Surface Tension and Coefficient of Viscosity of Liquid from the Diffraction Pattern of Surface Ripples

P.A. Nagpure

Assistant Professor,
Department of Physics,
Shri Shivaji Science College, Amravati, INDIA.

Abstract : This paper describes a simple technique for determining the surface tension of the liquids, based on laser light diffraction on capillary waves. Capillary waves of given frequency are created by an exciter needle acting on the surface of liquid which acts as a reflection grating, the constant of which(the wavelength of capillary waves) can be determined based on unknown incidence angle of light(grazing angle). This technique permitted accurate measurement of the spot and eliminates most of the fluctuations due to vibration. The surface tension of liquids are calculated by applying the dispersion relation for capillary waves and analyze the difficulties that will arise when setting up and conducting the experiment in detail. It also reports the refractive index liquids in the visible region by an Abbe's refractometer.

***IndexTerms* - Surface tension, Coefficient of viscosity of liquid, Refractive Index of liquids.**

I. INTRODUCTION

Formation and propagation of waves on a liquid surface are important and well-studied phenomena. For such waves, the restoring force on the oscillating liquid is partly due to gravity and partly due to surface tension. For wavelengths much smaller than a critical wavelength, the effect of gravity is negligible and only surface tension effects are needed to be considered.

Surface tension is a property of liquids due to which the liquid surface behaves like a stretched membrane [1]. At liquid-air interfaces, surface tension results from the greater attraction of liquid molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion) [2]. When the liquid surface is disturbed, the disturbance propagates as a wave just as on a membrane. An electrically-driven vibrator is used to produce waves on the water surface. When a laser beam is incident on these surface waves, they act as a reflection grating, producing a well-defined diffraction pattern.

In 1894, Lord Rayleigh measures the surface tension of water by analyzing ripple. Rayleigh's result of 74mN/m was remarkably close to accepted value, 72.75 mN/m of the surface tension for a water air interface at 20^0.

Surface tension waves are damped (their amplitude gradually decreases) as they propagate. This damping is due to the viscosity of the liquid, a property where adjacent layers of a liquid oppose relative motion between them [2]. At molecular level, viscosity is a results the interaction between the different molecules in a fluid. This can be also understood as friction between the molecules in the fluid.

The Abbe's instrument is the most convenient and widely used refractometer . The Abbe's refractometer is very popular and owes its popularity to its convenience, its wide range (n_D = 1.3 to 1.7), and to the minimal sample is needed. The accuracy of the instrument is about ±0.0002; its precision is half this figure. A precision Abbe's refractometer, that diminishes the uncertainties of the ordinary instrument by a factor of about three, is also available; the improvement in accuracy is obtained by replacing the compensator with a monochromatic source and by using larger and more precise prism mounts. The former provides a much sharper critical boundary, and the latter allows a more accurate determination of the prism position [2].

II. THEORETICAL BACKGROUND

The equation for displacement of simple harmonic progressive wave is given by,

$$Y = A\sin\frac{2\pi}{\lambda}(vt - x) \tag{1}$$

If V be the velocity of the wave under the action of both gravity and surface tension,

Then,

$$v = \sqrt{\frac{\lambda g}{2\pi} + \frac{2\pi T}{\rho\lambda}} \tag{2}$$

If $\lambda > \lambda_C$, the first term becomes more important as λ increases and therefore neglecting the second term , we have

$$v = \sqrt{\frac{\lambda g}{2\pi}} \tag{3}$$

Disturbances of this type, whose wavelength is greater than critical value, are called gravity waves. If $\lambda < \lambda_c$, the second term becomes more predominant. so that,

$$v = \sqrt{\frac{2\pi T}{\rho\lambda}} \tag{4}$$

The propagation of waves is due to surface tension and these waves are called ripple waves or capillary waves.

Surface ripple behave like a diffraction grating, and that the effective grating spacing λ_s of the surface waves is given by,

$$\lambda_s = \frac{2\pi}{q}\sin\theta \tag{5}$$

The vibration frequency (f) of the waves is related to the wave number q by

$$\omega^2 = \frac{T}{\rho} q^3 \tag{6}$$

Where, $\omega = 2\pi f$ and ρ is the density of the water.

For determination of surface tension

$$f^2 = \frac{1}{4\pi^2}\frac{\sigma}{\rho}\left(\frac{2\pi}{\lambda}\frac{\sin\theta}{L}\right)^3 (x_1)^3 \tag{7}$$

The surface tension waves are damped due to the viscosity of water. The wave amplitude, h decreases exponentially with the distance, s, measured from the vibrator,

$$h = h_0 e^{-\delta s} \tag{8}$$

Where, h0 is the amplitude at the vibrator position and is the attenuation constant.

Experimentally, amplitude h0 can be related to the voltage (Vrms) applied to the vibrator assembly as,

$$h_0 \alpha (V_{rms})^{0.4} \tag{9}$$

The attenuation constant is related to the viscosity of the liquid as

$$\delta = \frac{8}{3}\frac{\pi n f}{6} \tag{10}$$

Where, η is the viscosity of the liquid [5].

III. THE EXPERIMENT

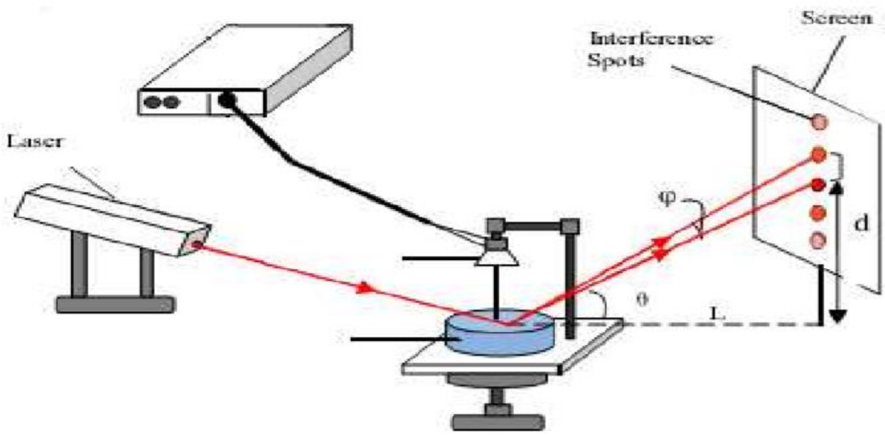

Fig: 1 A laser beam is aimed at a reservoir containing the sample, with ripples induced by a wire attached to a speaker driven by a function generator. The surface ripples act as a diffraction grating causing the interference spots on the screen [1].

Here, l1 is the length between the light sensor aperture and outer edge of the water tray i.e. line where the laser strikes the water surface. The centre of this line is the point of incidence of the laser. l2 is the distance of this point from the edge.

As shown in Fig. 1, a water tray of diameter about 18.5 cm is filled with the experimental liquid to a depth of 1 cm. A metal pin with its blunt end glued vertically upright to the diaphragm of a loud speaker (held above the water try) acts as an exciter. When slightly immersed in the liquid and driven by a low frequency sinusoidal signal generator, this exciter vibrates vertically up and down and generates the desired liquid surface waves. Light from He-Ne laser (wavelength=632.8 nm) having a beam diameter of 1.8 mm is directed to fall on the liquid surface at an angle of incidence. The laser beam incident on the dynamical phase grating formed on the liquid surface produces Fraunhofer diffraction pattern which is observed on a screen placed at a fairly large distance from the diffraction center [3].

Unlike the transmission diffraction grating in which the light passes through a series of narrow slits located between the opaque parts of a glass or plastic plate, with reflection gratings the light is reflected from a series of parallel, close, smooth surfaces and is absorbed or diffused by the surface areas located between them consequently, the destructive interference does not occur along every path where the reflected angle is not equal to the incidence angle, but on some of them the constructive interference will occur. As a result, a series of bright spots appears on the screen, rather than just one with reflection gratings the light is reflected from a series of parallel, close, smooth surfaces and is absorbed or diffused by the surface areas located between them [4].

Light from a 5mW He-Ne laser (= 632.8 nm) having a beam diameter of 1.8 mm is directed to fall on the liquid surface at an angle of incidence, of 5.6540 as noted in our experiment. The laser beam incident on the dynamical phase grating formed on the liquid surface produces Fraunhofer diffraction patterns which is observed on a screen placed at a fairly large distance (1.658 meters in our case) from the diffraction center. During our experiment, the room temperature was recorded at 250C [5].

Abbe's refractometer is used to measure the refractive index of the given organic liquid. Using a particular monochromatic light source, the apparatus is calibrated with water as the liquid [3].

IV. RESULT AND ANALYSIS

Five fluids were used in the experiment: double distilled water, 3 different types of tap water from different areas and rain water. Using the values of the frequency of capillary wave's ν, distance h, angle θ, the known wavelength of laser light λ, the distance L, amplitude of sine wave Vrms and the values of diffraction angles δ, gives the numerical values of surface tension σ and coefficient of viscosity η. Table 1 to 4 presents the results of measurements for double distilled water while the data tables for other liquids are not shown because of their enormous size. Using the procedure described, and based on measurement results, we obtained the coefficient of surface tension σ =0.074.21 N m−1 and viscosity η=0.011 Poise for double distilled water [4].

To determine the values of incident angle we measured the grazing angle of the laser beam θ. The value of this angle is calculated approximately from θ = arc tan X/Y. To measure this angle, a graph was plotted, showing the dependence of height X as a function of the distance Y. The height X was measured in the vertical plane of the screen, from the reference level of the horizontal surface of liquid in the plate to the point, which is the laser beam geometrically reflected from the calm surface of liquid.

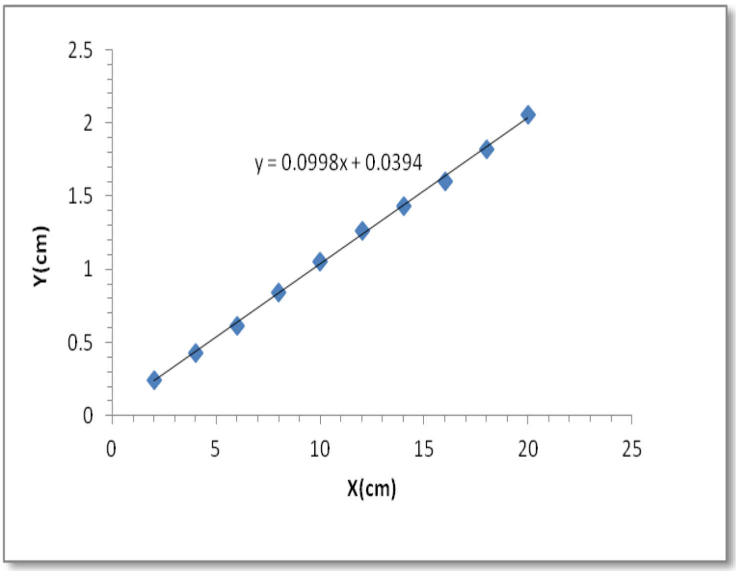

Fig: 2 Graph of x–displacement of the assembly and corresponding y-displacement of the laser spot

Measurement results for double distilled water $-l_2$=0.063m, l_1=1.595m, L=1.658m, θ=5.654^0 at 25^{0}C.

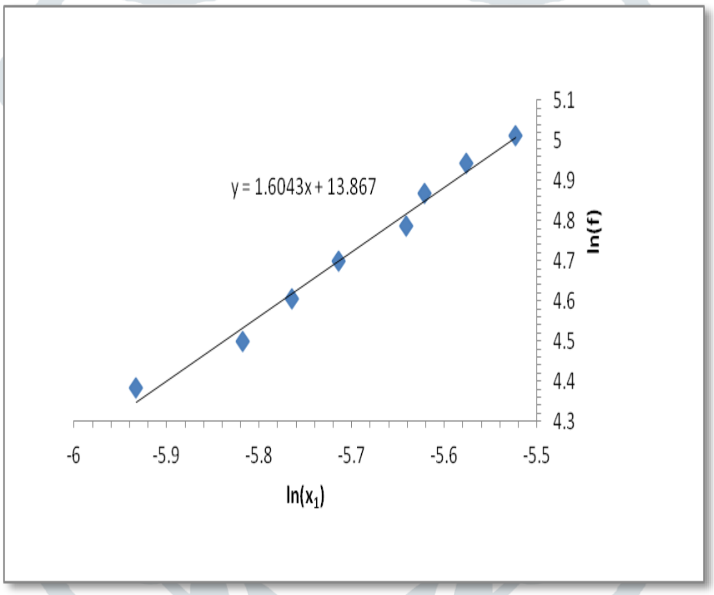

Fig: 3 Graph of ln(x_1) versus ln(f)

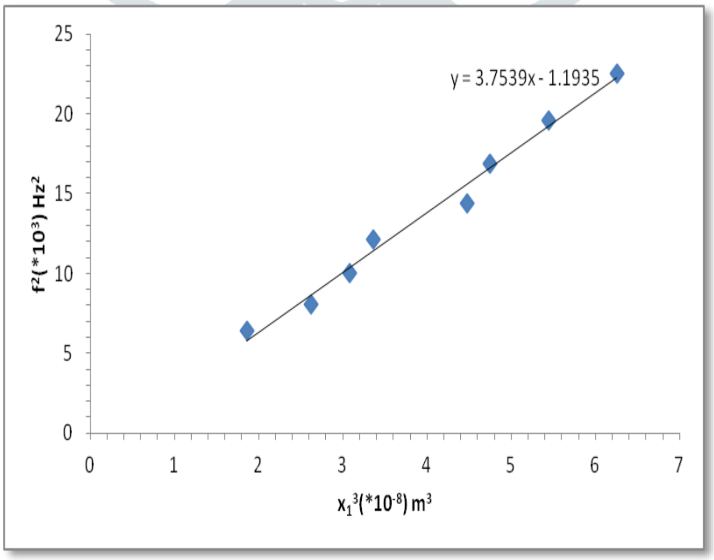

Fig: 4 Graph of $x_1$3(*10^{-8}) m^3 versus f^2(*10^3) Hz

Frequency of the signal generator = 100 Hz

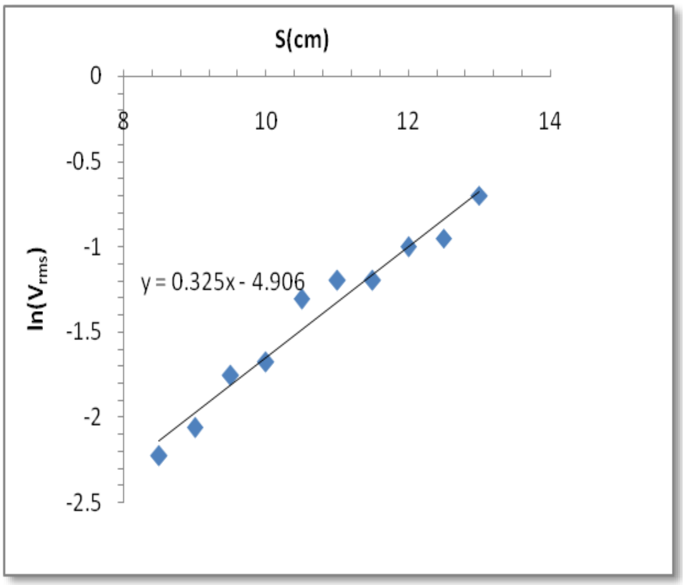

Fig: 5 Graph of vibrator position S(cm) versus ln(V_{rms})

Table 1: Measured values of the coefficient of surface tension viscosity and total dissolved salts for water samples

Liquids	σ (dyne/cm)	η (poise)	TDS (ppm)	Refractive index at 20^0C
Double distilled water	74.21	0.0111	1	1.32456
Rain water	67.48	0.00996	71	1.32365
Tap water sample 1	57.97	0.008210	231	1.32565
Tap water sample 2	44.37	0.009278	280	1.32565
Tap water sample 3	65.04	0.00855	173	1.32565

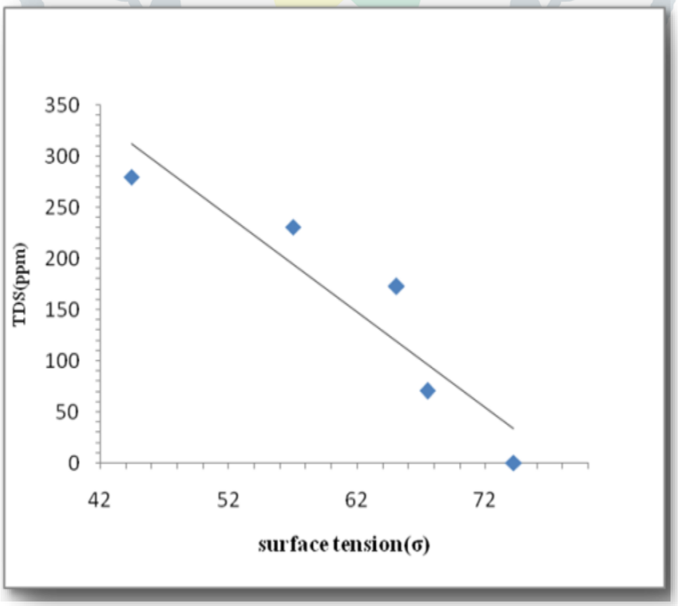

Fig: 6 represent the relation between surface tension and total dissolved salts present in the water samples.

Our special interest was the TDS dependence of the surface tension. In our study it is found that the surface tension of water decreased with TDS. The results of Fig. 6 show this correlation. When a surface is exposed to the air it gradually becomes contaminated and its properties progressively change.

V. CONCLUSION

The determination of surface tension and viscosity of water by ripple method using specially designed apparatus was carried out in the present research work. The values of surface tension and viscosity are consistent with the standard values.

The experimental results show that there is a decrease in surface tension with the addition of impurities. The fundamental surface properties are demonstrated in the relative enrichment of the volatile component in the surface. This enrichment strongly depends on composition of the liquid phase. The results obtained shows that impurity present in water greatly influences the surface tension with a linear relationship.

REFERENCES

[1] http://www.ipho2015.in/

[2] https://vlab.amrita.edu/?sub=1&brch=195&sim=545&cnt=1

[3] H. Ghahremani, Pelagia Research Library, "Measuring surface tension of binary mixtures of water + alcohols from the diffraction pattern of surface ripples", pp. 212-221, 2011.

[4] D Nikolic1 and Lj Nesic2 Eur. J. Phys, Determination of surface tension coefficient of liquids by diffraction of light on capillary waves.Vol. 33, pp. 1677–1685, 24 September 2012.

[5] T.K. Barik, P.R. Chaudhuri, A. Roy, S. Kar, *IOP Journal*, 2006, 17, 1553.