Design and Construction of a Simple and Reliable Temperature Control Viscometer and its Application for Measurement of Viscosities of Liquids and Liquid Mixtures

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--**ABSTRACT**---
In this paper, a capillary temperature control viscometer was designed and locally constructed using available materials obtained within Yola, Nigeria. The constructed viscometer was tested in measuring the viscosities of distilled water, pure ethanol, pure methanol, alcohol-alcohol mixture, and alcohols-water mixtures at various temperatures. From the measured data of viscosity and density, the activation energies of the pure liquids and liquid mixtures studied were calculated. The experimental data obtained from this work are comparable to results in the literature.

Keywords: Concentration, Construction, Design, Liquids ,Mixtures, Temperature, Viscometer

I.   INTRODUCTION

A capillary viscometer is an instrument used to measure the viscosity, or thickness, of a liquid by measuring how long it takes the liquid to flow through a small-diameter tube, or capillary. The flow, or efflux, time is directly proportional to the liquid's kinematic viscosity. Viscosity is generally temperature dependent, so the capillary viscometer is usually used in a controlled-temperature water bath set to a specific temperature.

In a mixture we can consider the major component as the base and the other components as impurities whether present in trace or in appreciable amounts. The lower the minimum limit of detection of impurity concentration/amount, the higher is the accuracy of the detection technique [1].

There is an increasing interest in proper estimation of impurities present in Active pharmaceutical ingredients (APIs). There are various methods of detecting and characterizing both components and concentrations of the impurities such as [2], Thin layer Chromatography, (TLC), High pressure liquid chromatography, (HPLC), combination of HPLC and TL, (HPTLC), Atomic absorption spectroscopy, (AAS), Mass spectroscopy, (MS), Nuclear magnetic resonance, (NMR), Fourier transform ion cyclotron mass spectroscopy, ((FTICR-MS), Gas chromatography, (GC) among other techniques. Guidelines and designated approaches have been stated for isolation and identification of process-related impurities and degradation of pharmaceutical products, using MS, NMR, HPLC, Fourier transform Ion Cyclotron Resonance - Mass spectrometry, FTICR-MS and Tandem Mass spectrometry, TMS, etc. Most of these techniques have capabilities of detecting impurities in ppm (parts per million) and some (e.g., GC) in ppb (parts per billion) ranges and thus are highly accurate and suitable for impurity estimations in pharmaceuticals where in majority cases detection of impurity below 0.05% is not necessary according to Internal conference on harmonization, (ICH) of Technical requirements for registration of pharmaceuticals for human consumption. This translates to 1 mg a day in drugs consumed by average patient.

The above techniques are capable of estimating impurity concentrations both in solid and solutions. Most of these techniques require highly sophisticated equipment, experienced technologist and obviously constant supply of electric power. These machines employ chemical analysis which is cumbersome. Application of such techniques in African countries is still at a premature stage, especially because of cost-prohibitive and lack of trained man-power. This calls for cheaper alternative methods of detecting impurities in liquid mixtures.

There are other techniques which can have capability of accurate estimation of impurity concentration, specially, in solutions. Some of these techniques are: (i) Surface tension (Υ) methods; (ii) density (ρ) methods; (iii) Electrical conductivity(σ) methods; (iv)Viscosity(μ) methods; (v) refractive index(η) methods etc. The major advantages of these techniques over the above sophisticated techniques are (i) Lower cost of operation;

(ii) does not require highly trained man power as the above techniques; (iii) some of these techniques (i, ii, iv) can be applied without electric power. In each of these methods it is important to have calibration of the equipment to find out the measured changes in the properties of the standard solution with known concentration of the impurity added to it. The minimum error δ(c) (which is the same as the minimum detectable impurity concentration) in the estimation of one component impurity concentration in an unknown solution can be obtained from the following equation,

$$\delta(c) = +\left[\frac{\Delta(c)\alpha}{\Delta(p)} + \beta \right] \tag{1}$$

where Δ(p) is the absolute value of the measured change in the given property (e.g., ϒ, ρ,σ,η, or μ etc.) with a change(+) of concentration Δ(c) of the one component in the solution. α is the absolute value of minimum error in the estimation of that given property. β is the absolute value of minimum error in the measurement of concentration of the impurity when preparing the standard solutions. For good applicability of the above techniques in estimation of impurity concentration Δ(c) should be the maximum spread of concentration changes over which a maximum change Δ(p) in the physical property can occur. The methods reliability ranges are the range of Δ(c) beyond which Δ(p)/Δ(c) becomes quite small compared to a few times α/ β. If the standard solutions are prepared with one component impurity concentration estimated with high accuracy, then β is small and the techniques can yield high accuracy in estimation of unknown concentration (i.e., very low δ(c)) if α can be kept small.

Surface Tension Methods: This method is definitely less expensive than the above mentioned methods. It is suitable to estimate the concentrations of surfactants in water with high accuracy, especially on the surface. There are various methods of measuring surface tension, each one having its limit of accuracy α.
(i) Capillary rise – Accuracy in , + 0.5 mN/m, (ii) Sessile drop - Accuracy + 1.8 mN/m, (iii) Pendant drop - Accuracy 4 to 5%, (iv) Drop weight (v) Maximum bubble pressure - +0.2 mN/m, (vi) Wilhelm plate, (vii) Capillary waves, (viii) Unstable jets (iii) Du Nong ring (rapid), (ix) Drop weight (fast), (x) Wilhelm plate, (xi) Spinning drop, etc.

There are various reports of highest accuracy (i.e., minimum detectable surface tension) by the above methods. There are reports that all the above static methods of surface tension can yield accuracy in measurement up to +0.1mN/m, if sophisticated optical methods of detection are used. On the other hand actual measurements by researchers provide different reports of accuracy: (i) For example, there are reports [3], [4], [5] of accuracy of pendant drop method at 5% for high surface tension material like glass melts, pendant drop measurement at 4% and surface tension measurements of mercury by sessile drop method at 3 mN/m, which is about 0.6%. All these accuracy depend on the sophistication of the optical system used in the measurement and the materials of investigation. No consistent measurements have been performed on variation of surface tension with multi-component (three or more) solutions. Surface tension [3], of water and ethyl alcohol at room temperature are 73 and 22 mN/m. If we assume conservative values of accuracy at 1% then assuming a linear relation the average accuracy in estimation of water concentration in alcohol will be about 2% by surface tension method. This is definitely less than that offered by Viscosity method.

The spinning drop seems to offer higher accuracy (0.001 mN/m) but suitable only for measurement of low surface tension (2^{-10} mN/m) and not high. Thus it is not applicable for water-alcohol mixture. It is highly suitable for measurement of concentration of surfactants in water.

A simple method for simultaneous measurements of surface tension and density was determined by Thirumiavukkarasu and Srinivasan [6]. The method consists of drawing two liquids; one standard (water) and the other experimental liquid by suction through two vertical capillary tubes connected at the top by a common horizontal tube that is connected to a vertical suction tube. The two capillary tubes are dipped in two beakers containing the two liquids.

Electrical Conductivity Method: Electrical conductivity of a solution changes significantly when concentration of ions changes. It is an important analytical measurement for certain water purity applications such as the treatment of boiler feed water, and the preparation of very high purity water used for semiconductor manufacture. Conductivity measurement is meaningful, when we know about the type of ions present in water/solutions or when the purpose is to eliminate all ions present in the solution such as the case of ultra-pure water treatment; in which case we don't care about type of ions present since the goal is zero-conductivity.

For application of electrical conductivity (σ) measurements to estimate unknown ion concentration, we need to have the standard curve of variation of electrical conductivity with the particular ion concentration or the theoretical equation connecting ion-concentration with electrolytic conductivity. As an example, for hydrochloric acid, (HCL), σ changes [7], from 11.8 (μS/cm/ppm) to 10.2 (μS/cm/ppm) when the concentration of HCL changes from 1 to 10000 ppm. Using this data the average minimum detection limit (ppm) of HCL in water (Eq.5.19) is 0.1α + β. α(μS/cm) depends on instrument. If the instrument is accurate to within 0.1% then average α (within the above data range) = 50(μS/cm). With β = 0.5 ppm, this gives a minimum detection limit of

HCl in water = 5.5 ppm. The minimum detection limit depends on the electrolyte apart from α and β. From the data reported in Aquarium technical Bulletin[7], the corresponding detection limit for sodium hydroxide (NaOH) and sodium chloride (NaCl) (with same α and β) are 10.5 and 30.5 ppm. Most of the equipment can be said to be accurate if they have accuracy of 1% which translates to average α (within the above data range) = 500(μS/cm) and the above minimum detection limits are then: 50.5, 100.5 and 300.5 ppm for HCl, NaOH and NaCl in water. An Equipment to measure electrical conductivity of solutions have been developed [8], that gives accuracy of conductivity measurements by +0.5%. The accuracy α of electrical conductivity measurements of solution depends on:

(i) Electronic stability and linearity of the instrument
(ii) Linearity of instrument/sensor with solutions
(iii) Accurate temperature measurements and corrections for temperature effects in solutions
(iv) Knowledge of the relationship between conductivity and solutions of interest.

The major problem in the application of conductivity measurements for estimation of solute (ionic) concentrations: (i) the temperature coefficient θ of conductivity varies anywhere from 1% to 4% per ^{0}C, and it also depends on concentration and temperature. For example, Robert [9], θ varies from 0.02 at 0 ^{0}C to 0.0225 at 29 ^{0}C for saturated NaCl. It varies from 0.0165 at 0 ^{0}C to 0.0175 at 27 ^{0}C for 0.1 M KCl solution. It varies from 0.0146 at 5 ^{0}C to 0.0133 at 65 ^{0}C for 1 M HCl. This can offset the high accuracy limit of measurement if the temperature is not quoted with accuracy. This application of conductivity measurement is somewhat difficult for estimation of unknown impurity concentration. Then the temperature coefficient θ for a given electrolyte (say HCl in water) has to be known over the possible variation of temperature range, so that from measurement of conductivity of the solution of the unknown concentration at one temperature we can get the conductivity corresponding to the temperature at which conductivity versus concentration calibration has been recorded. All these problems could have been overcome if precise theoretical formula connecting conductivity with concentration of each electrolyte and temperature is known.

(ii) The second major problem is that conductivity reaches a peak with electrolyte concentration in water. For example for HCl, Nitric acid, HNO_3, Sulphuric, H_2SO_4 and NaOH the conductivity peaks are reached at 18%, 30%, 30% and 15% by weight concentration. Moreover, the relationships between σ and c are not linear at all. The only perfectly linear relationship is exhibited by KCl up to concentration of 26% by weight. Conductivity method alone is not suitable for estimation of concentration beyond these limits. It must be accompanied by measurements of other parameters such as density, viscosity, dielectric constants etc. for reliably accurate estimation of concentration beyond these points.

(iii) the third major problem is that conductivity of solution cannot be applied to those solutes which are not electrolytes. Thus it is limited to ionic salts only.

Refractive Index Methods: Precision laser based method [10] of determination of refractive index of water, ethyl and methyl alcohol yielded values 1.3330, 1.3614, 1.3290 at 20 ^{0}C and at 589 nm. Even though they claimed that the accurate technique of refractive index measurement can yield accuracy in concentration measurement of +0.01% we estimate the average accuracy to be (using the equation) about 6% for ethyl alcohol water mixture and 42.5% for methyl alcohol-water mixture. Since the variation in refractive index with water concentration in methyl and ethyl alcohol is quite small, the refractive index method is not suitable, because it is much more expensive than the viscosity method and some other conventional methods suggested above. For the refractive index method to yield the accuracy of 0.01% the measurements have to be accurate to +0.000003 in refractive index. It is not easy to achieve that experimentally. Thus their claim of 0.01% accuracy in estimation of alcohol concentration may not be authentic. Moreover, for methyl alcohol the inaccuracy will be higher since the variation in refractive index with water is much less pronounced than for ethyl alcohol.

Using a high-precision measurement technique [11], for evaluating alcohol concentrations using optical metrology system based on a positioning sensor detector determined the refractive index of pure ethyl alcohol (95%) and water at 25 ^{0}C to be 1.36587 and 1.33128 accurate (+0.00005) to the fifth place of decimal. From their measurements they have developed an empirical relation between the concentration and refractive index as μ = - 0.00000234C^2+ 0.00056068C + 1.33227197. Using this relation and the experimentally determined refractive index of a known concentration (37%) of ethyl alcohol they found a maximum error in estimation of concentration using that relation is 0.7%. Refractive index of methyl alcohol is 1.328 quite close to that (1.333) of water at 20 ^{0}C. Thus employing refractive index method for estimation of water concentration in methyl alcohol would yield accuracy much less than that of the viscosity method.

In this work, our experimental studies discusses clearly that simple inexpensive viscosity method can have advantage over many other methods in estimating impurity concentration in an adulterated liquid if the accuracy of time counting can be improved to 100 ms or better. The technique has potential application as an analytical tool.

II. MATERIALS AND METHOD

Materials used in the design and construction of the viscometer include; Copper plate, glass tubes (3.5 mm radius), beakers (8), level screws (10), level indicators (4), three capillary tubes (30.8cm length, and 0.6mm radius) , thermometer (100^0 C), measuring cylinders (6), lagging materials, water bath (1), distilled water (4 litres), pure ethanol (2 litres), pure methanol (2 litres), precision balance (1), syringes (5), glues, seal tapes, and masking tapes.

The temperature control viscometer, which was designed to incorporate temperature control bath, is shown in Fig. (1). QP is a vertical uniform cylindrical plastic tube of diameter 2.5 cm and length 6.0 cm. At the two ends were attached two narrow glass tubes of internal diameter 7 mm). There are horizontal fixed marks A and B on these tubes. At the bottom end of the lower tube is attached a uniform capillary tube of length, (LD) 30.8 cm, and the internal radius, r of the very uniform laser drilled capillary brass tube, is 0.6 mm, where as the outer radius is 1.0 mm. While AQPB is held vertical, the capillary tube is enclosed inside and at the bottom of the cubical container, EFGHIJKM (filled with water), and fixed as horizontally as possible at right angle with the narrow glass tube, PBL.
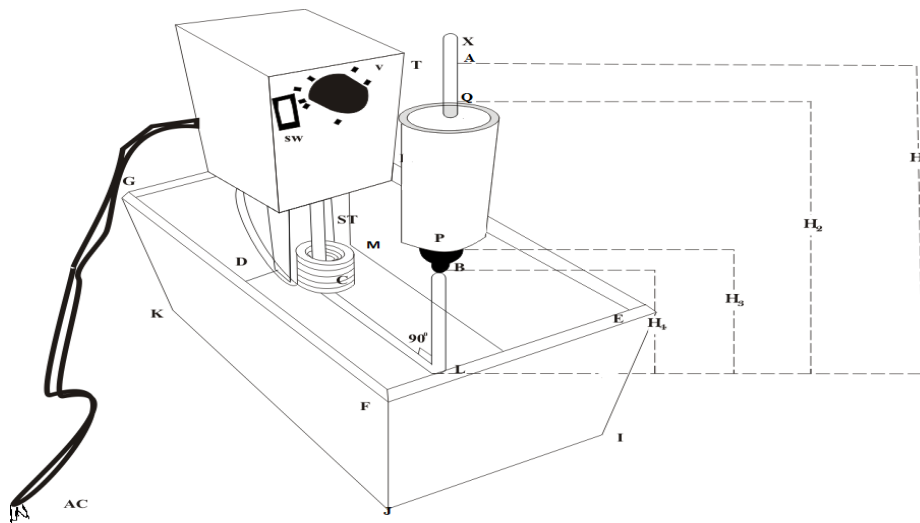

Fig 1 Design of the Temperature Control Viscometer

Level-indicators were used to ensure constant vertical alignment of the apparatus during different runs of experiments. The apparatus also incorporates the temperature controller, T (PHYWE product) with a heating coil, C and a stirrer, S, and required temperatures were set using the variable switch, V on the temperature controller. The whole portion XAQPBLD was filled with the liquid solution under investigation, and the time t taken by the liquid to descend from A to B was recorded by a sensitive stop watch. If the experiment was to be carried at temperatures above room temperature, the AC cord was fixed to electric power outlet and the required temperature set and left for 15 minutes before running the experiment.

A 100 ^{o}C calibrated thermometer is also inserted into the water to ensure accurate readings of the set temperature. As the upper tube is held vertically fixed, the solution descends and flows through the capillary tube and drops in a beaker. The time, required by the liquid to descend from mark A to B is noted with the help of a stopwatch with accuracy of 0.01 second. The capillary tube chosen must be in good condition to avoid turbulence flow.

2.1 Theory of Constructed Viscometer

The time t, taken by the liquid level to flow from mark A to B in Fig (1) is given by

$$t = \frac{K\mu}{\rho} \quad , \tag{2}$$

where $K = \left(a \ln \frac{H_1}{H_2} + b \ln \frac{H_2}{H_3} + c \ln \frac{H_3}{H_4} \right) \frac{8L}{\pi g r^4}$, $\qquad\qquad$ (3)

μ is the viscosity coefficient, ρ is the density, g is the acceleration due to gravity, H_1, H_2, H_3 and H_4 are the heights of the liquid levels as indicated in Fig. (1), a, b, and c are cross sections of tubes AQ, QP and PB respectively. For inclination of the upper tube axis at an angle θ with the vertical, g in above equation should be replaced by gcosθ (assuming that the capillary still remains horizontal), θ remains constant, as long as the vertical inclination of the apparatus in Fig. (1) is held constant for different sets of experiments conducted at a given place. With the same vertical inclination of the apparatus and at the same place (i.e., constant g), let t_2 and t_1 are the respective times for the solution under investigation and pure water at a given temperature, T to descend from mark A to mark B, (Fig.1). Then from equation (2) we get

$$\mu_2 = \frac{\mu_1 \rho_2 t_2}{\rho_1 t_1} \qquad (4)$$

An equivalent measurement is carried on a liquid of unknown viscosity, and then the unknown viscosity is calculated using equation (4). As long as the vertical inclination of the apparatus Plate I or Plate II was held constant for different sets of experiments conducted at a given place, (i.e., constant g), and t_2 and t_1 be the respective times for the solution under investigation and pure water at a given temperature, T, to descend from mark A to mark B (Fig. 1), then equation (4) holds [12], [13], [14]. The density ρ_2 can be easily determined using the simple relation of density equals mass/volume. ρ_1 at the given temperature can be easily known from a handbook of physical constant. For most purposes ρ_1 of distilled water can be taken as 1 kg/litre. The accuracy of determining μ_2 from equation (4) then depends on the accuracy of noting the time t_1 and t_2 and the accuracy of knowing μ_1. For manual observation, the inaccuracy in noting time t_1 and t_2 can be easily kept within ± 0.01 sec. From equation (4) we see that

$$\frac{t_2}{t_1} = \frac{\mu_2 \rho_1}{\mu_1 \rho_2} \qquad (5)$$

note where the quantities on the right side equation (5) depend only on the physical properties of the solution and that of pure water under investigation, where as both t_2 and t_1 depend also on the apparatus. Thus, the ratio t_2/t_1 when precise vertical inclination is maintained throughout the experiments at constant temperature T, is a unique signature of the nature and concentration of the solute in the particular solvent and independent of the physical dimensions of the apparatus used and the place where the experiment is carried out.

The effect of temperature variation on a particular liquid or liquid mixture can be studied using the Arrhenius equation [15],

$$\mu = B \exp\left(E_a / k_B T\right) \qquad (6)$$

where *B* is a constant for a given liquid, k_B is the Boltzmann constant; T is the temperature and E_a the activation energy for viscous flow. Hence, we re-write as

$$\ln(\mu) = \frac{E_a}{K_B T} + \ln B \qquad (7)$$

The activation energy, E_a can be calculated from equation (7) by plotting ln(μ) versus 1/T, and determining the value of the slope.

III. RESULTS AND DISCUSSION

The average of three readings of time of flow and densities of each liquid or liquid mixture at different temperatures were noted and the corresponding viscosity coefficients were calculated using equation (4) and recorded in Tables (1 to 6). Similarly, the activation energies of alcohol-water mixtures at various temperatures were determined using equation (7) and entered in Tables (3 to 6).

The viscosities of both methanol and ethanol mixtures with water, show an increasing trend with increase in water concentration in alcohol as can be seen from Table.(1 &2). It is also noticed from Table (1 & 2) that the viscosity of the mixture of ethanol and water is higher than the viscosities of methanol and water mixtures.

Table 1Reduced Time Ratio, Viscosity Coefficients of Ethanol-Water Mixture at 308 K

C_w $(v_w/v_a)100\%$	t_2/t_1 ±0.0001	μ_{ex} (10^{-4}Pa.sec) ±0.01	μ_{ex}/μ_1 ±0.0001
0	1.421	9.13	1.263
5	1.431	9.25	1.284
10	1.457	9.44	1.305
15	1.477	9.62	1.332
20	1.488	9.77	1.354
25	1.507	9.96	1.377
30	1.528	10.14	1.404
35	1.545	10.27	1.422
40	1.565	10.46	1.445
45	1.586	10.61	1.473
50	1.610	10.83	1.495

Table 2 Reduced Time Ratio, Viscosity Coefficients of the Methanol-Water Mixture at 308 K

C_w $(v_w/v_a)100\%$	t_2/t_1 ±0.0001	μ_{ex} (10^{-4}Pa.sec) ±0.01	μ_{ex}/μ_1 ±0.0001
0	0.823	4.94	0.683
5	0.832	5.04	0.698
10	0.836	5.15	0.711
15	0.845	5.22	0.722
20	0.853	5.29	0.733
25	0.857	5.38	0.745
30	0.864	5.47	0.757
35	0.873	5.54	0.767
40	0.877	5.65	0.782
45	0.888	5.76	0.797
50	0.895	5.82	0.808

Where $C_w=V_w/V_a(\%)$ = water concentration; t_2/t_1 = reduced time ratio; μ_{ex} = experimental viscosity co-efficient of mixture.

The total uncertainty in C_w thus determined above consists of the following parts: (i) due to uncertainty in t_2/t_1 ; (ii) due to uncertainty in the C_w and (iii) due to variation in temperature from that of the calibration curve. Let us address these three sources of errors. As mentioned above, for manual observation, the uncertainty in t_2/t_1 is around 2 x 10^{-5}.

Table (1) shows that a change of C_w from 0% to 50% causes a change of t_2/t_1 changes from 1.421 to 1.610 in ethanol, while in Table (2), t_2/t_1 changes from 0.823 to 0.895 in methanol. Therefore, one can easily see that the average uncertainly in C_w due to factor (i) is 0.053% in ethanol and 0.14% in methanol; the uncertainty in the measured volume is $\pm$ 0.5 cc. This leads to uncertainty in C_w ~ 0.16% Thus, the total uncertainty in the unknown water concentration, C_w that can result by using Fig (1) is roughly around 0.30% for methanol and 0.21% for ethanol respectively. Thus the measurement of time of flow through a capillary tube will yield much higher accuracy. The major source of error in the present technique are the errors in the measurement of volumes of the components during calibration and noting the time for the liquid to descend through the marks A and B (Fig.1).

Table 3 Viscosity coefficients and activation energy at different temperatures for methanol-water mixture, (volume to volume ratio of 1:1)

T (K) ±1	Viscosity μ (10^{-4}Pa.sec) ±0.01	1/T (1/K)	$\ln(\mu)$	E_{amw} (meV) ±0.01
308	6.010	0.003247	-7.417	168.16
313	5.545	0.003195	-7.497	144.70
318	5.125	0.003145	-7.576	121.23
323	4.799	0.003096	-7.642	100.29
328	4.405	0.003049	-7.728	73.27
333	4.168	0.003003	-7.783	54.28
338	3.923	0.002959	-7.843	32.94
343	3.711	0.002915	-7.899	12.72

Table 4 Viscosity coefficients and activation energy at different temperatures for ethanol-water mixture, (volume to volume ratio of 1:1)

T (K) ±1	Viscosity μ (10^{-4}Pa.sec) ±0.01	1/T (1/K)	$\ln(\mu)$	E_{aew} (meV) ±0.01
308	8.137	0.003247	-7.110	195.52
313	7.425	0.003195	-7.205	169.54
318	6.795	0.003145	-7.294	143.42
323	6.284	0.003096	-7.372	119.79
328	5.730	0.003049	-7.465	91.10
333	5.283	0.003003	-7.546	64.91
338	4.878	0.002959	-7.626	38.19
343	4.536	0.002915	-7.698	13.02

Table 5 Viscosity coefficients and activation energy with temperature for methanol-ethanol mixture, (volume to volume ratio of 1:1)

T (K) ±1	Viscosity μ (10^{-4}Pa.sec) ±0.01	1/T (1/K)	$\ln(\mu)$	E_{ame} (meV) ±0,01
308	6.955	0.003247	-7.271	177.72
313	6.440	0.003195	-7.348	155.50
318	5.960	0.003145	-7.425	132.47
323	5.515	0.003096	-7.503	108.37
328	5.095	0.003049	-7.582	83.46
333	4.785	0.003003	-7.645	62.33
338	4.465	0.002959	-7.714	38.77
343	4.205	0.002915	-7.774	17.16

Table 6 Viscosity coefficients and activation energies at different temperatures for methanol-ethanol-water mixture, (volume to volume ratio of 1:1:1).

T (K) ±1	Viscosity, μ (10^{-4} Pa.sec) ±0.01	1/T (1/K)	ln(μ)	E_{amew} (meV)
308	7.175	0.003247	-7.259	185.96
313	6.470	0.003195	-7.343	162.25
318	5.960	0.003145	-7.425	137.96
323	5.533	0.003096	-7.500	115.06
328	5.077	0.003049	-7.586	87.98
333	4.692	0.003003	-7.664	62.33
338	4.422	0.002959	-7.724	41.69
343	4.151	0.002915	-7.787	19.23

From Tables (3 - 6), generally, viscosity coefficient (μ) and activation energy (E_a) of methanol-water, ethanol-water, methanol-ethanol and methanol-ethanol-water mixtures decreased with increase in temperature. This could be due to the energy obtained to overcome the resistance to flow. The tables also show that the reduction of the viscosity is greater at the initial stage of the temperature increment, and subsequent increases in the temperature during the latter part had less influence on reducing the viscosity.

As in the case of variation of viscosity coefficients of the mixtures with temperature, the same trend is shown in their variation of activation energies (Tables 3- 6). It can be seen from that the viscosity of a mixture of ethanol, methanol and water is controlled mostly by ethanol and methanol since the temperature variation of viscosity of the mixture is almost the same as that of the mixture of ethanol and methanol. This feature is quite interesting and might throw light on the molecular modeling of the mixing of different molecules and formation of barrier heights with activation energy that the molecules have to overcome in flowing motion.

The molecules in a liquid are held together much more strongly than in a gas. A force is needed to overcome the mutual attraction of the molecules so that they can be displaced relative to each other. The more strongly the molecules are held together, the smaller the flow for a given shearing stress. With increasing temperature, the random kinetic energy of the molecules helps to overcome the molecular forces and reduces the viscosity [16].

IV.   CONCLUSION

The capillary viscosity method presented in this work is very simple but reliable equipment that can be constructed and operated upon at the local level, and has more advantages than several other methods. This method can estimate concentration of components easily within 0.05 % with a larger tube and a better optical time counting device capable of measuring time accurately up to 100 ms. It should find application to estimation of impurity levels around 0.1%, and concentrations of IV solutions.

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