Seismic Behaviour of CO_2 Saturated Fontainebleau Sandstone Under In Situ Conditions

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GeoConvention 2012:Vision

Summary:

Understanding the seismic response of a rock in the CO_2 sequestration is important for the societal acceptance of this process. We have done an ultrasonic pulse transmission experiments on a fully CO_2 saturated porous Fontainebleau sandstone within a range of pressures and temperatures which crosses the boundaries of gas, liquid and supercritical phases of the CO_2. This situation is most likely in the uppermost kilometer of most sedimentary basins. P- and S-wave velocities were determined from laboratory data and were plotted against the different pressures and temperatures to check the behavior of the sandstones in those situations.

Introduction:

In a geological CO_2 sequestration project, CO_2 leakage from the reservoir is a vital concern for which monitoring and verifying the subsurface movement and phase behavior of the injected CO_2 is important to ensure the storage integrity. Seismic methods are perhaps the best way to monitor the changes in subsurface in a CO_2 sequestration project as seismic velocities are equally sensitive to a rock's mineralogical composition, porosity and pore fluid contents. This work gives simultaneous measurements of ultrasonic compressional and shears wave velocities on Fontainebleau sandstones. Fontainebleau sandstones (collected from Paris region, France) are clay free, very pure (99.8% quartz) with a significant variation in their porosity, permeability and state of cracking. All these properties make them good candidates for the test. The main motivation of this work is to get a good understanding on the rock physics involved with CO_2 as pore fluid.

Physical and elastic properties of CO2:

The bulk modulus and density phase diagrams of CO_2 are shown in the Fig. 1 as function of pressure and temperature on the basis of Span and Wagner's (1996) thermodynamic model. The critical point of CO_2 according to this model is at 31^0 C and at 7.4 MPa. Depending on the subsurface situations CO_2 can be either gas or liquid under this temperature and pressure. A sudden change in physical properties of CO_2 clearly indicates the gas-liquid boundary in the diagram, which gradually vanishes as the red point (critical point) reached. The supercritical fluid phase state starts just after that point. The supercritical fluid phase has distinct property-it shows the physical behavior of gas and liquid in the same time. This results a smooth transition of liquid-supercritical or gas-supercritical phases.

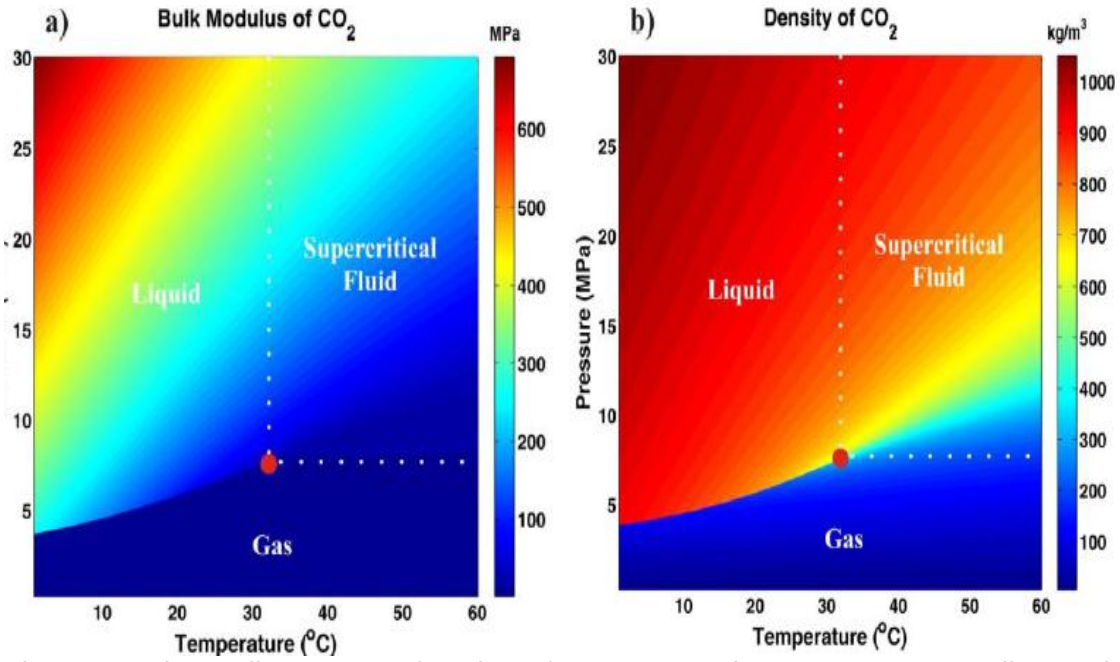

Fig1: CO_2 phase diagrams as function of pressure and temperature according to the thermodynamic model of Span and Wagner (1996). The left panel gives the bulk modulus and the right panel is for density phase diagram of CO_2 .The critical point of CO_2 is clearly indicated by the red dot in both phase diagrams. The gas-liquid boundary is easily noticeable because of the sudden change in physical properties. The white dotted line gives the boundaries for the supercritical fluid phase. (Figure after Yam, 2011).

Experiment:

Experiments are carried out on a Fontainebleau cylindrical shaped sample of 4.2 cm long and 3.7 cm diameter, cut from a block of the sandstone collected from the Ile de France region near Paris. This sample has a 10% porosity (measured by He porosimeter). It shows a significant variation in the pore geometry that makes it a suitable candidate to observe the changes of pores in rocks under seismic conditions.

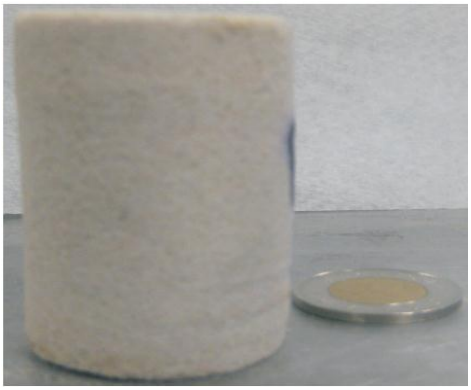

Fig. 2: Fontainebleau sandstone sample (porosity 10%).

Ultrasonic pulse transmission method was used to find out the elastic behavior of the sample. The experimental set-up is shown is the Fig.3.

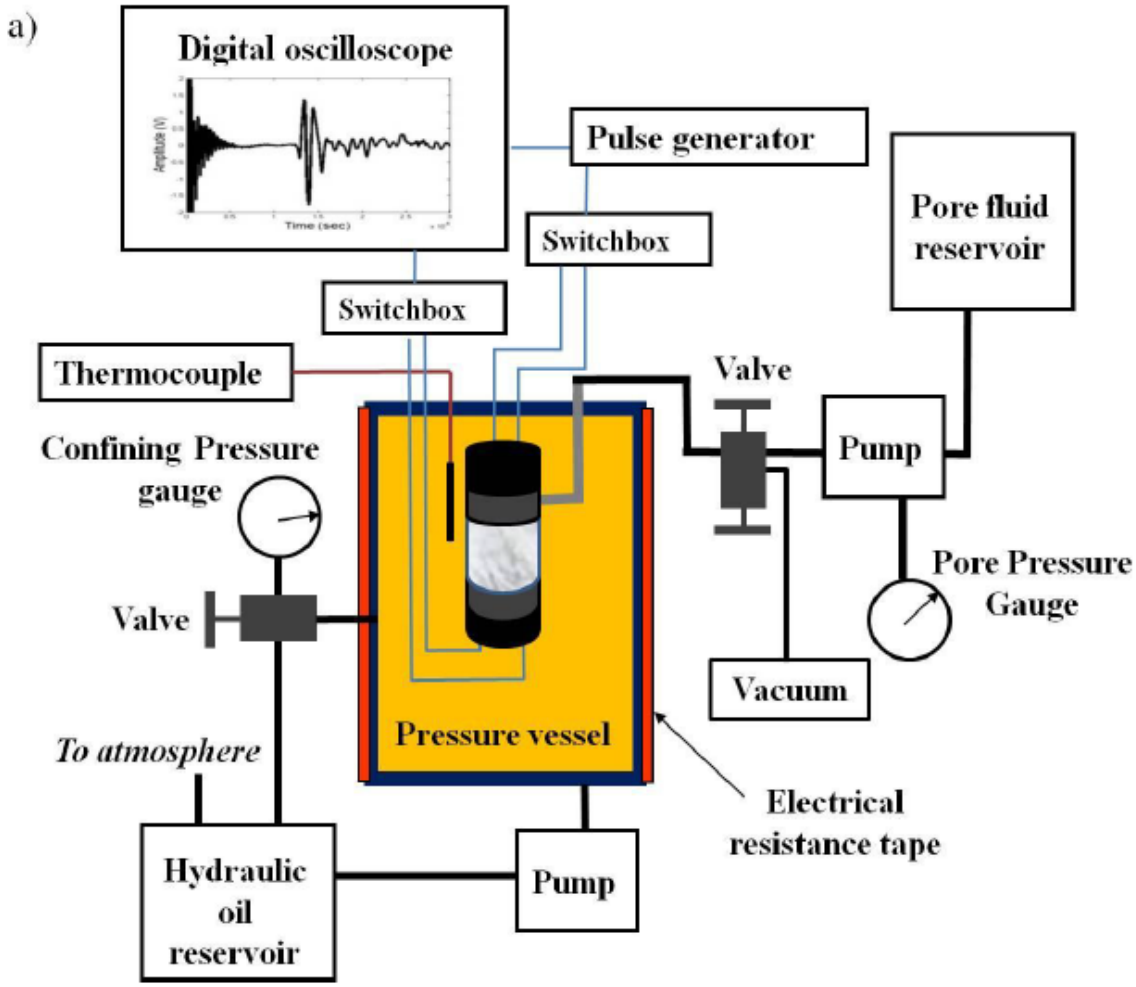

Fig. 3: A simplified schematic diagram of the experimental setup.

The pulse transmission method involves the travel time measurement through the sample. The experimental set up consists of a number of functional units. There is a pulse generator, source/receiving transducers, a digital oscilloscope (NI USB-5122 100MS/s), a pressure vessel that can apply confining pressure up to 200 MPa, a fluid reservoir and a thermocouple as shown in Fig.3. The sample was placed between the transducers made of P-and S-piezoelectric ceramics with center frequencies of 1MHz mounted on an aluminum buffer cap. A Tygon (a flexible clear plastic) tube is used to jacket the sample for sealing it from hydraulic oil contamination.

We carried out several ultrasonic measurements on the sample under dry and CO_2 saturated conditions. During the dry runs the pore space was under vacuum (P_p = 0 MPa) while the confining pressure varies from 2 MPa to 55 MPa. We did several dry runs to check the repeatability of the tests. Unfortunately, repeated cycling of the confining pressure up and down displays a good deal of hysteresis of the observed velocities with pressure that may be due to closing of pores and micro cracks in the sample. In the case of the CO_2 saturated measurements, 2 different temperature runs were done while pore pressure varied from 2 MPa to 25 MPa. The 2 constant temperatures are ~23^0 C (room temperature) and 50^0 C. A 15 MPa differential pressure is maintained in the each measurements of constant temperature by changing the confining pressure according with the pore pressure. Another 2 measurements are carried out at constant pore pressure (P_p ~7 MPa) while temperature is changed from 50^0 C to room temperature (~23^0 C). From the phase diagram (Fig. 1) we can see for the constant

room temperature (~23^0 C) runs where pore pressure increases illustrates a transition from a gas phase to liquid phase while the constant pore pressure and changing the temperature from higher (50^0 C) to room temperature gives the transition from Gas to liquid too. In the case for constant 50^0 C while changing the pore pressure shows the changes from gas phase to supercritical fluid phase.

Examples:

Figure 4 shows the P and S-wave velocities as a function of confining pressure in dry runs that on the sample from 2 MPa to 55 MPa pressure at room temperature. We can see some variation in the velocities between each dry run, which occurred due to the closing of micro cracks in the sample.

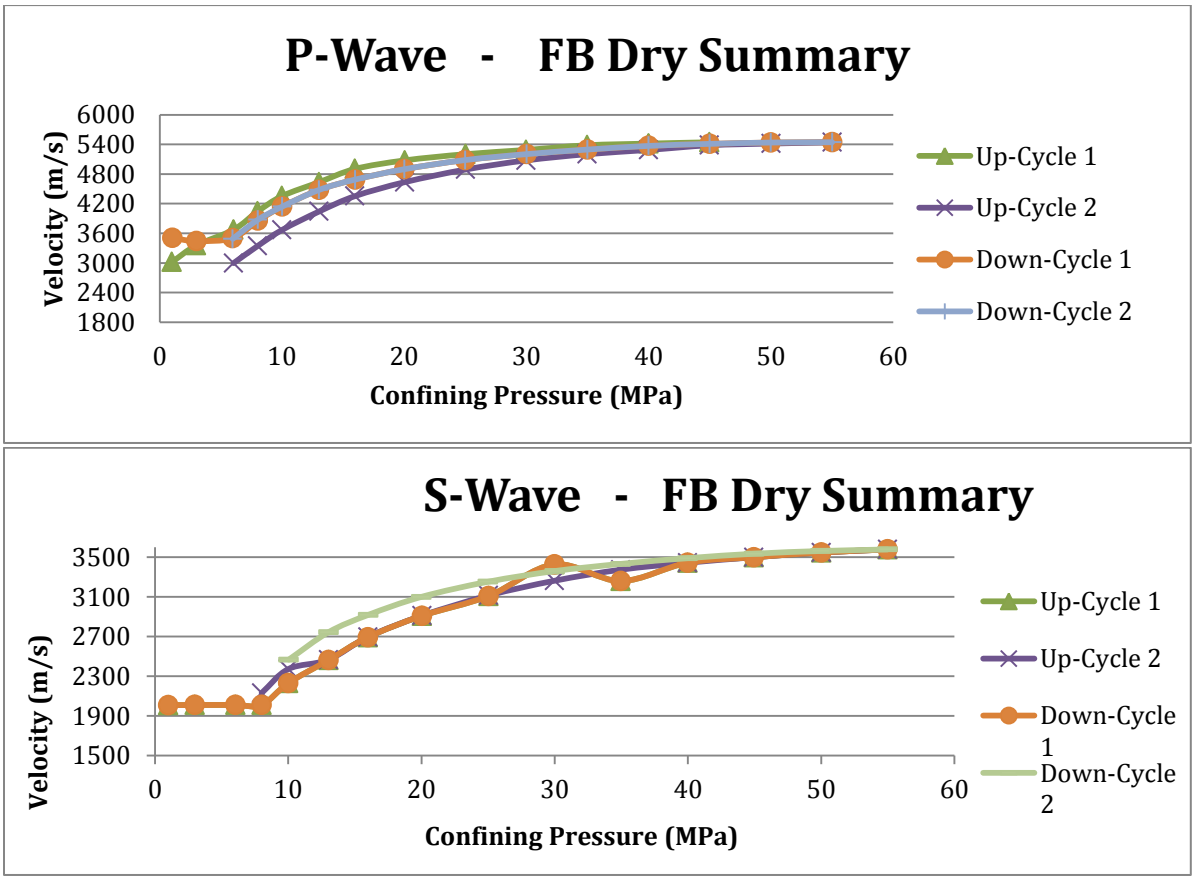

Figure.4: Ultrasonic P-wave and S-wave (up and down respectively) velocities measured when sample is not saturated with CO_2.

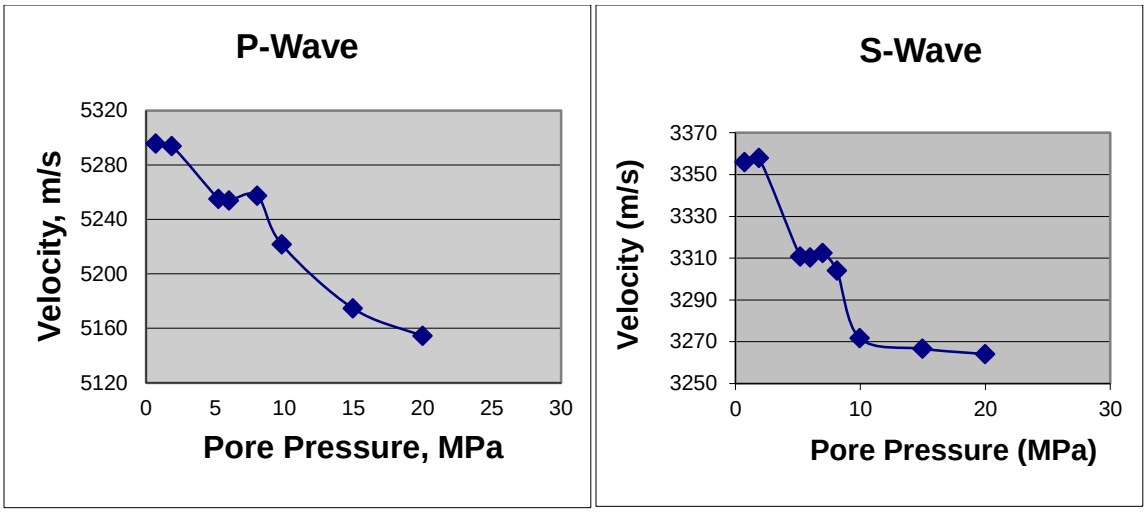

Fig. 5: Ultrasonic P-and S-wave velocities measured on the CO_2 saturated sample with 15MPa differential pressure during the constant low temperature (~room temperature).

In Fig 5. We can see the transition of gas to liquid phase with constant room temperature and changing pore pressure. We can see the changes happening in the P_p~7.4 MPa and the velocity become significantly low after the transition happened.

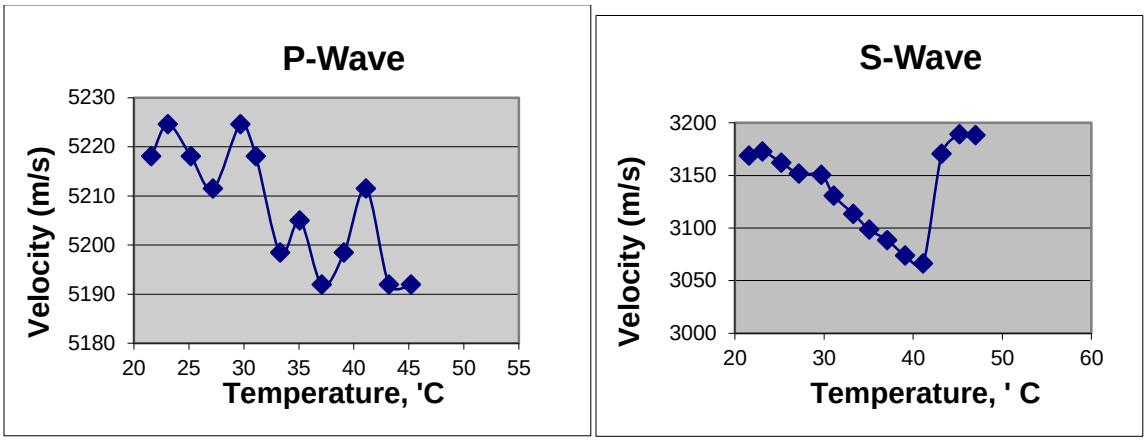

Fig.6: Ultrasonic P-and S-wave velocities measured on the CO_2 saturated sample with constant differential pressure 25MPa and changing the temperature to get the liquid to supercritical phase transition.

Fig.6 shows the transition of liquid to supercritical phase transition. The P-wave velocity-temperature graph is not giving much informatio but in S-wave profile we can see a clear transition happening in ~31^0 C.

Conclusions:

We have measured P-and S-wave velocities for various pressures and temperatures conditions in a porous Fontainebleau sample. Some variation in elastic wave velocities during phase transitions of CO_2 is noted. From these results we can see a sensitiveness of elastic waves with the change of pore pressure and CO_2 phase transitions. However in the real situation the rock may not only saturated with CO_2, there may be other pore fluid present there too.

Acknowledgements:

Mizan Chowdhury would like to thank professor Schmitt's Lab technician Randy Kofman and postdoctoral fellow Gautier Njiekak for their technical support in making this experiment.

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