# Use of ultrasound to monitor physical properties of soybean oil

**RM Baêsso[1], PA Oliveira[1], GC Morais[1], AV Alvarenga[1], RPB Costa-Félix[1],**

[1]Laboratory of Ultrasound (Labus), Directory of Scientific and Industrial Metrology (Dimci), National Institute of Metrology, Quality and Technology (Inmetro), Av. Nossa Sra. das Graças 50, Duque de Caxias, RJ, Brazil, ZIP 25250-020

E-mail:rmbaesso-cnpq@inmetro.gov.br

**Abstract**: The study of the monitoring physical properties of soybean oil was performed. The pulse-echo method allowed measuring the density and viscosity of the oil in real time and accurately. The physical property values were related to the acoustic time of flight ratio, dimensionless parameter that can be obtained from any reference. In our case, we used the time of flight at 20°C as reference and a fixed distance between the transducer and the reflector. Ultrasonic monitoring technique employed here has shown promising in the analysis of edible oils.

**Keywords**: Soybean, ultrasound, monitoring and physical properties.

## 1. INTRODUCTION

Liquid viscosity and density are important properties for designing equipment for the fatty acids industries. One example is the use in estimating the efficiency of distillation columns aimed at the separation and purification of acids. Data fluid viscosity and density are also used in heat transfer designs, process piping and determining pressure drop[1][2].

Currently, there is considerable demand for measurement instruments that are able to characterize liquids with high sensitivity, robustness and accuracy in the chemical, food, petrochemical plants, among others. Furthermore, due to process automation, in-line measurements become necessary. Thus, the use of ultrasound techniques is interesting because it is a robust method, accurate, non-destructive and can be applied in the process line [3][4].

Literature shows the possibility of using ultrasound to measure the physical properties from the acoustic parameters of the liquid [5][6].

The aim of this study was to establish a relationship between the viscosity and density of the soybean oil, and the acoustic time of flight ratio.

The work purpose is to facilitate obtaining reliable data online and automated, allowing acquisition of immediate and accurate results. The calculation of uncertainties of measurements was carried throughout the study and is described here.

## 2. METHODOLOGY

In this project, we used low-power ultrasound and pulse/echo techniques, in which the ultrasonic pulse signals pass through the sample, reach the reflector and return to the same transducer. The study was carried out with the assistance of a transducer with nominal frequency of 1 MHz and diameter of 12.7 mm (NDT-Panametrics-Olympus Corporation, Japan), a waveform generator (33250A, Agilent Technologies, CA, USA), an oscilloscope (DSO-X 3012A, Agilent Technologies, CA, USA), a

data acquisition unit (34970A, Agilent Technologies, CA, USA), and a computer with a program developed in LabView™, (National Instruments, Austin, TX, USA). In Figure 1, the experimental arrangement scheme is shown. It was possible to identified changes that occur in the density and viscosity of the soybean oil over the variations in temperature, through the signal of the ratio of acoustic time of flight.
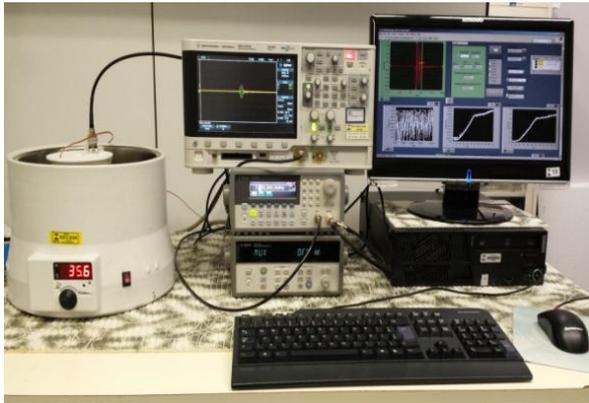


Figure 1 - Experimental arrangement used for determining the viscosity and density of the soybean oil.

According to the literature [7][8], the dependency of the viscosity of neat vegetable oils with temperature can be satisfactorily described by the Andrade relationship (1)

$$\mu = A_1 \cdot e^{\left(\frac{E}{RT}\right)} \qquad (1)$$

where $\mu$ is the dynamic viscosity, $T$ is the absolute temperature, $A_1$ is a constant, $E$ is the activation energy and $R$ is the universal gas constant.

The values of the parameters $A_1$ and $E$ to soybean oil have been obtained from literature [7] (Table 1), and used to establish the relationship between the dynamic viscosity of the soybean oil and the time of flight ratio.

**Table 1**. Values of the constants $A_1$ and $E$ for Eq.(1)and data fitting statistics for soybean oil.

| Oil | Soybean |
|---|---|
| $A_1^*(10^{-3}\text{mPa.s})$ | 1.616 |
| $E^*$ (J/mol) | 25649 |
| $r^2$ | 0.9964 |

*Valid only in the range (293.15-353.15) K*
**Source:** *Adapted from Nguyen, Q.D. (2011).*

On the other hand, studies have shown [7][8] that the density of oil, varies linearly with increasing absolute temperature from the equation (2)

$$\rho = \alpha + \beta.T \qquad (2)$$

where $\alpha$ and $\beta$ are empirical constants. The values of the parameters $\alpha$ and $\beta$ for the soybean oil were taken from the literature [7] (Table 2), and used to establish the relationship between the density of the soybean oil and the time of flight ratio.

**Table 2.** Values of the constants $\alpha$ and $\beta$ for Eq.(2) for the pure components of the soybean oils.

| Oil | Soybean |
|---|---|
| $\alpha$ (kg/m³) | 1197.0 |
| $\beta$ (kg/m³ K) | -0.959 |
| $r^2$ | 0.9978 |

**Source:** *adapted from Nguyen, Q.D. (2011).*

## 3. RESULTS AND DISCUSSION

The data obtained by processing the ultrasonic signals from the 5 repetitions provided two curves capable to specify relationships of viscosity (Figure 2) and density (Figure 3) versus time of flight ratio, respectively.
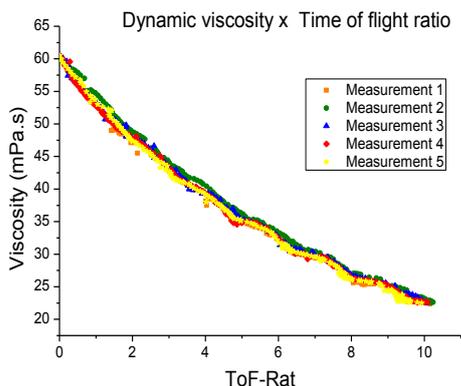
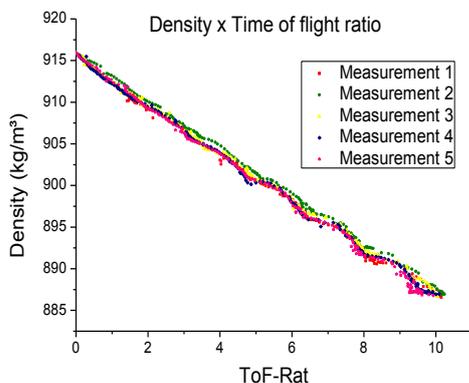Figure 2 - Relation between dynamic viscosity and time of flight ratio.



Figure 3 - Relation between density and time of flight ratio.

Characteristic functions were established, equations (3) and (4), able to describe the behavior of $\mu$ e $\rho$, respectively, as a function of time of flight ratio,

$$\mu = A \cdot e^{(B \cdot r_{tf})} \tag{3}$$

$$\rho = a + b \cdot r_{tf} \tag{4}$$

where $A$, $B$, $a$ e $b$ are constants and $r_{tf}$ is the ultrasonic time of flight ratio (dimensionless parameter). From the trials, it was calculated for

each set of the four parameters, the average ($A$, $B$, $a$ e $b$), the standard deviation ($\sigma_A$, $\sigma_B$, $\sigma_a$ e $\sigma_b$) and the coefficient of variation ($c_{vA}$, $c_{vB}$, $c_{va}$ e $c_{vb}$) (Table 3).

**Table 3.** Values of the constants $A$, $B$, $a$ and $b$ for Eq. (3) e (4) for the pure components of the soybean oil.

| Oil | Soybean |
|---|---|
| **Viscosity parameters** | |
| $A$ **(mPa.s)** | 58.75 |
| $\sigma_A$ | 0.64 |
| $c_{vA}$ **(%)** | 1.1 |
| $B$ | -0.09864 |
| $\sigma_B$ | 0.000934 |
| $c_{vB}$ **(%)** | 0.9 |
| **Density parameters** | |
| $a$ **(kg/m³)** | 914.14 |
| $\sigma_a$ | 0.13 |
| $c_{va}$ **(%)** | 0.01 |
| $B$ | -2.8914 |
| $\sigma_b$ | 0.06611 |
| $c_{vb}$ **(%)** | 1.7 |

It is important to note that as the data taken from the literature for soybean oil could only be applied in the range of 20-80 °C, the benchmark set for $r_{tf}$ calculation was obtained at 20.0 °C.

For the calculation of uncertainties obtained from these models, we used the equations (5) and (6) from the literature [9].

$$U_\mu = \sqrt{\sum \left(\frac{\partial \mu}{\partial x_i} \cdot U_i\right)^2} \tag{5}$$

$$U_\rho = \sqrt{\sum \left(\frac{\partial \rho}{\partial x_i} \cdot U_i\right)^2} \tag{6}$$

Tables 4 and 5 show the expanded uncertainty values calculated for the established models.

**Table 4.** Values of the calculated uncertainties for dynamic viscosity.

| Oil | ToF-Rat | $\mu$ (mPa.s) | $U_{exp}$ (mPa.s) | $U_{rel}$ (%) |
|---|---|---|---|---|
| Soybean | 0 | 58.7 | 0.8 | 1.3 |
| | 2 | 48.2 | 0.7 | 1.4 |
| | 4 | 39.6 | 0.6 | 1.4 |
| | 6 | 32.5 | 0.5 | 1.4 |
| | 8 | 26.7 | 0.4 | 1.4 |
| | 10 | 21.9 | 0.3 | 1.5 |

**Table 5.** Values of the calculated uncertainties for density.

| Oil | ToF-Rat | $p$ (kg/m³) | $U_{exp}$ (kg/m³) | $U_{rel}$ (%) |
|---|---|---|---|---|
| Soybean | 0 | 915.3 | 0.4 | 0.04 |
| | 2 | 909.6 | 0.4 | 0.04 |
| | 4 | 903.9 | 0.4 | 0.04 |
| | 6 | 898.2 | 0.4 | 0.05 |
| | 8 | 892.4 | 0.5 | 0.06 |
| | 10 | 886.7 | 0.6 | 0.07 |

Based on the data obtained from the study developed, there is a great capacity to estimate the viscosity and density from ultrasonic data.

Is important to clarify that since it uses the time of flight ratio as ultrasonic parameter, the dependence of the results with the distance between the transducer and the reflector does not exist anymore, being able to use any spacing whereas it has a reference established.

The development of easy techniques, inexpensive and capable to provide reliable results, makes the ultrasound feasible to be implemented in various industry segments.

## 4. CONCLUSION

Preliminary results suggest that the proposed method is feasible to monitor the physical properties in real time of soybean oil, making it possible to implement in production lines.

Thus, with the aid of ultrasound, any unexpected results that may occur during the production processes can be perceived, avoiding the waste of raw materials and products that do not meet compliance.

## ACKNOWLEDGMENTS

## REFERENCES

[1] Noureddini H, Teoh B C and Clements L D, 1992, *JAOCS,* 69, 1189-1191.

[2] Noureddini H, Teoh B C and Clements L D, 1992, *JAOCS,* 69, 1184-1188.

[3] Buiochi F, Adamowski J C., and Furukawa C M, 1998 *Proc. IEEE Ultrason.Symp.*, 1193-1196.

[4] Greenwood M S and Bamberger J A, 2002, *Ultrasonics*, 39, 623- 630.

[5] Figueiredo M KK, Silva C E R, Alvarenga A V, *Costa*-Félix, R P B, 2015, *Journal of Physics: Conference Series*, 575, 012001.

[6] Figueiredo M KK, Costa-Félix, R P B, Alvarenga A V, Maggi, L E, Romeiro, G A, 2012, *Fuel*,91, 209-212.

[7] Nguyen Q D, Franco Z, 2011, *Fuel,*90, 838–843.

[8] Krisnangkuraa K, Yimsuwanb T, Pairintraa R, 2006, *Fuel*, 85, 107–113.

[9] JCGM, 2008, *Evaluation of Measurement Data – Guide of the Expression of Uncertainty in Measurements,* JCGM 100:2008.