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Fibre optic sensor for the detection of adulterant traces in coconut oil

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Abstract
The design and development of a fibre optic evanescent wave refractometer for the detection of trace amounts of paraffin oil and palm oil in coconut oil is presented. This sensor is based on a side-polished plastic optical fibre. At the sensing region, the cladding and a small portion of the core are removed and the fibre nicely polished. The sensing region is fabricated in such a manner that it sits perfectly within a bent mould. This bending of the sensing region enhances its sensitivity. The oil mixture of different mix ratios is introduced into the sensing region and we observed a sharp decrease in the output intensity. The observed variation in the intensity is found to be linear and the detection limit is 2% (by volume) paraffin oil/palm oil in coconut oil. The resolution of this refractometric sensor is of the order of 10^{-3}. Since coconut oil is consumed in large volumes as edible oil in south India, this fibre optic sensor finds great relevance for the detection of adulterants such as paraffin oil or palm oil which are readily miscible in coconut oil. The advantage of this type of sensor is that it is inexpensive and easy to set up. Another attraction of the side-polished fibre is that only a very small amount of analyte is needed and its response time is only 7 s.

Keywords: evanescent wave refractometer, adulteration of oil, side-polished fibre, fibre optic sensor

1. Introduction

Many advances have been made in recent years in the use of optical fibres as sensors [1, 2]. Fibre optic sensors act as transducers that encode information, which describes a non-optical external perturbation on to an optical fibre. The advantages of optical fibre based sensors are well known, and include high sensitivity, insensitivity to electromagnetic radiation, spark free, light weight and minimal intrusiveness due to their relatively small size and also because they can be deployed in harsh and hostile environments. Of the range of optical fibre sensors reported in the literature, intensity-based optical fibre sensors represent one of the earliest and perhaps the most basic type of optical fibre sensor [3]. But the main drawback of these types of sensors is that the source fluctuations will affect the output intensity which can be overcome using a reference signal. The flexibility and sensitivity of fibre optic based sensors permit the monitoring of a variety of parameters, including temperature, pressure, strain, degree of cure, chemical content, viscosity, acoustic waves, magnetic fields and degree of rotation.

Over the past two decades, the use of optical fibre sensors for contaminant detection in food stuffs has been widely exploited. Edible oil such as coconut oil finds an important role in the day-to-day life of ordinary people of south Asia. Due to its high demand and good price, it is very much prone to adulteration. The most commonly used adulterants are paraffin oil, which is a relatively cheap petroleum by-product, and palm oil. These oils are very good candidates for adulteration due to their being odourless, colourless and tasteless. Since paraffin oil is not an edible oil, its detection plays an important role in determining the quality of coconut oil. Consumption of

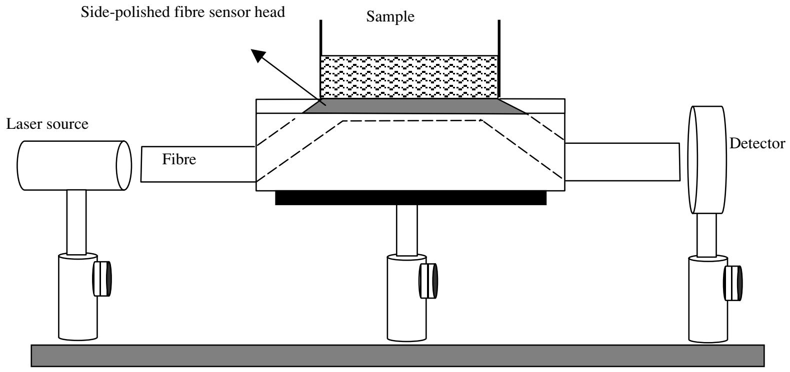

Figure 1. The side-polished fibre optic sensor for the detection of traces of adulterant oils in coconut oil.

paraffin oil causes many health hazards. Petroleum, paraffin, paraffin oil and propylene glycol are all derivatives of mineral oil which dissolve the natural oil of skin and hence skin becomes more dehydrated. It is indigestible and prolonged use may cause leukaemia. Hence it is very important to check the purity of coconut oil. There are no precise techniques for finding traces of paraffin oil or palm oil in coconut oil. Here, we describe a fibre optic evanescent wave based sensor for the detection of trace amounts of paraffin oil and palm oil in coconut oil. The sensing head is basically a multimode side-polished plastic fibre [4]. The plastic fibre has the advantage of low cost, high degree of mechanical flexibility, tensile strength and breaking strength. The fibre is polished in such a manner that a large number of core modes get coupled to the analyte. This increases the sensitivity of the sensor to a great extent. The main advantage of this type of sensor is that it is very rugged and is washable and reusable. In the side-polishing technique [5, 6], the core is exposed directly to the analyte and due to bending of the sensor head the sensitivity further increases.

2. Theory of operation

When light propagates in an optical fibre, a fraction of the radiation extends a short distance from the guiding region into the medium of lower refractive index that surrounds it. This is the evanescent field. This evanescent energy may interact with analytes that attenuate it by means of refractive index changes, absorption or scattering. We have the relation [7]

$$P_{\text{out}} = P_{\text{in}} \frac{\left(n_1^2 - n_s^2\right)}{\left(n_1^2 - n_2^2\right)} \tag{1}$$

where n_1 is the refractive index of the core, n_2 is the refractive index of the cladding, n_s is the refractive index of the sample surrounding the core, P_{in} represents the total power injected into the guided modes of the fibre from the source and P_{out} represents the power coupled to the fibre end after the sensing region to reach the detector. It is evident from this equation that power coupled to the fibre after the sensing region decreases linearly with the increase in n_s^2 [8]. Here, this result is exploited to construct a fibre optic refractive index based sensor to detect adulterants in coconut oil.

The amplitude $E(x)$ of the evanescent field decreases exponentially with the distance x from the core–cladding interface according to the equation

$$E(x) = E_0 \exp(-x/d_p) \tag{2}$$

where d_p is the penetration depth.

The penetration depth describes the distance from the interface where the intensity of the evanescent field has decreased to $1/e$ of the initial intensity E_0.

The magnitude of the penetration depth is given by

$$d_p = \frac{\lambda}{2\pi n_1\left[\sin^2\theta - \left(\frac{n_2}{n_1}\right)^2\right]^{1/2}} \tag{3}$$

where λ is the vacuum wavelength, θ is the angle of incidence and n_1, n_2 are the refractive index values of the core and the cladding, respectively. From equation (3) it is clear that the penetration depth d_p increases with the cladding refractive index, indicating an increase in the magnitude of the electric field present in the cladding medium and thus a reduction in the electric field within the core.

The normalized frequency (fibre V-parameter) is given by

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

where a is the core radius.

This equation shows that the V-parameter decreases when the cladding refractive index increases. Since the number of modes N propagating within the fibre is proportional to the square of the normalized frequency, it can be inferred that increasing the refractive index of the cladding reduces the number of modes propagating within the fibre. It can be concluded from the theoretical treatment that adulteration of coconut oil and the corresponding refractive index changes affect the higher order modes and these higher order modes can be used to detect the presence of adulterant oil in coconut oil [9–13].

3. Experimental setup

The experimental setup consists of a laser source, a side-polished fibre sensor head and a detector (figure 1). The contact area of the bent portion of the fibre with the sample is 7 mm × 0.5 mm. The laser source used for the investigation is an intensity stabilized 4 mW diode laser emitting at 670 nm. The laser beam is focused onto the sensor head. The output is measured from the other end of the sensor head using an optical power meter (Newport 1825C). The step index plastic optical fibre used (Super ESKA, SK-40) has a core diameter of 980 μm and a numerical aperture of 0.5. The core and the cladding refractive indices are 1.49 and 1.41, respectively. The core material is polymethylmethacrylate (PMMA) and the cladding is a thin layer of fluorinated polymer. The test samples for this investigation have been prepared by changing the concentrations of paraffin oil in a fixed volume of coconut oil. Studies were also carried out by mixing palm oil in a fixed volume of coconut oil. Here, paraffin oil and palm oil are used as adulterants. Sample mixtures of increasing refractive indices are prepared by taking increasing concentrations of paraffin oil and palm oil in coconut oil. The refractive indices of samples are measured using a multiwavelength Abbe refractometer (ATAGO DRM2). The refractive indices of pure coconut oil, paraffin oil and palm oil are found to be 1.449, 1.476 and 1.454, respectively.

Fabrication of the sensor head

The side-polishing of an optical fibre has been extensively studied and reported, and it is a very good method to access the evanescent field of the guided mode [14, 15]. For the fabrication of the sensor head we use a few centimetres of a multimode step index plastic optical fibre. To begin with an epoxy resin block is made and the fibre is inserted into the block. The resin block is manufactured in such a manner that the fibre sits inside it in a bent fashion. The bending provides added sensitivity to the sensing head by allowing more modes to get coupled to the sample placed on it. After the fibre is placed inside the resin block the top portion of it is polished by using abrasives. The polishing is continued until the top portion along with a portion of the cladding is peeled off. It is again polished by using finer abrasives. The polishing is done until a flat surface is obtained and enough power is coupled to the outside region. A glass sample holder is used to hold the sample over the sensing region. The whole assembly is made very compact so that only 0.5 ml of the sample is needed for the whole experimental investigation.

The intensity of the propagating electromagnetic field can be perturbed by the external medium present on the polished surface due to the penetration of the evanescent field into that medium. The propagating light output is sensitive to the refractive index of the surrounding medium.

4. Results and discussion

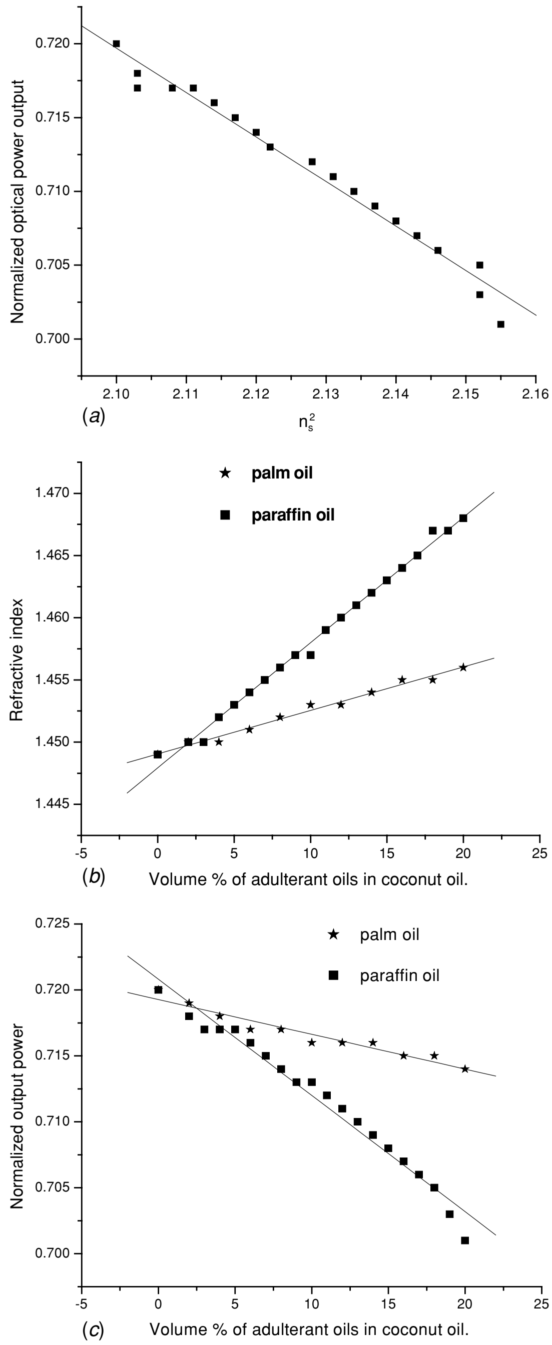

Figure 2. (*a*) Variation of the normalized output power P with n_s^2 of test samples of paraffin oil in coconut oil. (*b*) The refractive index of sample mixtures against the volume percentage of paraffin oil/palm oil in coconut oil. (*c*) Normalized output power against the volume percentage of paraffin oil/palm oil in coconut oil.

The results obtained on the basis of the experimental data are as follows. Figure 2(*a*) shows the plot of the normalized output power P as a function of n_s^2 of different concentrations of test samples of paraffin oil in coconut oil. To improve the reliability of our measurements the readings before and after the sample is added are noted each time and by taking the ratio we get normalized output. The graph shows linear behaviour as expected from equation (1). Figure 2(*b*) shows the variation in the refractive index with volume percentage of adulterants in coconut oil. Figure 2(*c*) shows the decrease in output intensity with the increase in the amount of adulterants. Since the adulterant oils used are colourless (low absorbance) at the wavelength of light being used (670 nm), the reduction in transmitted light intensity is only due to the refractive index variation. The refractive index variation occurs within the penetration depth d_p of the evanescent field of the guided wave. As the concentration of paraffin oil increases, the refractive index of the medium surrounding the sensor head increases, which results in a reduction of output power as illustrated by the theory. The slope of the calibration graph (figure 2(*b*)) gives the sensitivity of the sensor. From the plot it is clear that we can detect a minimum of 2% paraffin oil/palm oil in the test sample. To find the response time of the sensor, the output of the power meter is connected to a digital multimeter (HP 34401A) which in turn is interfaced to the computer using the

LabVIEW-7 software. A typical value of the response time is found to be 7 s.

5. Conclusion

Sensitive and versatile evanescent wave sensing systems featuring polished plastic optical fibre based sensor designs have been developed for the detection of trace amounts of adulterants in a coconut oil sample, which is one of the most commonly used edible oils in south Asia. The sensor exploits the evanescent field attenuation by refractive index modulation. Further it is concluded that the presence of tunnelling rays propagating in large diameter multimode fibres contributed an extra amount of energy available for evanescent field modulation. This side-polished fibre-based device which acts as a refractometer can not only differentiate chemicals based on their refractive index, such as palm oil/paraffin oil, but it can also act as a concentration indicator of a particular chemical solution. The observed sensitivity is almost linear and the detection limit is 2% (by volume) paraffin oil/palm oil in coconut oil. The developed sensor is user-friendly and reusable allowing instantaneous determination of the percentage concentration of adulterant in a coconut oil sample without involving any chemical analysis.

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