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Laboratory calibration of the seismo-acoustic response of CO_2 saturated sandstones

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Geological sequestration can be regarded as one of the promising mitigation strategies against the negative effects of atmospheric carbon dioxide on global climate change. Injection of CO_2into depleted natural gas reservoirs in particular, sandstone formations at depth with suitable porosity and seals, seems to be a promising scenario for on-land storage. In fact, a demonstration project is currently underway in the Otway Basin in South Eastern Australia under the auspices of the Australian CO2CRC.

One of the most useful geophysical remote sensing tools for monitoring sub surface CO_2 injection is seismic imaging. Interpretation of seismic data for the quantitative measurement of the distribution and saturations of CO_2 in the subsurface requires a knowledge of the effects of CO_2as a pore fluid on the seismo-acoustic response of the reservoir rocks. This report describes some recent experiments that we have conducted to investigate this aspect under controlled laboratory conditions at pressures representative of in-situ reservoir conditions.

Prior to the availability of core from the actual Otway injection site, two synthetic sandstones were tested ultrasonically in a computer controlled triaxial testing rig under a range of confining pressures and pore pressures representative of in-situ reservoir pressures. These sandstones comprised; (1) a synthetic material with calcite intergranular cement (CIPS) and (2), a synthetic sandstone with silica intergranular cement. Porosities of the sandstones were respectively, 32%,and 33%. Initial testing was carried on the cores at room temperature-dried condition with confining pressures up to 65MPa in steps of 5 MPa. Cores were then flooded with CO_2, initially at 6MPa, 22 degrees C, then with liquid phase CO_2at pressures from 7MPa to 17 MPa in steps of 5 MPa. Confining pressures varied from 10 MPa to 65 MPa. A limited number of experiments were also conducted in an additional rig at 50°C with supercritical phase CO_2.

Ultrasonic waveforms, both P- and S-wave were recorded at each effective pressure increment at nominal pulse centre frequencies of 250 kHz. Velocity–effective pressure responses were calculated from the experimental data for both P- and S-waves. Attenuations (*1/Qp*) were calculated from the waveform data using spectral ratio methods. Fluid substitution calculations for velocity-effective pressure for each sandstone with various saturants were made using Gassmann effective medium theory in combination with data from CO_2 phase diagrams. Once core from the Otway injection site (the CRC1 injection well) was available these experiments were repeated but with an intervening brine saturation step. The testing sequence for the CRC1 core materials was as follows: The dry core were tested at increments of effective pressure as above. This was followed by brine saturation, then gas saturation. The brine salinity used was 20,000 ppm of NaCl which is representative of the field conditions however the injected gas is predicted to replace existing CH_4 which has re-pressurised the depleted well to some extent. The $CO_2$was replaced with a CO_2/CH_4 gas mixture of 80% CO_2, 20% CH_4. A total of 6 core samples were prepared from the CR1 well but only 3 were successfully tested using the above procedures due to the friability of the materials. The core depths ranged from 2056 to 2077m within the Otway, Waarre C sandstone formation.

In general the velocities determined in the ultra-sonic experiments on the CRC1 core agreed well with the well-log acoustic data. It was found that flooding the cores with gaseous phase CO_2 or CO_2/CH_4 produced very small changes in velocity-effective stress response compared to the dry state (air saturated) for all cores including field and synthetic samples. Flooding with liquid phase CO_2at various pore pressures lowered the P-wave velocity-effective response by approximately 8% on average compared to the air saturated state. The S-wave velocities lowered from the dry state by 10% with liquid CO_2 saturation. Similarly, flooding the dry core samples with brine

increased the P-wave velocity–effective pressure response by approximately 3% but lowered the S-wave velocity response by 5%.

Attenuations increased with liquid-phase CO_2 flooding compared to the air-saturated case. Surprisingly, experimental data agreed well with the Gassmann fluid substitution calculations within experimental error for all saturants at higher effective pressures despite the theory being strictly only applicable to low-frequencies. The value of effective pressure, when this agreement occurred, varied with sandstone type. Discrepancies are thought to be due to differing micro crack populations equivalent to “soft porosity” in the microstructure of each sandstone type. The effective pressure at which the experimental data agreed with Gassmann occurred around 30 MPa. This is close to the effective pressure which will be present when injection is complete. Agreement with the Gassmann model at effective pressures is significant and gives some confidence in predicting seismic behaviour under similar field conditions from laboratory data when CO_2 is injected.