CHAPTER - III

USE OF THE ACOUSTO-OPTICAL DIFFRACTION TECHNIQUE FOR MEASURING THE REFRACTIVE INDICES OF LIQUIDS.
The interaction between acoustic standing waves and optical waves causes the diffraction of light. The laser light travelling through the liquid inside the glass cell is diffracted by the ultrasonic waves which are produced due to the overlapping of stationary progressive waves and their reflected part. Such stationary sound waves have nodes and antinodes, which behave, like opaque and transparent parts for light. Thus, a grating like structure is formed which diffracts the laser light. In other words such type of interaction between sound and light waves occurs resulting a grating like action, and the diffraction dots are displayed on a screen. A relation between the refractive index of a liquid and the velocity of ultrasonic waves inside the liquid has been derived which involves also the separation of diffraction dots.
3.1 INTRODUCTION:

The word Photo and Sonar stands for light and sound respectively. The word diffractrometer is used due to the fact that diffractive action is produced as a result of interaction of light waves with stationary sound waves formed inside the glass tank. Basically it behaves like an optical grating that can also be named as ultrasonic grating. Owing to the diffraction of light maxima and minima are observed in intensity pattern which can be utilized to determine the refractive index of a liquid. The light moves slowly in a medium and the decrease in the speed of light inside a medium affects in a proportional decrease in its wavelength. This chapter reports the characterization of this optical element, which has no physical existence.

The determination of the refractive index continues to draw the attention of scientists due to its significant physical and chemical characteristics, which plays an important role in optical and chemical engineering.

In view of its utmost importance many scientists have centered their attention on discovering practical techniques of determining the refractive index of different types of materials. For its accurate measurement, the various types of systems have been designed in the past (1-4). There are
various optical configurations depending upon physical state of samples namely, solid, liquid and gas.

In the year of 1990 Schieveier et-al (5) developed a general formula valid for a wide range of temperature, pressure and wavelength. The interferometric technique using two Michelson interferometers has been reported by Arnold et-al (6). A new interferometric system for the detection of refractive index differences of liquids or gases has developed (7-8).

The different aspects (9-15) of estimating the refractive index for the pure liquid can be classified as follows:-

- Optical beam path variation measurements
- Interferometric fringe detection
- Total internal reflection studies
- Diffractometric fringe detection

In the year 2001, a simple device was presented by Kasana and Jain (16). The aim of the work present in this chapter is to report applications of the diffraction of light by acousto-optic grating. The method utilizes the fact that the diffracted beam position alters due to change of liquids in ultrasonic cell. The diffracted beam position for different liquids have been determined.
This chapter elaborates the diffraction nature of light due to its incidence on a stationary sound wave.

The nodes and anti-nodes of the standing wave behave like opaque and transparent parts respectively. Thus a grating like structure is formed which produces diffraction dots.

3.2 OPTICAL CONFIGURATION AND PROCEDURE:

The details of the optical configuration used in this case is given in fig 3.1. The optical system as shown in fig (3.1). consists of several components namely laser light source, acoustical arrangement for generating standing waves, liquid cell, observation screen, light detecting system etc. For detection purposes a photographic paper/film may also be used by sticking it on the inner side of the wall. A travelling microscope with a photodetector can also be used.

To measure the distance (y) between two successive diffraction dots, a paper screen on glass cell wall and a moving microscope system are used.

The length D inside the glass cell from the center of the crystal to the paper screen can be measured by a vernier calipers. However, in the present case D is not required because of small diffraction
Fig.-3.1 “Optical system for measuring the refractive index of a liquid”
angles. The separation ‘y’ between the zero order on optical axis and the first order is measured by a moving microscope.

3.3 THEORY:

In this present chapter light and sound waves have been used. As a result of their interactions light diffraction phenomenon is observed. Ultrasonic waves are generated by using a piezoelectric crystal vibrator. Thus, the standing waves are produced due to the overlapping of ultrasonic waves and their reflected parts. The formation of nodes and antinodes are responsible for producing diffraction of incident light. The mathematical relations between n, y and V can be established with the help of the ray diagram as sketched in fig.-3.2

If the grating is ultrasonic, the grating equation becomes as follows:-

\[ \Lambda n \sin \theta = m\lambda \]  

(3.1)

where,

- \( \Lambda \) - sound wavelength
- n - refractive index of medium
- \( \theta \) - diffraction angle
- m - order of diffraction
- \( \lambda \) - wavelength of light
Fig. 3.2 "Ray diagram showing the diffraction of laser beams"
The equation (3.1) can be rewritten for air (a) and liquid (L) medium.

\[ m \lambda_a = \Lambda_a \sin \theta_a \cdot n_a \]  \hspace{1cm} (3.2)
\[ m \lambda_L = \Lambda_L \cdot \sin \theta_L \cdot n_L \] \hspace{1cm} (3.3)

On dividing equations (3.2) and (3.3)

\[ \frac{\lambda_a}{\lambda_L} = \frac{\Lambda_a}{\Lambda_L} \frac{\sin \theta_a}{\sin \theta_L} \frac{n_a}{n_L} \] \hspace{1cm} (3.4)

Now, according to the definition the refractive index \( n_L \) of a liquid is given by

\[ n_L = \text{Wavelength of light in air(} \lambda_a \text{)/Wavelength of light in medium(} \lambda_L \text{)} \]

Hence, equation (3.4) reduces to

\[ n_L = \left( \frac{\Lambda_a}{\Lambda_L} \right) \frac{\sin \theta_a}{\sin \theta_L} \frac{n_a}{n_L} \]
\[ n_L^2 = \left( \frac{\Lambda_a}{\Lambda_L} \right) \frac{\sin \theta_a}{\sin \theta_L} n_a \] \hspace{1cm} (3.5)

If \( y \) is the distance of 1\(^{st}\) order from the optical axis on the screen placed at a distance \( D \) from the ultrasonic grating, we can write for small values of \( \theta \) as

\[ \theta \approx \sin \theta \approx \tan \theta \]

Therefore,

\[ \frac{y_a}{y_L} = \frac{\sin \theta_a}{\sin \theta_L} \] \hspace{1cm} (3.6)

and for sound waves, the distance between successive nodes is

\[ \Lambda = \frac{V}{N} \] \hspace{1cm} (3.7)

Where,

\[ V \]- ultrasonic wave velocity
\[ N \]- ultrasonic wave frequency

Since energy \( h\nu \) is conserved, the frequency remains constant.

The, equation (3.4) reduces to

\[ n_L = \left( \frac{V_a}{V_L} \right) \left( \frac{y_a}{y_L} \right) \frac{n_a}{n_L} \] \hspace{1cm} (3.8)

For air
\( n_a = 1 \)
\( V_a = 332 \text{ m/s} \)

The equation (3.8) becomes

\[
\begin{align*}
    n_L^2 &= \frac{332 \cdot y_a}{(V_L y_L)} \\
    n_L &= \sqrt{332 \cdot y_a} / \sqrt{(V_L y_L)}
\end{align*}
\]  

(3.9)  

(3.10)

The equation (3.10) can also be written as

\[
\begin{align*}
    \lambda_L &= \lambda_a \{\sqrt{(V_L y_L)} / \sqrt{(332 \cdot y_a)}\} \\
    \lambda_L &= k \cdot \sqrt{(V_L y_L)}
\end{align*}
\]  

(3.11)  

(3.12)

where \( k = \lambda_a / \sqrt{(332 y_a)} = \text{constant} \)

By considering two liquids, equation (3.10) may be written as

\[
\begin{align*}
    n_1 &= \sqrt{(332 y_a)} / \sqrt{(V_1 y_1)} \\
    n_2 &= \sqrt{(332 y_a)} / \sqrt{(V_2 y_2)}
\end{align*}
\]  

(3.13)  

(3.14)

Dividing equation (3.14) by equation (3.13)

\[
\frac{n_2}{n_1} = [\sqrt{(V_1 y_1)} / \sqrt{(V_2 y_2)}]
\]  

(3.15)

For determining the refractive indices a graph by using equation (3.10);

\( n_L \) vs \( \sqrt{(V_L y_L)} \) is plotted which provides a straight line passing through the origin and has a slope equal to \( \sqrt{(332 \cdot y_a)} \)
3.4 **OBSERVATION**:

Room temperature = 25\(^{0}\)C

Wavelength in air = 6328 \(\text{A}^{0}\)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Liquids</th>
<th>(V_{L}) (m/s)</th>
<th>Distance (y_{L}10^{-2}) (m)</th>
<th>(V_{L}y_{L})</th>
<th>(1/\sqrt{V_{L}y_{L}})</th>
<th>Refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Acetone</td>
<td>1174</td>
<td>1.988</td>
<td>23.4565</td>
<td>0.20647</td>
<td>1.3582</td>
</tr>
<tr>
<td>2.</td>
<td>Benzene</td>
<td>1295</td>
<td>1.490</td>
<td>19.2955</td>
<td>0.20768</td>
<td>1.4676</td>
</tr>
<tr>
<td>3.</td>
<td>Ethanol</td>
<td>1207</td>
<td>1.9418</td>
<td>23.4375</td>
<td>0.20656</td>
<td>1.3593</td>
</tr>
<tr>
<td>4.</td>
<td>Methanol</td>
<td>1103</td>
<td>2.2316</td>
<td>24.6145</td>
<td>0.20156</td>
<td>1.3264</td>
</tr>
</tbody>
</table>

**Table –3.1**
3.5 RESULTS AND DISCUSSIONS :

The present method has various salient features and merits.

1. The acoustical grating has no physical presence. So the organic liquids can be used without any risk of gradual dissolution of grating base material.

2. There is no possibility of any traces of the liquids on grating. Thus the errors caused due to refraction are eliminated.

3. The screen is in contact with the liquid filled inside the glass cell. Hence, the possibility of error due to refraction are minimized.

The refractive index is measured up to a fourth decimal place.

The straight line of \( n_L \) vs \( 1/\sqrt{V_{LYL}} \) graph can be used to find the refractive index of an unknown liquid. Thus it is concluded that this straight can be treated as a refractrometer.

For \( N \) liquids there are \([N (N-1)] /2\) possible ways of calculating the refractive index of liquids. These are arranged in table (3.2). Where \( n_{ij} \) represents refractive index of liquid (i.e., \( n_L \)) which is calculated by using \( i^{th} \) and \( j^{th} \) liquids according to the formula given in equation (3.15).

It is concluded from this arrangement that \( n_{ij} = n_{ji} \neq 0 \) because the liquid-index equation requires at least two separate liquids of different indices being symmetrical in nature, this arrangements results in \( n_{ij} = n_{ji} \).
As a whole there are $N^2$ values of $n_{ij}$ for $N$ liquids, but $N$ values from those existing along the diagonal of this arrangement are zero. Therefore, the only possible values are $(N^2 - N)$. This number is further reduced to half of its value due to the symmetrical character of the arrangement as the elements existing above and below the diagonal are the same.

Therefore, it is calculated that there would be $N(N-1)/2$ ways of calculating the refractive index of liquids.

We have considered 4-liquids (i.e., $N = 4$), there will be $(4^2-4)/2 = 12/2 = 6$ combinations of two liquids at a time. Thus, the values of refractive index for all possible combinations can be represented by the elements of a matrix.

This refractive index matrix is symmetric matrix because

$$n_{ij} = n_{ji}$$

and

$$n_{jj} = n_{ii} = 0$$
3.6 CONCLUSIONS:

The separation between the diffraction dots on screen has been measured with an accuracy of .001 cm. The travelling microscope with linear vernier has been used for this purpose. Owing to smaller diffraction angles ($\theta_a$ and $\theta_L$), the measurement of distance (D) between the center of the crystal and the screen is not required. The errors in y are minimized by using liquid tank of larger dimensions.
Ways of calculating the refractive index $n_{ij}$ of a liquid.

**Table 3.2**

<table>
<thead>
<tr>
<th>j \ i</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$n_{11}$</td>
<td>$n_{12}$</td>
<td>$n_{13}$</td>
<td>$n_{14}$</td>
</tr>
<tr>
<td>2</td>
<td>$n_{21}$</td>
<td>$n_{22}$</td>
<td>$n_{23}$</td>
<td>$n_{24}$</td>
</tr>
<tr>
<td>3</td>
<td>$n_{31}$</td>
<td>$n_{32}$</td>
<td>$n_{33}$</td>
<td>$n_{34}$</td>
</tr>
<tr>
<td>4</td>
<td>$n_{41}$</td>
<td>$n_{42}$</td>
<td>$n_{43}$</td>
<td>$n_{44}$</td>
</tr>
</tbody>
</table>
Graph $n_L$ versus $1/\sqrt{(V_L y_L)}$

Fig. 3.3 - "A graph $n_L$ versus $1/\sqrt{(V_L y_L)}"
Graph $\lambda_L$ versus $\sqrt{V_L Y_L}$

Fig. 3.4 - "A graph $\lambda_L$ versus $\sqrt{V_L Y_L}$"
3.7 REFERENCES:

    Davis C. 2093