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Comparison of Heat Absorption and Retention Capacity in Fresh Water and Sugar Water Solutions

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Abstract

The effect of solute on freezing, melting, boiling and cooling rate on sugar water solution at different concentrations as well as on fresh water were investigated. Two methods were employed to determine the heat absorption and retention of freshwater, and of sugar solution of three different concentrations. Measured (5g, 10g and 15g) sugar samples were dissolved in a 100 ml of water in polypropylene beaker and kept in a freezer simultaneously till the solutions attained freezing point, with the temperature drop recorded. The beakers were removed simultaneously from the freezer and the temperature rise recorded till room temperature was attained. Fresh water and sugar solution were also heated to boiling point and time taken for each sample to reach boiling point was recorded. The results show that sugar solution has higher heat absorption capacity than fresh water and increases with concentration of sugar. The heat retaining capacity of sugar solution was also higher than that of fresh water and increases with the concentration of sugar solution. The result shows that addition of solute lowers the specific heat capacity of water which in turn increases the heat absorption capacity and decreases the heat retention capacity of water.

Keyword: heat retention, absorption, cooling rate, fresh water, sugar water and concentration

1. Introduction

Water is a transparent fluid that forms the world's streams, rivers, lakes, rain, and oceans. As a chemical compound, a single water molecule contains one atom of oxygen and two atoms of hydrogen connected by covalent bonds (Pullman *et. al.*,1985) except heavy water deuterium oxide ($2H_2O$) which is a form of water that contains a larger than normal amount of the hydrogen isotope deuterium. Fresh water is characterized by low concentrations of dissolved salts and other total dissolved solids. The term specifically excludes seawater and brackish water although it does include mineral-rich waters such as chalybeate springs. Most liquids boil at temperatures at which their vapor pressure is equal to the pressure of the gases above them (Goldberg, 1988). The presence of the solute decreases solvent vapor pressure by dilution.

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The vapor pressure of the solution is always less than the vapor pressure of the solvent for a non-volatile solute. A higher temperature is therefore required for the vapor pressure to reach the surrounding pressure such that the boiling point is elevated. The boiling point elevation which is a colligative property is an effect of the dilution of the solvent in the presence of a solute. It is a phenomenon that happens to all solutes in all solutions and is independent of solute-solvent interactions. The increase in boiling point occurs both when the solute is an electrolyte and a nonelectrolyte. The origin of the boiling point elevation is entropic that can be described in respect of the vapor pressure or chemical potential of the solvent (Atkins, 1994).

A substance changed from its liquid state to a solid state when its temperature is lowered below its freezing point. The presence of an additive in a liquid can lower the freezing point of the liquid; this phenomenon is referred to as freezing point depression. At the freezing point of a solvent, the chemical potential of the solution at the liquid state and solid state will be equal. Addition of solute to the solvent will reduce the chemical potential of the solution and consequently, its freezing point (Atkins, 1994). Melting point of a substance is the temperature at which a solid becomes a liquid at normal atmospheric pressure.

There are different kinds of sugar; a few of them are glucose, fructose, galactose, lactose, sucrose, and maltose, of all these different sugars, glucose and fructose are monosaccharaides. Table sugar is known as sucrose, its chemical composition involves two or more sugar molecules connected in a chain and its melting point is 186°C (Colonna and Samaraweera, 1999).

Impurities are substances inside a confined amount of liquid, gas, or solid, which differ from the chemical composition of the material or compound and are either naturally occurring or added during synthesis of a chemical or commercial product (Cheng *et al*., 2004).

Heat is a central concept in thermodynamics and statistical mechanics and is also important in chemistry, engineering, and other disciplines (Gould and Tobochnik, 2010). Heat capacity is the measurable physical quantity that characterizes the amount of heat required to change a body's temperature by a given amount. Camilloni and Barros (1997) defined heat capacity as an extensive property of matter that is dependent on the size of a system, which could be expressed as derived quantities that specify heat capacity as an intensive property that is independent of the size or extent of a sample (Lynden-Bell, 1998).

Temperature reveals the average total kinetic energy of particles in matter. Heat is the transfer of thermal energy that flows from regions of high thermal energy to regions of low thermal energy. The energy is kept as kinetic energy in the random modes of translation in monatomic substances and translations, and rotations of polyatomic molecules in gasses. Thermal heat may be stored as potential energy associated with the vibration when they occur in interatomic bonds in any matter. Translations, rotation, as well as other two types of energy in vibration (kinetic and potential) are responsible for the degrees of freedom of motion that classically contribute to the heat capacity of a thermodynamic system (Kittel and Herbert, 2000).

Absorption and retention of heat energy by materials are regular phenomena that occur in many materials, water inclusive. Water freezes or cools by release of energy to its environment, while absorption of heat occurs as a result of flow of heat from body of higher temperature to another body of lower temperature, which usually occur through conduction, convection or radiation. When a hot body is in conducting contact with a cold body, the temperature of the cold body rises and that of the hot body falls, this is because a quantity of heat has been absorbed by the cold body from the hot body (Kreith and Black, 1980). A substance that retains heat energy for a longer period is known to have high heat capacity while the substance that gives its energy easily within a short period is known to have low heat capacity.

In metal, a small addition of an impurity to alloy can greatly affect the specific heat capacity of the alloy, similarly the presence of impurity can also affect melting, boiling and freezing point of a liquid. Mohammad and Faramarz (2014) investigated influence of concentration of contaminants on the flow boiling heat transfer coefficient in deionized water and the results showed that the deionized water causes the flow boiling heat transfer coefficient to be deteriorated. Ogungbe *et al.* (2015) compared the heat retention of salt water and fresh water and reported that the salt water retains more heat than the fresh water and increasing the concentration of salt in the salt water solution affects the heat retaining ability.

The aim of this work is to compare the heat absorption and retention in fresh water and sugar water with a view to identifying which retains or absorbs heat energy more. Attempts would also be made to know the effect of sugar concentrations in the water on the heat retaining and absorption capacity.

2. Materials and Methods

The experiment was conducted in the laboratory at room temperature (30°C) and pressure (760 mmHg) with the following apparatus: beakers, digital thermometer, Bunsen burner, tripod stand, weighing scale, distilled water, sugar, volumetric flask, freezer, wire gauze, 150 ml copper calorimeters and stop watch.

2.1 Effects of impurities on freezing and melting point of water

An electronic weighing balance of precision of ± 0.01 was used to weigh 5g of granulated sugar and was dissolved in a 100 ml of freshwater placing in 150 ml beaker. A digital thermometer (Mextech) with resolution 0.1°, accuracy ±1°C in the Range Of -30°C to +150°C was used to measure the initial temperature by inserting its probe into the solution in the beaker. Corresponding volume of solutions of 10g and 15g mass of sugar with 100 ml freshwater were prepared and pour into 150 ml beaker. The whole setup was placed simultaneously inside a freezer and the temperature drop was recorded at every ten-minute interval, till the freezing point of freshwater was attained. The four beakers were removed from the freezer thereafter and the temperature rise of the solution in each of the beaker was taken at ten-minute interval till the solutions changed from their frozen state back into liquid state and room temperature was attained.

2.2 Effects of impurities on the boiling point and cooling rate of water

100 ml of distilled water at room temperature was measured and transferred into a 150 ml beaker which was placed on Bunsen burner. It was left to boil and the time taken to reach its boiling point (100^0C) was taken and recorded. Another 100 ml of distilled water at room temperature was measured and 5g of sugar was added and the solution was poured inside a beaker. The content was then placed on a Bunsen burner for it to boil and the time taken for it to reach boiling point (100^0C) was recorded.

A cooling system involving a well-lagged copper calorimeter with a stirrer was put in place to maintain uniform temperature during the cooling process. The content after been heated to its boiling point was then transferred from the beaker into the copper calorimeter. The probe of a digital thermometer dipped inside the calorimeter was used to record the temperature drop till room temperature was attained. The procedure was repeated for 10g and 15g of sugar dissolved in 100ml of distilled water.

3. Results and Discussion

3.1 Comparison of fresh water and sugar water on heat retention (Freezing)

The freezing rate at ten minutes' interval of fresh water and sugar water at different concentration were compared and recorded (Table 1 and Figure 1)

Table 1: Freezing rate of fresh water and sugar water of different concentrations (5g,10g and 15g)

Time (Minutes)	Temp. (^{0}C) of 100ml of distilled water	Temp (^{0}C) of 100ml of distilled water + 5g sugar	Temp (^{0}C) of 100ml of water +10g sugar	Temp (^{0}C) of 100ml of distilled water +15g sugar
0	27.0	26.9	26.9	27.0
10	24.6	24.5	23.5	26.5
20	21.5	20.9	20.6	24.5
30	18.2	17.5	17.3	21.3
40	15.1	14.3	14.4	18.4
50	12.1	11.5	11.8	15.8
60	10.0	9.3	9.1	13.3
70	7.8	7.3	7.3	11.1
80	6.0	5.8	5.3	9.1
90	3.2	4.3	4.2	7.5
100	1.0	2.3	3.1	6.1
110	0.00	0.3	2.0	4.5
120			1.5	3.3
130			0.6	2.2
140				1.2
150				0.3

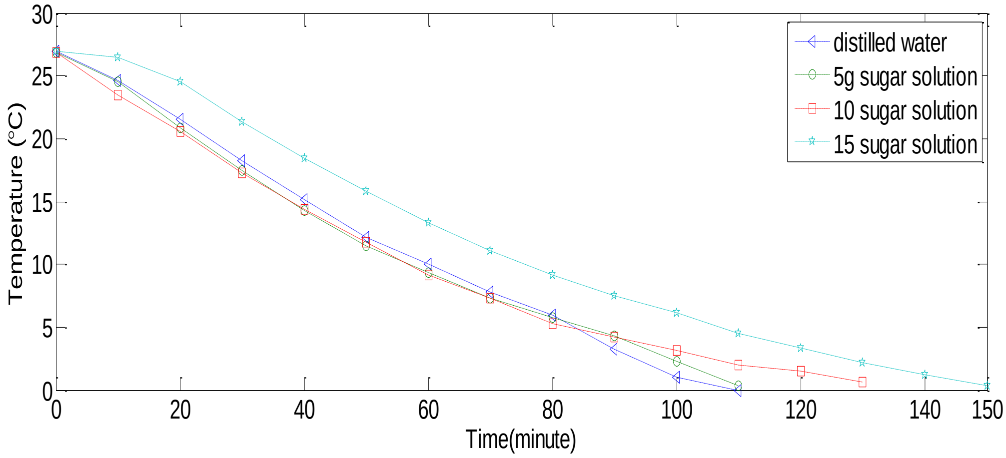

Figure 1: Temperature of fresh water and sugar water against time on freezing

The graphs of temperature of different concentrations (5g, 10g, and 15g) of sugar in 100 ml of distilled water against time for the freezing, alongside with a 100 ml fresh water only (Figure 1). It took distilled water 1hr 50mins to reach freezing point (0^0C), while the sugar solutions took 1hr 50mins, 2hrs 10mins and 2hrs 30mins for 5g, 10g and 15g respectively. The increase in concentration of solute in the solvent increased with time taken to reach the freezing point (Figure 1). This was because the sugar in this case "gets in the way" of the water's ability to make an orderly crystal, so when the ice crystal forms, almost all the sugar gets left behind in the liquid. This implies that freezing the water not only lines up the water molecules but also limits the room available for the sugar ions to move around, thereby making concentrated solution harder to freeze.

3.2 Comparison of fresh water and sugar water on heat retention (Cooling)

Temperatures drop of boiled fresh water and sugar solution were recorded in Table 2

Table 2: Cooling rate of fresh water and sugar water of different concentrations (5g, 10g and 15g)

Time (minutes)	Temp. (^{0}C) of 100ml of distilled water	Temp (^{0}C) of 100ml of distilled water + 5g Sugar	Temp (^{0}C) 100ml of distilled water + 10g sugar	Temp (^{0}C) of 100ml of distilled water + 15g sugar
0	99.0	99.0	99.0	99.0
10	63.8	58.9	62.0	82.9
20	55.2	50.4	54.1	79.8
30	49.5	45.3	49.0	65.4
40	45.8	42.8	45.3	53.8
50	42.7	39.6	42.3	49.7
60	40.0	38.0	40.3	45.4
70	38.0	36.4	37.0	43.2
80	36.3	35.1	35.6	39.7
90	35.0	34.0	34.3	38.2
100	33.8	32.9	33.3	36.9
110	32.9	32.1	32.5	34.2
120	32.0	30.2	31.9	32.5
130	31.5	29.3	31.2	31.0
140	30.8		30.3	29.5
150	30.3		29.8	
160	29.9			

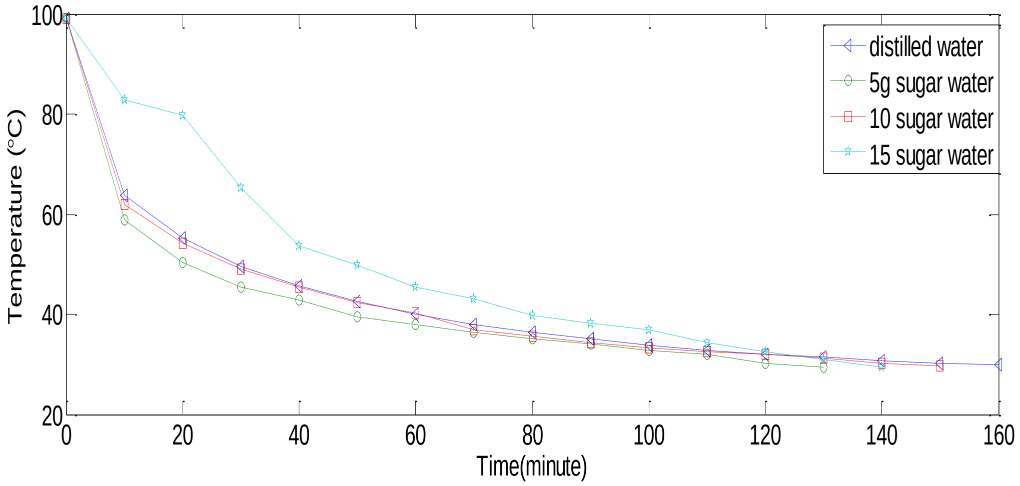

Figure 2: Temperature of fresh water and sugar water against time on cooling

Figure 2 shows the graph of temperature against time for the cooling of different concentrations (5g, 10g and 15g) of sugar in 100ml of freshwater. It took 100ml of freshwater 3mins 40s to attain boiling point, also figure 2 depicts that it took 2mins 30s, 2mins 45s and 2mins 55s for the sugar solution of concentrations 5g, 10g and 15g to respectively to reach boiling point. This gives an indication that sugar has an effect on the heat absorption rate of water; increase in concentration of sugar in water causes a decrease in heat absorption ability. From this result, it was observed that fresh water took the longest time to attain boiling point. The graph also shows that while it took freshwater the longest time of 2hrs 40mins to attain room temperature, it took 2hrs 30minutes, 2hrs 20minutes, and 2hrs 10minutes for freshwater containing 10g, 15g and 5g of dissolved sugar to attain room temperature respectively.. The consequence of this is that sugar has effect on the heat retention capacity of water, and an increasing in concentration of sugar in water would decrease the heat retention capacity. The effect was due to the solution, trapping water molecules in a cage around it; the water has a high specific heat because of its ability to rotate freely around its center of mass. There is a large number of degree of freedom that can randomly vibrate and rotate in fresh water. The molecules in solution trapped several water molecules close to them in lower-energy stiff configuration, and these molecules are like a tiny rigid body where thermal motion is not possible, because the quantum of oscillation frequency is higher than Boltzmann temperature (KT). This reduces the specific heat by an amount directly proportional to the quantity of solute.

3.3 Comparison of fresh water and sugar water on heat absorption (Melting)

The melting rate at ten minutes' interval of fresh water and sugar water at different concentration were compared and recorded (Table 3 and Figure 3)

Table 3: Melting rate of fresh water and sugar water of different concentrations (5g, 10g and 15g)

Time (minutes)	Temp. (^{0}C) of 100ml of distilled water	Temp (^{0}C) of 100ml of distilled water +5g sugar	Temp. (^{0}C) of 100ml of distilled water + 10g sugar	Temp (^{0}C) of 100ml of distilled water +15g sugar
0	1.3	0.3	0.6	1.2
10	4.3	4.8	5.7	8.0
20	6.5	10.1	9.9	13.7
30	10.3	15.4	14.6	17.2
40	15.5	18.2	18.2	19.5
50	19.8	20.1	21.9	21.3
60	22.2	23.0	23.1	22.5
70	23.7	24.1	24.8	23.6
80	24.5	26.3	27.2	25.2
90	25.1	28.2	29.8	28.5
100	26.3	29.7	30.9	30.2
110	28.7	30.9		
120	30.3			

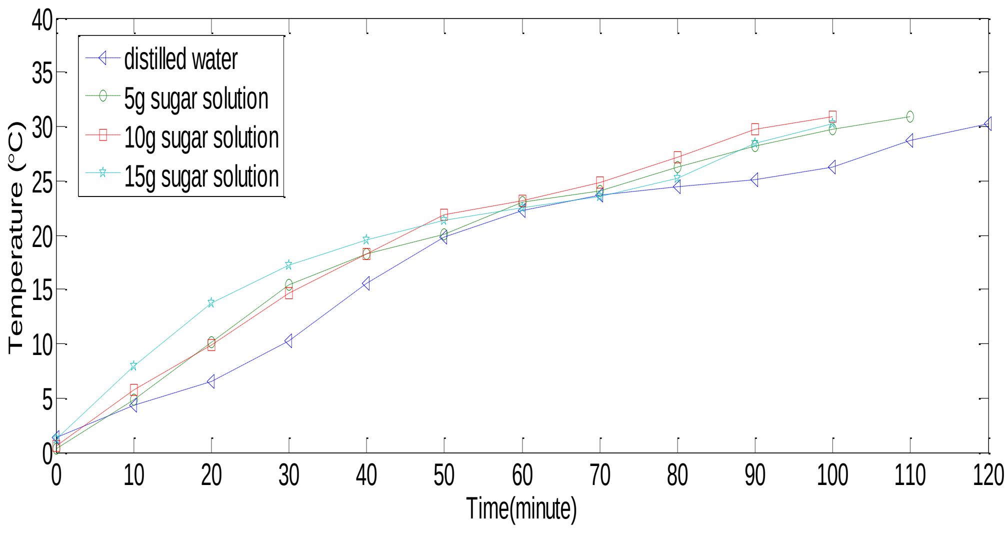

Figure 3: Temperature of fresh water and sugar water against time on melting

The graph of temperature of different concentrations (5g, 10g and 15g) of Sugar in 100ml of water, alongside with 100ml of fresh water shown in Figure 3. It took fresh water 2hrs to attain room temperature, while the sugar solutions took 1hr 50 minutes, 1hr 40minutes and

1hr 35minutes for 5g, 10g and 15g respectively. For melting to occur, energy (heat) must be flown to it from its surroundings to disrupt the hydrogen bounding in the lattice. Additional of sugar disrupts the system and prevents as many water molecules in solution from reaching its lattice surface. The result depicts that sugar has effect on the heat absorption of water, and an increasing concentration of sugar in water leads to high heat absorption ability of water. The graph also revealed that freshwater had the least heat absorption rate due to the high specific heat capacity of water compared to Sugar water.

3.4 Comparison of fresh water and sugar water on heat absorption (boiling)

Room temperature = 30^{0}C

Table 4: Boiling rate of fresh water and sugar water of different concentrations

No. of Trials	Time (Minutes) taken to boil 100ml of distilled water	Time (Minutes) taken to boil 100ml of distilled water +5g sugar	Time (Minutes) taken to boil 100ml of distilled water + 10g sugar	Time (Minutes) taken to boil 100ml of distilled water + 15g sugar
1st Trial	3.70	2.45	2.78	2.94
2nd Trial	3.60	2.60	2.74	2.92
3rd Trial	3.71	2.45	2.74	2.90
Average	3.67	2.50	2.75	2.92

Fresh water boils after 3.67 minutes (3 minutes 40 seconds) while sugar solution take lesser time to boil (Table 4). The time taken before boiling point was reached was increased with increasing concentration of the sugar in the distilled water. This is because water boils and moves from the liquid phase to the gas phase when the molecules of water overcome the atmospheric pressure of the surrounding. Different processes occur when a solute that increases the amount of energy (heat) needed for water to make the transition is added. The added sugar dissociates into ions and become charged particles which reduce the intermolecular forces between water molecules. Thus heat capacity of the water was decreased with increase in concentration of sugar in the distilled water.

4. Conclusion

The sugar solutions took longer time to freeze as the concentration of the sugar increases. The retention ability of heat increases with increasing concentration of solute in the water.

Addition of a solute to the solvent reduced the chemical potential of the solution and consequently lowered its freezing point. Fresh water also lost its heat content faster than the sugar solutions. The study shows that sugar water has a better heat retention ability when subjected to the cooling and freezing process. Addition of sugar in water increases the heat absorption rate of water. Sugar solution boils and melts faster than fresh water. The high heat capacity of water is responsible for this phenomenon and it shows that sugar water has less heat capacity than fresh water. From the two methods employed in determining the heat absorption and dissipation rate of fresh water and sugar solution, it has been shown that addition of sugar decreased the heat capacity of water, indicating that fresh water had higher heat capacity compared to sugar water.

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