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MEASUREMENT OF SURFACE TENSION BY UNSTABLE PENDANT DROPS

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ABSTRACT. A workable experimental technique has been evolved to subject the unstable pendant drops to surface tension measurements, utilising the expression derived earlier. The values calculated from the expression by the use of the observed data on three liquids compare favourably with the known constants on surface tension.

INTRODUCTION

Although the pendant drop method was studied long ago by Worthington (1881) and Fergusson (1912), it remained in disrepute for a considerable time. It is comparatively recently that it has been made useful for precision work as a result of critical study of it by Andreas, Hauser and Tucker (1938). The method has been laid on better foundations by Fordham (1948) by supplying a tabular set of values for the calculation of surface tension from measurements on pendant drops. Brown and McCormick (1948), while working out a new drop-weight method have shown by dimensional analysis that the shapes of all drops forming on a conical tip are similar at the stage of instability.

On this basis one of the present authors (Parvatikar, 1949) derived the following equation giving surface tension ratio γ_1/γ_2 of two liquids in terms of the parameters of the unstable pendant drops:

$$\frac{\gamma_1}{\gamma_2} = \frac{\sigma_1 \, de_1^2}{\sigma_2 \, de_2^2} \qquad \ldots \quad (1)$$

where, σ and de are respectively the effective density and equatorial diameter of a drop of the liquids 1 and 2. Thus by measuring the equatorial diameters de_1 and de_2 of the drops of two liquids at the stage of instability, and taking the surface tension of one of the liquids as known, the surface tension of the other can be calculated.

While doing some fundamental work on pendant drops, it was felt worthwhile to test the above equation experimentally, since such a study does not appear to be on record within the knowledge of the present authors. The experimental problem in work of this type, was of measuring the equatorial diameters of drops at the critical stage of instability, when the drops attain similar shapes and it was thought it could be solved by employing a conical tip as in the experiments of Brown and McCormick (1948). According to them a rop detaching from a conical tip is free to adjust its shape and size and consequently at the unstable state, all such drops are similar in shape. The point, however, for correct experimental adjustment is to fix the stage of instability of the drop and to measure its dimension at that state. If sufficient time is allowed for proper development of drops formed at a conical tip, one could follow the changing size of the drop until it just collapses from it. The experimental set-up devised for this purpose and operations involved in measurements are described below.

EXPERIMENTAL AND RESULTS

Drops were formed in air saturated with its own vapour in a thermostat at the tip of a cone. For the formation of drops, the liquid was sucked into a brass tube of external diameter 7 mm. and internal diameter of about 5 mm. One end of the tube was tightly screwed by the conical tip, similar to that of Brown and McCormick (1948), having three holes drilled on it symmetrically, the other end being connected to a glass syringe through a rubber tubing. The set-up is shown in figure 1. The solid cone (figure 2) forming the tip had an angle of 60°. The side of the cone was about 1.2 cms. The three narrow holes having equal bores of about 0.5 m.m. were symmetrically disposed with respect to the tip and had their out-lets almost equally spaced in the middle of the horizontal plane of the inverted cone. The similarity in shapes of the drops at the unstable state is realised in such a conical tip.

The general procedure is to first form a small nucleus of a drop at the conical tip by releasing the liquid to flow through the holes and then allow the drop to grow under gravity. In order to align the drop in the field of view, which was once for all set, the brass tube was inserted rigidly and fixed into a metal tube with its boss-head fitted well into the ceiling of the thermostat case. The conical tip was then screwed tightly at the lower end of the brass tube. By sliding this tube into the metal boss-head, it was possible to move it up and down, as well as slightly sideways, to bring the conical tip into optical alignment. The thermostat has two glass windows into its opposite walls, one for admitting light to illuminate the drop, and the other to observe it for measurements. The thermostat was heated electrically to any desired temperature by electronic temperature control, maintaining the temperature faithfully to within $\pm 0.1°C$.

The liquid to be investigated is sucked by way of the holes in the conical tip into the brass tube by manipulating the syringe. The rubber tubing connect-

ing the syringe with the metal tube is then squeezed by the screw of the pinch-cock, and then completely detached from the latter. The pinch-cock screw is then gradually loosened to allow air to get in. Through this procedure, a fairly long time of 6 to 7 minutes elapses before the drop develops fully to the point

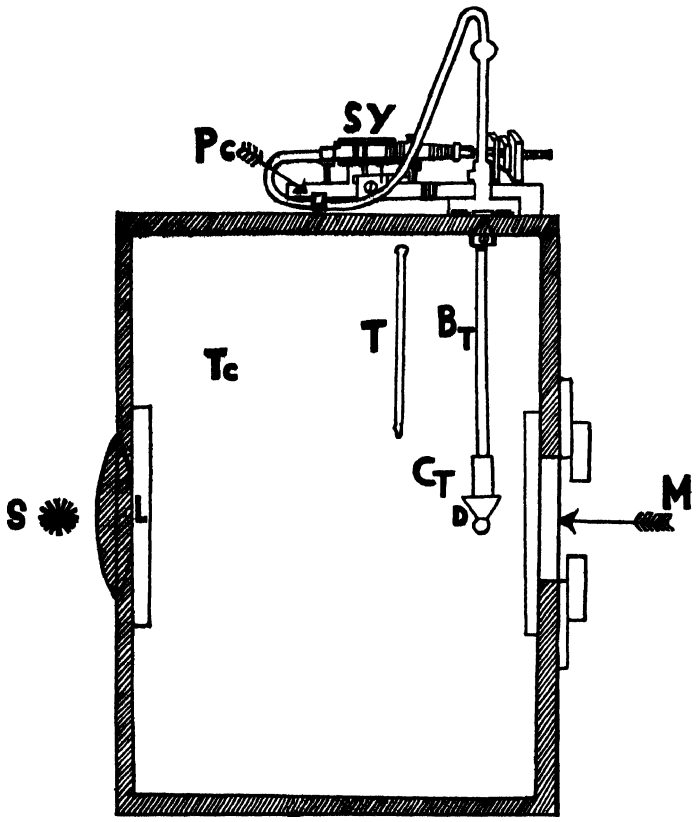

Fig. 1. The experimental assembly.

S – Source	C_T – Conical tip
L – Collimating lens	D – Drop
T_C – Thermostat chamber	M – Microscope
T – Thermometer	SY – Syringe
B_T – Brass tube	P_C – Pinch-cock

of detachment. The drop was observed against diffuse light through a microscope which was provided with a scale having hundred equally spaced divisions (equivalent to approximately 4 m.m.) in its eye-piece. Either the maximum equatorial diameter D_e or the maximum equatorial radius R_e of the drop, whichever could be accommodated and observed within the extent of the microscope scale, was measured for a number of drops, and the mean of the same was determined. Table I below is a sample set of such observations on water at 30°C.

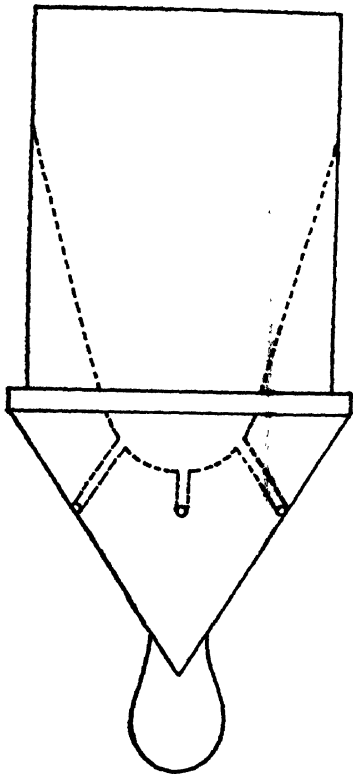

Fig. 2. The conical tip.

TABLE 1

Growth of a drop of water at 30°C

Time of formation of the drop				Max. Eq. radius R_e in scale div.
Mins.		Secs.		
0	—	0		—
1	—	0		—
2	—	0		—
3	—	0		—
4	—	0		—
4	—	30		62.0
4	—	50		61.3
5	—	10		60.6
5	—	30		59.8
5	—	50		59.0
6	—	10		58.1
6	—	20		57.2
6	—	30		56.3
6	—	40		55.4
6	—	55		55.2
6	—	56	(detached)	55.0

Without disturbing the microscope set-up, the metal tube with its conical tip was taken out and was thoroughly washed and dried. It was fixed in its original position for taking observations on drops of a liquid of known surface tension. Water was chosen in the present case. The liquids chosen for surface tension measurements were toulene, *m*-xylene, and benzene, Observations were also made on water at high temperatures to explore the capacity of the method to take account of the changes in dimensions of the drops with change in temperature. Assuming the surface tension of water at 30°C to be known, the values of surface tension of the above liquids were calculated from eq. (i). As the primary aim of the investigation was to explore the workability of the method, no attempt was made to obtain the estimate of accuracy of results. However, the observations on the sizes of the drops in Table II are the mean of at least ten independent observations, which did not vary appreciably from each other.

TABLE II

Liquid	Temp. °C	Effective density in gm/c.c.	Measured dimensions		Surface tension in dynes/cm.	
			R_e	D_e	Present work	I.C.T.
Water	30	0.9946	55.0	—	—	(71.18±0.05)
Toulene	30	0.8525	—	73.7	27.3	27.3 ±0.1
m-xylene	30	0.8530	—	74.4	27.9	27.8 ±0.1
Benzene	30	0.8622	—	73.8	27.7	27.56±0.05
Water	35	0.9928	54.8	—	70.5	70.38±0.05
Water	45	0.9891	54.2	—	68.7	68.74±0.05
Water	60	0.9822	53.3	—	66.0	66.18±0.05

On comparing the results in the last two columns of Table II, it is apparent that there is a fair agreement of measured values with the accepted constants of surface tension. While the above position is not unsatisfactory, there is scope for improving the technique of the method to obtain better precision in measurements. The method, therefore, seems to have practical potentialities. The work in this direction is proceeding.

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