

Photoacoustic Characterization of the Chattanooga Shale: Assessing Thermal Diffusivity and Microstructure in Geological Caprocks

Research Advisor: Dr. Park, Summer URP – 2027

Photoacoustic spectroscopy is an emerging non-destructive technique for evaluating the thermophysical properties of geological materials, providing high-resolution insights into subsurface formations due to sensitive optical-to-acoustic energy conversion. It is based on the photoacoustic effect, in which a modulated or pulsed light beam excites a sample and subsequent thermal expansion generates acoustic or ultrasound waves. Precise detection and collection of these pressure waves can provide extensive information about absorption contrast, thermal diffusivity, and internal pore structures at any location within a solid matrix.

In this research project, the Chattanooga Shale—a premier hydrocarbon source rock and regional caprock formation—will be analyzed to study the feasibility of photoacoustic characterization for assessing subsurface seal integrity. By focusing incident electromagnetic radiation onto shale specimens and recording the resulting photoacoustic response across varying modulation frequencies, the thermal transport properties and microstructural heterogeneity of the rock matrix will be investigated. The Chattanooga Shale provides an ideal, locally accessible substrate for undergraduate research, as prominent outcrops are situated along major thoroughfares in Hamilton County, TN (such as I-24 and US-27), allowing students to collect high-quality samples at minimal cost.

The photoacoustic experimental setup utilizes a pulsed or modulated Nd:YAG laser system capable of delivering high-intensity light (such as 1064 nm pulses). The laser beam is directed through a mechanical optical chopper or specialized optics to irradiate shale samples housed within a hermetic photoacoustic cell or monitored via a piezoelectric transducer configuration. Periodic laser-induced heating drives thermal expansion of the surrounding coupling medium or gas, generating a pressure wave captured by a high-sensitivity microphone or transducer. Signals are isolated and analyzed using a digital lock-in amplifier to extract precise amplitude and phase (ϕ) data. By maintaining a thermally thick regime, the linear relationship between the phase shift and the square root of the modulation frequency (f) allows for the direct calculation of thermal diffusivity (α):

$$\phi = \phi_0 - L \sqrt{\frac{\pi f}{\alpha}}$$

Here, L represents sample thickness, f is the modulation frequency, and ϕ_0 accounts for instrumental phase shifts. This approach offers a transformative framework to understand laser-matter interactions and petrophysical analysis in undergraduate research laboratories.

The student will learn how to build up experimental setups with optics, operate advanced laser systems, apply effective medium theories, and analyze complex geophysical data. Furthermore, the student will be required to present the completed work at a regional or national conference, such as the Southeastern Regional Meeting of the American Chemical Society (SERMACS).