INTRODUCTION

Over the past few decades, studies in the field of secondary batteries has attracted huge attention from scientists all around the world [1]. Intensive researches have been carried out to obtain an optimum green energy resource derived from natural resources. Natural base polymer electrolyte systems are always the main subject of discussion in secondary battery systems over synthetic polymer electrolyte systems [2]. This is mainly because they are environmentally friendly and thus, they give minimum impact to the environment. In addition, natural polymers are biodegradable, hence, they do not contribute to an increase in the environmental waste. The employment of natural polymers can be a solution to solve global warming, pollution, shortage of petroleum and price fluctuation issues [3].

Polymer electrolyte is macromolecules with ability to transport charged species such as ions or protons [4] and it is prepared by doping a polymer host with inorganic salt [3]. Traditionally, acting as host, polymer electrolyte is used in the formation of synthetic polymers such as polyethylene oxide (PEO) [3], polyacrylic acid (PAA) [5] and polyvinyl alcohol (PVA) [6]. However, it has several disadvantages due to the fact that they are synthetic, high-priced, possesses mixability issue and difficult to degrade [7]. Therefore, polysaccharide has been extensively explored to reduce the manufacturing cost and pollution [2]. Regarding the effectiveness of polysaccharides like cellulose, agar, and chitosan as polymer electrolyte, a vast number of research papers are published [3]. Other than its similarity in structure and properties, therefore, in this study the kappa carrageenan (κcar) is used to examine the ionic conductivity (κ) behaviour.

κappa-Carrageenan (κcar) is a linear hydrophilic polysaccharide polymer formed by alternate units of D-galactose and 3,6-anhydrogalactose bonded by α-1,3 and β-1,4-glycosidic linkage [8]. The κcar is extracted from several seaweeds from Eucheuma cottonii which is commonly found in Indonesia, Malaysia and Philippines [9]. Aside from being used as thickening, gelling and stabilizing agents in food products, κcar is also used in drugs, pharmaceuticals and cosmetics [9]. There are three main types of carrageenan that have been reported in...
literature which are kappa (κ), iota (ι) and lambda (Λ) [10]. These three types of carrageenan differ in the number and position of half-ester sulphate group. The half-ester sulphate group in carrageenan is strongly anionic since it is negatively charged. The conformation of carrageenan in the polymer chain as well as the associated cation will determine the physical properties. For instance, κ and ι carrageenan bearing ester sulphate content of 25-30 % and 28-30 % respectively are in the form of gel in presence of potassium and calcium ions, however, Λ-carrageenan which contains 32-39 % ester sulphate content does not form a stable gel [11] since the number of ester sulphate is inversely proportional to the gel strength and solubility temperature [12]. The formation of film of carrageenan is possible via self-aggregation due to the significant number of sulfonic groups in its helical structures. The film produced possesses good tensile strength, gelling ability and transparency. It is also reported that among the three types of carrageenan, κ-carrageenan is non-toxic [13], thus, based on these reasons, kappa-Carrageenan (κ-carr) was chosen in this research over other types of carrageenan.

In polymer electrolyte systems made up of κ-carr as polymer host, the ions are able to move through its hydrogen-bonded network and the hydroxyl groups present in the polymer structure enables the formation of coordinate bonds with cations or protons, which might enhance ion mobility in the electrolyte system. However, naturally, κ-carr has low κ (10⁻⁷ S cm⁻¹) [14], therefore, an alteration has to be done to enhance its κ. This can be accomplished by controlling the crystallinity of κ-carr in solid polymer electrolyte (SPE) system since κ is greatly influenced by the degree of crystallinity of polymer [15]. It was reported that the κ increases with the decrease in crystallinity due to the expansion of free volume for ion transport [16]. According to Rhodes [15], ion movement mostly takes place in the amorphous phase while the crystalline phase, which has ordered arrangement and limited free volume hinder ion transport.

Polyethylene oxide (PEO) is commonly chosen as a polymer substrate due to its stable mechanical properties. It can form sturdy and flexible films, in turn hinder electrolyte leakage and secure excellent electrode contact [17]. Hence, PEO is used in this research to increase the stability of polymer electrolyte, furthermore, PEO is soluble with various solvents. This feature is crucial in making polymer blends in order to obtain a well-mixed and stable polymer blend. Although it is widely acknowledged that NaClO₄ will act as a strong electrolyte in aqueous solution, the addition of polymer prompts inquiry into whether the α will decrease or remain unchanged. The salt dissociation (α) in the presence of polymer will elucidate the total free moving ions in the electrolyte, thereby influencing ionic conductivity (κ). The α might decrease due to ion pairing since the presence of polymer reduce the hydrodynamic volume.

In this work, the conductivity behaviour of κ-carr/PEO/NaClO₄ polymer blend in liquid polymer electrolyte (LPE) system was examined and the findings can be an advantage for SPE system. The data obtained in this research can help build the SPE system with destabilize crystallinity and better ions move-ment for enhanced conductivity [18,19]. The κ-carr and PEO polymer blend investigated in this work is in liquid phase. The solvent used in this polymer blend is water since both polymers are soluble in water and homogeneous [20,21]. Until now, there are few studies on the conductivity behaviour of κ-carr in solution. Consequently, the information that is obtained from this study might be used as an added value and will contribute to knowledge advancement for a better understanding of ionic conductivity behaviour, especially in the amorphous phase.

The data on the ionic conductivity (κ) of LPE system in dilute condition can provide insight on the interaction between ions and polymers in amorphous regions of solid polymer electrolyte system [22]. However, the effect of polymer concentration (Cpoly) on κ and α in polymer electrolyte membrane has been a secluded topic and unconfirmed theory. Therefore, the determination of κ and Λo for dilute LPE systems at various salt concentrations, Csalt could act as a method to understand the effect of Cpoly on salt dissociation (α) [23].

Surprisingly, none of the researchers report on the molar conductivity behaviour (Λ) values. Moreover, no prior research was reported in determining the κ and Λo of κ-carr and PEO blend. Therefore, in this study, we aim to determine the κ and Λo for dilute LPE systems at various salt concentrations, Csalt with > 99% purity was purchased from Sigma-Aldrich Chemical Company, USA. Anhydrous sodium perchlorate, NaClO₄ (Mw = 122.5 g mol⁻¹) with purity > 99% was purchased from Merck, USA and dried in oven for 48 h at 100 °C and vacuum condition to remove any traces of water prior to being dissolved in solvent. The solvent used was deionized water, which was prepared by pumping the water into a water deionizing system (Sartorious, Germany) producing 18 x 10⁶ megohm at 25 °C.

Conductivity: The ionic conductivity (κ) of the systems was measured using the Mettler Toledo Seven Compact S230 AC conductivity meter (Schwerzenbach, Switzerland). The probe used was Inlab 741, which possessed 0.001-500 μS cm⁻¹ measurement range and 0-70 °C temperature range. The conductivity meter’s cell constant was established using an automated calibration process conducted on a daily basis. The aqueous solution of KCl provided by Mettler Toledo (Schwerzenbach, Switzerland) was used to calibrate the conductivity meter. The buffer solution was available in concentrations of 0.1, 0.01 and 0.005 mol L⁻¹, with associated κ values of 12.88 mS cm⁻¹, 1413 μS cm⁻¹ and 84 μS cm⁻¹, respectively. The calibration procedure was conducted while the conductivity meter was linked to an Inlab® 741 electrode. After successfully calibrating the conductivity meter, electrolytic conductivity measurements were conducted on sample solutions at 25 °C and 20 °C. Each measurement was conducted at a minimum of three times (triplicate analysis) and later the mean values of κ were reported, ensuring a coefficient of variation of less than 5%.

Sample preparation: The purification process was performed using precipitated method. In brief, 1.0 g of κ-carr powder was linked to an Inlab® 741 electrode. After successfully calibration procedure was conducted while the conductivity meter was linked to an Inlab® 741 electrode. After successfully calibrating the conductivity meter, electrolytic conductivity measurements were conducted on sample solutions at 25 °C and 20 °C. Each measurement was conducted at a minimum of three times (triplicate analysis) and later the mean values of κ were reported, ensuring a coefficient of variation of less than 5%.

Sample preparation: The purification process was performed using precipitated method. In brief, 1.0 g of κ-carr powder was linked to an Inlab® 741 electrode. After successfully calibration procedure was conducted while the conductivity meter was linked to an Inlab® 741 electrode. After successfully calibrating the conductivity meter, electrolytic conductivity measurements were conducted on sample solutions at 25 °C and 20 °C. Each measurement was conducted at a minimum of three times (triplicate analysis) and later the mean values of κ were reported, ensuring a coefficient of variation of less than 5%.
was dissolved in 99 g of distilled water. The mixture was allowed to swell and stirred for 48 h at 50°C under fume hood to form a homogeneous solution and later the solution was filtered. Rotary evaporator was used to extract the solvent and leave 1/3 residue of $\kappa_{w}$ mixed solvent for the next process. The residue then underwent re-precipitation with n-hexane by the ratio of residue 1.5 n-hexane. The precipitate was then dried in oven under 50°C for 24 h. Similarly, purification of PEO followed the same procedure.

**Preparation of NaClO$_4$ solution:** An amount of sodium perchlorate salts was dissolved in 100 mL of deionized water and stirred at 50°C for 24 h. The stock solution was then diluted into a series of concentrations as tabulated in Table-1.

<table>
<thead>
<tr>
<th>Initial C$_{salt}$, M$_s$ (mol cm$^{-3}$)</th>
<th>Initial volume, $V_1$ (cm$^3$)</th>
<th>Final C$_{salt}$, M$_s$ (mol cm$^{-3}$)</th>
<th>Final volume, $V_2$ (cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.56 × 10$^{-7}$</td>
<td>10</td>
<td>3.12 × 10$^{-7}$</td>
<td>50</td>
</tr>
<tr>
<td>5.95 × 10$^{-8}$</td>
<td>10</td>
<td>1.19 × 10$^{-8}$</td>
<td>50</td>
</tr>
<tr>
<td>1.64 × 10$^{-8}$</td>
<td>10</td>
<td>3.28 × 10$^{-9}$</td>
<td>50</td>
</tr>
<tr>
<td>8.20 × 10$^{-9}$</td>
<td>10</td>
<td>1.64 × 10$^{-9}$</td>
<td>50</td>
</tr>
<tr>
<td>4.10 × 10$^{-10}$</td>
<td>10</td>
<td>8.20 × 10$^{-10}$</td>
<td>50</td>
</tr>
<tr>
<td>2.66 × 10$^{-10}$</td>
<td>10</td>
<td>5.32 × 10$^{-10}$</td>
<td>50</td>
</tr>
<tr>
<td>3.34 × 10$^{-11}$</td>
<td>10</td>
<td>6.67 × 10$^{-11}$</td>
<td>50</td>
</tr>
<tr>
<td>5.70 × 10$^{-11}$</td>
<td>10</td>
<td>1.14 × 10$^{-11}$</td>
<td>50</td>
</tr>
</tbody>
</table>

Preparation of polymer blend ($\kappa_{w}$/PEO/NaClO$_4$) in deionized water: The polymer blend was prepared with wt % of 50:50 ratios according to Table-2. The mixture was dissolved in 500 mL deionized water and stirred at 50°C for 48 h. These stock solutions were used to dissolve a known amount of NaClO$_4$ and stirred at 50°C for 24 h before being diluted into a series of concentrations. It was observed that phase separation in polymer blend will cause a significant problem that restricts the performance [24]. Hence, the 50:50 ratio polymer blend formed was carefully observed and mixed until a transparent solution with no phase separation was obtained. The solution appears homogeneous and the addition of salt does not cause any polymer salt-aggregation.

<table>
<thead>
<tr>
<th>C$_{poly}$ ($×10^3$) (g cm$^{-3}$)</th>
<th>Mass of $\kappa_{w}$ (g)</th>
<th>Mass of PEO (g)</th>
<th>Volume of deionized water (cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.250</td>
<td>0.250</td>
<td>500</td>
</tr>
<tr>
<td>1.5</td>
<td>0.375</td>
<td>0.375</td>
<td>500</td>
</tr>
<tr>
<td>2.0</td>
<td>0.500</td>
<td>0.500</td>
<td>500</td>
</tr>
<tr>
<td>2.5</td>
<td>0.625</td>
<td>0.625</td>
<td>500</td>
</tr>
<tr>
<td>3.0</td>
<td>0.750</td>
<td>0.750</td>
<td>500</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

**Determination of $\Lambda_s$ of NaClO$_4$ in deionized water after power law at 20°C and 25°C:** As a result of strong thermodynamic hydration interaction between salt and water, NaClO$_4$ undergoes full dissociation, yielding a high concentration of free moving ions, particularly at dilute condition where the $C_{salt}$ is less than 1.0 × 10$^{-4}$ mol cm$^{-3}$ as shown in eqn. 1 [25]:

NaClO$_4$ (aq.) → Na$^+$ (aq.) + ClO$_4^-$ (aq.) (1)

However, as the concentration increases above 1.0 × 10$^{-4}$ mol cm$^{-3}$ the possibility of ion pairing may happen. At higher concentration, the total free moving ions in the electrolyte decreases, which will cause a significant change in the ionic conductivity ($\kappa$).

The $\kappa$ of the salt solution at various concentrations has been measured and the $\Lambda_s$ at infinite dilution was determined after Kohlrausch’s equation (eqn. 2).

$$\Lambda = \Lambda_o - KC_{salt}^{1/2}$$ (2)

The relationship between temperature and $\Lambda_s$ is typically described by Kohlrausch’s law of independent migration of ions. According to this law, the increase in kinetic energy of ions leading to greater mobility and faster migration of ions in the solution. As temperature rises, the ions move more freely, resulting in higher $\kappa$ (Fig. 1) [26]. By comparing the $\Lambda_s$ value of NaClO$_4$ salt at 25°C obtained from experiment (119.9 S cm$^{-1}$mol$^{-1}$) to the theoretical value (117.42 S cm$^{-1}$mol$^{-1}$) [27], it suggests that the measurement of $\kappa$ was carried out in this research is reliable and accurate. The difference between the experimental to the theoretical value obtained is only 2.11%.

Kohlrausch’s equation is widely used and accepted in determining the $\Lambda_s$ for strong electrolyte, however, when approaching infinite dilution where the $C_{salt}$ is zero, the Kohlrausch’s equation is flawed since the extrapolation is deceptive. $\Lambda_s$ is a $\kappa$ value at $C_{salt} = 0$ mol cm$^{-3}$. The higher the dilution, the $\kappa$ data measured will give more precise $\Lambda_s$ value. However, the instrument such as conductivity meter has measurement limitation. Therefore, an alternative approach as suggested by Hanibah [25] named as Power law will be applied in order to obtain the $\Lambda_s$.

Power law is a double logarithmic plot of $\kappa$ against $C_{salt}$.

$$\log \kappa = K' + \gamma \log C_{salt}$$ (3)

Eliminating log from eqn. 3 will yield eqn. 4:

$$\kappa = K' C_{salt}^{\gamma}$$ (4)

Since,

$$\Lambda = \frac{\kappa}{C_{salt}}$$ (5)
Hence, dividing eqn. 4 with \( C_{\text{salt}} \) yield eqn. 6:

\[
\Lambda = K'(C_{\text{salt}})^{-1}
\]  
(6)

\( K' \) denotes as the average ion mobility and it is a constant value over a range of \( C_{\text{salt}} \). Hence, \( \Lambda \) of a system can be calculated at a selected \( C_{\text{salt}} \) known as reference salt concentration \( C_{\text{ref}} \):

\[
\Lambda_o = K'\gamma C_{\text{ref}}^{-1}
\]  
(7)

By substituting \( \Lambda_o \), \( K' \) and \( \gamma \) into eqn. 7, we can obtain \( C_{\text{ref}} \) value. It is obtained that the \( C_{\text{ref}} \) value for NaClO4 at 25 ºC is approximately two times lower than the lowest \( C_{\text{salt}} \) value that follows linearity in Power law graph as suggested by Hanibah [25]. Therefore, a backwards calculation is done to determine the \( \Lambda_o \) of a system. The lowest \( C_{\text{salt}} \) value will be obtained from Power law graph, then, will be further convert into \( C_{\text{ref}} \) respectively and substituted into eqn. 7 to obtain the \( \Lambda_o \). From Power law plot (Fig. 2) for NaClO4 (aq.) for 25 ºC,

\[
\log \kappa = 1.3484 + 0.8536 \quad (C_{\text{salt}}) \quad r^2 = 0.9982
\]  
(8)

\[
\kappa = 22.30 \quad C_{\text{salt}}^{-0.8536}
\]  
(9)

Rearranging according to eqn. 6 gives,

\[
\Lambda = 22.30 \quad C_{\text{salt}}^{-0.1464}
\]  
(10)

From eqn. 9, \( K' = 22.30 \) and \( \gamma = 0.8536 \).

Substituting \( K' \), \( \gamma \) and \( C_{\text{ref}} \) of NaClO4 (aq.) at 25 ºC from literature which is 117.42 S cm2 mol-1 into eqn. 7 gives the value of \( C_{\text{ref}} \):

\[
117.42 = (22.30) \quad (0.8536) \quad (C_{\text{ref}})^{-0.1464}
\]  
(11)

From the above calculation, \( C_{\text{ref}} \) obtained is estimated at 4.00 \times 10^{-6} \text{ mol cm}^{-3}. Since \( C_{\text{ref}} \) is approximately half the lowest \( C_{\text{salt}} \) value that follows linearity in Power law, the lowest \( C_{\text{salt}} \) that follows linearity should be approximately 8.00 \times 10^{-6} \text{ mol cm}^{-3}. By referring to Fig. 2, it gives the lowest \( C_{\text{salt}} \) that follows linearity a value of 7.0 \times 10^{-6} \text{ mol cm}^{-3}. This value is within the acceptable range when compared to the calculated value. Therefore, it is suggested that Power law method is reliable and accurate to determine the \( \Lambda_o \) for this electrolyte system.

Now, by adopting the same method, \( C_{\text{ref}} \) value as estimated is recalculated for NaClO4 (aq.) at 20 ºC according to eqn. 7. From Fig. 2, \( C_{\text{ref}} \) is 7.0 \times 10^{-6} \text{ mol cm}^{-3}, \( K' = 21.2667 \) and \( \gamma = 0.8600 \) and

\[
\log \kappa = 1.3277 + 0.8600 \quad (C_{\text{salt}}) \quad r^2 = 0.9988
\]  
(12)

\[
\kappa = 21.2677 \quad C_{\text{salt}}^{-0.8600}
\]  
(13)

Rearranging according to eqn. 6 gives,

\[
\Lambda = 21.2677 \quad C_{\text{salt}}^{-0.1400}
\]  
(14)

Substituting \( K' \), \( \gamma \) and \( C_{\text{ref}} \) into eqn. 7 gives the value of \( \Lambda_o \) for NaClO4 (aq.) at 20 ºC:

\[
\Lambda_o = (21.2677)(0.8600)(3.50 \times 10^{-6})^{-0.14}
\]  
(15)

\[
\Lambda_o = 106.18 \text{ S cm}^{-2} \text{ mol}^{-1}
\]

The \( \Lambda_o \) for NaClO4 (aq.) at 20 ºC was estimated using Power law and comparable to the value obtained using Kohlrausch’s law (with 0.02 S cm2 mol-1 difference), therefore, this shows the workability of Power law. The \( \kappa \) data from this experiment for strong electrolyte system fit well into Power law.

**Determination of \( \Lambda_o \) of polymer blend of NaClO4/PEO/NaClO4 in deionized water after Power law at 25 ºC and 20 ºC:** The blending of polymer was widely explored since the blending method can produce better flexibility and performance [24]. The 50:50 ratio is chosen since equal ratio of properties is desired in this liquid polymer electrolyte (LPE). Power law has also been applied to determine the \( \Lambda_o \) of the polymer blends at different \( C_{\text{poly}} \). The regression function for the polymer blends at 20 ºC and 25 ºC are tabulated in Table-3.

**Effect of salt concentration:** It is observed from Fig. 2 that the \( \kappa \) increases linearly as the \( C_{\text{salt}} \) increases. Hence, according to Arrhenius law of free ions, it completely dissociates in water and produce individual ions due to strong thermodynamic interaction between water and NaClO4. Nonetheless, it is also observed that the number of ions is not always proportional to the \( C_{\text{salt}} \) [28]. As the \( C_{\text{salt}} \) increases, the number of ions available per unit volume increases and consequently, more ions can move around in the electrolyte [29]. The charge transport of Na⁺ ions is enhanced, resulting in the separation of Na⁺ ions from their coordinating oxygen ions to a neighbouring site [30].

<table>
<thead>
<tr>
<th>( C_{\text{poly}} ) ( (\text{g cm}^{-2}))</th>
<th>SUMMARY OF THE ( \Lambda_o ) for ( \kappa_o/\text{PEO/NaClO4 POLYMER BLEND AT DIFFERENT } C_{\text{poly}} \text{ AT TEMPERATURE 25 AND 20 ºC} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Linear regression function} )</td>
<td>( \text{Correlation (r²)} )</td>
</tr>
<tr>
<td>( 25 )</td>
<td>( 20 )</td>
</tr>
<tr>
<td>1.0</td>
<td>( \Lambda = 12.14 \quad (C_{\text{salt}})^{-0.2182} )</td>
</tr>
<tr>
<td>1.5</td>
<td>( \Lambda = 11.30 \quad (C_{\text{salt}})^{-0.2262} )</td>
</tr>
<tr>
<td>2.0</td>
<td>( \Lambda = 8.06 \quad (C_{\text{salt}})^{-0.2698} )</td>
</tr>
<tr>
<td>2.5</td>
<td>( \Lambda = 7.42 \quad (C_{\text{salt}})^{-0.2690} )</td>
</tr>
<tr>
<td>3.0</td>
<td>( \Lambda = 5.64 \quad (C_{\text{salt}})^{-0.2902} )</td>
</tr>
</tbody>
</table>
Upon dilution, the \( \kappa \) deviates from linearity at certain dilute concentration. It is believed that the irregularities in \( \kappa \) obtained in this region is due to the limitation of conductivity meter. The fluctuation in \( \kappa \) observed is beyond the sensitivity capability of the probe. However, it is believed that this region will not affect our calculations and interpretations of the graph [25].

**Effect of polymer concentration:** Based on Table-3, the \( \Lambda_0 \) increases as the \( C_{\text{poly}} \) increases for both temperatures. According to eqn. 16, \( \Lambda_0 \) is inversely proportional to \( \alpha \) [31].

\[
\alpha = \frac{\Lambda}{\Lambda_0} \tag{16}
\]

Thus, as \( C_{\text{poly}} \) increases, the \( \kappa \) decreases, which is agreed by Szcz\'e\'{n}a-Chrzan et al. [32] as observed in their findings. This might be caused by the increases in viscosity of the solution as \( C_{\text{poly}} \) increases as agreed by Walden’s rule (eqn. 17).

\[
K = \Lambda \eta \tag{17}
\]

where \( K \) is a constant specific to temperature, \( \Lambda \) is molar conductivity and \( \eta \) is the viscosity.

Viscosity is the resistance of a fluid to flow. Hence, the increase in viscosity upon the increase in \( C_{\text{poly}} \) will decrease the \( \kappa \) since it restricts the movement of ions in response to the applied electric field [28]. It suggests that high viscosity controlled ion movement occurs in the electrolyte system [32]. Furthermore, the increase in viscosity reduces the volume of free space in the solution. Hence, the ions are pushed together and results in the formation of ion-pairs [25].

**Effect of temperature:** Based on Fig. 2, the \( \kappa \) increases as the temperature increases. The \( \kappa \) of a system at 25 \( ^\circ \text{C} \) is higher than 20 \( ^\circ \text{C} \). An increase in temperature weakens the dielectric constant of a solvent and lowering the viscosity of electrolyte [28]. A solvent especially those with low dielectric constant of solvent molecules to the applied electric field, predictively, \( \kappa \) will decrease due to the increase in ion association [28]. However, the increase in temperature also weakens ion pairing. This is due to the increase in thermal motions at high temperature, which makes the ions spread out over a larger area [34]. This implies the disruption of coordination between ions due to intense thermal motions. It seems that the increase in temperature breaks the ion pairing more efficiently than promoting ion pairing. Besides, as the temperature increases, the viscosity of electrolyte decreases [28]. Hence, the ions can move more freely and increase total ion transfer.

**Conclusion**

The utilization of Power law in this study was validated, demonstrating its effectiveness in determining the \( \Lambda_0 \) of the LPE systems. The double logarithmic plot of \( \kappa \) against \( C_{\text{salt}} \) gives a linear graph with high linear correlation, \( r^2 \) value and the calculation performed results in data with high precision when compared to the theoretical value. The \( \kappa \) and \( \Lambda_0 \) were measured for \( \kappa_{\text{car}}/\text{PEO}/\text{NaClO}_4 \) blend liquid electrolyte systems in aqueous solution at 25 \( ^\circ \text{C} \) and 20 \( ^\circ \text{C} \). The data shows linear correlation between \( C_{\text{salt}} \) and \( \kappa \), indicating an increase in total number of free ions as \( C_{\text{salt}} \) increases. Other than that, the decrease in \( \alpha \) is observed as \( C_{\text{poly}} \) increases while an increase in temperature disrupts ion pairing, consequently increase the ion movement. The experimental results demonstrate the feasibility of employment of \( \text{NaClO}_4 \) salt in polymer electrolyte systems, displaying in a significant increase in \( \kappa \) as \( C_{\text{salt}} \) increases. However, the usage of \( \kappa_{\text{car}}/\text{PEO} \) is not advisable as it inhibits ion transfer. Moreover, it is more prominent as \( C_{\text{poly}} \) increases because ion pairing increases due to an increase in average viscosity of solution. Despite the achievement of this research, the sensitivity limitation of conductivity meter may impose constrains in these findings. Hence, for future research, more refine instruments should be explored to expand the understanding regarding this topic. By addressing these challenges, we can continue to advance the field of renewable energy and contribute to the global transition toward a more sustainable and environmental friendly energy landscape.

**ACKNOWLEDGEMENTS**

The authors express their sincere gratitude to all those who have contributed to the completion of this work. Special thanks to our supervisors for their invaluable support, guidance and encouragement throughout the research process. Thanks are also due to University Teknologi MARA (UiTM) and Kolej Matrikulasi Selangor, Malaysia for providing the support and facilities.

**CONFLICT OF INTEREST**

The authors declare that there is no conflict of interests regarding the publication of this article.

**REFERENCES**

6. F.N. Jumaah, N.N. Mobarak, A. Ahmad, M.A. Ghani and M.Y.A. Rahman, *Ionics*, 21, 1311 (2014); https://doi.org/10.1007/s11581-014-1306-x


