

Equation of The Boiling Point in Concentrate Solution

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ABSTRACT

The increase in boiling temperature in an industry is very important because it greatly affects the heat so that it affects fuel Consumption. Therefore, the calculation of the boiling temperature of the solution is necessary. In the equation so far only to determine the boiling temperature of a solution that can be used in very dilute solutions and very small changes in boiling point, therefore research is needed to produce an equation for the boiling temperature of a concentrated solution. The experiment was carried out as much as 100 milliliters of pure water plus solid NaOH to form a solution with a 0.005 mole fraction. The mixture is heated while stirring until it boils and then measures the boiling temperature. The experiment was carried out by varying the fraction of the solution and the type of dissolved solids in the form of NaCl, $K_4Fe(CN)_6$, and benzoic acid. From the experiment, the results obtained are that the boiling temperature of the solution is influenced by whether the solution is easily electrolyzed, the easier the substance is to be hydrolyzed, the higher the temperature of the solution, for substances that are difficult to hydrolyze, the boiling temperature of the solution is slightly above the boiling temperature of the pure solvent. . For NaOH solution and NaCl solution, the larger the electrolysis factor fraction, the smaller the solution, while for $K_4Fe(CN)_6$, and for benzoic acid, the electrolysis factor price can always be considered to be one.

Key words : Dissolved solid, Fraximole, Boiling temperature, Electrolysis factor.

1. INTRODUCTION

Solids dissolved in a liquid cause a change in the vapor pressure of the liquid so that the boiling

temperature of the solution becomes higher than the boiling temperature of the pure solvent. The vapor pressure of the solution is always lower than the vapor pressure of the pure solvent, so that the vapor pressure of the solution is the same as the vapor pressure of the pure solvent, the boiling temperature of the solution will be higher than the boiling temperature of the solvent.

Many chemical industries apply boiling temperature because heat is closely related to fuel requirements. It is therefore important to improve understanding of the boiling temperature of solutions. Since the equation for the increase in the boiling temperature of concentrated solutions does not yet exist, it is necessary to conduct research to improve or change the equation for the increase in boiling temperature in order to predict the boiling temperature of concentrated solutions. The advantage of this research is to increase scientific knowledge and provide information to calculate the boiling temperature so that energy consumption is more controlled

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2. LITERATURE REVIEW

The standard boiling temperature set by IUPAC is the temperature at which boiling occurs at a pressure of 1 bar, but the boiling temperature of liquids is generally measured at a pressure of 1 atmosphere [1]. The boiling temperature of the dissolved solid in the liquid is always higher than the boiling temperature of the pure solvent, so the evaporation of the solvent requires more energy. The number of particles in a solution is determined by the concentration of the solution and the nature of the solution. At the same concentration the

number of particles in a non-electrolyte solution is not the same as the number of particles in an electrolyte solution, this is because the electrolyte solution can decompose into ions, while the non-electrolyte solution cannot decompose into ions [2]. The pressure is directly proportional to the temperature, the greater the temperature the greater the pressure. The temperature at which the saturated vapor pressure of the liquid equals the pressure of the gas above the liquid is called the boiling temperature. At that time, in all parts of the liquid gas bubbles are formed which are able to push molecules towards the surface to turn into the gas phase. Thus, the boiling point of a liquid depends on the external pressure [3].

The presence of hydrogen bonds between molecules causes the boiling temperature of the compound to be relatively higher than that of other compounds with the same molecular weight. The effect of hydrogen bonding is not so great if the distance between the molecules is close and the shape of the molecule is symmetrical. Compounds capable of forming hydrogen bonds are easily soluble in water [4]. Substances that are electrolytes and are used as solutes cause attractive forces between atoms or molecules, causing them to move apart. The particles are in close proximity to each other, so matter has a shape and volume. So liquids can flow in the shape of a container but cannot be compressed. Therefore a liquid has a fixed volume but an undefined shape. The particles (atoms, ions, molecules) of a substance depend on the forces of attraction and repulsion. Intermolecular forces are caused by the attraction or repulsion of the electric charges between molecules [5]. The arrangement of molecules determines the physical properties of a liquid such as boiling point, freezing point, and surface tension. This behavior affects the temperature and pressure as well as contact with other substances, so it also affects the increase in the boiling point. At the boiling point the molecules move from the liquid phase to the gas phase where the liquid and gas are in equilibrium. The boiling point begins when vapor bubbles form in the liquid, the bubbles rise to the surface of the liquid and then combine with gas molecules into the atmospheric air [6].

A compound breaks up into positive ions and negative ions, so that it has as much a factor as the sum of the charges on the ions. Charged particles are attracted to each other. Whenever positive and

negative ions come into contact they tend to stick together to form ion pairs and act as single particles. The closer the ions get to their partners, the contact between the ions with each other increases [4]

The solution has a lower vapor pressure than the pure solvent. The decrease in vapor pressure affects the boiling temperature, this follows the Clausius-Clapeyron equation as follows:

$$\frac{d \ln P}{dT} = \frac{\Delta H}{RT^2}$$

$$d \ln P = \frac{\Delta H}{RT^2} \cdot dT \dots\dots\dots$$

(1)

- d : differential
- Ln : logarithmic
- T : boiling temperature
- P : pressure
- ΔH : latent heat of vaporization
- R : ideal gas constant

The value of ΔH is approximated by the equation

$$\Delta H = a \cdot \left(1 - \frac{T}{T_c}\right) \dots\dots\dots$$

(2)

- T_c = critical temperature of solvent
- a = constant

Substitute equation (2) into equation (1)

$$d \ln P = \frac{a(1 - \frac{T}{T_c})}{RT^2} \cdot dT$$

$$\int_{P_0}^P d \ln P = \int_{T_0}^T \frac{a}{RT^2} \cdot dT - \int_{T_0}^T \frac{a}{RTT_c} dT$$

$$\ln \frac{P}{P_0} = -\frac{a}{R} \left(\frac{1}{T} - \frac{1}{T_0}\right) - \frac{a}{RT_c} (\ln T - \ln T_0) \dots\dots$$

(3)

$$\ln \frac{P}{P_0} = \ln(1 - X) \dots\dots\dots$$

(4)

[3].

Substitute equation (4) into equation (3)

$$\ln(1 - X) = -\frac{a}{R} \left(\frac{1}{T} - \frac{1}{T_0}\right) - \frac{a}{RT_c} (\ln T - \ln T_0)$$

$$\frac{1}{T} + \frac{\ln T}{T_c} = \frac{1}{T_0} + \frac{\ln T_0}{T_c} - \frac{R}{a} \ln(1 - X) \dots\dots\dots$$

(5)

For electrolyte solutions there is a factor j

$$j = \frac{\text{colligative properties of non electrolyte solutions}}{\text{colligative properties of electrolyte solution}}$$

$$j = \text{electrolysis factor}$$

so that equation (5) becomes

$$\frac{1}{T} + \frac{\ln T}{Tc} = \left(\frac{1}{T_0} + \frac{\ln T_0}{Tc} - \frac{R}{a} \ln(1 - X) \right) j \dots\dots (6)$$

The value of j is determined experimentally for each type of electrolyte solution, once j has been determined then j also applies to the colligative properties of other solutions [3]. For strong electrolyte solutions, the effect of attraction between ions is stronger than partial dissociation. A quantitative approach to the attraction between ions is that the electrolyte properties are determined by the interactions between the ions and depend on the concentration, temperature, and dielectric constant.

Experimental data in the form of a constant j is needed to solve problems in engineering. For further data analysis, the data that was originally presented in tabular form is represented in the form of mathematical equations. Therefore, the empirical equation is attempted in order to represent the data as well as possible but in a simple form. Determination of the form of the empirical equation that can be solved by linearization is:

$$j = n + m \cdot C \dots\dots\dots (7)$$

$$j = n \cdot C^m \dots\dots\dots (8)$$

$$j = n \cdot e^{m \cdot C} \dots\dots\dots (9)$$

$$j = n \cdot m^C \dots\dots\dots (10)$$

$$j = n + \frac{m}{C} \dots\dots\dots (11)$$

where n and m are constants while j and C are variables/functions. The least squares method is considered the most reliable in determining the value of the constants in the empirical equation. This method is based on the concept that the sum of the squared deviations or deviations from the simplest equation is a linear equation [8].

3. RESEARCH METHOD

3.1 Research Design

The temperature of the boiling solution was measured. Boiling temperature and solution concentration are used to calculate the value of the electrolysis factor j using equation (6). Furthermore, various values of j are used to make empirical equations in equations (7) to (11) where C is the molality in solution. The best equation that can be used in determining the boiling temperature is the one with the smallest error. Experiments were carried out using solid NaOH, NaCl, $K_4Fe(CN)_6$ and benzoic acid.

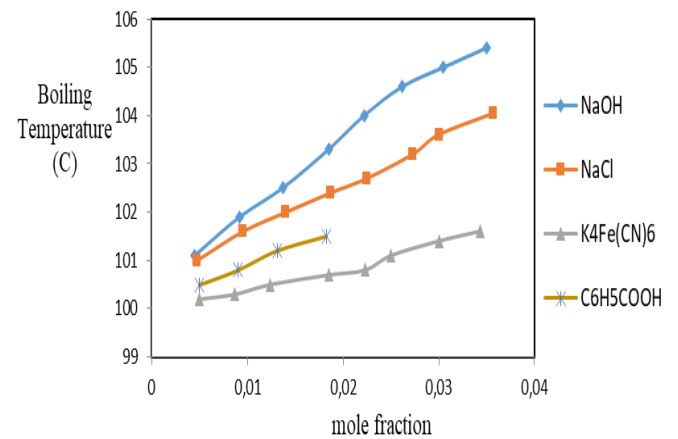


Figure 1. The relationship between mole fraction to Boiling temperature

3.2. Experimental Method

A total of 100 milliliters of pure water is put into a beaker glass measuring 200 milliliters. The NaOH compound is added to water to form a NaOH solution with a fraction of 0.035 moles. The mixture is heated while stirring until it boils and the boiling temperature is measured. The above experiment was carried out by varying the NaOH fraction. Experiments were carried out again with NaCl, $K_4Fe(CN)_6$, and benzoic acid.

3.3. Data analysis.

The calculation begins with determining the literature data for the prices of T_0 , T_c , a and R . Find the boiling temperature of the solution from the experiment. Calculating the electrolysis factor j with equation (6). Various values of j obtained as

well as fractional data were used to determine the empirical equations in equations (7) to (11). This method was repeated again but for NaCl, $K_4Fe(CN)_6$ and Benzoic Acid.

4. RESULTS AND DISCUSSION

The research carried out includes variations in the fraction of the solution and the type of dissolved solids used. The types of solids used are NaOH, NaCl, $K_4Fe(CN)_6$ and Benzoic Acid. The experimental results obtained are the boiling temperature of the solution with variations in the mole fraction of the solution and the type of dissolved solids. Then the boiling temperature data of the solution obtained from the experiment is used to find the value of the electrolysis factor (j) using equation (6). The experimental results obtained are in the form of a are presented in Figure 1 and Figure 2. In this experiment, the data for benzoic acid (C_6H_5COOH) could not reach 0.035 because the solubility of benzoic acid in water was not up to a mol fraction of 0.02

relationship between the type of solid and the fraction of moles with the boiling temperature. The calculation results produce an electrolysis factor j. These results.

4.1. Effect of solution to the boiling temperature

Determination of the colligative properties of the solution can be done by determining the specific gravity or fraction of the solution [9]. Figure 1 shows that the larger the fraction of the solution, the higher the boiling temperature of the solution, this is in accordance with the theory which states that the greater the density, the higher the boiling temperature rise [10]. Figure 1 also shows that the more solids dissolved in the liquid, the less solvent or water is in the solution so that the water vapor pressure above the solution is getting smaller, so that the solvent pressure is the same as the system pressure, a higher temperature is required as a result, the boiling temperature of the solution is high. For different amounts of dissolved solids in each solution, different heat energy is required, thus affecting the boiling temperature of the solution [11].

The graph in Figure 1 also shows that an electrolyte solution that is easily electrolyzed has a high

boiling temperature. This is because the colligative properties of weak electrolyte solutions are lower than the colligative properties of strong electrolyte solutions [12]. This means that the easier the solution is to ionize, the higher the boiling temperature. In this experiment, the NaOH solution has a higher boiling temperature than the NaCl solution, meaning that a strong base has a higher boiling temperature than salts from strong bases and strong acids. This means that this indicates that a strong base solution has a higher boiling temperature than a strong salt solution.

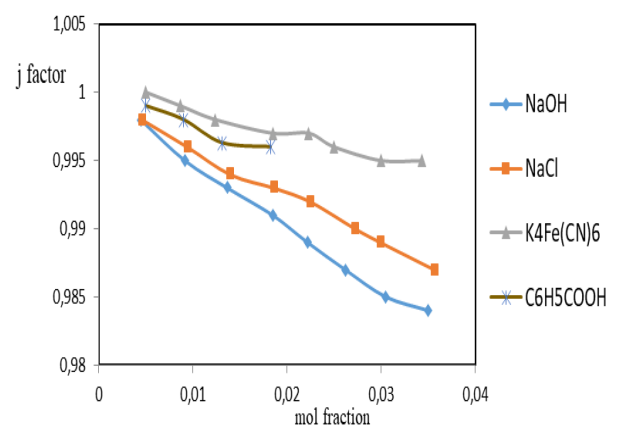


Figure 2. The relationship between mole fraction to electrolysis factor j

4.2. Effect of solution to the electrolysis factor

Colligative properties are the properties of a solution which are determined by the number of molecules or ions present in the solution. The relationship between colligative properties can be studied based on the specific gravity of the solution or the fraction of the solute in the solution [9]. Solutes in electrolyte solutions increase in number because they decompose into ions, the colligative properties of non-electrolyte solutions are lower than the colligative properties of electrolyte solutions and the colligative properties of electrolyte solutions also depend on the amount of solution that can be ionized [12].

Figure 2 shows that the NaOH solution has the smallest electrolysis factor, meaning a solution that is easily ionized has a small electrolysis factor or a salt which is a combination of a strong base and a strong acid causes a low electrolysis factor. This is because NaCl which is a combination of a strong base and a strong acid easily forms positive ions and negative ions and this salt is easier to ionize

and easily ionized completely or the degree of ionization is close to one. Likewise for NaOH it is also very easy to ionize and has a degree of ionization 1. In addition to the NaCl salt solution and NaOH solution there is a strong electrostatic force and the presence of intermolecular ionic strength which causes the compound to be easily electrolyzed. For K₄Fe(CN)₆ salt solution which is a complex salt and benzoic acid solution which is a weak acid, the electrolysis factor can be considered equal to one. So the Clausius-Clapeyron equation is very suitable for weak electrolyte solutions or solutions that are difficult to electrolyte

Table 1. Equation of electrolysis factor (j) at different types

Solid	Equation	Error (%)
NaOH	$j = 1 - 0,464 \cdot C$	3
	$j = 0,962 \cdot C^{-0,07}$	0,102
	$j = \exp(-0,47 \cdot C)$	0,03
	$j = 0,625^C$	0,03
	$j = \frac{0,0131}{C}$	6
NaCl	$j = 1 - 0,344 \cdot C$	1,36
	$j = 0,97 \cdot C^{-0,005}$	0,088
	$j = \exp(-0,347 \cdot C)$	0,0135
	$j = 0,707^C$	0,0136
	$j = \frac{0,0135}{C}$	5,843
K ₄ Fe(CN) ₆	$j = 1 - 0,225 \cdot C$	0,185
	$j = 0,983 \cdot C^{-0,003}$	0,064
	$j = 1,012 \cdot \exp(-0,226 \cdot C)$	0,015
	$j = 1,012 \cdot 0,8^C$	0,016
	$j = 0,99 + \frac{0,0001335}{C}$	0,5735
C ₆ H ₅ COOH	$j = 1 - 0,137 \cdot C$	0,022
	$j = C^{-0,005}$	0,0156
	$j = \exp(-0,264 \cdot C)$	0,0185
	$j = 0,77^C$	0,0185
	$j = 0,99 + \frac{0,000131}{C}$	0,4774

When a substance dissolves in a solvent, the solute particles will spread throughout the solvent resulting in a solvent-solute interaction. As a result of this interaction, a dissolution process occurs which determines the energy and the intrinsic tendency towards disorder [9]. Therefore, in a solution when solute molecules and solvent molecules mix to form a solution, the disorder will increase. Because in a pure state, the solvent and solute have a fairly high degree of order that can be seen from the fairly regular arrangement of the atoms. The particles (atoms, ions, molecules) of a substance

depend on the forces of attraction and repulsion. Intermolecular forces are caused by the attraction or repulsion of the electric charges between molecules. The arrangement of molecules determines the physical properties of the liquid such as the boiling point [6]. then it can be said that the electrolyte solution that is most easily ionized has the lowest electrolysis factor Table 1 shows that for NaOH and NaCl solutions having an electrolysis factor equation j cannot be considered linear because the electrolysis factor equation j in the form of a linear equation has a fairly large error, while for a solution of K₄Fe(CN)₆ and a solution of benzoic acid it can be considered linear.

. For substances that are not easily electrolyzed, it tends to produce a value of j equal to one so that all equations for substances that are difficult to electrolyze meet the requirements to determine the value of the electrolysis factor j.

So from the calculation results it can be said that the Clasius-Clapeyron equation can be directly used for solutions of weak acids and weak salts, while when used for strong base solutions and strong salt solutions, the electrolysis factor j must be used

5. CONCLUSION

To determine the boiling temperature of a solution of a strong base and a strong salt, the Clasius-Clapeyron equation can be used but added by using the electrolysis factor equation j. For solutions of weak acids and weak salts, the Clasius-Clapeyron equation can be used and there is no need to use the electrolysis factor equation j because the value of j tends to be equal to one.

The equation for the electrolysis factor j which has a small error for NaOH is

$$j = \exp(-0.47 \cdot C) \text{ and } j = 0.625^C$$

for C is the mole fraction of the solute

The equation for the electrolysis factor j which has a small error for NaCl is

$$j = \exp(-0.347 \cdot C) \text{ and } j = 0.707^C$$

for C is the mole fraction of the solute

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ATTACHMENT

A. Determine the value of the a constant

Latent heat of vaporization of water $\Delta H = 2258$ J/g
 Normal boiling point of water $T = 100^{\circ}\text{C} = 373.3^{\circ}\text{K}$

Critical temperature of water $T_c = 647.10\text{K}$

From equation 2

$$\Delta H = a \cdot \left(1 - \frac{T}{T_c}\right)$$

$$2258 \text{ J/g} = a \cdot \left(1 - \frac{373.3 \text{ K}}{647.1 \text{ K}}\right)$$

$$a = 3913,35 \text{ J/g} = 70440 \text{ J/mol}$$

B. Calculating the value of the electrolysis factor

For a NaOH solution with a fraction of 0.0045 the boiling temperature is $101.1^{\circ}\text{C} = 374.4^{\circ}\text{K}$

From equation (6)

$$\frac{1}{T} + \frac{\ln T}{T_c} = \left(\frac{1}{T_o} + \frac{\ln T_o}{T_c} - \frac{R}{a} \ln(1 - X) \right) j$$

$$\frac{1}{374,4} + \frac{\ln 374,4}{647,1} = \left(\frac{1}{373,3} + \frac{\ln 373,3}{647,1} - \frac{8,314}{70440} \ln(1 - 0,0045) \right) j$$

$$j = 0,997$$

C. Create an equation with least squares

For Equation $j = n + m.C$ (7)

This equation is already a linear equation so that the constants m and n can be directly searched.

Let $j = Y$ and $C = X$ so that equation (7) can be changed to

$$Y = n + m.X$$
 (12)

Equation (12) is multiplied by X so that it becomes

$$X.Y = n.X + m.X^2$$
 (13)

Equation (12) can be changed to

$$\Sigma Y = k.n + m.\Sigma X$$
 (14)

k is the amount of data
 Equation (13) can be changed to

$$\Sigma (X.Y) = n.\Sigma X + m.\Sigma X^2$$
 (15)

For NaOH

$$\Sigma Y = j_1 + j_2 + j_3 + j_4 + j_5 + j_6 + j_7 + j_8 = 7,92$$

$$\Sigma X = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8$$

$$= 0,16$$

$$\Sigma XY = C_1.j_1 + C_2.j_2 + C_3.j_3 + C_4.j_4 + C_5.j_5 + C_6.j_6$$

$$+ C_7.j_7 + C_8.j_8 = 0,1578$$

$$\Sigma X^2 = C_1^2 + C_2^2 + C_3^2 + C_4^2 + C_5^2 + C_6^2 + C_7^2 + C_8^2 = 0,004$$

From equation (14) :

$$\Sigma Y = k.n + m.\Sigma X$$

$$7.92 = 8 . n + m . 0,16 \dots\dots\dots (16)$$

From equation (16) :

$$\Sigma (X.Y) = n.\Sigma Y + m.\Sigma X^2$$

$$0,1578 = n . 0,16 + m . 0,004 \dots\dots\dots (17)$$

The solution between equation (16) and equation (17) yields the value of

$$m = -0,464$$

$$n = 1$$

So that equation (7) becomes

$$j = n - m . C$$

$$j = 1 - 0,464 . C$$

For Equation $j = n . C^m \dots\dots\dots (8)$

Equation (8) is not a linear equation so it must first be converted into a linear equation .

Equation (8) is converted into the following equation:

$$\begin{aligned} \text{Ln } j &= \text{Ln } (n . C^m) \\ &= \text{Ln } n + \text{Ln } C^m \\ &= \text{Ln } n + m.\text{Ln } C \dots\dots\dots \end{aligned}$$

(18)

Example $\text{Ln } j = Y$, $\text{Ln } n = b$ and $\text{Ln } C = X$ so that equation (18) can be changed to

$$Y = b + m.X \dots\dots\dots (19)$$

Equation (19) is already a linear equation so it can be solved by least squares.

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