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Acoustic velocities in petroleum fluids: Measurement and prediction

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ABSTRACT

Acoustic velocity or speed of sound is a thermodynamic property which may be used to estimate thermophysical properties needed for hydrocarbon production and processing. In this paper, experimental data is reported on the speed of sound in *n*-octane, a binary mixture of (*n*-octane + *n*-hexadecane), a binary mixture of (*n*-decane + *n*-hexadecane) and a ternary mixture of (*n*-octane + *n*-decane + *n*-hexadecane) at temperature of (293 to 393) K and at pressures up to 100 MPa. In addition a predictive method for the speed of sound in liquid hydrocarbons is presented and validated by comparison with both the present data and the literature data. The model is based on the extended principle of corresponding states with two reference fluids, chosen as n-C_{18} and n-C_{28} in which the parameters may be estimated from the knowledge of molecular weight. The method can be used for both pure liquid *n*-alkanes and their mixtures from propane to very heavy hydrocarbons ($\sim C_{50}$) at pressures of (0.1 to 150) MPa and at temperatures from (200 to 400) K. The method has been evaluated by comparison with over 2000 data points for pure normal alkanes (from C_3 to C_{36}), as well as for binary and ternary mixtures, petroleum fractions and crude oils, and is found to predict speed of sound in these fluids within $\pm 2\%$.

1. Introduction

Knowledge of thermodynamic and physical properties of hydrocarbons and especially complex hydrocarbon mixtures, such as crude oils and petroleum fractions, is vital in petroleum production and processing. Generally these properties are calculated through PVT relations and generalized correlations based on the principles of corresponding states. Such methods require knowledge of the critical constants and acentric factor which are not usually available for heavy hydrocarbons or their mixtures. Estimation methods for such properties applied to heavy hydrocarbons ($>C_{20}$) usually lead to significant errors with great impact on calculated properties needed for design and operation of processing equipment (Riazi, 2005).

It has been shown that acoustic velocity data can be used to generate and predict physical and thermodynamic properties of fluids and their mixtures (Shabani et al., 1998; Dayton and Goodwin, 1999; Estrada-Alexanders and Trusler, 1997). Colgate et al. (1991, 1992) and Ball and Goodwin (2002) have reported data on the speed of sound in some crude oils and have shown how bubble points may be determined from such data. Equations of state have been developed based on the speed of sound which may be used for thermodynamic property calculations (Riazi and Mansoori, 1993a; Peleties et al., 2010). Thus it appears that the speed of sound is a quantity that may be used for estimation of thermophysical properties of heavy compounds and complex fluid mixtures in which such properties are not available.

A number of researchers have measured and reported speed of sound in hydrocarbon systems at high pressures (Dutour et al., 2000, 2001, 2002a, 2002b). Queimada et al. (2006) have proposed a corresponding states approach for the speed of sound in long-chain hydrocarbons using a reduced speed of sound based on the ideal-gas equation of state.

In this paper, new experimentally measured data on the speed of sound in liquids at high pressures for several binary and ternary hydrocarbon systems are reported. In the second part of this work, we propose a new predictive method for estimation of the speed of sound in heavy liquid hydrocarbons and their mixtures based on the corresponding states principle (CSP) using parameters which can be estimated reliably from available data. The CSP approach is a widely used technique for predicting thermodynamic properties of pure as well as fluid mixtures. Standard methods are also suggested

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for the estimation of the input parameters required for the proposed method.

2. Experimental measurements

The experimental system was based on the design reported by Peleties et al. (2010); however, the present apparatus operates at a lower frequency of 4 MHz to permit measurements on liquids with viscosities up to approximately 150 mPa s. Measurements can also be made on liquid mixtures with dissolved gases and or dense compressed gases. The working ranges of the apparatus are pressures from (0.1 to 100) MPa and temperatures from (283 to 473) K and it was installed and commissioned by the manufacturer (Imperial College, UK). Fig. 1 illustrates a schematic of flow diagram showing ultrasonic, temperature control, pressure generation and automation sub-systems.

As shown in Figs. 2 and 3, the ultrasonic cell was mounted within a stainless-steel pressure vessel with an internal volume of approximately 100 cm^3. The pressure vessel was suspended within a temperature-controlled oil-bath (Fluke model 6040) where the temperature was controlled with a stability and uniformity of better than ± 0.01 K. The temperature was measured by means of a secondary-standard platinum resistance thermometer (Fluke model 5615) which was inserted into a thermowell in the wall of the pressure vessel. This thermometer was calibrated by the manufacturer with an expanded uncertainty of better than 0.02 K in the working range of the instrument.

Pressure of the fluid was measured with an expanded uncertainty of 0.25 kPa by means of a pressure transducer (Paroscientific model

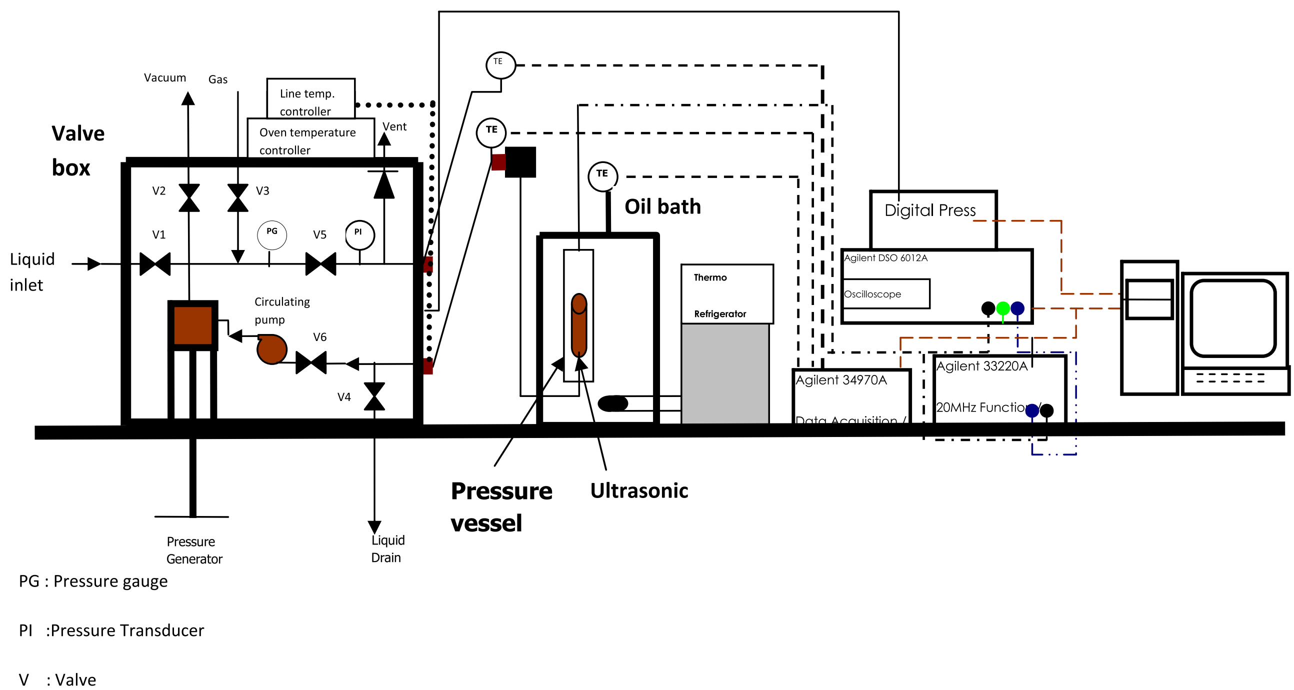

Fig. 1. Flow diagram of speed of sound experimental set up.

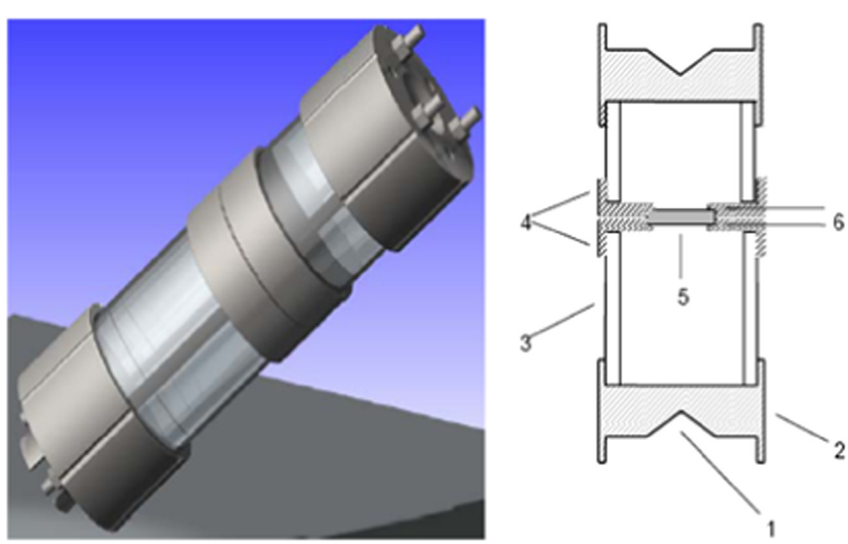

Fig. 2. Ultrasonic cell picture and diagram on right shows: (1) conical cavity; (2) reflector; (3) quartz spacer tube; (4) stainless steel clamping ring; (5) piezoceramic transducer; (6) lead wires.