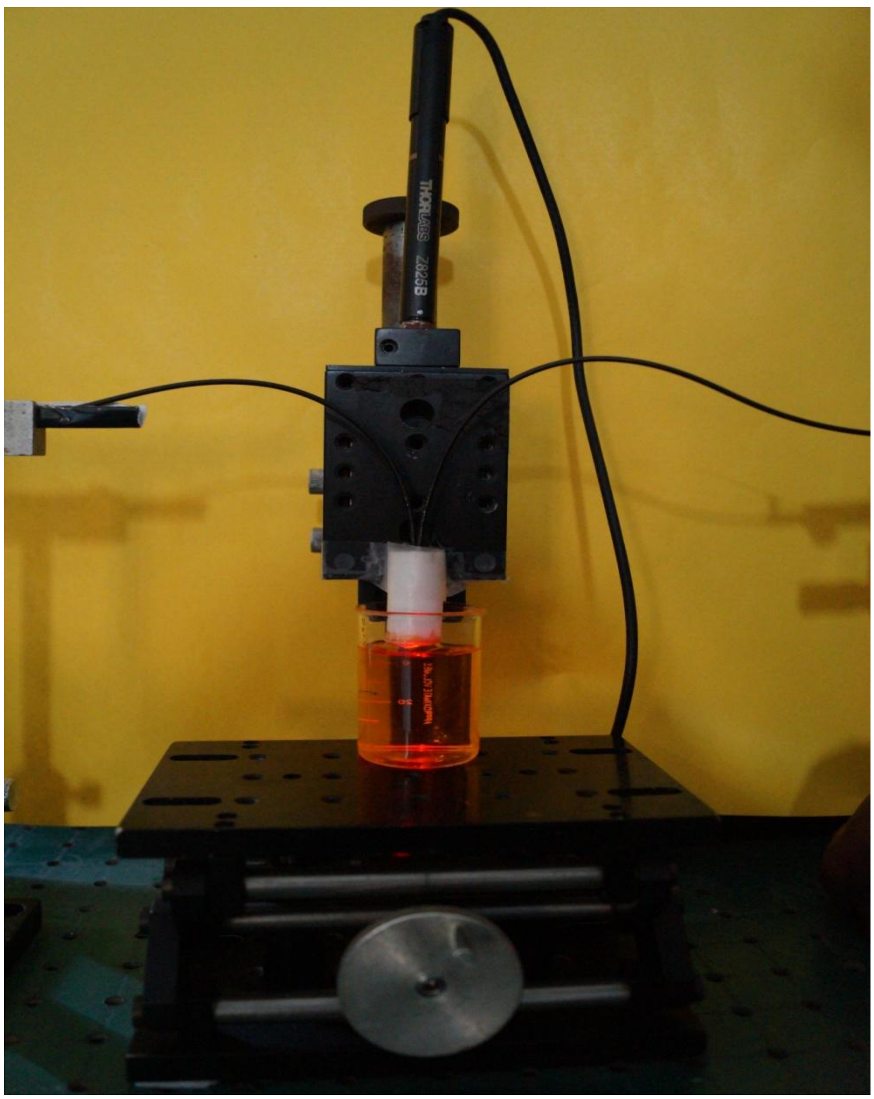
# TOTAL INTERNAL REFLECTION IN PRISM

## Analyzing purity of liquids based on sensor characteristics



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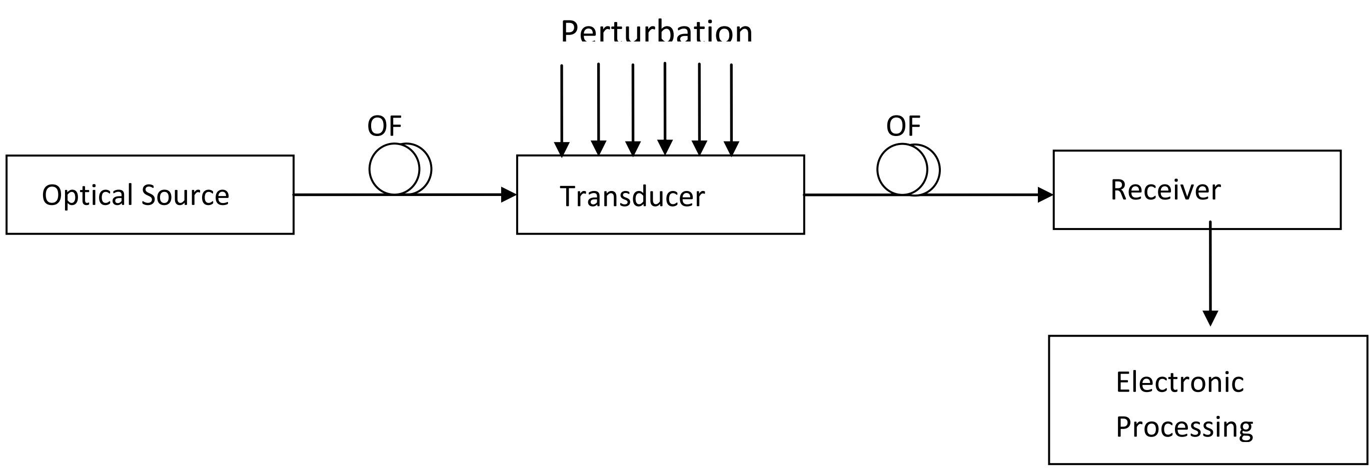
ABSTRACT

In recent years, fiber optic sensors are showing an escalating progress to be fitted as good candidates for smart structure technology.  Optical fiber prism based liquid level sensor are reported in literature and found to be a good candidate for determining both refractive index and liquid level sensing. The important characteristics of liquid level sensor are the hysteresis effect. This effect is used to demonstrate the change in output obtained when the sensor comes in contact with the ambient liquid. The area of hysteresis is calculated and compared to the concentration of liquids. A sensor is developed with feature to help determine the adulteration of liquids.

INTRODUCTION:

Over the past decades many product revolutions have taken place due to the growth of the optoelectronics and fiber optic communications industries. In the process of fiber optic developments, different researches had been done which are focused on suitable design of fibers. An offshoot of this observation was a new thoughts directed to use optical fibers in designing sensing systems, which led to the fiber based sensing devices and components. A high volume fiber requirement in the telecommunication industry has brought down substantially the material cost of fiber sensor and the performances of the fiber improve dramatically over the years . As a result, the ability of fiber optic sensors to displace traditional sensors for rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity, viscosity, chemical measurements, and a host of other sensor applications has been enhanced. The rapidly growing interest, with fiber-based sensing owed to some attractive reasons like small size, light weight, immunity to electromagnetic interference (EMI).



# Selection of Problem:

The present work may find many applications in fields such as petroleum industries, refractometery and bio medical fluids diagnosis etc  to identify the purity of liquids.

# Formulation of Hypothesis:

My hypothesis is that the hysteresis of a fiber optic sensor can be used to identify the viscosity of liquids and their concentration based on area produced by the sensor movement.

# Recent Study:

1. Design and construction of an optical fiber sensor for liquid level detection. this device was tested as a liquid level sensor, but the distinct results obtained for samples with different index of refractions demonstrate that the reported sensor can also be used as a liquid refractometer by Hossein Golnabi

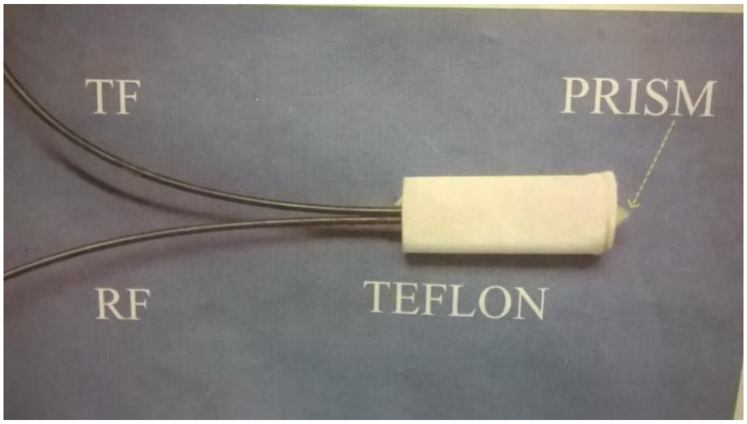
2. Analysis and the theoretical formulation of the prism based liquid level sensor operation and a comparison between theoretical estimation and experimental results. --- M. Razani1, H. Golnabi2

3. The performance of the liquid level sensor has been studied using four different shapes of the tips of the sensing elements: conical, rounded conical, second-order polynomial and third-order polynomial--- Pekka Raatikainen, Ivan Kassamakov, Roumen Kakanakov, Mauri Luukkala.

# SAMPLING:

The liquid level sensor mainly consists of sensor head which is made of up of a small Teflon block fitted with two multi-mode fibers and a solid prism. The construction of the sensor head described clearly in the following section. The selection of the material used for the sensor holder depends on the application. The liquids used may be chemically corrosive, hot , hence the holders need to be constructed from ceramic, polyethylene and Teflon – based materials as they are chemically inert, thermal stability up to 90C and mechanically rigid. A cylindrical Teflon block is taken as holder having a width of 1.93cm and height of 3.73cm.A bore of about 2mm is made through the block along its length. From one end of the bore two multimode fibers each of thickness 1mm, are inserted such that the fibers are symmetrically located on the opposite side of the holder.

The sensing element is a right angled prism made up of flint glass. The base of the prism is glued on to the other end of the Teflon block in such a way that above said two fibers are in contact with the base of the prism. The positions of the fibers are optimized before inserting them in the Teflon block such that they satisfy the condition of total internal reflection. One of the fibers is used for transmission of light from source to the prism and is called transmitting fiber (TF) and other one is used for receiving of the light from the prism is called receiving fiber (RF). When a light ray is given to the prism from transmitting fiber, it gets internally reflected and is received by the receiving fiber as shown in the figure. The sensor is attached to a movable section of the fixed stand to obtain a movement to and away from the liquid sample level.




EXPERIMENTATION:

The experimental arrangement consists of a He-Ne laser source with wavelength at 630nm, Sensor head (Prism with two fibers attached at the base), a stepper motor controller and a digital multi meter voltage measurement. The schematic of the experimental setup is shown in the figure.

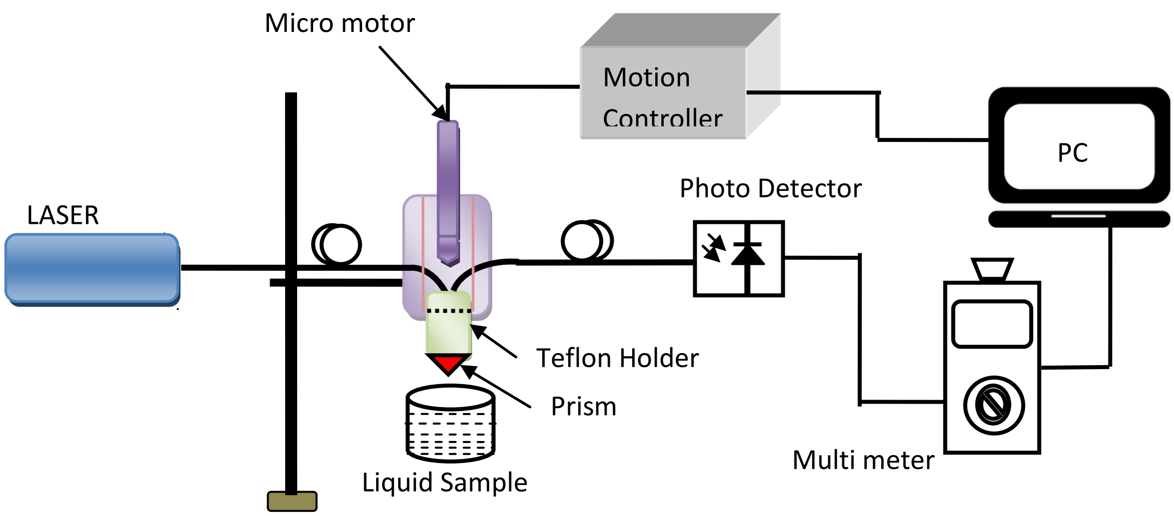
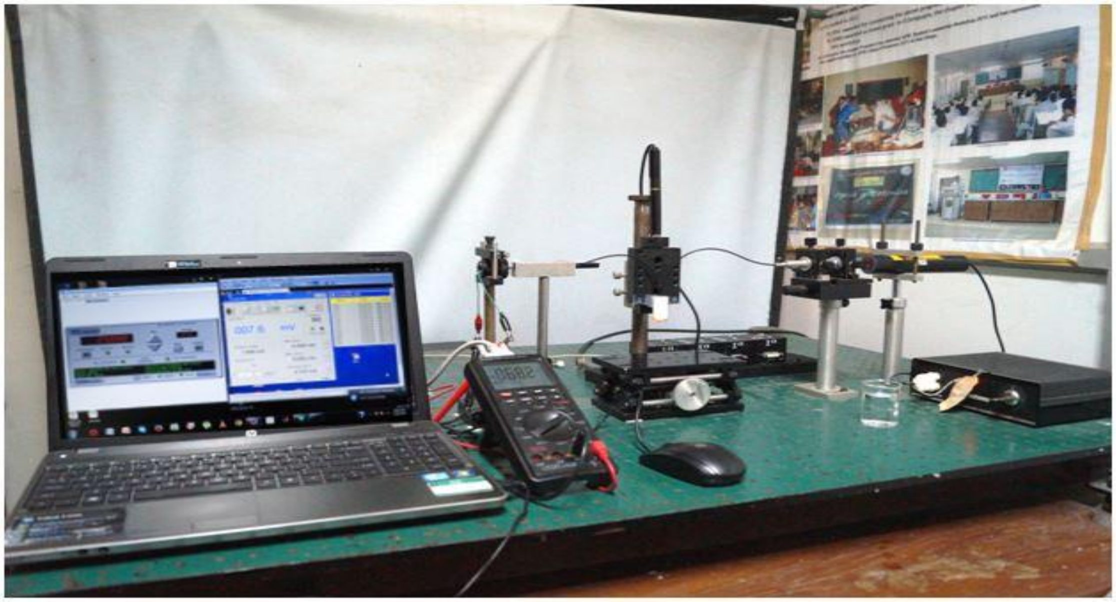



***Figure4.2: Schematic of the sensor***

The sensor head is attached to a friction less movable stand. On the roof of the movable stand, the tip of a micro meter is fixed which is being monitored by a Stepper motor. The stepper motor can be programmed such that a desired motion to the micrometer can be given and monitored. So when micrometer is given a movement by the stepper motor, it moves the movable stand which in turn moves the sensor head. The motor controller can be interfaced to a system and the typical series of moves and parameter adjustments required for sensor up and down movement are performed using the PC based APT software. An intuitive graphical instrument panel allows immediate control and visualization of the operation of the stepper controller.

He-Ne laser source light operating at 632.8nm is fixed with a stand. Two multimode fibers are used; one transmitting which allows the light from source to the prism and the other receiving which after total internal reflection inside the prism collects the reflected light and transmits to the photo detector. To measure the output voltage of the photo detector a multi meter is connected with a system interface. In order to match the movement of the stepper motor and continuous noting of readings by the detector, a sampling time of 1 sec is taken to note the readings of the per second movement of the stepper motor. Different samples of liquids are considered for the experiment. The experimental set up is fixed with a certain prism height so as to accommodate a liquid containing vessel under the prim. The prism can be moved up and down, towards the liquid sample and away from the sample level in order to obtain the hysteresis by plotting the output voltage of the sensor for the given liquid sample. The working experimental set up is shown in the figure.



**PROCEDURE:**

Before starting the experiment the sensor head should be cleaned with acetone and de ionized water in order to remove atmospheric dust and any other chemical residues. The negligence in cleaning will results in adverse effects.

A clean beaker is used to collect the required amount of sample liquid, a 50ml solution of liquid sample is taken in the beaker and placed below the prism tip to allow a free movement of the prism inside the beaker. Now the movable section which has been attached to a stepper motor is fed with a movement of 10µm (0.01mm). As shown in the figure the downward movement of the stepper motor screw pushes the section down hence moving the prism. This results in the prism movement towards the level of water.

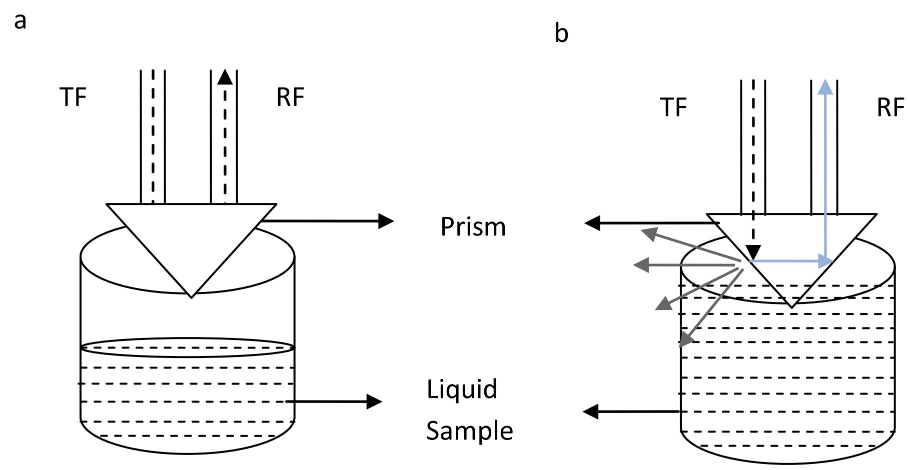



***Figure: Schematic representation of up and down movement of***

The water level is at a distance of 3mm from the prism tip. The prism tip approaches the water level and when it touches the water level the total internal reflection of the prism gets disturbed and there is a loss of light in to water and less light gets coupled in to the receiving fiber end. Hence the detector show a sudden drop voltage output and as long as the prism is inside the water the voltage output remains to less and almost constant. The prism height inside the water is 2mm, the prism is now fed with a backward movement. In other words, the stepper motor is allowed to move the screw back decreasing the height of the prism from the water level. As the prism leaves the water a meniscus forms between the water level and prism tip, the voltage starts increasing gradually. After a certain height the liquid completely drops of the prism tip this is due to the slow movement the surface tension of the liquid draws the liquid back hence the voltage increases (the initial voltage is observed).

**Preparation of Sucrose Concentrations:**

The sucrose solutions are prepared in terms of weight percentage concentrations. Twelve 50ml solutions each with an increment of 5% by weight is prepared.

***TABLE:Sucrose solutions and their properties***

| Concentration Of Sucrose | Refractive Index | Viscosity |
|---|---|---|
| **5%** | 1.3403 | 1.144cp |
| **10%** | 1.3478 | 1.333cp |
| **15%** | 1.3557 | 1.589cp |
| **20%** | 1.3638 | 1.941cp |
| **25%** | 1.3723 | 2.442cp |
| **30%** | 1.3811 | 3.181cp |
| **35%** | 1.3902 | 4.314cp |
| **40%** | 1.3997 | 6.150cp |
| **45%** | 1.4096 | 9.360cp |
| **50%** | 1.4200 | 15.400cp |
| **55%** | 1.4307 | 28.02cp |
| **60%** | 1.4418 | 43.05cp |

**Preparation of NaCl concentrations**:

The NaCl Solutions are prepared in weight percent concentrations, 4 Solutions each with an increment of 5% is prepared.

***TABLE: NaCl solutions and their properties***

| Concentration Of NaCl | Refractive Index | Viscosity |
|---|---|---|
| **5** | 1.3418 | 1.085 |
| **10** | 1.3505 | 1.193 |
| **15** | 1.3594 | 1.353 |
| **20** | 1.3684 | 1.557 |

**Area of Hysteresis Produced By Sucrose Solutions:**

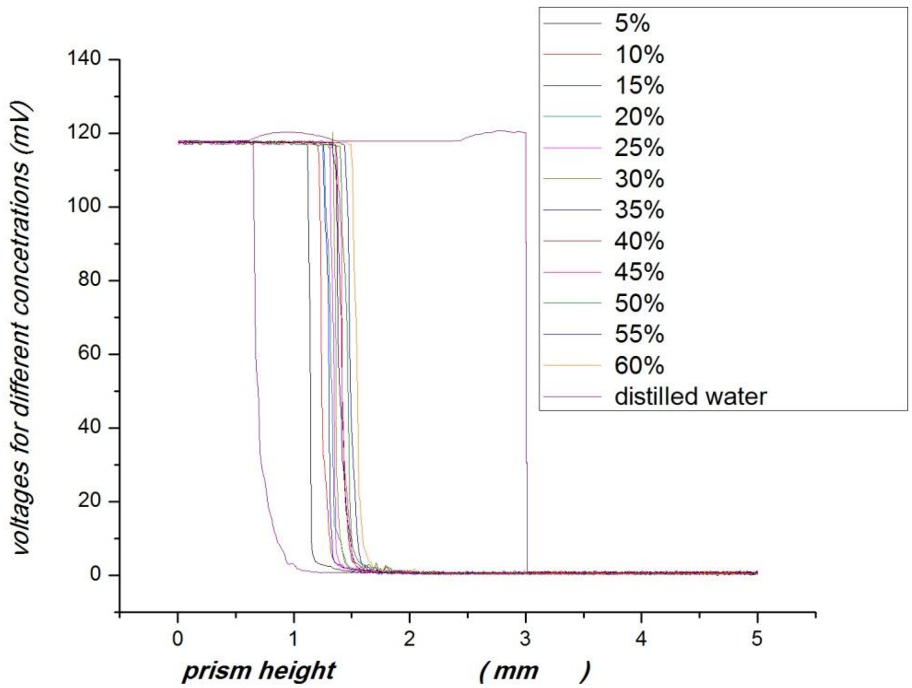



***Figure : The plot for sucrose solutions showing hysteresis effect***

| *Concentration Of Sucrose (%)* | *Hysteresis Area* |
|---|---|
| ***5*** | *219.99* |
| ***10*** | *206.645* |
| ***15*** | *201.158* |
| ***20*** | *198.906* |
| ***25*** | *196.647* |
| ***30*** | *193.485* |
| ***35*** | *188.941* |
| ***40*** | *187.392* |
| ***45*** | *186.694* |
| ***50*** | *183.017* |
| ***55*** | *179.024* |
| ***60*** | *172.725* |



***TABLE: Sucrose solutions and the Hysteresis Area***

## 2 Area of Hysteresis Produced By NaCl Solutions

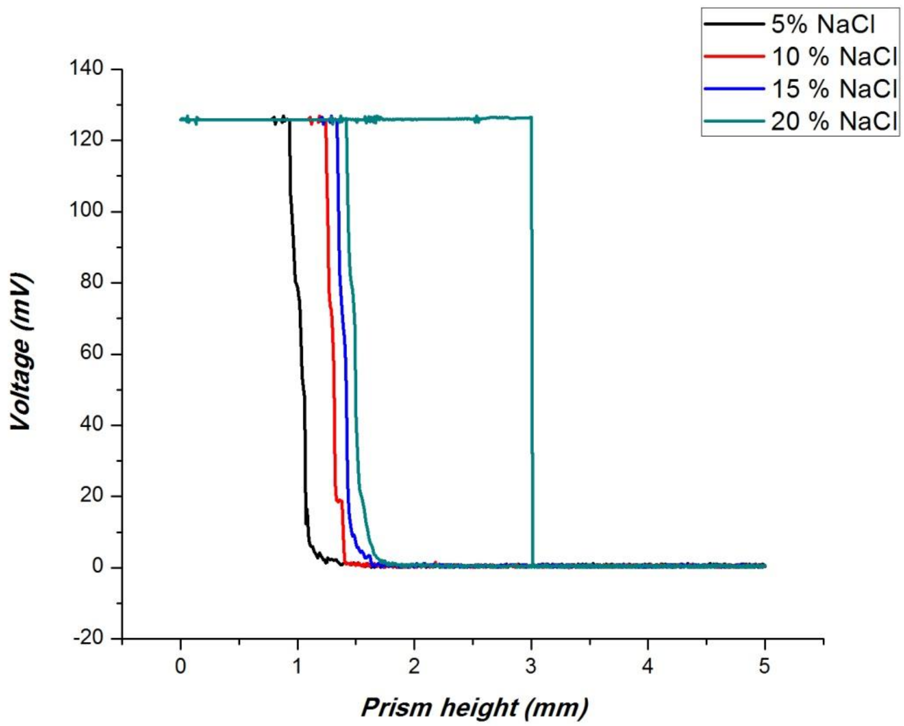



***Figure: The plot for NaCl solutions showing hysteresis effect***

| *Concentration(%)* | *Area* |
|---|---|
| **5** | 247.5092 |
| **10** | 212.7475 |
| **15** | 200.024 |
| **20** | 188.5345 |

***TABLE : NaCl solutions and the Hysteresis Area***

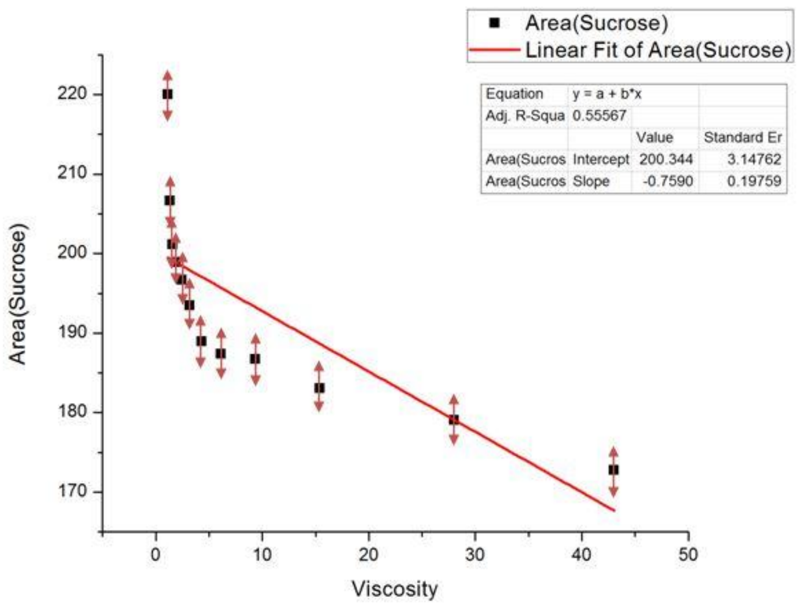
**Variation of Hysteresis area with Viscosity:**

The viscosity of the solutions and the obtained hysteresis area for the respective solutions are plotted to see the change of area with viscosity.

**Viscosity of Sucrose solutions:**

***TABLE: Values of Sucrose solutions and their Viscosity***

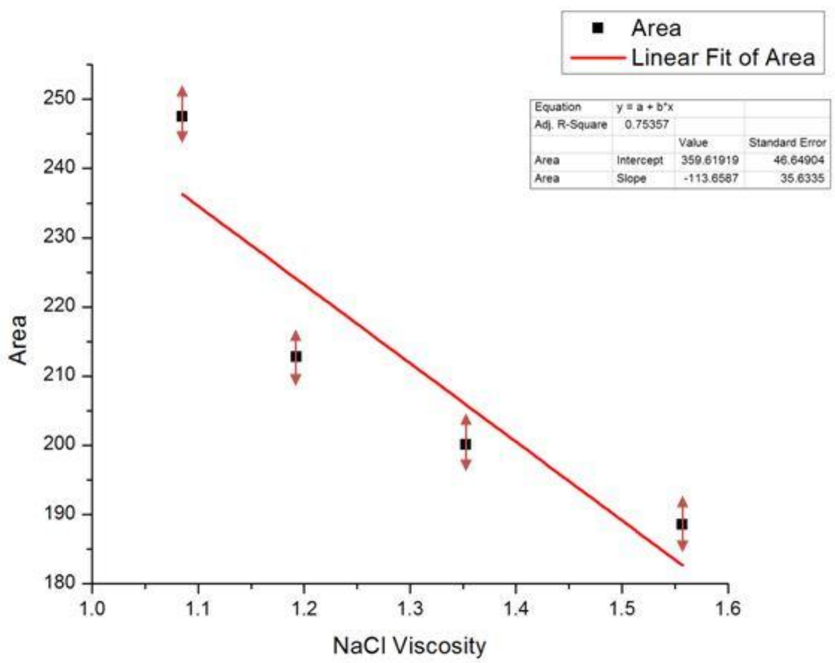
| *Concentration of Sucrose(%)* | *Viscosity* |
|---|---|
| **5** | 1.144 cp |
| **10** | 1.333cp |
| **15** | 1.589 cp |
| **20** | 1.941cp |
| **25** | 2.442 cp |
| **30** | 3.181cp |
| **35** | 4.314 cp |
| **40** | 6.150cp |
| **45** | 9.360 cp |
| **50** | 15.400cp |
| **55** | 28.02 cp |
| **60** | 43.05 cp |



**Viscosity of NaCl solutions:**

***TABLE : Values of NaCl solutions and their Viscosity***

| *Concentration of NaCl* | *Viscosity* |
|---|---|
| **5** | 1.085cp |
| **10** | 1.193cp |
| **15** | 1.353cp |
| **20** | 1.557cp |



**OBSERVATION**:

In the plots it is shown that the area of hysteresis effect produced by highly viscous solutions is less where as the less viscous solution produce greater area of hysteresis. In prism based liquid level sensors, there is a drop formation at the tip of the prism which is drew back to liquid surface due to the surface tension of the liquid sample. In this experiment the liquid samples of increasing concentration of individual solutions are used. Hence with the increase of concentration there is an increase of viscosity of the solutions. The increase in viscosity of the solutions increases the molecular weight also. The high viscous liquid in contact with the prism tip slides off early compared to the low viscous liquid due to the surface tension of the liquid. From the concept of critical surface tension, it can be shown that at a particular angle of contact for glass and liquid (of particular surface tension) the hydrophobicity is increased for glass. The prism is 45°-90°-45° angled prism, the angle of contact is at the 45° facet of the prism. Hence in this experiment the liquids of high concentration drops of the prism tip early resulting in early coupling of light producing less area of hysteresis.

**RESULT:**

The early rise of output voltage was observed for more concentrated solutions. This observation is presented as the consequence of the change of viscosity, refractive index, the slow movement of the sensor head which allowed the surface tension of the liquid to draw the liquid drop back to the surface and the shape of the prism.

**APPLICATIONS**:

This sensor can be used to determine the pure form of liquid by the calculation of hysteresis area of a pure liquid and its diluted concentration. This study has applications in fields such as petroleum industries, refractometery and bio medical fluids diagnosis etc.

References

[1] Hydrophobicity, Hydrophilicity and Silanes By Barry Arkles | Gelest Inc.,Morrisville, PA

[2] Design and operation of a fiber optic sensor for liquid level detection by Hossein Golnabi

[3] http: // hyperphysics.phy-astr.gsu.edu/hbase/phyopt/reflco.html.

[4] Fiber-optic liquid-level sensor by Pekka Raatikainen a,U, Ivan Kassamakov b, Roumen Kakanakov b, Mauri Luukkala

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