

# Use of Viscometer for Monitoring Purities of Clinical Solutions

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## Abstract

The activation energy,  $E_a$  of an original pure liquid should change when a solute molecule is added to it since the addition may change the bond strength of the given liquid molecule as the impurity (solute) molecules tend to occupy the neighboring positions in the liquid. The change in  $E_a$  is expected to be affected significantly by addition of impurity molecules and thus the viscosity coefficient and the time of flow of the mixture through a capillary tube. Monitoring purity level (concentration levels) of clinical intravenous fluids is very important for safety of patients. In this paper we study using a simple viscometer the viscosity coefficients of clinical Dextrose and Sodium Chloride solutions. We find that the viscosity, at 30.5°C, of dextrose solution with concentration range from 2.0% to 20.0% varied from  $8.71 \times 10^{-4}$  Pa.s to  $13.32 \times 10^{-4}$  Pa.s within an error of  $\pm 0.1\%$ . For sodium chloride solution with concentration range from 1% to 10%, viscosity coefficient varied from 8.91 to  $10.41 \times 10^{-4}$  Pa.s. With distilled water as a standard and using the concept of reduced time ratio of flow and the observed data, we find that the viscometer can be very reliably used to measure concentration of any unknown clinical Dextrose and Sodium Chloride solutions. From the measured data we also determine the positive changes of activation energy of the two types solutions with increase in solute concentrations. We recommend further measurements at three different temperatures which shall enable us to determine the absolute values of the activation energies of the two solutions of different concentrations. We present necessary theoretical analysis so that with the data, any viscometer can then be used as a reliable liquid purity (Dextrose and Sodium Chloride solutions) analyzer. The data can also be used to study variation of molecular properties of solutions with concentrations of solute. The latter studies can find applications in solution chemistry.

**Keywords:** Viscometer, Concentration, Activation energy, viscosity coefficient, clinical solutions, reduced time ratio.

## 1. Introduction

Some liquid products have the same color, odor and taste. It is not always easy, considering their appearance to distinguish between some liquids. Some of these liquid products when contaminated with certain impurities do not change their appearance but they become hazardous. In a study of deaths caused by medication errors reported to the food and drug administration (FDA) from 1993-1998, injectable drugs were most often the problem. (Philips et al. 2001). This could be as results of administering clinical solutions of wrong concentrations to patients. In order to identify a liquid among liquids of same appearance or determine the concentration of impurities in a liquid; we can rely on either chemical or physical properties. Techniques using chemical analysis are time consuming and expensive. Thus, physical analysis can be conveniently employed to carry out the studies. Physical properties of substances are perhaps the most important variables that enter into the design of different types of equipment in one way or the other. Precise estimation of concentration of clinical solutions products can be done within 30 minutes time using sophisticated techniques such as gas chromatography (GC) (Juvet, 1997), high pressure liquid chromatography (HPLC) (Dropsy, 1997) mass spectrometry (MS), spectrophotometry (UV) etc. These above techniques are capable of estimating impurity concentrations both in solid and solutions. However, all the techniques are highly expensive and require trained personals for proper estimation, apart from constant electric power supply.

Such techniques are however very expensive and cannot be applied in a mass scale by common people whenever needed and more so, during shortage of electric power which is very common in many parts of Africa. Moreover, these sophisticated techniques require highly experienced technicians for precise estimation of the contaminants in liquids. The less sophisticated techniques that employ the variation of refractive index or surface tension (Adamson, 1990) with water concentration in alcohol don't often yield very accurate result since the minimum in accuracy is usually not less than  $\pm 3.3\%$ . Such techniques also can't be applied in absence of electric power. The question then arises how can we find an inexpensive, simple yet very reliable, unique and yet quick method of determination of the concentration of water or any other liquid in alcohol, or in other words, a one component solute in a liquid solvent, in general. Is it possible to develop the technique such that it can be applied even when there is no electric power available? Obviously such a technique would be based on the strong dependence of a measurable physical property of the solution on the type and concentration of its component liquids or the solutes in the solvent. Our intensive investigation confirms that viscosity is such a property and we can uniquely employ the variation of viscosity coefficient and also density (in some cases) of a solution with its compositions

to determine the unknown concentration of its components. (Alkali et al. 2003) studied the rheological characteristics of canarium oil using Brookfield viscometer. They found that the viscosity of canarium oil decreased with increase in both shear rate and temperature. (Satimehin et al. 2003) used the rotational viscometer and studied the rheological behaviour of palm oil. They found that a reduction in viscosity of palm oil occurred as shear rate increased and the consistency index decreased exponentially with temperature. For analysis of liquid mixtures whose viscosity is not as high as palm oil or canarium oil, one does not need to use the rotational method. In the later method the shear rate influences the viscosity and may complicate the analysis of impurity concentration and types. Below, we first describe the design, construction and theory of a simple flow-type viscometer (where the shear rate is low), which can be readily fabricated in any laboratory of Nigeria and its application how to determine a one-component adulterant in a solvent. Our main focus in this paper will be its application to determine water concentration in ethyl and methyl alcohol and development of techniques to easily distinguish between the two types, when unknown. We also focus on the variation of activation energy of alcohol molecules as water molecules are added and the possible contribution of such studies to the development of liquid physics, which unlike solid state physics, is not in a mature stage yet. In this paper we try to present a part of the theory of the liquid mixture that is in progress.

## 2. Theory

### 2.1 Basic Physics and Underlying Assumptions of the New Technique

Like that of a crystalline solid, the molecules of a liquid execute thermal vibrations about the equilibrium position with frequency,  $\nu_o = 1/\tau_o$ . At an average time  $t_{av} \gg \tau_o$ , this position of equilibrium is displaced by a distance,  $\delta$ , which is of the order of magnitude of the average distance,  $d_{av}$  between the molecules given by  $d_{av} = (M/N_A \rho)^{1/3}$ , where  $M$ ,  $\rho$  and  $t_{av}$  are the molar mass, the density of the liquid and the relaxation time of the liquid molecule. We should note that in the absence of any external force the displacement of the liquid molecule occurs in random directions and is related to the average thermal velocity. The action of an external force (pressure) with time period  $T$  far greater than  $t_{av}$  enables the molecules to overcome the barrier ( $E_a$ ) in the form jumps (Yavorsky & Detlaf, 1980) that occur at intervals of  $t_{av}$ . The result is a stream of particles flowing in a preferred direction, which is the same as that of the applied force, and thus giving rise to fluidity, a measure of which is  $1/\mu$  ( $\mu$  = viscosity coefficient). If the applied force is just enough to enable the molecules overcome the said barrier (which is the same as the activation energy,  $E_a$ ) we get a streamline flow (without acceleration) that is governed by Poiseuille's equation (Sinha & Das Sarma, 1969; Smith, 1972). The activation energy (Yavorsky & Detlaf, 1980; Rakshit, 1997) results from the bonds between the molecules and the adjacent particles. With this idea the corresponding fluidity is then proportional to the jump frequency which is proportional to  $\exp(-E_a/K_B T)$ . Thermal vibration will try to randomize this streamline flow and thus giving another factor  $1/T$  to streamline fluidity. Thus  $1/\mu$ , is proportional to  $\exp(-E_a/K_B T)/T$  and thus

$$\mu = AT \exp(E_a/K_B T / T) \quad (1)$$

Where  $A$  is a constant .

The activation energy,  $E_a$  of the original pure liquid should change when a solute molecule is added to it since the addition may change the bond strength of the given molecule as the impurity molecules tend to occupy the neighboring positions. The change Equation (1)  $\mu$  is expected to be affected significantly by addition of impurity molecules and thus the time of flow of the mixture through a capillary tube. This time of flow can be measured very accurately and hence the type and concentration of the contaminant. This forms the scientific basis of developing the present new technique of analyzing contamination in a liquid by measuring the time flow the impure liquid.

## 3. Viscometer Design and Construction

The simple design of the viscometer is shown in Figure 1. EFGH is a uniform vertical glass tube of diameter 4.7cm and length 8 cm. At the two ends are attached two narrow tubes (ID~7mm). There are horizontal fixed marks C and D on these tubes. At the bottom end of the lower tube is attached a uniform capillary tube of length,  $L = 30.8$  cm. The internal radius,  $r$  of the very uniform LASER drilled capillary brass tube, KI, is 0.6 mm (obtained from SMALL PARTS INC. PO BOX 4650, MIAMI LAKES, FLORIDA 33014-0650, USA) where as the outer radius is 1.0 mm. While EFGH is held vertical, the capillary tube is enclosed in a larger tube and fixed as horizontally as possible. The glass tube and the attached capillary tube are mounted on a right angled solid wooden frame (Figure 1) fitted with leveling screws and level-indicators. The latter arrangement ensures constant vertical alignment of the apparatus during different runs of experiments. The whole glass tube is filled with the liquid solution under investigation. As the upper tube is held vertically fixed, the solution descends and flows through the capillary tube and drops in a beaker. The time,  $t$  required by the liquid to descend from mark C to D is noted with the help of a stopwatch. The diameter of the capillary should be chosen such that turbulence flow is avoided.

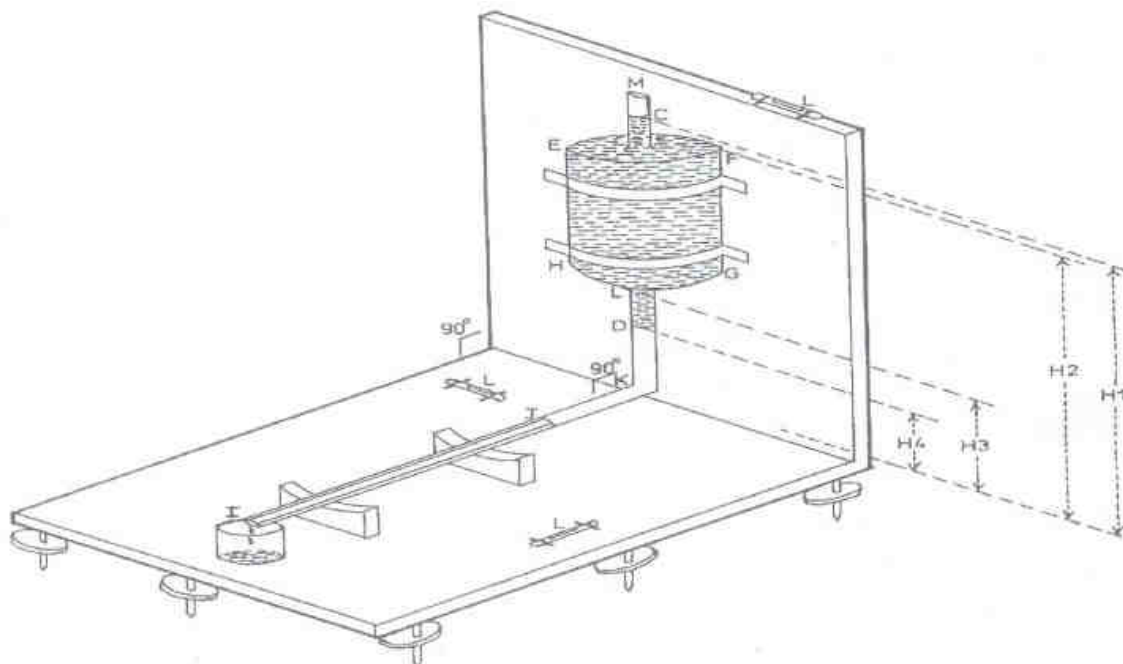


Figure 1. A simple viscometer with a highly uniform brass capillary tube (LASER drawn) that was used to measure the viscosities of clinical solutions reported in this paper

#### 4. Viscometer Theory

Referring to figure 1 as the liquid descends through an infinitesimal height  $dH$  in a time  $dt$ , the change in liquid volume,  $dV$  in the tube is given by the equation.

$$dV = -adH \quad (2)$$

$a$  = cross section of the tube EFGH  
 from equation (2) we get

$$dV/dt = -adH/dt \quad (3)$$

Applying Poiseuille's theory,  $dV/dt = \pi Pr^4/8\mu l$  (4)

where  $P = \rho gH$  is the pressure head for the liquid level at height  $H$  measure from the bottom end of the capillary,  $g$  is the acceleration due to gravity at the place of experiment,  $l$  is the length of the capillary tube,  $\mu$  and  $\rho$  are respectively viscosity coefficient and the density of the solution under investigation. The latter two quantities depend on the nature and the concentration of the solutes in a particular solvent. After integration from equation (3) and (4) we get

$$\ln(H_1/H_2) = \pi \rho g r^4 t / 8 \mu l \quad (5)$$

Where  $H_1$  and  $H_2$  are initial and final heights of the liquid level in the larger tube measured from the bottom end of the capillary tube.

From equation (5) we can write that

$$t = \ln(H_1/H_2) 8 \mu l / \pi \rho g r^4 \quad (6)$$

Following the above idea it can be easily shown that for the constructed apparatus as shown in( fig.1 ) we have

$$t = (a \ln H_1/H_2 + A \ln H_2/H_3 + b \ln H_3/H_4) 8 \mu l / \pi \rho g r^4 = C \mu / \rho \quad (7)$$

Where,

$$C = (a \ln H_1/H_2 + A \ln H_2/H_3 + b \ln H_3/H_4) 8 l / \pi \rho g r^4 \quad (8)$$

In equation (8)  $H_1$ ,  $H_2$ ,  $H_3$  and  $H_4$  are the heights of levels as indicated in fig.1 A,  $a$  and  $b$  are cross section of tube EFGH, MC and KM. For inclination of the upper tube axis at angle,  $\theta$  with the vertical,  $g$  in the above equation should be replaced by  $g \cos \theta$  (assuming that the capillary still remains horizontal).

A number of experimental methods are available for measuring viscosity. Many are based upon measuring the amount of time it takes for a given amount of liquid to flow through a thin glass tube. An equivalent measurement is carried on a liquid of know viscosity. The unknown viscosity is then calculated using the expression

$$\mu_2 = \mu_1 \rho_2 t_2 / \rho_1 t_1 \quad (9)$$

Where the subscripted 1 refer to the reference liquid.

As long as the vertical inclination of the apparatus (Fig.1) is held constant for different sets of experiments conducted at a given place, (i.e constant g), let  $t_2$  and  $t_1$  be the respective times for the solution under investigation and distilled water (at a given temperature, T) to descend from mark C to mark D (Fig.1), then Equ. (3) holds. Sinha et al. (1969) Smith, (1972). The density  $\rho_2$  can be easily determined using the simple relation at the given temperature. It can also be easily known from a handbook of physical constant. For most purposes  $\rho_1$  (water) can be taken as 1 kg/liter. The accuracy of determining  $\mu_2$  from Eq. (9) then depends on the accuracy of noting the time  $t_1$  and  $t_2$  and the accuracy of knowing  $\mu_1$ . For manual observation, the inaccuracy in noting time  $t_1$  and  $t_2$  can be easily kept within  $\pm 2$  sec. From Eq. (9) we see that

$$t_2/t_1 = \mu_2 \rho_1 / \mu_1 \rho_2 \quad (10)$$

Note that the quantities on the right side Eq. (10) depend only on the physical also on the apparatus.

Thus the ratio  $t_2/t_1$  (when precise vertical inclination is maintained throughout property of the solution and that of distilled water under investigation, where as both  $t_2$  and  $t_1$  depend 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 change in activation energy,  $\Delta E$  arising from different concentrations of the impurities (solute) in the mixture (solution) at constant temperature can be calculated using Eq.

$$(1) \text{ Thus, } \Delta E = K_B T \ln(\mu_2 / \mu_1) \quad (11)$$

Also from Equ(1), we can determine the change in activation energy,  $\Delta E$  for a particular concentration of impurity in a mixture at different temperatures. The average temperature for Figure 1 and for computations (see discussion) is taken to  $30.5^\circ\text{C}$ . To determine the viscosity coefficient of a given liquid using Equation (9) we need the absolute value of  $\mu_1$  of water at  $30.5^\circ\text{C}$ . The values of  $\mu_1$  at several temperatures are known (Rakshit 1997). By using PLOTIT program of MS Office 2000, the interpolated value of  $\mu_1$  at  $30.5^\circ\text{C}$  is found to be 7.98 poise. Using this value of  $\mu_1$ ,  $\rho_2$  from Tables 1 & 2 and  $t_2/t_1$ , the viscosity coefficient  $\mu_2$  of the water in clinical solutions mixtures are then calculated using equation (9) and the values are also given in Tables 1 and 2. With the maximum inaccuracy in time measurements around  $\pm 1$ sec, the typical inaccuracy in  $t_2/t_1$  can be easily kept around  $\pm 7.5 \times 10^{-4}$ . As seen from Tables 1 and 2 the observed change in time of flow with water concentration has been found to be quite appreciable for both glucose and sodium chloride solutions. This observation justifies the assumptions made in the theory section that the viscosity coefficient of a liquid should sensitively depend on the type and concentration of the solute.

## 5. Experiments

The apparatus described in above was also used for the present investigations of two different types of mixtures of glucose and sodium chloride (BDH grades) with distilled water at different concentration. The densities were determined by measuring the mass (M) of a given volume (V) of the mixture and using the relation,  $\rho = M/V$ . Time t required for the liquid to descend from Mark C to D (Figure 1) was measured by a stop-watch with accuracy of  $\pm 1$  s. The results of measurements are discussed below.

**Table 1: Densities; time of flow, reduced time ratio, viscosity coefficient and change of activation energy (from that of water) of dextrose solution at  $30.5^\circ\text{C}$  (303.5k)**

Conc. of dextrose (standard mixture) % $\pm 0.1$	Average time flow of mixture $t_2$ (s) $\pm 0.5$	Density of solution ( $\text{g}/\text{cm}^3$ ) $\pm 0.002$	Reduced time ratio $t_2/t_1 \pm 0.004$	Viscosity coefficient $\mu$ (pa.s) $\times 10^{-4} \pm 7 \times 10^{-6}$	$\ln \frac{\mu_2}{\mu_1}$ $\pm 0.005$	$\Delta E$ (mev) $\pm 0.01$
2.0	445.5	1.049	1.040	8.71	0.087	2.28
4.0	463.5	1.058	1.082	9.14	0.135	3.34
6.0	483.0	1.065	1.127	9.58	0.182	4.77
8.0	506.5	1.074	1.182	10.13	0.218	5.71
10.0	519.5	1.078	1.212	10.15	0.238	6.34
12.0	544.0	1.083	1.270	10.98	0.319	8.36
14.0	569.0	1.089	1.328	11.54	0.369	9.67
16.0	596.0	1.101	1.391	12.22	0.426	10.28
18.0	610.0	1.107	1.424	12.58	0.455	11.92
20.0	639.5	1.119	1.492	13.32	0.512	13.41

**Table 2: Densities, viscosity coefficient, activation energy changes of the NaCl-water solution mixtures of various amount of sodium chloride added to 250 cm<sup>3</sup> distilled water at 30.5<sup>o</sup>C.**  
 Time of flow of pure water = 428.5 s

Conc. of NaCl %±0.1	Mass of NaCl (g)±0.1	Time of flows (s)±0.5	Density of solution g/cm <sup>3</sup> ± 0.002	Reduce time ratio t <sub>2</sub> /t <sub>1</sub> ±0.004	Viscosity of the solution μ (pa.s) x 1.0 <sup>-4</sup> ±	In	
						$\frac{\mu_2}{\mu_1}$ ±0.005	ΔE (mev) ± 0.01
1.0	2.5	450.2	1.065	1.061	8.90	0.109	2.86
2.0	5.0	456.4	1.069	1.076	9.07	0.128	3.35
3.0	7.0	461.2	1.074	1.082	9.16	0.138	3.62
4.0	10.0	467.8	1.078	1.087	9.29	0.152	3.98
5.0	12.5	470.2	1.092	1.087	9.37	0.160	4.19
6.0	15.0	476.5	1.096	1.112	9.60	0.185	4.85
7.0	17.5	480.6	1.110	1.122	9.81	0.206	5.40
8.0	20.0	484.8	1.116	1.131	9.85	0.211	5.53
9.0	22.5	490.2	1.121	1.144	10.10	0.236	6.18
10.0	25.0	502.4	1.127	1.173	10.41	0.266	6.97

## 6. Discussion

### 6. 1. Techniques for the Analysis of Purity of Solutions

If we are given an unknown glucose and sodium chloride solution sample, how do we know the concentration of the solution? If we have as simple viscometer as described above, we can readily answer this question. Let us see how we accomplish this, first we determine t<sub>2</sub> for the sample solution and t<sub>1</sub> for pure distilled water employing the procedure described above and then take the ratio t<sub>2</sub>/t<sub>1</sub>. Let us assume that the type of the saline solution is known, say normal saline solution. Then looking at the calibration curve we see that the concentration normal saline change from (1.0% to 10.0%) ±0.1 reduce time ratio t<sub>2</sub>/t<sub>1</sub> change from (1.061 to 1.173) ±0.004 (table 2). It can be seen from Table 2 that the corresponding changes for normal saline solution are (1.0% and 10.0%) ± 0.1. Thus the present technique provides an easy way of knowing it. The t<sub>2</sub>/t<sub>1</sub> of the sample with concentration can be placed on Fig1 corresponding to the concentration.

In case where the type of saline is not precisely known, one can carry out the measurement of density of the solutions. Then using Table 2, one can easily determine concentration of the solution precisely. Ideally the technique can be applied to any of clinical solution. The studies thus provide a unique way of determinant both the type of clinical and the water concentration with appreciable accuracy.

### 7. Summary

We have discussed how a simple and reliable viscometer can be designed and constructed to measure reliably the viscosity coefficient μ, of any liquid within a short time (≅ 15 minutes). The non destructive technique is independent of the place. We have applied the technique to measure viscosity coefficient, of intravenous solutions and found that μ is a very sensitive function of concentration of intravenous solutions up to 45% within this range and using the techniques described in the paper, concentration of intravenous solution of an unknown solution (mixture) can be determined with an accuracy of ± 0.5%. It the accuracy in time counting is limited to ± 2secs. We have theoretically discussed a way to improve the accuracy to ± 0.04% or better. The viscosity coefficient (μ) of clinical solutions increases with concentration. The increase has been attributed to the change of activation energy (ΔE) of solution molecules as normal saline molecules occupy vicinity positions and influence the bond between mixture molecules. It may be mentioned that surface tension of a solution is found to change with solute concentration. However, application of this property for determination of purity concentration could be fraught with significant errors as compared to the present technique since the percentage error in measurement of capillary radius r, the capillary rise of the liquid is much higher than that in the time of flow

### 8. Conclusion and Recommendation for Future Work

Determining the time of flow of a solution and that of distilled water through a sensitive viscometer, one can determine the concentration of the solute as well as the type of contaminant in the solvent of the solution using the method developed above. These studies show that this local technique can be used with fairly good accuracy and speed to determine unknown concentrations of one-component solute (like sugar, salt, acid, etc) in water as solution. We can also easily distinguish between some of the intravenous solution using this technique. The technique has many potential laboratory and industrial application. This technique enable us

to study the change of activation energy of solvent molecules with the nature and concentration of a solute molecule and it can be extended by incorporating temperature variation and control facility to study the effect of temperature on such changes. Such data can then throw light on how solute molecules arrange themselves around the solvent molecules and how this in turn affects the bond strength and transport properties of solvent molecules. Analysis of such data can greatly help to develop liquid physics which unlike solid state physics which has not reached a matured stage yet and also can put the present technique of liquid purity analysis on a solid foundation. We recommend that further work be undertaken to introduce temperature variation and control capability and to measure the time of flow electronically so that the apparatus can be used as research equipment in the area of liquid physics or physical chemistry

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