Nahrain University, College of Engineering Journal (NUCEJ) Vol.14 No.1, 2011 pp.88-96

Laser Based Measurement for Liquid Refractive Index

Ziad T. Al-Dahan **Sinan A.. Al-Magazachi**
Laser Dept. College of Engineering Nahrain University.

Abstract

One of independent laser-based technique is presented to measure liquid refractive index, which is important in medical and other applications. Semiconductor laser diode of ≈ 630*nm* wavelength serves as alight source for measurement. Results are presented for different types of liquids in two methods, one of these methods is done by matlab language as the theoretical result, the other method is the opti-cad program which represented the simulation results.

Good matching found between the two the theoretical and simulation results. The experimental setup is high precision, non-contact between the tools and the liquid which is under test.

1- Introduction

The laser, though less than forty years old, has made a tremendous impact on science and technology. During this time, laser-based research has undergone rapid development and has seen wide use due to its unique properties, such as fast response, noninvasiveness, and sensitivity of laser based tools. Examples of laser applications include information storage and retrieval, measurement and inspection, medicine, material processing, and military applications. From the thermal perspective, transport phenomena (heat and mass transfer), and thermo-optical property measurements are current subjects of interest. The non-contact nature of laser-based techniques makes them valuably unique. Non-contact measurement techniques have played a significant role in the investigation of thermal and fluid phenomena. They have several distinct advantages over their direct-contact counterparts, including the non-invasive nature of the measurement, remote monitoring and location of test/analysis equipment, imperviousness to harsh and corrosive environments, very high spatial precision, fast response times, and high reliability and repeatability.

Liquid refractive index and its dependence on temperature or concentration are important for research of laser-liquid interaction and liquid thermo-optical property measurement. The refractive index of a liquid is a function of concentration only in an isothermal system ignoring variations in refractive index from pressure fluctuations [1].

The precise measurement of concentration in liquids is important in fields such as chemical processing, semiconductor manufacturing, waste inspection and environmental monitoring, and measurement of liquid diffusion coefficients.

2. - Theoretical Basis

To measure *n*, Snell's law is employed to relate the incident and exit laser beam angles, and the liquid refractive index as the beam passes through the cuvette. (Figure: 1)shows the laser beam is sent into the cuvette at an incident angle θ*i* such that it passes through the cuvette wall into the liquid and then strikes and passes through the cuvette wall perpendicular to the entrance wall. Applying Snell's law to this optical path, the exit position *W* and exit angle θ*o* become, as below[2,3]:

At node **(a)**:-

$$n * \sin\theta_i = n_g * \sin\theta_1$$

where : *n*= 1 for air media, n_g is the refractive index of the cuvette glass, θ_i is the incident angle of the laser into the cuvette

$$\boxed{n_g = \frac{\sin\theta_i}{\sin\theta_1}} \quad 2.1$$

At node **(b)**:-

$$n_g * \sin\theta_1 = n_L * \sin\theta_2$$

where n_L is the refractive index of the liquid inside the cuvette
by substituting eq.(2.1):

$$\boxed{\sin\theta_i = n_L * \sin\theta_2} \quad 2.2$$

from figure: (1):

$$\theta_2 = 90 - \theta_3 \tag{2.3}$$

by substituting eq.(2.3) in eq.(2.2):

$$\sin\theta_i = n_L * \cos\theta_3 \tag{2.4}$$

At node **(c)**:-

$$n_L \sin\theta_3 = n_g * \sin\theta_4 \tag{2.4.1}$$

At node **(d)**:-

$$n_g * \sin\theta_4 = n * \sin\theta_o \tag{2.4.2}$$

where θ_o is the output angle from the cuvette
From eq.(2.4.1) & (2.4.2) :

$$\sin\theta_o = n_L * \sin\theta_3 \tag{2.5}$$

From eq.(2.4):-

$$\theta_3 = \cos^{-1}\left(\frac{\sin\theta_i}{n_L}\right) \tag{2.6}$$

by substituting eq.(2.6) in eq.(2.5):-

$$\sin\theta_o = n_L * \sin\left[\cos^{-1}\left(\frac{\sin\theta_i}{n_L}\right)\right]$$

$$\theta_{o(nL)} = \sin^{-1}\left\{n_L * \sin\left[\cos^{-1}\left(\frac{\sin\theta_i}{n_L}\right)\right]\right\} \tag{2.7}$$

From eq.(2.1):-

$$\theta_1 = \sin^{-1}\left(\frac{\sin\theta_i}{n_g}\right) \tag{2.8}$$

From eq.(2.4.2):-

$$\theta_4 = \sin^{-1}\left(\frac{\sin\theta_o}{n_g}\right) \tag{2.9}$$

by substituting eq.(2.7) in eq.(2.9):-

$$\theta_4 = \sin^{-1}\left\{\frac{n_L}{n_g} * \sin\left[\cos^{-1}\left(\frac{\sin\theta_i}{n_L}\right)\right]\right\} \tag{2.10}$$

From eq.(2.4.1):-

$$\theta_3 = \sin^{-1}\left[\frac{n_g}{n_L} * \sin\theta_4\right] \tag{2.11}$$

By substituting eq.(2.10) in eq.(2.11)

$$\theta_3 = \cos^{-1}\left(\frac{\sin\theta_i}{n_L}\right) \tag{2.12}$$

From Figure (1):-

$$M = t * \tan\theta_1 \tag{2.12.1}$$

$$N = t * \tan\theta_4 \tag{2.12.2}$$

where t is the thickness of the cuvette wall

$$W = \tan\theta_3 * [L - M] + N \tag{2.13}$$

where L is the distance from the entrance laser point to the common corner between the entrance and exit faces of the cuvette. By substituting eq.(2.12.1) & eq.(2.12.2) in eq.(2.13):-

$$W = \tan\theta_3 * [L - t * \tan\theta_1] + [t * \tan\theta_4] \tag{2.14}$$

By substituting eq.(2.8) & eq.(2.10) & eq.(2.12) in eq.(2.14):-

$$W_{(n_L)} = \left\{ \tan * \left(\cos^{-1}\left(\frac{\sin\theta_i}{n_L} \right) \right) * \left[L - t * \tan\left(\sin^{-1}\left(\frac{\sin\theta_i}{n_g} \right) \right) \right] + t * \tan\left(\sin^{-1}\left(\frac{n_L}{n_g} * \sin\left(\cos^{-1}\left(\frac{\sin\theta_i}{n_L} \right) \right) \right) \right) \right\} \tag{2.15}$$

where: $W_{(nL)}$ is the distance from the exiting laser point to the common corner between the exiting and interior faces of the cuvette. Both θ_o & $W_{(nL)}$ are required, because a change in n_L results change in the exiting angle from the cuvette and a translation of the beam along the exit wall of the cuvette. So it will cause a beam position change at the position sensor [4]. The change in the beam position at the sensor, h, can be expressed as below: From figure (2):

$$\therefore h = \left\{ \frac{W}{\cos\theta_{nL1}\left[1 + \tan\theta_{nL2} \tan\theta_{nL1}\right]} + H * \tan\left(\theta_{nL2} - \theta_{nL1}\right) \right\}$$

$$W = W_{nL2} - W_{nL1}$$

In general

$$\therefore h_{nL2} = \left\{ \frac{W_{nL2} - W_{nL1}}{\cos\theta_{nL1}\left[1 + \tan\theta_{nL2} \tan\theta_{nL1}\right]} + H * \tan\left(\theta_{nL2} - \theta_{nL1}\right) \right\} \tag{2.16}$$

where : **h** is the distance beam position change at the position sensor**,** $\mathbf{W_{nL2}}$ is the distance from the exiting laser point to the common corner between the exiting and interior faces of the cuvette for the second liquid, $\mathbf{W_{nL1}}$ is the distance from the exiting laser point to the common corner between the exiting and interior faces of the cuvette for the fist liquid, $\boldsymbol{\theta_{nL1}}$ is the output angle from the cuvette for the first liquid, $\boldsymbol{\theta_{nL2}}$ is the output angle from the cuvette for the second liquid, **H** is the distance from the exiting laser point from the cuvette to the position sensor [5,6].

3. - Experimental Arrangement

The experimental configuration is shown in Figure: 3. A semiconductor diode laser with a wavelength of ≈ 630 nm with its power supply serves as the light source. To test the system, two liquids needed to be used, The liquid which has known refractive index is first placed in the liquid cell, and the position sensor is oriented perpendicular to the exit laser beam (Figure: 2"solid line") causing W_{nL1} and θ_{nL1} which will be as a reference point. Next, removing the liquid which has known refractive index and replacing it with the liquid which has unknown refractive index to the cell, which results in a beam displacement, *h* at the position sensor (Figure:.2"hidden line") and causing W_{nL2} and θ_{nL2}. The refractive index for the second liquid will be calculated from Eqs. (2.7), (2.15) and (2.16) where *h* measuring by the position sensor circuit. The displacement between the two positions *h* which is produced by the above two liquids will produce an output voltage linearly proportional to the beam position, which will measured using a 6.5 digit Keithley Model 2000 digital voltmeter (DVM) by position to voltage converter.

4.1 -Results and Discussion for the output Angle

By calculate the output angle "eq.(2.7)" for different types of liquids using a computer program "matlab language" and by using "opti-cad" program, the results was drawn for different input angles.

As the refractive index of the liquid which is under test increasing the output angle will increase, but the incident angle will limit the range of the refractive index value. So as in figure (4), it can be seen that the maximum value of the refractive index is 1.36 for incident angle = 70° because more than that value "refractive index", the output angle will be out of range. Figure (5) has the large range of the refractive index values because the incident angle = 80°, in other words, as the incident angle be large the range of the refractive index which can be measured will be large [7], but the maximum incident angle is 80°.

4.2-Results and Discussion for Displacement W

By calculate the displacement W "eq.(2.15)" for different types of liquids using a computer program "matlab language" and by using "opti-cad" program, the results was drawn for different input angles and different values for parameter L.

From the results, as the refractive index increasing the displacement W increases. The accuracy of the results will increase as the incident angle increases for the same value of parameter L, as in figures (6) and (7). the accuracy represented by the matching between the theoretical results and the simulating results [8]. But the accuracy will be more than the parameter L as increases "where parameter L representing the distance from the entrance laser point to the common corner between the entrance and exit faces of the cuvette", for the same value of the incident angle, the parameter L values was taken as 3, 5, 8 mm because the cuvette width is 10 mm so the maximum value of L was 8mm and it is found that the optimum accuracy results were when the incident angle and Parameter L be maximum, in other words the maximum matching between the theoretical and simulating results done when incident angle = 80° and L=8mm as in figure (8).

5.-References

1- Mark, H. F., McKetta, J. J., Jr., and Othmer, D. F., “**Kirk-Othmer Encyclopedia of Chemical Technology”**, 2nd ed., Vol. 17, New York, Interscience Publishers, 1970.

2- McAlister, E. D., Villa, J. J., and Salzberg, C. D., “**Rapid and ccurate Measurements of Refractive Index in the Infrared,**” *Journal of the Optical Society of America*, Vol. 46, pp. 485–487, 1956.

3- Malitson, I. H., “**Refractive Properties of Barium Fluoride**,” *Journal of the Optical Society of America*, Vol. 54, pp.628–632, 1964.

4- J. E. Geake , “**Linear Refractometers for Liquid Concentration Measurement**”, *Chem. Engineer*, pp. 305] 308, vol. 297, May, 1975.

5- Smirnov, I. K., Polyakov, Y. G., and Orlov, G. N., “**Arrangement for Measurement of Index of Refraction and Thickness of Transparent Dielectric Films by an Optical Method,**” *Journal of the Optical Society of America*, pp. 546–547, 1980.

6- T. L. Bergman, F. P. Incropera, and W. H. Stevenson, “**Miniature Fiber-Optic Refractometer for Measurement of Salinity in Double -Diffusive Thermohaline Systems**”, *Rev .Sci. Instrum.*, vol. 56, pp. 291-296, 1985.

7- Wilson, T. A. and Reed, W. F., **“Low Cost, Interferometric Differential Refractometer,**” *American Journal of Physics*, Vol. 61, pp. 1046–1048, 1993.

8- Spear, J. D., Russo, R. E., and Silva, R. J., “**Collinear Photothermal Deflection Spectroscopy with Light-Scattering Samples**,” *Applied Optics*, Vol. 29, pp. 4225–4234, 1990.

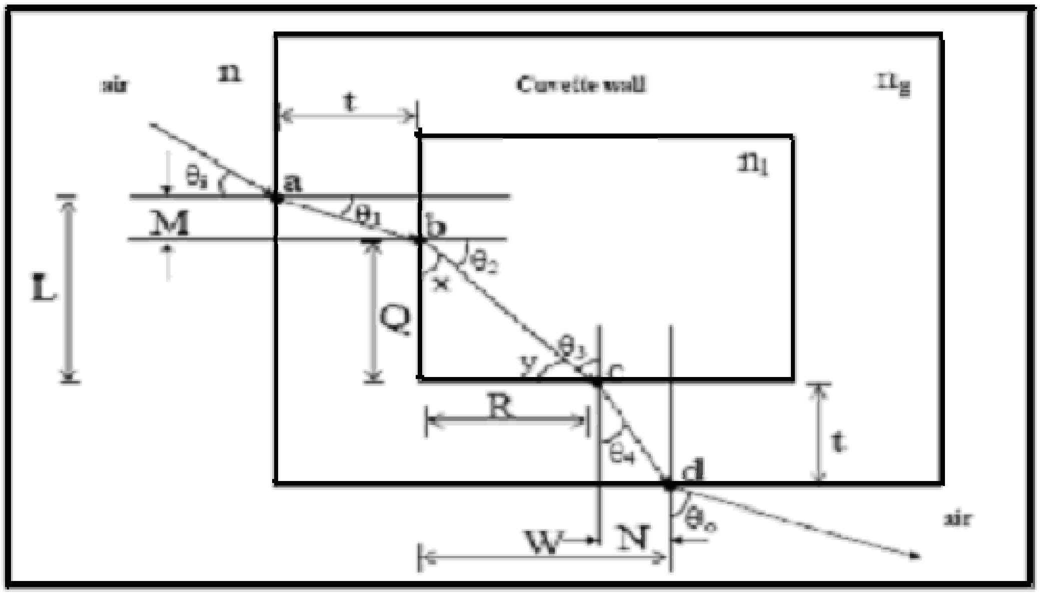

Fig (1) Geometry of Beam Path Through The Cuvatte

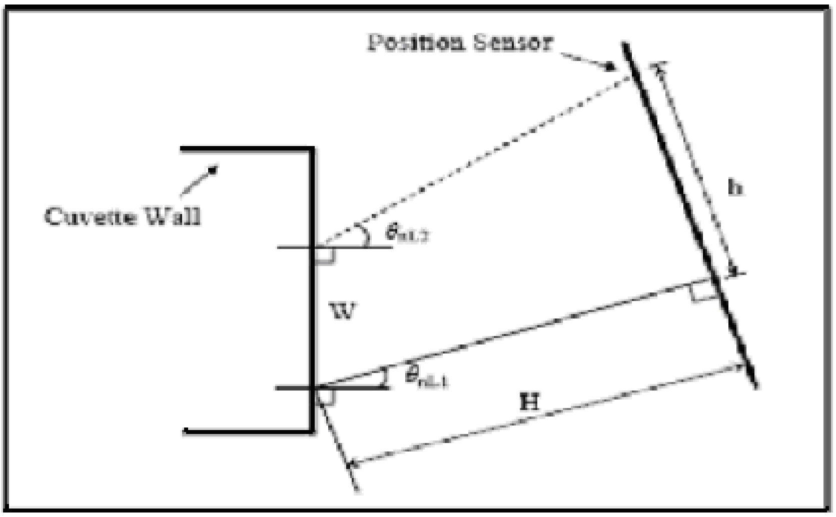

Fig (2) Geometry of Beam Path between The Cuvatte and position sensor

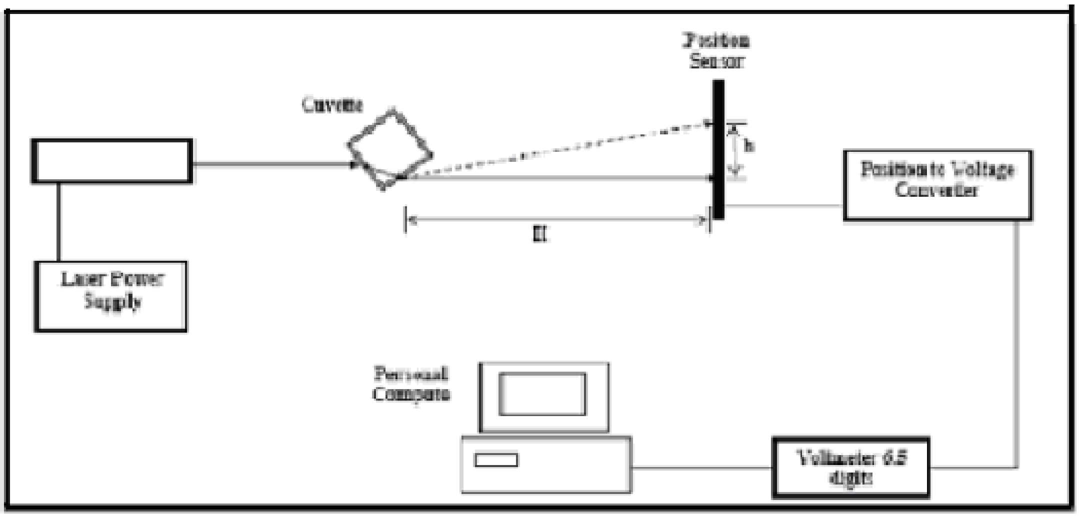

Fig (3) Experimental Setup for Refractive Indx

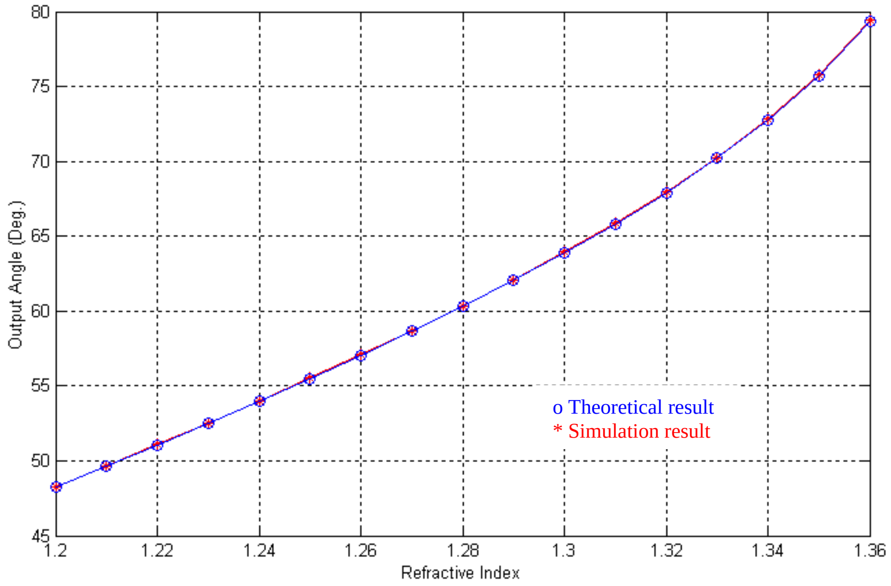

Fig (4): Output Angle (deg.) for input Angle=70 (deg.)

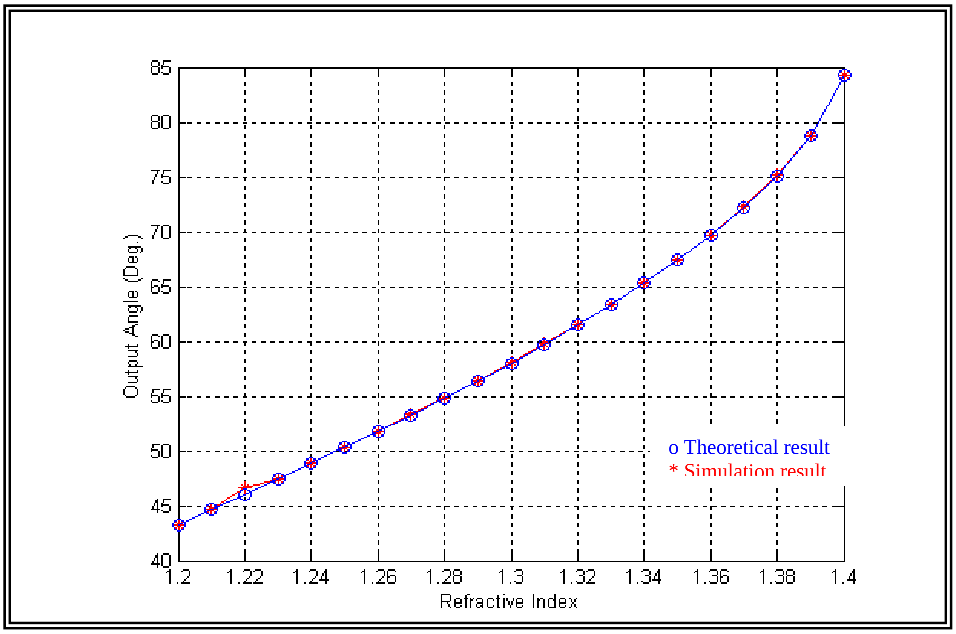

Fig (5): Output Angle (deg.) for input Angle=80 (deg.)

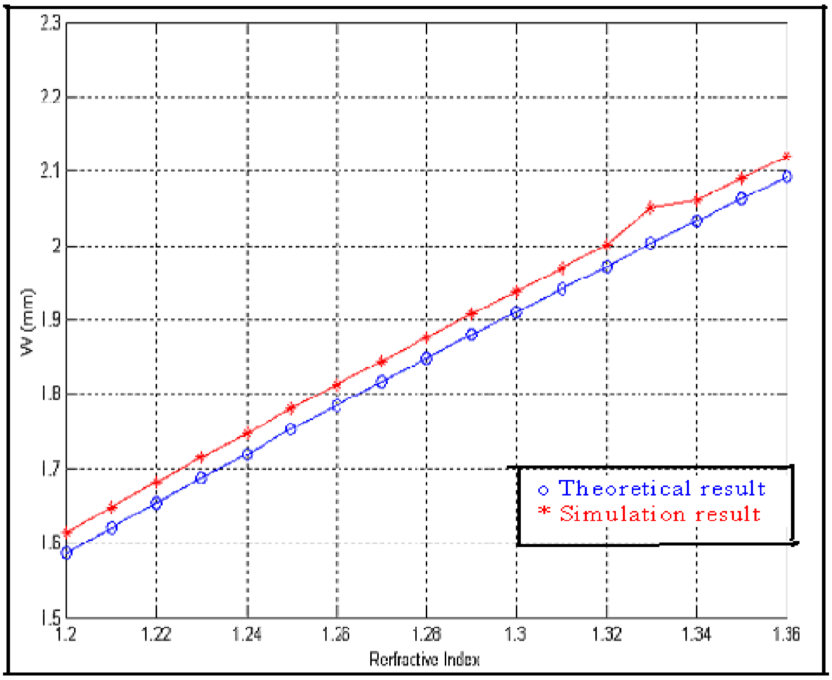

Fig (6) W with n_L for ip =70(deg) , L=2mm

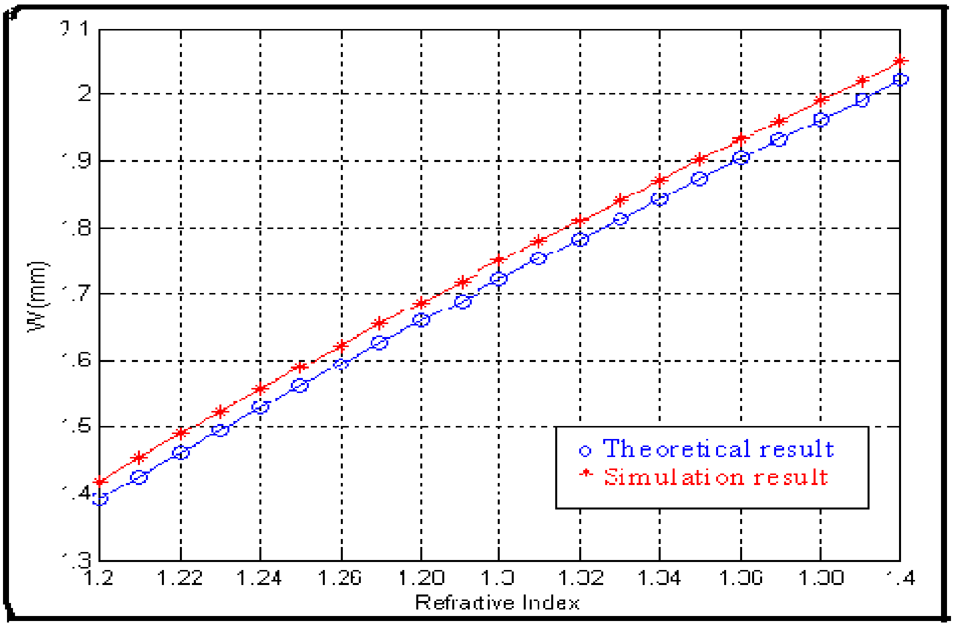

Fig (7) W with n_L for ip =80(deg) , L=2mm

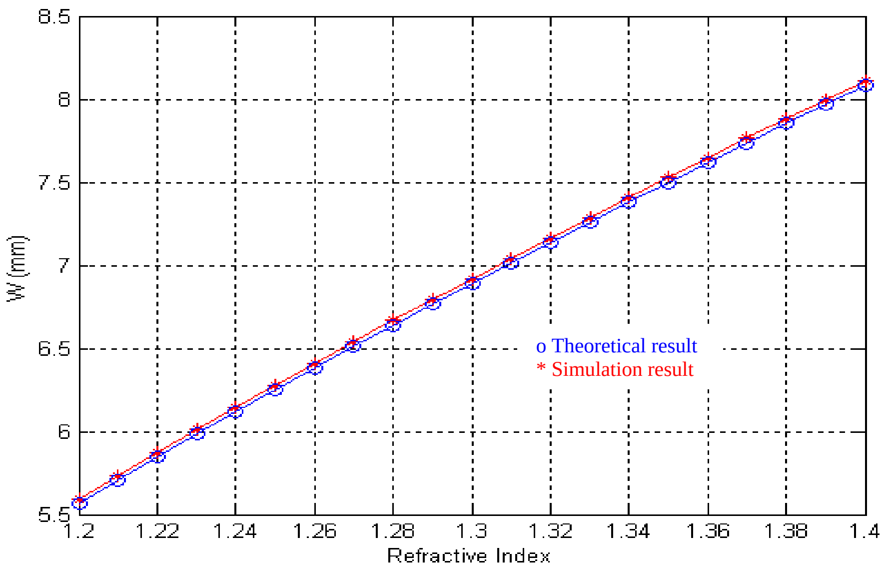

Fig (8): W with n_L for ip=80(deg.), L=8mm

قياس معامل انكسار السوائل باستخدام الليزر

د.زياد طارق الدهان **سنان عبد الحميد المغازجي**
جامعة النهرين / كلية الهندسة/ قسم هندسة الليزر

الخلاصة

لقد تم تقديم واحدة من تطبيقات الليزر لقياس معامل انكسار السوائل ,الذي هو مهم في التطبيقات الطبية والاخرى. لقد تم استخدام الليزر شبه الموصل بطول موجي 630nm كمصدر ضوئي للقياس تم تصميم وبناء جهاز مصدر الطاقة لليزر شبه الموصل وبقدرة 4.5 فولت. تم الحصول على النتائج لعدة سوائل مختلفة وبطريقتين :الاولى بطريقة التحليل النظري للمحاكاة بأستخدام برنامج opti-cad. والطريقة الثانية هي باستخدام برنامج matlab ان نتائج التحليل النظري والمحاكاة كانت متقاربة جدا. أن هذه المنظومة هي ذو دقه عالية ,وليس هنالك اي ملامسه بين اداة القياس والسائل الذي هو تحت الاختبار