Examination of Adulteration of Edible Oils at the Wavelength of 660nm using a U–Shaped Sensing Element Based Extrinsic Fiber Optic Sensor

S. Srinivasulu, S. Venkateswara Rao

ABSTRACT: Edible oils such as groundnut oil and coconut oil etc, play a vital role in a consumer applications. These oils are used as compulsory ingredient in almost all culinary items large scale in the major part of the world. Therefore the study of purity of these oils becomes essential in order to maintain good health and hygiene of the consumers across the world. A novel approach has been adopted to develop an advanced fiber optic sensor to study the adulteration of coconut and groundnut oils more accurately by using U–shaped glass element based extrinsic fiber optic sensor in the present work. A U–shaped glass rod having specific geometrical parameters is used as an extrinsic sensing probe, which is connected in between a source operating at the wavelength of 660nm and an optical power detector by using two PCS fibers of 200/230µm. For the study of adulteration of edible oils two cheap oils i.e., paraffin oil and palm oil have been selected and mixed at different ratios and are introduced into the sensing region one after the other. A gradual decrease in the optical output power has been observed in the output detector, when the mixtures with increased cheap oil introduced around the sensing element. Thus, a relationship can be formed between the powers observed at output to the amount of cheap oil mixed in pure oils. Calibrated curve can be drawn between power reaching at the output end of the sensor and refractive index of the mixtures of pure oils adulterated with cheap oils, which can be used to measure the unknown amount of cheap oil in pure edible oil at room temperature accuracy of 10^{-5}.

Keywords: Adulteration, Calibrated curve, Coconut oil, Groundnut oil, Palm oil, Paraffin oil.

II. INTRODUCTION

In 1970's when optical fiber technology was developing to implement in communication system, it was observed that the propagation characteristics of optical fibers are sensitive to certain internal and certain external perturbations [1–6]. The internal perturbations occur due to the presence of micro structural variations in the glass matrix, presence of hydrogen, hydroxyl ion, voids, impurities, change in refractive index, etc. The external perturbations occur due to variation in temperature, pressure, macro-bend, micro-bend, humidity, etc [7–11]. On the observation of sensitivity of transmission characteristics of optical fibers a new though began in scientific world, to develop various kinds of sensing systems [12–19]. These new sensor systems have many advantages comparing with the existing sensors, such as

- Offers large bandwidth (10^{15}Hz), due to which, they can be multiplex to detect the various parameters at a time.
- They are cheap in cost due to abundant availability of raw material sand.
- Exhibits immunity to RFI and EMI.
- They are portable and light in weight.
- Due to their inertness they can be used at hazardous environment i.e., in the presence of nuclear radiation field.
- They can be used to measure the parameters from otherwise inaccessible regions due to their small size.
- As they are non-reactive they can be used in the measurement of chemical parameters during their chemical reactions.
- They can be used in the OTDR (optical time domine reflectometer) to measure the parameters that are distributed randomly at different regions.

Due to these innumerable advantages, fiber optic sensors with different design schemes depending upon the parameter to be measured, have been developed and successfully implemented across the world for the last few decades [20–22]. In the beginning they were implemented as hydrophones in military and defence applications, later on they are introduced into medical field, industry, food technology and consumer application, etc., to measure various parameters ranging from temperature, humidity, refractive index, pressure, vibration, strain, magnetic field, electric field, etc [23–27]. The optical fiber sensing technology in the recent years has taken advancement with respect to their different schemes of geometry, fabrication, design to measure various parameters [28–33]. Among many modulation schemes, the intensity modulation scheme occupies wide range

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of fiber optic sensors, which are compatible with the multimode optical fiber operation [34–37]. Basically optical fiber sensors act as transducers to transform various kinds of external perturbations into an optical power signal, and thus permit the detection and monitoring of several parameters.

As the groundnut oil and coconut oils are frequently and widely used as ingredients in the food related items in the most of regions across the world, they are prone to adulteration due to their low supply, high cost and high demand throughout the year. Most of the cheap oils that are used as adulterants in the edible oils are paraffin oil, palm oil, etc. Unless the adulterations of these pure oils with cheap oils are detected accurately, the usage of these edible oils in the culinary items will severally and adversely affect on the heath and hygiene of the consumers across the world.

II. EXPERIMENTAL DETAILS

The constitution of the experimental setup of the sensor consists of a light source operating at the wavelength of 660nm, a power detector compatible to read the light reaching from the source and a uniform U–Shaped borosilicate glass rod, connected between source and detector at both the ends using two PCS fibers of 200/230µm by proper connectroization. Experimental arrangement of U–shaped sensing element based extrinsic fiber optic sensor and geometrical parameters of U–shaped glass sensing element has been shown in fig. [1&2].

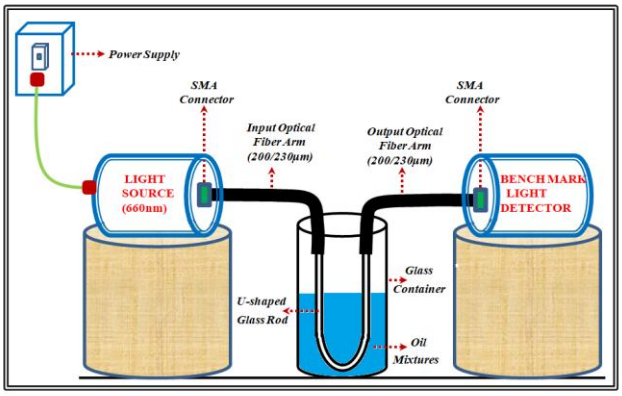
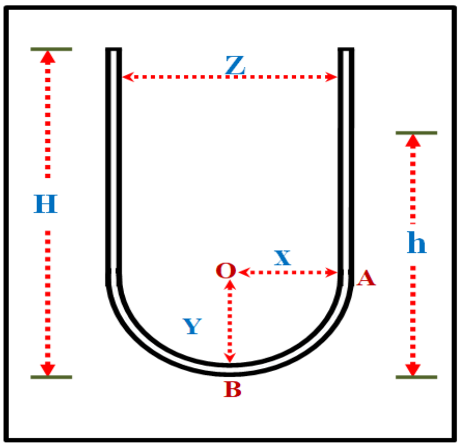


Fig.-1: U–shaped sensing element based extrinsic fiber optic sensor setup



Thickness of rod	0.5mm
Total height of the glass rod(H)	40mm
Height of the glass rod immersed in liquid(h)	1cm, 2cm & 3cm
Width between two prongs(Z)	5mm
Radius of the Curvature(X)	2.5mm
Depth of the Curvature(Y)	2.5mm

Fig.-2: Geometrical Parameters of U–shaped sensing element

With this arrangement of sensor, it is proposed to study the adulteration of coconut oil and groundnut oil using a light source of fixed operating wavelength of 660nm and at different depths of immersions of sensing element into the oil mixtures of various ratios. The light emitted from the source will be injected into a insensitive part (input PCS fiber), transmitting without any attenuation and couples into the input end of the sensitive part of the sensor (U–shaped glass rod), wherein the light is subjected to some loss and then couples out into the other insensitive part (output PCS fiber), then finally enters into light detector. The oil mixtures are prepared by taking a fixed quantity 10ml of pure coconut oil mixed with palm oil increasing in steps of 2ml each time. In the first case by immersing the U–shaped sensing element into a beaker consisting of 10ml pure coconut oil, the light is launched from the source and the power reaching the detector is noted at a fixed depth of immersion of 1cm, this procedure is repeated for all other mixtures (10ml: 2ml, 10ml: 4ml, 10ml: 6ml, 10: 8ml, 10ml: 10ml) of coconut oil and palm oil at depth of immersion of 1cm.

In the second case by increasing the depth of immersion to 2cm, the output powers are noted for all the mixtures maintaining around the sensing element. In the third case, the depth of immersion increased to 3cm and again maintaining all mixtures around the sensing element, the light is launched from the source and output powers corresponding to all mixtures are noted and tabulated. To come to a conclusion on the study of adulteration of oils, another cheap oil i.e., paraffin oil is used as cheap oil in the adulteration of coconut oil and the experiment is carried out again and reading of both output powers and refractive indices are noted and recorded. The concentrations of different ratios of oil mixtures are determined in terms of their refractive index by using a “Digital Refractometer of modal number RX7000i”.

To ascertain the results obtained by adulterating the coconut oil with both palm oil and paraffin oil, a new set of adulterated oil mixtures consisting of groundnut oil mixed with both palm oil and paraffin oil, again the experimental study has been taken up and resultant of variations in the output powers and refractive indices are noted down and tabulated.

III. RESULTS AND DISCUSSION

Relation between output power and concentration of oil mixtures: From the above recorded values of refractive indices and output powers, it is observed that the output power decreases linearly as the concentration and hence the refractive index of oil mixtures around the sensing element increases. The relationship between output power with respect to refractive index of core (n_1), refractive index of cladding (n_2), refractive index of oil mixtures (liquid) surrounding the sensing probe (n_l), total input power injected into fiber from the source (P_{in}) mathematically can be expressed in the form of an equation as

$$P_{out} = \frac{P_{in}[n_1^2 - n_l^2]}{[n_1^2 - n_2^2]}$$

These results are represented graphically in fig. [3–14].

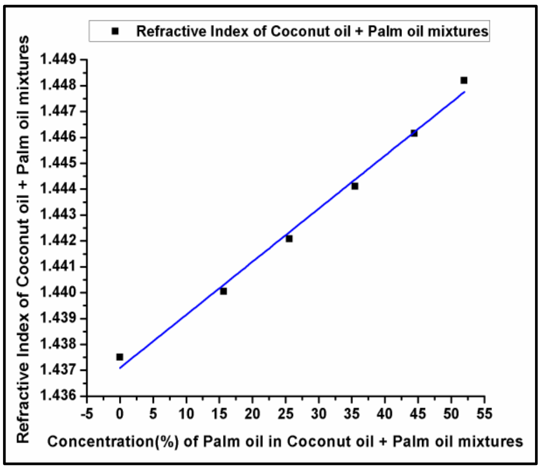


Fig.-3: Relation between Concentration (%) of Palm oil Vs Refractive Index of Coconut oil + Palm oil mixtures

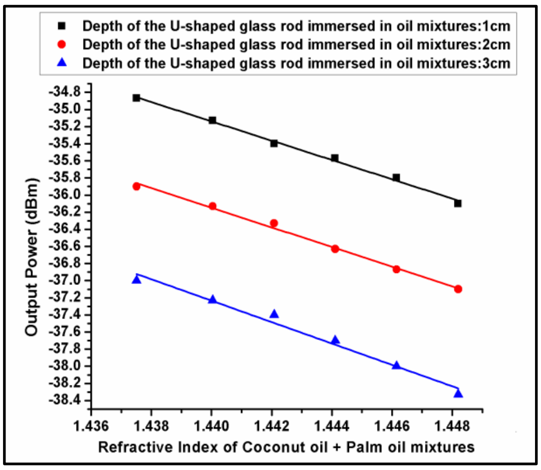


Fig.-4: Relation between Refractive Index Vs Output Power (dBm) of Coconut oil + Palm oil mixtures

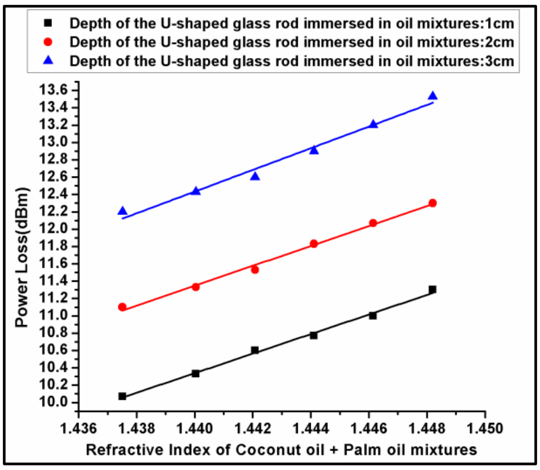


Fig.-5: Relation between Refractive Index Vs Power Loss (dBm) of Coconut oil + Palm oil mixtures

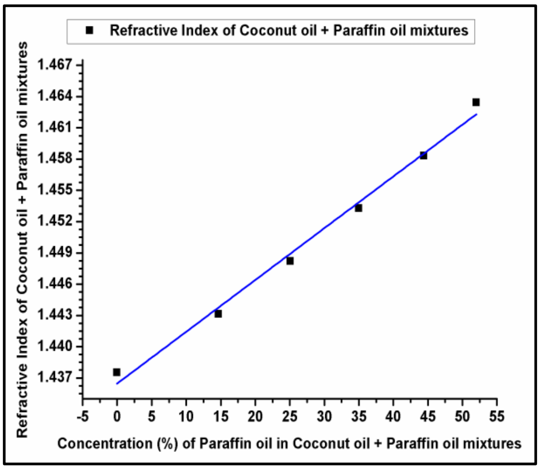


Fig.-6: Relation between Concentration (%) of Paraffin oil Vs Refractive Index of Coconut oil + Paraffin oil mixtures

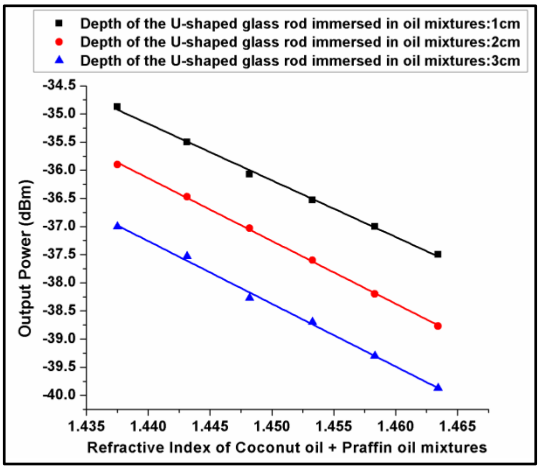


Fig.-7: Relation between Refractive Index Vs Output Power (dBm) of Coconut oil + Paraffin oil mixtures

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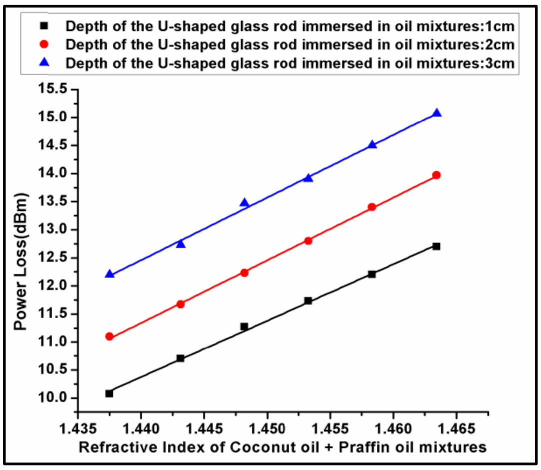

Fig.-8: Relation between Refractive Index Vs Power Loss (dBm) of Coconut oil + Paraffin oil mixtures

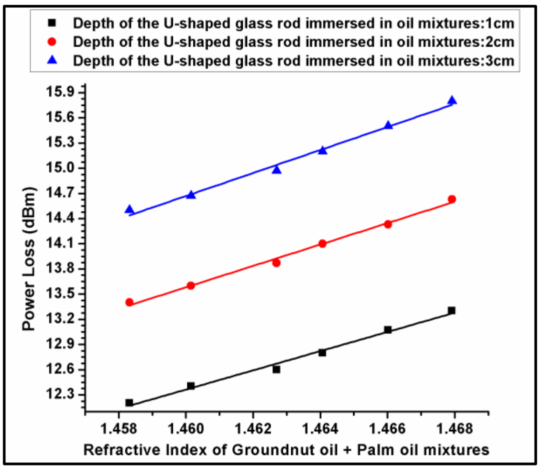

Fig.-11: Relation between Refractive Index Vs Power Loss (dBm) of Groundnut oil + Palm oil mixtures

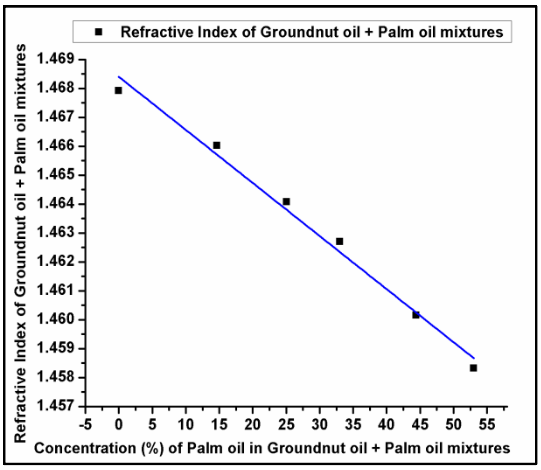

Fig.-9: Relation between Concentration (%) of Palm oil Vs Refractive Index of Groundnut oil + Palm oil mixtures

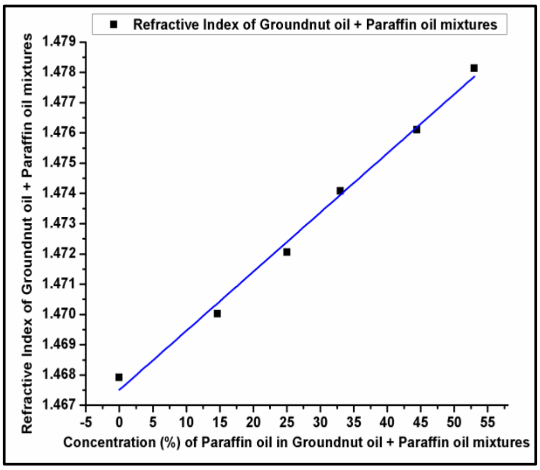

Fig.-12: Relation between Concentration (%) of Paraffin oil Vs Refractive Index of Groundnut oil + Paraffin oil mixtures

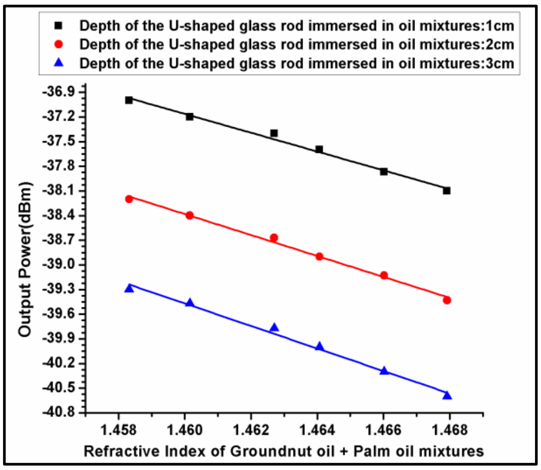

Fig.-10: Relation between Refractive Index Vs Output Power (dBm) of Groundnut oil + Palm oil mixtures

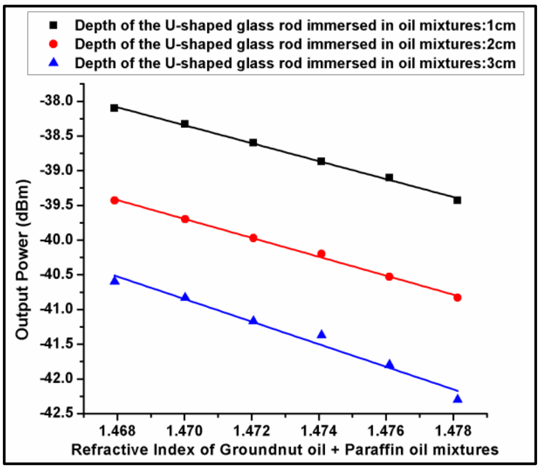

Fig.-13: Relation between Refractive Index Vs Output Power (dBm) of Groundnut oil + Paraffin oil mixtures

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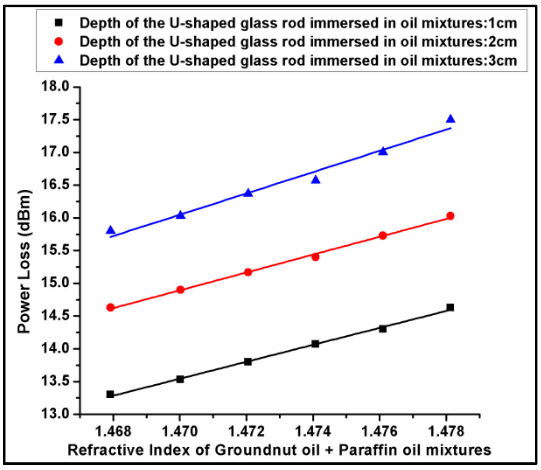

Fig.-14: Relation between Refractive Index Vs Power Loss (dBm) of Groundnut oil + Paraffin oil mixtures

Variation of electric field with respect to depth of penetration: During the course of transmission of light in the sensing zone, a fraction of light enters into the liquid cladding as an evanescent wave into certain distance from the core and cladding interface, can be termed as penetration depth or height of penetration (h_p), which increases with the increase in contraction of liquid cladding. The mathematical form of relation for 'h_p' as a function of angle of incidence of light 'θ', wavelength of light 'λ', refractive index of core 'n_1' and refractive index of liquid cladding 'n_l', is given by

$$h_p = \frac{\lambda}{2\pi n_1}\left[\sin^2\theta - \left(\frac{n_l}{n_1}\right)^2\right]^{-1/2}$$

The electric filed component of light, which penetrates into the liquid cladding, depends upon the depth of penetration of light into the liquid cladding. The relation between electric field E(z) of light that is penetrating into liquid as a function of distance 'z' from the core-cladding interface and depth of penetration or height of penetration (h_p) is given by

$$E[z] = E\exp\left(\frac{-z}{h_p}\right)$$

The origin for the variation of output power related to variations in the concentration in liquid is the "process of polarization" that take place in the particles of the liquid compounds.

Variation of output power with respect to dielectric constant: The macroscopic quantities of the liquid medium, i.e., refractive index is directly related to a microscopic quantity, i.e., dielectric constant. Dielectric constant inturn can be obtained by determining the three kinds of polarizabilities ($\alpha_e + \alpha_o + \alpha_i$). The relationship between dielectric constant and refractive index is "k or $\varepsilon_r = n^2$". As refractive index and dielectric constant have direct relationship, the output power variation can be made as a function of dielectric constant of liquid cladding as is represented graphically in fig. [15–22].

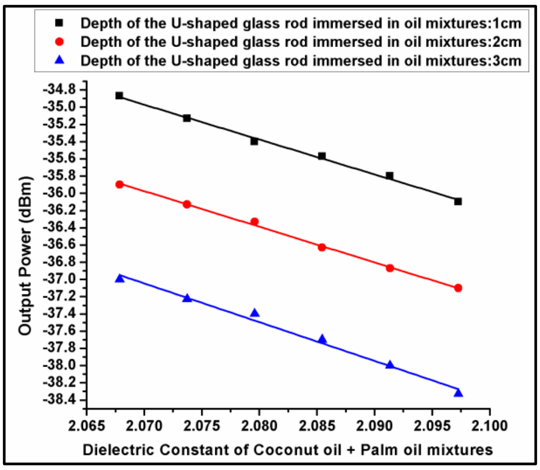

Fig.-15: Relation between Dielectric Constant Vs Output Power (dBm) of Coconut oil + Palm oil mixtures

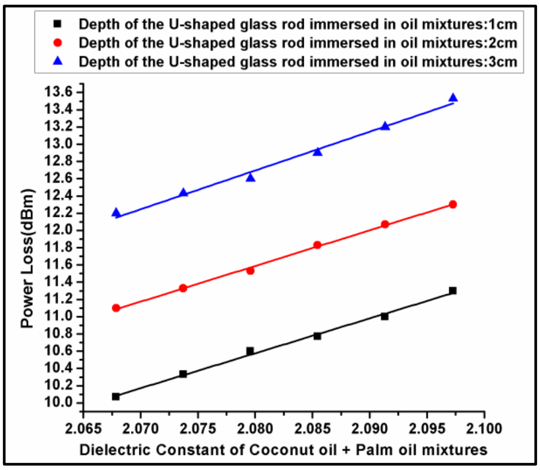

Fig.-16: Relation between Dielectric Constant Vs Power Loss (dBm) of Coconut oil + Palm oil mixtures

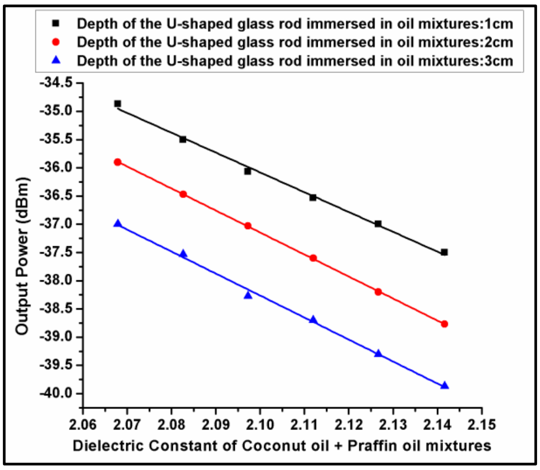

Fig.-17: Relation between Dielectric Constant Vs Output Power (dBm) of Coconut oil + Paraffin oil mixtures

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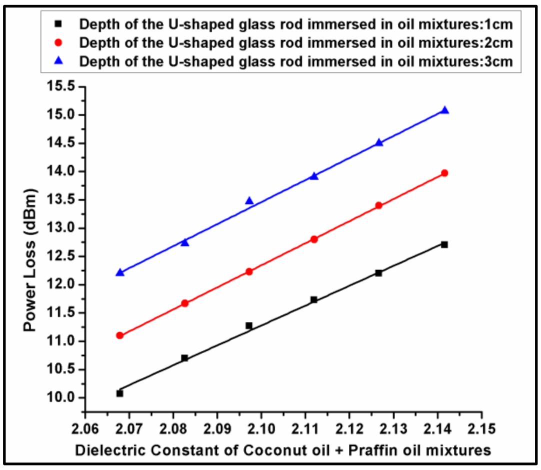

Fig.-18: Relation between Dielectric Constant Vs Power Loss (dBm) of Coconut oil + Paraffin oil mixtures

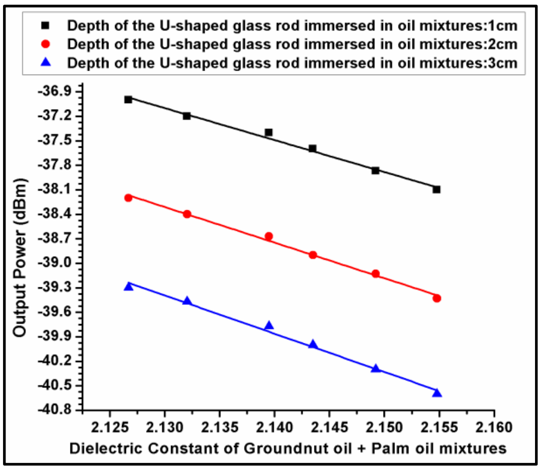

Fig.-19: Relation between Dielectric Constant Vs Output Power (dBm) of Groundnut oil + Palm oil mixtures

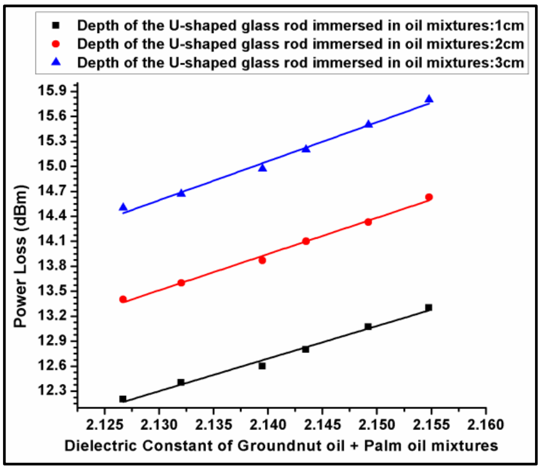

Fig.-20: Relation between Dielectric Constant Vs Power Loss (dBm) of Groundnut oil + Palm oil mixtures

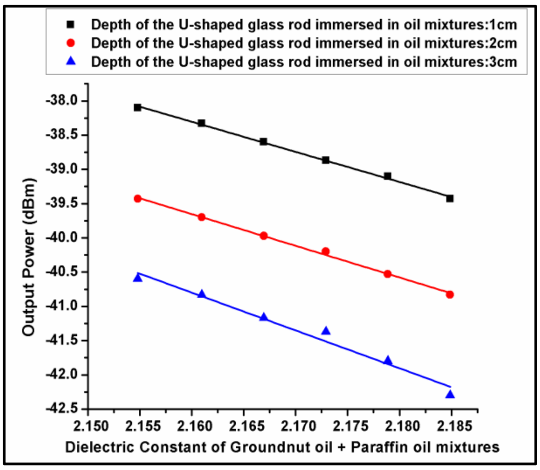

Fig.-21: Relation between Dielectric Constant Vs Output Power (dBm) of Groundnut oil + Paraffin oil mixtures

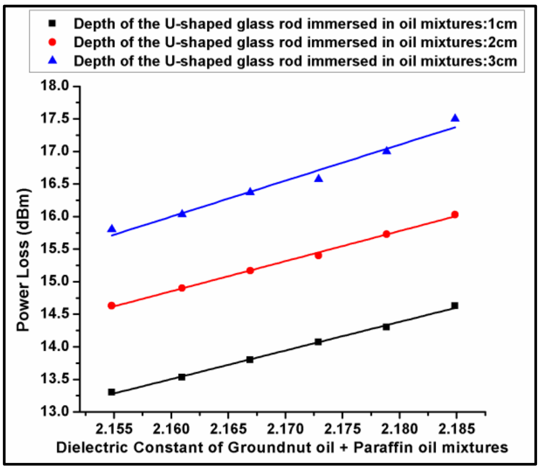

Fig.-22: Relation between Dielectric Constant Vs Power Loss (dBm) of Groundnut oil + Paraffin oil mixtures

CONCLUSION

An advanced multimode extrinsic fiber optic intensity modulated sensor has been designed and calibrated, operating at the wavelength of 660nm, at room temperature and having a dynamic range from $1.437n_D$ to $1.478n_D$. Hence, with this sensor design, adulterations of pure coconut and groundnut oils adulterated with unknown quantities of palm oil and paraffin oil can be determined. The relationship between refractive index and dielectric constant with respect to output power and power loss has been studied. The adulteration of coconut and groundnut oils also studied by considering different depth of immersions and concluded that the output power decreases with increasing the depth of immersion, as the increase in the length of interaction of liquid with the liquid cladding. The sensor is

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highly reliable, rugged and offers high sensitivity, comparing to the presently available sensors in the market, expected to play a major role in the consumer applications.

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