between pore fluid and rock skeleton. Our modeling result also displays (Figure 3) the compressional velocity (Vp, blue curve) increases with the increasing water saturation.

The compressional wave velocity (Vp, blue curve) trends from 6098 m/s, 4123 m/s, 6012 m/s and 4636 m/s at full water saturation to 3860 m/s, 2730 m/s, 4079 m/s and 2838 m/s at full gas saturation for New Gas Zone, Upper Gas Zone and New Gas Zone I, respectively.

During the production for upper Gas Zone and New Gas Zone I the water saturation varies from water saturation 40% to 80% and 43% to 80% respectively at reservoir conditions. Within this saturation range a significant variations has been found in the compressional velocity (Vp, blue curve) increases with the increasing water saturation.

The Figures 4a-d and Figures 4i-l show that the bulk density and PR increase linearly with the increase of water saturation. The bulk density (blue line in Figures 4a-d) increases from 2.1999 and 2.1948 g/cm³ to 2.2866 and 2.2737 g/cm³, respectively for Upper Gas Zone and New Gas Zone I with the water saturation increases from reservoir condition to irreducible gas saturation (20% gas). Similarly, for Upper Gas Zone and New Gas Zone I, IPR (blue line in Figures 4i-j) values are trending from 0.457 and 0.458 at full water saturation to 0.386 and 0.356, at full gas saturation, respectively. The acoustic impedance (blue line in Figures 4e-h) values are increased with the increasing water saturation. The properties of the pore fluids have amplitude variation with offset at the interface between the overlying shale and the reservoir [11]. The acoustic impedance values are trending from 13941 and 10688 m²/s·g/cm³ at full water saturation to 8710 and 6033 m²/s·g/cm³ at full gas saturation for Upper Gas Zone and New Gas Zone I, respectively. The point labeled (red mark) in Figures 3a-d. If the water saturation increases, the fluid bulk modulus and density increase, according to the green marked direction in Figs.3a-d, it has an increasing effect on PR and the acoustic impedance, and it can clearly identify from Figures 5a-h is a cross-plot of the compressional velocity of a compressional wave passing through the fluid and rock matrix versus the bulk density. These Figures show the changes in velocity and density values as the reservoir becomes increasingly water saturated. It is easily recognizable from the Figures 5e-h that compressional wave velocity and bulk density increases as water saturation increases. However, the Figures 5i-j is a cross-plot of shear wave velocity versus compressional wave velocity is consistent with the finding of Batzle and Wang model (Figures 3a-d).

### Fluid models for varying saturation and pressure

Batzle and Wang model: In this section, we considered gas saturation would change from 90% to 10% at reservoir pressure of 2000 psi, 1500 psi and1000 psi pressure for New Gas Zone III and at reservoir pressure of 2500 psi, 2000 psi, 1500 psi and1000 psi for New Gas Zone II, Upper Gas Zone and New Gas Zone I. For different saturation and pressure conditions the moduli and densities were calculated from this model are listed (Table 7). The cross plot between fluid moduli and density versus pressure shows that the fluids have a wide range of fluid moduli and densities of different saturation conditions (Figure 6). The different fluid moduli and densities for the initial reservoir pressure conditions are shown by the yellow diamonds. The red diamond indicates the initial saturation point in the yellow line. The light brown diamond series is for 17.236893 MPa (2500 psi), dark brown series is for 3.789514 MPa (2000 psi), blue diamond series is for 10.342136 MPa (1500 psi) and the black diamond series is for 6.894757 MPa (1000 psi) pressure. For New Gas Zone III, we assumed that during production fluid saturations (Gas: Brine) would change from 0.54 to 0.46, (0.50: 0.50), (0.40: 0.60) and (0.30: 0.70) at different pressure, respectively. Similarly, during production we assumed fluid saturations (Gas: Brine) would change from (0.36: 0.64), (0.32: 0.68), (0.28: 0.72), (0.24: 0.76) and (0.20: 0.80) for New Gas Zone II, (0.60: 0.40), (0.50: 0.50), (0.40: 0.60), (0.30: 0.70) and (0.20: 0.80) for New Gas Zone I, (0.70: 0.30), (0.60: 0.40) and (0.50: 0.50) at different pressure, respectively. The dry frame modulus is held constant. The figures 6a-d is showing the predicted fluid moduli path versus pressure fall. The black connecting line with arrow head shows the downward curve for the decreasing value of fluid modulus with respect to pressure fall during production. The fluid modulus increases with water saturation at a constant pressure, but decreases with pressure fall and overall it

| Input Parameter | New Gas Zone III | New Gas Zone II | Upper Gas Zone | New Gas Zone I |
|-----------------|------------------|----------------|---------------|---------------|
| Depth (m)       | 1656-1680        | 1992-2017      | 2030-2086     | 2148-2154     |
| Pressure (MPa)  | 16.3888          | 19.7328        | 20.112        | 21.2841       |
| Temperature (°C)| 46.67            | 51.11          | 51.67         | 55.56         |
| Solid Material Bulk Modulus (Gpa) | 30 | 30 | 30 | 30 |
| Solid Material Density (g/cc) | 2.829 | 2.4577 | 2.772 | 2.75 |
| Water Bulk Modulus (Kw) | 2.483 GPa | 2.523 GPa | 2.529 | 2.549 |
| Water Density (ρw) | 1.002 g/cc | 1.002 g/cc | 1.002 | 1.002 |
| Hydrocarbon Bulk Modulus (Km) | 0.032 Gpa | 0.040Gpa | 0.042 | 0.044 |
| Hydrocarbon Density (ρm) | 0.115 g/cc | 0.1346 g/cc | 0.137 | 0.141 |
| Logged P-wave velocity (Vp) | 2650 m/s | 2540 m/s | 2850 | 2160 |
| Logged S-wave velocity (Vs) | 1606 m/s | 1540 m/s | 1730 | 120 |
| Logged Bulk Density (ρbi) | 2.2 g/cc | 2.2 g/cc | 2.2 | 2.2 |
| Fluid Bulk Modulus at logged condition (Kf) | 0.584 Gpa | 1.0878 Gpa | 0.680 | 0.766 |

Table 5: Input values of Gassmann-Biot model (for varying saturation with constant pressure).
precisely forecasts velocity ratios with respect to differential pressure. Figs. are same as the Figure 6. All the outputs from Gassmann-Biot saturation and decreases with pressure fall for both gas zones. affected as strongly as the modulus by pressure changes and variations. pressure fall is dominating here for fluid modulus changes. So, the effect of decreases through the assumed production path. So, the effect of pressure fall is dominating here for fluid modulus changes.

However, a reverse condition has been seen from the Figures 6e-h, which indicates that the fluid density of the reservoir is not affected as strongly as the modulus by pressure changes and variations of saturation. The density is increasing with the increase of water saturation and decreases with pressure fall for both gas zones.

Gassmann-Biot Model: In this section, the initial conditions of the Figs. are same as the Figure 6. All the outputs from Gassmann-Biot model are listed in Table 8. As we know that the Biot- Gassmann theory precisely forecasts velocity ratios with respect to differential pressure for given porosity. However, because the velocity ratio is weakly associated to porosity, it is not suitable to investigate the velocity ratio with respect to porosity (\(q\)). The velocity ratio has been used for many purposes, such as a lithology indicator, determining degree of consolidation, identifying pore fluid, and predicting velocities [18-20].

Table 6: Calculated values of Gassmann-Biot model (for varying saturation with constant pressure).

| Water Saturation, \(p_w\) | Dry Frame Rigidity, \(G\) | Bulk Density, \(\rho/\text{g/cm}^3\) | Fluid Bulk Modulus, \(K_f\) | Saturated Bulk Modulus, \(K_s\) | P-Wave Velocity, \(V_p\) | S-Wave Velocity, \(V_s\) | Poisson’s Ratio, \(\sigma\) | Acoustic impedance, \(A_l\) |
|--------------------------|--------------------------|-------------------------------|--------------------------|-------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 0.1                      | 5.67431                  | 2.11280                       | 0.03536                  | 23.9203                       | 3860.38                  | 1638.80                  | 0.39008                  | 8156.221                 |
| 0.2                      | 5.67431                  | 2.13701                       | 0.03971                  | 26.0534                       | 3966.33                  | 1629.49                  | 0.39847                  | 8476.134                 |
| 0.3                      | 5.67431                  | 2.16123                       | 0.04528                  | 28.6042                       | 4090.94                  | 1620.34                  | 0.40696                  | 8841.479                 |
| 0.4                      | 5.67431                  | 2.18544                       | 0.05267                  | 31.7087                       | 4329.21                  | 1611.33                  | 0.41556                  | 9264.569                 |
| 0.46                     | 5.67431                  | 2.19997                       | 0.05838                  | 33.9173                       | 4342.36                  | 1606.00                  | 0.42076                  | 9553.107                 |
| 0.5                      | 5.67431                  | 2.20966                       | 0.06294                  | 35.5690                       | 4418.25                  | 1602.48                  | 0.42426                  | 9762.856                 |
| 0.6                      | 5.67431                  | 2.23387                       | 0.07818                  | 40.4996                       | 4638.59                  | 1593.77                  | 0.4307                  | 10306.06                |
| 0.7                      | 5.67431                  | 2.25089                       | 0.10316                  | 47.0173                       | 4916.51                  | 1585.20                  | 0.44199                  | 11101.95                 |
| 0.8                      | 5.67431                  | 2.28230                       | 0.15159                  | 56.0348                       | 5278.9                   | 1576.77                  | 0.45102                  | 12048.07                 |
| 0.9                      | 5.67431                  | 2.30652                       | 0.28574                  | 69.3323                       | 5774.02                  | 1568.47                  | 0.46016                  | 13137.93                 |
| 0.95                     | 5.67431                  | 2.31663                       | 0.51251                  | 78.6664                       | 6098.44                  | 1564.37                  | 0.46478                  | 14140.03                 |
| 0.1                      | 5.21752                  | 2.13342                       | 0.04469                  | 8.940381                      | 2729.727                 | 1563.84                  | 0.25572                  | 5823.6798                |
| 0.2                      | 5.21752                  | 2.14600                       | 0.050141                 | 9.758707                      | 2790.889                 | 1559.25                  | 0.273109                 | 5989.6291                |
| 0.3                      | 5.21752                  | 2.15858                       | 0.057142                 | 10.74193                      | 2863.418                 | 1554.703                 | 0.290863                 | 6106.9368                |
| 0.4                      | 5.21752                  | 2.17116                       | 0.066415                 | 11.94548                      | 2950.952                 | 1550.192                 | 0.30936                  | 6406.2241                |
| 0.5                      | 5.21752                  | 2.18374                       | 0.079281                 | 13.45275                      | 3057.135                 | 1545.721                 | 0.32828                  | 6676.0001                |
| 0.6                      | 5.21752                  | 2.19632                       | 0.098329                 | 15.39553                      | 3190.143                 | 1541.289                 | 0.347748                 | 7006.5848                |
| 0.7                      | 5.21752                  | 2.20315                       | 0.108784                 | 16.33908                      | 3253.073                 | 1539.526                 | 0.365666                 | 7161.1596                |
| 0.8                      | 5.21752                  | 2.20890                       | 0.129425                 | 17.99361                      | 3360.853                 | 1536.894                 | 0.377795                 | 7423.7942                |
| 0.9                      | 5.21752                  | 2.2211                        | 0.189                    | 21.647                        | 3588.306                 | 1528.212                 | 0.4097                  | 8730.5641                |
| 0.95                     | 5.21752                  | 2.2342                        | 0.352                    | 27.162                        | 3907.938                 | 1521.286                 | 0.4097                  | 9270.4531                |

J Fundam Renewable Energy Appl
ISSN: 2090–4541 JFRA, an open access journal
Volume 5 • Issue 1 • 1000144
Figure 3: Velocity versus saturation shows how water saturation affects a two phase mixture of gas and brine in a sandstone matrix from water to gas saturated conditions for a) New Gas Zone III, b) New Gas Zone II, c) Upper Gas Zone and d) New Gas Zone I.
Figure 4: (a-d) Bulk density versus saturation; (e-h) Acoustic Impedance versus saturation; and (i-l) Poisson’s ratio versus saturation shows how water saturation affects a two phase mixture of gas and brine in a sandstone matrix from water to gas saturated conditions.
Figure 5: (a-d) Acoustic impedance Vs. Poisson’s ratio cross-plot; (e-h) Compressional wave velocity Vs. Bulk density cross-plot; (i-j) Shear wave velocity Vs. Compressional wave velocity cross-plot for a two phase mixture of gas and brine in a sandstone matrix from water to gas saturated conditions.

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 19.73279 Mpa (2862psi)
Density of Gas: 0.1346 g/cc
Modulus of Gas: 0.040273 Gpa
Density of Brine: 1.0022 g/cc
Modulus of Brine: 2.523198 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.2214        | 0.0447       |
| 80   | 20     | 0.2581        | 0.0501       |
| 70   | 30     | 0.2948        | 0.0571       |

**Calculation for New Gas Zone III** (Islam et al. 2014)

Pressure: 16.3884 Mpa (2377psi)
Density of Gas: 0.115 g/cc
Modulus of Gas: 0.031754 Gpa
Density of Brine: 1.0019 g/cc
Modulus of Brine: 2.483332 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.02038       | 0.0305       |
| 80   | 20     | 0.02924       | 0.0393       |
| 70   | 30     | 0.03611       | 0.0452       |
| 60   | 40     | 0.04698       | 0.0531       |

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 10.3421 Mpa (1500psi)
Density of Gas: 0.0707 g/cc
Modulus of Gas: 0.018361 Gpa
Density of Brine: 0.9994 g/cc
Modulus of Brine: 2.445394 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.1636        | 0.0204       |
| 80   | 20     | 0.2563        | 0.0229       |
| 70   | 30     | 0.3493        | 0.0261       |
| 60   | 40     | 0.4422        | 0.0304       |

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 17.236893 Mpa (2500psi)
Density of Gas: 0.1346 g/cc
Modulus of Gas: 0.03909 Gpa
Density of Brine: 1.0012 g/cc
Modulus of Brine: 2.506883 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.2038        | 0.0305       |
| 80   | 20     | 0.2924        | 0.0393       |
| 70   | 30     | 0.3611        | 0.0452       |
| 60   | 40     | 0.4698        | 0.0531       |

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 13.7895 Mpa (2000psi)
Density of Gas: 0.0963 g/cc
Modulus of Gas: 0.025795 Gpa
Density of Brine: 1.0008 g/cc
Modulus of Brine: 2.468893 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.01868       | 0.0294       |
| 80   | 20     | 0.02722       | 0.0324       |
| 70   | 30     | 0.3677        | 0.0375       |
| 60   | 40     | 0.4681        | 0.0436       |

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 6.8948 Mpa (1000psi)
Density of Gas: 0.0454 g/cc
Modulus of Gas: 0.011486 Gpa
Density of Brine: 0.9979 g/cc
Modulus of Brine: 2.42472 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.9104        | 0.2364       |
| 80   | 20     | 0.124         | 0.0844       |
| 70   | 30     | 0.639         | 0.0634       |
| 60   | 40     | 0.7295        | 0.0644       |

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 10.3421 Mpa (1500psi)
Density of Gas: 0.0707 g/cc
Modulus of Gas: 0.018361 Gpa
Density of Brine: 0.9994 g/cc
Modulus of Brine: 2.445394 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.01407       | 0.0128       |
| 80   | 20     | 0.2359        | 0.0143       |
| 70   | 30     | 0.3312        | 0.0164       |
| 60   | 40     | 0.4264        | 0.0191       |

**Calculation for New Gas Zone II** (Islam et al. 2014)

Pressure: 17.236893 Mpa (2500psi)
Density of Gas: 0.1346 g/cc
Modulus of Gas: 0.03909 Gpa
Density of Brine: 1.0012 g/cc
Modulus of Brine: 2.506883 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.2065        | 0.0376       |
| 80   | 20     | 0.2948        | 0.0422       |
| 70   | 30     | 0.3831        | 0.0482       |
| Gas% | Brine% | Density, g/cc | Modulus, Gpa | Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|--------------|--------------|------|--------|--------------|--------------|
| 90   | 10     | 0.1847       | 0.0229       | 90   | 10     | 0.1621       | 0.0205       |
| 80   | 20     | 0.2752       | 0.0322       | 80   | 20     | 0.255        | 0.0230       |
| 70   | 30     | 0.3658       | 0.0368       | 70   | 30     | 0.3479       | 0.0262       |
| 60   | 40     | 0.4564       | 0.0428       | 60   | 40     | 0.4408       | 0.0306       |
| 50   | 50     | 0.5469       | 0.0512       | 50   | 50     | 0.5338       | 0.0366       |
| 40   | 60     | 0.6375       | 0.0636       | 40   | 60     | 0.6267       | 0.0456       |
| 30   | 70     | 0.7281       | 0.0841       | 30   | 70     | 0.7196       | 0.0604       |
| 20   | 80     | 0.8186       | 0.1241       | 20   | 80     | 0.8125       | 0.0895       |
| 10   | 90     | 0.9092       | 0.2363       | 10   | 90     | 0.9054       | 0.1727       |

Pressure: 6.894757 Mpa (1000 psi)
Density of Gas: 0.0445 g/cc
Modulus of Gas: 0.024096 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|--------------|--------------|
| 90   | 10     | 0.1397       | 0.0128       |
| 80   | 20     | 0.2349       | 0.0144       |
| 70   | 30     | 0.3302       | 0.0164       |
| 60   | 40     | 0.4255       | 0.0192       |
| 50   | 50     | 0.5207       | 0.0229       |
| 40   | 60     | 0.6159       | 0.0286       |
| 30   | 70     | 0.7112       | 0.0381       |
| 20   | 80     | 0.8064       | 0.0566       |
| 10   | 90     | 0.9017       | 0.1107       |

Calculation for Upper Gas Zone

Pressure: 20.112006 Mpa (2917 psi)
Density of Gas: 0.1367 g/cc
Modulus of Gas: 0.041259 Gpa
Density of Brine: 1.0025 g/cc
Modulus of Brine: 2.529461 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|--------------|--------------|
| 90   | 10     | 0.2232       | 0.045761     |
| 80   | 20     | 0.3098       | 0.051365     |
| 70   | 30     | 0.3964       | 0.058533     |
| 60   | 40     | 0.4829       | 0.068026     |
| 50   | 50     | 0.5656       | 0.081194     |
| 40   | 60     | 0.6561       | 0.100685     |
| 30   | 70     | 0.7427       | 0.132489     |
| 20   | 80     | 0.8293       | 0.193661     |
| 10   | 90     | 0.9159       | 0.35977      |

Pressure: 13.789514 Mpa (2000 psi)
Density of Gas: 0.0938 g/cc
Modulus of Gas: 0.025849 Gpa
Density of Brine: 0.9999 g/cc
Modulus of Brine: 2.488241 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|--------------|--------------|
| 90   | 10     | 0.1844       | 0.0287       |
| 80   | 20     | 0.275        | 0.0322       |
| 70   | 30     | 0.3656       | 0.0368       |
| 60   | 40     | 0.4562       | 0.0428       |
50 50 0.5469 0.0512 50 50 0.5337 0.0367
40 60 0.6375 0.0636 40 60 0.6267 0.0456
30 70 0.7281 0.084123 30 70 0.7196 0.0604
20 80 0.8187 0.1281 20 80 0.8126 0.0895
10 90 0.9093 0.2364 10 90 0.9055 0.1728

Pressure: 6.894757 Mpa (1000 psi)
Density of Gas: 0.0444 g/cc Modulus of Gas: 0.011546 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.1397        | 0.0128       |
| 90   | 20     | 0.2349        | 0.0144       |
| 70   | 30     | 0.3302        | 0.0165       |
| 60   | 40     | 0.4254        | 0.0192       |
| 50   | 50     | 0.5267        | 0.0229       |
| 40   | 60     | 0.6159        | 0.0286       |
| 30   | 70     | 0.7112        | 0.0381       |
| 20   | 80     | 0.8065        | 0.0567       |
| 10   | 90     | 0.9018        | 0.1108       |

Calculation for New Gas Zone I

Pressure: 21.284115 Mpa (3087 psi)
Density of Gas: 0.1412 g/cc Modulus of Gas: 0.044235 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.2272        | 0.0491       |
| 80   | 20     | 0.3133        | 0.0551       |
| 70   | 30     | 0.3993        | 0.0627       |
| 60   | 40     | 0.4854        | 0.0729       |
| 57   | 43     | 0.5112        | 0.0766       |
| 50   | 50     | 0.5714        | 0.0869       |
| 40   | 60     | 0.6474        | 0.1078       |
| 30   | 70     | 0.7435        | 0.1417       |
| 20   | 80     | 0.8295        | 0.2068       |
| 10   | 90     | 0.9158        | 0.3826       |

Pressure: 13.789514 Mpa (2000 psi)
Density of Gas: 0.0941 g/cc Modulus of Gas: 0.025843 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.1847        | 0.0229       |
| 80   | 20     | 0.2752        | 0.0322       |
| 70   | 30     | 0.3658        | 0.0368       |
| 60   | 40     | 0.4564        | 0.0428       |
| 50   | 50     | 0.5469        | 0.0512       |
| 40   | 60     | 0.6375        | 0.0636       |
| 30   | 70     | 0.7281        | 0.0841       |
| 20   | 80     | 0.8186        | 0.1241       |
| 10   | 90     | 0.9092        | 0.2363       |

Pressure: 6.894757 Mpa(1000 psi)
Density of Gas: 0.0445 g/cc Modulus of Gas: 0.011539 Gpa

| Gas% | Brine% | Density, g/cc | Modulus, Gpa |
|------|--------|---------------|--------------|
| 90   | 10     | 0.1397        | 0.0129       |
| 80   | 20     | 0.2349        | 0.0144       |
| 70   | 30     | 0.3302        | 0.0165       |
| 60   | 40     | 0.4255        | 0.0192       |
| 50   | 50     | 0.5207        | 0.0229       |
| 40   | 60     | 0.6159        | 0.0286       |
| 30   | 70     | 0.7112        | 0.0380       |
Table 7: Calculated fluid properties from Batzle and Wang Model (for varying saturation and pressure).

| 20  | 80  | 0.8064 | 0.0566 |
|-----|-----|--------|--------|
| 10  | 90  | 0.9017 | 0.1107 |
The phenomenon is based on the relationship between the reflection coefficient and the angle of incidence. Zoeppritz Equation:

\[ R(\theta) = A + B \sin^2 \theta \]

Conclusion

The fluid properties for both of the constant/varying saturation with constant/varying pressure condition are analyzed by the Batzle and Wang model that predicted near precise forecasting. Increase.
### Calculation for New Gas Zone III (Islam et al. 2014)

| Input Parameters (Fixed) | Symbol | Value | Unit |
|--------------------------|--------|-------|------|
| Depth                    | D      | 1656-1680 | m    |
| Temperature              | T      | 46.67  | °C   |
| Solid Material Bulk Modulus | \( K_s \) | 30     | Gpa  |
| Solid Material Density   | \( \rho_s \) | 2.8297 | g/cc |
| Logged P-wave velocity   | \( V_p \) | 2650   | m/s  |
| Logged S-wave velocity   | \( V_s \) | 1606   | m/s  |
| Logged Bulk Density      | \( \rho_v \) | 2.2    | g/cc |
| Fluid Bulk Modulus at logged condition | \( K_f \) | 0.5839 | Gpa  |
| Parameter(Variable)      | Symbol | Value | Unit |
| Pressure                 | P      | 16.3884 | Mpa  |
| Water Bulk Modulus       | \( K_w \) | 2.483332 | GPa  |
| Water Density            | \( \rho_w \) | 1.0019 | g/cc |
| Hydrocarbon Bulk Modulus | \( K_{hyd} \) | 0.031754 | Gpa  |
| Hydrocarbon Density      | \( \rho_{hyd} \) | 0.115 | g/cc |

| Parameter(Variable) | Symbol | Value | Unit |
|---------------------|--------|-------|------|
| Sw                  | Sg     | pb in g/cc | Vp in m/s | Vs in m/s | \( \sigma \) | Al |
| 0.1                 | 0.9    | 2.113    | 3860.397  | 1638.807  | 0.390 | 8156.245 |
| 0.2                 | 0.8    | 2.137    | 3966.357  | 1629.497  | 0.398 | 8476.153 |
| 0.3                 | 0.7    | 2.161    | 4090.965  | 1620.343  | 0.407 | 8841.49 |
| 0.4                 | 0.6    | 2.185    | 4239.234  | 1611.342  | 0.4157| 9264.577 |
| 0.46                | 0.54   | 2.199    | 4342.395  | 1606.013  | 0.421 | 9553.111 |
| 0.5                 | 0.5    | 2.209    | 4418.285  | 1602.490  | 0.424 | 9762.857 |
| 0.6                 | 0.4    | 2.234    | 4638.628  | 1593.782  | 0.433 | 10362.051 |
| 0.7                 | 0.3    | 2.258    | 4916.553  | 1585.214  | 0.442 | 11101.938 |
| 0.8                 | 0.2    | 2.283    | 5278.937  | 1576.783  | 0.451 | 12048.043 |
| 0.9                 | 0.1    | 2.307    | 5774.068  | 1568.489  | 0.460 | 13317.877 |
| Parameter(Variable)  | Symbol | Value | Unit |
| Pressure             | P      | 13.7985 | Mpa  |
| Water Bulk Modulus   | Kw     | 2.466993 | GPa  |
| Water Density        | \( \rho_w \) | 1.0008 | g/cc |
| Hydrocarbon Bulk Modulus | \( K_{hyd} \) | 0.025795 | Gpa  |
| Hydrocarbon Density  | \( \rho_{hyd} \) | 0.0963 | g/cc |

| Parameter(Variable) | Symbol | Value | Unit |
|---------------------|--------|-------|------|
| Sw                  | Sg     | pb in g/cc | Vp in m/s | Vs in m/s | \( \sigma \) | Al |
| 0.1                 | 0.9    | 2.108    | 3638.347  | 1640.603  | 0.372 | 7670.271 |
| 0.2                 | 0.8    | 2.133    | 3739.577  | 1631.079  | 0.383 | 7976.023 |
| 0.3                 | 0.7    | 2.157    | 3860.010  | 1621.718  | 0.393 | 8328.205 |
| 0.4                 | 0.6    | 2.182    | 4005.194  | 1612.517  | 0.403 | 8740.347 |
| 0.5                 | 0.5    | 2.207    | 4183.198  | 1603.471  | 0.414 | 9232.092 |
| 0.6                 | 0.4    | 2.232    | 4406.289  | 1594.575  | 0.424 | 9833.247 |
| 0.7                 | 0.3    | 2.256    | 4694.208  | 1585.825  | 0.436 | 10591.69 |
| 0.8                 | 0.2    | 2.281    | 5081.197  | 1577.219  | 0.447 | 11590.34 |
| 0.9                 | 0.1    | 2.306    | 5633.261  | 1568.750  | 0.458 | 12988.708 |

| Parameter(Variable) | Symbol | Value | Unit |
|---------------------|--------|-------|------|
| Pressure             | P      | 10.342 | Mpa  |
| Water Bulk Modulus   | Kw     | 2.445 | GPa  |
| Water Density        | \( \rho_w \) | 0.999 | g/cc |
| Hydrocarbon Bulk Modulus | \( K_{hyd} \) | 0.0184 | Gpa  |
| Hydrocarbon Density  | \( \rho_{hyd} \) | 0.071 | g/cc |

| Parameter(Variable) | Symbol | Value | Unit |
|---------------------|--------|-------|------|
| Pressure             | P      | 6.8948 | Mpa  |
| Water Bulk Modulus | Kw 2.424272 GPa |
| Water Density | pw 0.9979 g/cc |
| Hydrocarbon Bulk Modulus | Khyd 0.011486 Gpa |
| Hydrocarbon Density | phyd 0.0454 g/cc |
| Sw | Sg | pb in g/cc | Vp in m/s | Vs in m/s | α | Al |
| 0.1 | 0.9 | 2.0956 | 2916.857 | 1645.522 | 0.267 | 8116.725 |
| 0.2 | 0.8 | 2.122 | 2990.867 | 1635.407 | 0.287 | 8345.401 |
| 0.3 | 0.7 | 2.148 | 3080.426 | 1625.476 | 0.307 | 8615.509 |
| 0.4 | 0.6 | 2.174 | 3193.738 | 1615.724 | 0.328 | 8941.906 |
| 0.5 | 0.5 | 2.1994 | 3340.516 | 1606.145 | 0.350 | 7347.808 |
| 0.6 | 0.4 | 2.226 | 3536.966 | 1596.735 | 0.372 | 7871.892 |
| 0.7 | 0.3 | 2.252 | 3812.577 | 1587.488 | 0.395 | 8584.432 |
| 0.8 | 0.2 | 2.278 | 4228.153 | 1578.399 | 0.419 | 9630.092 |
| 0.9 | 0.1 | 2.304 | 4936.554 | 1569.466 | 0.444 | 11371.922 |

**Calculation for New Gas Zone II** (Islam et al. 2014)

| Input Parameters (Fixed) | Symbol | Value | Unit |
|--------------------------|--------|-------|------|
| Depth | D | 1992-2017 | m |
| Temperature | T | 51.11 | °C |
| Solid Material Bulk Modulus | Ks | 30 | Gpa |
| Solid Material Density | ps | 2.458 | g/cc |
| Logged P-wave velocity | Vpi | 2540 | m/s |
| Logged S-wave velocity | Vsi | 1540 | m/s |
| Logged Bulk Density | pbi | 2.2 | g/cc |

| Fluid Bulk Modulus at logged condition | Kfi 1.088 | Gpa |

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Pressure | P | 19.733 | Mpa |
| Water Bulk Modulus | Kw | 2.523 | GPa |
| Water Density | pw | 1.0022 | g/cc |
| Hydrocarbon Bulk Modulus | Khyd | 0.040 | Gpa |
| Hydrocarbon Density | phyd | 0.135 | g/cc |

| Sw | Sg | pb in g/cc | Vp in m/s | Vs in m/s | α | Al |
| 0.1 | 0.9 | 2.133 | 2729.726 | 1563.842 | 0.256 | 5823.681 |
| 0.2 | 0.8 | 2.146 | 2790.886 | 1559.251 | 0.273 | 5989.272 |
| 0.3 | 0.7 | 2.159 | 2863.414 | 1554.701 | 0.291 | 6180.940 |
| 0.4 | 0.6 | 2.171 | 2950.586 | 1550.190 | 0.309 | 6406.228 |
| 0.5 | 0.5 | 2.184 | 3057.127 | 1545.719 | 0.328 | 6676.004 |
| 0.6 | 0.4 | 2.196 | 3190.132 | 1541.286 | 0.348 | 7006.588 |
| 0.64 | 0.36 | 2.201 | 3253.057 | 1539.523 | 0.356 | 7161.162 |
| 0.7 | 0.3 | 2.209 | 3360.838 | 1536.890 | 0.368 | 7423.795 |
| 0.8 | 0.2 | 2.221 | 3588.285 | 1532.532 | 0.388 | 7971.348 |
| 0.9 | 0.1 | 2.234 | 3907.908 | 1528.211 | 0.4097 | 8730.550 |

| Pressure | Symbol | Value | Unit |
|--------------------------|--------|-------|------|
| Pressure | P | 17.237 | Mpa |
| Water Bulk Modulus | Kw | 2.507 | GPa |
| Water Density | pw | 1.001 | g/cc |
| Hydrocarbon Bulk Modulus | Khyd | 0.034 | Gpa |
| Hydrocarbon Density | phyd | 0.118 | g/cc |

| Sw | Sg | pb in g/cc | Vp in m/s | Vs in m/s | α | Al |
| 0.1 | 0.9 | 2.132 | 2632.695 | 1564.632 | 0.227 | 5610.100 |
| 0.2 | 0.8 | 2.144 | 2690.399 | 1559.953 | 0.247 | 5768.429 |
| 0.3 | 0.7 | 2.157 | 2759.534 | 1555.316 | 0.267 | 5951.993 |
| 0.4 | 0.6 | 2.169 | 2843.596 | 1550.721 | 0.288 | 6169.713 |
| 0.5 | 0.5 | 2.182 | 2947.724 | 1546.165 | 0.310 | 6433.378 |
| 0.6 | 0.4 | 2.195 | 3079.830 | 1541.650 | 0.333 | 6761.131 |
| 0.7 | 0.3 | 2.208 | 3252.839 | 1537.174 | 0.356 | 7182.584 |
| 0.8 | 0.2 | 2.221 | 3489.582 | 1532.736 | 0.380 | 7750.014 |
| 0.9 | 0.1 | 2.234 | 3835.119 | 1528.337 | 0.406 | 8566.521 |

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Pressure | P | 13.789 | Mpa |
| Water Bulk Modulus | Kw | 2.485 | GPa |
### Water Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Density        | $\rho_w$ | 0.999 | g/cc |

### Hydrocarbon Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Hydrocarbon Bulk Modulus | $K_{hyd}$ | 0.026 | GPa |

### Hydrocarbon Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Hydrocarbon Density  | $\rho_{hyd}$ | 0.004 | g/cc |

### Pressure

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Pressure             | $P$    | 30.342| Mpa  |

### Water Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Bulk Modulus   | $K_w$  | 2.4626| GPa  |

### Water Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Density        | $\rho_w$ | 0.9983 | g/cc |

### Hydrocarbon Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Hydrocarbon Bulk Modulus | $K_{hyd}$ | 0.0184 | GPa |

### Hydrocarbon Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Hydrocarbon Density  | $\rho_{hyd}$ | 0.0692 | g/cc |

### Pressure

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Pressure             | $P$    | 6.895 | Mpa  |

### Water Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Bulk Modulus   | $K_w$  | 2.441 | GPa  |

### Solid Material Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Temperature          | $T$    | 51.670| °C   |

### Temperature

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Temperature          | $T$    | 51.670| °C   |

### Solid Material Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Solid Material Density | $\rho_s$ | 2.772 | g/cc |

### Solid Material Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Logged P-wave velocity | $V_{pi}$ | 2850 | m/s |
| Logged S-wave velocity | $V_{si}$ | 1730 | m/s |

### Logged P-wave velocity

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Logged Bulk Density  | $\rho_{bi}$ | 2.2  | g/cc |

### Logged Bulk Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Fluid Bulk Modulus at logged condition | $K_{fi}$ | 0.680 | GPa |

### Parameter (Variable)

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Pressure             | $P$    | 20.112| Mpa  |

### Pressure

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Bulk Modulus   | $K_w$  | 2.529 | GPa  |

### Water Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Density        | $\rho_w$ | 1.0025| g/cc |

### Water Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Hydrocarbon Bulk Modulus | $K_{hyd}$ | 0.041 | GPa |

---

**Calculation for Upper Gas Zone**

### Input Parameters (Fixed)

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Depth                | $D$    | 2030-2086 | M |
| Temperature          | $T$    | 51.670 | °C |

### Temperature

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Solid Material Bulk Modulus | $K_s$ | 30.000 | GPa |

### Solid Material Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Logged P-wave velocity | $V_{pi}$ | 2850 | m/s |
| Logged S-wave velocity | $V_{si}$ | 1730 | m/s |

### Logged P-wave velocity

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Logged Bulk Density  | $\rho_{bi}$ | 2.2  | g/cc |

### Logged Bulk Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Fluid Bulk Modulus at logged condition | $K_{fi}$ | 0.680 | GPa |

### Parameter (Variable)

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Pressure             | $P$    | 20.112| Mpa  |

### Pressure

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Bulk Modulus   | $K_w$  | 2.529 | GPa  |

### Water Bulk Modulus

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Water Density        | $\rho_w$ | 1.0025| g/cc |

### Water Density

| Parameter (Variable) | Symbol | Value | Unit |
|----------------------|--------|-------|------|
| Hydrocarbon Bulk Modulus | $K_{hyd}$ | 0.041 | GPa |

### Hydrocarbon Bulk Modulus
| Parameter (Variable)          | Symbol | Value   | Unit |
|-------------------------------|--------|---------|------|
| Pressure                      | P      | 17.237  | Mpa  |
| Water Bulk Modulus            | Kw     | 2.511   | GPA  |
| Water Density                 | pw     | 1.001   | g/cc |
| Hydrocarbon Bulk Modulus      | Khyd   | 0.034   | Gpa  |
| Hydrocarbon Density           | phyd   | 0.118   | g/cc |

| Sw   | Sg   | pb in g/cc | Vp in m/s | Vs in m/s | σ   | Al   |
|------|------|------------|-----------|-----------|-----|------|
| 0.1  | 0.9  | 2.135      | 4079.303  | 1756.119  | 0.386 | 8709.495 |
| 0.2  | 0.8  | 2.157      | 4182.055  | 1747.284  | 0.357 | 9019.397 |
| 0.3  | 0.7  | 2.178      | 4301.285  | 1738.582  | 0.402 | 9369.639 |
| 0.4  | 0.6  | 2.199      | 4441.005  | 1730.008  | 0.411 | 9770.122 |
| 0.5  | 0.5  | 2.222      | 4606.738  | 1721.559  | 0.419 | 10234.44 |
| 0.6  | 0.4  | 2.243      | 4806.326  | 1713.234  | 0.427 | 10781.89 |
| 0.7  | 0.3  | 2.265      | 5051.346  | 1705.028  | 0.438 | 11440.87 |
| 0.8  | 0.2  | 2.286      | 5359.735  | 1696.939  | 0.444 | 12255.35 |
| 0.9  | 0.1  | 2.308      | 5761.096  | 1688.963  | 0.453 | 13297.79 |

| Parameter (Variable)          | Symbol | Value   | Unit |
|-------------------------------|--------|---------|------|
| Pressure                      | P      | 13.789  | Mpa  |
| Water Bulk Modulus            | Kw     | 2.488   | GPA  |
| Water Density                 | pw     | 0.999   | g/cc |
| Hydrocarbon Bulk Modulus      | Khyd   | 0.027   | Gpa  |
| Hydrocarbon Density           | phyd   | 0.094   | g/cc |

| Sw   | Sg   | Pb in g/cc | Vp in m/s | Vs in m/s | σ   | Al   |
|------|------|------------|-----------|-----------|-----|------|
| 0.1  | 0.9  | 2.125      | 3877.3871 | 1757.883  | 0.371 | 8261.790 |
| 0.2  | 0.8  | 2.153      | 3977.849  | 1748.842  | 0.380 | 8563.714 |
| 0.3  | 0.7  | 2.175      | 4095.747  | 1739.939  | 0.389 | 8907.994 |
| 0.4  | 0.6  | 2.197      | 4235.677  | 1731.171  | 0.399 | 9305.888 |
| 0.5  | 0.5  | 2.219      | 4404.119  | 1722.534  | 0.409 | 9773.237 |
| 0.6  | 0.4  | 2.241      | 4610.553  | 1714.025  | 0.419 | 10333.171 |
| 0.7  | 0.3  | 2.263      | 4869.488  | 1705.641  | 0.430 | 11021.051 |
| 0.8  | 0.2  | 2.285      | 5204.487  | 1697.378  | 0.440 | 11894.201 |
| 0.9  | 0.1  | 2.307      | 5656.952  | 1689.235  | 0.451 | 13053.201 |

| Parameter (Variable)          | Symbol | Value   | Unit |
|-------------------------------|--------|---------|------|
| Pressure                      | P      | 10.342  | Mpa  |
| Water Bulk Modulus            | Kw     | 2.466   | GPA  |
| Water Density                 | pw     | 0.995   | g/cc |
| Hydrocarbon Bulk Modulus      | Khyd   | 0.019   | Gpa  |
| Hydrocarbon Density           | phyd   | 0.069   | g/cc |

| Sw   | Sg   | Pb in g/cc | Vp in m/s | Vs in m/s | σ   | Al   |
|------|------|------------|-----------|-----------|-----|------|
| 0.1  | 0.9  | 2.119      | 3307.406  | 1762.468  | 0.302 | 7010.674 |
| 0.2  | 0.8  | 2.143      | 3391.417  | 1752.885  | 0.318 | 7267.569 |
| 0.3  | 0.7  | 2.167      | 3493.488  | 1743.457  | 0.334 | 7567.488 |
| 0.4  | 0.6  | 2.189      | 3619.404  | 1734.179  | 0.351 | 7924.359 |
| 0.5  | 0.5  | 2.213      | 3777.875  | 1725.048  | 0.368 | 8359.115 |
| 0.6  | 0.4  | 2.236      | 3982.724  | 1716.059  | 0.386 | 8904.934 |
| 0.7  | 0.3  | 2.259      | 4257.467  | 1707.209  | 0.404 | 9618.172 |
| 0.8  | 0.2  | 2.282      | 4646.112  | 1698.496  | 0.423 | 10604.146 |
| 0.9  | 0.1  | 2.306      | 5243.464  | 1689.914  | 0.442 | 12089.383 |

| Parameter (Variable)          | Symbol | Value   | Unit |
|-------------------------------|--------|---------|------|
| Pressure                      | P      | 8.895   | Mpa  |
Water Bulk Modulus $K_w$ 2.444 GPa
Water Density $\rho_w$ 0.997 g/cc
Hydrocarbon Bulk Modulus $K_{hyd}$ 0.012 GPa
Hydrocarbon Density $\rho_{hyd}$ 0.044 g/cc
Sw Sg $\rho_b$ in g/cc $V_p$ in m/s $V_s$ in m/s $\sigma$ Al
0.1 0.9 2.114 2849.535 1764.779 0.221 8235.738
0.2 0.8 2.138 3015.529 1754.921 0.244 8447.061
0.3 0.7 2.162 3097.940 1745.227 0.268 8697.058
0.4 0.6 2.186 3202.626 1735.692 0.292 8999.643
0.5 0.5 2.209 3338.768 1726.311 0.317 7376.716
0.6 0.4 2.233 3521.704 1717.081 0.344 7864.777
0.7 0.3 2.257 3779.366 1707.997 0.372 8530.210
0.8 0.2 2.281 4169.341 1699.056 0.400 9509.705
0.9 0.1 2.305 4836.157 1690.254 0.430 11145.805

Calculation for New Gas Zone I

Input Parameters (Fixed)
Symbol Value Unit
Depth D 2148-2154 M
Temperature T 55.56 °C
Solid Material Bulk Modulus $K_s$ 30 Gpa
Solid Material Density $\rho_s$ 2.75 g/cc
Logged P-wave velocity $V_{pi}$ 2180 m/s
Logged S-wave velocity $V_{si}$ 1320 m/s
Logged Bulk Density $\rho_{bi}$ 2.2 g/cc
Fluid Bulk Modulus at logged condition $K_{fi}$ 0.766 Gpa

Parameter(Variable)
Symbol Value Unit
Pressure P 21.284 Mpa
Water Bulk Modulus $K_w$ 2.548 GPa
Water Density $\rho_w$ 1.002 g/cc
Hydrocarbon Bulk Modulus $K_{hyd}$ 0.044 Gpa
Hydrocarbon Density $\rho_{hyd}$ 0.141 g/cc

Sw Sg $\rho_b$ in g/cc $V_p$ in m/s $V_s$ in m/s $\sigma$ An
0.1 0.9 2.124 2838.477 1343.297 0.356 6029.941
0.2 0.8 2.146 2915.875 1336.598 0.367 6256.589
0.3 0.7 2.167 3007.933 1330.011 0.378 6518.003
0.4 0.6 2.188 3118.426 1323.500 0.390 6824.298
0.43 0.57 2.195 3156.109 1321.568 0.394 6926.969
0.5 0.5 2.210 3253.869 1317.094 0.402 7190.139
0.6 0.4 2.231 3423.369 1310.779 0.414 7637.742
0.7 0.3 2.252 3641.761 1304.555 0.426 8202.703
0.8 0.2 2.274 3934.676 1298.419 0.439 8946.434
0.9 0.1 2.295 4351.228 1292.368 0.452 9986.421

Parameter(Variable)
Symbol Value Unit
Pressure P 17.237 Mpa
Water Bulk Modulus $K_w$ 2.548 GPa
Water Density $\rho_w$ 0.999 g/cc
Hydrocarbon Bulk Modulus $K_{hyd}$ 0.034 Gpa
Hydrocarbon Density $\rho_{hyd}$ 0.115 g/cc

Sw Sg $\rho_b$ in g/cc $V_p$ in m/s $V_s$ in m/s $\sigma$ An
0.1 0.9 2.119 2641.934 1345.127 0.325 5597.142
0.2 0.8 2.141 2712.832 1338.217 0.339 5806.945
0.3 0.7 2.162 2798.289 1331.413 0.354 6051.141
0.4 0.6 2.184 2902.865 1324.712 0.368 6340.949
0.5 0.5 2.206 3033.368 1318.111 0.384 6692.550
0.6 0.4 2.228 3200.497 1311.608 0.399 7131.485
0.7 0.3 2.250 3422.209 1305.199 0.415 7700.573
0.8 0.2 2.272 3731.514 1298.855 0.431 8478.406
0.9 0.1 2.294 4197.637 1292.661 0.448 9629.556

Parameter(Variable)
Symbol Value Unit
Pressure P 13.789 Mpa
Water Bulk Modulus $K_w$ 2.548 GPa
Water Density $\rho_w$ 0.999 g/cc
of water saturation effects on fluid properties by increasing the fluid density, modulus and acoustic velocity among the all gas sand layers of the Fenchuganj Gas Field. The compressibility of fluid declines as the water in fluid rises. Similarly, due to temperature rise, the velocity and density of the fluid fall. The cross plots using the Batzle and Wang model on densities and moduli allows to predict the fluid properties as the reservoir is produced and shows the effect on the reservoir as water saturation rises and gas saturation drops. The modify in P-wave and S-wave velocity, bulk density, acoustic impedance, Poisson’s ratio, and bulk modulus were predicted using the Batzle and Wang and Gassmann-Biot model which show that the reservoir changes from irreducible water saturation conditions in residual gas conditions which provide an avenue to calculate values at reservoir conditions from logging conditions. Coupling with the Batzle and Wang, Gassmann-Biot, the AVO models can be used to determine expected seismic responses throughout the production path of the reservoir and coincide with previous results [17]. In case of the Fenchuganj Gas Field, it is shown that an AVO response is presented as a result of the fluid and rock properties and also show that the reservoir is pressure decreases due to increasing the gas production. The AVO modeling for fluid property investigation will help in determining the usefulness of time lapse seismic, predicting AVO and amplitude response, and making decision on forecasting and production for the reservoir.

Acknowledgement
The authors are grateful to BAPEx authority, especially Geological and Geophysical Division for allowing collecting the necessary data and use their software for this work. The first author is also grateful to Mr. Md. Shofiqul Islam, Geology Division (BAPEx) and Mr. Pulok Kanti Deb, Department of Petroleum and Mining Engineering, Shahjalal University for their help and suggestions to improve this work.
Figure 7: (a-d) P-wave velocity versus pressure shows how the velocity changes as the pressure and saturation in the reservoir changes; (e-h) The Poisson's ratio versus pressure shows how the velocity changes as the pressure and saturation in the reservoir changes; and (i-j) Acoustic impedance versus pressure show how the Poisson's ratio changes as the pressure and saturation in the reservoir changes.
Figure 8: Reflection amplitude versus offset shows the AVO between a definite pressure-saturation condition and reservoir condition for a) New Gas Zone III, b) New Gas Zone II, c) Upper Gas Zone and d) New Gas Zone I. Reflection amplitude versus offset shows the AVO between e) New Gas Zone III and above shale zone, b) New Gas Zone II and above shale zone, c) Upper Gas Zone and above shale zone, and h) New Gas Zone I and above shale zone.

| Above Shale Zone/ Gas Zone | P-Velocity (Vp) (m/sec) | S-Velocity (Vs) (m/sec) | Bulk Density (ρb) (g/cm³) |
|----------------------------|------------------------|------------------------|---------------------------|
| Shale Zone Above New gas Zone III | 4000 | 13123 | 2116 | 6942 | 2.40 |
| Shale Zone Above New gas Zone II | 3800 | 12467 | 2011 | 6598 | 2.40 |
| Shale Zone Upper gas Zone | 4300 | 14107 | 2275 | 7464 | 2.40 |
| Shale Zone New gas Zone I | 3300 | 10826 | 1746 | 5728 | 2.40 |
| New gas Zone III | 2650 | 8694 | 1606 | 5269 | 2.20 |
| New gas Zone II | 2540 | 8333 | 1540 | 5053 | 2.20 |
| Upper gas Zone | 2850 | 9350 | 1730 | 5676 | 2.20 |
| New gas Zone I | 2180 | 7152 | 1320 | 4330 | 2.20 |

Table 9: The inputs for Shale zones above gas layer and Gas zones for determining AVO.
References

1. Zoeppritz K (1919) Erdbebenwellen, VIIIB, On the reflection and propagation of seismic waves. Gottinger Nachrichten 1: 66-84.
2. Gassmann F (1951) Elastic waves through a packing of spheres. Geophysics 16: 673-685.
3. Biot MA (1956) Theory of propagation of elastic waves in a fluid-saturated porous solid. J Acoustic Soc America, 28: 168-191.
4. Kuster GT, Toksöz MN (1974) Velocity and attenuation of seismic waves in two-phase media: Part I. theoretical formulations. Geophysics 39: 587-606.
5. O'Connell R, Budiansky B (1974) Seismic velocities in dry and saturated crack solids. J Geophy Res 79: 5412-5426.
6. Rutherford SR, Williams RH (1989) Amplitude-versus-offset variations in gas sands. Geophysics 54: 680-688.
7. Mavko G, Jizba D (1991) Estimating grain-scale fluid effects on velocity dispersion in rocks. Geophysics 56: 1940–1949.
8. Batzle M, Wang Z (1992) Seismic properties of pore fluids. Geophysics 57: 1396-1408.
9. Sheriff RE (1991) Encyclopedic Dictionary of Exploration Geophysics. (3rd Edn) SEG Geophysical References Series1, Tulsa, USA.
10. Castagna JP, Swan HW (1997) Principles of AVO cross plotting. The Leading Edge 16: 337-342.
11. Bulloch TE (1999) The investigation of fluid properties and seismic attributes for reservoir characterization. M.Sc thesis for Geological Engineering, Michigan Technological University, USA.
12. http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=amplitude%20variation%20with%20offset
13. Annual Report (2010) Bangladesh Petroleum Exploration and Production Company Limited (BAPEX), Bangladesh.
14. Geological Survey Bulletin (2001) U.S Geological Survey -Petrobangla cooperative assessment of undiscovered natural gas resources of Bangladesh. U.S. 2208-A: 119.
15. Evans P (1964) The tectonic framework of Assam. J Geol Soc Ind S: 80–96.
16. Hiller K, Elahi M (1984) Structural development and hydrocarbon entrapment in the Surma Basin, Bangladesh (northwest Indo-Burman fold belt). Singapore Fifth Offshore Southwest Conference, Singapore.
17. Islam S M A, Islam M S, Hossain M M (2014) Investigation of fluid properties and their effect on seismic response. A case study of Fenchuganj Gas Field, Surma Basin, Bangladesh. Int J Oil Gas Coal Engg 2: 36-54.
18. Hilterman F (1989) Is AVO the seismic signature of rock properties? 59th Ann Internat Mtg, Soc. Expl. Geophys. Expanded Abstracts.
19. Knigh R, Nolen-Hoeksema RA (1990) laboratory study of the dependence of elastic wave velocities on porescale fluid distribution. Geophys Res Lett 17: 1529-1532.
20. Liu Zhupin WU, Xiaowei Chu Zehan (1994) Laboratory study of acoustic parameters of rock. Chinese J Geophys 37: 659-666.
21. Gregory AR (1976) Fluid saturation on dynamic elastic properties of sedimentary rocks. Geophysics 41: 895-921.
22. Aki K, Richards PG (1980) Quantitative seismology: Theory and methods. W.H.Freeman and Co.
23. Shuey RT (1985) A simplification of the Zoeppritz equations. Geophysics 50: 609-614.