A Model Applied to Surface Tension of Liquids

D.V. Singh[1], A. Kumar[2], R.Kumari[3] and N.Dass[3*]

[1]Physics Department, College of Engineering Roorkee, Roorkee, India
[2]Physics Department, Gurukula Kangri Vishwavidyalaya, Haridwar, India
[3]Physics Department, M S Post Graduate College, Saharanpur, India

*Corresponding Author: ndass2@rediffmail.com

Abstract- In the present paper, a model is suggested to study the temperature dependence of surface tension in liquids and is applied in more than sixty liquids including liquid metals, rare gas liquids, inorganic and organic liquids. A very good agreement is found between the experimental values and the computed results in case of each liquid.

Keywords- Surface tension, temperature, liquid metals and liquefied gases, organic and inorganic liquids

I. INTRODUCTION

Surface tension of liquid is an important property and has wide applications in understanding the phenomenon of (i) wettability (ii) migration (iii) atomic bonding and (iv)two-phase heat transfer along with the correlation with other thermodynamic properties. Further, the surface tension is found to have the practical applications in material science, chemical engineering and environmental science besides physics, chemistry and petroleum engineering. However, the surface tension of liquid is found to decrease with rise in temperature and vanishes at critical temperature. Under these circumstances, a study of temperature dependence of surface tension of liquids become quite important and particularly in the development of a model for the liquid state with the help of physical thermodynamic properties.

In literature, many empirical and semi-empirical relations [1-14] are available to represent the temperature dependence of surface tension of liquids. All these relations make use of reduced parameters which include the critical temperature or some other property of the concerned liquid and hence adjustable parameters required for the study of temperature dependence of surface tension in the liquids become quite large. Further, these relations have limited success in the sense that these relations could not be applied in case of those liquids whose critical temperature is not known. Hence, there is a need of a model/relation between surface tension and temperature which can be applied to different types of liquids and that too for the widest possible temperature range even without knowing the value of the critical temperature or some other physical property of the concerned liquid.

Therefore, the aim of the present paper is to suggest a model/relation between surface tension of liquid and the temperature .The model/relation can be further used to obtain thermo-physical properties like para-chore, surface entropy and surface enthalpy.

II. THEORY

To study the temperature dependence of surface tension in liquids, it is suggested that the ratio of second to first temperature derivative of surface tension is a constant and is expressed as

$$(\frac{d^2\sigma}{dT^2})/(\frac{d\sigma}{dT}) = -Z$$

(1)

Successive integration of eq.(1) with respect to temperature in limits $T = T$ and $T = T_0$ gives the following relations:

$$\frac{d\sigma}{dT} = \sigma'(T_0)\exp[-Z(T-T_0)] \qquad (2)$$

and

$$\sigma(T) = \sigma(T_0) + \frac{\sigma'(T_0)}{Z}[1-\exp\{-Z(T-T_0)\}]$$

(3)

In eqs.(1)-(3). $\sigma(T_0)$ and $\sigma'(T_0)$ represent surface tension and its first temperature derivative at $T = T_0$ where

T_0 is the reference temperature. Z is a temperature independent constant.

III.   RESULTS AND DISCUSSIONS

The relation given by eq.(3) is applied in liquid metals, rare gas liquids, inorganic and organic liquids including ionic liquids. In total, we have applied eq.(3) in more than sixty liquids. The results are reported in table 1. Table1 includes the temperature range studied, the values of constants $\sigma'(T_0)$ and Z along with root mean square deviation (RMSD) in case of each liquid studied here. RMSD is a parameter which represents the goodness of fit. The values of the constants are determined by least square fit.

The surface thermodynamic properties like surface entropy and surface enthalpy can be estimated once the temperature dependence of surface tension is known. The surface entropy, S^σ, and surface enthalpy, H^σ, can be computed from the relations:

$$S^\sigma = -(\frac{d\sigma}{dT})$$

(4)

$$H^\sigma = \sigma - T(\frac{d\sigma}{dT})$$

(5)

It is evident that $\sigma'(T_0)$ expresses the value of surface entropy at temperature T_0. With the help of eq.(2), one can easily calculate the values of surface entropy and surface enthalpy as a function of temperature.

IV.   CONCLUSION

Following important points emerges out from the present study:

(a)   It is evident from table 1 that the present relation is quite successful and valid in representing the temperature dependence of surface tension in all the liquids studied here.

(b)   From the present relation, one can easily obtain surface thermodynamic properties like surface entropy and surface enthalpy. To save space, these properties are not reported in the present paper.

(c)   The present relation is free from critical temperature and other physical properties of the liquid concerned.

(d)   The present model has only two adjustable parameters and one of the parameter represents the surface entropy.

(e)   The relation is useful in the interpolation as well as in the extrapolation of surface tension data at any given temperature.

REFERENCES

[1] N.Auerbach, Experientia, vol.4, pp.473, 1948.

[2] K. Alterburg, Z.Phys.Chem., pp.145-147, 1950.

[3] J. R. Brock and R B Bird, AICHE journal, vol.1, pp.174-177, 1955.

[4] D. D Patterson and A. K. Rastogi, J Phys. Chem., vol.74, pp.1067-1071, 1970.

[5] D. I. Hakin, D. Steinberg and L I Stiel, Ind.Eng.Chem.Funda., vol.10, pp.174, 1971.

[6] J. A. Hugill and A J Van Welsenes, Fluid Phase Equil., vol.29, pp.383, 1986.

[7] R. P. Chhabra, High Temp-High Press., vol.21,pp.171-174, 1990.

[8] H.M.Lu and Q. Jiang, J.Phys.Chem.B, vol.109, pp.15463-15468, 2005.

[9] K. S. Pitzer Thermodynamics, 3rd ed. Mcgraw-Hill, Nework, 1995.

[10] Y.X.Zuo and E. H. Stenley, Can. J. Chem. Eng., Vol.75,pp.1130-1132, 1997.

[11] C. Mrqueu et al, Fluid Phase Equil, Vol. 172, pp.169-171, 2000.

[12] S. T. Bowden, J Chem Phys., vol.23,pp.2454, 1955.

[13] N. K. Sanyal and S S Mitra, J.Chem Phys., vol.24, pp.473-474, 1956.

[14] N. Dass and O. Singh, J Phy. Soc Japan, vol 28, pp.806-807, 1970.

[15] V.W. Lazarev, Teoreticheskaya i Eksperimental'naya Khimiya,vol.3,pp.504-507, 1967.

[16] F. Aqra and A. Ayyad, Phys and Chem Liquids, vol.50, pp.336-345, 2012

[17] M. H. Ghatee and A. Boushehri, High Temp- High Pressures, vol.26, pp507-514, 1994.

[18] S. Kim and S. Chang, Daehan Hwahak Hwoejee, vol.9, pp.110-114, 1965.

[19] J. Amoros, J, R, Solana and E. Villar, Materials Science, vol.7, pp.127-136, 1982.

[20] L. Lomba et. al. J. Chem. Thermodynamics, vol.65, pp. 34-41, 2013.

[21] M. H. Ghatee et. al., J. Chen. Engg. Data , vol.57, 2095-2101, 2012.

[22] P. Jianxin and L. Yigang, Phys. and Chem Liquids, vol.47,pp.267-273, 2009.

[23] W. Gao, X. Zhao and Z. Liu, J. Chem. Engg. Data, vol.54, pp.1761-1763, 2009.

[24] J. Klomfar, M. Souckova and J. Patak, J. Chem. Engg. Data, vol.59, pp. 2263-2274, 2014.

[25] T. M. Koller et. al.; J. Chem. Engg. Data, vol.60,pp. 2665-2673, 2015.

[26] G. Vazquez, E. Alvarez and M. Navaza, J. Chem. Engg. Data, vol.40, pp. 611-614, 1995.

[27] L. G. Sanchez et. al., J. Chem. Engg. Data, vol.54, pp. 2803-2812,2009.

[28] H. F. D. Almeida et. al. J. Chem. Thermodynamics, vol. 57, pp.372-379, 2013.

[29] E. M. Fendu and F. Oprea, J. Chem. Engg. Data, vol.58, pp.2898-2903,2013.

[30] J. Vijande et. al. J. Chem. Engg. Data, vol.51,pp. 1778-1782, 2006.

[31] P. K. Chhotaray and R.L. Gardas, J. Chem. Engg. Data, vol.60,pp. 1868- 1877, 2015.

[32] L. Lomba et. al. J. Chem. Engg. Data, vol. 59, pp. 329-338, 2014.
[33] L. Lomba et. al. J. Chem. Engg. Data, vol. 58, pp.1193-1197, 2013.

[34] S. Halas and T. Durakiewicz, J. Phys.: Condens. Matter, vol. 14, pp.L735-L737, 2002.
[35]   IAWPS Release on Surface Tension of Ordinary Water, September, 1994.
[36] I. C. Sanchez, J. Chem. Phys., vol79, pp. 405-407, 1983.

Table 1- Input parameters and RMSD in case of different liquids

S. No.	Liquid	Temp Range (K)	$-\sigma'(T_0)$ (mNm^{-1} K^{-1})	Z(K^{-1})	RMSD (mNm^{-1})	Ref.
1	Sn	250-1700	0.0738	0.0001	2.07	15
2	In	200-1700	0.1194	0.0003	3.68	15
3	Pb	330-1400	0.1246	0.0001	2.91	15
4	Tl	310-1100	0.0834	0.0001	1.35	15
5	Bi	300-1300	0.0814	0.0001	1.58	15
6	Cd	325-600	0.2085	-0.0001	0.93	15
7	Ge	950-1700	0.0976	0.0001	2.38	15
8	Si	1687-1825	0.2968	-0.0003	0.11	16
9	K	336.4-1032.2	0.0066	-0.0001	0.003	17
10	Li	453.7-1645	01410	0.0001	0.012	17
11	Na	371.0-1151.2	0.0010	0.0001	0.002	17
12	Rb	312.7-959.2	0.0058	0.0002	0.003	17
13	Cs	301.6-943.0	0.0048	-0.0001	0.003	17
14	I	398.15-428.5	0.1110	0.0105	0.033	18
15	Ar	83.81-140.0	0.2642	-0.0072	0.039	19
16	Xe	170.0-280.0	0.1970	-0.0046	0.084	19
17	Ne	24.55-30.0	0.3574	-0.0031	0.013	19
18	Kr	115.79-119.04	0.2091	0.0543	0.026	19
19	Methyl Levulinate	278.15-338.15	0.1111	-0.0001	0.034	20
20	2-HEAF	298.15-353.15	0.0731	0.0003	0.027	21
21	CO_2	221.0-298.20	0.3122	-0.0115	0.142	22
22	2,2Dimethylbutane	233.08-378.23	0.1083	0.0011	0.067	23
23	[THTDP][NTf$_2$]	273.49-364.76	0.0541	-0.0021	0.068	24
24	[THTDP][DCA]	283.61-365.21	0.0725	-0.0027	0.080	24
25	[EMIM][C(CN)$_3$]	283.18-353.36	0.0714	-0.0061	0.144	25
26	[BMIM][C(CN)$_3$]	283.39-353.37	0.1517	0.0136	0.143	25
27	[HMIM][C(CN)$_3$]	283.23-353.53	0.0756	0.0001	0.075	25
28	[OMIM][C(CN)$_3$]	283.28-353.03	0.0906	0.0054	0.088	25
29	[EMIM][B(CN)$_4$]	283.10-353.45	0.1137	0.0070	0.081	25
30	[BMIM][B(CN)$_4$]	283.23-353.30	0.0825	-0.0022	0.111	25
31	[HMIM][B(CN)$_4$]	283.27-353.27	0.0811	-0.0020	0.101	25
32	[OMIM][B(CN)$_4$]	283.23-353.28	0.0824	-0.0022	0.112	25
33	[DMIM][B(CN)$_4$]	283.19-353.24	0.0866	0.0027	0.091	25
34	1-Propanol	293.15-323.15	0.0794	-0.0001	0.009	26
35	2-Propanol	293.15-323.15	0.1012	-0.0001	0.008	26
36	Methanol	293.15-323.15	0.0949	0.0022	0.025	26
37	Ethanol	293.15-323.15	0.0909	0.0065	0.022	26
38	[BMIM] MeSO$_4$	294.55-353.15	0.0235	-0.0371	0.601	27
39	[p$_{666}$(14)][NTf$_2$]	298.20-343.20	0.0744	0.0074	0.050	28
40	[p$_{666}$(14)][Deca]	298.00-343.00	0.0541	-00057	0.034	28
41	[p$_{666}$(14)][phosh]	297.90-342.90	0.0592	-0.0073	0.035	28
42	[p$_{666}$(14)][N(CN)$_2$]	298.40-343.40	0.0755	0.0078	0.025	28
43	[p$_{666}$(14)][Br]	289.20-343.40	0.0712	0.0022	0.060	28
44	[p$_{666}$(14)][Cl]	298.60-343.30	0.0620	-0.0055	0.050	28
45	[p$_{666}$(14)][CH$_3$SO$_3$	298.30-343.50	0.0736	0.0030	0.028	28

46	Tetrapropylene Glycol	298.15-468.15	0.0823	-0.0001	0.035	29
47	1-Butanol	288.15-308.15	0.0848	0.0098	0.022	30
48	1-Octanol	288.15-308.15	0.0848	0.0098	0.022	30
49	1-Rexanol	288.15-308.15	0.0848	0.0098	0.022	30
50	PAAC	293.15-333.15	0.0858	-0.0019	0.022	31
51	3 HPAF	293.15-333.15	0.1017	-0.0200	0.020	31
52	3 HPATFac	293.15-333.15	0.0831	-0.0001	0.026	31
53	5-Methylfurfural	278.15-338.15	0.1210	0.0007	0.030	32
54	Tetrahydrofurfuryl Alcohol	288.15-338.15	0.1013	0.0001	0.003	32
55	Methyl Acrylate	278.15-338.15	0.1350	0.0017	0.035	33
56	Ethyl Acrylate	278.15-338.15	0.11920	0.0001	0.028	33
57	Butyl Acrylate	278.15-338.15	.1085	-0.0005	0.080	33
58	Mercury	273.15-523.15	0.1548	-0.0027	0.070	34
59	Water	273.15-423.15	0.1460	-0.0029	0.040	35
60	Heptane	273.15-523.15	0.1056	0.0017	0.113	36
61	Benzene	278.65-473.15	0.1364	0.0013	0.049	36

Author Profile

Mr. N. Dass obtained B.Sc and M.Sc from Birla Science College, Pilani (India) in year 1960 and 1962. He obtained his Ph.D from University of Roorkee (now IIT) in year 1969.He has published more than seventy research papers in International and National Journals. Thirty papers have been accepted for presentation in various International Conferences. He has been the reviewer to some International Journals. After retiring from University of Roorkee, he is presently working in College of Engineering Roorkee, Roorkee (India).