

# **SURFACE, SOLUTION AND LIQUID PROPERTIES OF I<sub>E</sub> WATER**

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Physical properties of I<sub>E</sub> water were measured and compared with those of purified by distillation and/or deionization water. The densities, viscosities, and conductivities of I<sub>E</sub> water and purified water were essentially identical. However, initial tests demonstrated that I<sub>E</sub> water, either distilled or prepared without distillation, has surface properties and foaming behavior that differ from ordinary water. Some I<sub>E</sub> water solutions (undistilled samples) demonstrated reduction in surface tension as much as 17% compared to pure water and promoted formation of larger volumes of more stable foam. Further research is suggested to explore potential uses of I<sub>E</sub> water in combination with surface active agents in commercial applications.

## **1. Introduction**

Surface-active agents (surfactants) are among the most widely-used products of the chemical industry that have application in detergents, pharmaceuticals, motor oils, biotechnology, printing, etc. Surfactants usually greatly reduce the surface tension, although some applications of surfactants do not involve large surface tension effects. Surface tension, the amount of work required to create a unit area of surface, is one of the key characteristics of surface phenomena.

Surfactants are organic compounds consisting of two parts: hydrophilic (water-loving) and hydrophobic (water-hating). This characteristic molecular structure is responsible for concentration of the surfactant at the surface and resulting reduction of the surface tension of water due to less work required to create unit area of water-air interface. When used in detergent formulations, surfactants improve the wetting ability of water, help to loosen and remove soil, emulsify and solubilize soils in the wash solution.

A new form of water, described as “containing ice formed under electric field ( $I_E$ )”, has been discovered by the American Technologies Group (ATG) of Monrovia, CA. ATG suggested that this form of water has properties which make it far more advantageous than normal water for a variety of applications, including detergency. Surfactant Associates, Inc. (SA), a company with extensive experience in studies using surfactants in detergency and other processes, was asked to measure specific parameters of the  $I_E$  water and solutions made up using it as a solvent and to compare those to properties of normal water and aqueous solutions.

SA performed a number of experiments which we believe elucidate the differences in fundamental properties of  $I_E$  water (compared to ordinary water) and its effects in modifying the behavior of aqueous surfactant solutions. In these tests, blank experiments were carried out using water purified by SA as well as the distilled/deionized water ordinarily used by ATG in preparing  $I_E$  water. The results reported here are preliminary in the sense that they cover a range of properties that need to be measured for numerous systems before it will be possible to conclude that  $I_E$  water clusters are responsible for the effects observed.

## 2. Experimental Methods

A variety of experimental methods are regularly used in our laboratories for studying the properties of aqueous solutions of surfactants. These include: the Ross-Miles foam test (supplemented by a foam stability method for use with smaller volumes of solutions); the du Noüy ring and Wilhelmy balance methods for measuring surface tensions; direct gravimetric methods for measuring liquid and solution densities; the Ostwald viscometer for measurement of viscosity; electrical conductivity measurements using a resistance bridge (null) method; a highly-precise total vapor pressure method developed by Professor Edwin E. Tucker of the University of Oklahoma Chemistry Department; and methods for measuring solubility and solubilization of organic or inorganic compounds in aqueous micellar solutions. So far, methods in each of these categories, except the last (solubility and solubilization), have been used to measure the properties of  $I_E$  water and solutions made with  $I_E$  water and other added components. Additional work is underway to determine the effects of  $I_E$  water on solubility and solubilization, as well as the utility of foam-fractionation as a method for removing surface active components (including organic impurities and possibly  $I_E$  clusters).

Sonication was used as a method of pre-treating some samples before measurements. Effects of sonication on surface tension was noted and will be discussed.

$I_E$  aqueous solutions were prepared using ATG's proprietary technology and are referred to as undistilled  $I_E$  samples. Some  $I_E$  solutions were distilled, and the distillates, referred to as distilled  $I_E$  samples, were tested. A relative concentration of  $I_E$  crystals in the aqueous solutions was determined by measuring UV absorbance at 195 nm. The higher absorbance, the higher the relative concentration of  $I_E$  crystals in the solution. The concentration of  $I_E$  crystals decreased in the following order: Undistilled (1) > Undistilled (2) > Distilled (1) = Distilled (2), where the numbers identify different batches of the  $I_E$  solutions.

### 3. Experimental Results

#### 3.1 Surface Tension

Surface tension of I<sub>E</sub> water and its solutions is a key to the interpretation of many effects caused by the presence of I<sub>E</sub> water clusters. The ability of I<sub>E</sub> water to cause foaming, its apparent effects on detergency, and the possibility that I<sub>E</sub> clusters are surface active themselves or promote surface activity of naturally-surface active compounds, need to be investigated. Although all of the studies described here need to be extended and repeated, some of the results indicate that the surface tensions of solutions containing I<sub>E</sub> water vary with time, particularly for samples that have been sonicated for several minutes prior to making the surface tension measurements. The tendency of I<sub>E</sub> water to foam can also be modified by pre-foaming, followed by removal of some of the foam. In other words, some surface active components can be removed by foaming.

Surface tension of I<sub>E</sub> water, purified water and their solutions, with or without sonication or pre-foaming, was measured (Tables 1-4 and Figure 1). Control water samples, labeled SA Water and ATG Water, were purified by distillation and deionization by, respectively, Surfactant Associates and by American Technologies Group. In a number of systems, sonication was used to disperse the chemical substances responsible for forming films at the liquid/air interface (Table 3); foaming was also used to remove surface active materials (Table 2).

Table 1 Surface Tension Measurements of Purified Water and I<sub>E</sub> Water.

Sample	Average Surface Tension (Standard Deviation), dyne/cm	Temperature, °C
<b>Controls (purified water)</b>		
SA Water	71.9 (0.1)	25.0
ATG Water	71.6 (0.4)	25.0
<b>I<sub>E</sub> water</b>		
Distilled (1)	72.0	25.0
Distilled (2)	71.4 (0.1)	27.5
Undistilled (1)	59.6 (1.0)	25.0
Undistilled (2)	70.3 (0.3)	25.4

A KRUSS digital tensiometer, model K10T, was used for these measurements. Temperature was controlled using a Brinkmann MGW/LAUDA (RC3) Cooling Unit. Each measurement was repeated 3-5 times, except for the Distilled (1) sample, where only one measurement was made.

Table 2 Effect of Foam Removal on Surface Tension.

$I_E$ Sample	Average Surface Tension (standard deviation), dyne/cm
<b>Prior to foam removal</b>	59.8 (0.8)
<b>After foam removal</b>	63.9 (0.7)

A KRUSS digital tensiometer, model K10T, was used for these measurements. Temperature was controlled using a Brinkmann MGW/LAUDA (RC3) Cooling Unit. Each measurement was repeated at least 5 times.

Table 3 Effect of Sonication on Surface Tension of  $I_E$  and Water Solutions.

Sample	Time of sonication, min.	Time elapsed after sonication, seconds	Surface Tension, (standard deviation) dyne/cm	Temperature, °C
<b>Control</b>				
ATG Water	10	10 min.	71.5	27.5
<b><math>I_E</math> water</b>				
Undistilled (1)	7	10 min.	61.0 (0.9)	25.2
Distilled (1)	8	10 min.	71.4 (0.1)	25.2
Undistilled (1)	2	70	64.5	26.1
		150	63.8	26.1
		360	62.6	26.1
		600	60.5	26.1
		900	60.6	26.1
Undistilled (1)	15	90	61.6	26.1
		240	60.9	26.1
		390	60.9	26.1
		540	60.5	26.1
Undistilled (1)	2	60	63.3	25.5
		180	61.6	25.5
		420	60.1	25.5
		5 hours	62.8	25.2
Undistilled (2)	2	90	70.3	25.5
		240	69.9	25.5
		420	69.2	25.5
		600	69.4	25.5
		5 hours	64.6	25.2

A KRUSS digital tensiometer, model K10T, was used for these measurements. Temperature was controlled using a Brinkmann MGW/LAUDA (RC3) Cooling Unit. Standard deviations are shown for measurements that were repeated 2-3 times.

Table 4 Surface Tensions of Solutions Prepared with Sodium Dodecyl Sulfate (SDS) Surfactant and a Commercial Detergent (CD) provided by ATG.

Solvent	Surfactant type	Surface Tension, (Standard Deviation) dyne/cm	Temperature, °C
SA water	SDS	39.9	25.0
ATG water	SDS	39.9	25.0
Distilled (1)	SDS	39.9	25.0
<b>Solvents were mixed with CD 2 days prior to measurements</b>			
ATG water	CD	32.4 (0.1)	25.2
Distilled (1)	CD	31.2 (0.1)	25.4
Undistilled (1)	CD	30.8 (0.2)	25.4
<b>Solvents were mixed with CD immediately before measurements</b>			
ATG water	CD	32.8 (0.1)	25.4
Distilled (1)	CD	32.3 (0.1)	25.4
Undistilled (1)	CD	33.3 (0.3)	25.4

A KRUSS digital tensiometer, model K10T was used for these measurements. Temperature was controlled using a Brinkman MGW/LAUDA (RC3) Cooling Unit. SDS solution was prepared by dissolving 1.6 g of SDS per liter of a solvent (SA or ATG control water, or I<sub>E</sub> water). CD solution was prepared by mixing 0.04 ml of CD with 50 ml of solvent (SA or ATG control water, or I<sub>E</sub> water). All measurements were repeated at least 3 times.

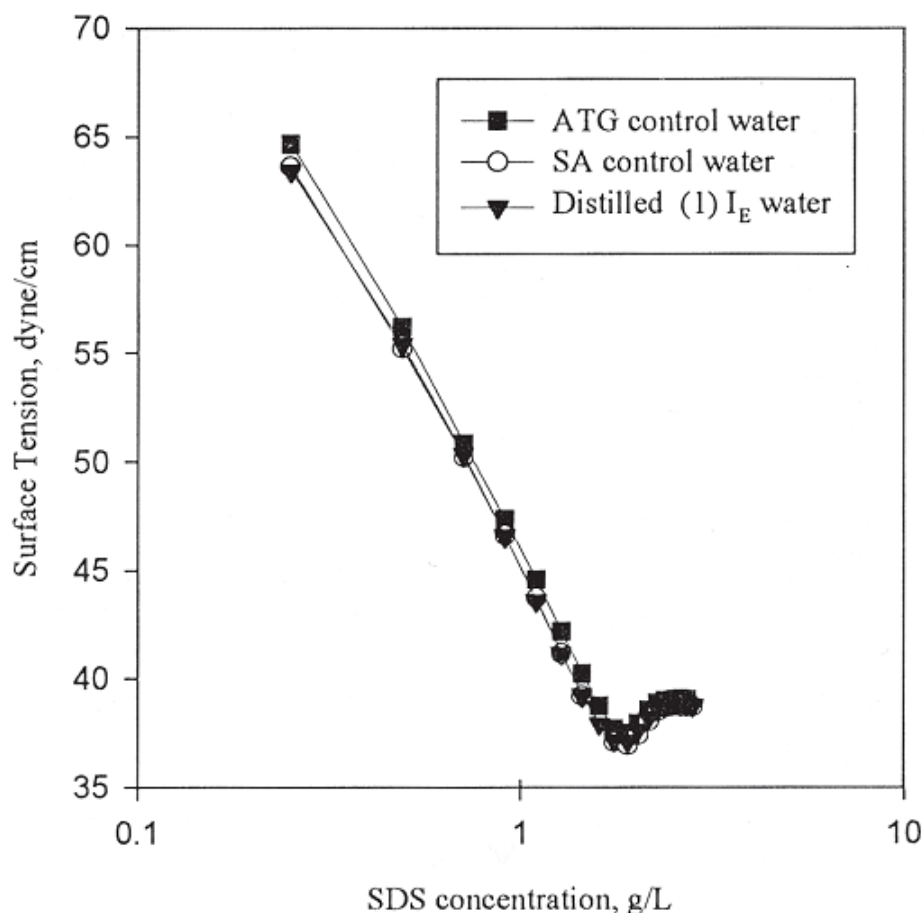


Figure 1 Surface Tension of Solution of Sodium Dodecylsulfate (SDS) in ATG or SA control water or Distilled (1) I<sub>E</sub> Water as a Function of SDS Concentration in the Solution.

A Cahn Dynamic Contact Angle Analyzer (model DCA-322) was used to carry out these measurements. A predetermined amount of stock SDS surfactant was added incrementally to control or I<sub>E</sub> water, and the surface tension of the obtained solution was measured. The concentration of SDS in the stock solution was 24 mM.

### 3.2 Vapor Pressure

Vapor pressures were measured at 25°C for control water and for I<sub>E</sub> samples. The values for all of the samples were equal within  $\pm 0.03$  torr, the approximate maximum uncertainty in absolute vapor pressure, allowing for errors in calibration, temperature uncertainty, and incomplete removal of dissolved air and/or impurities. These results are in good agreement with reported values for the vapor pressure of water at 25 °C (Table 5).

Table 5 Vapor Pressure of Control and I<sub>E</sub> Water.

Sample	Average Vapor Pressure (Standard Deviation), Torr	Temperature, °C
<b>Control</b> ATG Water	23.795 (0.001)	25
<b>I<sub>E</sub> Water</b> Undistilled (1)	23.770 (0.005)	25
Undistilled (2)	23.744 (0.003)	25
Distilled (1)	23.750 (0.008)	25

All measurements were repeated 4 times.

### 3.3 Bulk Liquid Properties

Density, viscosity (Table 6), and conductivity (Figure 2) of control water as well as two types of I<sub>E</sub> water were measured. No significant differences in the values of the parameters measured were observed. Evaporation of samples to dryness (at approximately 140° C) did not yield a measurable residue for 10 g samples of either water control or distilled I<sub>E</sub> water samples. On the other hand, residuals of about 2 to 4 mg were obtained when 10 ml of an undistilled I<sub>E</sub> water sample was evaporated.

Table 6 Density and Viscosity Measurements of Control and I<sub>E</sub> Water.

Sample	Viscosity, cp	Density, g/ml
<b>Control</b> SA Water	nd	0.991
ATG Water	0.91	0.995
<b>I<sub>E</sub> Water</b> Distilled (1)	0.90	0.991
Undistilled (1)	0.92	0.991
Undistilled (2)	0.94	0.990

Viscosity was measured with Ostwald viscometer.  
nd -- the parameter was not determined.

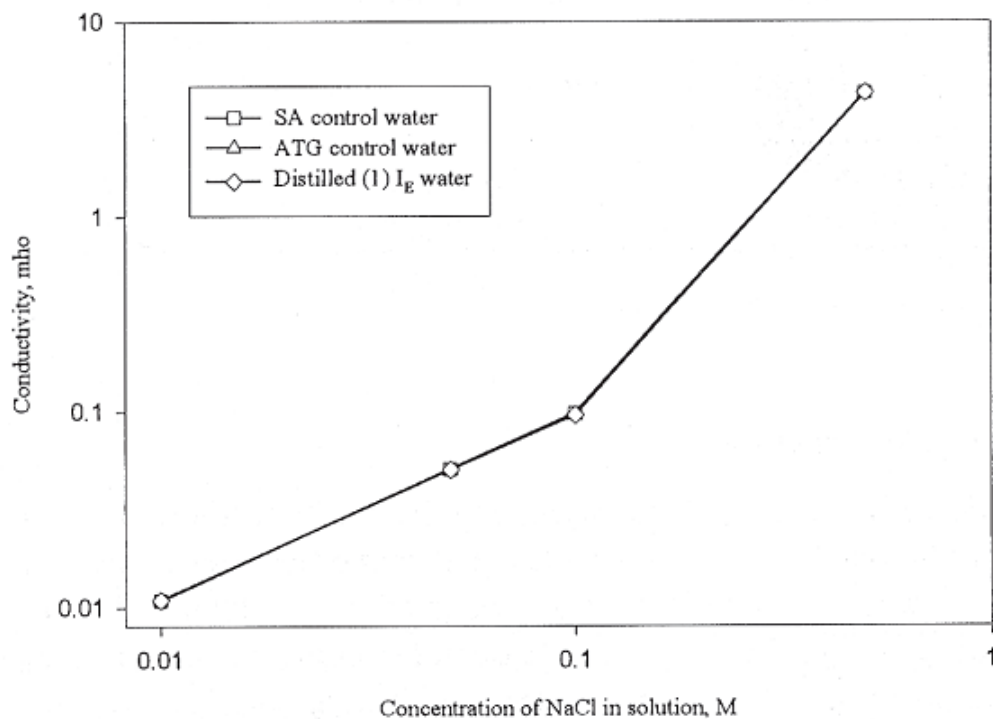


Figure 2 Conductivity Measurements of SA and ATG Control Water and Distilled I<sub>E</sub> Water. An Orion Research Conductivity Meter-101 was used in this study.

### 3.4 The Foaming of I<sub>E</sub> Water

The volume of the foam layer formed in a sample of control or I<sub>E</sub> water after 20 s of vigorous shaking (up and down) in a 50 ml burette was measured (Table 7). In all of the foaming experiments, with control and distilled I<sub>E</sub> water, most of the foam disappeared fairly rapidly, while in the case of undistilled I<sub>E</sub> water more foam was formed and it persisted for longer time. Preliminary experiments were carried out to show the feasibility of removing foam from I<sub>E</sub> water samples to concentrate surface active component(s) of the system. It was observed that the surface tension is raised following removal of foam, indicating that some surface active material had been removed (Table 2).



Table 7 Foaming of Control and I<sub>E</sub> Water.

ATG Control Water		Distilled (1) I <sub>E</sub> Water		Undistilled (1) I <sub>E</sub> Water	
Time after end of shaking, s	Foam volume, ml	Time after end of shaking, s	Foam volume, ml	Time after end of shaking, s	Foam volume, ml
0	0.1	0	0.3	0	1.5
		35	0.1	20	0.5
		60	0.005	30	0.4
				50	0.35
				70	0.35
				90	0.3
				360	0.3
				600	0.3
				1200	0.25

A 50 ml burette filled with 20 ml of ATG control water or Distilled (1)I<sub>E</sub> water or Undistilled (1) I<sub>E</sub> water was shaken vigorously for 20 seconds. The volume of foam was measured at time intervals.

#### 4. Discussion of Surface Tension, Foaming, and Adsorption at the Water-Vapor Interface

Before discussing differences in surface tensions and foaming characteristics of the individual samples of I<sub>E</sub> water, as compared with the water control samples, we will comment on the significance of surface tension as a method for determining the presence and surface concentration of components dissolved in water. It is possible for trace amounts of slightly soluble impurities (usually organic compounds) to lower surface tensions considerably, producing nearly a monolayer of organic compounds at the boundary between the bulk liquid and the vapor. The Gibbs adsorption equation can be used to determine the surface (excess) concentration of such solutes if they are present in the bulk at known concentrations.

When a water sample contains dissolved impurities that possess both hydrophilic and hydrophobic chemical groups (e.g., neutral compounds like alkylated phenols, naphthols, and ethers), the surface tension can be lowered considerably from the expected value of about 72 dyne/cm at 25°C. This effect is particularly pronounced for compounds that have quite low solubilities in water. Such compounds, at very low concentrations, will act somewhat like the commercial surfactants in their ability to decrease the surface tension of water.

Their solubility is much more limited than that of the commonly used surfactants, so they cannot perform as well as these compounds in detergency or the formation of relatively stable foams and emulsions. It is certainly an important question whether any of the surface tension and foaming effects studied here can be attributed to impurities present in  $I_E$  water. On the other hand, if  $I_E$  water is able to change the surface activity of compounds that are useful in detergency, that would be an important observation in relation to the potential use of  $I_E$  water in a wide variety of cleaning processes and in forming aqueous colloids (emulsions, foams, dispersions, etc.). We do not consider that the question of the role of  $I_E$  water in modifying the properties of aqueous surfactant solutions has yet been answered, but several additional studies of systems involving both surfactants and  $I_E$  water still should be performed to answer this question.

The question of the importance of  $I_E$  water in promoting foaming also needs to be examined in greater detail. Most observers, on handling samples of  $I_E$  water in glass containers, seem to believe that this water is more viscous than ordinary water, although our quantitative measurements of bulk viscosity do not confirm this. On the other hand, there is little doubt that the  $I_E$  water samples do foam, although most of the foam disappears quickly.

It is well known in the chemical engineering literature that foaming (by a process called foam-fractionation) is an important method for collecting surface active materials dissolved in water. Simple foam fractionators can be set up in the laboratory to recover the surface active compounds, and although we have not yet had time to do these experiments, it would be advantageous in our opinion to develop programs to collect and determine the concentration of the materials responsible for foaming and depression of surface tension. To be sure, if the  $I_E$  samples contain surface-active organic impurities, one result will be that these will become highly concentrated in the removed foam. On the other hand, if the collected foaming materials are highly enriched in the  $I_E$  water (as determined by physical and structural methods), foaming could be a valuable method for obtaining  $I_E$  clusters in highly-concentrated form.

## **5. Conclusions and Suggestions for Further Development**

Initial results indicate that  $I_E$  water, either distilled or prepared without distillation, has surface properties and foaming behavior that differ from ordinary water. Sonication is a method that changes surface properties of some samples, in several cases, causing a decrease in the apparent concentration of the agent(s) responsible for the surface tension effects. Removal of foam also reduces the concentration of surface active materials (at least temporarily), although with time, the surface tension of the  $I_E$  water does change part way back to its initial value before foaming.

Synergistic effects of  $I_E$  clusters and detergents have not been systematically studied. Experiments to determine the properties of mixtures of various commercial detergents (including some that are pure individual compounds) need to be planned for the future. The feasibility of concentrating  $I_E$  water by foaming and reusing the concentrate in subsequent detergency studies needs to be investigated.

The possibility that detergent action can be enhanced by  $I_E$  water clusters needs to be examined in detail. Either by foaming or other methods, attempts should be made to obtain  $I_E$  water in highly concentrated form. If the clusters are surface active, the effect needs to be put on a quantitative basis. The foam concentrate should be analyzed carefully to determine the content of organics as well as the quantity and structure of  $I_E$  water clusters. This concentrate could be used in a variety of ways, including substituting it for some of the components in heavy duty or

specialty household cleaning formulations. Moreover, the effect of the  $I_E$  water in stabilizing foams, emulsions, and suspensions of solids in aqueous (or other) systems needs to be evaluated. Finally, the possibility that  $I_E$  water may adsorb at a variety of surfaces or interfaces and modify film properties should be explored. To summarize, the potential use of  $I_E$  water in combination with well-characterized surface active agents might lead to important commercial applications.