RUPTURE OF WATER DROPS OVER LIQUID SURFACES

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ABSTRACT. The critical height to produce rupture of water drops of different sizes over oils and their mixtures have been observed. A linear relation is found to exist between the critical height and the reciprocal of the mass of the drop, for a given liquid. The variation of the critical height for a particular size of the drop with different liquids of different viscosities, shows a distinct minima in each case of the experimental curves. The surface tension, interfacial surface tension, and density of the oils have also been measured, which may throw light on the true mechanism of the rupture of water drops.

INTRODUCTION

When water drops are allowed to fall on certain liquids whose densities are less than that of water and which are not miscible with it, it has been found (Singh and Sinha, 1944) that either the drops sink as a whole or rupture into two distinct droplets permanently. There is a certain critical height such that when the drops fall through a height less than this critical value they sink as a whole but as soon as the height exceeds this critical value, they rupture into two or more distinct droplets.

EXPERIMENTAL

The experimental arrangement to produce the water drops of different sizes was as follows :—A glass jar was filled with water having a side-hole near the bottom. Capillary tubes of different sizes were taken and joined to the side hole of the glass jar by means of a rubber tubing, having a pinch cock to regulate a steady formation of the water drops. The glass jar was raised to a certain level to produce the hydrostatic pressure for forcing out the water from the end of the capillary tube. This hydrostatic pressure was kept constant throughout by an adjustment of the water level in the jar. The velocity of impact of the water drop on the liquid surface to produce its rupture is given by $v = \sqrt{2gh}$, if it starts initially from rest, where g is the acceleration due to gravity and h is the critical height. This condition can be rigidly obtained if the capillary tube through which the water drops fall is kept in a horizontal position. For the sake of experimental facility, the capillary tube was kept in a vertical position, but here also the initial velocity is approximately zero as the drop remains sticking at its tip bofore falling under gravity.

There was considerable difficulty in selecting the liquids which are lighter than water, not miscible with it and at the same time their vicosities and other properties are changing in regular order. The only alternative was to take a

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mixture of two liquids in which one is highly viscous and not the other has got a low coefficient of viscosity and the two mix completely without any chemical reaction. A mixture of turpentine oil and castor oil satisfied these criterions to a considerable extent and hence their mixtures of different proportion by volume were taken.

There was considerable difficulty in ascertaining the critical height for turpentine oil. Fluctuating results were obtained on different occasions. The probable reason for this is that penene $C_{10}H_{16}$, which is the chief constituent of turpentine oil absorbs oxygen from air with the formation of H_2O_2 and production of resin etc. The constitution of penene is based largely upon that of pinole, $C_{10}H_{16}O$ a product obtained by the elimination of water from soberol, $C_{10}H_{16}(OH)_2$ which is formed when penene is left exposed to sunlight in contact with air and water. The constitution of turpentine oil was changing daily and the critical height was fluctuating on different days.

The mixture of turpentine oil and castor oil in various proportions were not transparent at first. After the passage of a number of water drops and exposure to air, the mixtures became clear and the rupture of water drops was visible with ease. As all the liquids contained turpentine oil in a definite proportion, the readings of the critical heights were taken rapidly and they were kept in corked bottles after separating the water from the liquids which settled below them.

The experimental liquid was kept in a beaker which was raised or lowered by means of a screw arrangement. The height was measured from the centre of the drop at the end of the capillary tube to the surface of the liquid in the beaker. At first when the liquid surface was quite near the end of the capillary tube, the drops sink as a whole. With increase in height a very tiny droplet is occasionally seen either along with the parent drop or sometimes saparated from it which soon disappears instead of becoming more distinct as the height is further increased. Hence heights at which this happened was discarded. With further increase in height, the tiny droplet again reappears which increases in size as the height is increased. This was the critical height and was measured carefully. After further increase of the height, the satellite droplet coalesces with the parent one and then ruptures into two or more distinct droplets as the height is still further increased. It seems that there are more than one critical height and further work on them is still in progress. Here the observation was only confined with the first critical height, to break the drop permanently into two or more droplets.

The density of the liquid mixtures was determined by means of asp. gr. bottle. The surface tension was measured by means of the capillary ascent method while the interfacial surface tension was measured by the drop weight method (Guye and Perrot 1901). In order to find the coefficient of viscosity of the liquids, the time of flow of a certain volume of the liquid as well as that of the same volume of water was noted. Knowing the coefficient of viscosity of water at that temperature, the coefficients of the other liquids were calculated out.

Table 1 gives the first critical height of the water drops of different masses, for the various mixtures. Table 2 gives the values of density, coefficient of viscosity, surface tension and interfacial surface tension of the various liquids used. The market castor oil was taken and hence much reliance cannot be put on the absolute values of these measursments. Only the relative values may be emphasised which mark the qualitative features of the experimentally obtained graphs.

TABLE 1

Capillary tube no.	Wt. of water drop m in gm.	$\frac{1}{m}$	Critical height in cms.						
			Liq. 1	Liq. 2	Liq. 3	Liq. 4	Liq. 5	Liq. 6	Liq. 7
1	·0107 gm.	93·46 gm.	9·0	8·4	3·9	3·2	3·1	5·4	10·0
2	·0160 ,,	62·5 ,,	6·4	6·0	3·1	2·7	2·5	4·2	7·2
3	·0271 ,,	36·9 ,,	4·2	3·9	2·5	2·2	2·0	3·0	5·1
4	·0364 ,,	27·47 ,,	3·4	3·2	2·2	2·0	1·8	2·6	4·3
5	·0494 ,,	22·43 ,,	3·0	2·8	2·0	1·8	1·7	2·4	4·0
6	·0831 ,,	12·03 ,,	2·1	2·0	1·8	1·7	1·5	1·9	3·1
7	·1116 ,,	8·96 ,,	1·9	1·8	1·7	1·6	1·4	1·8	2·7

TABLE 2

Liq. No.	Comp. by volume	Density in gm./cc.	Cofficient ot viscosity in c. g. s. units at 28°C	Surface tension in dynes/cm	Interfacial S. T. in dynes/cm.
1	50% C. O. 50% T. O.	·92	·1942	7·88	20·94
2	40% ,, 60% ,,	·91	·1738	5·75	19·82
3	30% ,, 70% ,,	·89	·0562	5·51	19·31
4	20% ,, 80% ,,	·88	·0324	5·48	18·14
5	10% ,, 90% ,,	·87	·0182	5·33	17·46
6	0% ,, 100% ,,	·85	·0105	5·18	20·66
7	Kerosene oil	·77	·0082	4·20	22·84

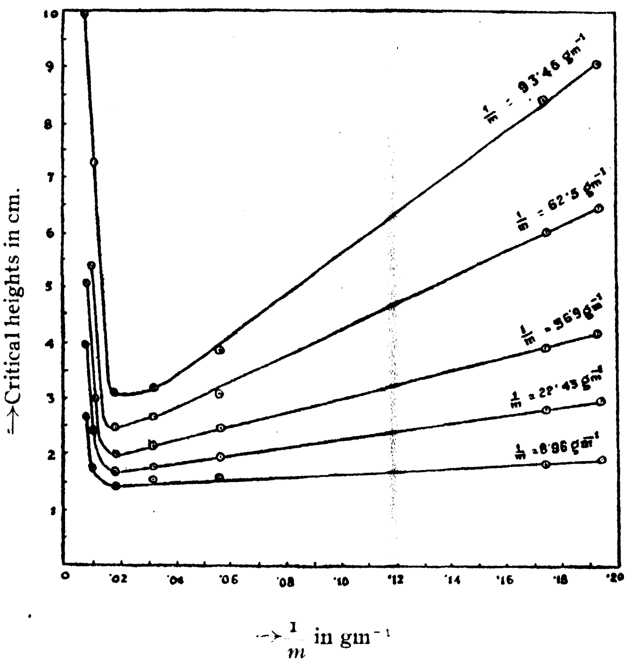

FIG. 1

DISCUSSION OF RESULTS

A plot of h the critical height in cm. against $1/m$ where m denotes the mass of each drop in gms. gives a straight line characteristic of the liquid used as shown in Fig. 1. The equations of the straight lines are $h = 1/m \tan e + c$ where $\tan e$ is the inclination and c is the intercept on the y-axes. Therefore $mh - mc = \tan e$ or $mgh - mgc = g \tan e \times a$ constant quantity for a particular st. line, where g is the acceleration due to gravity. The dimension of c is that of height and hence the left hand side denotes the difference of two energy terms. The first energy term is the kinetic energy generated at the expense of the potential energy which tends to produce the rupture of the water drop while the second term represents a constant energy for a particular drop. Probably it may be due to the adhesive forces of surface tension, the symmetry of the drop and the other properties of the liquid which oppose the rupture of the water drop. It may be noted that there is a tendency of convergence of all the straight lines of the various mixtures except that of kerosene oil whose intercept on the y-axes is of a different length. It may also be noted that the slope of the straight lines goes on diminishing as the coefficient of viscosity becomes less, but after a certain value of the coefficient it begins to increase instead of decreasing with further decrease in the coefficient of viscosity.

A plot of h the critical height in cms. against μ the coefficient of viscosity of the various liquids for a particular value of the mass of the drop is shown in

Fig. 2. Only five curves for five masses of water drops have been plotted here for fear of too much congestion. The critical height at first decreases, takes a stationary value and then increases all of a sudden as the value of the coefficient of viscosity gradually decreases. The particular value of the coefficient of viscosity of which the curves takes a sharp bend and the value of the critical height becomes stationary, is nearly the same in all the curves of different masses of the water drop.

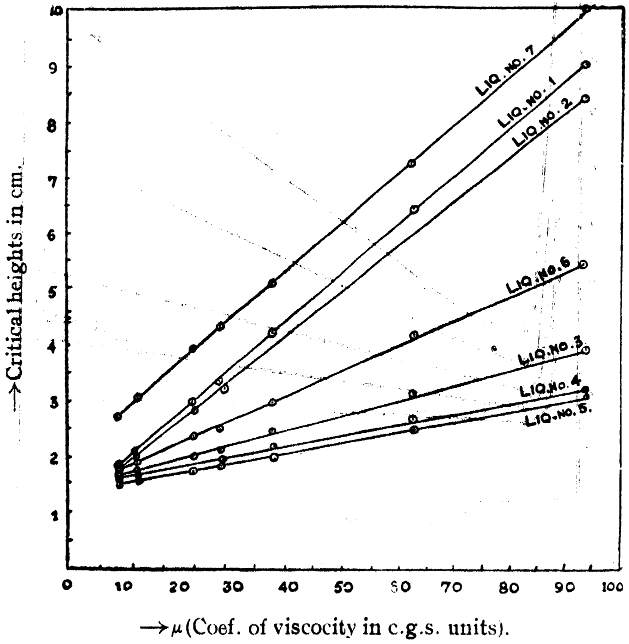

FIG. 2

With the present data, it is not safe to suggest anything about the actual mechanism of the rupture of the water drop and whether there is more than one such type of mechanism. Further work on the second and third critical height is still in progress which may help in the understanding of the hydrodynamics of the drop.

ACKNOWLEDGMENTS

The author is highly indebted to Dr. B. N. Singh for suggesting the problem and to Rev. Dr. C. P. Saldanha, S. J., for giving all facilities for the work.

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REFERENCES

Guay and Perrot, 1901, *Arch. Sci. Phys. et Nat.*, **11**, 225.
Singh and Sinha, 1944, *Curr. Sci.*, **13**, 157.