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Determination of Phase Transitions in Porous Media Using Acoustic Resonance Technology

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ABSTRACT

The determination of phase transitions (bubble points, dew points, hydrate points, solids precipitation and cloud points as well as critical saturations) in porous media has been an area of interest for many years. Classic techniques involve the use of expensive and, in many cases, low resolution and inaccurate types of imaging equipment, such as CT scans, MRI, etc., which often have limited utility for full reservoir temperature and pressure evaluations. Acoustic technology has been used in the past to determine accurate phase transitions in bulk samples of reservoir fluid. This paper describes an extension of this technology which allows the technique to also be used to determine the point of a phase transition in actual samples of reservoir porous media at full reservoir conditions of temperature and pressure using reservoir fluids. Further extension of the work holds the promise of the ability to evaluate critical and possibly in-situ fluid saturations in an accurate, cost-effective and non-invasive fashion.

INTRODUCTION

Acoustic Resonance Technology (ART) is based on measurement of the response of a fluid or fluids contained in a medium or cavity to acoustic variable stimulation. The medium in this context is a cylindrical consolidated sandstone. The study of state and time evolution of the resonance response of fluids in a core or porous media under variable and well-controlled conditions of pressure and temperature is one of the most powerful tools of modern times. Ultrasonic pulse techniques have been used[1] previously to determine the bubble nucleation rate during depletion experiments in rock samples. There is a strong need for determining the critical or phase behavior of live fluids in the core sample. The following paper discusses a novel technique based on acoustic resonance technology

(ART) to determine phase transitions of pure ethane in porous media.

EXPERIMENTAL

Sample

Pure ethane (purity 99.99%) obtained from PraxAir Company, Alberta was used as a fluid for phase transition measurements. A cylindrical core sample of consolidated sandstone with 22% porosity and 162 mD permeability with a length of 3.33 cm and a diameter of 3.70 cm was used for the following measurements.

Procedure

The core material was mounted in a ductile sleeve and sealed in a 316 SS core assembly capable of applying biaxial overburden pressures up to 2000 psia. The core heads were equipped with special acoustic transducers to transmit and receive acoustic data through the sample. The core holder was also equipped with a digital strain gauge to measure pressure and a platinum resistance thermometer (PRT) for temperature measurement. The entire assembly was mounted in a temperature controlled oven. The core material was evacuated at 35°C (308 K), pressurized with pure ethane to 735 psia and stabilized for approximately one hour at 35°C.

The AR control system, discussed by Sivaraman et al[2,3] and developed at Hycal Energy Research Laboratories, for bulk fluid (bottomhole reservoir fluid) phase behavior studies was used for the current investigation. The system was connected to the transducers which were mounted on the core heads. The transducer (T_T) on one end of the core generated acoustic waves into the core while the second transducer (T_R) on the other end of the core received the signal which transmitted through the fluids in the core. The resonance pattern depends on the type of fluid phase present as well as the nature of their interfaces for a given geometry of the core.

A schematic illustration of the high pressure acoustic resonance coreflood system is shown in Figure 1. One computer controls the temperature and monitors the pressure and temperature of the core while a second computer controls the acoustic excitation and acquires acoustic response data. An interfaced function generator supplied the signal necessary to excite the transmitter (T_T). The acoustic response is processed through a low noise amplifier and then through a fast, high precision analog to a digital converter (ADC). Acoustic data, at a sampling rate of 100 KHz, acquired by ADC is synchronized by a trigger signal generated by the function generator. This second computer displays the acoustic spectrum (frequency domain) through a graphic interface and also stores the data. The acquisition computer is interfaced to the control computer in a network configuration. Pressure and temperature data gathered during acoustic data acquisition are also displayed and stored. During sweeps, control of all system functions, including those of the acquisition computer, is directed by the control computer.

The main objective of the present work is to investigate the phase transition of the fluids in a porous media under critical conditions as one does for a bulk fluid. In a way, the current system was analogous to a constant volume system. The core which was charged with 735 psi (close to critical density) of ethane at 35°C (308 K) was slowly cooled to 30°C (303 K) at a constant rate of 0.1°/min. The pressure change of the fluid in the core was constantly monitored and recorded as well as temperatures and acoustic data. The raw time domain data collected were processed to obtain frequency domain data using custom software.

The fingerprint of the spectrum was carefully examined to sort changes in the acoustic response when pure ethane fluid in the core has gone through the phase transition.

RESULTS AND DISCUSSION

Figure 2 shows a typical normalized acoustic response versus temperature with nominal acoustic responses of 17,350 Hz at 35°C and 17,600 Hz at 30°C. A large change in the acoustic response curve can be seen at the temperature where the fluid ethane in the core (changed to critical density) went through the critical point (i.e. from a complete vapor phase (gaseous) to a liquid phase). The reason for this is that there is a short range order in liquids when the randomness dominates in the gaseous state. Hence, sound propagates four to five times faster in liquids than in gas. This is clearly shown by the drastic change at 32.3°C (305.45 K) as seen in Figure 2.

Figure 3 shows the behavior of normalized acoustic response versus pressure. A sharp change at approximately 713 psia was observed. Since the core system was charged with ethane to critical density, we believe that the temperature (32.3°C) and pressure (713 psia) at which the drastic changes in acoustic responses occurred are the critical temperature and pressure respectively. This was confirmed by the critical point data ($t_c = 32.22$°C and $p_c = 707.7$ psia) for pure ethane (bulk measurements) obtained previously by the acoustic resonance method[4].

Comparison of the present experimental critical temperature and pressure with other reported values for ethane are presented in Table 1. The agreement is good.

CONCLUSIONS

Acoustic responses display distinct features of the phase transitions of the fluid (ethane) in a porous media. Results obtained from the AR technology applied to porous media compare well with those obtained for bulk fluid studies. There is also good agreement reported with other (visual and conventional methods) for critical point values of ethane.

The current demonstration suggests that it is possible to utilize the AR technology to determine the bubble point pressures for reservoir fluids in porous media and can also be used to ascertain the point of critical gas saturation mobility.

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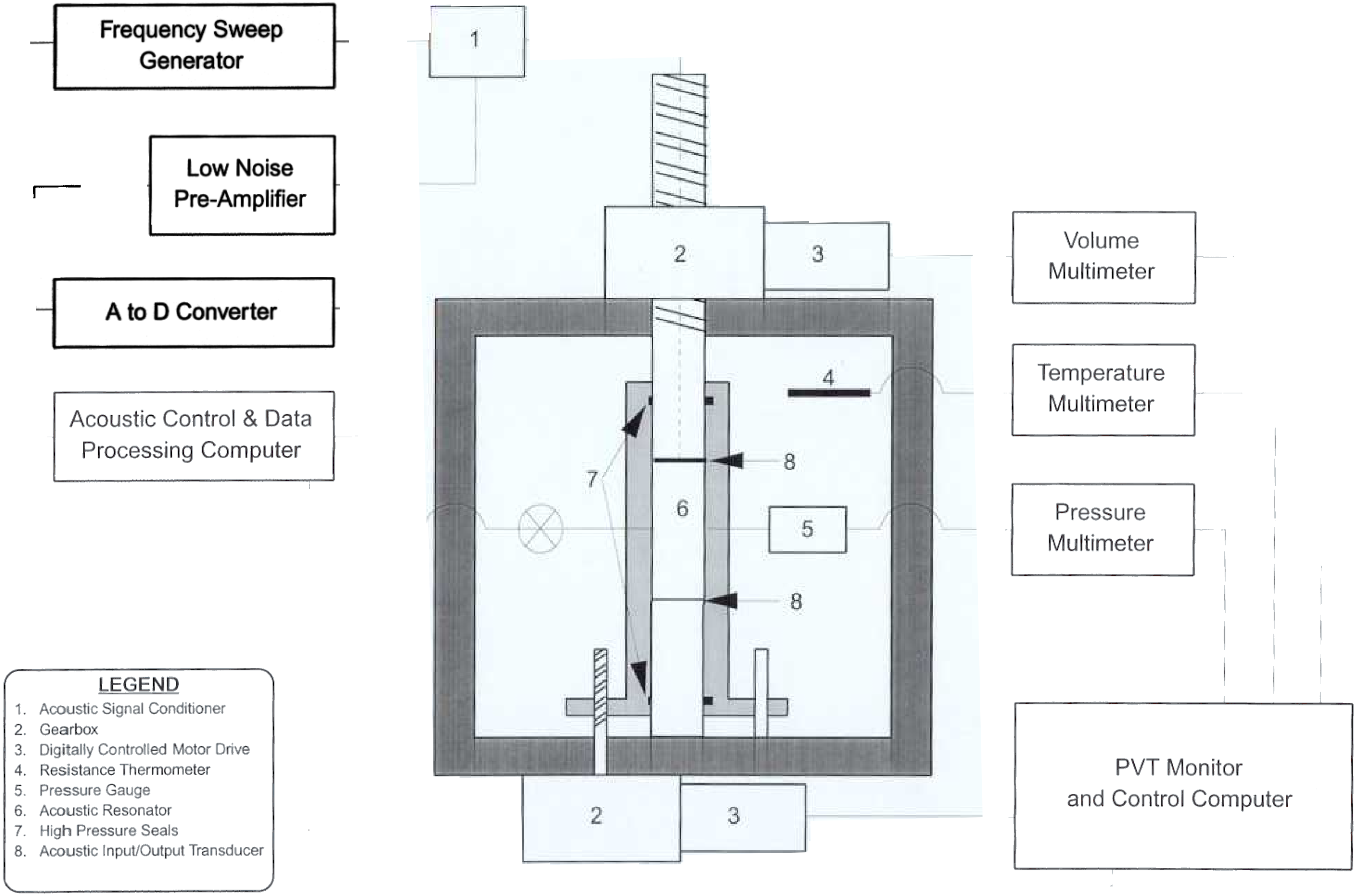
TABLE 1. Comparison of Critical Point Parameters of Ethane

Temperature (K)	Pressure (psia)	Reference
305.4	712.1	(Kay, 1938[5])
305.25	713.6	(Lu et al, 1941[6])
305.37	707.3	(Goodwin, 1975[7])
305.34	706.5	(Moldover and Gallagher, 1978[8])
305.39	702.2	(Morrison and Kincaid, 1984[9])
305.37	707.7	(Colgate, Sivaraman and Dejsupa, 1992[4])
305.45	713.0	(Current work)

FIGURE 1
HIGH PRESSURE CYLINDRICAL ACOUSTIC RESONATOR SYSTEM



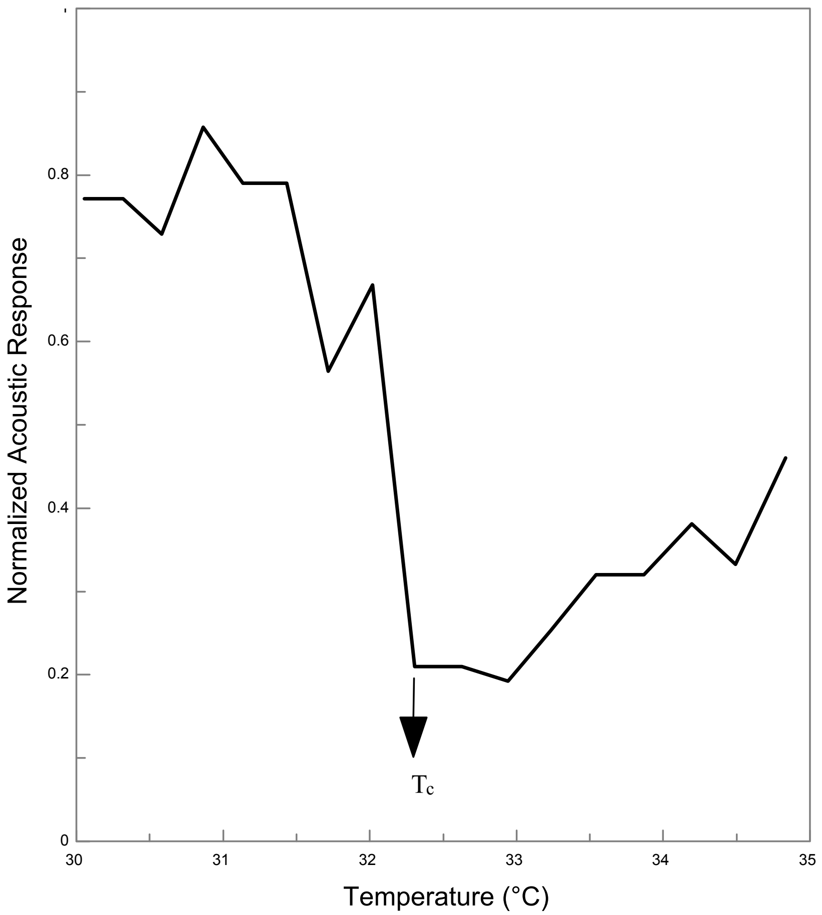


Figure 2. Acoustic Determination of Critical Temperature for Pure Ethane in Porous Media

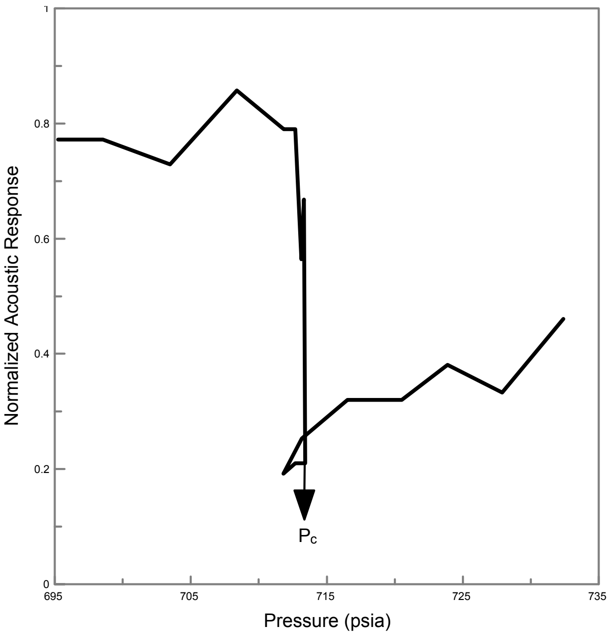


Figure 3. Acoustic Determination of Critical Pressure
For Pure Ethane in Porous Media