Fiber optic Sensors for Measurement of Refractive Index of Liquids by Using Fresnel Ratio Meter

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ABSTRACT

In this research was used a single-mode coupler fiber optics to measure liquid refractive index (Sugar). Refractive index (RI) was studied by changing the temperature at 850nm wavelength. The calculated experimental RI result was compared with the measured results. They were almost identical and reflection Fresnel ratio have been adopted to measure the refractive index. Reflection signals from air-fiber was produced change in path length interface to obtain the refractive index. This fiber sensor was measured the refractive index change of sugar concentration solution.

Key words: refractive index, fiber sensor, Fresnel reflection, Fresnel ratio.

1. INTRODUCTION

The measurement of the RI of liquid is an important work in engineering and science. Transmission or reflection detections near critical angles related to total internal reflection are common methods in refractive index measurements. Commercial Abbe refract meters modified Abbe refract meters are instruments for measuring the index of a specimen using these methods. Refractive indices of turbid colloidal fluids were measured by the transmission method near the critical angle [1].

RI is an important characteristic constant of optical materials. Although there are some techniques that have been proposed for measuring RI, almost all of them are related to the measurement of light intensity variations [1–3]. However, the stability of a light source, the scattering light, the internal reflection, and other factors influence the accuracy of measurements and decrease the resolution of results [4]. Refractive indices of absorbing and turbid were measured by reflection methods near the critical angle [5]. For absorbing and heterogeneous materials there are analyses of RI errors for critical angle and Brewster angle methods. When Refractive indices of various liquids were measured, we use a fiber optic technique based on the Fresnel reflection of the light tip of the fiber for the measurement of RI for different fluids at 850nm wavelength.

2. PRINCIPLE OF OPERATION

The principle of this technique is based in two pieces of a single-mode glass fiber optic. The first fiber transfer the light to measure liquid to be refracted coefficient, while the second fiber works as a medium to transport carrier light to be merged when the window enclosed. The comparing of reflected signal from the liquid-fiber interface a power (P_s) is proportional to \( (n_f - n_l)^2 / (n_f + n_l)^2 \) with those reflected from the air-fibre induced power (P_i) is proportional to \( (n_a - n_l)^2 / (n_a + n_l)^2 \). \( n_a \) and \( n_l \) are the indices of air and liquid and \( n_f \) is the reflective index of single mode fiber waveguide. The ratio \( R=P_s/P_i \) is given by

\[
R = \frac{(n_f - n_a)/(n_f + n_a)^2}{(n_f - n_l)/(n_f + n_l)^2} \tag{1}
\]

Where

\[
R = \left( \frac{n_a - n_l}{n_a + n_l} \right) \times \frac{1}{\sqrt{R}} \tag{2}
\]

The refractive index of air \( n_a = 1.000273 \) [6]

\[
n_l = n_f \left\{ \frac{(1 - 5)}{(1 + 5)} \right\} \tag{3}
\]
To measure a refractive index by finding measuring the proportion of Fresnel reflection of the two signals. When subjected fiber to the air, the reference urges the ability of at a way out magnifier be proportional to the reflection of the Fresnel air at the contact surface (air-fiber). Similarly, when a fiber liquid, the signal is proportional to the Fresnel reflection from powers two ability of the refractive index can be calculated be measured. The dispersion relation for silica is given by the Sellmeier formula [7].

\[
 n_{s1}(\lambda) = \sqrt{1 + \sum_{i=1}^{3} A_i \cdot \frac{\lambda^2}{\lambda^2 - \lambda_i^2}} \quad (4)
\]

With \( A_i = \begin{cases} 0.6961663, & 0.4079426, & 0.8974794 \end{cases} \)

\[
 n^2 - 1 = \frac{A_1 \lambda^2}{\lambda^2 - \lambda_1^2} + \frac{A_2 \lambda^2}{\lambda^2 - \lambda_2^2} + \frac{A_3 \lambda^2}{\lambda^2 - \lambda_3^2} \quad (5)
\]

Table 1: Represents Sellmeier transactions [8].

<table>
<thead>
<tr>
<th>Pure silica</th>
<th>0.6961663</th>
<th>0.4079426</th>
<th>0.8974794</th>
<th>0.068043</th>
<th>0.1162414</th>
<th>9.896161</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5m/o GeO\textsubscript{2} + 86.5m/o SiO\textsubscript{2}</td>
<td>0.73454395</td>
<td>0.4271082</td>
<td>0.8210339</td>
<td>0.08697693</td>
<td>0.1119519</td>
<td>10.84654</td>
</tr>
<tr>
<td>7.0 m/o GeO\textsubscript{2} + 93.5 m/o SiO\textsubscript{2}</td>
<td>0.6869829</td>
<td>0.4447950</td>
<td>0.7907351</td>
<td>0.07808758</td>
<td>0.1155184</td>
<td>10.43662</td>
</tr>
<tr>
<td>4.1m/o GeO\textsubscript{2} + 95.9m/o SiO\textsubscript{2}</td>
<td>0.68671774</td>
<td>0.4348150</td>
<td>0.8965658</td>
<td>0.07267518</td>
<td>0.1151435</td>
<td>10.00239</td>
</tr>
</tbody>
</table>

From Table 1 and equation (4) we get \( n_i = 1.4696 \) and from equation (3), the RI of liquid \( n_l \) can then calculated from \( n_i \) and \( n_a \) and the measured \( R \) using normalized power.

3. EXPERIMENTAL WORK

The measurement was performed by our fiber optic Fresnel ratio meter, a block diagram of experimental work is shown in figure 1. The operation of the Fresnel ratio meter is described as follows:

An optical beam, derived from a laser diode or LED driven by electronic circuit is launched into a fibre. The optical beam is divided into two paths by a 1 × 3 single-mode fused fiber coupler. The fiber coupler chosen has a maximum polarization-dependent loss of 0.02 dB.

The short path serves as the probe and the long path (reference fibre), that is 1 Km in length serves as a delay time such that reflected beam from both fiber ends are time separated. The ratio of the power of the two reflected beam are neither dependent on source power fluctuation nor on any change in the detector–amplifier response, there by increasing the sensitivity of the measurement by this normalization technique. The normalized probe signal is first taken in air for calibration, then in the liquid. The measured value of \( R \) given in equation (1) is the ratio of the normalized probe signal for air and liquid.

Table 1: Represents Sellmeier transactions [8].

![Figure 1: Sketch of Experimental setup](image-url)
4. RESULTS

In this work, sugar solution is tested for some different concentrations are shown in figures (3), (8). All measures are taken at the 850 nm wavelength sugar solution. Figure(3),(4) are represent the variation of power and RI as function of temperatures for the first concentration($C_1$). When increase the temperatures the power increase linearly and RI decrease, that means the Fresnel reflectivity increase. The same characteristics are applied at the other concentration $C_2$ and $C_3$. The result of their concentration are shown in figure(5),(6) for $C_2$ and figure (7),(8) for the $C_3$.

![Graph 1](image1.png)

**Figure (3):** The relation of temperature and RI $C_1$ consecration of sugar solution

![Graph 2](image2.png)

**Figure (4):** The relation of temperature and power $C_1$ consecration of
sugar solution

Figure (5): The relation of temperature and RI C₂ consecration of sugar solutions

Figure (6): The relation of temperature and power C₂ consecration of sugar solutions

Figure (7): The relation of temperature and RI C₃ consecration of sugar solutions
Figure (8): The relation of temperature and power $C_3$ concentration of sugar solutions

The relation between RI and the power is shown in fig(9). From this figure, we can take the RI value directly from the measured value.

Figure (9): The relation between RI and the power $C_1$ is shown

The same characteristics are applied at the other concentration $C_2$ and $C_3$. The result of their concentration are shown in figure(10) for $C_2$ and figure (11) for the $C_3$.

Figure (10): The relation between RI and the power $C_2$ is shown
Figure (11): The relation between RI and the power $C_3$ is shown

We adopted the wavelength (850 nm) in the measurement of the refractive index of several liquids, using the fibre optic Fresnel ratio meter. Measurements of refractive index was very close with the derived values in supported devices. We can adopt this method to study change the refractive index of liquids with different temperatures.

Table(2): shows the values of RI $C_1$ construction and practically for Sugar solution at a temperature 22°C:

<table>
<thead>
<tr>
<th>Constructions</th>
<th>Practically measurement</th>
<th>Standard measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>1.3565</td>
<td>1.35</td>
</tr>
<tr>
<td>$C_2$</td>
<td>1.3617</td>
<td>1.363</td>
</tr>
<tr>
<td>$C_3$</td>
<td>1.3791</td>
<td>1.365</td>
</tr>
</tbody>
</table>

Table(3): shows ranging ratio of RI $C_1$ construction for Sugar solution:

<table>
<thead>
<tr>
<th>Constructions</th>
<th>RI at 22 °C</th>
<th>RI at 38 °C</th>
<th>Ranging ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>1.3565</td>
<td>1.3505</td>
<td>0.006</td>
</tr>
<tr>
<td>$C_2$</td>
<td>1.3617</td>
<td>1.3549</td>
<td>0.0067</td>
</tr>
<tr>
<td>$C_3$</td>
<td>1.3791</td>
<td>1.3686</td>
<td>0.0105</td>
</tr>
</tbody>
</table>

5.CONCLUSIONS

We measured the refractive index of sugar solution at wavelength of 850 nm using the optical fiber Fresnel ratio meter. The observation to RI of water which gave, during suppling the rays that have different frequency, mesurements close so far to the literature side is n’t out of the assumption and estimation. Somehow, a little difference might be found but it could be sorted as an accepted slight deviation to the linear behaviour showing the dependency on temperature as mentioned in [9] and in this study too. It was found that the mapping of optimized value of the fiber effective indicates is major factor to give accurate results.

REFERENCES


