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Original Research Article

A simple approach of optical fiber-based sensor for liquid turbidity measurement

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ABSTRACT
The paper deals with a systematic study of optical fiber-based turbidity sensor. Intensity modulated sensing mechanism has been incorporated and determination of sensitivity has been confided on output signal sustain some loss. Three different mediums, such as, glucose mixed with water, milk mixed with water, soil mixed with water have been used as sample. Beer-Lambert law has been implemented to study the transmittance and absorbance of the light while passing through different concentration of liquid sample. The output power range, sensitivity and resolution of the reported sensor have been achieved as 1.82 μW, 0.091 μW/NTU and 0.109 NTU respectively. Various future prospects of the basic experimental set-up have been estimated, specially using its sensing features for detection of liquid food quality. Finally, a blueprint of fiber optics turbidimeter has been presented with simple, repeatable measurement technique.

1. Introduction

Turbidity is decrease of transparency of liquid sample due to availabilities of suspended or dissolved particles. Light passing through such turbid sample can be scattered or absorbed. Turbidimeter is the instrument that can measure the said Turbidity [1]. Advanced photodetector or photosensor can sense the scattered or absorbed light due to small change in turbidity. Existing electronics sensors are unable to detect the scattered light which become unrecognized in electronic noise [2]. The simplest, efficient way of measurement of turbidity is detection of the absorption light intensity passing through the turbid medium. There are two more measurement techniques available, one is Nephelometers, which detects scattered light partially at angle 90° from the incident beam and other is backscattering which is detection of scattered light at an angle between 90° to 180° [3]. World Health Organization (WHO) has published the importance of regular monitoring of Turbidity in water for regulators and water suppliers. According to WHO Guidelines for Drinking-water Quality, high turbidity in source waters encourage disinfection, and ideally safe range of turbidity is <1 NTU [4]. For domestic use, the acceptable level of turbidity of water ranges between 5 to 25 NTU according to international standard [5].

Recently optical fiber sensor (OFS) technology has been overwhelmed around world in parallel with the optoelectronic and fiber optics communication industries. There are numerous advantages of optical fiber if it is used as turbidity sensor, such as high speed, rust resistance, and comparatively cost effective [6-11].

In this present study, we have proposed optical fiber-based turbidity sensor which is working on intensity modulated sensing mechanism. Three different samples (glucose mixed with water, milk mixed with water, soil mixed with water) have been used to study absorbance, % transmittance and variation of output power with turbidity of the three samples. Experimental set-up has been arranged with visible range light source, optical fiber as light waveguide, sample and visible range photodetector with power meter. Performance parameters of the proposed lab scale turbidity meter has been tabulated.

2. Theoretical background

A. Optical properties of turbid media

There are many properties in turbid media such as viscosity, transmittance, surface tension, density etc. which can be determined by optical sensing measurements. But now in our study we are interested to determine the absorbance and the % transmittance of various turbid liquids. In spectroscopy, the absorbance of a medium is a logarithmic ratio of the radiation falling upon a material, to the radiation transmitted through a material. Absorbance measurements are often carried out in analytical chemistry. The transmittance of a medium is defined as the ratio of the radiation transmitted through the medium to the radiation falling upon it. Hence multiplying 100 to this ratio, the parameter known as the % transmittance of the medium can be obtained [12].

B. Beer-Lambert law and optical parameters

The law states that there is a logarithmic dependence between the transmission (or transmissivity), T, of light through a substance and the product of the absorption coefficient of the substance, α, and the distance the light travels through the material (i.e., the path length), ℓ. The absorption coefficient can, in turn, be written as a product of either a molar absorptivity (extinction coefficient) of the absorber, ε, and the molar concentration c of absorbing species in the material, or an absorption cross section, σ, and the (number) density N of absorbers.

For liquids, Transmission is written as:

$$T = \frac{I}{I_0} \tag{1}$$

The incident light beam is I_0, transmitted through medium light beam *I*.

Percentage transmittance is described as

$$\%T = \left({}^{I}/_{I_0} \right) \times 100 \tag{2}$$

The transmission (or transmissivity) is expressed in terms of an absorbance which, for liquids, is defined as

$$A = -\log_{10}\left(\frac{I}{I_0}\right) = -\log_{10} T \tag{3}$$

The absorbance has a logarithmic relationship to the transmittance.

The Bear-Lambert law is a linear relationship between the absorbance and the concentration, molar absorption coefficient and optical coefficient of a solution.

$$A = \varepsilon c l \tag{4}$$

where A is absorbance, ($\mu^{-1}\text{cm}^{-1}$), c is molar concentration (moles L^{-1}) and l is optical path length (cm).

3. Experimental details

A. Experimental set-up

A simple method is described here to estimate the absorbance of various turbid mediums by Beer-Lambert law with fiber optic sensor. The experimental set up has been arranged using following apparatus as shown in Fig.1.

- Fiber used for this purpose is Single Mode fiber (SFS 8 /125Y)
- Laser Diode (632 nm) (Holmarc DL series)
- One MO, light condenser, fiber holder, XYZ stand etc.
- Visible range photo detector with power meter
- Turbid mediums: Glucose mixed with water, Milk mixed with water, Soil mixed with water

Light is collecting through MO from laser source and it is passing through optical fiber(incident) small section. In the beginning, intensity of the incident light (I_0) is measured by photodetector for reference sample deionized water. Afterward, the turbid medium sample container has been placed in adjusted height next to incident optical fiber section. The receiver optical fiber is arranged in suitable position using optical fiber stand after sample. Then, the photodetector has been placed to collect transmitted light (*I*) from the extreme end of the receiver optical fiber. It is shown in Fig.1 that Z is the distance between extreme end of optical fiber (Receiver) and photo detector head. When light passes through the turbid medium, most of the photons get absorbed by the suspended impurities in the medium. Absorbance and % transmittance of turbid liquid can be measured by detecting the intensity of laser light incidents on the medium and the intensity of the light transmitted through it.

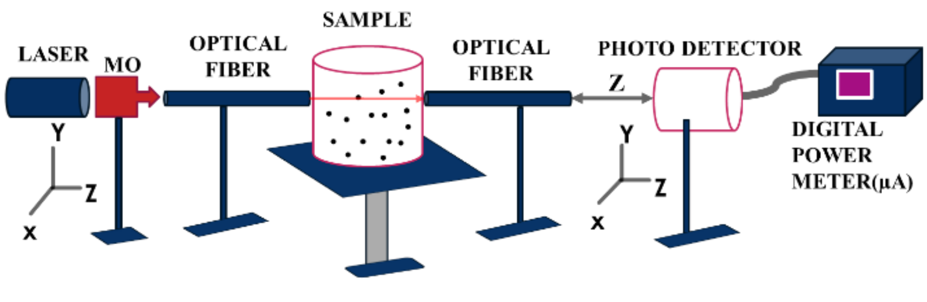
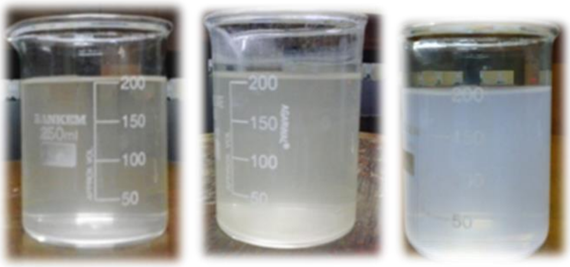


Figure 1: Schematic diagram of the experimental setup.

B. Turbid medium sample preparation

Three turbid mediums are prepared for experiment and it has been kept in glass beaker which is highly transparent to the visible range light and attenuation due to material of sample container can be ignored. 7 gm glucose (92% carbohydrate) of a well reputed brand is used in 200 ml DI water to produce a turbid medium (35mg/l=105 Nephelometric Turbidity Units or NTU). 0.5 ml milk (fat 1.5% and SNF 9.0%) of a well renowned company is been added in 200 ml DI water to produce a turbid medium. A sufficient amount of soil (in powder form) is been mixed up with DI water to produce a turbid medium.

Transmitted light has been detected by photodetector for three samples respectively for same variation of Z and corresponding power has been measured using digital power meter. The measured power is normalized with respect to reference power incident on power meter for reference sample (DI water) with corresponding Z values.



(a) (b) (c)

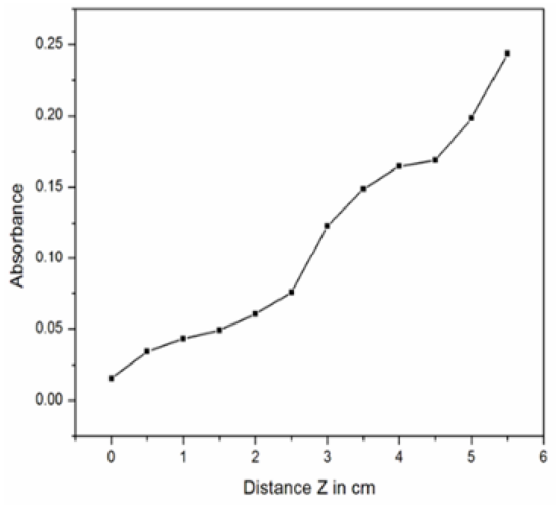
Figure 2: (a) Turbid medium of glucose; (b) Turbid medium of soil; (c)Turbid medium of milk.

4. Results and discussion

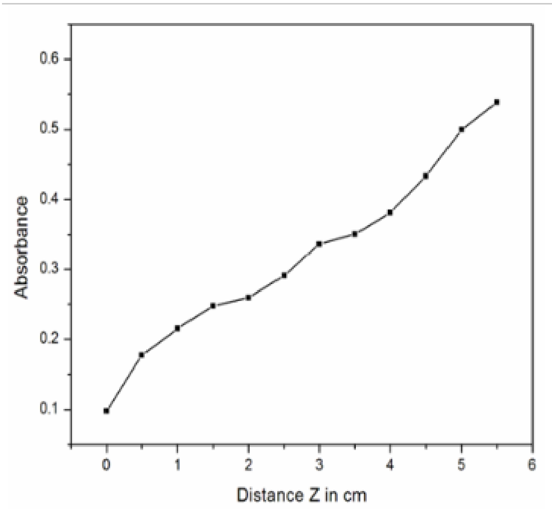
The transmission power is collected by the detector and it is measured for different values of Z, and normalized with respect to the corresponding power when the turbid sample is replaced by reference sample (i.e., DI water or solvent with which the turbid medium is prepared).

A. Absorbance & %Transmittance study

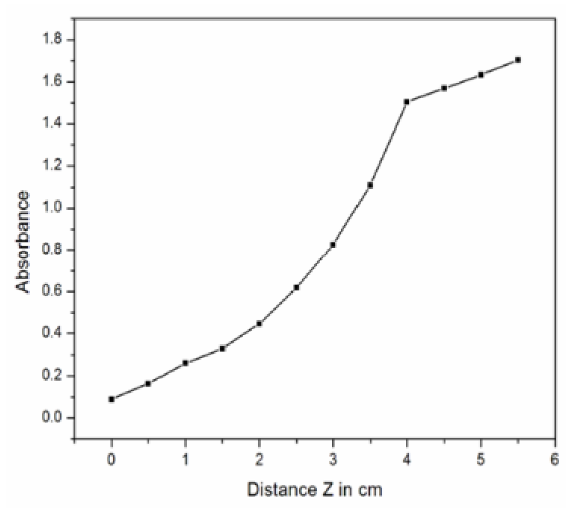
Fig. 3(a, b and c) shows the three curves for different turbid mediums (glucose, soil and milk) for same variation of Z. These curves show that power absorbance of the turbid medium increases with Z. Whenever the absorbance increases, turbidity also increases. As absorbance increases, it means that impurity of the fluid is also getting higher.



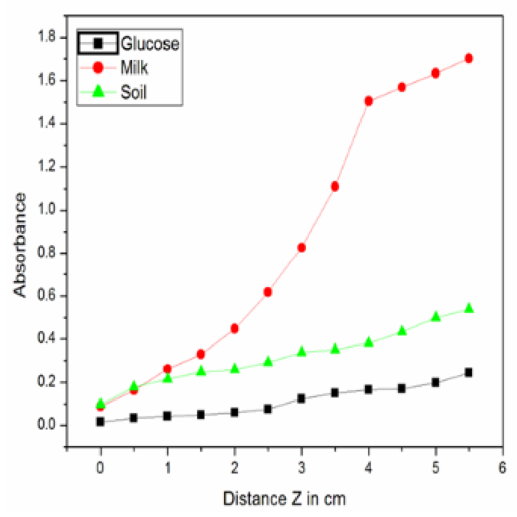
(a)



(b)



(c)



(d)

Figure 3: (a) Absorbance vs. Distance curve for turbid medium of glucose; (b) Absorbance vs. Distance curve for turbid medium of soil; (c) Absorbance vs. Distance curve for turbid medium of milk; (d) Comparative study for three turbid mediums.

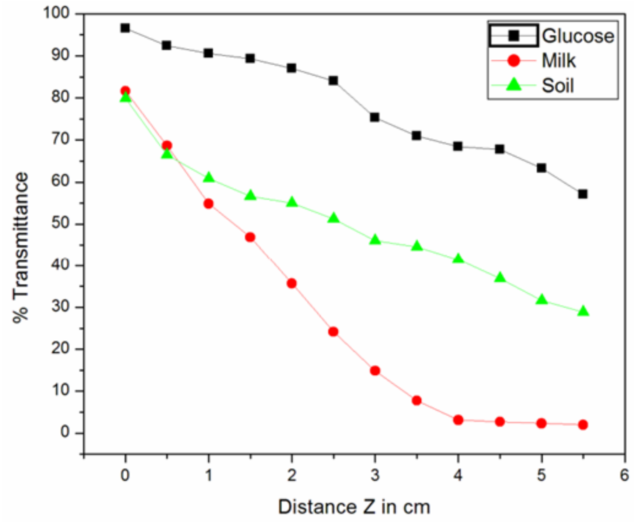


Figure 4: % Transmittance vs. distance curve for three turbid mediums.

Fig. 3. (d) and Fig. 4 are describing comparative study of absorbance and % transmittance versus distance Z for three mediums respectively.

B. Calibration of Turbidity sensor

Fig. 5 is depicting the variation of transmitted power (in μW) with varying concentration (in NTU) of reference and three sample respectively.

1 mg/l = 3 Nephelometric Turbidity Units (NTU) = 1 ppm

The conversion relationship between NTU into mg/l for Alberta Transportation's Turbidity specification is given by the expression [13,14];

$$y = 3.421x \quad (5)$$

where y = Total suspended solids (TSS) (mg/l),
x = Turbidity (NTU).

It is clear that variation in output power of the sensors is inversely proportional to the level of turbidity of liquid medium. The turbidity (NTU) of the liquid medium is increasing with the output power decreasing. It is happening because of increasing absorbance with turbidity of medium.

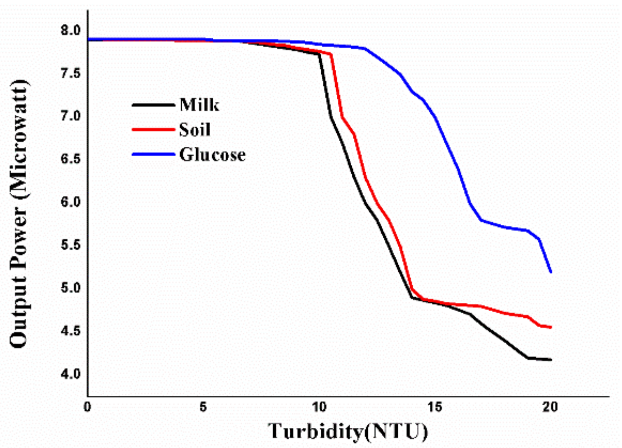


Figure 5: Variation of transmitted output power(μW) with different turbidity (NTU).

C. Performance parameters of the proposed sensor

Performance parameters of the proposed optical fiber-based turbidity sensor, such as, output power range values, sensitivity, and resolution have been analyzed from the experimental data.

The following formula has been used for calculation of performance parameters [15-17].

Output power range

$$\Delta = V_{max} - V_{min} \quad (6)$$

With V_{max} as output voltage at maximum load and V_{min} as output voltage at minimum load.

Sensitivity

$$S = \frac{V_{max} - V_{min}}{N_{max} - N_{min}} \quad (7)$$

The sensor resolution is the value of the smallest quantity measurable by turbidity sensor.

Resolution

$$R = \frac{N}{S} \quad (8)$$

With N as the smallest scale of an optical power Meter used is 0.01 μW (measuring corresponding current).

Table 1: Performance parameters of proposed turbidity sensor.

Output power range	Sensitivity	Resolution
1.82 μW	0.091 μW/NTU	0.109 NTU

5. Conclusions

An effort has been made to design a simple optical fiber-based turbidity sensor which is reported in this paper. Beer-Lambert law has been implemented to analyze working principle of the proposed intensity modulated sensor. Various concentrations of three samples of turbidity mediums (glucose mixed with water, milk mixed with water, soil mixed with water) have been prepared and used to study absorbance and % transmittance. The variation of output power (μW) of the transmitted light with turbidity (NTU) of the medium has been realized. Finally, performance parameters of the described optical fiber-based turbidity sensor have been reported. The output power range, sensitivity and resolution of the reported sensor are 1.82 μW, 0.091 μW/NTU and 0.109 NTU respectively. The proposed turbidity sensor could be low cost, stable and re-usable for liquid medium. There are enormous future prospects of the proposed lab-scale turbidity meter. It could be commercialized to detect liquid food impurities, where the set-up might be modified in reflection mode.

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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