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Effect of sodium chloride on the critical solution temperature of a partial miscible phenol-water solution

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ABSTRACT: Background: Phenol's have the properties that it is particularly partial miscible with water. Generally, partially miscible liquids become more soluble with the increase in temperature and at a certain temperature they are completely miscible. This temperature is known as the critical solution temperature (CST) or consolute temperature. **Aim:** The study was aimed to observe the effect of sodium chloride on critical solution temperature (CST) of a partial miscible phenol-water solution. **Method:** To find the miscibility temperature, the mixture was heated in a boiling tube until the turbidity disappeared and the final temperature was noted. Then, the mixture was cooled down and the temperature was noted when the turbidity reappeared. Solutions of impurities of different concentrations were formed and their effect on the Upper Critical Temperature (UCT) was analyzed. **Results:** It was found that the ionic compound NaCl, which get hydrated with water, shows lesser increase in CST as they decrease the miscibility to a lesser extent. **Conclusion:** It was observed that the Upper Critical Solution Temperature (UCST) of Phenol-Water system increases with increase in concentrations of impurities irrespective of their nature.

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INTRODUCTIONS:

A homogenous mixture of a solute and a solvent is called as a true solution. The liquid-liquid are of three types such are; completely miscible liquid pairs (Water-Alcohol and Water-Sulphuric acid), partially miscible liquid pairs (Ether-Water and Phenol-Water) and liquid pairs that are practically immiscible (Mercury-Water and Nitrobenzene-water) [1].

When phenol and water are mixed, a certain amount of the two liquids dissolves with the other due to hydrogen bonding and two conjugate layers of liquids are obtained. The upper layer of this system is water dissolved in phenol and the lower layer is phenol dissolved in water. The composition of these layers depends only on the temperature of the system and is independent of the quantities of the liquids mixed. For every temperature two solubilities can be obtained, one for phenol dissolved in water and the other for water dissolved in phenol.

Generally, for partially miscible liquids solubility increases with increasing temperature and the temperature at which they are completely miscible is termed as the Critical Solution Temperature (CST) or Consolute Temperature [2]. The temperature above which the phases of a system are completely miscible is known as the Upper Consolute Temperature (UCT) or Upper Critical Solution Temperature (UCST). Similarly, the temperature below which the phases of a system are completely miscible is known as the Lower Critical Solution Temperature (LCST). The phenol water system exhibits an upper critical solution temperature and this critical solution temperature can be used for testing the purity of the mixture.

To Phenol–water system if impurities of ionic and covalent substances are added, a ternary system is formed. For a ternary system, there are three components co-existing in a system. The addition of a third substance to a partially miscible system to increase its miscibility is known as blending. This is also called as the 'salting-out' in Pharmaceuticals and is used to select the best solvent for the drugs. In this process, a salt is added to separate the aqueous phase from the organic phase. If the added salt dissolves in one of the phases only, it results in an increase in the UCST, and a decrease in the LCST, thus decreasing the miscibility of the system [3,4]. Further, if the added salt is soluble in both the phases, then the UCST is lowered and the LCST is raised, thus increasing the miscibility of the system. This increase or decrease in the CST depends on the nature and the mass of the added substance and the composition of the system. The various factors affecting the solubility of a liquid-liquid system are solute-solvent interactions, common ion effect, molecular size and polarity. If the attraction between the added substance and the solvent particles is greater, higher miscibility can be observed in a system and vice versa. When a substance containing an ion, which is already present in the equilibrium state of the system, is added to that system, a decrease in miscibility is observed. This decreasing effect of the miscibility is known as the common ion effect. As the size and mass of the molecule of the added substance increases, the miscibility of the system decreases and hence, the CST increases. Ionic solutes dissolve in polar solvents whereas organic solutes dissolve in non-polar solvents. Thus, the addition of impurities like NaCl, KCl, Naphthalene and Camphor should reduce the miscibility of phenol and water [5]. The main objective of study was to find the effect of NaCl on miscibility temperature the phenol-water mixture.

MATERIALS AND METHODS:

Materials:

Sodium chloride was obtained from Qualigens Fine Chemicals, India. Phenol was purchased from Standard Chemicals, Hyderabad, India and distilled water was collected from distillation unit from college.

Methodology:

Firstly the CST of a Phenol-water system without adding impurity was calculated. In this procedure different phenol concentration scales of 8, 15, 40, 55 and 80 % were prepared. The five different solution of (20 ml) of the mixture of phenol and water with the concentration scales were prepared in the test tubes. The measured amount of water and phenol were transferred into a test tube. The phenol transfer process must be done in the fume cupboard as the phenol is very toxic. A thermometer was placed into the test tube and sealed by using para film followed by aluminium foil and it was to make sure that the thermometer did not touch the bottom surface of the test tube. During the process of heating, the test tube was shaken gently in the water bath to increase the rate of speed of the dispersion of two liquids until a clear mixture was obtained. The temperature at which the turbid liquid becomes clear (T_1) was observed and recorded. The test tube was removed from the hot water and it was cooled by applying ice bath until the liquid became turbid and the temperature at this point was immediately recorded (T_2). Similarly15, 40, 55 and 80 % of phenol concentration scales in the experiment were prepared. The average miscibility temperature for each test tube at which two phases were no longer seen or at which two phases existed were determined [6].

Table 1. Phenol-Water System in absence of impurity.

T	P	W	T_1 (^{0}C)			T_2 (^{0}C)			T (^{0}C)
	%	%	I	II	A	I	II	A	
A	8	92	54	50	52	49	47	48	50
B	15	85	56	54	55	55	51	53	54
C	40	60	73	67	70	68	62	65	67.5
D	55	45	70	66	68	62	58	60	64
E	80	20	58	54	56	50	46	48	52

TT – Test tube, P – Phenol, W – Water and A – Average. T1 and T2 are average temperature clear and turbid. T_{set1} and T_{set1} are the temperature from set 1 and 2. T is the Average miscibility temperature. CST is 67.5.

Table 2. Effect of 0.2 % NaCl on the miscibility of Phenol-Water System.

T	P	W	T_1 (^{0}C)			T_2 (^{0}C)			T (^{0}C)
	%	%	I	II	A	I	II	A	
A	8	92	55	52	53.5	51	47	49	51.25
B	15	85	58	54	56	55	50	52	54.25
C	40	60	76	68	72	70	62	66	69
D	55	45	70	64	67	64	56	60	63.5
E	80	20	60	54	57	52	48	50	53.5

TT – Test tube, P – Phenol, W – Water and A – Average. T1 and T2 are average temperature clear and turbid. T_{set1} and T_{set1} are the temperature from set 1 and 2. T is the Average miscibility temperature. CST is 69.

Similarly the effect of NaCl on the CST of the Phenol-water system was determined. To know the effect of NaCl on CST of phenol-water system different concentrations of NaCl solutions were prepared. For the preparations 1% w/v NaCl solution, one gram of sodium chloride (NaCl) salt was dissolved in 100 ml distilled water. Similarly 0.2, 0.4, 0.6, and 0.8 % w/v of NaCl solutions were prepared by adding 0.2, 0.4, 0.6 and 0.8 g of NaCl to 100 ml of distilled water respectively in 4 different 100 ml beakers, with the help of measuring cylinders. From the prepared solution, 5 ml of various w/v % NaCl solutions were taken and added in the boiling tube containing different percentage of phenol-water composition solution respectively. The miscibility temperatures for the mixture prepared at different concentrations of phenol were found by repeating steps.

For the calculations the following equations were used.

T_1 (°C) = (T_{set1} + T_{set2})/2 …….. (1)

T_2 (°C) = (T_{set1} + T_{set2})/2 …….. (2)

T (°C) = (T_1 + T_2)/2 ………… (3)

Where, T1 and T2 average temperature clear and turbid. T_{set1} and T_{set1} are the temperature from set 1 and 2. T is the Average miscibility temperature.

Table 3. Effect of 0.4 % NaCl on the miscibility of Phenol-Water System.

T	P	W	T_1 (^{0}C)			T_2 (^{0}C)			T (^{0}C)
	%	%	I	II	A	I	II	A	
A	8	92	56	52	54	51	47	49	51.5
B	15	85	60	54	57	55	51	53	53
C	40	60	77	69	73	72	62	67	70
D	55	45	71	65	68	66	56	61	64.5
E	80	20	60	52	56	54	50	52	54

TT – Test tube, P – Phenol, W – Water and A – Average. T1 and T2 are average temperature clear and turbid. T_{set1} and T_{set1} are the temperature from set 1 and 2. T is the Average miscibility temperature. CST is 70.

RESULTS AND DISCUSSION:

The result showed that, it was found that when the concentration of phenol was increased from 8 to 40 %, the miscibility increased and consequently the miscibility temperature increased from 51.25 to 72.5 ^{0}C. But further increased concentration of phenol 55 to 80 %, the miscibility decreased and consequently the miscibility temperature decreased. The highest miscibility temperature is known as CST. The CST obtained from pure phenol-water system was 67.5 ^{0}C. Similarly by addition of NaCl to CST of phenol water system was slightly increased by the increase in concentration. All the observed values were reported in Table 1 to 5. The CST calculated for these concentrations of NaCl using the Tables 1 to 5 shows that as the concentration increases, CST also increases. This is because the effect of an impurity on the CST of the system depends on whether the impurity is partially or completely soluble in one or both the components of the system and in this case, as NaCl is completely soluble in water whereas insoluble in phenol solution, it increased the UCST of the system, hence decreasing the miscibility. From the data comparison, it was found that CST was affected by the concentration of sodium chloride. All the observed values were depicted in Table 6 and Fig 1.

Table 4. Effect of 0.6 % NaCl on the miscibility of Phenol-Water System.

TT	P	W	T_1 (^{0}C)			T_2 (^{0}C)			T (^{0}C)
	%	%	I	II	A	I	II	A	
A	8	92	58	52	55	52	48	50	52.5
B	15	85	61	55	58	56	52	54	56
C	40	60	78	69	73.5	74	62	68	70.75
D	55	45	72	65	68.5	66	57	61.5	65
E	80	20	62	52	57	55	51	53	55

TT – Test tube, P – Phenol, W – Water and A – Average. T1 and T2 are average temperature clear and turbid. T_{set1} and T_{set1} are the temperature from set 1 and 2. T is the Average miscibility temperature. CST is 70.75.

Table 5. Effect of 0.8 % NaCl on the miscibility of Phenol-Water System.

TT	P	W	T_1 (^{0}C)			T_2 (^{0}C)			T (^{0}C)
	%	%	I	II	A	I	II	A	
A	8	92	58	54	56	54	50	52	54
B	15	85	62	56	59	58	52	55	57
C	40	60	78	72	75	74	66	70	72.5
D	55	45	73	65	69	66	58	62	65.5
E	80	20	63	53	58	57	51	54	56

TT – Test tube, P – Phenol, W – Water and A – Average. T1 and T2 are average temperature clear and turbid. T_{set1} and T_{set1} are the temperature from set 1 and 2. T is the Average miscibility temperature. CST is 72.5.

Table 6. Comparison of CST with different concentration of NaCl addition.

Sl. No.	Concentration of NaCl added (% w/v)	CST, ^{0}C
1	0	67.5
2	0.2	69
3	0.4	70
4	0.6	70.75
5	0.8	72.5

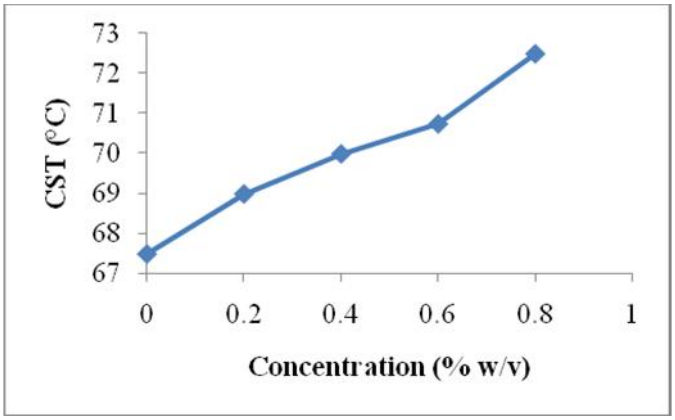

Fig 1. Effect of NaCl on CST of phenol-water mixture.

CONCLUSION:

When phenol and water are mixed, a certain amount of the two dissolves with the other due to hydrogen bonding and two conjugate layers of liquids are obtained. The upper layer of this system is water dissolved in phenol and the lower layer is phenol dissolved in water. The composition of these layers depends only on the temperature of the system and is independent of the quantities of the liquids mixed. The addition of impurity like NaCl, should reduce the miscibility of phenol and water. This is because of the nature of combining of the water molecules with these ions and hence, simple ions reduce the tendency of water to solvate phenol. As a result, the addition of salt should always increase the critical solution temperature. It was observed that the UCST of Phenol-Water system increases with increase in concentrations of impurities irrespective of their nature.

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