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Research Article

Characteristics of all organic redox flow battery (AORFB) active species TEMPO-methyl viologen at different electrolyte solution

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Abstract. The practice of using wind and solar energy to generate electricity represents a solution that would be beneficial for the environment and ought to be explored. However, in order to ensure users' stability and continuous access to electricity, the increasing usage of renewable energy needs to align with the advancement of energy storage technologies. Redox flow batteries, which use an organic solution as the electrolyte and a proton exchange membrane as an ion exchange layer, are currently the subject of extensive research as one of the alternative renewable energy storage systems with the benefit of a techno economy. This study investigated the solubility of organic solution, namely 2,2,6,6-Tetramethylpiperidinyloxy or 2,2,6,6-Tetramethylpiperidine 1-oxyl (TEMPO) and methyl viologen (MV) in various essential electrolyte solutions such as NaCl, KCl, KOH, and H_2SO_4 that can be used as electrolytes of all organic redox flow battery (AORFB) system to produce high energy density and charging and discharging capacity. The result shows the optimum condition for effective charge transfer in AORFB is TEMPO catholyte and MV anolytes in the 0.08 M H_2SO_4 electrolyte solution. Additionally, a correlation between the acquisition of electrolyte solutions on TEMPO catalyst and MV anolytes was discovered by the data. Electrolyte solution can improve electrical conductivity in TEMPO solution, which in turn can improve the efficiency of AORFB charging and discharging. Contrarily, MV anolytes exhibit a different pattern where the addition of electrolyte solutions reduces their electrical conductivity. RFBs systems with the aforementioned catholyte and anolyte can be used to store solar energy with a maximum current of 0.6 A for 35 minutes. Storage effectiveness is characterized by a change in colour in the catholyte and anolyte. The findings firming the possibility of using AORFB as one of the alternative energy storage systems that can accommodate the intermittence of the renewable energy input resource.

Keywords: redox flow battery, anolyte, catholyte, methyl viologen, TEMPO

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1. Introduction

Energy supply stability and capacity are critical to the long-term development of society since they are both the foundation for human existence and the source of power for societal advancement. Enhancements to energy supply capacity and security face significant challenges because the current fossil fuel-based energy infrastructure cannot meet the demands of sustainable societal growth. Consequently, research into clean and effective renewable energy is required (Kim *et al.*, 2011; H. Zhang *et al.*, 2019).

Although renewable energy sources like solar and wind can produce electricity, natural factors like seasonal variations and day-night cycles greatly affect their availability (Chamundeswari *et al.*, 2021; Soloveichik, 2015; Strielkowski *et al.*, 2021; Zsiborács *et al.*, 2019). Frequently, the electricity produced is unpredictable, erratic, and sporadic (Díaz-González *et al.*, 2012; Kim *et al.*, 2011; H. Zhang *et al.*, 2019). Technology for energy storage is required to address this problem. According to (Dunn *et al.*, 2011; Leadbetter & Swan, 2012; Yuan *et al.*, 2018), it may stabilize power output, regulate power generation, and provide amplitude modulation and frequency regulation. These features enable electricity continuity, stability, and controllability.

The relationship between intermittent renewable power sources and energy demands is crucially dependent on energy storage (H. Chen *et al.*, 2018; Singer & Peterson, 2011; Zanzola *et al.*, 2017). To successfully use renewable energy sources and create a sustainable society, advanced large-scale energy storage technologies are essential. Flow batteries have been recognized as a promising technology for large-scale energy storage among other energy storage devices (Alotto *et al.*, 2012; S. Liu *et al.*, 2020; Pan *et al.*, 2023; Yuan *et al.*, 2018).

One or more electroactive species dissolved in a liquid electrolyte store energy in a rechargeable flow battery (Zhen & Li, 2019). In order to directly transform chemical energy into

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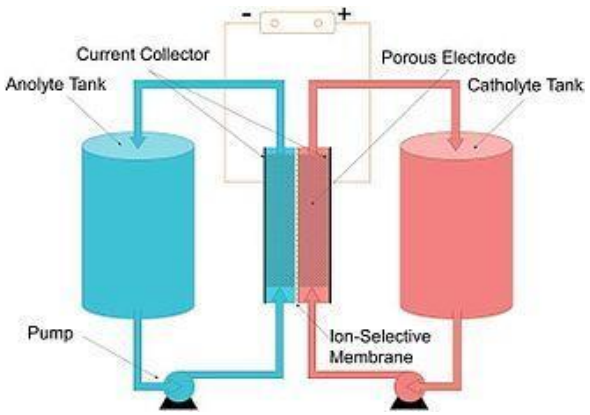

Fig 1. General scheme of arrangement of redox flow battery

electrical energy and vice versa, electrolytes are kept apart in a box outside of their electrochemical cells and pumped through electrochemical compartments (Asenjo-Pascual *et al*., 2022). While energy density or output is dependent on the size of the tank, power density is determined by the design and size of electrochemical cells (Y. Liu *et al*., 2021). These qualities enable flow batteries to be used for an extended period of time in a variety of static energy storage systems (Badwal *et al*., 2014; H. Chen *et al*., 2018; Joseph *et al*., 2022; Nguyen & Savinell, 2010).

According to various studies (Chai *et al*., 2020; Soloveichik, 2015), flow batteries are highly efficient (Likit-Anurak *et al*., 2017; Wu *et al*., 2014), and they are inexpensive. They can also be utilized extensively (Aren & Walsh, 2022; Lim *et al*., 2015). The system's scalability and adaptability allow the flow battery to effortlessly achieve the kW to MW range (Arabkoohsar, 2021). It promotes the development of flow batteries, which are presently concentrated on energy storage in networks in conjunction with renewable energy generation, or power systems in isolated, stand-alone locations (Arnbjerg *et al*., 2019; Park *et al*., 2019).

Two liquid electrolytes with dissolved metal ions are pumped in the direction of electrochemical cells in the redox flow battery (RFB). Catholyte and anolyte are the terms used to describe the electrolytes in negative and positive electrodes. During charging and discharging, metal ions stay dissolved in the electrolyte fluid and do not undergo any phase shifts. Membranes that permit positive ions to cross for electron transfer activity separate the anolyte and catholyte. Batteries-powered devices can exploit the current that runs over the electrodes during charge exchange. The dissolved active mass of the tank is constantly fed to the electrodes during discharging; the converted product is then returned to the tank (Arabkoohsar, 2021; Badwal *et al*., 2014; R. Chen *et al*., 2017; Zhen & Li, 2019). In Figure 1, the RFB flow system is displayed.

Initially, RFBs are not suitable for static rechargeable batteries due to its dissociated energy (the volume of the electrolyte reservoirs) and power (the electrode surface area). This is good for essential power-supplying operations, nevertheless. The distinct cell architecture is the cause of this characteristic. Second, due to its quick electrochemical kinetics and the high conductivities of the supporting electrolytes, RFBs can function at large currents (> 50 mA/cm^2) and high-power densities (in the order of 102 mW/cm^2). Third, the non-flammable aqueous electrolyte used in aqueous redox flow batteries (RFBs) makes them safe options for energy storage (B. Hu *et al*., 2018; Soloveichik, 2015; Wang *et al*., 2013; Z. Yang *et al*., 2011).

The performance of RFBs is defined by energy density and cycle stability (Yao *et al*., 2021; Zhou *et al*., 2023). Equation 1 below can calculate the number of charges stored and can be determined by calculating theoretical energy density.

$$Energy\ Density\ \left(\frac{Wh}{L}\right) = \frac{nCFV}{\mu_v} \qquad (1)$$

where n = number of electrons involved in the reaction; C = lower concentration of two electrolytes (mol/L), F = Faraday's constant, V = working voltage of the cell, and μ_v = 1 + (lower electrolyte concentration)/(higher electrolyte concentration).

The three primary properties of RFBs—solubility, cell voltage, and electron transfer—are clearly displayed in equation (1). Theoretical energy density is dependent on the concentration of redox-active species, the operating voltage of the cell, and the number of electrons involved in the reaction, according to Equation 1. High energy density is equivalent to good RFB performance because: (1) redox-active species should be very soluble; and (2) to guarantee high cell voltage, anolyte and catholyte redox potentials should be low and high, respectively (C. Zhang, Zhang, *et al*., 2018). Simultaneously, the primary factors influencing power density are membrane ionic conductivity as an electrolyte and separator, electrode surface area, redox-active species kinetics, and cell working voltage.

When assessing RFB performance, energy efficiency (EE) is essential (Yao *et al*., 2021). The ratio of average discharge and charging voltage at constant current, as well as the ratio of discharge and charging capacity (CE), determine EE. As an active pair of total reversible redox, high selectivity membranes can prevent cross-redox species, thereby protecting electrodes from corrosion. The durability of the RFB system is a representation of the stability of redox-active species, membrane separators, and electrodes (H. Chen *et al*., 2018; C. Zhang, Niu, *et al*., 2018).

First-generation RFBs, such as Zn-Br_2 and vanadium RFB, have developed into comparatively well-established technology. However, because to its high cost and restricted and caustic active components, its usage for large-scale energy storage is constrained by technological and economic limitations (B. Hu *et al*., 2017; Y. Liu *et al*., 2021). Recently, organic RFBs—a novel system—have been developed. Though it uses water-soluble organic molecules made of elements that are common on Earth, like carbon, hydrogen, oxygen, nitrogen, and sulphur, it functions on similar principles to vanadium RFB (Ding *et al*., 2018; Y. Liu *et al*., 2021; Pan *et al*., 2023; Wei *et al*., 2017; B. Yang *et al*., 2014; Zsiborács *et al*., 2019). It is economical and provides better safety. More crucially, organic molecules' great diversity and ease of structural tailoring may result in qualities like water solubility, redox potential, kinetics, and stability that are needed for real-world applications (Kwabi *et al*., 2020; Y. Liu *et al*., 2021; Winsberg *et al*., 2017). Thus, organic RFB is viable for large-scale electrical energy storage (Zhou *et al*., 2023).

High power can be produced by the kinetics of organic chemical reactions occurring rapidly. It is possible to regulate the solubility of functional groups of active substances by utilizing the high solubility of organic molecules. Organic substances like quinone (Ding *et al*., 2016; Han *et al*., 2019; Jones *et al*., 2022; Wedege *et al*., 2016). Because the reactions are fast and inexpensive, TEMPO and viologen are feasible (T. Liu *et al*., 2016a). Research on RFBs with organic compounds is exciting to develop because the combination of these chemical compounds has not been extensively examined. When 9,10 anthraquinone-2,7-sulfonic acid (AQDS)-bromide was used as the electrolyte in RFBs systems, power densities of up to 1 W/cm^{-2} were obtained; these values were almost identical to those of 1.34 W/cm^{-2} vanadium RFBs systems (R. Chen *et al*., 2017).

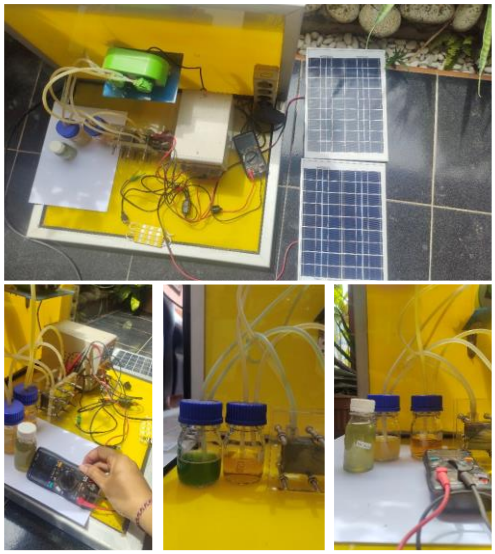

Fig 2. AORFBs systems for solar energy storage applications

2. Experimental method

2.1 Materials

TEMPO (2,2,6,6-Tetramethylpiperidinyloxy or 2,2,6,6-Tetramethylpiperidine 1-oxyl) used in this experiment were purchased from Shandong Zhi Shang Chemical Co., Ltd. Methyl Viologen (98%), NaCl (Sodium chloride, ≥99.0%), KCl (Potassium chloride, ≥99.0%), KOH (Potassium hydroxide, ≥85%), H_2SO_4 (Sulfuric acid, 99.9%) were purchased from Sigma Aldrich. All the chemicals were used without prior pre-treatment.

2.2 Measurement of Solubility

In order to test the solubility of TEMPO and Methyl Viologen (MV) in various electrolyte solutions, the electrolyte solutions—NaCl, KCl, KOH, and H_2SO_4—are first prepared at a concentration of 1 M. Next, TEMPO is dissolved in the electrolyte at a concentration of 0.02, 0.04, 0.06, 0.08, and 0.1 M. Based on the solution's absorption measurement on the UV-Vis Spectrophotometer, which reads 476 nm for TEMPO and 420 nm for Methyl Viologen, solubility is determined.

2.3 Implementation of the Active Species as AORFB for Solar Energy Storage System

After the solubility and conductivity test, the active species of MV and TEMPO in the electrolyte solution is implemented in AORFB for solar energy storage system. The AORFB system is assembled as Figure 2. The system consists of an AORFB cell, anolyte and catholyte solution feeder with peristaltic pump, in connection with solar panel system. The AORFBs cell consist of sandwiched of aluminium plate 100 x 80 mm in sequence with current collector, carbon felt, silicone foam frame, proton exchange membrane (Commercial Nafion), silicone foam frame, Carbon felt, another current collector, and aluminium plate as shown in Figure 3.

3. Result and Discussions

3.1 Solubility of TEMPO Solution on various electrolyte solutions

An earlier work to build a totally organic aqueous redox flow battery served as model for the assessment of a water-soluble TEMPO derivative as a catholyte candidates. When used as the positive electrolyte in non-aqueous RFB, TEMPO exhibits reversible one-electron storage as well as a high redox potential in the organic solvent (S. Hu *et al.*, 2021; Li *et al.*, 2011; T. Liu *et al.*, 2016a; Y. Liu *et al.*, 2019). The molecule can be utilized in an aqueous redox flow battery attributed to its hydrophilic functionalization (S. Hu *et al.*, 2021; T. Liu *et al.*, 2016a). Considering its strong positive redox potential, quick charge transfer kinetics, high water solubility (high storage capacity), and superior structural stability, TEMPO derivatives are particularly desirable as catholyte candidate materials for aqueous RFBs (Alotto *et al.*, 2012; Chai *et al.*, 2020; B. Hu *et al.*, 2017; Janoschka *et al.*, 2015).

This study examined the solubility of TEMPO catholyte solution in several electrolyte solutions, such as NaCl, KCl, KOH, and H_2SO_4. The solubility of TEMPO as active species in electrolytes is essential in determining the energy density produced in AORFB systems (Fischer *et al.*, 2022). A few can increase the solubility of active species in several ways. In most cases, the solubility of both inorganic and aqueous organic molecules is influenced by the choice of counter-ion (Fischer *et al.*, 2022). The results of TEMPO solubility in several different electrolyte solutions can be seen in Figure 4. TEMPO is perfectly dissolved in 1 M NaCl solution, up to 0.1 M, and in 1 M KOH solution and 1 M H_2SO_4. Meanwhile, TEMPO solubility in KCl electrolyte solution is a maximum of 0.08 M because it is seen that the addition of TEMPO can no longer increase the concentration of TEMPO itself. In comparison to other electrolyte solutions (NaCl, KCl, and KOH), the solubility of TEMPO solution in the H_2SO_4 electrolyte solution is high, suggesting that the effect of salting out is minimal. Adding TEMPO to the saturated solution even causes a decrease in TEMPO due to deposition. This phenomenon follows previous research that found that the solubility of TEMPO at 0.5 M of KCl solution ranges from 0.79 M (W. Zhou *et al.*, 2020). In general,

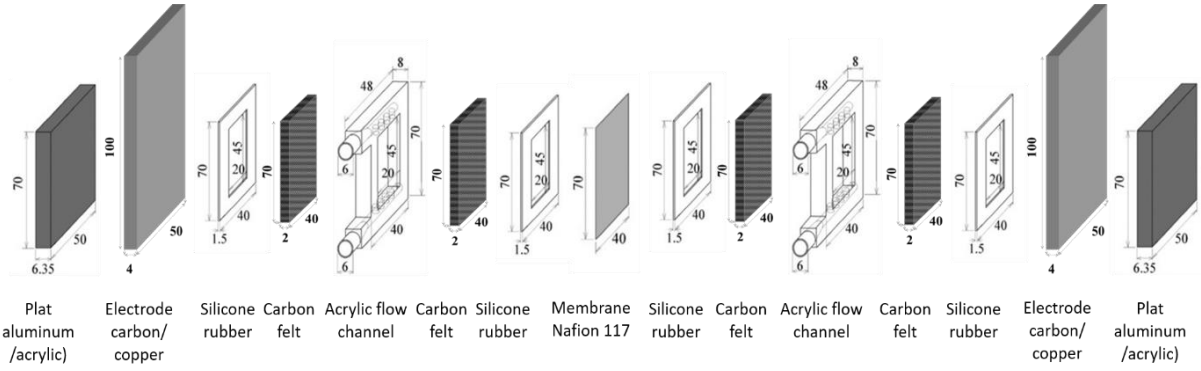

Fig 3. AORFB cells for all organic flow battery used in this experiment

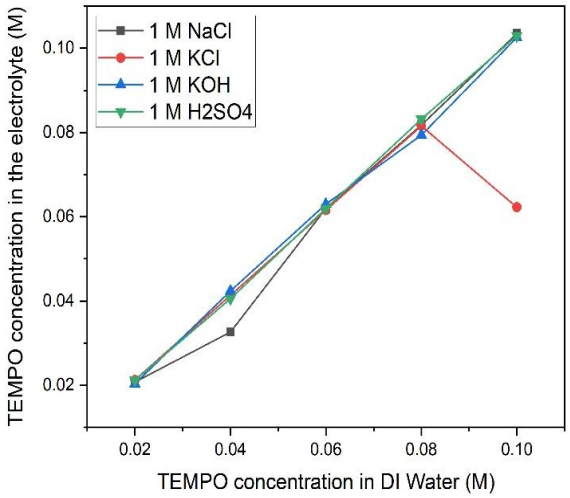

Fig 4. TEMPO Solubility in various electrolyte solution

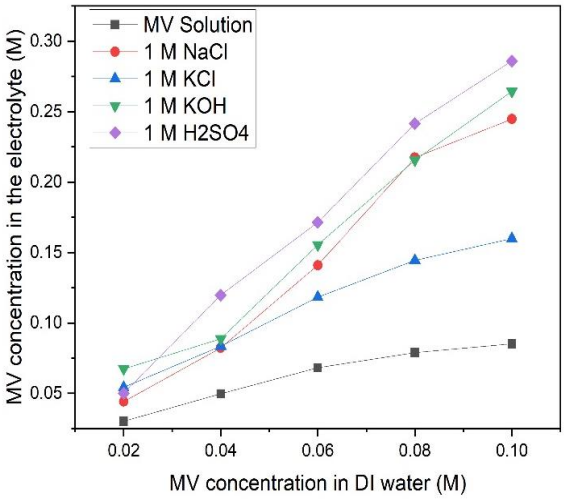

Fig 5. MV solubility in various electrolyte solutions (1M)

TEMPO solubility in NaCl, KCl, KOH, and H_2SO_4 electrolyte solutions rises with increasing TEMPO solution concentration. Supporting electrolytes and the functional groups of TEMPO as demonstrated by earlier research, TEMPO solution functions well as a catholyte in RFB. The chemical can be utilized in an aqueous redox flow battery (ARFB) because to its hydrophilic functionalization (S. Hu *et al*., 2021). For instance, 4-hydroxy-2,2,6,6-tetramethylpiperidin-1-oxyl (4-HO-TEMPO), a TEMPO molecule, has a high-water solubility of 2.1M, according to (T. Liu *et al*., 2016a). Then, as an example, they created RFB using 0.5M methyl viologen(-)/4-HO-TEMPO(+). It has been demonstrated that quaternization is a successful method for raising the redox potential and solubility. N,N,N-2,2,6,6-heptamethylpiperidinyl oxy-4-ammonium chloride (TEMPTMA) was synthesized by (Janoschka *et al*., 2016). It has a high redox potential of 0.99 V and produces a high energy density of 25.2 WhL-1 in RFB. In 2019, Yahua Liu and colleagues produced 4-[3-(tri-methylammonium) propoxy]-2,2,6,6-tetramethylpiperidine-1-oxyl chloride (TMAP-TEMPO), a more stable compound that demonstrated an energy density of 12.0WhL-1 and a potential of 0.81V in RFB. Furthermore, according to the same author, there is a risk to the stability of the battery during operation since the neutral TEMPO molecule might readily pass through the separator membrane from the positive to the negative side. According to (S. Hu *et al*., 2021) the battery stability can be enhanced by the quaternary ammonium cation by successfully preventing the molecule from crossing the anion exchange membrane (AEM) through the Donnan effect.

3.2 Solubility of Methyl Viologen Solution on various electrolyte solutions

A type of redox-active molecules known as viologen compounds, having two redox potentials, have been studied in previous years (DeBruler *et al*., 2017; Gu *et al*., 2014; B. Hu *et al*., 2018; Janoschka *et al*., 2016; S. Liu *et al*., 2020; Murugavel, 2014). With the steady redox reaction MV2+/MV·+, MV is the most promising redox species among the redox active compounds in aqueous RFB. The counter-anion has a major impact on its solubility and electrochemical characteristics. The solubility and reversible potential of viologen are impacted by substitutes (Chai *et al*., 2020; DeBruler *et al*., 2017; Jang *et al*., 2021).

The solubility of MV anolyte solutions in several electrolyte solutions, such as NaCl, KCl, KOH, and H_2SO_4, will be discussed here. As already stated, the solubility of MV in electrolytes is essential in determining the energy density produced in the RFB system (Kwabi *et al*., 2020). Because of their great water solubility, inexpensive cost, synthetic tunability, fast electrochemical kinetics, and superior chemical stability at pH neutrality, viologen molecules are very attractive anolyte materials. The most reliable cycling performance to far has been shown by viologen-based neutral AORFBs, which are considered to be the cutting edge of organic redox flow batteries (Chai *et al*., 2020; DeBruler *et al*., 2017; B. Hu *et al*., 2018).

The results of the study of MV solubility in several different electrolyte solutions can be seen in Figure 5. In general, the solubility of MV varies greatly and is influenced by its electrolyte solution. The solubility in H_2O is relatively very low. It indicates that MV, under normal conditions, has low solubility. However, after the addition of an electrolyte solution in the form of 1 M of NaCl solution, the solubility of the MV increased to 0.25 M. At 1 M of H_2SO_4, the solubility of MV almost 0.3 M. It suggests the corresponding viologen compounds' hydrophilicity is decreased by the larger organic substituents on N atoms (Jang *et al*., 2021; T. Liu *et al*., 2016a). The color, solubility, and electrochemical characteristics of viologen molecules are influenced by counter anions and substituents (Jang *et al*., 2021).

Similar trends reported in the previous research, by using nitrate as a counter anion to MV and forming new water-soluble methyl viologen dictation (MVdN), it can increase the solubility up to 3.5 M with good electrochemical reversibility (Jang *et al*., 2021). Meanwhile, other literature reported two reversible reductions that can be achieved using methyl viologen with bis(trifluoromethane)sulfonamide counter anion in a non-aqueous supporting electrolyte (B. Hu & Liu, 2018). Regarding solubility, there are two kinds of counter anion for viologen: hard bases in the Lewis sense (F^-, Cl^-, Br^-, or I^-) and comparatively big counter-anions (NO^{3-}, ClO^{4-}, BF^{4-}, or PF^{6-}). Depending on the solution conditions (aqueous or organic) and charge state (radical-cation or viologen-dictation), the anions' effects on the solubility of viologen differ (Bird & Kuhn, 1981; Monk, 1999).

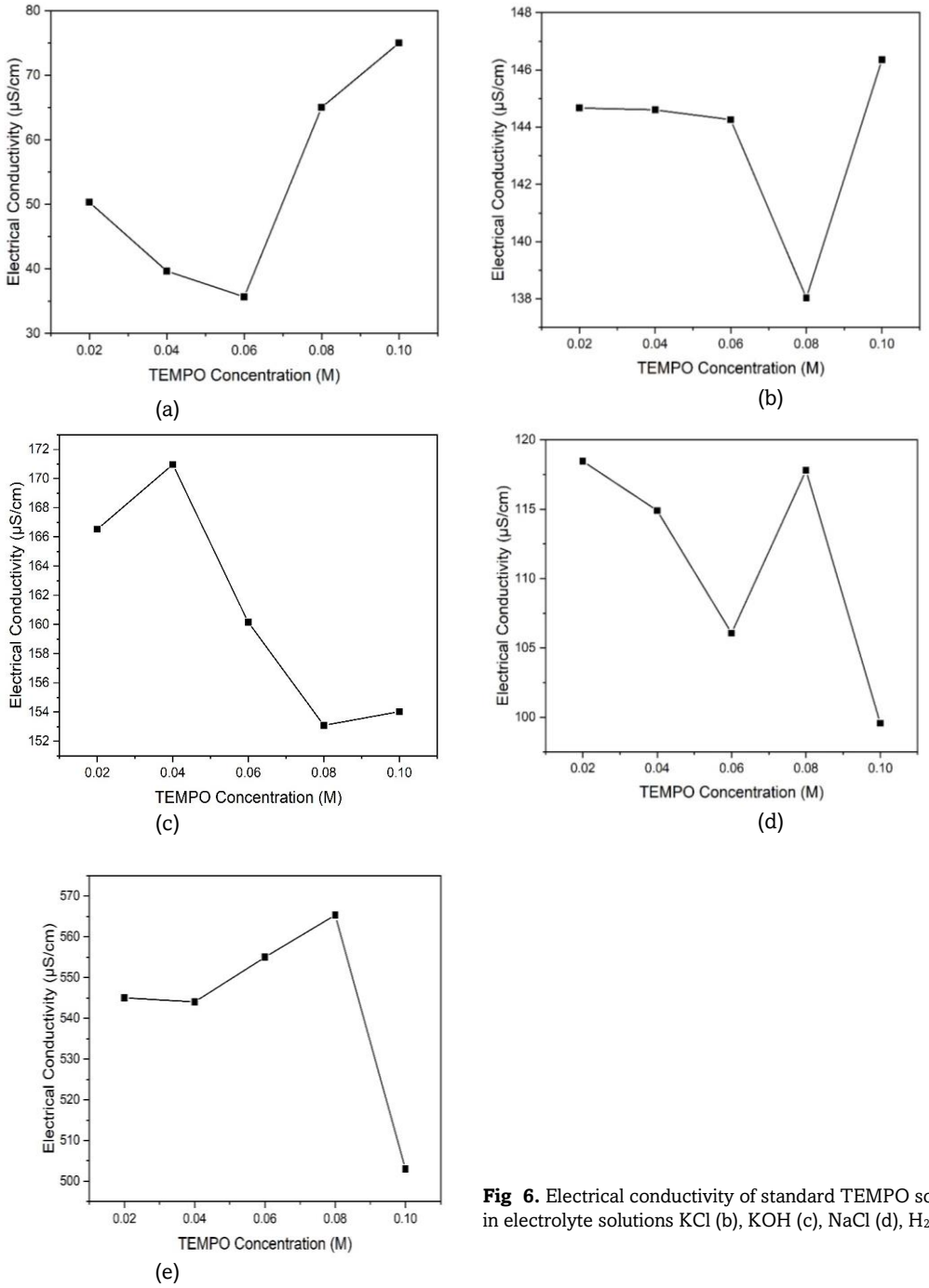

Fig 6. Electrical conductivity of standard TEMPO solutions (a), and in electrolyte solutions KCl (b), KOH (c), NaCl (d), H_2SO_4 (e)

3.3 Conductivity Measurement of TEMPO Solutions on various electrolyte solutions

Ohmic losses in the charge-discharge processes are directly related to the ionic conductivities of the supporting electrolytes, which are the capacity to transmit supporting ions for electrical conduction. For larger power outputs and significant cost savings in electrode regions and many cells/stacks, conductive electrolytes are necessary. Strong electrolytes are supportive electrolytes that have high levels of ionization. At higher concentrations, smaller free ion sizes are typically associated with enhanced conductivities (Gong *et al.*, 2014; Tang *et al.*, 2022).

This paper studies the electrical conductivity of TEMPO solutions in several electrolyte solutions. It can be seen in Figure 6. In general, electrical conductivity has a varied trend. As in TEMPO solutions without electrolyte, its electrical conductivity decreases to a concentration of 0.06 M and then increases to above 70 µS/cm. Another study stated that tempo solution in the form (4-glycidyl oxy-2,2,6,6-tetramethylpiperidine-1-oxyl) (GTEMPO) has electrical conductivity in the range of 10^{-3} µS/cm to 1 µS/cm (Bhat *et al.*, 2021). While the TEMPO used in this study was measured to have electrical conductivity at a TEMPO concentration of 0.02 M to 0.1 M is 50-75 µS/cm.

Meanwhile, TEMPO in KCl electrolyte solution has an electrical conductivity value of 138 to 144 µS/cm, TEMPO in KOH electrolyte solution has an electrical conductivity value of 153 to 166 µS/cm, TEMPO in NaCl electrolyte solution has an electrical conductivity value of 99 to 118 µS/cm, TEMPO in H_2SO_4 electrolyte solution has an electrical conductivity value

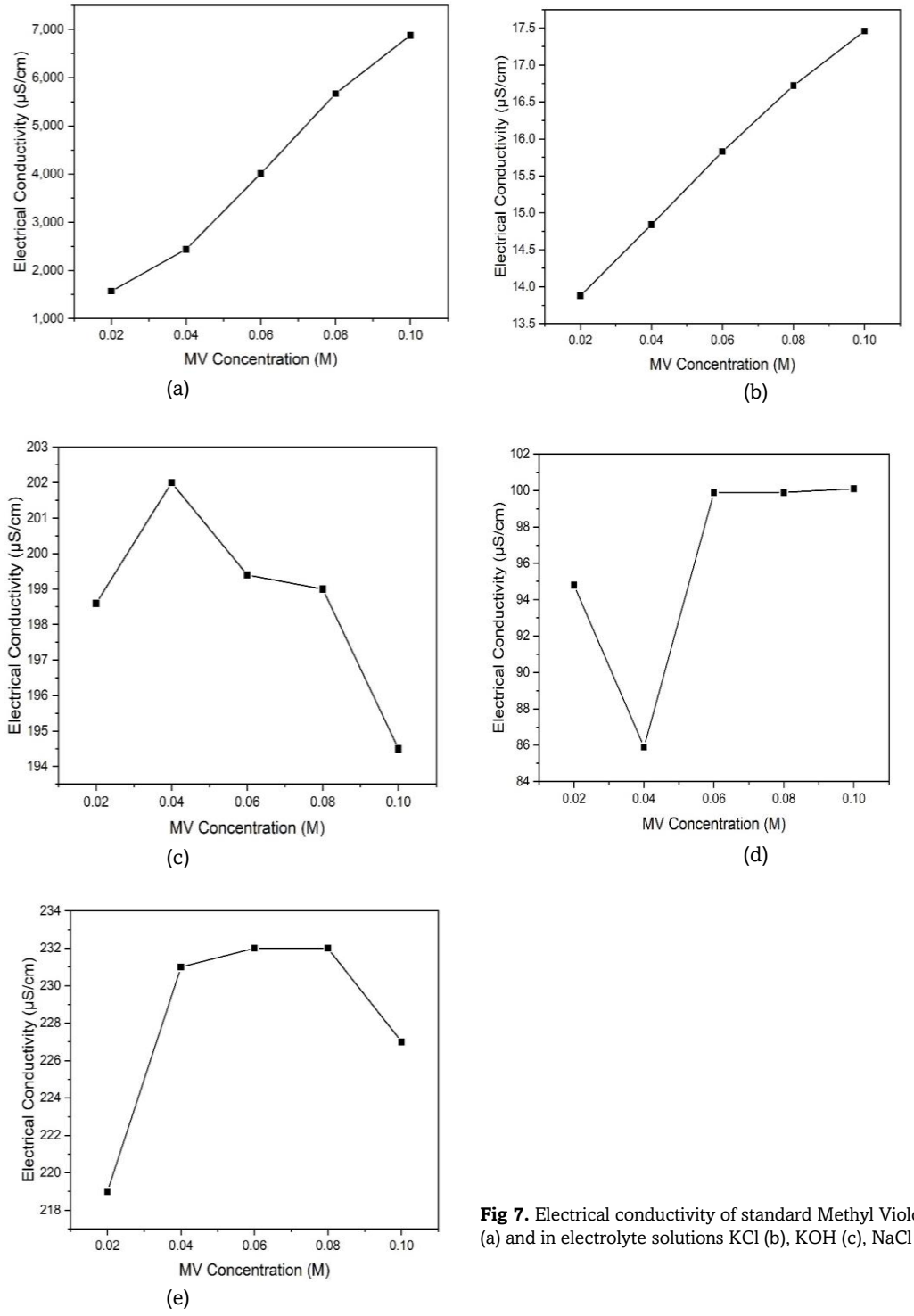

Fig 7. Electrical conductivity of standard Methyl Viologen solutions (a) and in electrolyte solutions KCl (b), KOH (c), NaCl (d), H_2SO_4 (e)

of 501 to 567 µS/cm. Electrical conductivity is influenced by how many ions are contained in the solution. Electrolyte solutions such as KCl, KOH, NaCl, and H_2SO_4 help to improve electrical conductivity, which can support the increased charging and discharging capacity of AORFB. From several electrolyte solutions tried, using a 0.1M H_2SO_4 electrolyte solution can significantly improve electrical conductivity from TEMPO up to 501-567 µS/cm. Ionic conductivities generally rise with supporting electrolyte concentrations; however, depending on the electrolytes, the effects of active material concentration on conductivities might vary greatly (Gong *et al*., 2015).

3.4 Conductivity Measurement of Methyl Viologen Solution on various electrolyte solutions

One factor that largely affects the ohmic resistance and, consequently, the discharge power density of an electrolyte system is the ionic conductivity of the electrolyte. The ionic composition of the electrolyte has a close correlation with the ionic conductivity (Fischer *et al*., 2022). The results of the study of the electrical conductivity of MV solution in several different electrolyte solutions can be seen in Figure 7. In general, electrical conductivity has a varied trend. As in MV solutions

without electrolytes, their electrical conductivity increases with an increase in concentration, starting from 1670 µS/cm at a concentration of 0.02 M and then rising to 6880 µS/cm at 0.1 M. The mobility of the hydronium/hydroxy ions is restricted at increasing concentrations because more water molecules are bonded to the counter ion. Moreover, the viscosity of the solutions rises and influences the ionic conductivities (Fischer *et al*., 2022).

In contrast to TEMPO solutions, adding electrolyte solutions such as KCl, KOH, NaCl, and H_2SO_4 decreases electrical conductivity in MV solutions. The decrease is quite significant; MV in KCl electrolyte solution has an electrical conductivity value of 14 to 17 µS/cm, in KOH electrolyte solution the electrical conductivity value of 194 to 202 µS/cm, in NaCl electrolyte solution has an electrical conductivity value of 85 to 100 µS/cm. In an electrolyte solution, H_2SO_4 has an electrical conductivity value of 219 to 232 µS/cm, respectively. Intermolecular contact is the origin of these occurrences because it modifies the ionic conductivity and transference number of electrolytes (Leverick & Shao-Horn, 2023).

3.5 Effectivity of the AORFB for Solar Energy Storage System

The RFBs system with a TEMPO solution of 0.1 M combined with 0.1 M H2SO4 as the catholyte and 0.1 M methyl viologen as the anolyte, as stated in the previous sub-section produces a fairly high conductivity compared to other variables, then tested on a solar energy storage system harvested through solar panels. In this study, 2 pieces of 10 W solar panels were used with a maximum current of 0.57 A and a maximum voltage of 17.8 W. Sunlight harvesting was carried out in the morning at 09.00 – 12.00 WIB every day. The measured current increase over approximately 35 minutes can be seen in Figure 8.

The process that occurs is the exchange of ions between catholyte, namely TEMPO solution, and anolyte, namely methyl viologen solution. TEMPO undergoes an electron addition reaction that causes TEMPO to change to $TEMPO^-$ which is characterized by a colour change from dark orange to light orange. Methyl viologen changes to Methyl $Viologen^{2+}$ which is characterized by a colour change from light yellow to dark green, as seen in Figure 9.

The same phenomena were reported Liu *et al* 2016, in the AORFB system of MV and TEMPO in NaCl solution (T. Liu *et al*., 2016b). During charging process, in the anolyte system, the MV solution is oxidised by donating electrons through an

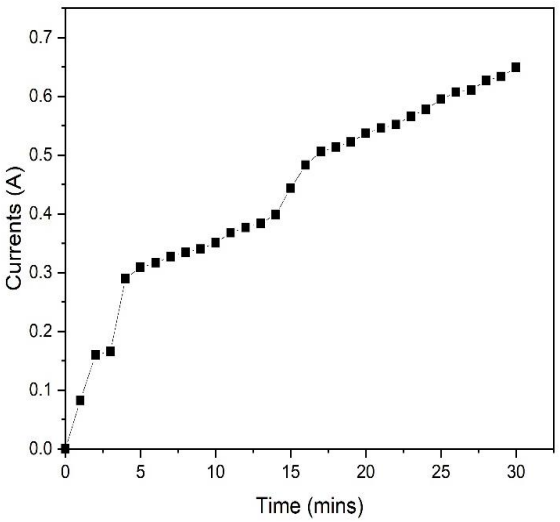

Fig 8. Measured current during charging in RFBs systems for solar energy storage applications

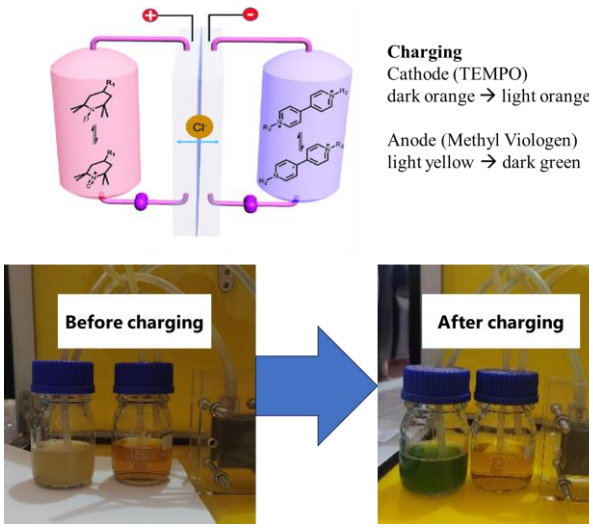

Fig 9. The charging mechanism and colour change that occurs during the charging process, the process of harvesting solar energy from solar panels.

electrode and convert the MV to become radical cations MV2+. The reaction further exhibits colour change of the MV solution from light yellow into dark green. Meanwhile in the catholyte system, the TEMPO solution also received one electron turning TEMPO into its radicals $TEMPO^-$. The reaction is noticeable by the colour changing from dark orange into lighter orange.

4. Conclusion

Analysis of the effectiveness of the electrolyte in the AORFB system has been carried out. The investigation found that TEMPO solutions with high solubility can be achieved quickly, and the dissolved amount is not increased or reduced. As for methyl viologen (MV), the result is still below the expected solution concentration, even with several types of electrolyte addition. An electrical conductivity analysis has also been carried out. The results found an influence of the acquisition of electrolyte solutions on TEMPO catholyte and MV anolytes. In TEMPO solution, the addition of electrolyte solution can increase electrical conductivity, which can later increase the effectiveness of charging and discharging of AORFB. Meanwhile, a different trend is found in MV anolytes, the addition of electrolyte solutions decreases their electrical conductivity, so for the effectiveness of AORFB in anolytes, there is no need to add electrolyte solutions. The optimum condition for effective charge transfer in AORFB is TEMPO catholyte and MV anolytes in the 0.08 M H_2SO_4 electrolyte solution. RFBs systems can be used to store solar energy with a maximum current of 0.6 A for 35 minutes. Storage effectiveness is characterized by a change in colour in the catabolite and anolyte.

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Author Contributions:

Dessy Ariyanti: supervision, conceptualization, methodology, conducting the experiment, writing—original draft, Aprilina Purbasari; methodology and formal analysis; Farida Diyah Hapsari; writing

additional chapter; Erwan Adi Saputra and Fazlena Hamzah: review and editing.

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