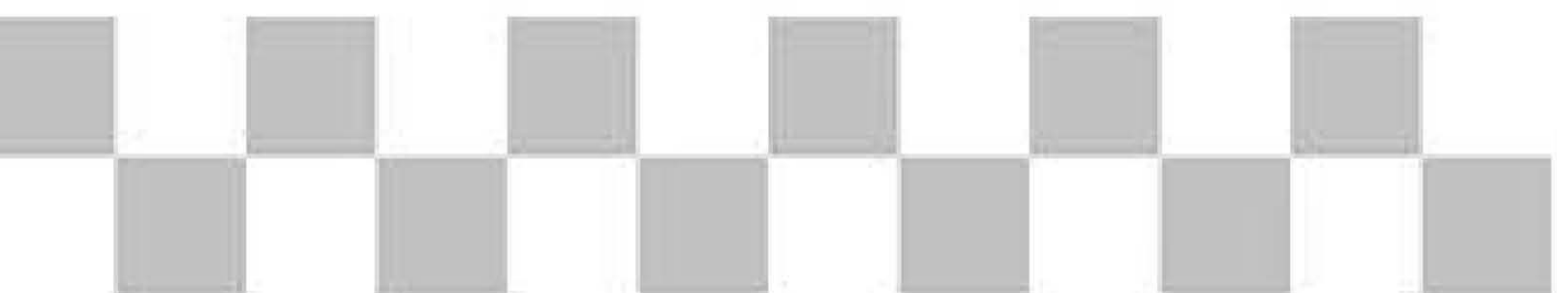


ISSN 2231-5705 (Print)
ISSN 2231-5713 (Online)

Asian Journal of
Pharmacy and Technology

An International Peer-reviewed Journal of Pharmaceutical Sciences



AJPTech.

A₁PhP
asian pharma press
www.asianpharmaonline.org

ISSN- 2231-5705 (Print)
ISSN- 2231-5713 (Online)

www.asianpharmaonline.org



RESEARCH ARTICLE

Surface Tension Prediction of Organic Binary Liquid Mixtures

Prof. Dr. Ulhas Balkrishna Hadkar^{1*}, Miss. Munira Aunali Loliwala²

¹Director, Mumbai Education Trust's, Institute of Pharmacy, Bandra (west), Mumbai- 400050, Maharashtra, India.

²Mumbai Education Trust's, Institute of Pharmacy, Bandra (west), Mumbai- 400050, Maharashtra, India.

*Corresponding Author E-mail: ulhashadkar@yahoo.com, mloliwala72@gmail.com

ABSTRACT:

Equations have been reported in the literature to predict the surface tension of binary liquid mixtures. However, the equations involve large number of variables and are very complex. In the present article an attempt is made to propose an empirical equation to predict the surface tension of binary organic liquid mixtures. A simple equation, 'Hadkar Equation', has been proposed and was used to calculate the surface tension of binary liquid mixtures that have already been reported in the literature and was found to give the results close to the reported values. To verify the utility of the equation for the prediction of surface tension of liquid mixture, the surface tension of a few organic binary liquid mixtures was determined using drop weight method. The 'Hadkar Equation', was found to be useful in the prediction of surface tension of organic binary liquids having weak force of attraction.

KEY WORDS: Surface tension, Drop weight method, Dielectric constant, Intermolecular forces.

INTRODUCTION:

Surface tension of a liquid is defined as the force in dynes acting along the surface of the liquid at right angles to any line one centimeter in length¹. The various methods² to determine surface tension of a liquid are drop weight method, capillary rise method, Du-Nuoy ring method. The plot of surface tension versus concentration has been used to determine critical micelle concentration of a surfactant³. It is also used to determine the cross sectional area of a surfactant molecule⁴. In general, surface tension is an important physical property due to its influence on several natural phenomenon as well as its industrial applications⁵, such a detergency, lubrication, chemical reactions that occur at the fluid surfaces. Surface tension of pure liquids such as heptanes, toluene, cyclohexane etc and binary liquid mixtures has been determined by Hike Kahl, Tinowadewitz and Jochem Winkelmann⁶.

Surface tension has been shown to have a significant effect on the dissolution rate of drugs and their release rate from solid dosage forms⁷. Surfactants and wetting agents lower the contact angle and consequently improve penetration by dissolution medium.

Finholt and Solvang⁸ compared the dissolution behavior of phenacetin and phenobarbital tablets in human gastric juice to that in dilute hydrochloric acid with and without various amounts of polysorbate 80 in the dissolution medium. The data showed that both pH and surface tension have significant influence on the dissolution kinetics of the drug studies.

Mixtures of liquids are often used in industry and it is necessary to know the surface tension of liquid mixtures. The surface tension of binary liquid mixtures γ_m by ideal mixing rule is given by the equation

$$\gamma_m = (x_A \gamma_A + x_B \gamma_B) \text{----- (1),}$$

in which x_A and x_B are the mole fractions of components A and B and γ_A and γ_B are the surface tensions of pure components A and B respectively. The equation (1) is

valid if there is no interaction between the components of the mixture. The difference in actual surface tension of the mixture γ_{mix} and that calculated using equation (1) is represented by $\gamma_E = \gamma_{\text{mix}} - (x_A \gamma_A + x_B \gamma_B)$ and is the direct measure of interaction between the two liquids.

The intermolecular attractive forces that exist between like or unlike molecules are (a) Van der Waals Forces that include dipole-dipole attractive forces, dipole-induced dipole attractive forces (London forces). (b) Ion-ion dipole force of attraction. When two liquids are mixed, the surface tension of the mixture is different from the calculated values using equation (1) given above because of the intermolecular forces of attraction between the molecules of the components of the mixture. J.R Block and Bird⁹ found the following correlation between critical constants and surface tension σ_c

$$\sigma = (P_c^2 \cdot T_c)^{1/3} (-0.951 + 0.432/Z_c) (1-T_r)^{11/9},$$

Where P_c , T_c and Z_c and T_r are the critical pressure, critical temperature, critical compressibility factor and reduced temperature respectively.

$$Z_c = \frac{P_c \cdot V_c}{R \cdot T_c} \text{ and } T_r = \frac{T}{T_c}$$

where T_r and R are absolute temperature and gas constant respectively.

Glisniki¹⁰ suggested the equation assuming additively with the volume fractions ϕ of the components as

$$\sigma_{\text{cal}} = \frac{\sigma_1 \sigma_2}{\phi_1 \sigma_1 + \phi_2 \sigma_2}$$

where σ_{cal} = theoretical surface tension of binary liquid mixture.

σ_1, σ_2 = surface tension of pure components liquids 1 and 2 respectively.

ϕ_1, ϕ_2 = volume fractions of components 1 and 2 respectively.

A few equations have been proposed to predict the surface tension of pure liquids and binary liquid mixtures, which are mostly derived from statistical mechanics. The expression initially given by Escobedo and Mansoori¹¹ for pure liquids has been extended to the mixtures of organic liquids by Joel Escobedo and G. Ali Mansoori¹². For the surface tension σ , of pure liquids, Escobedo and Mansoori proposed,

$$\sigma = [P (\rho_l - \rho_v)]^4 \text{----- (2)}$$

and ρ_l and ρ_v are the densities of the liquid and its vapor.

$$\text{Where, } P = P_o (1 - T_r)^{0.37} T_{\text{rexp}} (0.30066/T_r + 0.86442 T_r^9) \text{----- (3)}$$

The equation reported by Joel Escobedo and G. Ali Mansoori for the prediction of surface tension of binary liquid mixtures suffers from the serious defect of not having the same units of the two sides of the equation. The equation is too complicated to include in this introduction. Looking at the complexity of the equation to predict the surface tension of binary liquid mixtures used by Escobedo and Mansoori and the number of parameters involved in the equation, the authors of the present article tried to find a simple empirical equation to predict surface tension of binary liquid mixture. One of the authors of the present article has proposed an empirical equation which would be referred to as 'Hadkar Equation' for the prediction of surface tension of a binary liquid mixture. It involves only one parameter that is dielectric constant. The surface tension of a few binary liquid mixtures was determined to verify the utility of the 'Hadkar Equation'.

MATERIAL AND METHODS:

The liquids benzaldehyde, carbon disulphide, carbon tetrachloride and toluene used were BDH quality, 10ml graduated pipette. A 10ml graduated pipette held in vertical position was used to determine the surface tension of the liquid and liquid mixture using drop weight method. The drop rate was adjusted to about 15-20 drops per minute so that each drop was detached from the tip of the pipette under its own weight. The number of drops was determined for a fixed volume of the liquid and for the same volume of distilled water. The surface tension of average of four readings was recorded. The surface tension of liquid was calculated using equation

$$\gamma_2 = (n_1/n_2) \cdot (\rho_2/\rho_1) \cdot \gamma_1,$$

where n_1, ρ_1, γ_1 are the number of drops, density and surface tension of water and n_2, ρ_2, γ_2 are the number of drops, density and surface tension of the liquid or the binary liquid mixture. The surface tension of the following binary liquid mixtures was determined using the drop weight method. Toluene and CS₂ 2. CCl₄ and toluene and 3. Chloroform and benzaldehyde. The experimental values of surface tension are compared with the theoretical value calculated using equation 1 and calculated using 'Hadkar Equation' in Table 1.

Table 1: Comparison between surface tension calculated using equation 1, experimental values and calculated using ‘Hadkar equation’ at 25 ±1°C.

Binary mixture	Mole fraction		γ m dynes/cm (Theoretical)	γ m dynes/cm (Experimental) (25 ±1°C)	$(\gamma \text{ m}).(H_3)=\gamma_{\text{mixH}}$ dynes/cm (Using ‘Hadkar eq’)
(A) Toluene+ (B)CS ₂	x_A	x_B	$\epsilon_A=2.38$	$\epsilon_B=2.6$	$H_3=0.9770$ (For mixtures 2 to 5)
1.	0.0	1.0	32.30	34.25	32.30(H ₃ =1)
2.	0.2	0.8	31.52	30.02	30.795
3.	0.4	0.6	30.74	29.20	30.03
4.	0.6	0.4	29.96	28.54	29.27
5.	0.8	0.2	29.18	27.03	28.50
6.	1.0	0.0	28.40	25.92	28.40(H ₃ =1)
(A) CCL ₄ +(B)Toluene	x_A	x_B	$\epsilon_A=2.238$	$\epsilon_B=2.38$	$H_3=0.9856$ (For mixtures 2 to 5)
1.	0.0	1.0	28.40	25.92	28.40(H ₃ =1)
2.	0.2	0.8	27.74	27.12	27.340
3.	0.4	0.6	27.72	26.85	27.32
4.	0.6	0.4	27.38	26.42	26.98
5.	0.8	0.2	26.96	25.31	26.57
6.	1.0	0.0	26.7	23.15	26.7(H ₃ =1)
(A) Chloroform+ (B)Benzaldehyde	x_A	x_B	$\epsilon_A=4.806$	$\epsilon_B=17.8$	$H_3=0.9154$ (For mixtures 2 to 5)
1.	0.0	1.0	38	36.42	38(H ₃ =1)
2.	0.2	0.8	35.9	33.27	32.862
3.	0.4	0.6	33.8	30.69	30.94
4.	0.6	0.4	31.7	28.28	29.01
5.	0.8	0.2	29.6	26.86	27.09
6.	1.0	0.0	27.50	25.17	27.50(H ₃ =1)

RESULTS AND DISCUSSION:

The proposed ‘Hadkar Equation’ for the prediction of surface tension of an organic binary liquid mixture is

$$\gamma_{\text{mixH}} = (x_A \gamma_A + x_B \gamma_B). H_3 \text{ ----- (4)}$$

where γ_{mixH} = surface tension of the binary liquid mixture

γ_A = surface tension of component A

γ_B = surface tension of component B

x_A = mole fraction of component A

x_B = mole fraction of component B

$$H_3 = (\epsilon_A / \epsilon_B)^F \text{ and } F = 1/4 (\epsilon_B / \epsilon_A) \text{ and } \epsilon_A < \epsilon_B.$$

ϵ_A = Dielectric constant of liquid A

ϵ_B = Dielectric constant of liquid B and $\epsilon_A < \epsilon_B$.

It may be noted that the factor F and H₃ are just numbers, that is, dimensionless fractions and that the units of left hand side as well as right hand side are that of the surface tension. The Hadkar equation (equation 4 above) can be used to predict the surface tension of the organic binary liquid mixtures which do not have strong interactions such as hydrogen bond formation. The equation is found to be useful for organic liquids having low values of dielectric constants less than 10. The Hadkar equation (equation 4) was used to predict the surface tension of various organic liquid mixtures reported by Joel Escobedo and G. Ali Mansoori¹³. The calculated values agreed within 3% to 4% for almost all the liquid mixtures. The values of the surface tensions of the liquid mixtures calculated by using Escobedo et al equation and that calculated from Hadkar equation are compared in the Tables 2 to 5.

Table No. 2: Comparison between surface tension calculated using equation 1, reported value¹¹ and calculated using 'Hadkar equation' at 25 ±1°C.

Binary mixture	Mole fraction		γ m dynes/cm (Theoretical)	γ m dynes/cm (Reported)	$(\gamma \text{ m}) \cdot (H_3) = \gamma_{\text{mixH}}$ dynes/cm (using 'Hadkar eq')
(A) n- Dodecane + (B)Benzene			$\epsilon_{A=2.002}$	$\epsilon_{B=2.275}$	$H_3= 0.9337$ (For mixtures 2 to 5)
	x_A	x_B			
1.	0.0	1.0	27.5	27.5	27.5 (H ₃ =1)
2.	0.2	0.4	26.84	25.8	25.06
3.	0.4	0.6	26.18	24.6	24.44
4.	0.6	0.4	25.52	24.2	23.82
5.	0.8	0.2	24.86	24.2	23.21
6.	1.0	0.0	24.4	24.4	24.4(H ₃ =1)
(A) n-Hexane + (B) Benzene			$\epsilon_{A=1.89}$	$\epsilon_{B=2.275}$	$H_3= 0.962$ (For mixtures 2 to 5)
	x_A	x_B			
1.	0.0	1.0	27.5	27.5	27.5(H ₃ =1)
2.	0.2	0.8	25.6	23.6	24.67
3.	0.4	0.6	23.7	21	22.79
4.	0.6	0.4	21.8	19.2	20.97
5.	0.8	0.2	19.9	17.6	19.14
6.	1.0	0.0	18	18	18(H ₃ =1)
(A) Benzene + (B) O-xylene			$\epsilon_{A=2.275}$	$\epsilon_{B=2.57}$	$H_3= 0.9733$ (For mixtures 2 to 5)
	x_A	x_B			
1.	0.0	1.0	29.4	29.4	29.4(H ₃ =1)
2.	0.2	0.8	29.15	29.15	28.37
3.	0.4	0.6	28.9	28.75	28.12
4.	0.6	0.4	28.65	28.6	27.88
5.	0.8	0.2	28.4	28.3	27.64
6.	1.0	0.0	28.15	28.15	28.15(H ₃ =1)
(A) CCL ₄ + (B) Benzene			$\epsilon_{A=2.238}$	$\epsilon_{B=2.275}$	$H_3= 0.9959$ (For mixtures 2 to 5)
	x_A	x_B			
1.	0.0	1.0	28.15	28.15	28.15(H ₃ =1)
2.	0.2	0.8	27.86	28.0	27.74
3.	0.4	0.6	27.57	27.8	27.45
4.	0.6	0.4	27.28	27.4	27.17
5.	0.8	0.2	26.99	27.05	26.88
6.	1.0	0.0	26.70	26.70	26.70(H ₃ =1)
(A) Cyclopentane + (B) Benzene			$\epsilon_{A=1.96}$	$\epsilon_{B=2.275}$	$H_3= 0.9684$ (For mixtures 2 to 5)
	x_A	x_B			
1.	0.0	1.0	28.1	28.1	28.1(H ₃ =1)
2.	0.2	0.8	26.82	26.4	25.94
3.	0.4	0.6	25.54	24.6	24.73
4.	0.6	0.4	24.26	23.5	23.49
5.	0.8	0.2	22.98	22.4	22.25
6.	1.0	0.0	21.7	21.7	21.7(H ₃ =1)

Table 3: Comparison between surface tension calculated using equation 1, reported value¹¹ and calculated using 'Hadkar equation' at 25 ±1°C.

Binary mixture	Mole fraction	γ m dynes/cm (Theoretical)	γ m dynes/cm (Reported)	$(\gamma_m) \cdot (H_3) = \gamma_{mixH}$ dynes/cm (using 'Hadkar eq')
(A) Cyclopentane + (B) CCL₄	$x_A \quad x_B$	$\epsilon_{A=2.238}$	$\epsilon_{B=2.275}$	H₃= 0.9959 (For mixtures 2 to 5)
1.	0.0	1.0 26.2	26.2	26.2(H ₃ =1)
2.	0.2	0.8 25.32	25.3	24.59
3.	0.4	0.6 24.4	24.2	23.70
4.	0.6	0.4 23.56	23.4	22.88
5.	0.8	0.2 22.68	22.6	22.03
6.	1.0	0.0 21.8	21.8	21.8(H ₃ =1)
(A) Cyclopentane + (B) Toluene	$x_A \quad x_B$	$\epsilon_{A=1.96}$	$\epsilon_{B=2.38}$	H₃= 0.9608 (For mixtures 2 to 5)
1.	0.0	0.0 28	28	28(H ₃ =1)
2.	0.2	0.8 26.76	26.4	25.71
3.	0.4	0.6 25.52	25.1	24.52
4.	0.6	0.4 24.28	24.0	23.33
5.	0.8	0.2 23.04	22.8	22.13
6.	1.0	0.0 21.8	21.8	21.8(H ₃ =1)
(A) Cyclopentane +(B) Tetrachloroethylene	$x_A \quad x_B$	$\epsilon_{A=1.96}$	$\epsilon_{B=2.30}$	H₃= 0.9665 (For mixtures 2 to 5)
1.	0.0	1.0 31.4	31.4	31.4(H ₃ =1)
2.	0.2	0.8 29.48	29.25	28.49
3.	0.4	0.6 27.56	27.0	26.63
4.	0.6	0.4 25.64	25.0	24.78
5.	0.8	0.2 23.72	23.2	22.92
6.	1.0	0.0 21.8	21.8	21.8(H ₃ =1)
(A) Cyclohexane + (B) Benzene	$x_A \quad x_B$	$\epsilon_{A=1.9890}$	$\epsilon_{B=2.275}$	H₃= 0.9709 (For mixtures 2 to 5)
1.	0.0	1.0 28.8	28.8	28.8(H ₃ =1)
2.	0.2	0.8 28.04	27.0	27.22
3.	0.4	0.6 27.28	26.2	26.48
4.	0.6	0.4 26.52	25.4	25.74
5.	0.8	0.2 25.76	25.2	25.01
6.	1.0	0.0 25	25	25(H ₃ =1)
(A) Cyclohexane + (B) Toluene	$x_A \quad x_B$	$\epsilon_{A=1.9890}$	$\epsilon_{B=2.38}$	H₃= 0.9632 (For mixtures 2 to 5)
1.	0.0	1.0 31.2	31.2	31.2(H ₃ =1)
2.	0.2	0.8 29.84	29.4	28.74
3.	0.4	0.6 28.48	24.6	27.43
4.	0.6	0.4 27.12	26.2	26.12
5.	0.8	0.2 25.76	25.1	24.81
6.	1.0	0.0 24.4	24.4	24.4(H ₃ =1)

Table 4: Comparison between surface tension calculated using equation 1, reported value¹¹ and calculated using ‘Hadkar equation’ at 25 ±1°C.

Binary mixture	Mole fraction		γ m dynes/cm (Theoretical)	γ m dynes/cm (Reported)	$(\gamma_m) \cdot (H_3) = \gamma_{\text{mixH}}$ dynes/cm (using ‘Hadkar eq’)
(A) CCL₄ + (B) iodomethane	x_A	x_B	$\epsilon_{A=2.238}$	$\epsilon_{B=7.0}$	H₃= 0.9128 (For mixtures 2 to 5)
1.	0.0	1.0	31.0	31.0	31.0(H ₃ =1)
2.	0.2	0.8	30.16	29.2	27.53
3.	0.4	0.6	29.32	28.0	26.76
4.	0.6	0.4	28.48	27.6	26.00
5.	0.8	0.2	27.64	27.0	25.23
6.	1.0	0.0	26.8	26.8	26.8(H ₃ =1)
(A) Benzene + (B) Carbon disulphide	x_A	x_B	$\epsilon_{A=2.275}$	$\epsilon_{B=2.641}$	H₃= 0.969 (For mixtures 2 to 5)
1.	0.0	1.0	32.7	32.7	32.7(H ₃ =1)
2.	0.2	0.8	31.8	30.6	30.83
3.	0.4	0.6	30.94	29.4	29.98
4.	0.6	0.4	30.06	28.7	29.12
5.	0.8	0.2	26.18	28.3	28.27
6.	1.0	0.0	28.3	28.3	28.3(H ₃ =1)
(A) Isooctane + (B) n-Dodecane	x_A	x_B	$\epsilon_{A=1.95}$	$\epsilon_{B=2.00}$	H₃= 0.9938 (For mixtures 2 to 5)
1.	0.0	1.0	24.4	24.4	24.4(H ₃ =1)
2.	0.2	0.8	23.08	23.0	22.93
3.	0.4	0.6	21.76	21.6	21.62
4.	0.6	0.4	20.44	20.7	20.31
5.	0.8	0.2	19.12	19.2	19.10
6.	1.0	0.0	17.8	17.8	17.8(H ₃ =1)
(A) Isooctane + (B) n-Cyclohexane	x_A	x_B	$\epsilon_{A=1.95}$	$\epsilon_{B=1.989}$	H₃= 0.995 (For mixtures 2 to 5)
1.	0.0	1.0	23.7	23.7	23.7(H ₃ =1)
2.	0.2	0.8	22.56	21.3	22.44
3.	0.4	0.6	21.42	20.4	21.31
4.	0.6	0.4	20.28	19.2	20.17
5.	0.8	0.2	19.14	18.3	19.04
6.	1.0	0.0	18.0	18.0	18.0(H ₃ =1)
(A) Cyclohexane + (B) cis-Decalin	x_A	x_B	$\epsilon_{A=1.9890}$	$\epsilon_{B=2.219}$	H₃= 0.975 (For mixtures 2 to 5)
1.	0.0	1.0	32.2	32.2	32.2(H ₃ =1)
2.	0.2	0.8	30.64	30.4	29.89
3.	0.4	0.6	29.08	29.1	28.35
4.	0.6	0.4	27.52	27.6	26.86
5.	0.8	0.2	25.96	25.9	25.31
6.	1.0	0.0	24.4	24.4	24.4(H ₃ =1)

Table 5: Comparison between surface tension calculated using equation 1, reported value¹¹ and calculated using 'Hadkar equation' at 25 ±1°C.

Binary mixture	Mole fraction		γ m dynes/cm (Theoretical)	γ m dynes/cm (Reported)	$(\gamma \text{ m}).(H_3)=\gamma_{\text{mixH}}$ dynes/cm (using 'Hadkar eq')
(A) Cyclohexane + (B) trans-Decalin	x_A	x_B	$\epsilon_{A=1.9890}$	$\epsilon_{B=2.184}$	$H_3=0.979$ (For mixtures 2 to 5)
1.	0.0		1.0 30.0	30.0	30.0($H_3=1$)
2.	0.2		0.8 28.88	28.8	28.27
3.	0.4		0.6 27.76	27.8	27.17
4.	0.6		0.4 26.64	26.7	26.7
5.	0.8		0.2 25.52	25.5	25.5
6.	1.0		0.0 24.4	24.4	24.4($H_3=1$)
(A) CCL ₄ + (B) Carbon disulphide	x_A	x_B	$\epsilon_{A=2.238}$	$\epsilon_{B=2.641}$	$H_3=0.9656$ (For mixtures 2 to 5)
1.	0.0		1.0 32.6	32.6	32.6($H_3=1$)
2.	0.2		0.8 31.2	30.2	30.31
3.	0.4		0.6 30.2	28.96	29.16
4.	0.6		0.4 29	27.8	28
5.	0.8		0.2 27.8	26.66	26.84
6.	1.0		0.0 26.60	26.60	26.60($H_3=1$)
(A) Benzene + (B) Ethylacetate	x_A	x_B	$\epsilon_{A=2.275}$	$\epsilon_{B=6.02}$	$H_3=0.9122$ (For mixtures 2 to 5)
1.	0.0		1.0 23.8	23.8	23.8($H_3=1$)
2.	0.2		0.8 24.72	24.4	23.98
3.	0.4		0.6 25.64	25.2	23.38
4.	0.6		0.4 26.56	26.0	24.22
5.	0.8		0.2 27.48	27.0	25.06
6.	1.0		0.0 28.4	28.4	28.4($H_3=1$)
(A) Carbon disulphide + (B) Dichloromethane	x_A	x_B	$\epsilon_{A=2.641}$	$\epsilon_{B=9.08}$	$H_3=0.914$ (For mixtures 2 to 5)
1.	0.0		1.0 27.3	27.3	27.3($H_3=1$)
2.	0.2		0.8 28.16	27.3	25.74
3.	0.4		0.6 29.02	27.4	26.52
4.	0.6		0.4 29.88	28.2	27.31
5.	0.8		0.2 30.74	29.2	28.09
6.	1.0		0.0 31.6	31.6	31.6($H_3=1$)

LIMITATION:

The 'Hadkar Equation' to predict surface tension of organic binary liquid mixtures is applicable only if there is weak interaction between the two liquids such as London force of attraction between the molecules of the liquids. For example, the surface tension values calculated for the mixture of ethyl alcohol and water using 'Hadkar Equation' and the practical values differ significantly because of strong interaction between the molecules of the two liquids due to formation of hydrogen bond. The surface tension values obtained for the liquid mixtures having weak interactions reported in the tables 2-5, were in good agreement (within 3-4%) with the calculated values using 'Hadkar Equation'.

CONCLUSION:

The 'Hadkar Equation' proposed for predicting the surface tension of organic binary liquid mixtures was found to give results close to the reported literature values. The predicted values of surface tension are in close agreement (within 3-4%) with the reported literature values.

ACKNOWLEDGEMENTS:

The authors wish to thank the Trustees Mr. Chhagan Bhujbal, Mrs. Meenatai Bhujbal, Mr. Sameer Bhujbal, Mr. Pankaj Bhujbal for the laboratory facilities provided to complete the work.

REFERENCES:

1. A. Bahl, B. Bahl, G. Tuli "Essentials of Physical Chemistry" S. Chand and company Ltd, New Delhi, 2009, Pg 423.
2. <http://zzm.umcs.lublin.pl/Wyklad/FGF-Ang/2A.F.G.F.%20Surface%20tension.pdf>
3. Handbook of detergents, Part A, Edi Guy Broze, Marcel Dekker, INC. New York. Basel, 1998, Pg 51.
4. A. Martin, P. Bustamante, A.H.C. Chun "physical Pharmacy" Indian Edition, Lippincott Williams and Wilkins, 2005, Pg375
5. M.L.L. Paredes, J.M.T. Santos and E.S. Bezerra Latin American Applied Research 2012 42: Pg 389-395
6. Hike Kahl, Tinowadewitz and JochemWinkel Mann J. Chem. Engg. Data, 2003, 48(3) Pp 580-586.
7. Remington "The Science and Practice of Pharmacy" 22nd Edition, Philadelphia College of Pharmacy 2013, Pg 442.
8. Finholt, Solvang S. "Effect of tablet processing and formulation factors on dissolution rate of the active ingredients in human gastric juice". J.Pharm Sciog 1970, 59(1) Pg 49 to 52
9. J.R. Block and R.B. Bird, Am. Inst.Chem.Engg.J.1, 74 (1965).

10. J. Glinski, J. Chem. Phys. Vol. 18 p.2301-2307, 2003.
11. Joel Escobedo and Ali Mansoori AICHE Journal Vol 44, No.10, Pp 2324-2332, (1998).
12. J. Escobedo and G. Ali Mansoori AICHE J. 42(5), 1425. 19.96.
13. ibid 11.

ABBREVIATION:

Abbreviation used in the Tables no. 1 to 5

Binary liquid mixture of A and B

γ_A = Surface tension of liquid A at 25 ± 1 degrees Celsius in dynes/cm.

γ_B = Surface tension of liquid B at 25 ± 1 degrees Celsius in dynes/cm.

x_A = Mole fraction of liquid A in the binary mixture of A and B.

x_B = Mole fraction of liquid B in the binary mixture of A and B.

Note: $x_A = (1 - x_B)$

ϵ_A = Dielectric constant of liquid A at 25 degrees Celsius.

ϵ_B = Dielectric constant of liquid B at 25 degrees Celsius.

$\gamma_{m(\text{Theoretical})}$ = surface tension of the mixture using equation 1.

$\gamma_{m(\text{Experimental})}$ = surface tension determined using drop weight method.

$\gamma_{m(\text{Reported})}$ = Surface tension of liquid mixture reported in Ref No.11

γ_{mixH} = Surface tension of liquid mixture using Hadkar equation (equation 4) for prediction of the surface tension of the binary mixture.

Hadkar equation for the surface tension of a binary liquid mixture is

$$\gamma_{\text{mixH}} = (x_A \gamma_A + x_B \gamma_B) \cdot H_3 \quad \text{--- (4)},$$

where, H_3 is the Hadkar Factor given by

$$H_3 = (\epsilon_A / \epsilon_B)^F \text{ and } F = 1/4 (\epsilon_B / \epsilon_A) \text{ and } \epsilon_A < \epsilon_B.$$

It may be noted that for pure liquid A or B, the Hadkar Factor $H_3 = 1$

Note:

$$(1) H_3 = (\epsilon_A / \epsilon_B)^F \text{ and } F = 1/4 (\epsilon_B / \epsilon_A) \text{ and } \epsilon_A < \epsilon_B.$$

(2) Pure liquid A may be considered as mixture of liquid

A and liquid B and $\epsilon_A = \epsilon_B$.

The value of $H_3 = 1$ for pure liquid A or pure liquid B.