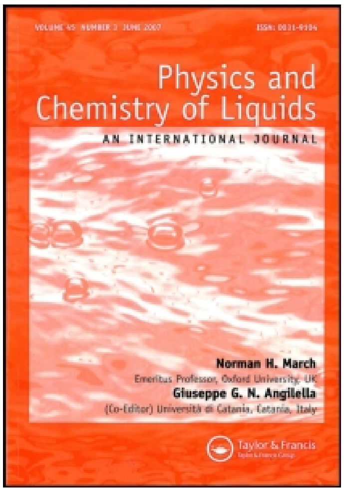

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Surface tension and viscosity measurements of liquids with the survismeter: a single instrumental unit

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Surface tension and viscosity measurements of liquids with the survismeter: a single instrumental unit

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Surface tension (γ) and viscosity (η) data of aqueous solutions of the deoxyadenosine (DOA) and the deoxyribose (DOR) sugars have been measured with the survismeter, a new instrument, along with tetrahydrofuran (THF), dimethylformamide (DMF), acetonitrile and dimethylsulphoxide (DMSO) solvents. The same properties have also been measured with a stalagmometer and a viscosimeter, respectively, which afford the same information, albeit at the expense of a larger amount of chemicals and solvents. We obtain comparatively better accuracy in both kinds of measurements than with conventional methods. Therefore, the survismeter lends itself as a simple and reliable instrument.

Keywords: Surface tension; Viscosity; Survismeter; Viscous flow

1. Introduction

Surface tension (γ) and viscosity (η) are the fundamental properties of liquids, and it is important to rely on accurate methods for their determination [1–3]. Recently, the γ and η of some liquids were measured with a newly designed survismeter [4], thereby reducing the amounts of chemicals used and some experimental effort. The survismeter is particularly suitable for measuring physical properties of biological liquids, as they get oxidized/reduced with time during the measurements. The instrument is a novel one for the accurate determination of the rheological properties of sols and gels [5]. It can accurately measure the viscosity average molecular weights of the polymeric solutions [6–8]. A previously designed survismeter [4] was equipped with a U-shaped capillary with unit viscosity, whereas the present model is quite simple with minimum sophistication for enough accuracy for academic, research and development laboratories. It accurately determines critical micellar concentration (CMC) of surfactants and detergents. The instrument is a step forward in the field of solution engineering [6,7].

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It is simple in operation, designing and handling, and allows to measure several physical properties with a single instrumental unit. The model described here is an advanced version and is most appropriate to measure rheological properties and characteristics of surfactants, sols and gels, paints, pigments, textile, paper pulps and petroleum products. The bulbs, limbs and capillaries are incorporated in it to control the flow pressure of liquids.

2. Experimental details

Aqueous solutions of deoxyadenosine (DOA, Sigma) and deoxyribose (DOR, Sigma), w/w, were prepared in distilled water and their flow times were measured with a survismeter using an electronic racer of 1×10^{-2} s. The THF, DMF, acetonitrile and DMSO were distilled. The deionized water was distilled three times in $KMnO_4$ and KOH for removing dissolved CO_2 and boiled off for further removal of the dissolved gases. Its conductivity was checked and found to be $1 \times 10^{-6}\,\Omega^{-1}$. The survismeter was washed very cautiously with freshly prepared chromic acid followed by ordinary and distilled water, the final washing was made with aqueous acetone. It was dried in oven for 24 h at 120°C. Similar washings were made on a bicapillary pyknometer for density measurements.

Figure 1 illustrates the survismeter, which is made of Borosil glass material, consisting of four limbs and five bulbs. The limbs 1–4 have stopper arrangements at upper ends. The bulbs 5–7 measure the flow times t for solution, t_0 for solvent, for viscous flows, within the fixed mark of the bulb 6 (locking the limb 2 with stopper) for viscosity (η). Limbs 9 and 7 measure drop counts n for solution, and n_0 for solvent, within the fixed marks of the bulb 9 (locking the limb 4) for surface tension (γ). The bulb 8 contains liquid solution and the numbers marked on the vertical line illustrate the dimensions, the bulbs 6 and 9 are connected to bulb 7 through 0.5 mm capillaries. The solution is sucked to bulb 9 with stoppered limbs 1 and 4, for dropwise downward flow, and limb 1 is opened. Similarly the solutions are sucked up to bulbs 5 and 6 with stoppered limbs 1 and 2, and limb 1 is opened for viscous flow, thus each time limb 1 is opened for pressure control and limb 3 remains open for pressure control. The solutions were thermostated for 20 min at fairly constant temperature with ± 0.01°C control, read with Beckman thermometer. The densities (ρ) were measured with $15 \times 10^{-3}\,\mathrm{dm}^3$ bicapillary pycnometer with 0.01 mg analytical balance model 100DS (Instruments Pvt Ltd., Calcutta, India).

3. Results and discussion

The viscosity (η) is calculated with

$$\eta = \left(\left(\frac{t}{t_0}\right)\left(\frac{\rho}{\rho_0}\right)\right)\eta_0 \tag{1}$$

where t and t_0 are the flow times, ρ and ρ_0 the densities of solution and solvent, respectively, and η_0 is the viscosity of the solvent. Similarly the surface tension

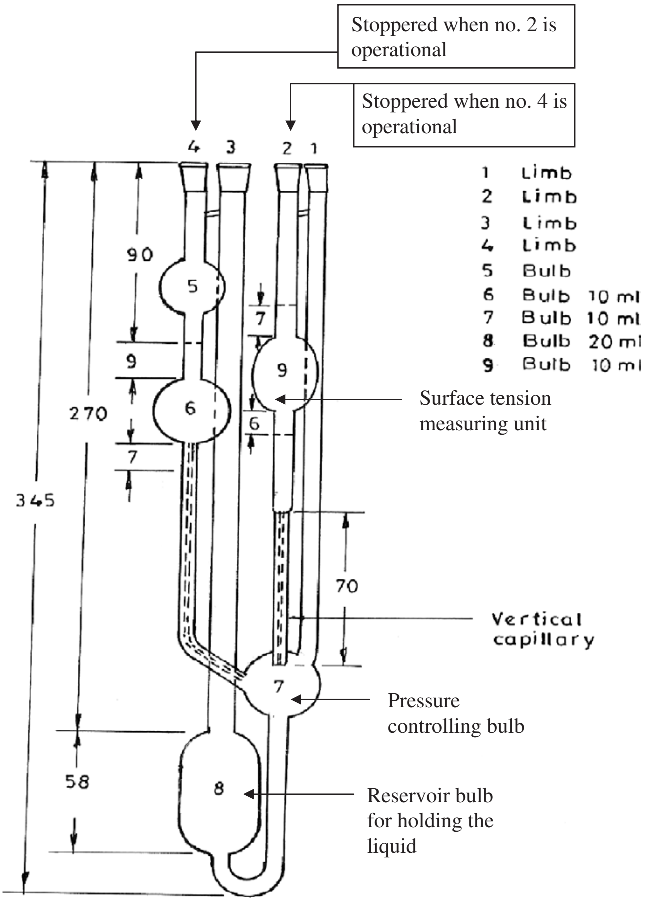

Figure 1. Survismeter for simultaneous surface tension and viscosity measurements, all dimensions are in millimeter, the numbers between vertical arrows marked lines depict the dimensions of the individual parts of the instrument.

data are calculated with

$$\gamma = \left(\left(\frac{n_0}{n}\right)\left(\frac{\rho}{\rho_0}\right)\right)\gamma_0 \tag{2}$$

where n_0 and n denote the drop numbers for solution and solvent, respectively, and γ_0 is the surface tension for water. Table 1 reports the limiting γ^0 (dyne cm^{-1}) and η^0 (g cm^{-1} s^{-1}) data at infinite dilution obtained by extrapolation of γ and η values for aqueous 0.0004–0.0016 mol kg^{-1} (at an interval of 0.0004 mol kg^{-1}) DOA and DOR solutions measured with survismeter and the literature values (with stalagmometer and Ubbelohde viscosimeter). The experimental data agreed to 1×10^{-4} with those of the literature.

The densities (ρ) were calculated from equation (3).

$$\rho = \left(\left(\frac{w}{w_0}\right)\left(\frac{w_0}{w_e}\right)\right)\rho_0 + 0.0012\left(1 - \left(\frac{w - w_0}{w_0 - w_e}\right)\right) \tag{3}$$

The last term is the buoyancy correction in weights in air, where w_e, w_0 and w are weights of empty pycnometer, solvent and solution filled, respectively. Furthermore, η and γ data of DMSO, DMF, THF and acetonitrile are fitted by the following equation.

$$\frac{\eta}{\gamma}=\left(\frac{\eta_0}{\gamma_0}\right)\left(\frac{tn}{t_0 n_0}\right). \tag{4}$$

We denote the ratio (η/γ) with the symbol σ (in $\mathrm{S\,m^{-1}}$), and analogously $(\eta_0/\gamma_0)=\sigma_0$ for the solvent. The parameter σ measures the so-called frictiohesity [9], and is related to the frictional and cohesive forces of the liquid solutions. In terms of this new parameter, equation (4) becomes [9]:

$$\sigma=\sigma_0\left[\left(\frac{t}{t_0}\pm\frac{B}{t}\right)\left(\left(\frac{n}{n_0}\right)+0.0012\left(1-\frac{w}{w_0}\right)\right)\right] \tag{5}$$

The σ values were plotted against known μ values of the DMF, DMSO and acetonitrile for a standard calibration curve and standard equation with appropriate coefficients at 293.15 K given as follows:

$$\mu=4.20141-25.02689\sigma+385.37892\sigma^2. \tag{6}$$

Further the σ values of the unknown solutions were obtained and put in equation (6) to calculate the μ values. The measured values of ρ, η, γ, σ and μ along with literature ρ values are given in table 2. In general, the plot of the μ values against the σ values of the desired solutions can be generalized as

$$\mu=\mu^0\pm B\sigma\pm B'\sigma^2\pm B''\sigma^3 \tag{7}$$

Table 1. The densities, viscosities and surface tension (literature and experimental) data of the aqueous solutions of DOA and DOR.

T (K)	ρ^0 (g cm^{-3})	η (Lit.)	η (exp.)	Δ = exp. − Lit. values	γ^0 (Lit.)	γ^0 (exp.)	Δ = exp. − Lit. values
DOA							
288.15	0.99933	1.1090	1.1089	−0.0001	75.713	75.714	0.001
293.15	0.99917	1.0031	1.0029	−0.0002	72.849	72.849	0.000
298.15	0.99817	0.8906	0.8907	0.0001	69.063	69.063	0.000
DOR							
288.15	0.99973	1.1125	1.1124	−0.0001	75.803	75.803	0.000
293.15	1.00057	1.0164	1.0163	−0.0001	80.717	80.718	−0.001
298.15	0.99811	0.9762	0.9763	0.0001	66.599	66.600	−0.001

Table 2. Density, viscosity, surface tension, frictiohesity and dipole moment of the pure and aqueous solutions at 293.15 K.

Systems	ρ (g cm^{-3})	ρ (g cm^{-3}), Lit.	η (g cm^{-1} s^{-1})	γ (dyne cm^{-1})	σ (S m^{-1})	μ (Debye)
THF	0.88587	0.886	0.53790	25.7230	0.02091	1.63
DMF	0.94391	0.944	1.56510	39.0653	0.04006	3.82
Acetonitrile	0.83911	0.839	0.43778	29.8579	0.01466	3.92
DMSO	1.10628	1.1049	2.21274	41.7599	0.05299	3.96

where μ^0 denotes the state of the solution or the solvent at infinitely low dipole moment values, B, B' and B'', are the Singh coefficients. The survismeter was calibrated with distilled water and survismeter constant k was determined from $k = \eta/\rho t$ relation, and B/t and kinetic correction (k) for survismeter were obtained from $\eta = (k - B/t)$ relation with solution of known η values, and the B/t and k values are found to be -0.182×10^{-4} and 1.898×10^{-4}, and -0.2051×10^{-5} and 2.327×10^{-5} at 298.15 and 303.15 K, respectively. The survismeter constant B with distilled water is calculated from $(\eta/\rho = B_t - (V/8\pi rLt))$, where V is total volume of water that flows, r radius and L is length of capillary. The close agreement of the experimental data with those of the literature validates the reliability of the survismeter.

The σ investigates the dipole moment, as heteromolecules cause molecular dipole moment (μ_{m}). Thus, σ accurately predicts binding forces during drop formation applied on the circular rim of the capillary end, as well as on the liquid layer being formed. From table 2, one finds that ρ, η and σ values can be arranged as DMSO > DMF > THF > acetonitrile, while the γ values as DMSO > DMF > acetonitrile > THF, and the μ values as DMSO > acetonitrile > DMF > THF. This enables one to infer that the electron donating CH_3 may influence the electronegativity of the stronger $O^{-\delta}$ with another DMSO molecules. Further CH_3–C–N = O^{2-} (acetonitrile) intermolecular interactions are weaker due to reduction of the electrostriction of acetonitrile. The higher ρ values for DMSO imply stronger intermolecular interactions while weaker for acetonitrile infer a decrease in electrostriction. Thus higher μ values for DMSO imply stronger electrostrictional force while weaker electrostrictional forces for acetonitrile. Similar considerations can be made for the values of η and γ. Thus σ, η, γ and μ values illustrate the intermolecular forces due to stronger electrostrictional forces while in case of dissociating molecules where electrostriction interactions increase molecular association. This technique is useful for molecular interactions.

4. Conclusions

The survismeter can accurately measure σ, η, γ and μ values to elucidate the structural interactions in the liquid solutions. The frictiohesity, a newly proposed physico-chemical function of the liquids is very useful to determine the dipole moment of the solutions.

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