Performance of Nata de Bamboo and Nata de Chayote Membranes as Zinc-Carbon Battery Separators

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The performance of nata de bamboo (NDB) and nata de chayote (NDCh) membranes as zinc-carbon battery separators has been investigated. NDB and NDCh are bacterial cellulose produced from a fermentation process by bacterium acetobacter xylinum on bamboo shoots and chayote substrate, respectively. Two types of membranes, i.e., complete sheet (type 1) and homogeneous (type 2) from both natas were fabricated with various weights. The membranes were pressed, dried, and placed on the zinc-carbon battery as a separator. The digital caliper was used to measure the thickness of the membranes. The electrochemical properties of the membranes as zinc-carbon battery separators were observed by Linear Sweep Voltammetry (LSV) and Electrochemical Impedance Spectroscopy (EIS) techniques. A comparison study was conducted with an original membrane separator of a zinc-carbon battery. The results showed that the thickness of type 1 membranes from both NDB and NDCh in all variations is thinner than that of type 2 membranes and original membranes. NDB and NDCh membranes' resistance was similar to the original membrane separator. The best result was achieved from type 1 of NDB and NDCh membranes. This indicates that NDB and NDCh membranes have the potency to replace an original membrane separator of zinc-carbon batteries.

Keywords: Membrane, Separator, Zinc-carbon battery, Innovation, Research, Technology.

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1. INTRODUCTION

Advances in technology have demanded more energy [1-4]. There are various forms of energy, which can be changed from one form to the other form. According to the first law of thermodynamics, energy can be changed from one form to another form, but energy cannot be created or destroyed. The energy conservation law states that the total amount of energy in nature is always the same constant. The increasing demand for clean and renewable energy resources causes scientists to compete to develop energy storage technologies [2, 3, 5]. Today, batteries are one of the most promising energy storage technologies. Batteries have a high energy density, long cycle lifetime, and high safety [6]. The important thing part of batteries is the separator. The primary function of the separator is separating the anode and cathode to avoid the internal short circuit from direct contacting of the two electrodes [7-9]. The separator can be classified as polymeric porous membranes, non-woven membranes, and inorganic composite membranes. Despite being an electric insulator, the separator has a porous structure to provide ion mobility [9-11]. Therefore, a porous structure of the separator membrane is necessary. Innovation of new porous structure of separator membrane for efficient with renewable properties still needs to develop. Cellulose membranes offer a solution to overcome this problem [12-14].

Cellulose is the most abundant natural polymer in the world. This material has high decomposition temperature and excellent electrolyte wettability. Cellulose can be used as membranes by direct isolation from plants' natural fiber (cellulose) or synthesized by acetic acid bacteria. The cellulose obtained from the synthesis process of acetic acid bacteria is well known as bacterial cellulose (BC) [5, 15]. BC is a nanomaterial produced by various Acetobacter strains, Pseudomonas, Arcobacter, Alcaligene, Aerobacter, or Azotobacter species. The BC or natural hydrogel is better than hydrogels that are produced from synthetic polymers. BC shows high moisture content (98-99 %), good liquid absorption, high wet strength, and high chemical purity and also can be sterilized safely without changing the structure and its properties [16]. Kurniawan et al. have been fabricated new bacterial cellulose membranes from chayote fruit and bamboo shoots. The membranes have good mechanical properties, such as the tensile strength of 74.64 MPa and 57.28 MPa for BC membranes from chayote fruit and bamboo shoots. Chayote fruit and bamboo shoots membranes also have a good strain value of 8.370 % and 6.052 %, respectively. The water absorption capacity of the membranes is 591.857 % and 836.226 % [17]. These properties show the potency of BC membranes from chayote fruit and bamboo shoots to be used as a battery separator. Several scientists have been reported that bacterial cellulose from another plant source can be used as a good battery separator [12-14].

In the present work, we utilize a bacterial cellulose membrane from chayote fruit and bamboo shoots as a battery separator. The nata de bamboo (NDB) and nata de chayote (NDCh) was made by Acetobacter xylinum bacteria and formed into thin membranes. The membranes will be applied as a zinc-carbon battery separator to replace the original. The electrochemical method observed the power and resistance of the zinc-carbon battery with and without NDB or NDCh membranes. A

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comparison study by the original separator of the zinc-carbon battery was also investigated.

2. EXPERIMENTS

2.1 Chemicals and Materials

Urea ($CO(NH_2)_2$, 98 %), acetic acid glacial (CH_3COOH, 99.8 %) and sodium hydroxide (NaOH) were purchased from Sigma-Aldrich. Sugar was bought from the local market. All chemicals were used without any purification. Acetobacter xylinum was obtained from Microorganism Chemical Laboratory, Chemistry Department, Faculty of Science and Data Analytics, Institut Teknologi Sepuluh Nopember, and Surabaya, Indonesia. Demineralized water was used for cleaning and chemical preparation. Zinc-carbon batteries with a local brand, i.e., ABC dry cell heavy duty®, were obtained from the local market.

2.2 Instrumentation

Electrochemical experiments were performed using two-electrode cell systems. The connector of reference and counter electrodes were connected to the positive side of the battery, while the working electrode connector was connected to the negative side of the battery. All electrochemical measurements were performed using AUTOLAB PGSTAT128N, which is equipped with the Nova 1.11 software.

2.3 Fabrication of Nata de Bamboo and Nata de Chayote Membranes

Nata de bamboo (NDB) and nata de chayote (NDCh) were fabricated as described from our previous work [17]. Fresh materials, i.e., bamboo shoots and chayote fruit, were bought from a local market in Surabaya, Indonesia. The fresh bamboo shoots and chayote fruit were cut into small pieces and weighed 250 g and 225 g, respectively. Each material was put in a clean container, added 1 l of demineralized water, and then blended. Furthermore, each material was boiled and cooled at room temperature. The cooled material was filtered to obtain residue and filtrate. The filtrate was used as a substrate to get nata. The substrate was mixed by 100 g sugar and 4-gram urea under heating and stirring conditions. The mixture solution was cooled in an ice bath and adjusted to pH 4 by adding acetic acid glacial. 300 ml of the mixture solution was put down at the nata mold. Afterward, the mixture solution was added 30 ml of Acetobacter xylinum for fermentation. The fermentation process was conducted for 10 days. After 10 days, the layer of nata was rinsed and immersed in hot water for 15 min. Furthermore, the nata was immersed in 1 % NaOH solution for 24 h and 1 % acetic acid solution for 24 h consecutively. The nata from bamboo shoots and chayote was stored at a sterile place prior to use.

Two different treatments carried out fabrication of the membranes from NDB and NDCh as battery separators. Type 1 membranes were obtained from the complete sheet of NDB or NDCh, whereas type 2 membranes were made from a homogenous sheet of NDB or NDCh. Type 1 was made by cutting the complete sheet of NDB or NDCh appropriate to the zinc-carbon battery's separator pattern (blanket, base, and cover). Each piece was weighed with 3-15 g for the blanket and 3 g for the base and cover pieces. Type 2 was made by cutting and blending the NDB or NDCh. The blended NDB or NDCh was filtered and weighed. The separator membranes type 2 was prepared as type 1 which consists of a blanket, base, and cover. The weight of the blanket was varied from 3-15 g and 3 g for base and cover. Furthermore, the materials were molded into rectangular (5×10 cm^2) for blanket and circle form (diameter of 3 cm) for base and cover. The hydraulic press pressed all materials of both type 1 and 2 with a pressure of 2.5 tons for 2 min. Afterward, all materials were dried at 60 ºC for 30 min to get a thin layer. The thin layer is then referred to as membrane type 1 and type 2 of NDB and NDCh. All preparation membranes were repeated three times. The thickness of each type of membrane from NDB and NDCh was measured by a digital caliper (e-inhill).

2.4 Performance of Nata de Bamboo and Nata de Chayote Membranes as Zinc-Carbon Battery Separators

The zinc-carbon battery was disassembled (Fig. 1a). Electrolyte battery was added 2 ml water and then placed inside the battery cell (Fig. 1b). After that, the membranes type 1 or 2 of NDB or NDCh was placed inside the battery cell to replace the original battery separator (Fig. 1c). The battery with NDB or NDCh membranes was ready to be tested (Fig. 1d).

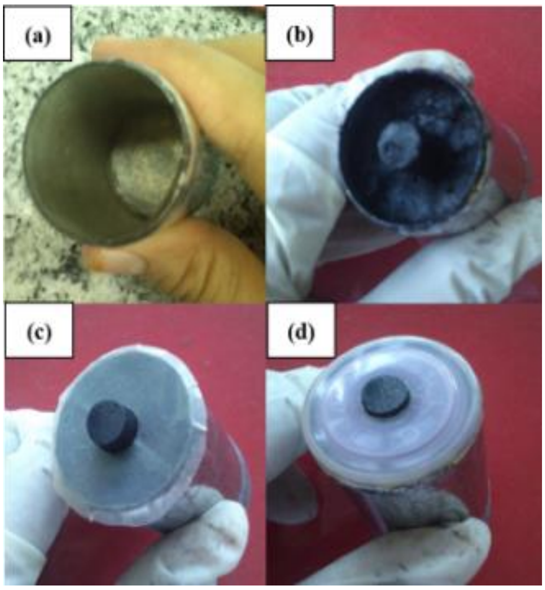

Fig. 1 – The image of zinc-carbon battery after dissembles process (a), electrolyte filling process (b), adding NDB or NDCh membranes as battery separator, and zinc-carbon battery ready to test (d)

The power and resistance of the batteries were measured by the electrochemical method. The original zinc-carbon battery performed a comparison study. The electrochemical experiments were done in Fig. 2. The power of batteries with and without the NDB or NDCh membranes was measured by the linear sweep voltammetry (LSV) technique. The LSV measurement was carried out at a density of 10-100 mA with a range potential of 1.5-0 V with a scan rate of 0.1 V/s. The result will be displayed in a current vs. potential curve as a power function of batteries.

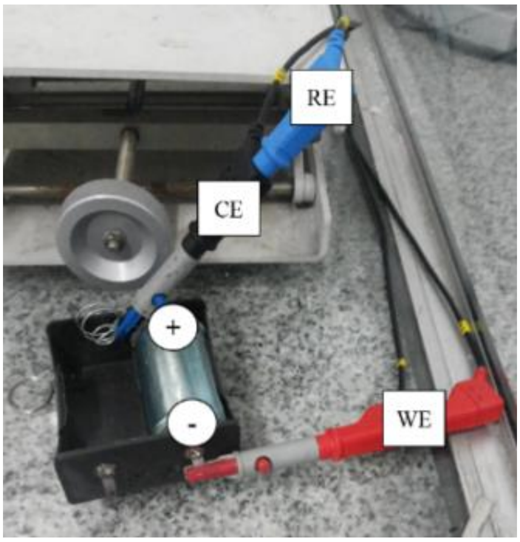

Fig. 2 – The electrochemical experiments

The resistance of batteries with and without the NDB or NDCh membranes was observed using the electrochemical impedance spectroscopy (EIS) technique. EIS was performed at open circuit potential (OCP) in the frequency range of 20 kHz-10 Hz using a signal amplitude of 0.1 A. The result will be presented as a Nyquist plot. The impedance parameters, such as polarization resistance of the material (R_p) and solution resistance (R_s) were obtained by extrapolation process in the Nyquist plot.

3. RESULTS AND DISCUSSION

3.1 Characterization of Nata de Bamboo and Nata de Chayote Membranes

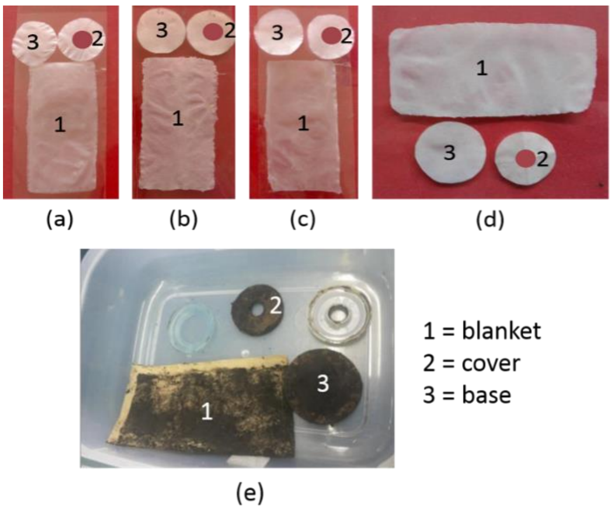

Fig. 3 – The image of original membrane from the zinc-carbon battery. The image of type 1 (a) and type 2 (b) of NBD membranes. The image of type 1 (c) and type 2 (d) of NDCh membranes

The image of type 1 and type 2 of NDB membranes can be found in Fig. 3a and Fig. 3b, respectively. In comparison, the image of type 1 and type 2 of NDCh membranes was displayed in Fig. 3c and Fig. 3d, respectively. The image of the original membrane from the zinc-carbon battery is shown in Fig. 3e. We found that the type 1 membrane of NDB and NDCh was smoother than type 2. The thickness of the membranes is summarized in Table 1. It can be shown that type 1 membranes from both NDB and NDCh in all variations are thinner than type 2 and original membranes.

3.2 Performance of Nata de Bamboo and Nata de Chayote as Membrane Separator in Zinc-Carbon Battery

Table 1 – The thickness of membranes battery separator

Membranes	Type of membranes	Weight variation of the blanket (g)	Thickness of membranes (mm)		
			blanket	base	cover
Original	A	–	0.100	0.410	0.570
	B	–	0.130	0.430	0.620
	C	–	0.160	0.450	0.450
Nata de bamboo	Type 1	3	0.053	0.087	0.110
		6	0.060	0.100	0.103
		9	0.087	0.103	0.083
		12	0.090	0.070	0.087
		15	0.097	0.080	0.070
	Type 2	3	–	–	–
		6	0.080	0.140	0.120
		9	0.107	0.127	0.130
		12	0.137	0.140	0.150
		15	0.147	0.143	0.123
Nata de chayote	Type 1	3	0.033	0.033	0.033
		6	0.050	0.047	0.047
		9	0.080	0.080	0.080
		12	0.067	0.067	0.060
		15	0.083	0.087	0.080
	Type 2	3	0.050	0.077	0.080
		6	0.083	0.090	0.090
		9	0.117	0.090	0.090
		12	0.093	0.100	0.100
		15	0.133	0.107	0.110

Table 2 – Resistance of membranes battery separator

Membranes	Type of membranes	Weight variation of the blanket (g)	Resistance of membranes (Ω)	
			R_p	R_s
Original	A	–	0.220	0.889
	B	–	0.220	0.889
	C	–	0.220	0.889
Nata de bamboo	Type 1	3	0.220	0.782
		6	0.326	0.706
		9	0.276	0.750
		12	0.250	1.131
		15	0.369	0.711
	Type 2	3	–	–
		6	0.392	0.836
		9	0.364	1.018
		12	0.308	0.725
		15	0.551	0.607
Nata de chayote	Type 1	3	0.476	4.027
		6	0.428	0.666
		9	0.527	0.831
		12	1.076	0.645
		15	1.199	0.618

Mem-branes	Type of mem-branes	Weight varia-tion of the blanket (g)	Resistance of membranes (Ω)	
			R_p	R_s
	Type 2	3	0.356	0.788
		6	0.713	0.700
		9	0.916	0.497
		12	0.369	0.543
		15	0.824	0.566

Table 3 – Power of membrane battery separator

Parameter	NDCh membrane		NDB membrane	
	Type 1	Type 2	Type 1	Type 2
Optimum power	1.141 VA	1.140 VA	1.146 VA	1.145 VA
Weight at optimum power	12 g	15 g	3 g	6 g
Optimum R_p	1.198 Ω	0.915 Ω	0.369 Ω	0.551 Ω
Weight at optimum R_p	15 g	9 g	15 g	15 g

The thickness of the membranes was shown in Table 1. The resistance of batteries with and without the NDB or NDCh membranes was observed using the electrochemical impedance spectroscopy (EIS) technique. EIS was performed at open circuit potential (OCP) in the frequency range of 20 kHz-10 Hz using a signal amplitude of 0.1 A. The result will be presented as a Nyquist plot. The impedance parameters, such as polarization resistance of the material (R_p) and solution resistance (R_s), were obtained by the extrapolation process in the Nyquist plot. The result of EIS measurement was summarized in Table 2. The power of the membranes was shown in Table 3. The result showed that NDB and NDCh membranes' resistance was similar to the original membrane separator. This result proved that NDB and NDCh membranes could potentially replace an original membrane separator of a zinc-carbon battery.

4. CONCLUSIONS

Nata de bamboo (NDB) and nata de chayote (NDCh) membranes can be used as zinc-carbon battery separators. The best result was achieved from type 1 of NDB and NDCh membranes. The result showed that NDB and NDCh membranes' resistance was similar to the original membrane separator. This result proved that NDB and NDCh membranes could potentially replace an original membrane separator of a zinc-carbon battery.

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Продуктивність мембран Nata de Bamboo та Nata de Chayote як сепараторів цинк-вуглецевих акумуляторів

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Досліджено ефективність мембран nata de bamboo (NDB) та nata de chayote (NDCh) як сепараторів цинк-вуглецевих акумуляторів. NDB і NDCh являють собою бактеріальну целюлозу, отриману в процесі ферментації бактерією acetobacter xylinum на пагонах бамбука та субстраті з чайота відповідно. Були виготовлені мембрани двох типів: цільнолистові (тип 1) та однорідні (тип 2) з NDB та NDCh різної маси. Мембрани пресували, сушили і поміщали на цинк-вуглецевий акумулятор як сепаратор. Цифровий штангенциркуль використовували для вимірювання товщин мембран. Електрохімічні властивості мембран як сепараторів цинк-вуглецевих акумуляторів отримали за допомогою методів вольт-амперометрії з лінійною розгорткою (LSV) та електрохімічної імпедансної спектроскопії (EIS). Порівняльне дослідження проведене з оригінальним мембранним сепаратором цинк-вуглецевого акумулятора. Результати показали, що товщина мембран 1-го типу як NDB, так і NDCh у всіх варіантах менша, ніж у мембран 2-го типу і оригінальних мембран. Опір мембран NDB та NDCh аналогічний оригінальному мембранному сепаратору. Найкращий результат був досягнутий з мембранами NDB та NDCh 1 типу. Це свідчить про те, що мембрани NDB та NDCh здатні замінити оригінальний мембранний сепаратор цинк-вуглецевих акумуляторів.

Ключові слова: Мембрана, Сепаратор, Цинк-вуглецевий акумулятор, Інновація, Дослідження, Технологія.