

Effect of Solvent System on Critical Micelle Concentration Using Viscosity Equations for Anionic Surfactants at Various Temperatures

Yogyta Singh¹, Pratima Jain²

Department of Chemistry, Government KRGPG (Autonomous) College, Gwalior, M.P., India

Abstract: The critical micelle concentration (CMC) of Potassium Stearate (PS), Sodium Oleate (SO) and Sodium Dodecyl Sulphate (SDS) in alcohol- water solvent system (0%, 50%, 80%, 90%, and 100%) was driven from the density and viscosity measurements. The concentrations of PS, SO and SDS in different solvent systems used for the density and viscosity measurements were kept between 0.010 to 0.065g mol L⁻¹ and measurements were taken at different temperatures. Experimental density values were seen to get decreased with the increase of the temperature. The viscosities are also represented in terms of Einstein, Vand, Moulik and Jones-Dole equations. We found that the viscosity of the salts in various solvent mixture decrease with increase in temperatures and all the values show positive trends.

Keywords: Density, Viscosity, PS, SO, SDS, Critical Micelle Concentration (CMC)

1. Introduction

Potassium Stearate (C₁₈H₃₅KO₂) is a fine, white powder that has a fatty odour. Potassium Stearate is used in Food, Beverage, Pharmaceuticals, Health & Personal care products, Agriculture/Animal Feed/Poultry etc. Potassium Stearate is used as an emulsifier from the Stearate salt family in cosmetics and beauty products to stabilize formulas and increasing the thickness, or add lubricating properties. It is used in a wide variety of skin care and hair care products, including eyeliner, eye shadow, mascara, lipsticks, blushers, face powders and foundations, and less often in perfumes, deodorants, and hair and skin care formulas.¹

Sodium oleate (C₁₈H₃₃O₂Na) is an unsaturated fatty acid. It is used for variety of commercial purposes, especially for the production of soap. It is often used in the production of insoluble metallic stearates. It is also used in industries as industrial lubricants and various oil-based cosmetics as a thickening or gelling agent.²

Sodium dodecyl sulphate (SDS) also known as sodium lauryl sulphate (CH₃(CH₂)₁₁SO₄Na) is an important ingredient in industrial products such as car wash soaps, engine degreasers and floor cleaners.³ The specific molecular structure of SDS, represented by long aliphatic chains with a sulphate ester group, confers amphiphilic properties and significant surface activity to the molecule.⁴ It is widely used in cleansers because it is a cheap, highly effective cleansing and foaming agent. Like most detergents, it can irritate the skin.⁵

Many physical properties of surfactant solutions exhibit a characteristic transition over a narrow range of concentration. This transition is generally related to association of surfactant molecules arising from the intrinsic amphiphilic nature. The transition region could be used to determine the critical micelle concentration CMC above which multi-molecular aggregates are formed. CMC is a measure of surfactants efficiency.

Present investigation has been done with determination of densities and viscosities of Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate solutions of varying concentrations in ethanol-water solvent systems of varying percentage at various temperatures. An attempt has been made to determine intermolecular interactions in PS, SO and SDS in alcohol and water solvent systems. CMC values have been determined using densities and viscosities data which are further studied with the help of some well known equations.⁶

Measurement of viscosity in solution provides an excellent method of obtaining data on ion-ion and ion-solvent interactions. Hydrophobic and hydrophilic characters of the solute such as H-bonding formation and disruption are correlated to changes in the viscosity.⁷

Viscosity values were also calculated in terms of Einstein, Moulik, Jones-Dole and V and equations. These equations are -

$$\text{Einstein equation: } \eta_{sp} = \eta_0(1 + 2.5 V)C \quad \dots\dots\dots(1)$$

$$\text{Moulik equation: } (\eta/\eta_0)^2 = M + KC^2 \quad \dots\dots\dots(2)$$

$$\text{Jones-Dole equation: } \eta_{sp}/C = A + B\sqrt{C} \quad \dots\dots\dots(3)$$

$$\text{Vand equation: } 1/C = (0.921/V) 1/\log(\eta/\eta_0) + \phi V \quad \dots\dots\dots(1)$$

Where C is the concentration, η_{sp} is the specific viscosity, η is the viscosity of the solution, η_0 is the viscosity of solvent, ϕ is the interaction coefficient, and V is the molar volume. The solute-solute and solute-solvent interactions are represented by the constants A and B in Jones-Dole equation and M and K in Moulik equation respectively. In the present study viscometric properties of Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate have been found out in alcoholic and aqueous solvents systems as well as in their mixtures of varying composition at 298.15K, 303.15K, 308.15K and 313.15K temperatures over the entire concentration range. The solute-solute and solute-solvent

interactions as well as the effect of solvent systems on anionic surfactants have also been studied.¹²⁻¹⁵

2. Experimental Section

Material:

Potassium Stearate (PS, 98%CDH), Sodium Oleate (SO, 98%CDH) and Sodium Dodecyl Sulphate (SDS, 90%CDH) were used as purchased. All solutions have been prepared using absolute alcohol and conductivity water. Conductivity water was obtained by initially distilling distilled water with acidified KMnO₄ and later with tiny amount of NaOH pellets and resulting vapours were condensed and collected as conductivity water. Potassium Hydroxide was used to purify alcohol by keeping over it for a day and distilled. The distillate was refluxed with 1% of Calcium metal for about eight hours and then redistilled. Only analytical grade reagents were used.

Density Measurement:

The solutions were prepared by weight using Keroy digital balance with least count ±0.0001g in water or ethanol or in binary solutions of these as per requirement. Bi-capillary pycnometer calibrated with double distilled water at room temperature was used for finding densities of solutions.

Viscosity Measurement:

Ostwald Viscometer was initially calibrated using double distilled water and henceforth used for analysing viscosity. For ensuring precision in measurements, each solution was reckoned three times for finding time of flow of fluid in viscometer. The exactness of stopwatch was set at ±0.01s for estimation of liquid stream.

Temperature Control

All the measurements were carried out in a thermostatically controlled and well-stirred water bath with an accuracy of 0.1K. All the measurements of density and time of flow were made in a thermostatic water bath (Model: MD/ME-31A, JULABO, Germany) in order to maintain the desired uniform temperature. The sample was allowed to stand in the bath for about 30 minutes in order to maintain thermal equilibrium between the test samples and the bath liquids.

Table 1: Density and viscosity of pure solvents and solvent systems (water and ethanol) and comparison with literature values

System	Temperature (K)	Density(ρ) (gm mL ⁻¹)		Viscosity(η) (centipoise)	
		Experimental	Literature	Experimental	Literature
0% alcohol	298.15	1.006	0.997	0.9000	0.8920
	303.15	0.999	0.995	0.8002	0.7972
	308.15	0.997	0.994	0.7211	0.7192
	313.15	0.993	0.992	0.6526	0.6527
50% alcohol	298.15	0.938	.....	0.8391	.....
	303.15	0.930	.....	0.7449	.....
	308.15	0.924	.....	0.6683	.....
	313.15	0.919	.....	0.6039	.....
80% alcohol	298.15	0.872	.....	0.7801	.....
	303.15	0.865	.....	0.6928	.....
	308.15	0.851	.....	0.6155	.....
	313.15	0.844	.....	0.5546	.....
90%	298.15	0.850	.....	0.7604	.....

alcohol	303.15	0.844	.....	0.6760	.....
	308.15	0.838	.....	0.6061	.....
	313.15	0.831	.....	0.5461	.....
100% alcohol	298.15	0.804	0.7852	1.0862	1.0606
	303.15	0.798	0.7809	0.9834	0.9613
	308.15	0.791	0.7767	0.8903	0.8735
	313.15	0.789	0.7724	0.8132	0.7957

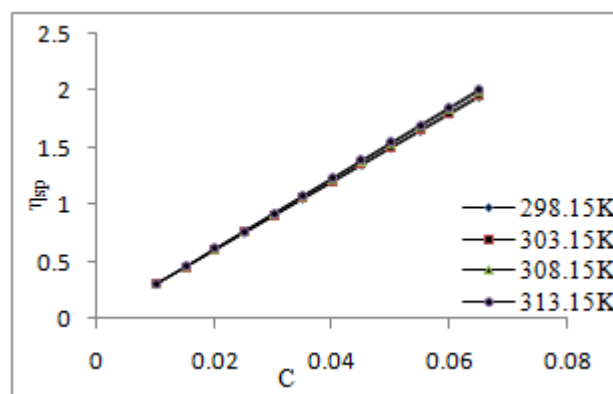
3. Results and Discussion

Jones-Dole, Moulik, Einstein and Vand equations are used to predict the nature and extent of solute-solute and solute-solvent interactions among surfactant molecules and solvent molecules utilising viscosity data which are tested and verified by many workers earlier.

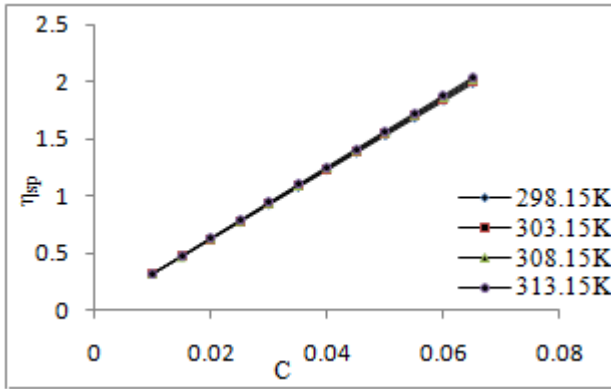
The critical micelle concentration (CMC) of Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate (SDS) in ethanolic and aqueous solutions were determined from the density and viscosity measurement. The density and viscosities increase with increasing PS, SO and SDS concentration and decrease with increasing temperatures. The density and viscosity of the pure components are shown in Table 1. Table 2 shows CMC values (in gm/lit) of Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate (SDS) in alcohol-water solvent systems at different temperatures.

Table 2: CMC values (in gmmol/lit) of Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate (SDS) in alcohol-water systems at different temperatures.

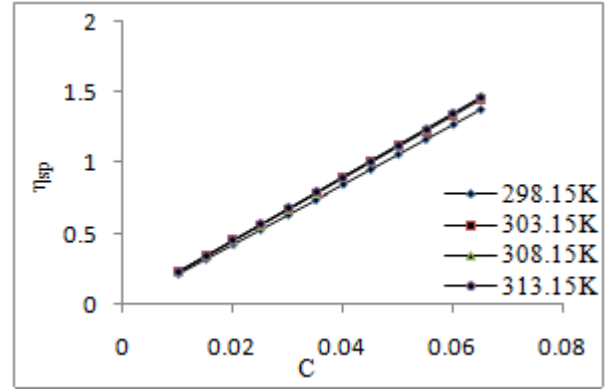
Temperature	0% alcohol	50% alcohol	80% alcohol	90% alcohol	100% alcohol
Potassium Stearate					
298.15	.....	.....	0.025	0.020	0.025
303.15	.....	.....	0.030	0.025	0.030
308.15	.....	.....	0.035	0.025	0.035
313.15	.....	.....	0.035	0.030	0.040
Sodium Oleate					
298.15	0.030	.....	.....	.....	.....
303.15	0.035	.....	.....	.....	.....
308.15	0.040	.....	.....	.....	.....
313.15	0.045	.....	.....	.....	.....
Sodium Dodecyl Sulphate					
298.15	0.020	0.030	0.025	0.020	0.025
303.15	0.020	0.035	0.025	0.025	0.025
308.15	0.030	0.035	0.030	0.030	0.030
313.15	0.035	0.040	0.035	0.030	0.035



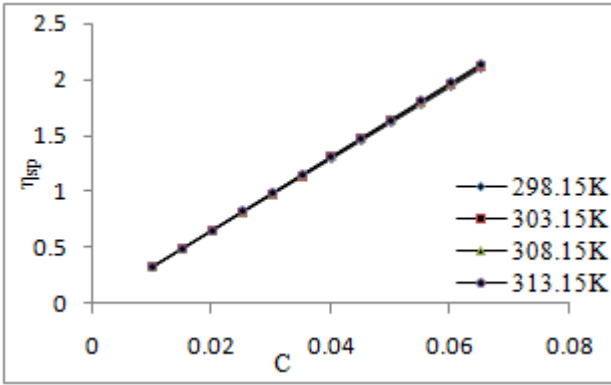
(a)



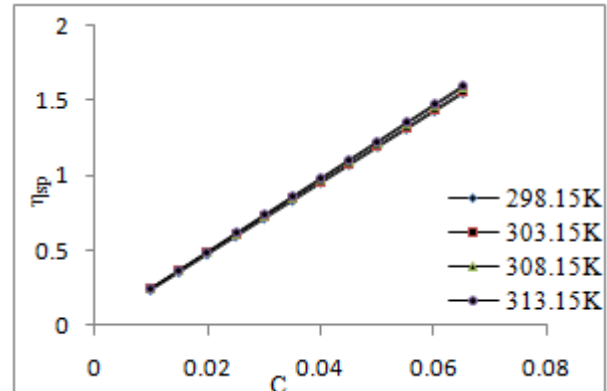
(b)



(b)

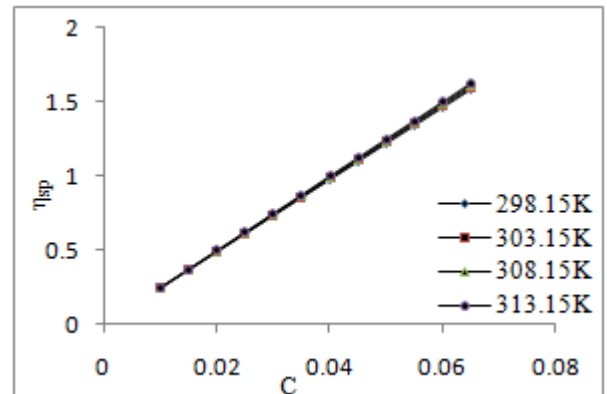
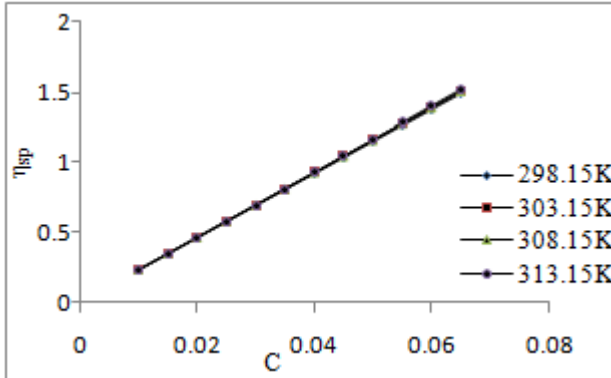


(c)



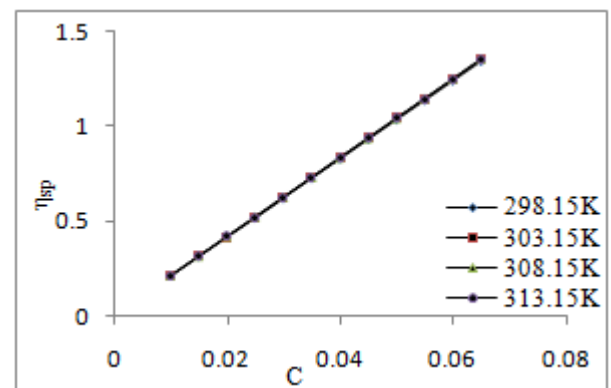
(c)

Figure 1: Plots of η_{sp} vs. C for Potassium Stearate in alcohol water solvent system (a) 80% alcohol, (b) 90% alcohol and (c) 100% alcohol at various temperatures according to Einstein's equation

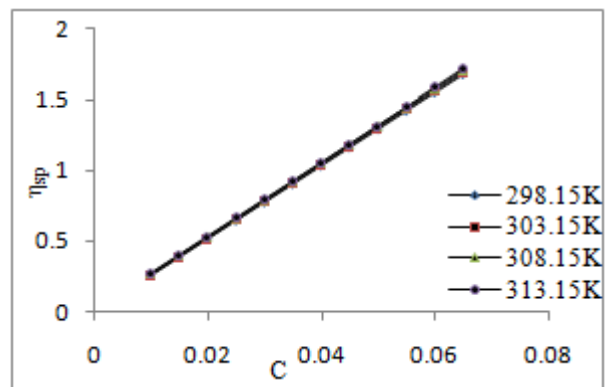


(d)

Figure 2: Plots of η_{sp} vs. C for Sodium Oleate in 0% alcohol at various temperatures according to Einstein's equation



(a)



(e)

Figure 3: Plots of specific viscosity (η_{sp}) vs. Concentration for SDS in alcohol water solvent system (a) 0% alcohol, (b) 50% alcohol, (c) 80% alcohol, (d) 90% alcohol and (e) 100% alcohol at various temperatures according to Einstein's equation

Figures 1, 2 & 3 (the plots of specific viscosity vs. Concentration for Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate) are characterized by an intersection of straight lines at a concentration which corresponds to the CMC of Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate. The curves below the CMC are linear with intercept equalling zero indicating that Einstein's equation is applicable to dilute solutions of PS, SO and SDS below the CMC. The curves specific viscosity vs. Concentration for PS, SO and SDS salts at all temperatures almost overlap showing specific viscosity changing in the same trend though viscosity vs. concentration plots are well separated at different temperatures.

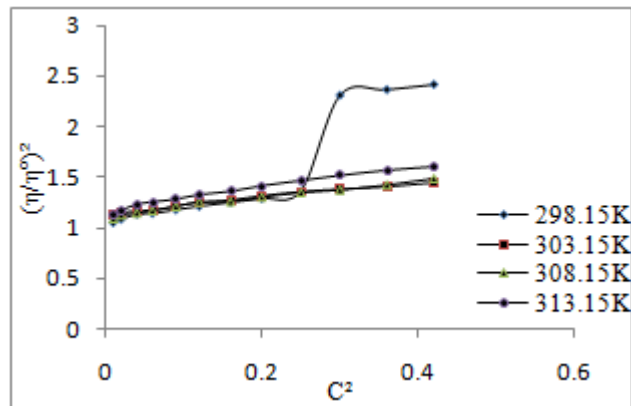
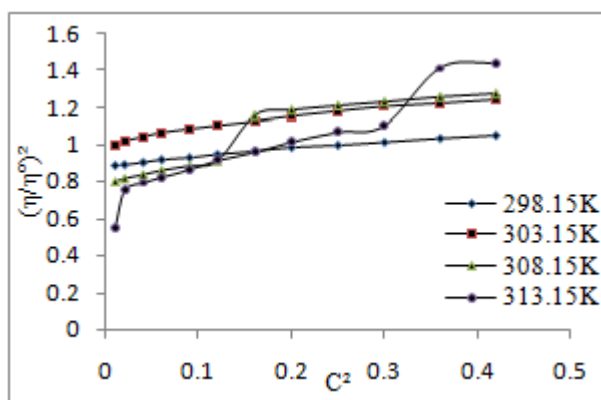
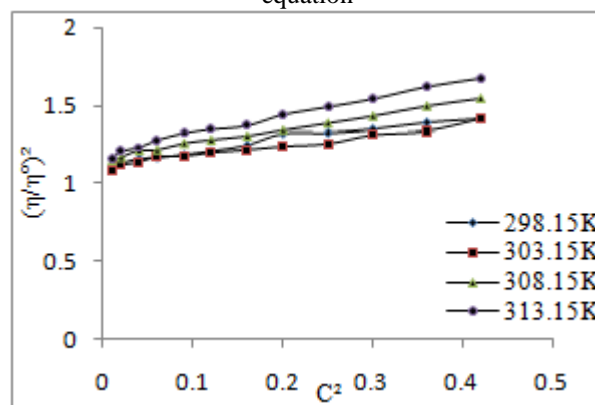


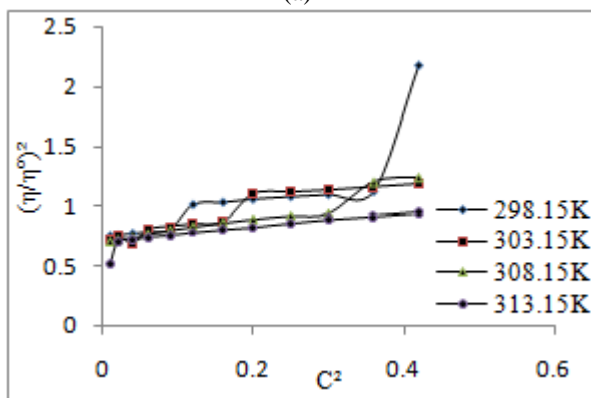
Figure 5: Plots of $(\eta/\eta^0)^2$ vs. C^2 for Sodium Oleate in 0% alcohol at various temperatures according to Moulik equation



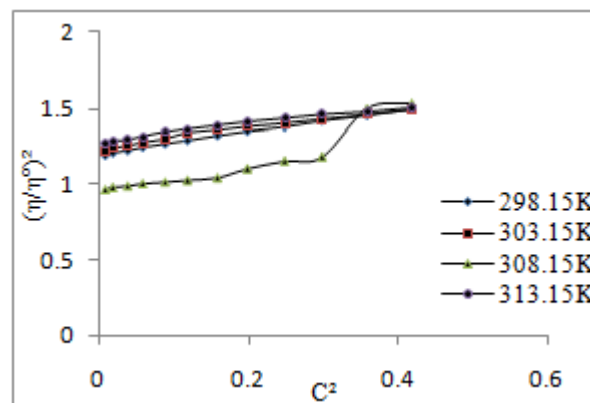
(a)



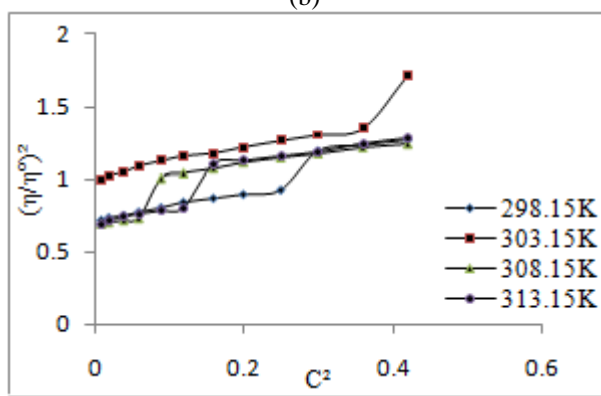
(a)



(b)

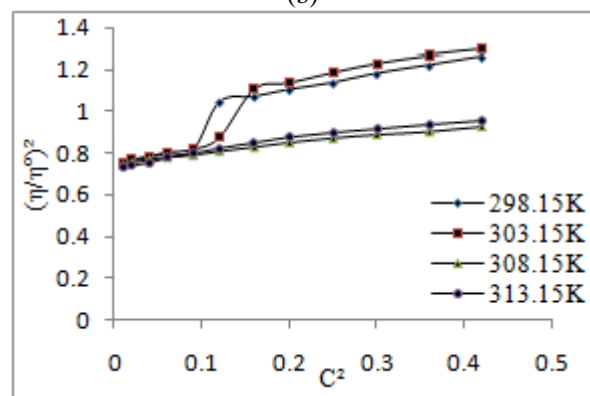


(b)

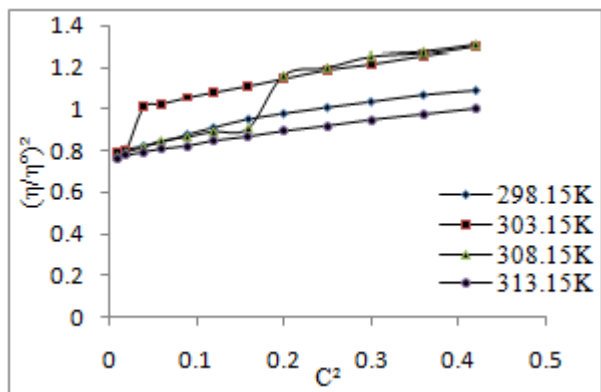


(c)

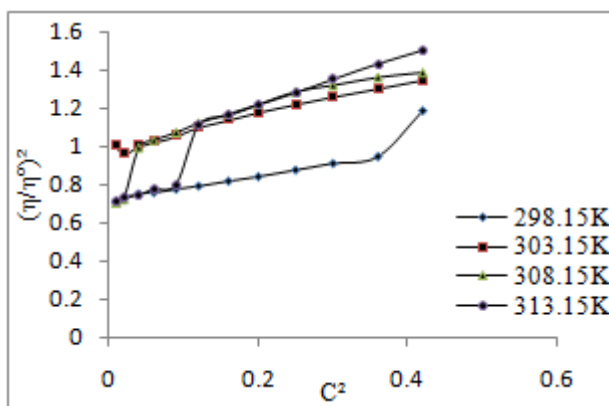
Figure 4: Plots of $(\eta/\eta^0)^2$ vs. C^2 for Potassium Stearate in alcohol water solvent system (a) 80% alcohol, (b) 90% alcohol and (c) 100% alcohol at various temperatures according to Moulik equation



(c)



(d)



(e)

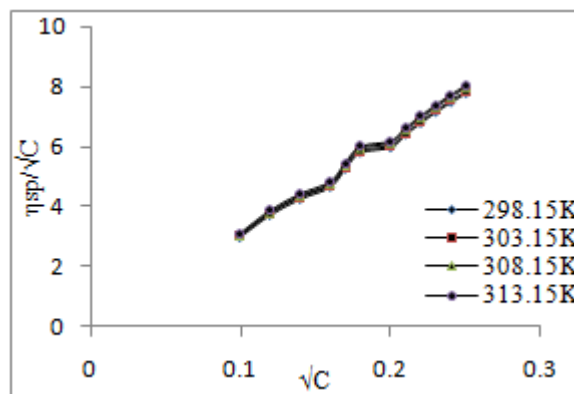
Figure 6: Plots of $(\eta/\eta^0)^2$ vs. C^2 for SDS in alcohol water solvent system (a) 0% alcohol, (b) 50% alcohol, (c) 80% alcohol, (d) 90% alcohol and (e) 100% alcohol at various temperatures according to Moulik equation

The results show that the Moulik equation is in general applicable to PS solutions and SO solutions showing abrupt change in trend at CMC but in case of SDS it is applicable for dilute solutions. For all the cases ideal results are seen at higher temperatures i.e. at 308.15K and 313.15K. The values of Moulik constants M & K which give interactions between solute-solute and solute-solvent molecules have been calculated from the intercept and slope of the plots. The value of $(\eta/\eta^0)^2$ increases linearly for increasing concentrations.

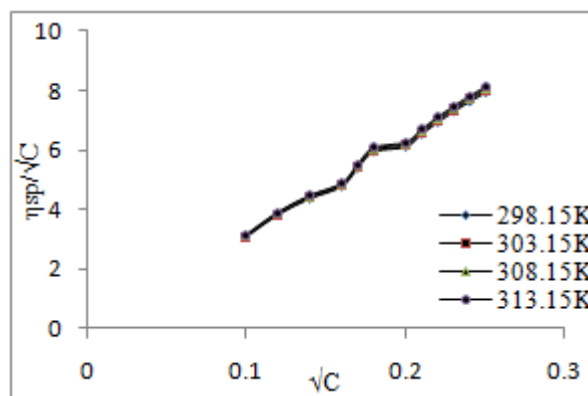
Table 3: Physical constants M & K calculated from Moulik equation for Potassium Stearate, Sodium Oleate and Sodium dodecyl Sulphate at various temperatures

Solvent system	298.15K		303.15K		308.15K		313.15K	
	M	K	M	K	M	K	M	K
Potassium Stearate								
80%alcohol	0.891	0.388	1.018	0.585	0.807	1.336	0.663	1.823
90%alcohol	0.654	2.3	0.716	1.289	0.678	1.218	0.665	0.735
100%alcohol	0.682	1.412	0.983	1.322	0.743	1.419	0.698	1.581
Sodium Oleate								
0%alcohol	0.878	3.572	1.132	0.789	1.114	0.914	1.168	1.11
Sodium dodecyl Sulphate								
0%alcohol	1.122	0.756	1.101	0.697	1.162	0.934	1.187	1.2
50%alcohol	1.189	0.73	1.233	0.655	0.893	1.325	1.276	0.593
80%alcohol	0.807	0.742	0.904	1.063	0.76	1.472	0.773	0.56
90%alcohol	0.767	1.338	0.74	1.547	0.751	0.444	0.746	0.547
100%alcohol	0.689	0.894	0.975	0.912	0.867	1.48	0.713	2.089

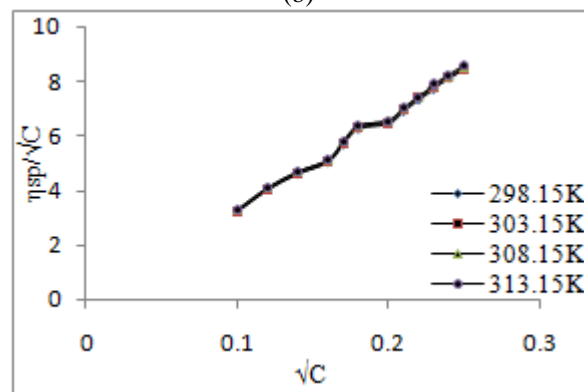
Observation of above table show that in general the solute-solute interactions are greater than solute-solvent interactions when the solvent is pure water or percentage of water is higher. With the increasing percent of ethanol the trend seems to get reversed. At higher percentage of alcohol solute-solvent interactions become greater. It can be explained on the basis of high dielectric constant of water therefore greater ionization in water and lesser solvation of molecules.



(a)



(b)



(c)

Figure 7: Plot of η_{sp}/\sqrt{C} vs. \sqrt{C} for Potassium Stearate in alcohol water solvent system (a) 80% alcohol, (b) 90% alcohol and (c) 100% alcohol at various temperatures according to Jones-Dole equation

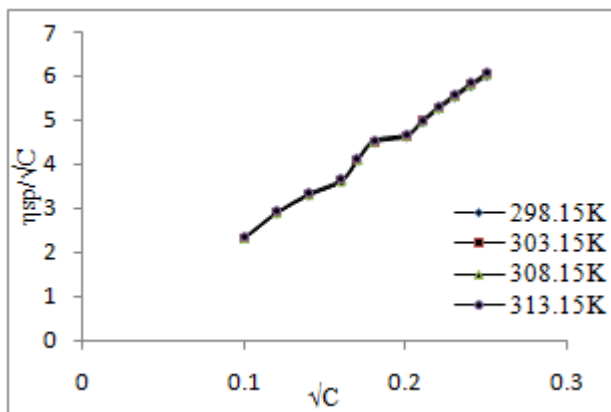
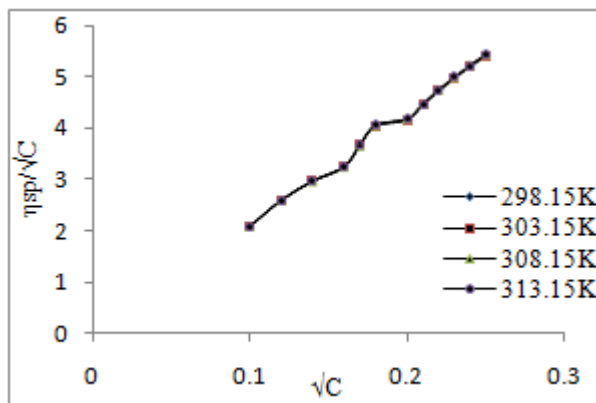
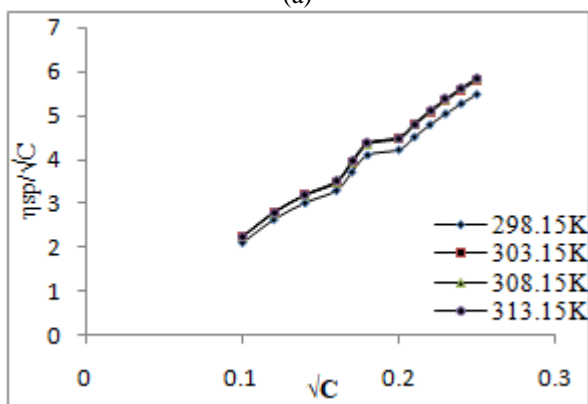


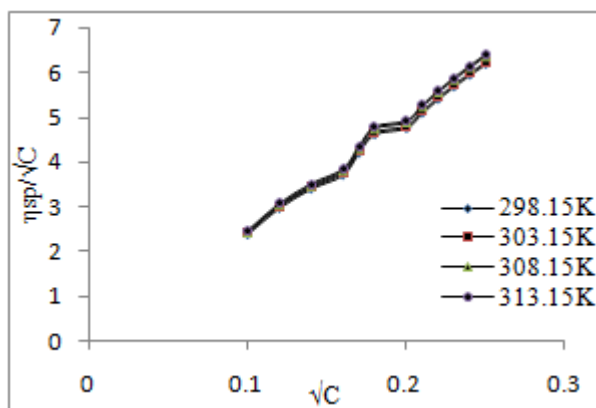
Figure 8: Plots of η_{sp}/\sqrt{C} vs. \sqrt{C} for Sodium Oleate in 0% alcohol at various temperatures according to Jones-Dole equation



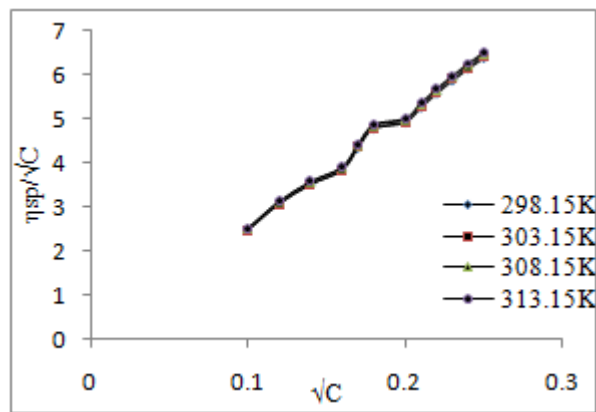
(a)



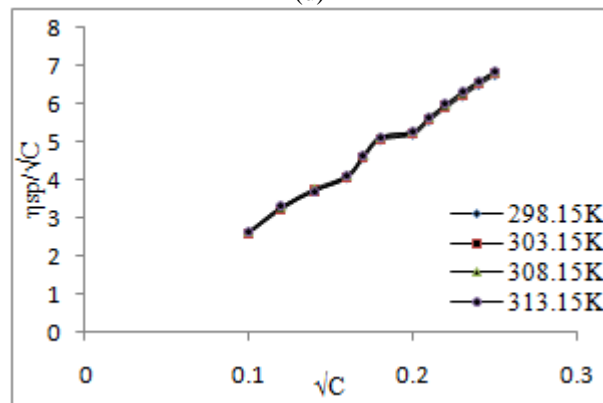
(b)



(c)



(d)



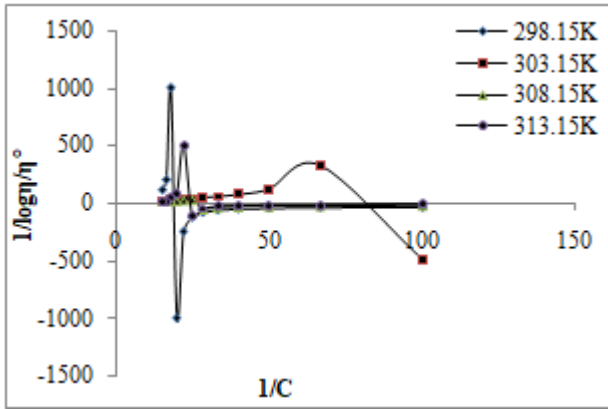
(e)

Figure 9: Plot of η_{sp}/\sqrt{C} vs. \sqrt{C} for SDS in alcohol water solvent system (a) 0% alcohol, (b) 50% alcohol, (c) 80% alcohol, (d) 90% alcohol and (e) 100% alcohol at various temperatures according to Jones-Dole equation

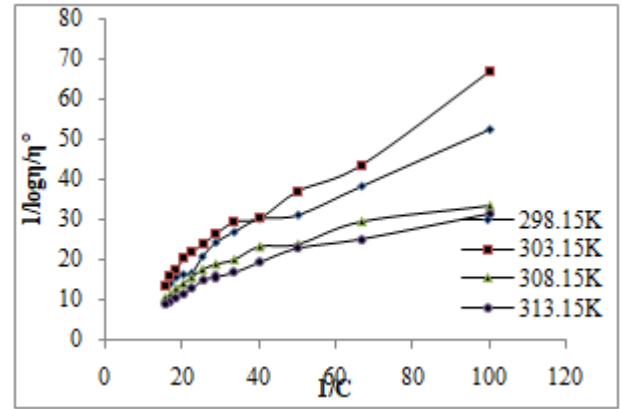
Shown in figures 7, 8 and 9 plots of η_{sp}/\sqrt{C} vs. \sqrt{C} for PS, SO and SDS respectively and these are characterized by a break at points which correspond to the CMC. The values of Jones-Dole constants A & B calculated from the intercept & slope of linear portions below the CMC for the salts under experimentation are represented in table 4. The results show that the solute-solute interaction is lower than the solute-solvent interaction which is partially in agreement with the information obtained from Einstein's equation.

Table 4: Physical constants A & B calculated from Jones-Dole equation for Potassium Stearate, Sodium Oleate and Sodium dodecyl Sulphate at various temperatures

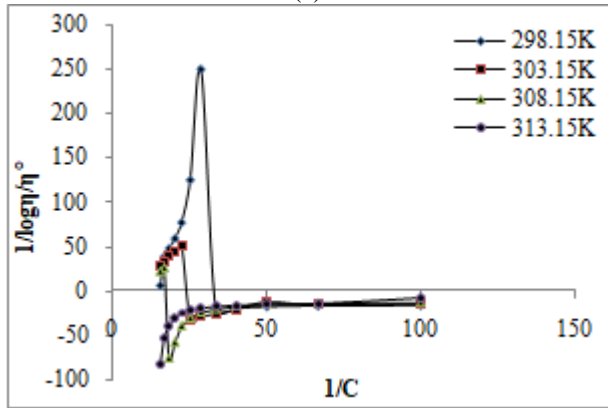
Solvent system	298.15K		303.15K		308.15K		313.15K	
	A	B	A	B	A	B	A	B
Potassium Stearate								
80% alcohol	0.157	31.52	0.153	31.73	0.161	32.29	0.153	32.53
90% alcohol	0.148	32.29	0.149	32.50	0.160	32.77	0.158	33.05
100% alcohol	0.159	34.13	0.169	34.41	0.169	34.72	0.167	34.79
Sodium Oleate								
0% alcohol	0.121	24.32	0.124	24.49	0.117	24.51	0.124	24.65
Sodium dodecyl Sulphate								
0% alcohol	0.116	22.13	0.097	21.92	0.112	22.04	0.116	22.13
50% alcohol	0.104	22.30	0.111	23.57	0.111	23.73	0.115	23.87
80% alcohol	0.123	25.16	0.122	25.36	0.122	25.77	0.127	26.01
90% alcohol	0.125	25.82	0.127	26.01	0.121	26.17	0.125	26.40
100% alcohol	0.137	27.32	0.134	27.51	0.131	27.72	0.156	27.91



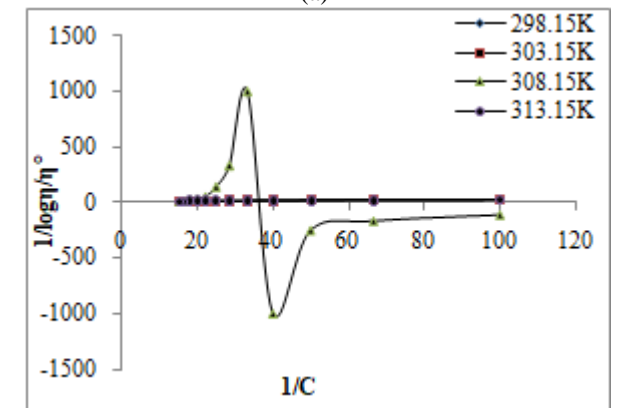
(a)



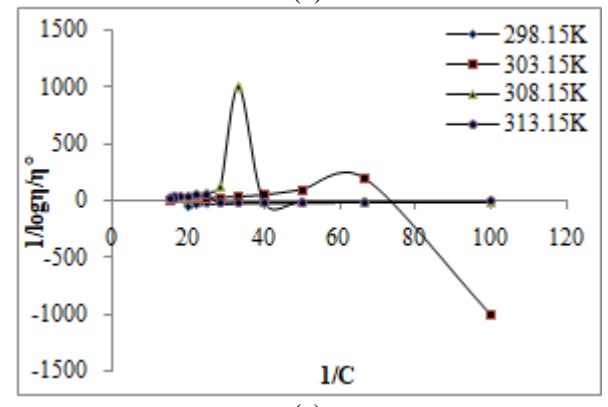
(a)



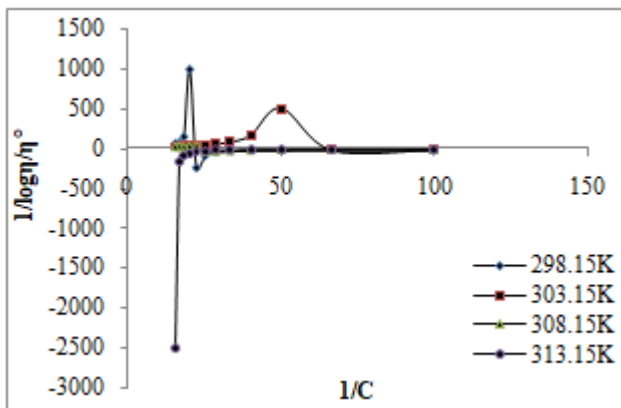
(b)



(b)



(c)



(c)

Figure 10: Plot of $1/C$ vs. $1/\log \eta/\eta^\circ$ for Potassium Stearate in alcohol water solvent system (a) 80% alcohol, (b) 90% alcohol and (c) 100% alcohol at various temperatures according to Vand equation.

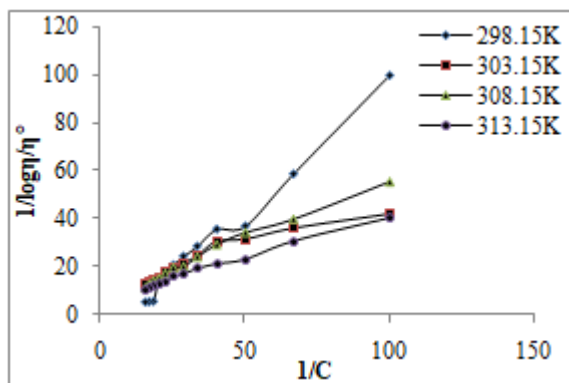
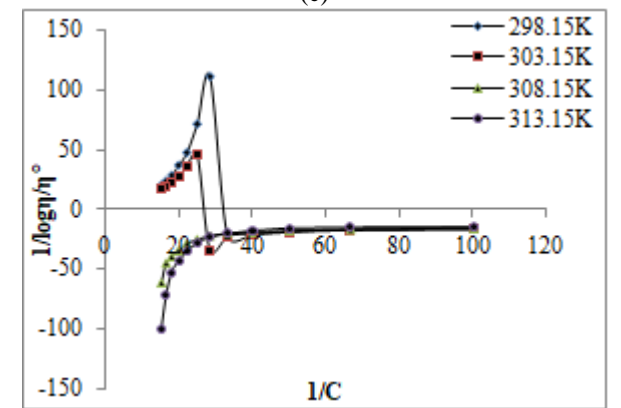


Figure 11: Plot of $1/C$ vs. $1/\log \eta/\eta^\circ$ for Sodium Oleate in 0% alcohol at various temperatures according to Vand equation



(d)

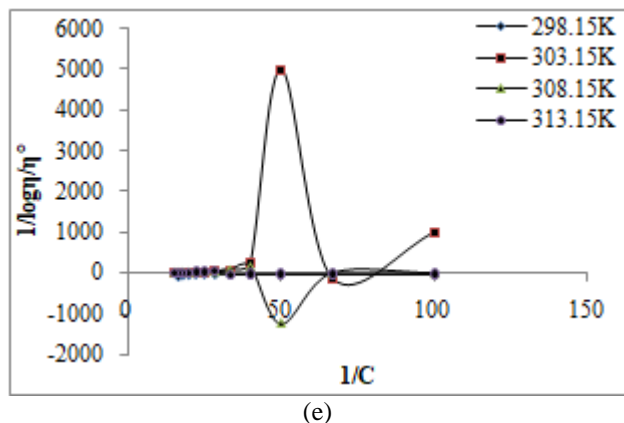


Figure12: Plot of $1/C$ vs. $1/\ln\eta/\eta^\circ$ for SDS in alcohol water solvent system (a) 0% alcohol, (b) 50% alcohol, (c) 80% alcohol, (d) 90% alcohol and (e) 100% alcohol at various temperatures according to Vand equation

Vand equation is showing abnormal behaviour in alcohol water dissolvable system (50%, 80%, 90% and 100% alcohol), yet 0% alcohol tends to normal behaviour. Behaviour also tends to normal at higher temperatures. Alcohol's hydroxyl group can take an interest in H-bonding, leaving it more viscous and less polar natural compound. The dielectric constant of ethanol is lesser than that of water therefore in alcohol ionization of surfactant is similarly less. Ionization of surfactant continues increasing with the increasing percentage of water in the solvent system. Further H-bonding may likewise affect the ionization of salt and viscosity of the solution. Mobility of ions should increase with increasing temperatures due to which again tendency turning towards ideal nature. The estimations of the molar volume V for Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulfate as got from the slopes of the plots (figure 10, 11 and 12) are shown in table 5. The estimations of the interaction coefficients ϕ calculated from the intercept of the plots are presented in table 5.

Table 5: Physical constants molar volume (V) & interaction coefficient (ϕ) calculated from Vand equation for Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulphate at various temperatures

Solvent system	298.15K		303.15K		308.15K		313.15K	
	V	ϕ	V	ϕ	V	ϕ	V	ϕ
Potassium Stearate								
80%alcohol	0.003	-36.19	0.059	-37.87	0.434	-34.87	0.035	-37.46
90%alcohol	0.125	-41.63	0.383	-37.54	0.112	-38.77	0.725	-56.75
100%alcohol	0.083	-34.99	0.055	-34.15	0.01	-37.38	0.557	-40.39
Sodium Oleate								
0%alcohol	0.92	9.113	2.51	21.8	1.904	10.69	2.779	15.13
Sodium dodecyl Sulphate								
0%alcohol	2.113	16.73	1.695	12.58	3.371	28.5	3.582	23.00
50%alcohol	4.390	-45.11	5.770	-60.01	0.012	-36.39	7.616	-79.00
80%alcohol	0.017	-37.38	0.010	-35.50	0.342	-33.36	0.010	-38.90
90%alcohol	0.313	-42.66	0.506	-37.88	1.148	-69.39	0.590	-58.05
100%alcohol	0.254	-42.47	0.005	-33.32	0.013	-35.29	-0.670	-40.63

4. Conclusion

An extensive and near investigation of anionic surfactants Potassium Stearate, Sodium Oleate and Sodium Dodecyl Sulfate in alcoholic and watery dissolvable system (0%, 50%, 80%, 90%, and 100% alcohol) has been completed.

The density and viscosity of PS, SO and SDS solutions increases with increases concentration. The viscosity results of the salts in binary solvent systems have been agreeably clarified as far as Einstein, Vand, Moulik, and Jones-Dole equations. The outcomes obtained from different conditions demonstrate almost similar trend, yet results got from Vand equation indicate abnormal behaviour in solvent systems of changing composition. The values of different constants got from these known equations show that there is a significant interaction between PS, SO and SDS molecules themselves and with those with dissolvable particles.

References

- [1] Newseed Chemical Co., Ltd, food sweeteners/ applications and uses of C18H35KO2, <https://www.foodsweeteners.com>
- [2] Rita Martin, world of chemical, <https://www.quora.com/What-is-sodium-oleate-used-for>
- [3] VELJKO KRSTONOŠIĆ, LJUBICA DOKIĆ, IVANA NIKOLIĆ, TAMARA DAPČEVIĆ and MIROSLAV HADNAĐEV, Influence of the sodium dodecyl sulphate (SDS) concentration on the disperse and rheological characteristics of oil-in-water emulsions stabilized by octenyl succinic anhydride modified starch-SDS mixtures, *J. Serb. Chem. Soc.*, 77 (1) 83–94 (2012).
- [4] B. Jovčić, J. Begović, J. Lozo, L. Topisirović, M. Kojić, *Arch. Biol. Sci.* 61 (2009) 159.
- [5] M. A. MOTIN, M. A. HAFIZ MIA, A. K. M NASIMUL ISLAM, K M SALIM REZA AND M. A. YOUSUF, *Journal of Bangladesh Chemical Society*, Vol. 25(2), 110-123, 2012.
- [6] Kamal Kishore, Manpreet Singh and SujataNegi, Investigating Aggregation and Interaction for Stearalkonium Chloride in Methanol at 301 K, *Pharmaceutical Sciences & Analytical Research Journal*, 1(1), 2018.
- [7] Pratima Jain, Shweta Sharma & R.K. Shukla, *physical and chemistry of liquids: an international journal*, <http://dx.doi.org/10.1080/00319104.2012.760074>.
- [8] A. Einstein, Eineneue Bestimmung der Molekül dimensionen, *Annalen Der Physik*, Band. 19 (1906) 289–306.
- [9] V. V, Viscosity of solutions and suspensions, I Theory. *J Phys Chem.* 52 (1948) 277–299.
- [10] S.P. Moulik, Proposed viscosity-concentration equation beyond Einstein's region, *The Journal of Physical Chemistry.* 72 (1968) 4682–4684. doi:10.1021/j100859a054.
- [11] G. Jones, M. Dole, The viscosity of aqueous solutions of strong electrolytes with special reference to barium chloride, *Journal of the American Chemical Society.* 51 (1929) 2950–2964. doi:10.1021/ja01385a012.12.
- [12] E. Peyrin and Y.C. Guillaume, *talanta* 49, (1999) 415–423.
- [13] C.P. Royall, M.E. Leunissen, and A.V. Blaaderen, *J. Phys. Condens. Matter.* 15, (2003).3581–3596
- [14] R.W. Gurney, *Ionic Process in Solution* (McGraw Hill, New York, 1953).

- [15] R.H. Stokes and R. Mills, the viscosity of Electrolytes and Related Properties (Pergamon Press, London, 1965).
- [16] Newseed Chemical Co., Ltd, food sweeteners/ applications and uses of C18H35KO2, (2018). <https://www.foodsweeteners.com>.
- [17] R. Martin, World of chemical, (2018). <https://www.quora.com>.
- [18] V. Krstonošić, L. Dokić, I. Nikolić, T. Dapčević, M. Hadnaiev, Influence of the sodium dodecyl sulphate (SDS) concentration on the disperse and rheological characteristics of oil-in-water emulsions stabilized by octenyl succinic anhydride modified starch-SDS mixtures, *Journal of the Serbian Chemical Society*. 77 (2012) 83–94. doi:10.2298/JSC100630150K.
- [19] B. Jovicic, J. Begovic, J. Lozo, L. Topisirovic, M. Kojic, Dynamics of sodium dodecyl sulfate utilization and antibiotic susceptibility of strain *Pseudomonas* sp. ATCC19151, *Archives of Biological Sciences*. 61 (2009) 159–164. doi:10.2298/ABS0902159J.
- [20] M. Motin, M.H. Mia, A.N. Islam, K.S. Reza, M. Yousuf, Effect Of Sodium Dodecyl Sulfate On Viscometric Properties Of Methanol, Ethanol, n-Propanol And iso-Propanol At Different Temperatures, *Journal of the Bangladesh Chemical Society*. 25 (2013). doi:10.3329/jbcs.v25i2.15046.
- [21] A. Khan, I. Bibi, S. Pervaiz, K. Mahmood, M. Siddiq, M. Siddiq, Surface Tension, Density and Viscosity Studies on the Associative Behaviour of Oxyethylene-Oxybutylene Diblock Copolymers in Water at Different Temperatures, *International Journal of Organic Chemistry*. 2 (2012) 82–92. doi:10.4236/ijoc.2012.21014.
- [22] C. Booth, D. Attwood, Effects of block architecture and composition on the association properties of poly(oxyalkylene) copolymers in aqueous solution, *Macromolecular Rapid Communications*. 21 (2000) 501–527. doi:10.1002/1521-3927(20000601)21:9<501::AID-MARC501>3.0.CO;2-R.
- [23] K. Kishore, M. Singh, S. Negi, Investigating Aggregation and Interaction for Stearalkonium Chloride in Methanol at 301 K, 1 (2018) 1–5.
- [24] P. Jain, S. Sharma, R.K. Shukla, Density and viscosity of tetrabutyl ammonium hydrogen sulphate and tetrabutyl ammonium chloride salts in aqueous and methanolic solution at 303 K, *Physics and Chemistry of Liquids*. 51 (2013) 547–566. doi:10.1080/00319104.2012.760084.
- [25] M. Sarwar Hossain, A. Chandro Sarker, T. Khandaker, M. Kamrul Hasan, M. Nuruzzaman Khan, Volumetric and viscometric studies of sodium dodecyl sulphate in aqueous and in amino acid solutions at different temperatures, *IOSR Journal of Applied Chemistry*. 9 (2016) 30–41. doi:10.9790/5736-09113041.
- [26] A. Einstein, Eineneue Bestimmung der Molekül dimensionen, *Annalen Der Physik*, Band. 19 (1906) 289–306.
- [27] V. V, Viscosity of solutions and suspensions, I Theory. *J Phys Chem*. 52 (1948) 277–299.
- [28] S.P. Moulik, Proposed viscosity-concentration equation beyond Einstein's region, *The Journal of Physical Chemistry*. 72 (1968) 4682–4684. doi:10.1021/j100859a054.
- [29] G. Jones, M. Dole, The viscosity of aqueous solutions of strong electrolytes with special reference to barium chloride, *Journal of the American Chemical Society*. 51 (1929) 2950–2964. doi:10.1021/ja01385a012.