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Surface Tension of Rainwater

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Abstract

Surface tension is a property of liquid where liquid surface at rest contract into minimum possible area. Surface tension has a tendency to create a stretched membrane of liquid on which heavy objects like needle can float or waterspider can walk. Aim of the research is to estimate value of surface tension of rainwater and compare with the standard value of surface tension of water at temperature 25℃. Surface tension of rainwater is calculated experimentally by using capillary-rise method in laboratory. In this experiment one capillary is inserted in liquid and the rise of liquid in the capillary is measured using travelling microscope from the level of water in beaker. In this research, measurement of radii, height of liquid in capillary and surface tension are carefully analyzed. Researcher found that surface tension of rainwater is greater than the standard value of surface tension of water at 25℃. The height of liquid depends on radii of capillary, as radii increases height of liquid column inside the capillary decreases. It is observed that as height of liquid column in capillary decreases, the surface tension of rainwater increases.

Keywords: Surface tension, capillary-rise method, rainwater, ecological balance.

1. Introduction - Existence of surface tension

Water is basic element of biological system and basic need of human body. Rainwater is an essential component of ecological system as rain is the only source of water on the earth. Surface tension is a property of water which helps to reduce evaporation and conserve water in the ecosystem. Surface tension supports aquatic life to survive and maintain ecosystem balance. Surface tension facilitates water absorption by soil and increase groundwater reservoirs level. Surface tension also helps the plants and trees to absorb the water inside the roots and stem. Surface tension is taken into account in an industrial process like coating, printing, and cleaning.

Surface tension is microscopic as well as macroscopic phenomenon which shows elastic tendency due to attractive cohesive forces acting between molecules of liquid in the surface film when the liquid is at rest. Surface tension refers the composition of liquid and strength of bonding between molecules of liquid. The tension created on the free surface to increase the surface area by unit area with increase in energy is called surface tension. Water molecules cling to each other to form strong bonds as number of molecules on free surface are less and these molecules are also in contact with air molecule. So cohesive force acts strongly in case of water between surface molecules giving rise to surface tension phenomenon. Now it's really interesting to estimate the surface tension phenomenon of newly formed water, i.e., rainwater.

For this purpose researcher has used the capillary rise method to calculate the rainwater surface tension. Researcher found the capillary rise method as a quick and easy tool to find the surface tension of rainwater and also more accurate than other complicated techniques. Researcher noted the standard value found by other researchers as in further discussion. D.P. Adikari, TB Budha and Anup Banst found the standard value of surface tension at 23℃ as 72 dyne/cm. Similarly Concetto Gianio found surface tension of water as 72.53dyne/cm at 20℃. Anasafya found the value of surface tension of water as 72.4 dyne/cm in her research. International table of surface tension has value at 25℃ as 72.73 dyne/cm.

Mechanical analogy – Molecular theory of surface tension.

Consider liquid molecules possess definite size and shape which can allow relative motion to each other. This relative motion of liquid molecule help to explain the tendency of liquid surface to contract. In liquid, the motion of molecules is due to cohesive forces acting between them. This property gives rise to fluidity. This fluidity helps water to pile up in the capillary, i.e., water in the capillary rises to some height when inserted in beaker full of water.

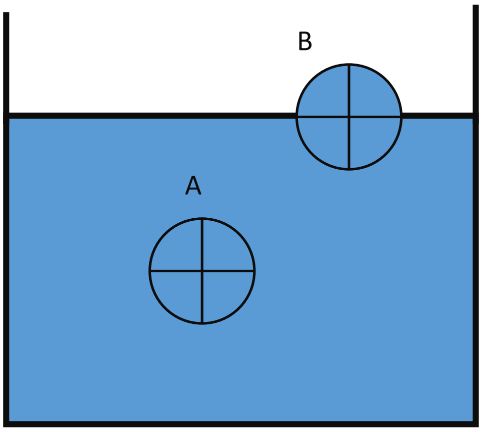

Fig 1

Let's discuss the molecular theory to understand the surface tension phenomenon. Consider a molecule of a liquid which is completely inside the liquid having sphere of influence of the order 10^{-7} cm. The molecule a situated deep inside the liquid below free surface is attracted in all direction by other liquid molecule due to cohesive force of attraction. This net cohesive force acting on molecule A due to all other liquid molecules is zero.

Consider molecule B on the surface of liquid as in fig 1. Molecule B is attracted half by air molecules and half by water molecules. The number of air molecules around the molecule B is less than the number of liquid molecule. The density of air molecules is less than the density of liquid molecules. Therefore the Molecule B is pulled inside by the cohesive force exerted by other liquid molecule. Due to this, there is net downward cohesive force acting on the molecules of surface film. This gives rise to force on free surface on both sides of an imaginary line of length l. this force on acting on both sides of free surface gives rise to an elastic membrane. Thus the free surface of a liquid at rest behave like stretched membrane which summarize the phenomenon as surface tension.

2. Method of research

Different method used for determination of surface tension are discussed further so as to understand the benefits of using capillary-rise method. Jaeger's method is based on the principle that excess pressure inside the air bubble in a liquid is 2T/r. The apparatus of Jaeger's method consist Woulf's bottle fitted with thistle funnel. Water is poured in funnel and allow to run through Woulf's bottle by means of stop watch pressure difference is calculated

$P = P_1 - P_2 = g\,(\sigma h - \rho x) = 2S/r$

In Quincke's method surface tension and angle of contact of mercury obtained in the form of a sessile drop can be found. Surface tension is found by equation,

$S = \frac{g\sigma h'^2}{2}$

Rayleigh's ripple method is method where the velocity with which waves travel over the surface of a liquid depends is estimated using gravity and surface tension.

$$v_2^2 - v_1^2 = \frac{8\pi Cr}{T}$$

All these method and many more are lengthy in measurements, time consuming, and complicated in calculation. Also the availability of instruments for these method is rare.

So researcher has used the capillary-rise method (Laboratory method) for this research study. The capillary rise method is easy, simple and accessible faster with respect to time management. This research gives accuracy in measurement than other method if all precautions are followed. In this method, the capillary is dipped inside the rainwater in the beaker and we see the rise of rainwater inside the capillary. This phenomenon of rise of water column in capillary is term as capillarity action. Capillarity is effect of surface tension. The principle of capillarity is simple and accurate to measure the surface tension of rain water. Only challenge are capillary should be sundried and rise in height measured accurately using travelling microscope.

When rain water rises in capillary it shows concave meniscus in nature. We explain this convexity or concavity of liquid surface from the consideration of cohesive and adhesive forces. Cohesive forces are force of attraction between molecules of same substances and adhesive forces are force of attraction between molecules of different substances. As the wall of capillary is vertical and uniform the adhesive force acts horizontally to the wall. The cohesive force is directed inside the liquid with an acute angle. The net adhesive force is stronger than the cohesive force the resultant force is directed in solid interface which is normal to free surface at all points. This makes the water to pile up inside the capillary giving rise to concave nature to the meniscus. Such liquids wet the solid surface.

During equilibrium, when all the forces acting on molecules near the wall are stable we see concave meniscus. Let us consider the height h of the liquid raised inside the capillary up to lower of meniscus from level of water in beaker. Let r and R be radii of capillary and meniscus. The pressure at point p below meniscus is $p_i + g\rho(h + h') = p_0$ where h' is height attained by the volume of liquid lens bet APC and DPE.

$\frac{2S}{R} = p_0 - p_i = g\rho(h + h')$…………………..(1)

From figure (2), r =R cos θ. Substitute value of R in equation (1), we get,

$\frac{2S\cos\theta}{r} = g\rho(h + h')$…………………………..(2)

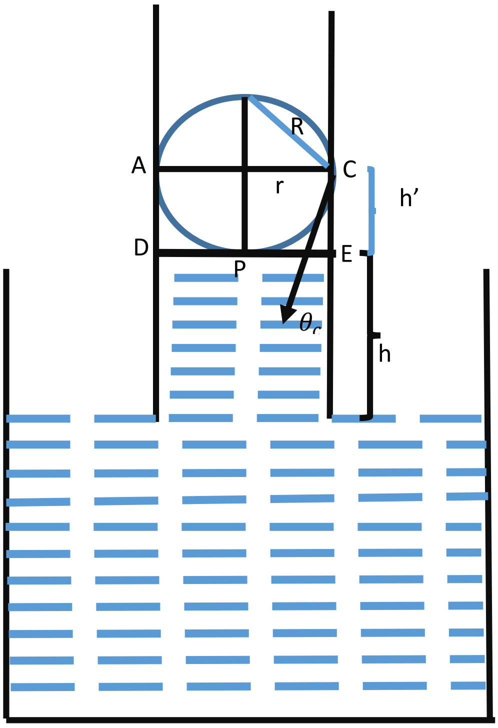

Figure 2

In equation (2), if we consider h>>h' and h' is negligible in length then,

S = $\frac{rg\rho h}{2\cos\theta}$ …………………..(3)

In case of rain water, the angle of contact observed is less than 10°.

$\therefore \cos\theta = \cos 0° = 1$………Substitute in equation (3)

$\therefore S = \frac{rg\rho h}{2}$…………………(4)

Now we will use this equation (4) for further estimation of surface tension of rain water. For water, density of water (ρ) = 1g/cm^3

3. Material and experiment

In this study to estimate the surface tension of rainwater following material was used : three capillary tube of different radii, a pointed tip needle, travelling microscope, adjustable stand, flask of 100ml, thermometer, rainwater in beaker, clamp stand. The arrangement of experiment is as shown in the figure

2. In this experiment, the researcher used single capillary at a time for estimating surface tension. The single capillary is inserted in the rainwater kept inside the flask of 100 ml at 25℃. As soon as the capillary is inserted the rainwater raises in the capillary and shows concave meniscus at certain height. This meniscus reading is measured using travelling microscope. Then the needle is allowed to just touch the water level present in the flask. The bottom of the needle which is touching water level in flask is measured using travelling microscope. Then the difference between the meniscus reading and needle reading, i.e., pointer reading is calculated as height of the liquid column in the capillary. This height is substituted in equation (4) and surface tension is estimated.

Calculation and analysis

Least count of main scale of travelling microscope = 0.05 cm

Vernier divisions of travelling microscope = 50

Least count of travelling microscope = $\frac{0.05}{50}$ = 0.001 cm

Figure 3

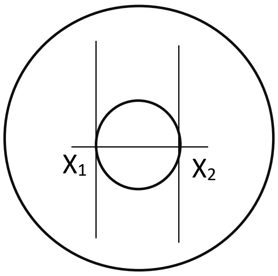

Table 1. Radii of capillary tube (r)

Sr no.	Inner wall X_1	Inner wall X_2	Radius of capillary (r)
1	4.165	4.105	0.06
2	4.270	4.177	0.093
3	4.130	4.030	0.1

Table 2. Hieght of liquid (h)

Sr no.	Meniscus reading (m)	Pointer reading (n)	Height (h = m-n)
1	9.535	6.695	2.84
2	8.210	6.170	2.04
3	8.705	6.705	2.00

Table 3. Surface tension of rainwater (S) using equation (4).

Sr no.	Height of liquid column in capillary	Radius of capillary tube	Surface tension of rainwater (dyne/cm)
1	2.84	0.06	83.496
2	2.04	0.093	92.962
3	2.00	0.1	98.000

Table 4. Comparing standard and experimental value of surface tension.

Sr no.	Measured value of surface tension of rainwater	Measured temperature(℃)	Standard value of surface tension of water	Temperature (℃)
1	91.486	25	72.53	25

4. Result

The concave meniscus observed indicate that the resultant force on the surface molecule is to be upward and cohesion pressure decreases. The value of surface tension of rainwater is positive which signifies that surface tension acts in the upward direction from the free surface. The positive value also signifies the strength of bonding between molecules. If we compare the standard value 72.53 dyne/cm of surface tension of water at 25 ℃ with experimental value of surface tension of rainwater then it was surprisingly found higher. The surface tension value of rainwater is 91.518 dyne/cm which is very high then the standard value of surface tension of water. This high value reveals the fact that rainwater is newly formed water which needs time for relaxation and to be in equilibrium condition. The surface tension value in equilibrium state is 72 dyne/cm. The surface tension of water in reservoir is in equilibrium for longer time so has standard value of surface tension. But rainwater has high surface tension because its free surface is not at equilibrium with time. The missing bonds of H^+ and OH^- needs time to settle down on the surface of water. Thus the bonds in rainwater are stronger and less in number on free surface. Rainwater is not yet contaminated so also its surface tension is higher.

5. Conclusion

This research has significantly opened the insight about newly formed rainwater and its dynamics. This research has experimentally proved that the measured value of surface tension is greater than the surface tension of water in equilibrium condition. This research also focused on the capillary rise method and its benefits. The method was found to be effective and accurate as per readings collected. The surface tension value of rainwater in future can help to design and improve efficiency of rainwater harvesting system. Reading the surface tension value of rain water can help to understand the water management and its use.

This research will help the undergraduate students to estimate the further implications of rainwater in balancing the ecosystem.

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