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Thermodynamic method for measuring the B/A nonlinear parameter under high pressure

PIOTR KIEŁCZYŃSKI, MAREK SZALEWSKI, ANDRZEJ BALCERZAK, KRZYSZTOF WIEJA
Institute of Fundamental Technological Research
Polish Academy of Sciences
Warsaw, Poland
pkielczy@ippt.gov.pl

ALEKSANDER J. ROSTOCKI, RYSZARD M. SIEGOCZYŃSKI
Faculty of Physics
Warsaw University of Technology
Warsaw, Poland

Abstract— **The nonlinearity parameter B/A is a measure of the nonlinearity of the equation of state for a fluid. It plays a significant role in acoustics, from underwater acoustics to biology and medicine. The nonlinearity parameter is important because it determines distortion of a finite amplitude wave propagating in the fluid. Moreover, it can be related to the molecular dynamics of the medium and it can to provide information about structural properties of medium, internal pressures, clustering, inter-molecular spacing, etc. Importance of the B/A parameter increases with the development of high-pressure technologies. The thermodynamic method has been applied for determination of B/A parameter in diacylglycerol (DAG) oil as a function of pressure at various temperatures.**

Keyword: Nonlinearity parameter, thermodynamic method, high pressure, ultrasonic velocity

I. Introduction

The nonlinearity parameter B/A is a physical parameter often used in acoustics, biology and medicine. The B/A parameter determines distortion of a finite amplitude wave propagating in fluid. The parameter B/A determines the nonlinear correction to the velocity due to the influence of nonlinear effects caused by the propagation of finite amplitude wave. It can provide information about structural properties of the medium, internal pressure and inter-molecular spacing.

The experimental techniques for the B/A parameter measurement can be classified by the two basic approaches: thermodynamic method and finite-amplitude method. In the first method, B/A is evaluated from the definition using measurements of the sound velocity as a function of pressure and temperature [1]. The second method is based on the analysis of waveform distortion due to harmonics generation during wave propagation [2]. Thermodynamic method is more reliable method for measuring the nonlinearity parameter B/A [3].

The authors applied thermodynamic method to determine B/A parameter in diacylglycerol (DAG) oil composed of 82% of DAGs and 18% of triacylglycerols (TAGs), with a vestigial amount of monoacylglycerols (MAGs) and free fatty acids. The fractions were determined by means of the gas chromatography method. DAG is an important constituent of oils and fats [4].

II. Measuring Method and Setup

In thermodynamic method B/A parameter is calculated from the relation [1]:

$$B/A = 2\rho_0 c_0 \left(\frac{\partial c}{\partial p}\right)_T + 2c_0 T \alpha_p c_p^{-1} \left(\frac{\partial c}{\partial T}\right)_p \qquad (1)$$

where: ρ_0 is the density of undisturbed medium, c_0 is the sound velocity for acoustic waves of infinitesimal amplitude, p is the pressure, T is the temperature, α_p is the isobaric thermal expansion coefficient, c_p is the isobaric specific heat capacity.

The contribution to B/A parameter from temperature changes is always much smaller than that from pressures changes [1].

To determine B/A parameter it is necessary to measure accurately sound velocity in the investigated medium as a function of pressure and temperature.

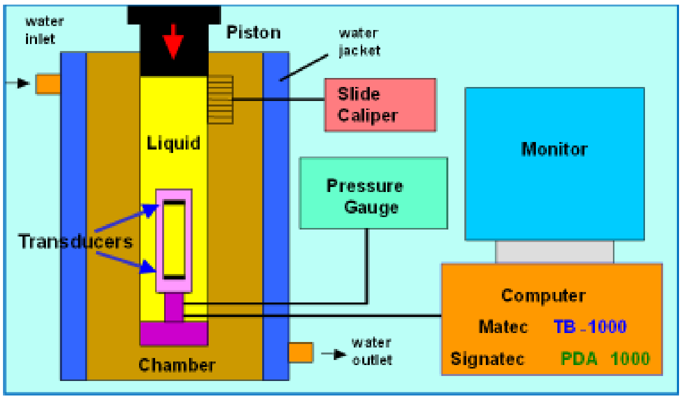

Fig.1. Experimental ultrasonic setup for measuring the sound velocity in liquids at high pressure and various values of temperature.

For measurements of the phase velocity of longitudinal ultrasonic waves, the authors have constructed the computerized setup especially designed to obtain a low level of parasitic ultrasonic signals. A special mounting of transducers in the high-pressure chamber was fabricated. The time of flight of the ultrasonic pulses was evaluated by applying the cross-correlation method. The measuring setup is presented in Fig.1 and described in [5,6].

For pressure measurements a typical 100 Ω manganin transducer was used. The temperature in the chamber was measured using T-type thermocouple (Cu-constantan). A thermostatic bath was circulating in a thermostatic jacket around the chamber. The thermostatic jacket was connected to a precision thermostat. The applied measuring setup and method provided high measurement accuracy.

During DAG pressurization phase transitions occur [7,8]. B/A parameter has been evaluated in the pressure range before the beginning of the phase transition.

III. RESULTS

Figure 2 shows the results of longitudinal ultrasonic wave velocity measurements (frequency 2 MHz) at temperatures: 20, 30, 40, 50 °C. In Fig.2 three different parts of each curve can be seen: 1) low-pressure phase of DAG oil, 2) region of phase transition, 3) high-pressure phase of DAG oil.

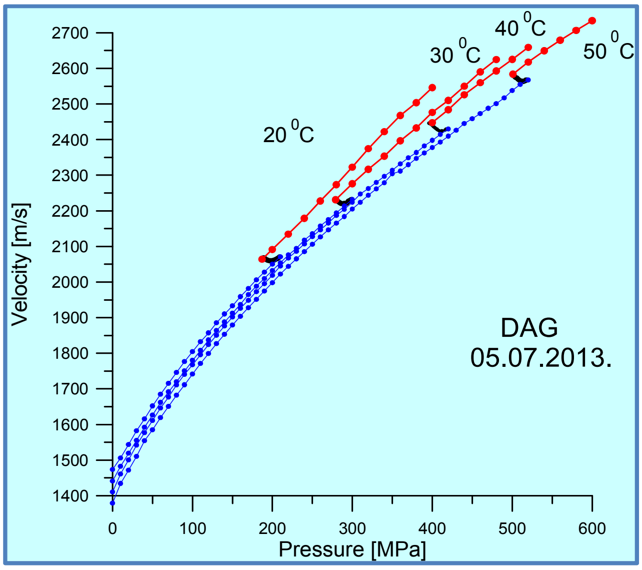

Fig.2. Plots of sound velocity in DAG oil as a function of pressure along various isotherms ($T = 20, 30, 40, and\ 50\ °C$). Blue color refers to low-pressure phase of DAG oil. Red color indicates high-pressure phase of DAG oil.

The plots of calculated values of B/A nonlinear parameter as a function of pressure, at temperatures: 20, 30, 40, 50 °C are shown in Fig.3.

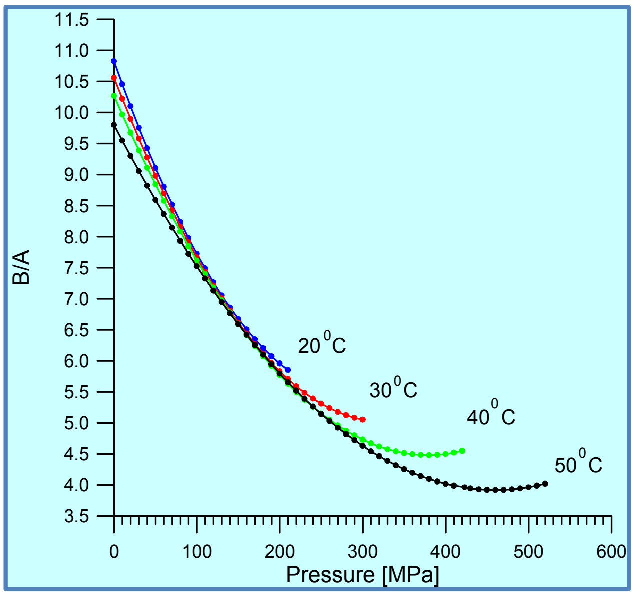

Fig.3. Nonlinearity parameter B/A as a function of pressure at various temperatures.

IV. Conclusions

The usefulness of the ultrasonic thermodynamic method to evaluate the nonlinear parameter B/A was stated. The performed analysis shows a large monotonic decrease of B/A nonlinearity parameter for DAG oil, with increasing pressure. For example, at temperature t = 50 ^{0}C, B/A nonlinearity parameter decreases from 9.8 at atmospheric pressure, to about 4.0 at 520 MPa.

The measuring ultrasonic high-pressure setup and applied procedure have been employed successfully to evaluate the nonlinear parameter B/A for a wide range of pressures and temperatures. Presented in this paper method, can also be applied to investigate other liquids, e.g. fuels and biofuels, lubricants, polymers, etc.

Measurements of sound velocity are relatively easy therefore determination of B/A nonlinearity parameter offers a simple way to evaluate the molecular properties of liquids under high pressures at various temperatures. Acoustic nonlinearity is related to the internal pressure, free energy of binding, the effective van der Waals' constants, the translational diffusion coefficient, and the rotational correlation time [9]. This method can be used not only for pure liquids but also for mixtures [10].

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