

Speed of sound as a function of temperature for ultrasonic propagation in soybean oil

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Abstract. Ultrasound has been used for characterization of liquid in several productive sectors and research. This work presents the studied about the behavior of the speed of sound in soybean oil with increasing temperature. The pulse echo technique allowed observing that the speed of sound decreases linearly with increasing temperature in the range 20 to 50 °C at 1 MHz. As result, a characteristic function capable to reproduce the speed of sound behavior in soybean oil, as a function of temperature was established, with the respective measurement uncertainty.

1. Introduction

The production the use of biodiesel has attracted attention because it is a renewable source of energy. Thereby, numerous oleaginous have been studied with the aim of evaluating them as raw material for biodiesel production. In Brazil, soybean oil predominates as raw material for the production of biodiesel due its availability.

There is agreement about potential application of methods for characterization of liquid in several productive sectors and research. The acoustic techniques have non-destructive characteristics, with the possibility of online non-invasive applications 0.The ultrasonic parameters more frequently measured to characterize materials are the speed of sound, attenuation coefficient and acoustic impedance. Many studies have used the speed of sound for characterization of liquids.0-0.

Generally, the speed of sound is determined by measuring the arrival time of the ultrasonic pulse both with and without the test sample positioned in the ultrasonic beam. The difference in these times is the time-shift caused by the different speed of sound in the material0.

This article reports the measurement of the speed of sound in soybean oil along the temperature range 20 °C at 50 °C using longitudinal waves at 1 MHz, with its respective measurement uncertainty.

2. Methodology

In this study, the ultrasound technique known as pulse/echo was applied at low power. The measuring systemconsists of a cell containing the sample immersed in a thermal bath, a transducer with a nominal center frequency of 1 MHz and 12.7 mm diameter (A303 S, Panametrics - NDT Olympus Corporation, Japan) excited by an arbitrary function generator (model 33250A, Agilent Technologies, CA, USA) with a of 4-cycles burstand 20 volts peak-to-peak emission.



The emitted ultrasonic signal propagates through the sample, reaches the reflector target, and returns to the same transducer. The echo signals acquired are digitized by an oscilloscope (model DSO-X 3012A, Agilent Technologies, CA, EUA) and saved on a computer in a given time interval (20 s) with the aid of a software developed in LabView™ (National Instruments, Austin, TX, EUA). The bath temperature is set initially at 20 °C and increases in a steps of 5 °C up to 50 °C. The sample temperature is monitored during the measurement process with the aid of a thermocouple type K and a temperature measuring system (model 34970A, Agilent Technologies, CA). Figure 1 illustrates the experimental setup of the measuring system described above.

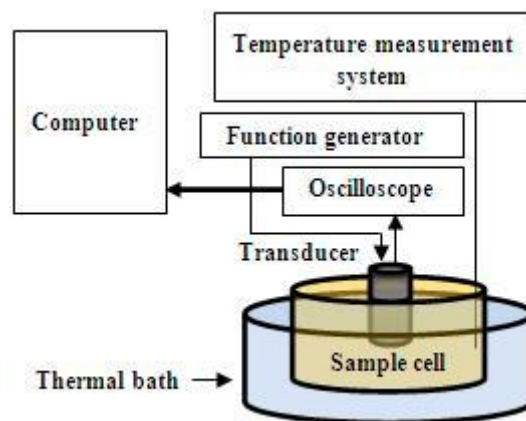


Figure 1.Speed of sound measuring system.

Five repetitions were performed under repeatability conditions for each temperature. The speed of sound of the oil is given by equation (1):

$$v_{oil} = \frac{c_{H_2O} \cdot t_{H_2O}}{t_{oil}} \quad (1)$$

where c_{H_2O} is the speed of sound in the water [m.s^{-1}], t_{H_2O} is the time of flight [s] in the cell filled with water, and t_{oil} is the time of flight [s] in the cell filled with soybean oil.

The speed of sound in the water was determined as a function of temperature, using equation (2), given by0:

$$C_{H_2O} = A + B.T - C.T^2 + D.T^3 - E.T^4 + F.T^5 \quad (2)$$

where: A, B, C, D, E and F are constants and T is the temperature of the water in °C.

The measurement uncertainty is a parameter that provides positive dispersion characteristics of a measured quantity. Here, the measurement uncertainty is calculated according to the Guide of the Expression of Uncertainty in Measurements0.

Standard uncertainties Type A and Type B were considered. The standard uncertainty Type A was obtained by calculating the standard deviation of the mean for five repetitions. The standard uncertainty Type B was estimated from the temperature uncertainty acquired from the digital thermometer calibration certificate (0.08 °C), time of flight uncertainty obtained from the oscilloscope calibration certificate (0.0018%), and the speed of sound uncertainty in water, obtained from the curve fit error (0.002 m.s^{-1}) declared in 0.

The combined standard uncertainty $uc(v_{oil})$ is the positive square root of the combined variance, and is given by (3):

$$uc(v_{oil}) = \sqrt{\sum \left(\frac{\partial v_{oil}}{\partial x_i} \cdot ux_i \right)^2} \quad (3)$$

The expanded uncertainty $U(v_{oil})$ was obtained by multiplying the combined standard uncertainty $uc(v_{oil})$ by a coverage factor k that takes into account a t -distribution with coverage probability of 0.95.

3. Results and Discussion

The measurement results of the speed of sound in soybean oil, with its respective uncertainties are shown in table 1.

Table 1. Average values of speed of sound in soybean oil and their respective expanded (U_{exp}) and relative uncertainties (U_{rel}).

T(°C)	Speed of sound (m.s ⁻¹)	U_{exp} (m.s ⁻¹)	U_{rel} (%)
20	1484.1	4.3	0.3
25	1466.6	4.9	0.3
30	1452.8	6.4	0.4
35	1434.9	5.9	0.4
40	1419.9	5.2	0.4
45	1402.0	4.0	0.3
50	1383.6	2.0	0.1

The results from five repetitions are presented in Figure 2. Averaging those results, one can obtain a curve representing the relationship between the speed of sound and the temperature, which is shown in Figure 3, with its associated uncertainty. Analyzing Figure 3, one can observe a linear relation between the speed of sound and temperature, in the temperature range studied. Moreover, the speed of sound in soybean oil decreases with the increasing of temperature. The speed of sound can vary according several factors, though it regarded as a constant characteristic of each material, particularly for liquids.

Note that the contribution to uncertainty in the propagation velocity was barely significant. A possible explanation is given by the docking of the transducer in the vessel lid used; this fit must be performed carefully as a possible variation directly affects the distance.

From measurements, it was established a characteristic function to demonstrate the behavior of the speed of sound in soybean oil as a function of temperature (4).

$$v_{oil} = a + b * T \quad (4)$$

where a and b are constants and T is the temperature in °C.

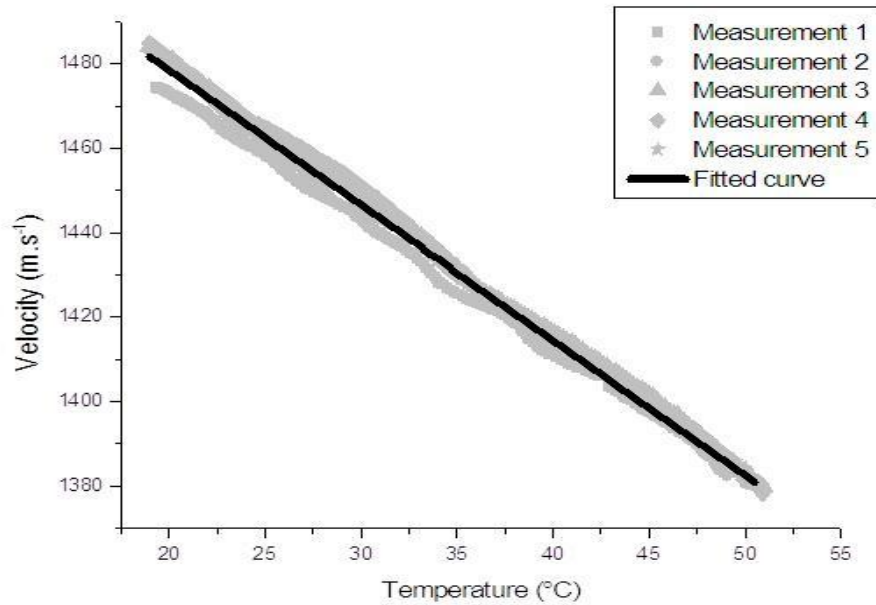


Figure 2. Curves from the five repetitions and the fitting curve.

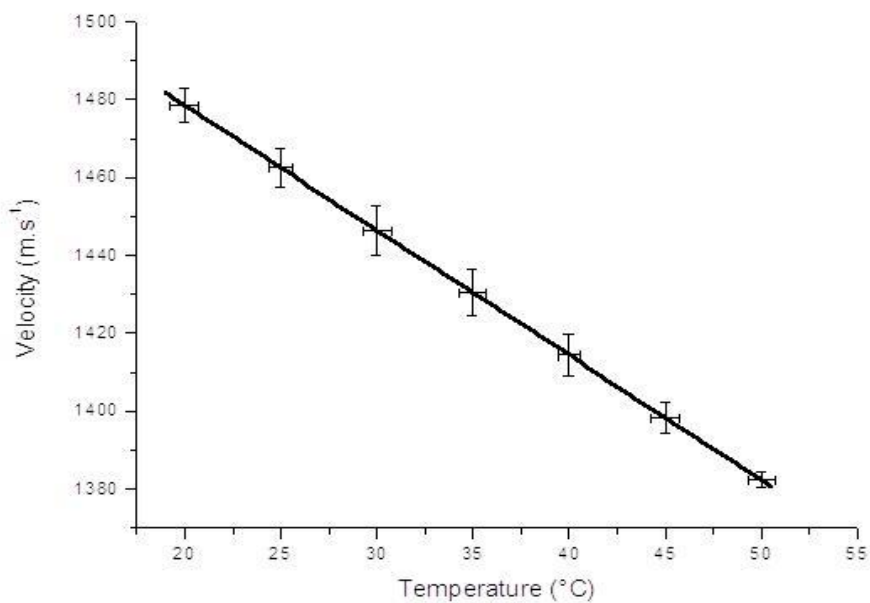


Figure 3. Relationship between the speed of sound and the temperature with its associated uncertainty.

The temperature measurement uncertainty was also calculated and depicted in Table 2. By analyzing the measurement uncertainty values it is possible to verify that the relative uncertainty of the temperature is higher than the relative uncertainty of the velocity of propagation. However, this uncertainty does not influence significantly the temperature measurement efficiency.

Table 2. Values of expanded (U_{exp}) and relative (U_{rel}) uncertainties at different temperatures.

T (°C)	U_{exp} (°C)	U_{rel} (%)
20	0.74	3.7
25	0.62	2.5
30	0.75	2.5
35	0.70	2.0
40	0.57	1.4
45	0.77	1.7
50	0.68	1.4

Table 3 shows the linear regression parameters of the characteristic function that relates the speed of sound in soybean oil and temperature, with respective standard deviation. Assessing the variation coefficient values, one can suggest that the data set is homogeneous.

Table 3. Values of the constants a and b for Eq. (4).

Propagation velocity parameters	
a (m.s ⁻¹)	1542.60
σ_A	5.4122
c_{vA} (%)	0.35
b (m.s ⁻¹ .°C ⁻¹)	-3.2037
σ_B	0.1072
c_{vB} (%)	3.35
R^2	0.99748

4. Conclusion

Ultrasound, being a non-destructive technique and low-cost has great potential to contribute to the industrial development. Here, it was developed and a method for measuring the speed of sound in soybean oil. The results demonstrated that the propagation velocity varies linearly with temperature increasing in the range of 20 °C to 50 °C. A characteristic function representing the behavior of the speed of sound in soybean oil as a function of temperature was determined and a linear regression was estimated. With the help of linear regression function one can establish the speed of sound in soybean oil at different temperatures, with an expanded uncertainty of 7.0 m/s-1 (0.5%), and maximum error of 6.4 m/s-1.

5. References

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Acknowledgements

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