Elaeis Vol. 8 No. 1, June, 1996, pp. 37–44.

ULTRASONIC STUDIES OF PALM OIL AND OTHER VEGETABLE OILS

Keywords: Ultrasonic properties; sound waves; attenuation; palm oil; palm olein

SIDEK, H A A ; CHOW, S P ; SHAARI, A H AND SENIN, H B*

This paper reports the propagation and the attenuation of sound waves in crude palm oil (CPO), refined bleached deodorized (RBD) palm oil, palm olein and some other vegetable oils: coconut oil, corn oil and soyabean oil. The ultrasonic pulse echo overlapped technique has been employed to obtain the ultrasonic properties of the oils from room temperature up to 90°C. The velocity of sound in vegetable oil products decreases linearly with temperature, while their ultrasonic attenuation (α) decreases exponentially with temperature. By using an MBS 8040 ultrasonic analyzer, we observed that α/f^2 decreases nonlinearly with frequency (f), which is mainly due to a relaxation process. The ultrasonic properties of the oils are very dependent on their viscosity, density and molecular structure. The ultrasonic wave velocity and attenuation coefficient can be used as a basic tool to identify Malaysian palm oil.

INTRODUCTION

Ultrasonic techniques have been widely used to study a number of the physical properties of oils, *e.g.* in solid fat content determinations, the estimation of adiabatic compressibilities and the investigation of phase transitions (Bhattacharya and Deo, 1981; Hussein and Povey, 1984). The temperature dependence of the velocity of ultrasonic waves has also been employed to detect adulteration in a number of animal and vegetable oils (Rao *et al.*, 1980) and to determine particle size

* Ultrasonic Research Laboratory, Department of Physics, Universiti Pertanian Malaysia, 43400 UPM Serdang, Selangor, Malaysia

distribution in food emulsions (McClements *et al.*, 1990). So far, only a few studies on Malaysian palm oils using ultrasonic techniques have been carried out. Jaafar *et al.* (1993) employed an ultrasonic technique to determine the oil content in a homogeneous solution of crude palm oil and hexane (michella). They proposed that the three main parameters affecting the velocity of ultrasonic waves in the solution were density, acoustic impedance and temperature.

The aim of the present work was to characterize quantitatively Malaysian palm oil and palm olein, along with some other vegetable oils, using an ultrasonic technique in order to obtain a valuable insight into their dynamic properties. The sound velocity and attenuation coefficient are closely related to the physico-chemical properties of oils through which sound waves propagate, and can therefore be used to provide information about these properties. Such physical properties will determine the dynamic compressibility, kinematic viscosity, and acoustic impedance of oils, as well as particle size distribution in emulsion. These may need to be known in various applications in the food processing industry (Chouikhi and Richmond, 1988) and perhaps in the automobile industry, *e.g.* in relation to the use of palm oil as fuel for Elsbett engines (Hitam, 1995). There is a lack of data on the ultrasonic properties of Malaysian palm oil and its products, so this study is an effort to fill the gap and hence if possible, to determne the quality or the type of palm oil and its products using ultrasonic methods. So far their physical identification has been determined by their iodine value, slip melting point, cloud point, refractive index, kinematic viscosity and apparent density (Pantzaris 1985, Siew *et al.* 1992, Hitam 1995); however the difference between oils is not large and most of the physical properties of oils change with temperature.

THEORY

Ultrasound is an elastic sinusoidal wave which can propagate through any liquid, semisolid or solid material. However, only a longitudinal wave can be transmitted in liquid since such a medium possesses only one elastic modulus, the bulk modulus K (Trevena, 1969). The propagation velocity v of the wave depends on this modulus and on the density of the liquid according to the relationship:

$$v = \sqrt{(K_s/\rho)}$$

where the subscript s indicates the adiabatic bulk modulus, K_s. Adiabatic conditions apply because the pressure variations occur so rapidly that there is no time for the temperature to equalize itself throughout a volume element during a compression or rarefaction. The velocity of sound in liquids varies from 900 to 2000 metres per second (ms^{-1}). For example, at 20° C the values of v for carbon tetrachloride, water and pure glycerol are 950,1490, 1940 ms^{-1} respectively. These sound velocities are also very dependent on the temperature, pressure and chemical composition of liquids. In most cases the intensity of a sound wave decreases continuously as it is propagated through a liquid due to attenuation. The ultrasonic attenuation is a characteristic of the particular liquid where the absorption process occurs. There are three main causes for absorption and velocity dispersion in liquids: viscosity, thermal conduction and molecular phenomena. However we only consider the attenuation of a plane wave in a liquid due to its viscosity. As the wave travels there is a relative motion of adjacent layers of the liquid and this results in the creation of viscous forces which act against the acoustic pressure due to the wave. Energy is taken out of the wave to overcome these viscous forces and this progressive extraction of energy results in a corresponding progressive decrease in the intensity of the wave (and hence of pressure, particle displacement, *etc.*).

The ultrasonic pulse echo technique can be used to measure the absorption and velocity as the wave travels through materials. The ability to propagate a wave depends on the forces holding the atoms together in a material, and therefore the study of sound velocity and attenuation reveals the nature and strength of these forces, making this one of the basic tools of materials science. The magnitude of attenuation and ultrasonic wave velocity (v) in a liquid depend on various factors such as its density (ρ) and compressibility (ρ), viscosity, relaxation effect and vibrational anharmonicity. It also varies with the temperature and concentration of the liquid.

MATERIALS AND METHODS

Refined, bleached, deodorized (RBD) palm olein, crude palm oil (CPO) with 0.3% (w/w) moisture content, and palm olein were supplied by the Palm Oil Research Institute of Malaysia (PORIM). Details of their physical properties are well documented by Tan and Oh (1981), and Hitam (1995). Coconut oil, corn oil and soyabean oil were commercially available from our local suppliers. Each liquid sample was placed in a small glass cuvette with a flat base in a temperature controlled thermobath. The chromel-alumel thermocouple was used to measure the temperature of liquid samples.

A schematic diagram of the ultrasonic pulse echo overlapped system (MATEC 7700) used in this study is given in *Figure 1*. In principle, the system comprises a frequency synthesizer and decade divider, a double strobe dual delay generator, a pulse generator and a 20 MHz analog oscilloscope (Sidek *et al.*, 1994). A 5 MHz immersion piezoelectric transducer was used as the transmitter and receiver of ultrasonic waves. The longitudinal ultrasonic velocity and attenuation of oil samples were measured as a function of temperature. For the frequency dependence of the ultrasonic wave velocity and its attenuation, the Ultrasonic Analyzer - Matec Bin System (MBS 8040) was employed. Water was used to calibrate both systems, and similar acoustic behaviours to those found in earlier studies were observed (Trevena, 1969). We have also observed that, by comparison with other liquids, water behaves extraordinarily: in it, ultrasound velocity initially increases with temperature until it reaches a maximum at about 60°C and thereafter decreases with increasing temperature. In general, the velocity is determined from the time taken to traverse a known acoustic path length. The distance between two successive echo trains represents the transit time, whereas the ratio of heights of a pair of successive peaks in the echoes enables one to estimate the attenuation coefficient for each oil sample.

RESULTS AND DISCUSSION

The experimental measurements of ultrasonic velocity versus temperature for four vegetable oil samples are depicted in *Figure 2 (a)* to *(d)*. As expected, we observed that the sound velocity in them decreases approximately linearly with increasing temperature as has been found in other ordinary liquids. *Table 1* shows the linear fitting of our present experimental data. *Table 2* shows the ultrasonic wave velocities and their temperature derivatives v/T of sound velocity at 20°C - 25°C for a number of vegetable oil samples. Also shown are the ultrasonic attenuations at various frequencies as reported

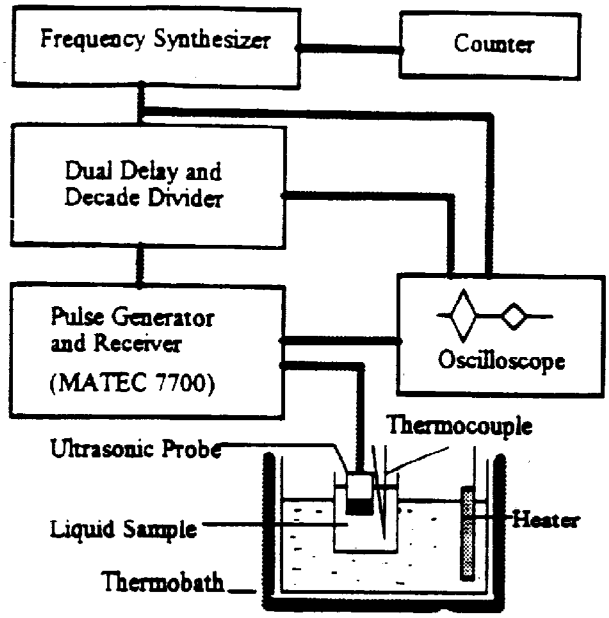

Figure 1. Schematic diagram of an ultrasonic pulse echo overlapped system.

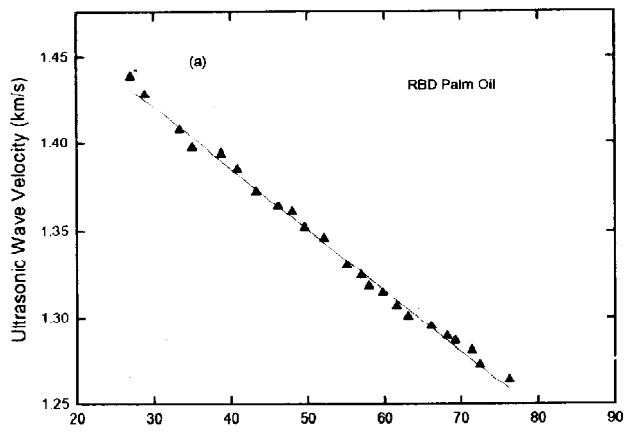

Figure 2a.

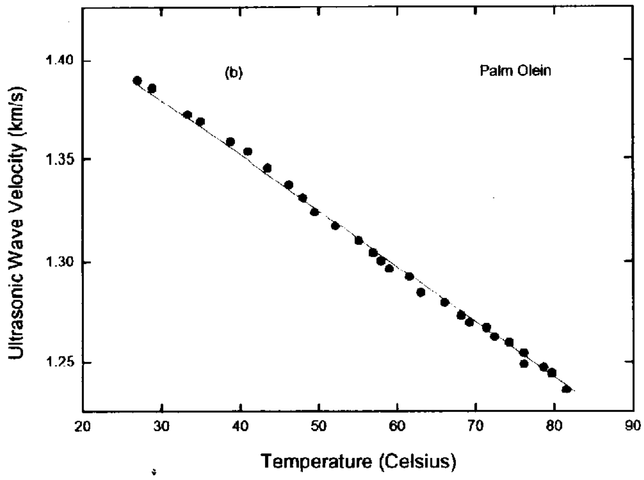

Figure 2b.

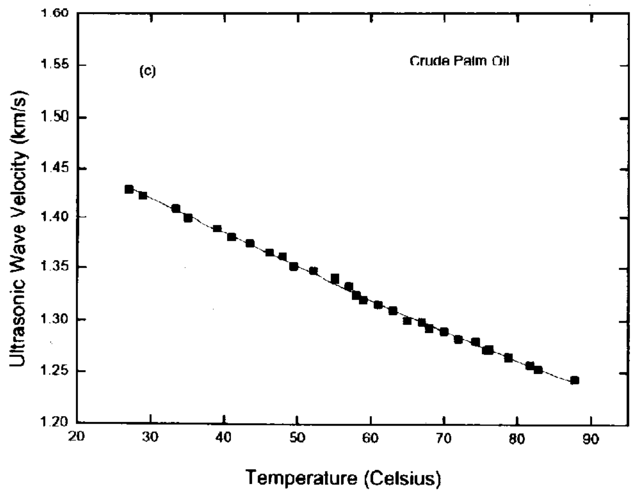

Figure 2c.

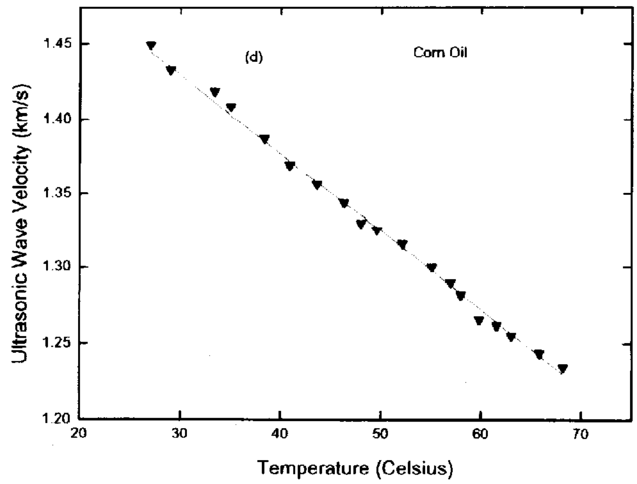

Figure 2d.

Figure 2 (a), (b), (c) and (d). Ultrasonic velocity versus temperature for selected vegetable oils.

by some other workers. Both RBD palm oil and crude palm oil (CPO) solidify at about 30°C–34°C and their physical properties depend on the tempering conditions. In this work, the oils were heated to about 90°C and their ultrasonic wave velocities and attenuations were measured as they cooled down. No hysterisis were observed in any of the oil samples. Except for RBD palm oil, the values of $\Delta v/\Delta T$ for the vegetable oils varied from -3.1 to -3.8 $ms^{-1o}C^{-1}$. Since the ultrasonic wave velocity, and its temperature derivative ($\Delta v/\Delta T$) and ultrasonic attenuation (α) of each oil sample is different from each other (*Table 2*), so these basic ultrasonic parameters can be employed as a tool to identify Malaysian palm oil.

Generally, the properties of oils are very dependent on their glyceride composition and to a lesser extent on their minor components. But glyceride composition is usually very complex and often the physical properties of an oil can be explained with sufficient accuracy by its fatty acid composition (Pantzaris 1985).

TABLE 1. THE TEMPERATURE DEPENDENCE OF ULTRASONIC WAVE VELOCITY PROPAGATED IN SOME VEGETABLE OILS[a].

Oil Samples	Temperature Range (°C)	Linear Fit a (ms^{-1})	(v = a + bT) b (x 10^{-3} ms^{-1} °C-1)	r
CPO	35-90	1469.97	-2.61	0.97
RBD	27-80	1528.22	-3.86	0.96
Palm Olein	27-80	1518.28	-3.29	0.99
Palm[b]	50-70	1515.00	-3.10	1.00
Soyabean	28-90	1680.81	-3.37	0.98
Soyabean[b]	25-70	1536.20	-3.29	0.99
Corn	27-80	1518.56	-3.11	0.99
Corn[b]	20-70	1532.40	-3.23	0.99
Groundnut[b]	20-70	1528.90	-3.23	0.99

[a] Data are presented in the form of linear regression fit; r is the correlation coefficient.
[b] Data from McClement *et al.* (1990).

TABLE 2. ULTRASONIC PROPERTIES OF SOME VEGETABLE OILS AT SELECTED TEMPERATURES AND FREQUENCIES[a,b,c].

Oil Samples	T (°C)	f (MHz)	v (ms^{-1})	-Δv/ΔT (x 10^{-3}) (ms-1 $°C^{-1}$)	α ($dBcm^{-1}$)
Corn oil [a]	20	6.2	1470	3.4	
Corn oil [b]	25	5.0	1454	3.7	6.7
Corn oil [c]	20	1.2	1469	3.2	
Groundnut oil [a]	20 (2.0)[d]	6.2	1468	3.4	5.4[d]
Groundnut oil [c]	20	1.2	1465	3.2	
Olive oil [a]	20 (2.0)[d]	6.2	1465	3.4	6.5[d]
Olive oil [c]	20	1.2	1465	3.3	
Palm olein [b]	25	5.0	1429	3.8	0.6
Palm oil [c]	20	1.2	1459	3.1	
RBD palm oil [b]	25	5.0	1450	4.7	0.8
Crude palm oil [b]	35	5.0	1376	3.2	1.0
Coconut oil [b]	25	5.0			4.4
Safflower oil [a]	20 (2.0)[d]	6.2	1471	3.4	4.0[d]
Safflower oil [c]	20 (2.0)[e]	1.2	1471	3.2	4.9[e]
Soyabean oil [a]	20 (2.0)[e]	6.2	1469	3.4	5.5[e]
Soyabean oil [c]	20	1.2	1469	3.3	
Sunflower oil [a]	20	6.2	1470	3.4	
Sunflower oil [c]	20	1.2	1471	3.3	

[a] Data from Javanaud and Rahalkar (1988).
[b] Data from the present study.
[c] Data from McClements *et al.* (1990).
[d] Data from Gladwell *et al.* (1985)
[e] Data from Kuo (1971).

Since most edible oils and fats are made up of similar fatty acids, *i.e.* mono-basic acids of the general formula R-COOH, most of their physical properties can be expressed as simple functions of their molecular weight and degree of unsaturation. The slight differences in the ultrasonic wave velocities of each oil sample (*Table 2*) are probably due to their chemical structure, *i.e.* chain length and degree of unsaturation (Javanaud and Rhalkar, 1988).

The ultrasonic attenuation has been used to provide information about the dynamic rheological properties of oils (Gladwell *et al.*, 1985). By measuring longitudinal ultrasonic wave attenuation over a wide range of temperatures or frequencies it is possible to determine the dynamic bulk viscosity of the oils. It has been proposed that the relaxation in the bulk viscosity is due to structural changes. Variations of ultrasonic attenuation with temperature for a number of vegetable oils have also been studied and compared with previous work carried out by Sidek *et al.* (1993). The relative 5 MHz attenuation of RBD palm oil, palm olein, corn oil and soyabean oil decreases nonlinearly as the temperature increases. The present results indicate that the attenuation of the liquid oils drop rapidly with temperature and their variations are mainly due to viscosity, thermal conduction and molecular effects; such results have also been observed by others (Trevena, 1969). Since the ultrasonic attenuation of our samples of palm oil and palm olein shows a pattern very similar to the change in their viscosity with temperature (Viswanath and Natarajan 1989), the present finding indicates that the ultrasonic attenuation in palm oil is caused mainly by viscosity or visco-elastic effects. The attenuation due to thermal conduction of most liquids is negligible compared with that due to viscosity.

Measurements were also made of the ultrasonic velocity and attenuation in the frequency range 0.25 – 7.00 MHz using the MBS 8040 ultrasonic analyzer. *Figure 3 (a)* and *(b)* shows the frequency dependences of the ultrasonic attenuation for soyabean oil and palm olein. Only a slight change in velocity with frequency was observed with both these oils. However in contrast to the velocity, their attenuations increase strongly with frequency: α is proportional to f.

Figure 4 (a) and *(b)* shows the attenuation-frequency relationships (α/f^2) in soyabean oil and palm olein. Analysis of experimental data suggests that the nonlinear decrease of (α/f^2) over a wide range of frequency is due to relaxation processes (Trevena, 1969).

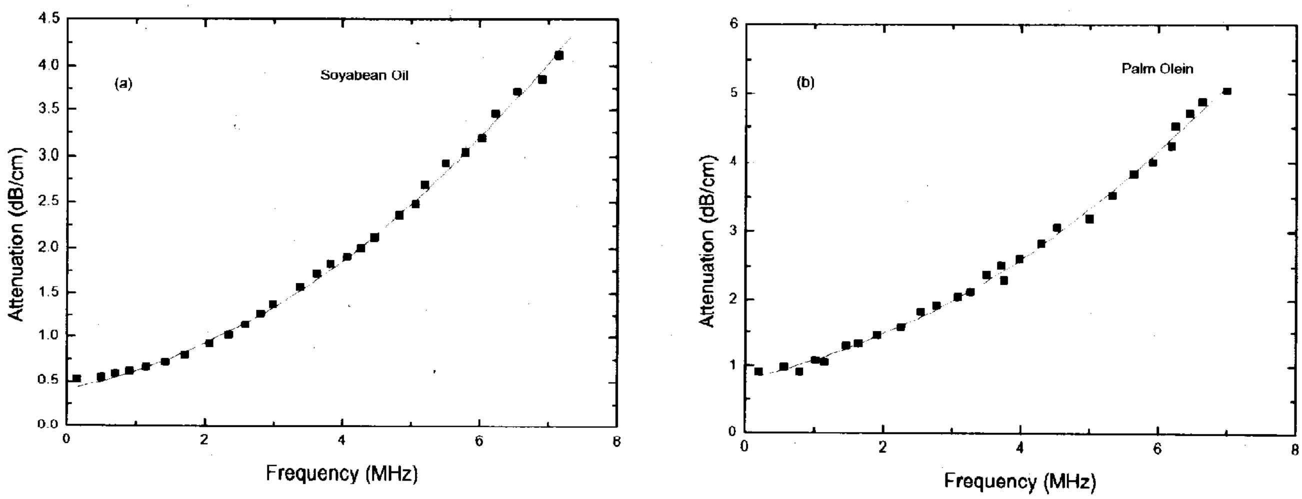

Figure 3 (a) *Figure 3 (b)*

Figure 3 (a) and (b). Ultrasonic attenuation versus frequency for soyabean oil and palm olein at room temperature.

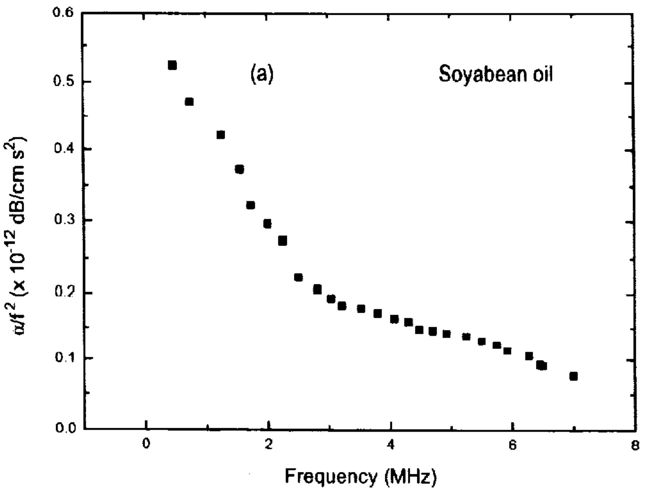

Figure 4 (a)

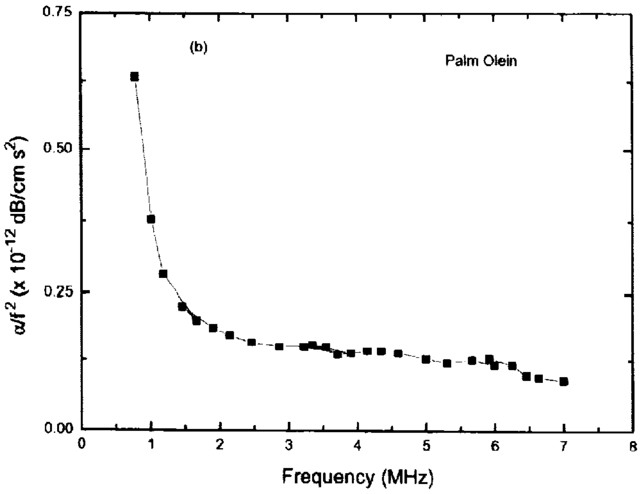

Figure 4 (b)

Figure 4(a) and (b). Attenuation-frequency relationships (α/f^2) in soya bean oil and palm olein at room temperature.

According to standard hydrodynamic laws, the ultrasonic velocity and the attenuation of a longitudinal elastic wave of angular frequency (=2πf) is given by (Berne and Pecora, 1976):

$$\alpha(\omega) = \frac{\omega^2}{2V^3}[D_l+(\gamma - 1)D_T]$$

where D_l is the longitudinal kinematic viscosity and D_T is the thermal diffusity. The latter is usually ignored in liquid oils since it is negligible compared with D_l. γ is the ratio of the specific heat measured at constant pressure (Cp) to the specific heat measured at constant volume (Cv). Palm oil and palm olein, like most other liquid systems, do not follow hydrodynamic behaviour, *i.e.* v and (α/f^2) depend on frequency. This behaviour can be explained through thermodynamic relaxation theories. Because of a lack of other important physical parameters, we are unable so far to explain our results in term of thermodynamic relaxation theories. Further extensive ultrasonic experimental work will produce new information on the thermal behaviour of palm oil and its products.

CONCLUSION

Measurements have been made of ultrasonic wave velocity and attenuation at 5 MHz frequencies for samples of Malaysian palm oil and palm olein and other vegetable oils. The decrease of sound velocity in these liquids with increasing temperature is probably related to their chemical structure, *i.e.* chain length and degree of unsaturation. However the continuous decrease of sound wave intensity (termed attenuation loss) in a liquid is due to viscosity, thermal conduction and molecular effects. The ultrasonic wave velocity and attenuation coefficient can be used as a basic tool to identify Malaysian palm oil and palm olein. The nonlinear decrease of (α/f^2) over a wide range of frequency in most vegetable oils is due to the relaxation processes.

ACKNOWLEDGMENTS

The authors wish to thank Ms. Noor Azizah Shaari, Mrs. Rabiah Abdul Wahid and Ms. Tijah Pardi for their technical help. We are indebted to the Malaysian Science Research Council (MPKSN) under Intensified Research Programme in Priority Area (6th. Malaysia Plan 1991-1995) for the financial support.

REFERENCES

BERNE, B J and PECORA, R (1976). Dynamics of Light Scattering (Wiley and Sons, New York).

BHATTACHARYA, A C and DEO, B B (1981). Ultrasonic Propagation in Coconut Oil in the Vicinity of Phase Transition. *Ind. J. Pure Appl. Phys. 19*, 1172.

CHOUIKHI, S M and RICHMOND, P (1988). Non-Destructive Testing: *Proceedings of the 4th. European Conference* (Eds. Farley J.M and Nicholas R W) Pergamon Press, Oxford, UK, pp. 273-288.

GLADWELL, N, JAVANAUD, C, PEERS, K E and RAHALKAR, R R (1985). Ultrasonic Behaviour of Edible Oils: Correlation with Rheology. *J. Am. Oil Chem Soc., 62*, 1231-1236.

HITAM, A (1995). Palm Oil as Fuel for Cars Fitted with Elsbett Engines. *Palm Oil Technical Bulletin, 1(3)*, 1-2.

HUSSEIN, A B B H and POVEY, M J W (1984). A Study of Dilation and Acoustic Propagation in Solidifying Fats Oils: II. Experimental. *J. Am. Oil Chem. Soc. 61*, 560.

JAAFAR, R , SHAARI, A , KASSIM, R and NAWI, M N (1993). Ultrasonic Determination of Palm Oil Content in Michella, *Proc. 3rd. Seminar on Industrial Physics, 192-199* (MASS Publisher, Bangi Selangor, Malaysia)

JAVANAUD, C and RAHALKAR, R R (1988). Velocity of Sound in Vegetable Oils. *Fat. Sci. Tech, 90*, 73–75.

KUO, H I (1971). Variation of Ultrasonic Velocity and Absorption with Temperature and Frequency in High Viscosity Vegetable Oils. J. *Appl. Phys. 10*, 167–170.

MCCLEMENTS, D J , POVEY, M J W, JURY, M and BETSANIS, E (1990). Ultrasonic Characterization of a Food Emulsion. *Ultrasonics 28*, 266–272.

PANTZARIS, P T (1985). The Density of Oils in the Liquid State (with Special Reference to Palm Oil), *PORIM Technology, 12*, 1–14.

RAO, C R , REDDY, L C S and Prabhu, C A R (1980) Study of Adulteration in Oils and fats by Ultrasonic Method. *Current Sci. 49*, 185.

SIDEK, H A A , CHOW, S P , SHAARI, A H and MUDA, Z (1993). 5 MHz. Ultrasonic Attenuation of Vegetable Oils. *Bul. Fiz. UTM, 6(2)* 60–67.

SIDEK, H A A, CHOW, S P, SENIN, B H and A. RAZAK, I (1994). Elastic Study of Materials Using Ultrasonic Pulse Echo Overlapped Technique. *Bul. Mal. Solid St. Sci. Technol. 4(2)* 9–16.

SIEW, W L, CHONG, C L, TAN, Y A, TANG, T S and OH, C H (1992). Indentity Characteristics of Malaysian Palm Oil Products, *Elaeis 4(2)*, 79–85.

TAN, B K and OH, C H (1981). Malaysian Palm Oil: Chemical and Physical Characteristics. *PORIM Technology, 3*, 1–5.

TREVENA, D H (1969). Ultrasonic Wave in Liquids. *Contemp. Phys., 10(6)* 601–614.

VISWANATH, D S and NATARAJAN, G (1989). Data Book on the Viscosity of Liquids, (Hemisphere Publishing Company, New York).