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Application of fiber-optical module for broadband scattering measurements with rod lenses and CCD photodiode in mobile analyses of peach juice

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It is well known that the use of peach juices in Europe is significant. Therefore, it is important to study scattering as the interaction of light with turbid biological media such as peach juices. This phenomenon is mainly related to the chemical composition of the material of the latter.

The objectives of the present study are to establish the mobile application of a broadband fiber optic system in the analysis of peach juice. The system should be compact enough to perform field analyses. The system must perform precise analysis of peach juices in the factory where they are produced or in the food chain where they are offered. It was established that a fiber-optical module for broadband scattering measurements with rod lenses is significantly sensitive even to a small number of particles in the composition of the peach juice. This fact means that precise analysis of peach juices can be carried out with the system, at the factory where they are produced or at the point of sale where they are available.

Keywords: peach juice, rod lenses, scattering, mobile analyses

INTRODUCTION

The use of natural juices in Europe has almost doubled in recent decades. For many, they are part of a healthier lifestyle. The problem with the quality of natural juices in the food industry is of great importance, since these are widely distributed products [1, 2].

80% of natural juices sold in the EU come from Brazil and the USA. The EU is the largest importer of peach juice in the world. However, this means high CO_2 emissions coming from transport. A Spanish MEP (Member of the European Parliament) presented a report to the EP Environment Committee proposing to encourage the use of locally produced juices that meet European quality standards [3-5].

The interactions of light with turbid biological media such as orange juice are complex phenomena, especially absorption and scattering. Photons often undergo multiple scatterings before being absorbed or passing through the medium in strongly scattering materials. The phenomena considered in the field of quantum electronics are mainly related to the chemical composition of the material.

As an effective replacement for optical fibers in endoscopes, in the late 1960s, Harold Hopkins first introduced rod lenses into optical production. Due to their increased efficiency for light transmission, they are quickly replacing the previously common lenses, almost completely filling the air gaps between the individual lenses. To increase the quality of the transmitted light signal, rod lenses are usually constructed as achromats. Achromats greatly reduce the effects of chromatic and spherical aberration. They are made in such a way that they bring two or more spectra of a light source into focus [6, 7].

The most common achromat is the achromatic doublet. It is composed of two fused lenses with different dispersion coefficients. Usually, one lens is convex from flint glass, e.g., F2 with a higher dispersion coefficient, and the other is concave from crown glass, e.g., BK7 with a low dispersion coefficient. The radii of the two lenses are selected so that the chromatic aberration of one lens compensates for that of the other [8].

A CCD contains an array of square photosensitive cells that convert incoming photons of light into electrons and accumulate a resultant charge. The cells are connected in series, forming rows and columns, with each cell representing one element of the matrix, called a pixel. Quantum efficiency (QE) refers to the sensor's ability to match the incoming photon signal and convert it to a measurable electronic signal. It is wavelength-dependent or a function of photon energy, and the sensor is usually selected when considering the best QE region of interest for the best wavelength spectral range. Various means have been used to improve the quantum efficiency of CCD sensors [9].

By dint of the constructed fiber-optical module for broadband scattering measurements with rod lenses, a comprehensive analysis of the angular scattering of peach juices of 3 different companies and of freshly squeezed peach juices on site in the food chain that offers them was made [10].

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MATERIALS AND METHODS

Samples

Samples of peach juices from three different companies producing peach juice and one sample of multivitamin juice containing peach juice were used. The samples should represent 20 g of liquid biological material.

Spectral measurements using a fiber-optical module for broadband scattering measurements with rod lenses and CCD photodiode

The installation is applicable in the spectral range of 450 – 710 nm and serves to register non-regulated constituents or bacteria by using the phenomenon of light scattering. The installation is compact enough to perform field analysis (it can be adjusted over an area 40 cm long and 50 cm wide) locally at the research site. The developed installation was applied to practical on-site research in the store that offers the products.

The aim of the mobile application of the system for the analysis of peach juice is to offer their rapid tests. The designed mobile installation is a perfect solution for optimization of experiments when repeated measurements are required for the analysis. A key point in the construction is the unique combination between speed, accuracy of the study and analysis of several scattering angles at the same time. This is a substantial advantage for rapid analysis of peach juices. The scattering effect was investigated by different producers of peach juice. It was precisely shown that the module successfully satisfied their needs.

The fiber-optical module for broadband scattering measurements with rod lenses performs rapid sample tests, and through the scattering effect it registers impurities in natural liquid samples. The detector surface is a 128-pixel InGaAs CCD (G9204-512D Hamamatsu Photonics) linear matrix with a built-in low-noise amplifier characterized by high sensitivity, low current in the dark and high stability in the 410-900 nm spectral range. Two capacitive high-speed analog-to-digital converters (ADCs) transform the analog signals received by the CCD sensor. The spectrum from each lens is visualized on a computer using specially developed software adapted to the specific CCD matrix model. During image generation, the control lines of the CCD cause their charge to be transferred to the adjacent cell in the row or column. Accumulated charge is transferred from cell to cell. Reading the image from the digital camera contains multiple repeated transfers by rows or columns. After all, the CCD output gives one pixel for each clock.

The rod lenses included in the composition of the fiber-optic system are arranged in a special way according to the dimensions of the cuvette, in order to cover the entire outer perimeter. The size of the quartz cuvette was matched to the size of the staff lenses. The latter are arranged in such a way around it that they cover its entire diameter. This precise alignment is done in order to be able to correctly detect the scattering angles of the particles that make up a particular liquid sample that is poured into the cuvette. One lens is convex from flint glass, e.g., F2 with higher dispersion coefficient and the other is concave from crown glass, e.g., BK7 with low dispersion coefficient. The radii of the two lenses are selected so that the chromatic aberration of one lens compensates that of the other, as shown in Figure 1.

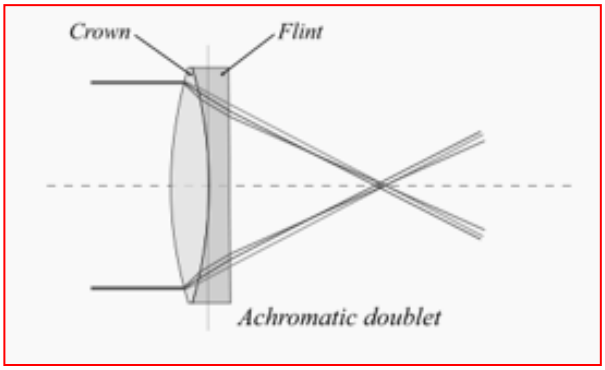

Fig. 1. Drawing of the achromatic doublet

As can be seen, there is more than one lens in the construction of the mobile fiber-optical module for broadband scattering measurements with rod lenses. Bearing in mind that scattered light falls on each lens at a different angle, it can be noted that the module is designed to simultaneously detect 7 scattering angles.

This advantage provides fast and high-quality measurements in biosensors for the analysis of peach juice. Various independent scattering angles can be probed with a single broadband source. Thus, a constructed fiber-optical module for broadband scattering measurements with rod lenses, can be used to determine the angular scattering spectra of peach juice. A quartz cuvette is included in the construction of the module where the desired sample is poured, after which it is irradiated with white light. Each one of the rod lenses receives the light from the different scattering angles of the particles included in the composition of the tested sample.

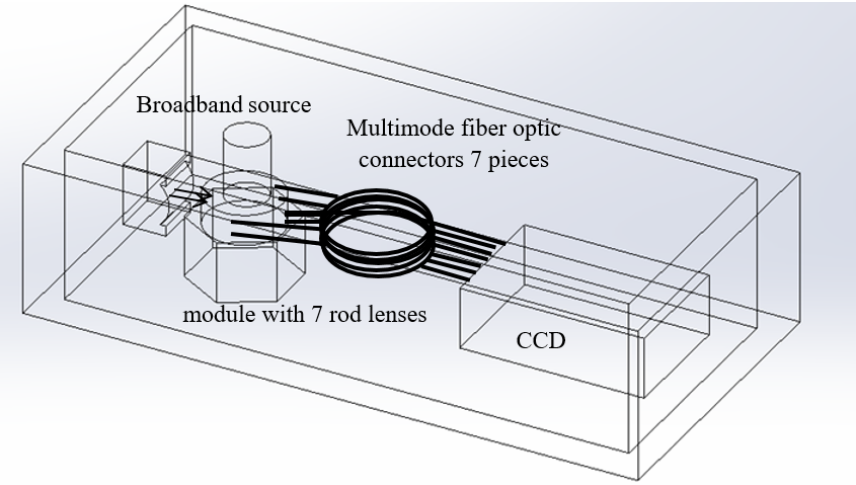

Fig. 2. Fiber-optical module for broadband scattering measurements with rod lenses and CCD photodiode

The multi-functionality of the fiber-optic module allows to detect several particles included in the composition of the liquid sample and thus to optimize the time for liquid analysis.

RESULTS AND DISCUSSION

By means of the constructed fiber-optical module for broadband scattering measurements with rod lenses and CCD photodiode, a comprehensive analysis of peach juices of 3 different companies and of freshly squeezed peach juices was made.

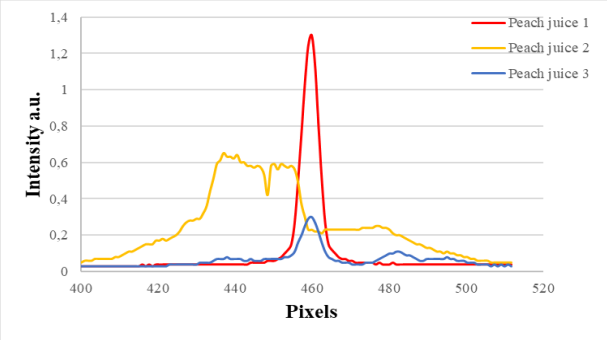

Fig. 3. Angular scattering comparison between the peach juices of three different producers

Figure 3 clearly shows the difference between the angular scattering of peach juice by three different manufacturers. The juice of the 1st producer company is the purest. There are no deviations from the angular scattering typical for peach juice. The peach juice of the first producer is naturally squeezed fresh at the time of the study. For this reason, we are sure that the distribution is pure peach fresh.

In Figures 4, 5 and 6, there is no significant deviation in the angular scattering comparison of natural peach juices and multivitamins, which means that peach is contained in multivitamin juice.

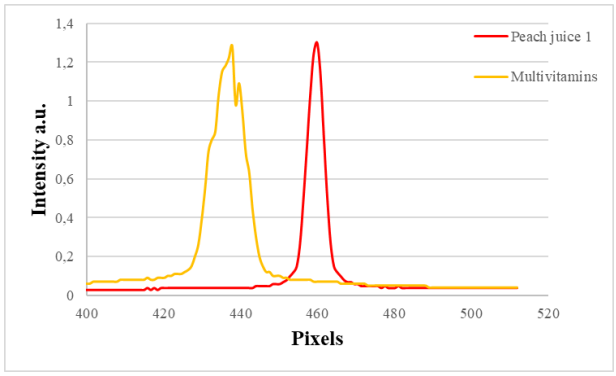

Fig. 4. Angular scattering comparison between the peach juice of producer 1 and multivitamins

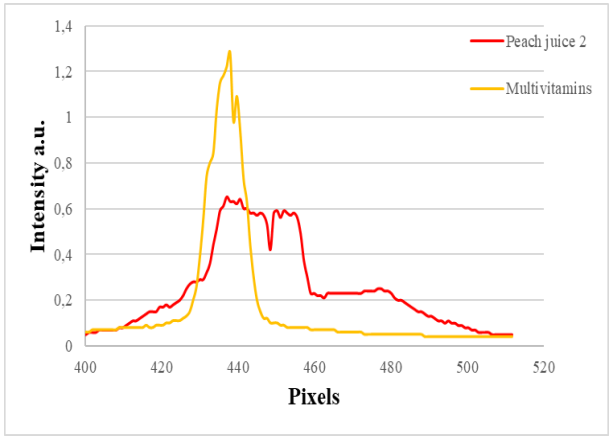

Fig. 5. Angular scattering comparison between producer 2's peach juice and multivitamins

From the analysis of the samples of peach juice it can be concluded that most of the companies producing peach juices work with preservatives and colorings, and not with natural products. Given the sensitivity of the module to very small particles, we can say that there are almost no peach organic substances in the composition of factory juices, with the exception of sample 1, which is the purest.

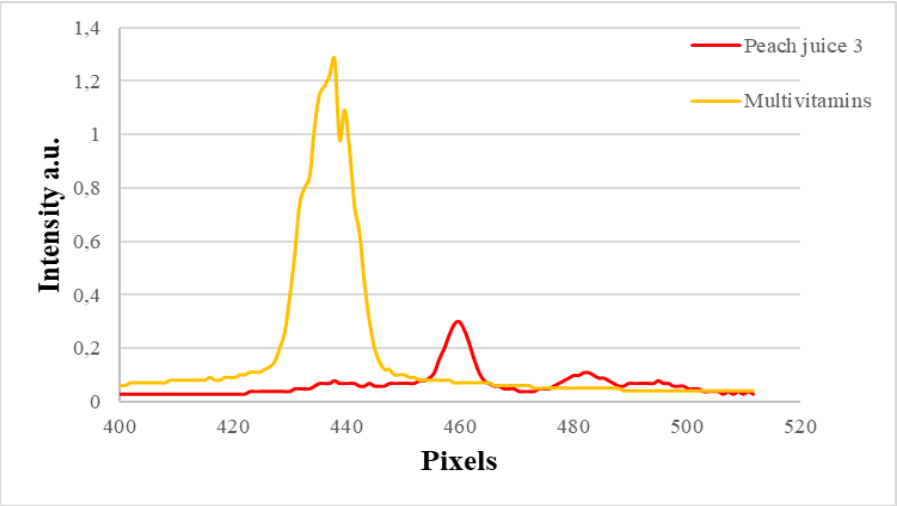

Fig. 6. Angular scattering comparison between the peach juice of producer 3 and multivitamins

A literature survey was conducted on similar research. It turned out that until now the described experimental approach for mobile analysis of peach juice has not been applied nationally or internationally. This gives us reason to claim that, for the first time, a module for broadband scattering measurements was applied for the analysis of peach juice at the distributor site.

CONCLUSIONS

It can be concluded that:

✓ A mobile wide-spectrum fiber-optic system with a staff lens is compact enough to perform field analysis (it is aligned on an area 40 cm long and 50 cm wide).

✓ The developed installation is applied for practical research in analysing peach juice.

✓ The wide-spectrum fiber-optic system with staff lenses is significantly sensitive even to a small number of particles in the composition of the peach juice.

✓ The system can perform precise analysis of peach juices, in the factory where they are produced or in the food chain where they are offered.

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