**Investigators:**
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**Introduction:**

The goal of my research is to estimate the change in the properties of porous rock, like compressibility and attenuation, with changing reservoir conditions. In order to accomplish this goal several major tasks must be completed. The first major task is to develop the methodology for the attenuation estimate using data from the current Differential Acoustics Resonance Spectroscopy (DARS) system. DARS uses the shift in the resonant frequency from an empty cavity to a sample loaded cavity to estimate sample properties. The current DARS measurements are carried out using atmospheric pressure, a single saturating fluid and ambient temperature. The second major task is to design and construct DARS II. DARS II will incorporate the ability to change pressure and saturation in order measure the changes in attenuation and compressibility. The third major task is to measure and interpret the changes in the rock compressibility and attenuation as a function of changes in pressure and saturation.

This quarter the first and second tasks are starting to be addressed. There were four goals to be completed by the end of the Spring 2007 quarter:

1. Pass my qualifying exam
2. Correct the asymmetry in the attenuation model curve fit
3. Improve the attenuation estimate
4. Complete DARS II design

**Results:**

The goal of this project is to measure and relate the changes in compressibility and attenuation of porous samples with changes in pressure and saturation. For a fluid filled cavity, as shown in Figure 1, a set of longitudinal resonance modes dominate the low frequency motion. The longitudinal resonance modes dominate as long as the ratio of cavity length to cavity radius is large enough. The longitude resonant frequencies of the empty cavity is given by (Bourbie et.al., 1987)

$$f_0 = n\frac{v}{2l} \qquad \textbf{(1)}$$

where $v$ is the acoustic velocity of the medium in the cavity, $l$ is the length of the cavity and $n = 1,2,3\ldots$ is the mode at which the measurement was made.

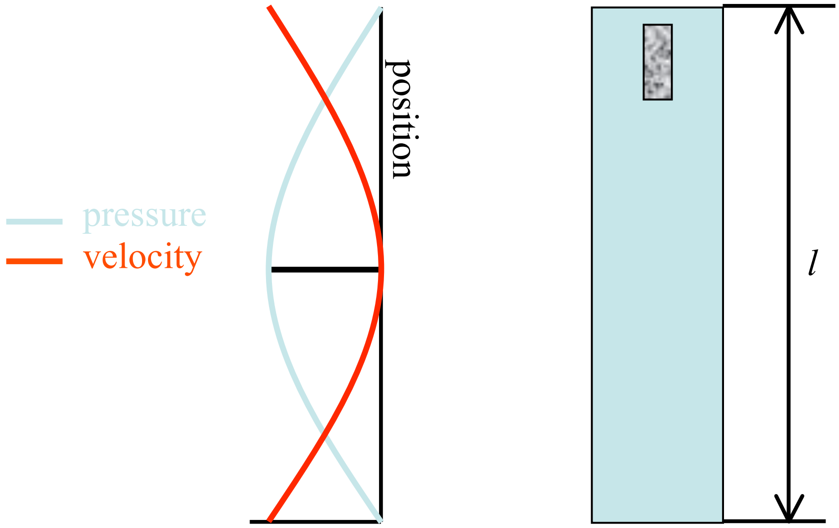


**Figure 1 Pressure and velocity curves as a function of cavity position**

*Attenuation*

Attenuation is the reduction in amplitude or energy caused by the physical characteristics of the transmitting media or system. The attenuation is affected by sample parameters like pressure, pore fluid, rock matrix, porosity, and permeability, which also affect compressibility. $Q$ is the quality factor or the inverse of the attenuation. Mathematically quality factor, $Q$ is defined as

$$Q = \frac{f}{W} \tag{2}$$

where $f$ is the resonant frequency of the sample and $W$ is the half-power linewidth. The equation for the change in quality factor is [2]

$$\Delta W = -\omega_0^{'}\alpha A \frac{\kappa_2 Q_1 - \kappa_1 Q_2}{\kappa_0 Q_1 Q_2} - \omega_0^{'}\alpha B \rho_0 \frac{q_2\rho_2 - q_1\rho_1}{q_1\rho_1 q_2\rho_2} \tag{3}$$

where subscript 0 denotes empty cavity value, 1 the reference sample, and 2 the unknown sample, $\Delta W = W_2 - W_1$, $W$ is the half-power linewidth, $\omega_0^{'}$ is the real part of the empty cavity resonant frequency, $\alpha = \frac{V_s}{V_c}$, $V_s$ is the sample volume, $V_c$ is the cavity volume, $A$ and $B$ are system constants based on the geometry and the fluid medium of the system, $\kappa$ is the compressibility, $\rho$ is the density and $q$ is related to the fluid path or drag through and around the sample.

Five coal samples were measured using the current DARS system and their compressibility and volume measurements are shown below. The compressibility and attenuation of the coal samples were modeled using the perturbation theory. Only the attenuation results will be discussed in this document.

| Coal Sample | Sample Volume (Cubic Inches) | Bulk Modulus (GPa) (measured) |
|---|---|---|
| **1** | 1.21 | 2.858 |
| **2** | 1.15 | 3.372 |
| **3** | 0.95 | 3.128 |
| **4** | 0.47 | 3.247 |
| **5** | 0.41 | 3.228 |

**Table 1** Bulk Modulus of Coal using Perturbation Equation

The W curves for the five coal samples are shown below.

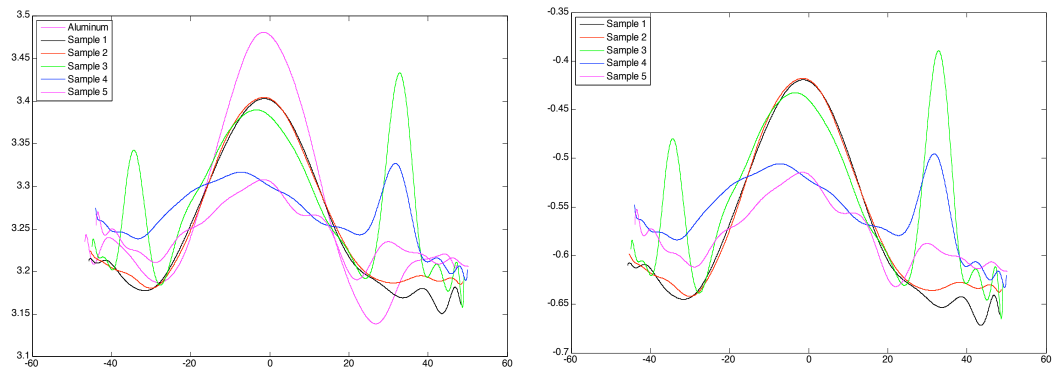


**Figure 2** W and Delta W curves for five coal samples

Samples 4 and 5 are very irregular in shape and their volume is less than 1% of the volume of the cavity. These reasons may be what caused the noisy W curves.

The double difference perturbation equation model fit is shown below applied to sample 1 W curve.

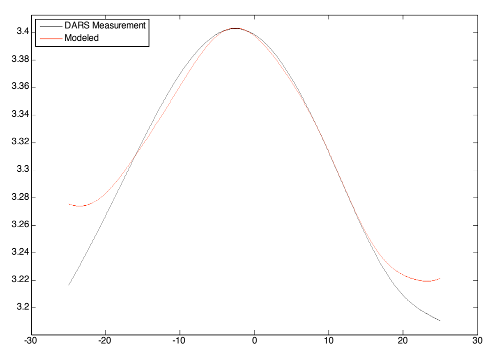


**Figure 3** Sample 1 W curve with double difference model line fit

The model curve is asymmetric. This problem was corrected and the new curve fit is shown below.

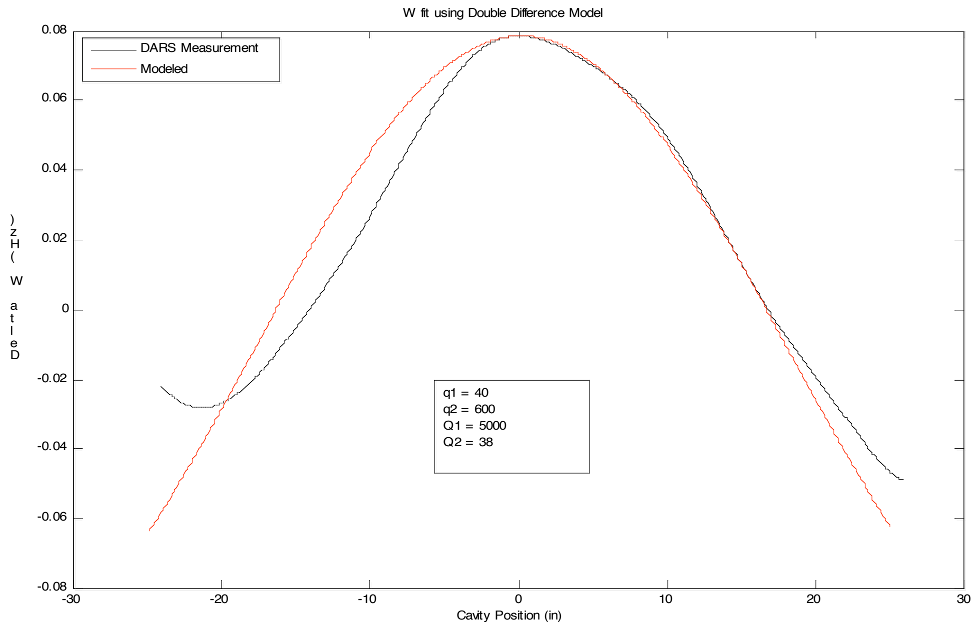


**Figure 4** Sample 1 W curve and double difference model line fit

This corrected the asymmetry in the attenuation model curve fit. The next goal is to improve the attenuation estimate using Comsol.

*DARS II*

DARS I measures the resonant frequency at room temperature, atmospheric pressure and with one fluid, silicon oil. The compressibility and attenuation can be measured using this system, however, the change in compressibility and attenuation as a function of pressure and saturation can not be measured. In order to quantify the change in these sample parameters a new system is needed. DARS II will operate using variable pressure and saturation, so that changes in sample properties with changes in pressure and saturation change can be quantified.

Currently we are designing the DARS II system. This next generation DARS will provide changes in pressure and saturation. The pressure variation can be accomplished by enclosing the system in a pressure vessel. The saturation variation can be accomplished using a separate pore fluid delivery system. Pressure and saturation system requirements for DARS II:

Pressure: 1000 – 2000 psi

Fluids: The fluids of interest are $CO_2$, $CH_4$, $N_2$ and water.

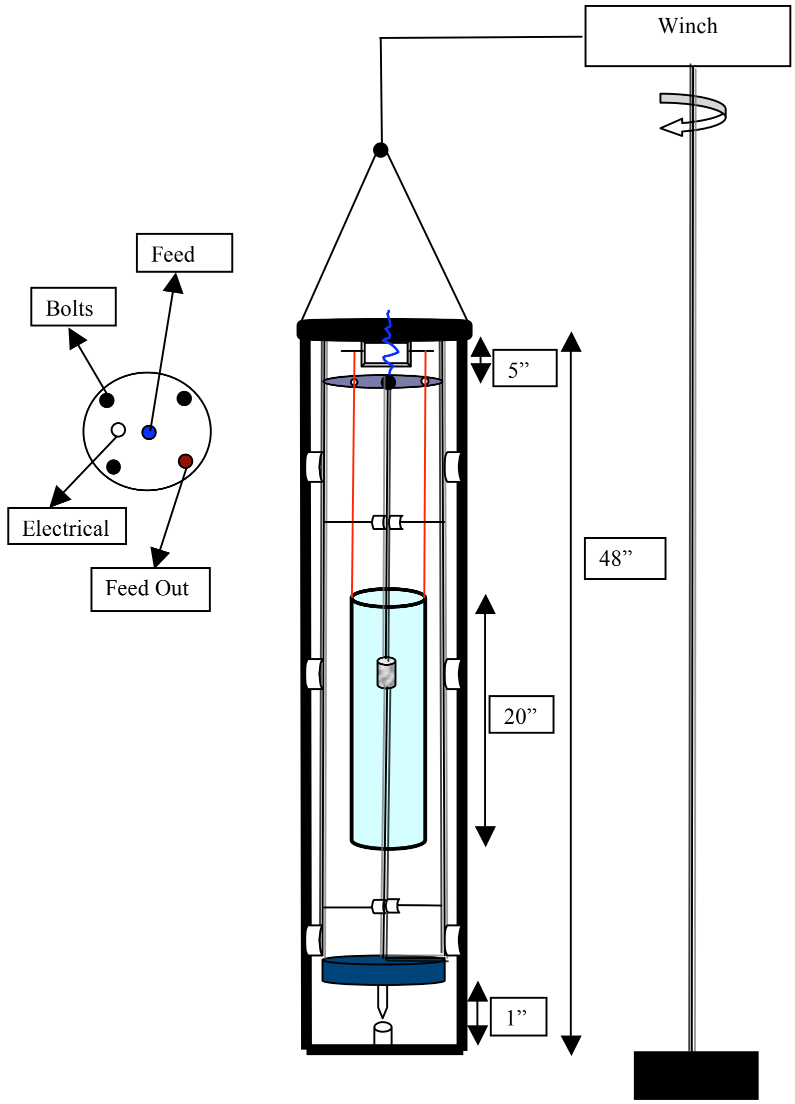


**Figure 5** DARS II Design

The main concern is the height of the pressure vessel which is 48 inches currently. If only half of the curve is measured rather than the full profile the height can be reduced to 28 inches.

**Progress:**

This project, if successful, will directly impact the way $CO_2$ is injected and monitored. It will answer the question of how the acoustic properties of coal will change with injection.

**Future plans:**

This summer I will be in Houston for a summer internship. However, by the end of the summer, I plan to have the ability to invert the DARS data using Comsol for compressibility and attenuation.

**References:**


1. Bourbie, T. et.al.. 1987. Acoustics of Porous Media, Gulf of Publishing Company.
2. Harris, J. 2003. DARS Attenuation, private notes

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