Fluid-filled Cracks and Seismic Anisotropy: An Experimental Study

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ABSTRACT

Seismic characterization of subsurface fractures has important applications in reservoir assessment. Recent studies have also shown that azimuthal anisotropy can not only help delineate orientation and intensity of fractures, but also indicate the fluid infill of these cracks. To explore the influence of different fluids on seismic response in a transversely isotropic background medium, a physical modeling study using vertically aligned and grooved plexiglass material embedded in isotropic resin was conducted. The theoretical motivation for this experimental study is the Hudson and Thomsen theories for penny-shaped cracks. The composite model was designed to simulate a single set of aligned vertical cracks (HTI symmetry) filled with fluids. In a series of ultrasonic and scaled seismic experiments, the model is initially filled with air (gas-saturated) and then fluids (distilled water and glycerin) are gradually injected into the composite material to simulate different rates of fluid saturation. Porosity in our assembled cracked media is about 2.5% and crack density is estimated as 14%. Our results show changes in ultrasonic compressional and shear wave velocities in different directions as a function of different saturating fluids. Most significant velocity change is observed in vertically propagating P-waves. We also detect changes in delay between fast and slow split shear waves with different saturating fluids. NMO velocity measured from scaled ultrasonic response shows not only changes in velocity values on saturation, but also a difference in the trend of NMO velocities as a function of source-receiver azimuth. Anisotropic parameters also varied with different levels of saturation. Our experiments show that anisotropic parameters ε is reduced by 30% on full saturation with brine and 50% with Oil. Anisotropic parameter Υ increases by 50% from a gas to brine saturated medium and 60% from gas to oil saturated medium. Our results conclude that most significant changes in anisotropic and stiffness properties occurs when gas is substituted for brine (distilled water) or Glycerol (Oil substitute). These changes are however much smaller when brine is substituted for Oil or vice versa.

OBJECTIVES

1) To explore the effect of different fluids on seismic response and consequently anisotropy in an inherently anisotropic medium.

2) To compare predictions of various theories of wave propagation in fractured media.

MODEL DESCRIPTION & EXPERIMENTAL METHODS

Our composite model is composed of 95 grooved or scratched plexiglass sheets embedded or encased in isotropic resin material. Plexiglass sheets are aligned vertically to serve as HTI type fracture plane. Each plexiglass sheet has a thickness of about 1.1mm to 1.3mm. The depth of the indents or grooves is about 0.2mm to 0.3mm. These indents are randomly placed and are in all directions on the plexiglass sheet. This is designed to mimic circular or penny-shaped (vertically aligned) cracks that lead to HTI symmetry. The fabrication process was conducted in a vacuum chamber at the Allied Geophysical Laboratories at University of Houston.

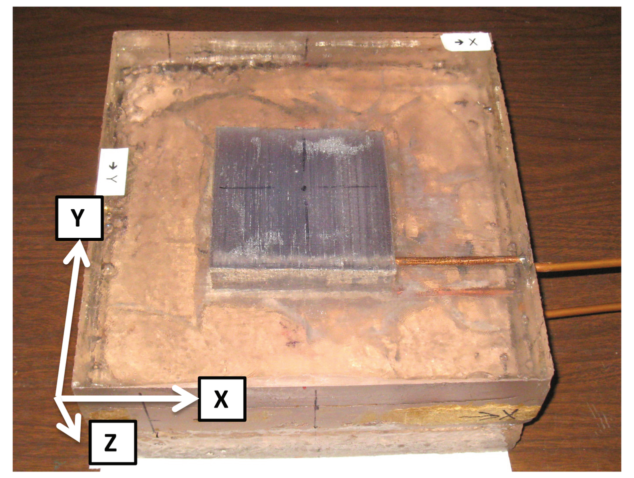

Figure 1. Snapshot of physical model showing aligned fractures in the center and copper tube for fluid injection.

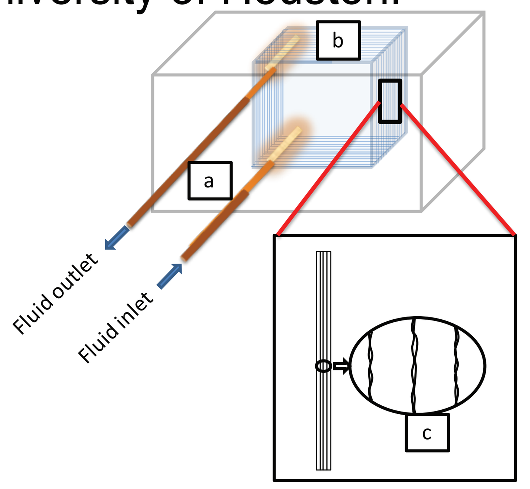

Figure 2: Schematic of composite model showing fracture system: a) Copper tubes for fluid injection, b) Fracture zone made up of 95 plexiglass sheets and c) Zoom on plexiglass sheets showing crack indents (not to scale).

The physical properties of the plexiglass sheets used are as follows: ρ=1.188 g/cm3, Vp=2300 m/s and Vs=1320 m/s. The containing resin has the following physical properties: ρ=1.22 g/cm3, Vp=2540 m/s and Vs=1250 m/s. The resin material is sufficiently homogeneous for the smallest wavelength used for our investigation.

Physical properties of Constituent Materials

Isotropic resin:

$$\begin{pmatrix} 7.79 & 4.04 & 4.04 & & & \\ 4.04 & 7.79 & 4.04 & & & \\ 4.04 & 4.04 & 7.79 & & & \\ & & & 1.87 & & \\ & & & & 1.87 & \\ & & & & & 1.87 \end{pmatrix} \text{GPa}$$

Fracture zone only (HTI):

$$\begin{pmatrix} 5.01 & 1.56 & 1.56 & & & \\ 1.56 & 1.73 & 1.25 & & & \\ 1.56 & 1.25 & 1.73 & & & \\ & & & 0.25 & & \\ & & & & 0.09 & \\ & & & & & 0.09 \end{pmatrix} \text{GPa}$$

Composite Model (HTI):

$$\begin{pmatrix} 7.33 & 2.46 & 2.46 & & & \\ 2.46 & 3.61 & 1.48 & & & \\ 2.46 & 1.48 & 3.61 & & & \\ & & & 1.07 & & \\ & & & & 0.98 & \\ & & & & & 0.98 \end{pmatrix} \text{GPa}$$

Experimental Set-up

Two sets of experiments were carried out on the composite sample in the work presented here. (1) Ultrasonic travel time measurements in all axes and directions to estimate velocities and consequently stiffness coefficients as a function of fluid saturation. (2) Scaled surface reflection (CMP) measurements before and after fluid saturation.

RESULTS

Compressional Wave Velocity

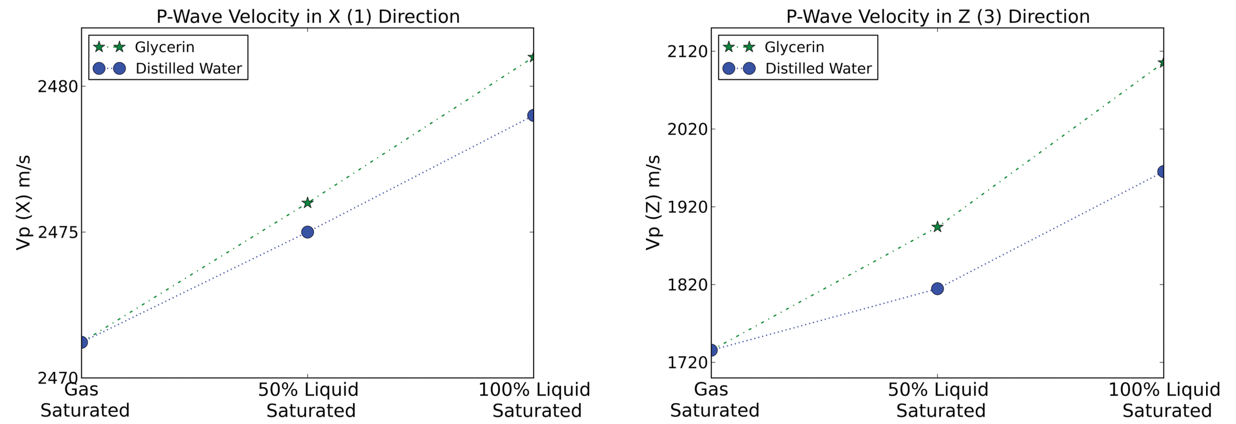

Figure 3. Compressional wave velocity as a function of liquid saturation in X and Z directions.

Shear Wave Seismogram

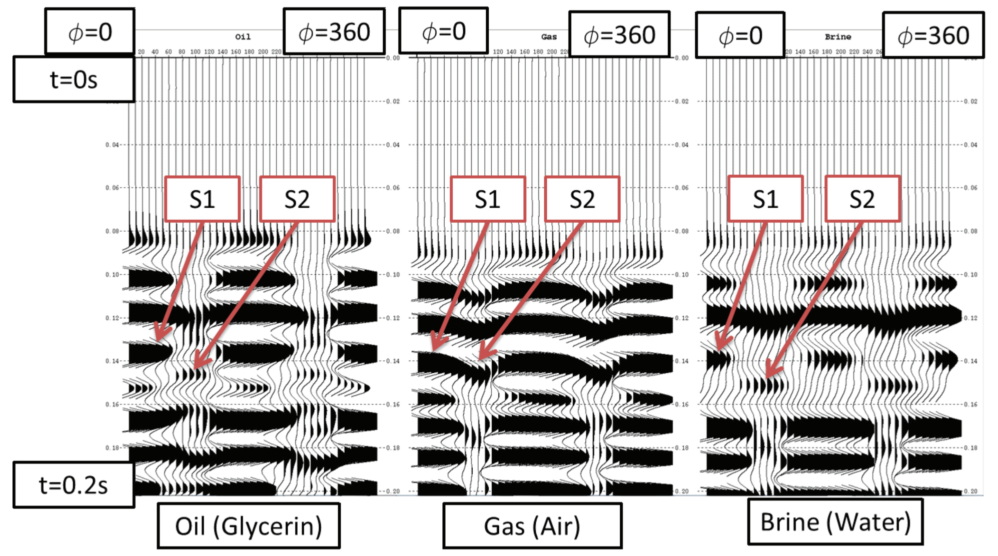

Figure 4. Shear wave seismogram as a function of polarization angle, showing fast and slow arriving shear waves.

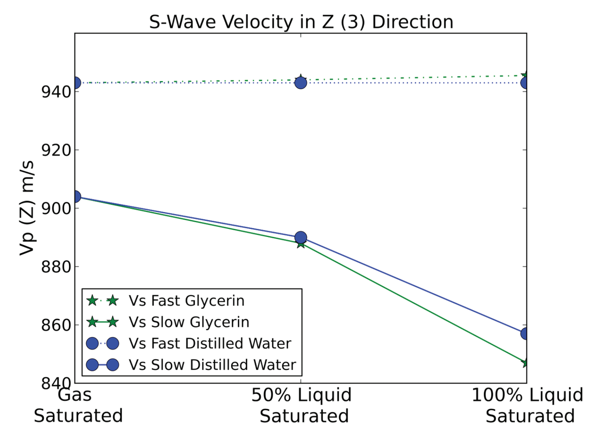

Figure 5. Shear wave velocity as a function of liquid saturation in Z direction.

Azimuthal P-wave NMO Analysis

The P-wave azimuthal measurements were acquired with ultrasonic transducers in a typical scaled physical modeling experimental setup. In a physical modeling experiment, an attempt is made at estimating the seismic response of a geologic model by measuring the reflected or transmitted wave field over the scaled model (Ebrom and McDonald, 1994). The scaling is on travel time and consequently wavelength but all other wave attributes such as velocity remain intact. In this experiment, source-receiver configuration was designed to mimic common-midpoint measurements. The measurements were repeated for every 15 degrees azimuth interval from azimuths 0 degree to 180 degrees (90 degrees being the axis of symmetry). Minimum offset was 400m (4cm) and maximum offset was 2200m (22cm) with 30m (0.3cm) offset interval. Scaling is by a factor of 10,000

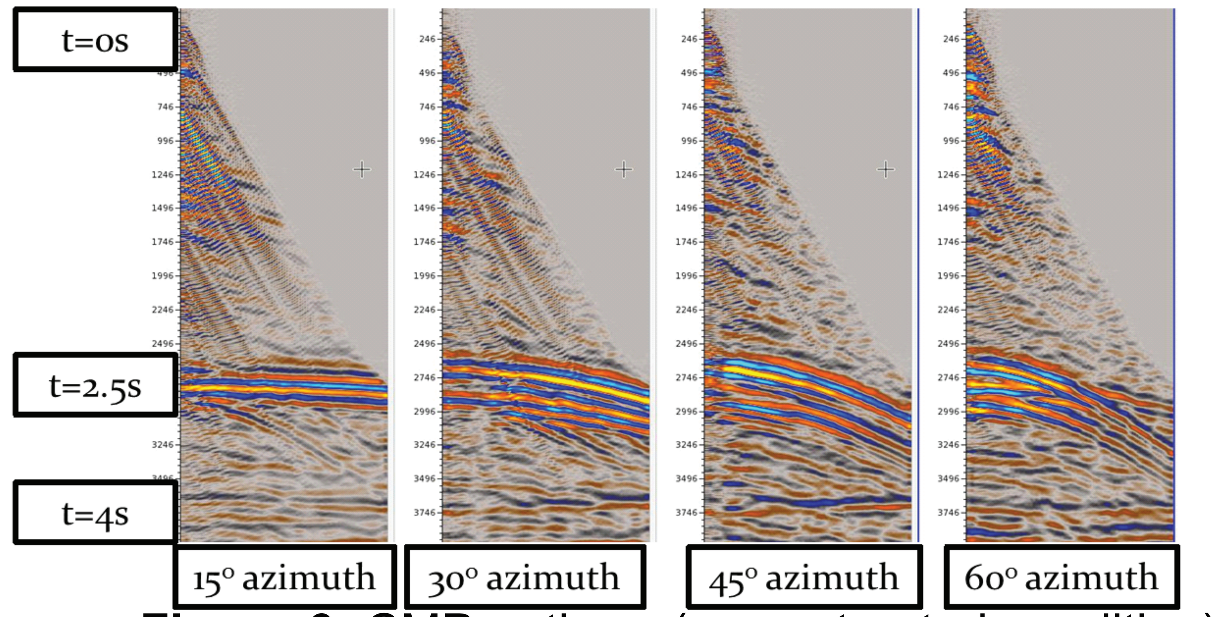

Figure 6. CMP gathers (gas saturated condition) with source-receiver azimuths 15, 30, 45 and 60 degrees respectively min offset=400m (4cm), max offset=2200 (22cm) offset interval=30m(0.3cm).

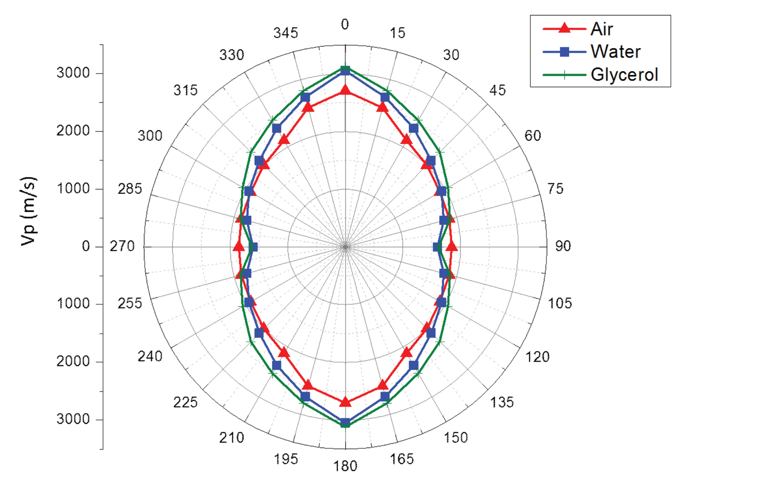

Figure 7. NMO ellipse from azimuthal CMP gathers in different saturating conditions (air, water and glycerol).

Stiffness Coefficients and Anisotropic Parameters

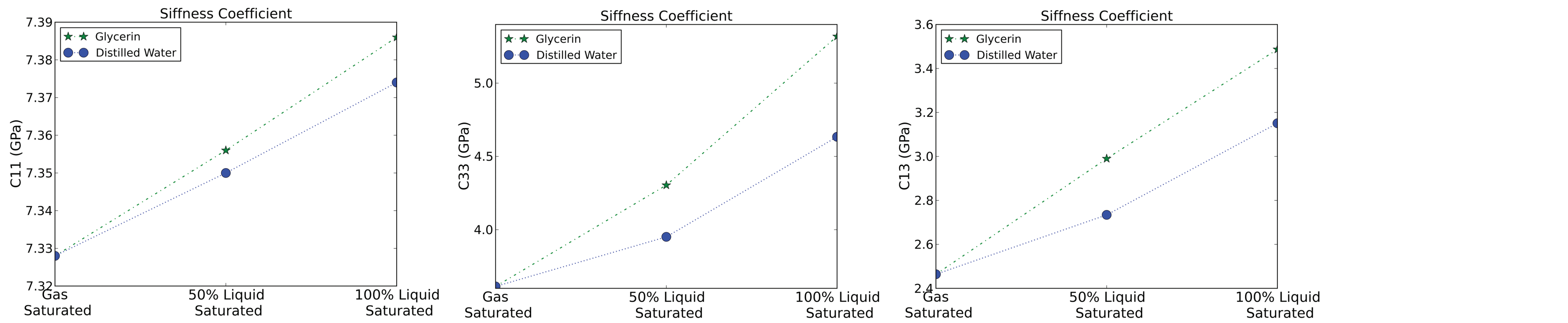

Figure 8. P-wave dependent stiffness coefficients as a function of liquid saturation

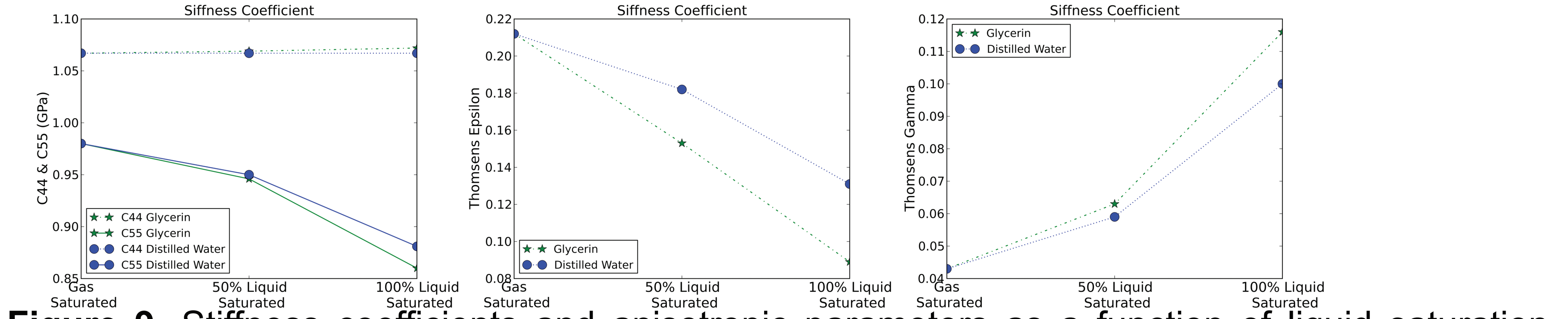

Figure 9. Stiffness coefficients and anisotropic parameters as a function of liquid saturation

CONCLUSION

This experimental study has investigated the influence of different saturating fluids on anisotropy in an azimuthally anisotropic medium. Our results reveal that the nature of saturating fluid has a direct influence on shear wave splitting as well as the trend of azimuthal NMO. Within the limit of our experiments, we find that there is significant change in anisotropy when gas is substituted by brine or oil, but very little change when oil or brine is substituted for each other

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