# A Simple and Low Cost Set -Up for Surface Tension Measurement of Highly Viscous Liquids

A. R. SOLANGI AND A.W.K. KHANZADA*
*Center of Excellence in Analytical Chemistry*
*University of Sindh, Jamshoro, Sindh, Pakistan*

(Received 7th August, 2002, revised 10th January, 2003)

**Summary**: A simple and low-cost set up has been described for measurement of surface tension of highly viscous liquids by drop-weight method. The set up has been described in literature for normal liquids. Data in terms of $V/R^3$ and corresponding factor $F$ are given in literature for normal liquids. An equation has been developed between $V/R^3$ versus a factor $F$ by polynomial regression using EXCEL-2000 spreadsheet software in Window-98. Here $V$ is volume of drop of liquid passing through a tube of radius $R$. The tube of 3mm internal diameter has been used and this diameter has been measured by a vernier caliper.

The setup has been applied to glycerol and the results are accurate within ± 2.5% of literature values obtained by this simple setup. Further this apparatus has been used in determination of viscosity of commercial highly viscous unknown liquids. The results are reproducible. This simple apparatus can be used in Physical Chemistry practicals, with the help of the cubic equation found from EXCEL-2000 software.

## Introduction

In a liquid, a molecule is subjected to attractions in all directions by interior molecules. The direction of overall force of attraction lies in a plane tangent to the surface at a particular point. This makes liquid surface as small as possible. The magnitude of this force on a surface is called surface tension. It is perpendicular to a unit length of a line drawn on the surface where liquid is present. Surface tension tries to contract the surface area. To increase the area of surface, work must be done against the inward directing attractive forces. Surface tension is dependent upon temperature. It generally decreases with the temperature. It is also dependent on types of solutes. Inorganic solutes like NaCl or $CaCl_2$ increase surface tension of water at high concentrations. Second types of solutes called surfactants are strongly adsorbed at surfaces and these compounds decrease surface tension. These types of compounds are very important in detergent and pharmaceutical industry [1]. In pharmaceutical industry sometime highly viscous compounds are encountered and measurement of surface tension by ordinary method becomes difficult. This simple apparatus solves this problem in a nice way.

Generally surface tension is measured by three methods [2].

(i) . Capillary Rise Method

(ii) Ring Method (Du Nouy Ring-Pull Torsion Balance)

(iii) Drop-Weight Method

The present method describes a home built simple apparatus to find surface tension of highly viscous liquids by third method i.e., the drop-weight method. It is applied to a problem referred to us by a pharmaceutical industry. The data for correction

*To whom all correspondence should be addressed.

factor are taken from the literature [1-4] given by Harkins and Brown [4].

*Principle*

The hanging drop of liquid is slowly formed on a circular glass tip. Force $F_1$ causing drop to adhere to the tip is:

$F_1$ = Circumference × surface tension

$$= 2\pi R \times \gamma = 2\pi R\gamma \quad (1)$$

Where $R$ is internal radius of tube tip.

Force $F_2$ causing the drop to fall is:

$F_2$ = mass × acceleration due to gravity

$$= m \times g = mg \quad (2)$$

Equating both forces i.e.,

$$F_1 = F_2 \quad (3)$$

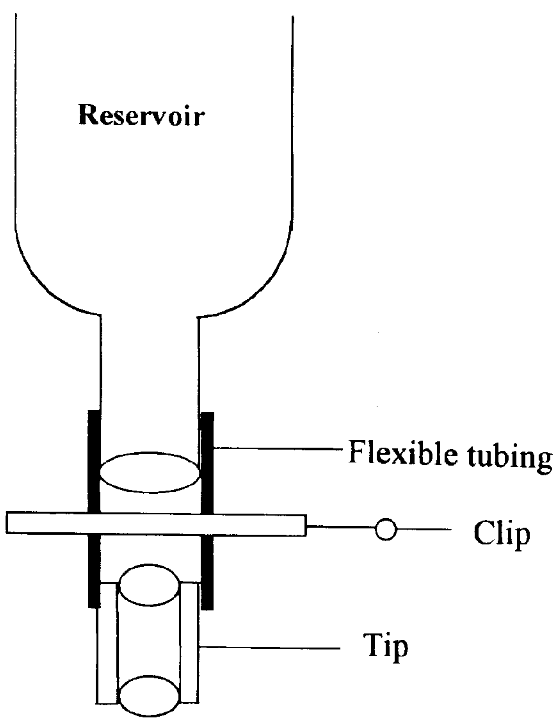


Fig. 1: Drop-weight apparatus for determination surface tension of highly viscous liquids.

$$2\pi R\gamma = mg \quad (4)$$

which gives $\gamma = \frac{m\ g}{2\ \pi\ R}$ (5)

The simple theory is complicated and is modified by Harkins and Brown [4] with a correction factor F i.e.,

$$\gamma = \frac{mgF}{R} \quad (6)$$

A table is provided in literature between $V/R^3$ and factor $F$ where $V$ is volume of the drop [1-3]

**Results and Discussion**

The data of $V/R^3$ and correction factor $F$ which suits to our experimental data is given in Daniel et al. [2]. The data of Beckett and Stenlake [1] and Levitt [3] lie outside our range.

A polynomial regression using TRENDLINE in Microsoft EXCEL-2000 is done on the data given by Daniel *et al.* [2]. The data of Daniel *et al.* [2] are reproduced in Table 1.

Table. 1 $V/R^3$ and correction factor $F$ as given by Daniel et al.[2]

| S. No. | $V/R^3$ | F |
|---|---|---|
| 1 | 2.995 | 0.261 |
| 2 | 2.637 | 0.262 |
| 3 | 2.341 | 0.264 |
| 4 | 2.093 | 0.265 |
| 5 | 1.706 | 0.266 |
| 6 | 1.424 | 0.265 |
| 7 | 1.211 | 0.264 |
| 8 | 1.124 | 0.263 |
| 9 | 1.048 | 0.262 |

Graph of these data is shown in Fig. 2.

A cubic equation

$$y = 0.0032x^3 - 0.0234\ x^2 + 0.0518\ x + 0.2298 \quad (7)$$

fits nicely to these data with a coefficient of determination $R^2$ = 0.9889 (R=0.9944) as shown in graph of Fig. 2.

Here $x = V/R^3$ and $y = F$.

This cubic equation [Eq. (7)] is now used in all experiments of known standard sample of glycerol and unknown viscous liquids supplied by a pharmaceutical industry.

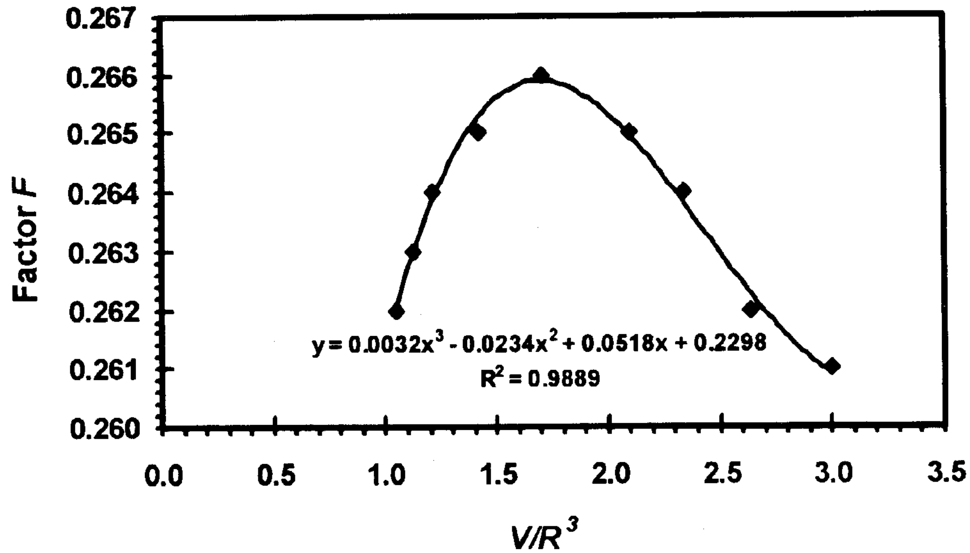


Fig. 2: Graph between $V/R^3$ and factor $F$

*(a) Result on standard Glycerol sample*

Temperature = 26 °C

Volume of drops collected = 3ml

Number of drops = 42

Volume of one drop = $\frac{3ml}{42}$ = 0.07ml

Radius $R$ of tube = 3mm = 0.3cm

$R^3 = (0.3)^3 = 27 \times 10^{-3}\ cm^3$

$$\frac{V}{R^3} = \frac{0.07}{27 \times 10^{-3}} = 2.59$$

y $=F = 0.0032\ x^3 - 0.0234\ x^2 + 0.0518\ x + 0.2298$ is calculated by putting the values of x = 2.59.

$$F = 0.0032\ (2.59)^3 - 0.0234\ (2.59)^2 + 0.0518(2.59) + 0.2298$$

$= 0.263$

Total mass of Glycerol = 3.1765g

No. of Drops collected = 42

Mass $m$ of one drop $= \frac{3.1765}{42} = 0.0756g$

$g$ = 980 cm/s

Therefore $\gamma = \frac{mgF}{R}$

$$= \frac{0.0756g \times 980cm/s \times 0.263}{0.3cm}$$

= 64.95 = 65.0 dyne/cm or mN/m

The reported value at 20°C [5] = 63.4 dyne/cm

% error = 2.52%

*(b) Calculations on Unknown Samples*

Nine samples were tried and their results are summarized in Table 2.

Table. 2 provide the reading on a number of drops, their total volume and total weight. From number of drops, average volume $V$ and mass $m$ is calculated. $R$= 0.3cm. $F$ is calculated using cubic equation given by Eq . 7. Finally surface tension is

Table. 2

| Sample No. | No. of Drops | Total Volume *ml* | Total Mass *g* | Volume $V$ of a Drop *ml* | Mass m of a Drop *g* | $V/R^3$ | $F$ | $\gamma = mgF/R$ dyne/cm or mN/m |
|---|---|---|---|---|---|---|---|---|
| 1 | 32 | 2 | 2.0064 | 0.0625 | 0.0627 | 2.315 | 0.2640 | 54.1 |
| 2 | 34 | 2 | 1.9328 | 0.0588 | 0.0568 | 2.179 | 0.2647 | 49.2 |
| □ | 47 | 2 | 1.8977 | 0.0426 | 0.0404 | 1.576 | 0.2658 | 35.1 |
| 4 | 48 | 2 | 2.1202 | 0.0417 | 0.0442 | 1.543 | 0.2658 | 38.3 |
| 5 | 40 | 2 | 1.956 | 0.0500 | 0.0489 | 1.852 | 0.2658 | 42.5 |
| 6 | 14 | 1 | 0.8662 | 0.0714 | 0.0619 | 2.646 | 0.2623 | 53.0 |
| 7 | 16 | 1 | 0.7739 | 0.0625 | 0.0484 | 2.315 | 0.2640 | 41.7 |
| 8 | 32 | 2 | 1.8737 | 0.0625 | 0.0586 | 2.315 | 0.2640 | 50.5 |
| 9 | 52 | 2 | 1.989 | 0.0385 | 0.0383 | 1.425 | 0.2654 | 33.2 |

calculated by the formula given by Eq.6. The table is constructed using EXCEL -2000 spread sheet software.

The data on glycerol provides an error of 2.5%. Values of surface tension at three temperatures 20, 90 and 150 °C are given in literature as 63.4, 58.6, and 51.9 dyne/cm respectively. Extrapolating these results to 26 °C gives $\gamma$ =63.3 mN/m. This gives an error of 2.7%, which is still acceptable with such a simple apparatus. A recent value at 25°C is 62.5 mN/m [6] which gives an error of 4%. The results on some of unknown samples were repeated three or four times and they are reproducible at that temperature. This apparatus can be made locally and physical chemistry experiments can be performed in a nice way. The results are fairly accurate and reproducible and commercial samples can be analyzed by this simple apparatus. Moreover student can be trained on use of EXCEL-2000 spreadsheet software and polynomial regression.

## Experimental

The diagram of drop - weight apparatus is shown in Fig. 1. The reservoir for viscous liquid is constructed from a 3.5cm diameter glass tube. The lower end is narrowed and a glass tube of 5mm diameter is blown to it.

The tube for surface tension measurement is a 3mm internal diameter glass tube. Its internal diameter is measured by a precision vernier caliper. Outer tip of tube is made smooth by brazing the glass. Reservoir lower end tip and upper end of 3mm tube tip is connected by transparent flexible plastic tubing available locally. For controlling the drop formation a stopcock or clip is attached to plastic tubing. The number of drops is counted and these are collected in a small and accurate measuring cylinder. Average volume of one drop and its weight is found from total volume occupied in the cylinder and total weight of all drops.

## References

1. A.H. Beckett and J.B. Stenlake Eds., "Practical Pharmaceutical Chemistry", 4th Ed., Part Two, CBS Publishers and Distributors, New Delhi, India, , pp 45, 1997.
2. F. Daniels, J.H. Mathews, J.W. Williams, P. Bender and R.A. Alberty,"Experimental Physical Chemistry" 6th ed., Chapter 14, McGraw - Hill, U.S.A., 1962.
3. B.P. Levitt, Ed. "Findlay's practical physical chemistry", 9th ed., Longman, London, pp 97-108, 1973.
4. Harkins and Brown, *J. Am. Chem. Soc.*, **41**, 499 (1919)
5. R.C. West Ed. "CRC Handbook of Chemistry and Physics," 67th ed., CRC Press Inc., USA, pp F-34, 1986-87.
6. D.R. Lide Ed. in Chief "CRC Handbook of Chemistry and Physics," 82nd ed., CRC Press Boca Raton, USA, pp 6-150, 2001-2002