Arabian Journal of Chemistry (2012) 5, 41–44

King Saud University

Arabian Journal of Chemistry

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

The effect of NaCl and Na_2SO_4 concentration in aqueous phase on the phase inversion temperature O/W nanoemulsions

Amir A. Mehrdad Sharif [a], **Ali M. Astaraki** [a,*], **Parviz Aberoomand Azar** [b], **Saeed Abedini Khorrami** [a], **Shahram Moradi** [a]

[a] *Department of Applied Chemistry, Faculty of Chemistry, Islamic Azad University, North Tehran Branch, Tehran, Iran*
[b] *Department of Analytical Chemistry, Islamic Azad University, Science and Research Branch, Tehran, Iran*

Received 5 July 2010; accepted 17 July 2010

KEYWORDS

Nanoemulsion;
Phase inversion temperature (PIT);
Emulsion formation

Abstract The effect of NaCl and Na_2SO_4 concentrations in aqueous phase on the phase inversion temperature (PIT) in nanoemulsions of water/Brij30/*n*-hexadecane system has been studied separately, and then compared. The variation of conductivity with temperature was measured by Cyber Scan PC510 conductivity meter for emulsions with 20 wt% hexadecane and 8 wt% Brij30 concentration and different concentrations of NaCl and Na_2SO_4 in aqueous phase. The results showed that with increasing concentrations of NaCl and Na_2SO_4 in aqueous phase, the PIT of nanoemulsions decreases. The effect of the elevation of concentration on the decrease of PIT was more for Na_2SO_4 in aqueous phase than NaCl with equal concentrations.

1. Introduction

Nanoemulsions are a class of emulsions with droplets of extremely small diameters; typically in the range 20–200 nm (Solans et al., 2002). This makes them transparent or translucent in most cases. Unlike microemulsions, nanoemulsions are not thermodynamically stable, and the size of their droplets tends to increase with time before the macroscopic phase separation. However, due to their initial small droplet size and low polydispersity, they may have a long kinetic stability, which means that the small droplets practically do not increase their size for a long time. All these characteristic properties have increased the importance of nanoemulsions in different practical applications, especially in cosmetics and as colloidal drug carriers for

---

[*] Corresponding author. Address: Department of Applied Chemistry, Faculty of Chemistry, Islamic Azad University, North Tehran Branch, P.O. Box 1913674711, Tehran, Iran. Tel.: +98 9163650338.
E-mail address: am_astaraki@yahoo.com (A.M. Astaraki).

Peer review under responsibility of King Saud University.
doi:10.1016/j.arabjc.2010.07.021

Production and hosting by Elsevier

pharmaceutical applications (Baboota et al., 2007; Wulff-Pérez et al., 2009; Sadurní et al., 2005; Date and Nagarsenker, 2007).

Nanoemulsions can be achieved by high-energy emulsification methods (Sudol and El-Aasser, 1997), which make use of mechanical energy, or by low-energy emulsification methods, which use the chemical energy stored in the components of the system to be emulsified. When the low-energy emulsification methods are used, the spontaneous curvature of the surfactant changes during the emulsification process. This change of curvature in the low-energy emulsification methods can be achieved at constant composition through the change of temperature (phase inversion temperature method, PIT) (Shinoda and Saito, 1968), or at constant temperature through the change of composition (phase inversion composition method, PIC) (Forgiarini et al., 2001).

The phase inversion temperature (PIT) method, introduced by Shinoda and Saito (1968) is, among these methods, the most widely used in industry (Förster and Rybinski, 1998). It is based on the changes in solubility of polyoxyethylene-type non-ionic surfactants with temperature. These types of surfactants become lipophilic with increasing temperature because of dehydration of the polyoxyethylene chains. At low temperature, the surfactant monolayer has a large positive spontaneous curvature forming oil-swollen micellar solution phases (or O/W microemulsions) which may coexist with an excess oil phase. At high temperatures, the spontaneous curvature becomes negative and water-swollen reverse micelles (or W/O microemulsions) coexist with excess water phase. At intermediate temperatures, the hydrophilic-lipophilic balance (HLB) temperature, the spontaneous curvature becomes close to zero and a bi-continuous, D phase micro-emulsion containing comparable amounts of water and oil phases coexists with both excess water and oil phases (Shinoda and Kunieda, 1983).

In this research the phase inversion temperature (PIT) is investigated with different concentration of electrolytes (NaCl and Na_2SO_4) in aqueous phase and two statistical logarithmic models are obtained to predict the PIT from the concentration of electrolytes.

2. Material and methods

2.1. Materials

The organic phase (*n*-hexadecane, 99%) and non-ionic surfactant, known as Brij30 (polyoxyethylene-4-lauryl or $C_{12}E_4$), were obtained from Sigma–Aldrich chemicals. The Na_2SO_4 and NaCl were supplied by Merck chemical company. There are different solutions of Na_2SO_4 and NaCl which are prepared with concentrations about 0.01, 0.05, 0.10, 0.25, and 0.50 mol/l as the aqueous phases.

2.2. Methods

2.2.1. Phase inversion temperature determination

The hydrophilic–lipophilic balance temperature was determined using the electrical conductivity method (Izquierdo et al., 2002). The emulsions contain 20 wt% *n*-hexadecane, 8 wt% surfactant of Brij30 (polyoxyethylene-4-lauryl ether) and Na_2SO_4 or NaCl solutions. Different emulsions with different concentrations of Na_2SO_4 and NaCl in aqueous phase were prepared at room temperature, separately. The temperature was increased by a controllable warm water bath gradually and the conductivity was determined during the increase of temperature. The conductivity fall at PIT arises from the phase inversion from oil-in-water to water-in-oil emulsion.

3. Results and discussion

Figs. 1 and 2 offer the evolution of the conductivity curves during the temperature cycling process for various concentrations of Na_2SO_4 and NaCl in aqueous phases, respectively. In some of the Na_2SO_4 and NaCl concentrations, the conductivity of the emulsion initially decreases gradually with the increase of temperature, and then it suddenly falls down. The phase inversion temperature (PIT) was taken as the average value between the maximum and the minimum values of conductivity.

The PIT of all Na_2SO_4 and NaCl concentrations are reported in Tables 1 and 2, respectively.

The results show a gradual decrease of the PIT from 34 to 23 °C vs. the increase of Na_2SO_4 concentrations from 0.01 to 0.5 M; whereas, the gradual decrease of the PIT was from 41 to 26 °C vs. the increase of NaCl concentrations from 0.01 to 1.00 M.

There is a logarithmic model fitted to the data for emulsions with Na_2SO_4 in aqueous phase. Table 3 shows that the coefficient and constant are significant (p-value < 0.01). The analysis of variance (ANOVA) is reported in Table 4. The significance value of the F statistic (p-value) is less than 0.05, which means that the variation explained by the model is not due to chance.

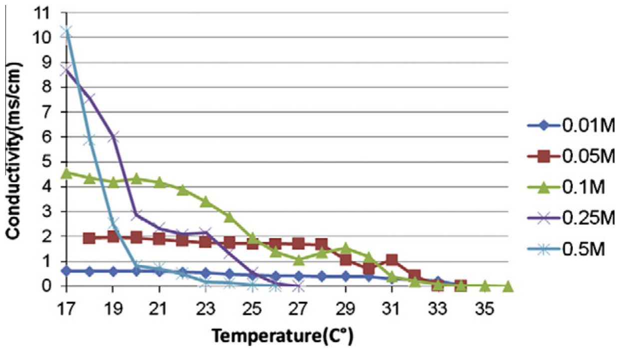

Figure 1 The curves of conductivity vs. the temperature for various concentration of Na_2SO_4 in aqueous phases.

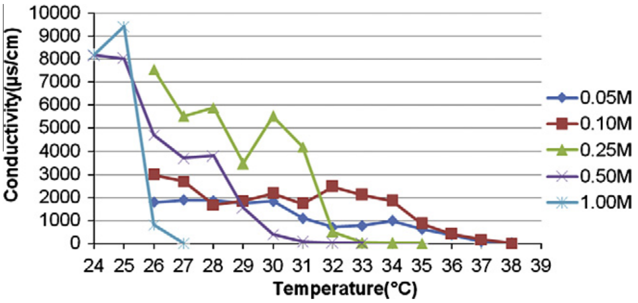

Figure 2 The curves of conductivity vs. the temperature for various concentration of NaCl in aqueous phases.

Table 1 The PIT of emulsions with various concentrations of Na_2SO_4 in aqueous phase.

Concentration of Na_2SO_4 (M)	PIT (°C)
0.01	34
0.05	31
0.10	28
0.25	25
0.50	23

Table 2 The PIT of emulsions with various concentrations of NaCl in aqueous phase.

Concentration of NaCl (M)	PIT (°C)
0.01	41[a]
0.05	34
0.10	32
0.25	30
0.50	28
1.00	26

[a] From Izquierdo et al. (2002).

Table 3 The logarithmic model fitted to the data for emulsion with Na_2SO_4 in aqueous phase.

	Constant and coefficient		p-Value
		Standard error	
(Constant)	21.25	0.672	0.000
ln(Concentration of Na_2SO_4)	−2.90	0.244	0.001

Table 4 The analysis of variance (ANOVA) of the model that is reported in Table 3 for emulsion with Na_2SO_4 in aqueous phase.

	Sum of squares	df	Mean square	F	p-Value
Regression	77.159	1	77.159	141.093	0.001
Residual	1.641	3	0.547		
Total	78.800	4			

Table 5 The logarithmic model fitted to the data for emulsion with NaCl in aqueous phase.

	Unstandardized coefficients		p-Value
		Standard error	
(Constant)	25.55	0.562	0.000
ln(Concentration of NaCl)	−3.14	0.224	0.000

Consequently, the model is exhibited in the following equation:

$$\mathrm{PIT} = -2.90 \ln C + 21.25 \tag{1}$$

$$r^2 = 0.98$$

Table 6 The analysis of variance (ANOVA) of the model that was reported in Table 5 for emulsion with NaCl in aqueous phase.

	Sum of squares	df	Mean square	F	p-Value
Regression	138.045	1	138.045	198.003	0.000
Residual	2.789	4	0.697		
Total	140.833	5			

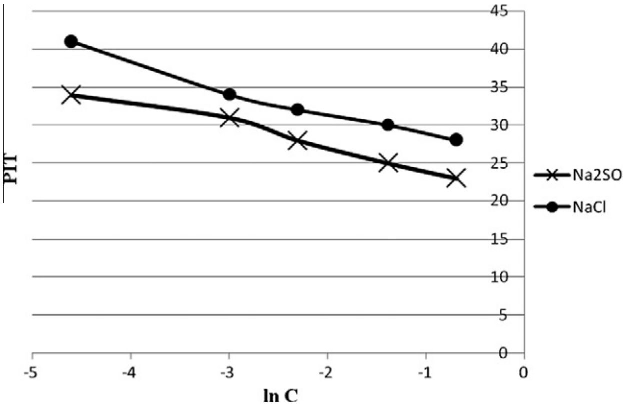

Figure 3 The curves of PIT as a function of natural logarithm of concentrations of Na_2SO_4 and NaCl. (*C* is concentration of NaCl or Na_2SO_4 by mol/l.)

where *C* is the concentration of Na_2SO_4 in aqueous phase (mol/l), *r* is the correlation coefficient and PIT is phase inversion temperature (°C).

There is a logarithmic model fitted to the data for emulsions with NaCl in aqueous phase. Table 5 shows that the coefficient and constant are significant (p-value < 0.01). The analysis of variance (ANOVA) is reported in Table 6. The significance value of the *F* statistic (p-value) is less than 0.05, which means that the variation explained by the model is not due to chance.

Consequently, the model is exhibited in the following equation:

$$\mathrm{PIT} = -3.14 \ln C' + 25.55 \tag{2}$$

$$r^2 = 0.98$$

where C' is the concentration of NaCl in aqueous phase (mol/l), *r* is the correlation coefficient and PIT is phase inversion temperature (°C). The curve of PIT as a function of natural logarithm of concentrations of Na_2SO_4 and NaCl is shown in Fig. 3.

The phase inversion temperature (PIT) of emulsions accurately reflects that the real HLB of surfactant in a given system changes sensitively with the amount and kinds of added salts. The PIT of the emulsion and the cloud point of the aqueous (or nonaqueous) solution of the non-ionic surfactant containing solubilized oil (or water) are close to each other. These characteristic temperatures shift to a similar extent on the addition of salt, acid, or alkali to the water (Shinoda and Takeda, 1970).

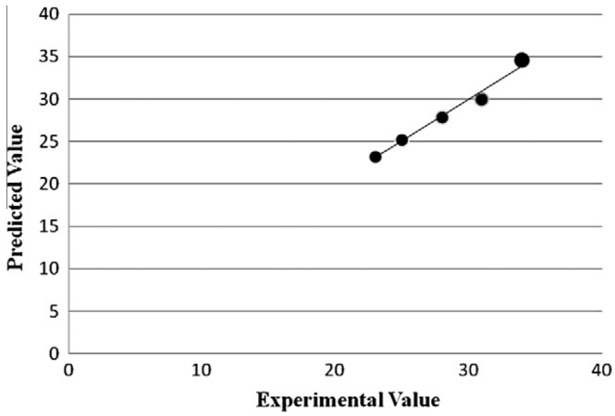

Figure 4 The scatter plot of predicted PIT by Eq. (1) vs. experimental PIT for electrolyte of Na_2SO_4 in aqueous phase.

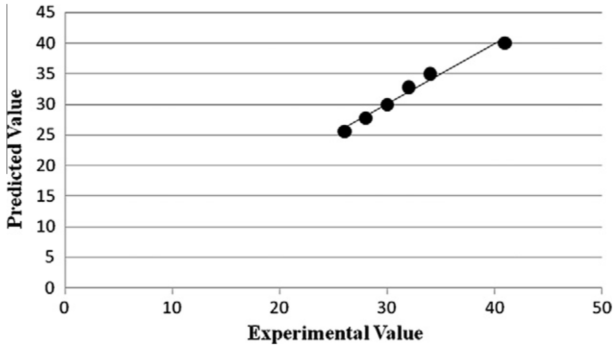

Figure 5 The scatter plot of predicted PIT by Eq. (2) vs. experimental PIT for electrolyte of NaCl in aqueous phase.

4. Conclusions

The results showed that with the increasing of concentrations of NaCl and Na_2SO_4 in aqueous phase, the PIT of nanoemulsions decreases. A natural logarithmic equation is used for predict of PIT of a nanoemulasion as follows:

$$\mathrm{PIT} = a \ln C + b$$

where a is a coefficient and b is a constant value. The values of a and b depend on the type of electrolyte. Figs. 4 and 5 show scatter plots of predicted PITs by Eqs. (1) and (2) vs. experimental PITs for Na_2SO_4 and NaCl electrolytes in aqueous phases, respectively.

It is generally accepted that added electrolytes cause electrostriction of water and increase the internal pressure of the solution. Thus, the interaction between water and non-ionic surfactant is weakened, the activity of non-ionic surfactant is increased, the cloud point is depressed, and the HLB of non-ionic surfactant is made more lipophilic on addition of electrolytes.

Acknowledgment

The authors would like to thank the Nano Technology Development Center of Iran for financial support of this research.

References

Baboota, S., Shakeel, F., Ahuja, A., Ali, J., Shafiq, Sh., 2007. Design, development and evaluation of novel nanoemulsion formulations for transdermal potential of celecoxib. Acta Pharm. 57, 315–332.

Date, A.A., Nagarsenker, M.S., 2007. Design and evaluation of self-nanoemulsifying drug delivery systems (SNEDDS) for cefpodoxime proxetil. Int. J. Pharm. 329, 166–172.

Forgiarini, A., Esquena, J., González, C., Solans, C., 2001. Formation of nano-emulsions by low-energy emulsification methods at constant temperature. Langmuir 17, 1076–2083.

Förster, T., Rybinski, W.V., 1998. Applications of emulsions. In: Binks, B.P. (Ed.), Modern Aspects of Emulsion Science. The Royal Society of Chemistry, Cambridge, pp. 395–426.

Izquierdo, P., Esquena, J., Tadros, Th.F., Dederen, C., Garcia, M.J., Azemar, N., Solans, C., 2002. Formation and stability of nano-emulsions prepared using the phase inversion temperature method. Langmuir 18, 26–30.

Sadurní, N., Soans, C., Azemar, N., Garía-Celma, M. José, 2005. Studies on the formation of O/W nano-emulsions, by low-energy emulsification methods, suitable for pharmaceutical applications. Eur. J. Pharm. Sci. 26, 438–445.

Shinoda, K., Kunieda, H., 1983. Phase properties of emulsions: PIT and HLB. In: Becher, P. (Ed.), Encyclopedia of Emulsion Technology, vol. 1. Marcel Dekker, New York, pp. 337–367.

Shinoda, K., Saito, H., 1968. The effect of temperature on the phase equilibria and the types of dispersions of the ternary system composed of water, cyclohexane, and nonionic surfactant. J. Colloid Interface Sci. 26, 70–74.

Shinoda, K., Takeda, H., 1970. The effect of added salts in water on the hydrophile–lipophile balance of nonionic surfactants: the effect of added salts on the phase inversion temperature of emulsions. J. Colloid Interface Sci. 32, 642.

Solans, C., Esquena, J., Forgiarini, A.M., Uson, N., Morales, D., Izquierdo, P., Azemar, N., Garcla-Celma, M.J., 2002. Surfactants in solution: fundamentals and applications. In: Mittal, K.L., Shah, D.O. (Eds.), Surfactant Science Series. New York, Dekker.

Sudol, E.D., El-Aasser, M.S., 1997. In: Lovell, P.A., El-Aasser, M.S. (Eds.), Emulsion Polymerization and Emulsion Polymers. Wiley, Chichester, UK, p. 700.

Wulff-Pérez, M., Torcello-Gómez, A., Gálvez-Ruíz, M.J., Martín-Rodríguez, A., 2009. Stability of emulsions for parenteral feeding: preparation and characterization of O/W nanoemulsions with natural oils and pluronic f68 as surfactant. Food Hydrocolloids 23, 1096–1102.