Effects of magnetic fields on the Current-Voltage (I-V) characteristics of the chitosan membrane

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Abstract. This work aimed to study the effect of magnetic fields on the current-voltage (I-V) characteristics of a chitosan membrane. The study consists of the plateau length, limiting current density (LCD), and the ratio of resistance of region III (RIII) and region I (RI) (RIII/RI). The chitosan membranes were prepared by a casting method using chitosan as a matrix and acetic acid as a solvent. The chitosan membranes polymerized under a strong magnetic field of 1.5 mT applied along the membrane surface with various times i.e. 2, 4, 8, and 12 h. The I-V measurements were conducted using a cell model with two working electrodes made of platinum and two reference electrodes connected to a voltmeter. The electrolyte solutions used were HCl and CaCl$_2$ with a concentration of 0.025 M. All experiments were carried out at a room temperature of 28.6 °C. The results showed that the plateau length, LCD and RIII/RI of the chitosan membrane is influenced by the magnetic field given during the membrane formation reaction. The magnitude of the impact depends on the length of exposure. These results can be used in tailoring the chitosan membrane according to the application needed.

Key words: Chitosan membrane, magnetic field, current-voltage (I-V) curve, concentration polarization, limiting current density.

1. Introduction

Chitosan is one of a natural polymer which derived from the deacetylation of chitin [1, 2]. It is characterized by being cationic, biodegradability, nontoxic, and biocompatible [3, 4]. Chitosan has antibacterial effect, heavy metal adsorption, and antioxidation [5]. These characteristics make chitosan has significant application in numerous areas such as biomedical engineering and pharmaceutical, agriculture, wastewater treatment and food industry [1].

Chitosan can be changed into forms of powders, beads, films, membranes, coatings, and fibres, further improving its utility [1, 5]. The characteristics of chitosan film depend on its morphology, which is affected by molecular weight, free amine regenerating mechanism, degree of N-acetylation and solvent evaporation [5, 6]. Also, it depends on the material, the preparation method, and the environments [5].

It is known that a magnetic field can affected on chemical reactions, growth of organic films and functional state of organic materials [7]. The magnetic field can affect the orientation of a molecule through rotation of molecular fragments possessing a magnetic moment to adjust it to the applied field direction or renders the effect of translational motion of a molecule bearing a magnetic moment along
the gradient of the applied field [7, 8]. It was reported that the magnetic field can induce an orientation effect on biological molecules and some organic polymers [9], as well as it can enhance mass transfer and morphological changes in organic films via magnetomechanical effect [10, 11].

Several studies on the effects of magnetic fields on formation and properties of films have been reported. The strong and stationary magnetic fields effect on formation and properties of polyaniline (PANI) [12, 13]. The PANI molecules can be oriented in a solution [14] and that PANI films polymerized under a strong magnetic field applied along the film surface become anisotropic and improved electroactivity and conductivity [15]. The applied magnetic field affected interaction of PANI chains with paramagnetic metal ion impurities and induced formation of magnetically ordered regions in the complex film [7]. It suppressed the interaction of PANI chains and paramagnetic metal ions, and lowers conductivity of the resulting complex film up to one order of magnitude [7].

It has reported that ion trans-membrane transport through graphene oxide (GO) membranes is controlled by electric and magnetic fields. Electric field can either decrease or increase the ion transport through GO membranes dependent on its direction, and the magnetic field can enhance the ion penetration monotonically. The electric fields dominate the ion migration process while the magnetic fields tune the structure of nano capillaries within GO membranes. The ion selectivity of GO membranes can be tuned with the electric fields while the ions transport can be enhanced synchronously with the magnetic fields [16].

Based on the studies reported, most of the studies are the effects of magnetic fields on the formation or chemical reactions, morphology, and film structure. The study of the effect of the magnetic field on the characteristics of current-voltage (I-V) polymer membranes is scarcely, especially on chitosan membranes. So, the study of the effect of magnetic fields on the I-V characteristics of the chitosan membrane is important and interesting. The I-V characteristic is the electrical properties of membranes that provide information about the mechanism of ion transport, including concentration polarization.

2. Experimental method

2.1. Materials
The materials used are chitosan, acetic acid and sodium hydroxide (NaOH). The chitosan used was of molecular weight of 900 kDa, a degree of deacetylation (DD) of 87.4%. For the I-V experiment, the electrolyte solutions used were HCl and CaCl\textsubscript{2}. All chemicals were analytical grade and demineralized water was used in the preparation of the electrolyte solutions.

2.2. Procedures
Based on our earlier studies in Rupiasih et al [17] and Rupiasih et al [18], the chitosan membrane 2% was used this study. The membrane is made by a casting method using chitosan as matrix and acetic acid 1% as solvent. The membranes made were chitosan membrane without and with the magnetic fields. The magnetic field applied was 1.5 mT in a parallel direction and it was given at the casting process (the membrane-forming reaction) in various time e.g. 2, 4, 8, and 12 h. The membrane without magnetic field is called M-0, and the membranes with magnetic fields are called M-2h, M-4h, M-8h, and M-12h, respectively.

The I-V experiments were done using a two-compartment measuring cell, which consisted of two platinum (Pt) electrodes as the working electrodes connected to the DC current source and two Single Hg/Hg\textsubscript{2}Cl\textsubscript{2} reference electrodes as the reference electrodes connected to a voltmeter. All measurements were conducted at room temperature of 28.6 °C. The electrolyte solutions used were HCl and CaCl\textsubscript{2} with a concentration of 0.025 M.

3. Results and discussion
From the I-V measurement, it obtained the potential membrane (V) as a function of the current given (I) as shown in Figure 1.
Figure 1. Current-voltage (I-V) curve of chitosan membrane without magnetic field (M-0) in contact with 0.025 M HCl solution.

Figure 1 shows the I-V curve of chitosan membrane without magnetic fields (M-0) which obtained in ion transport experiment in 0.025 M HCl solution. The curve shows the three characteristic regions such as region I (ohmic region), region II (limiting current density (LCD)) and region III (over limiting current density (OLCD)). This I-V curve shows that the chitosan membrane is an ion exchange membrane [19]. The similar curves obtained on the I-V curves of chitosan membranes with magnetic fields (M-2h, M-4h, M-8h, and M-12h) in HCl and CaCl$_2$ solutions, as shown in Figure 2 and 3.

Figure 2. Current-voltage (I-V) curves of chitosan membranes with magnetic fields (M-2h, M-4h, M-8h, and M-12h) in contact with 0.025 M HCl solution.

Figure 3. Current-voltage (I-V) curves of chitosan membranes without (M-0) and with magnetic fields (M-2h, M-4h, M-8h, and M-12h) in contact with 0.025 M CaCl$_2$ solution.

From the I-V curve in Figure 1, 2 and 3, it obtained the characteristic values such as the plateau length, limiting current density (LCD), and the ratio of the resistance of region III (RIII) and the region I (RI) (RIII/RI) for M-0 membrane. The limiting current density is determined by joining of...
two slopes of the region I and region II (point 1) [12]. The length of the plateau (ΔV plateau) is determined by projecting points 1 and 2 on the horizontal axis [12]. The resistance of RI and RIII are obtained from the slope of the curve region I and region III, respectively. By using the same method, it obtained the characteristic values for each membrane as written in Table 1.

Table 1. The characteristic values of I-V of chitosan membranes without (M-0) and with magnetic fields (M-2h, M-4h, M-8h, and M-12h) in HCl and CaCl$_2$ solutions.

| Membranes | Electrolyte solutions | LCD (mA/cm$^2$) | Plateau length (V) | $R_I$ (ohm-cm$^2$) | $R_{III}$ (ohm-cm$^2$) | $R_{III}/R_I$ |
|-----------|-----------------------|----------------|-----------------|------------------|------------------|--------------|
| M-0       | HCl                   | 0.265          | 0.020           | 882.690          | 972.952          | 1.102        |
| M-2h      | HCl                   | 0.265          | 0.020           | 866.476          | 1136.880         | 1.312        |
| M-4h      | HCl                   | 0.265          | 0.020           | 1082.603         | 1394.895         | 1.288        |
| M-8h      | HCl                   | 0.265          | 0.020           | 1205.110         | 1182.033         | 0.981        |
| M-12h     | HCl                   | 0.265          | 0.030           | 1259.446         | 993.049          | 0.788        |
| M-0       | CaCl$_2$              | 0.041          | 0.054           | 490.629          | 1234.416         | 2.516        |
| M-2h      | CaCl$_2$              | 0.204          | 0.047           | 1052.964         | 1293.661         | 1.229        |
| M-4h      | CaCl$_2$              | 0.204          | 0.030           | 1231.527         | 1229.407         | 0.998        |
| M-8h      | CaCl$_2$              | 0.224          | 0.030           | 1127.142         | 980.104          | 0.870        |
| M-12h     | CaCl$_2$              | 0.306          | 0.040           | 1179.106         | 1298.196         | 1.101        |

Table 1 shows that the I-V characteristic values such as the plateau length, limiting current density, and resistances ratio of the membranes with magnetic fields (M-2h, M-4h, M-8h, and M-12h) in HCl and CaCl$_2$ solutions. For a better view of the I-V characteristic values of all membranes, data in Table 1 are plotted in Figure 4 and 5.

Figure 4. The resistance of region I (RI) and the region III (RIII) values of M-0, M-2h, M-4h, M-8h, and M-12h membranes in HCl and CaCl$_2$ solutions.

Figure 4 shows the resistance of region I (RI) and the region III (RIII) values of M-0, M-2h, M-4h, M-8h, and M-12h membranes in HCl and CaCl$_2$ solutions. It shows that magnetic fields given at the membrane-forming reaction affected the values of RI and RIII. In HCl solution, the RI value is slightly decreased at M-2h membrane, then increased sharply on M-4h, M-8h, and M-12h. Meanwhile, the RIII value is increased on M-2h and M-4h membranes then decreased on M-8h and M-12h. In CaCl$_2$ solution, it observed that RI value is increased sharply on M-2h and M-4h membranes, then decreased on M-8h and M-12h. Meanwhile, the RIII value is slightly increased on M-2h membrane, decreased on M-4h and M-8h, then increased sharply on M-12h. Based on this results, it can be said that the exposure to the magnetic field during the formation of the membrane reaction greatly affects the
resistance value of the chitosan membrane. The magnitude of the impact depends on the length of exposure.

Figure 5 shows the limiting current density (LCD) and plateau length values of M-0, M-2h, M-4h, M-8h, and M-12h membranes in HCl and CaCl$_2$ solutions. It shows that in HCl solution, the magnetic fields did not affect the values of LCD and plateau length of chitosan membrane. Meanwhile in CaCl$_2$ solution, the LCD values increased as increased the time of exposure to the magnetic fields, from 2 h to 12 h, but the length of plateaus were decreased.

Based on the above results, it can be said that the I-V characteristic value of the chitosan membrane is influenced by the magnetic field given during the membrane formation reaction. The magnitude of the impact depends on the length of exposure. It was also observed that the characteristic I-V values of the chitosan membrane depend on the type of electrolyte solution used. The same properties were also reported in references [17-19]. These results can be used in tailoring the chitosan membrane according to the application needed.

4. Conclusion
The study has demonstrated the effect of magnetic fields on the current-voltage (I-V) characteristics of chitosan membrane. The I-V characteristic value of the chitosan membrane is influenced by the magnetic field given during the membrane formation reaction. The magnitude of the impact depends on the length of exposure. It was also observed that the characteristic I-V values of the chitosan membrane depend on the type of electrolyte solution used.

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