

Photothermal Techniques Used to Evaluate Quality in Dairy Products.

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Abstract. Photothermal systems were used to quantify thermal and optical properties of commercial and natural dairy products. Thermal diffusivity and light absorption coefficient were analyzed. It was found that water content easily alters thermal properties in samples of milk. In addition, all samples showed strong light absorptions at 405 nm, 980 nm and 488 nm, evidencing presence of proteins, fat and vitamins (riboflavin), respectively. Therefore, it was shown that thermo-physical properties measured in this work could be used as complementary parameters for quality evaluation of dairy products.

1. Introduction

Milk is a complex colloidal suspension, it is mainly composed by fat, casein micelles, proteins, lactose, and some vitamins [1]. It is widely promoted as a main staple food for pediatric population and it is an important component of other marketed products, such as cheese, yoghurts, creams, etc.,. However, dairy industry faces two main problems: on one side, it is subjected to a variety of adulteration in all different processes of chain distribution, from production to final consumption; on the other side, it degrades its quality in short periods of time due to the presence of microorganisms. For these reasons, dairy industry applies a set of biochemical and biophysical tests to evaluate milk coming from stables [2,3]. Each component in milk is characterized for having specific thermal and optical properties [4-6]. Thermal diffusivity of water, for instance, is relatively larger than other components of milk; therefore, a minimal addition of water can modify greatly thermal properties of milk. Other components, such as proteins and lactose, absorb light at specific wave-lengths, since microbial activity can modify the natural proportion of these components, optical properties can also be used to study adulteration of milk. Photothermal techniques are used in this work to measure thermal diffusivity and optical absorption coefficient (at 405 nm, 488 nm and 980 nm) of dairy products. Results show the feasibility of using these properties as a tool to assess products quality in dairy industry.

2. Experimental set-ups

Two photopyroelectric techniques, for thermal diffusivity [7,8] and optical absorption coefficient measurements [9], were used. Details of these different photothermal methodologies are reported elsewhere for which just a brief description of these is provided in this work.



Related with thermal diffusivity measurements it has been shown that [7,8], under appropriate experimental conditions, photopyroelectric signal, δP , behaves as: $\delta P = C \exp(-\sigma L)$. In this equation L is the sample's thickness, C and $\sigma = (1 + i)\sqrt{\pi f/\alpha}$, are complex expressions, where f and α are modulation frequency and sample's thermal diffusivity, respectively. This thermal property can be obtained from linear fittings on phase and amplitude of δP , by means of the fitted parameter $M = \sqrt{\pi f/\alpha}$, taking the photopyroelectric signal as function of the sample's thickness. For optical absorption coefficient measurements, on the other hand, it has been shown that [9], under appropriate experimental conditions, photopyroelectric signal, δP , behaves as: $\delta P = D \exp(-\beta L)$, where D is a complex expression, L is sample's thickness and β is the sample's optical absorption coefficient. As for thermal diffusivity measurements, the optical absorption coefficient can be measured by fitting the amplitude of δP as function of the sample's thickness. In this experiment, pyroelectric phase signal remains constant, consequently, it can be used as an experimental criterion for the analysis.

2.1 Photopyroelectric setup for thermal diffusivity measurements

Figure 1 shows a cross section of the photopyroelectric setup for thermal diffusivity measurements [7,8], where a diode laser at 875 nm (Thorlabs, model L785P090) was used as a light source.

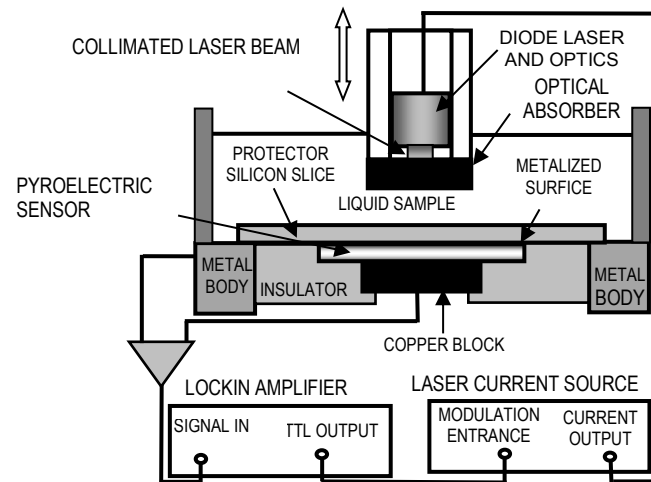


Fig. 1. Cross section of the photopyroelectric setup for thermal diffusivity measurements of liquids.

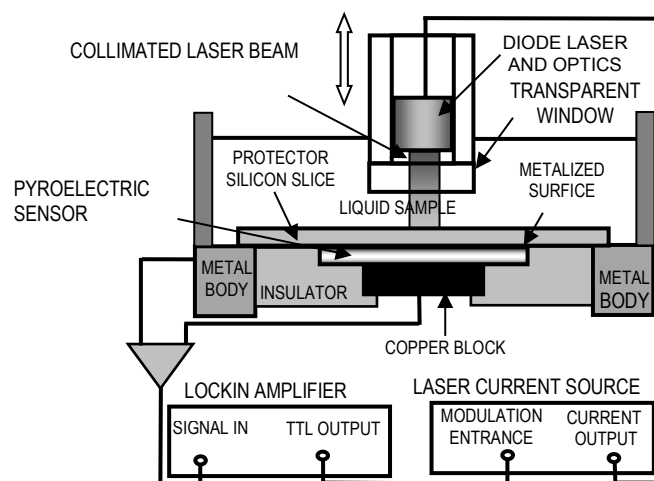


Fig. 2. Cross section of the photopyroelectric setup for optical absorption coefficient measurements of liquids.

2.2 Photopyroelectric setup for optical absorption coefficient measurements

Figure 2 shows a cross section of the photopyroelectric setup for optical absorption coefficient measurements [9]. Three diode lasers at different wave-lengths, 405 nm (laser pointer), 488 (Thorlabs, model L488P60) and 980 nm (Thorlabs, model L980P030), were used to determine optical measurements.

Intensity lasers modulation was achieved, in both cases, by means of a current source (Thorlabs, model LDC205C) controlled by the TTL output (transistor-transistor logic) of the lockin amplifier (Research Scientific Instruments, model SRS830) using a PZT element as a pyroelectric sensor. Pyroelectric signal was first pre-amplified (Stanford Research Systems, model SR550) before to be sent to the lockin amplifier.

3. Materials and Methods

Different variety of milks (Table I), bought in local markets and stables in Mexico City, were used in this work. All measurements were made at a fixed modulation frequency of 1 Hz, liquid sample's thickness was changed in steps of 50 microns by taking 15 experimental data for thermal diffusivity measurements and 30 experimental data for optical absorption coefficient measurements.

Table I. Optical and Thermal Properties of different type of Milks as measured by means of the photothermal techniques presented in this work.

Milk type	Optical Absorption Coefficient β (cm ⁻¹)			Thermal Diffusivity α (cm ² /s)	
	488 nm	405 nm	980 nm	Phase	Amplitude
Raw Milk	7.03	7.06	5.07	0.00139	0.00140
“Alpura Clásica”	6.08	7.56	5.89	0.00135	0.00135
“Alpura Deslactosada”	5.58	7.87	5.21	0.00138	0.00137
“Alpura Light”	6.14	6.84	3.92	0.00141	0.00141

4. Results

Figures 3 and 4 show phase (3a and 4a) and amplitude (3b and 4b) profiles, as function of sample's thickness, for “Alpura Clásica” and raw milks, respectively. The experimental set up shown in Fig. 1 was used to measure thermal diffusivity in samples.

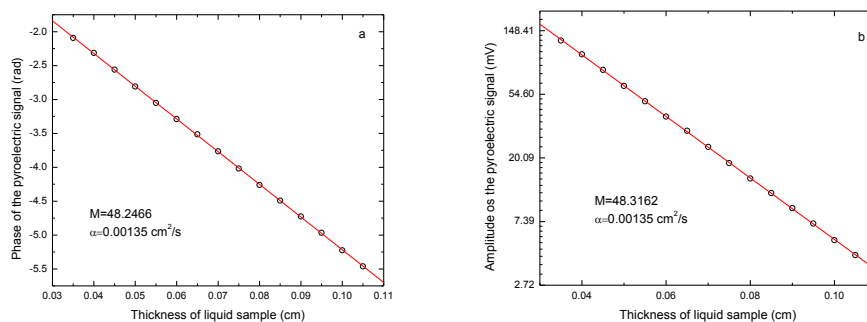


Fig. 3. Phase (a) and amplitude (b) of the photopyroelectrical signal for “Alpura Clásica” milk sample, as a function of liquid's sample thickness. Continuous lines represent linear fits as for to obtain thermal diffusivities.

Thermal diffusivities of milk samples studied in this work are summarized in Table I, columns 5 (for phase) and 6 (for amplitude). The close agreement between thermal diffusivity values from these two pyroelectric signals is evident, situation that proof the photopyroelectric technique consistency. It is also evident that thermal diffusivity values for all milk samples are very similar to each other. Thus, values of this thermal property can't be considered as a parameter to differentiate kinds of milks.

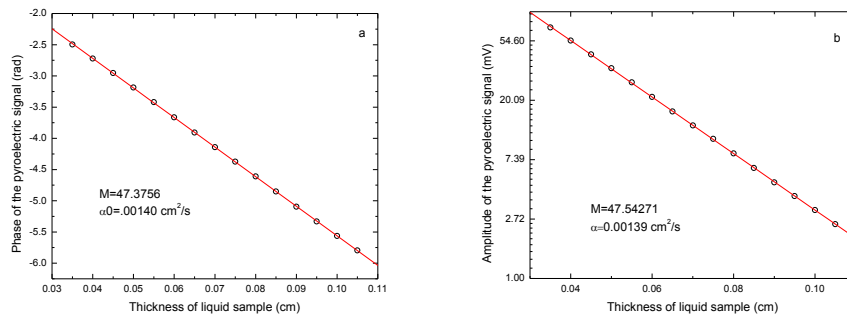


Fig. 4. Phase (a) and amplitude (b) of the photopyroelectric signal for raw milk sample, as a function of liquid's sample thickness. Continues lines represent linear fits as for to obtain thermal diffusivities.

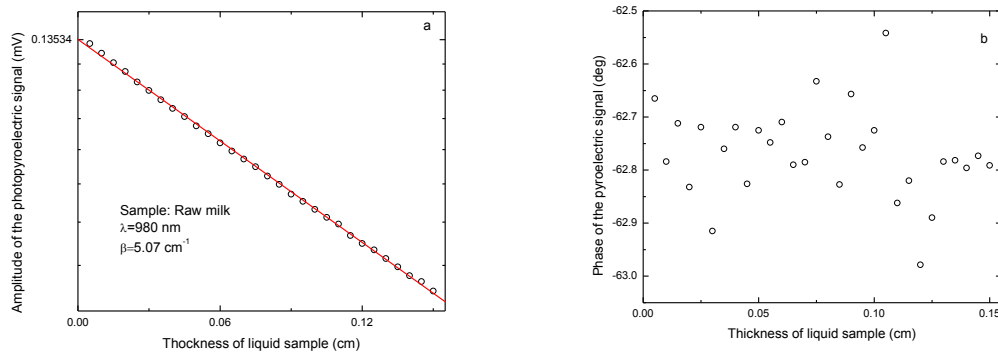


Fig. 5. Photopyroelectric signal for amplitude (a) and phase (b), as a function of sample's thickness for raw milk sample. Continues line represents the linear fit as to obtain the sample's optical absorption coefficient at 980 nm.

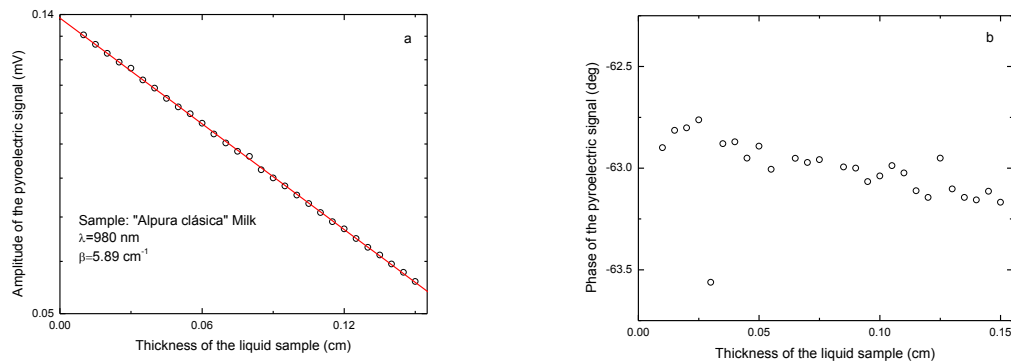


Fig. 6. Photopyroelectric signal for amplitude (a) and phase (b), as a function of sample's thickness for "alpura clásica" milk sample. Continues line represents the linear fit as to obtain the sample's optical absorption coefficient at 980 nm.

Figures 5 and 6 show, on the other side, photopyroelectric signal profiles, as function of sample's thickness, for raw milk and "Alpura Clásica" milk at 980nm, by using the experimental setup shown in Fig. 2, for optical absorption measurements.

Constants phases in these two figures (5b and 5b) certify that the mathematical model for optical absorption coefficient measurements applies for these substances. The set of optical properties measured for all milk samples at 488 nm, 405 nm and 980 nm are summarized in Table I, columns 2, 3 and 4, respectively.

Important variations on optical parameter here presented are obvious for each milk sample. The optical absorption coefficient value depends on both, wavelength and kind of milk. Important differences are particularly observed for "Alpura Clásica" and "Alpura Light" milks at 980 nm (column 4). This fact can be clearly attached to the different fat content of these two kinds of commercial milks.

Another important difference in optical properties happens between raw and "Alpura Deslactosada" milk, at 488 nm. This fact could be due to their different vitamins concentration, especially for riboflavin content which has an absorbing band around 470 nm. Since this optical parameter is larger for raw milk, this difference can be explained as some reduction of this vitamin due to any removing lactose industrial process.

These conclusions shall be verified by means of some other conventional tests by quantifying the fat and lactose concentrations for these kinds of milks.

Thermal diffusivity measurements as a function of water content were also carried out for "Alpura Descremada" milk sample. Thermal diffusivity values, amplitude and phase, are summarized in Table II, columns 3 and 4, respectively. The results show that this thermal property increase with water content for which this thermal property could be used for the assessment of milk adulteration with water. Since adulteration is a common practice in dairy industry, this is a very important outcome.

Table II. Thermal diffusivity measurements for “alpura descremada” milk, as a function of water content, by means of the photothermal technique presented in this work.

Volumetric Milk fraction	Thermal Diffusivity (cm ² /s)	Thermal Diffusivity (cm ² /s)
0.0	0.00147	0.00147
0.1	0.00142	0.00142
0.2	0.00141	0.00141
0.3	0.00141	0.00141
0.4	0.00140	0.00140
0.5	0.00140	0.00139
0.6	0.00139	0.00139
0.7	0.00139	0.00139
0.8	0.00138	0.00138
0.9	0.00138	0.00138
1	0.00138	0.00137

5. Conclusions

Convenience of photothermal techniques in thermal and optical properties of dairy products has been proved. Potential of these thermophysical properties as parameters of food products quality assessment has been shown. It is important to notice that no other conventional spectroscopy technique conducts direct measurements of optical absorption coefficients as the photopyroelectric technique reported in this work does. High light dispersion is an important limitation to conventional spectroscopy but it is not in photothermal techniques. In the last case, signal generation is caused mainly by the direct light absorption.

This condition particularly applies for milk, therefore, analyzing its optical properties with conventional methods is a harder practice. Other more convenient wave-length (in the UV and infrared regions) could also be used for optical absorption coefficient measurements in milk, this could allow to establish quality criteria for these important products.

6. References

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