EFFECTS OF ELECTROLYTE CONCENTRATION ON PROPERTIES OF BATTERIES

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Project Title	EFFECTS OF ELECTROLYTE CONCENTRATION ON PROPERTIES OF FLEXIBLE BATTERIES
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Abstract

Current batteries are bulky, heavy and rigid. It is necessary to develop small, light and flexible batteries for advanced applications. In this project, we fabricated Zinc-Manganese dioxide and investigated effects of (1) potassium hydroxide concentration ranging from 1 M to 9 M and (2) effects of bending angles (0°, 30°, 45°, 60°and 90°) on the performance of the batteries. We found that the highest voltage (1.679V) is achieved when 9 M of potassium hydroxide is used and the bending angle does not affect the voltage of the batteries.

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We hope that people who read this project would find the results are useful and benefit for them. We are willing to receive all comments and suggestions from everyone.

Chanoknan Gomest
Warakorn Suriyatun

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LIST OF ABBREVIATIONS

M = Molarity
K = Kelvin
V = Voltage
C = Coulomb
g = gram
A = Amperes
hr = hours
s = Second
cm = Centimeter
°C = Degree Celsius
ml = Milliliter
LED = Light Emitting Diode
Ah = Amperes xhours
W = Watt
µm = Micrometer
sq = Square

Chapter 1
Introduction

1.1 History and Importance of The Project

New gadget configurations such as flexible cell phones, smart clothes, wearable medical devices, etc. are gaining huge interest. One of the main challenges to make these advanced electronics available is to make normal batteries become flexible, stretchable, foldable, rollable or a combination of these features. In This Project, we propose to create a process to make flexible batteries and investigate the effects of electrolyte concentrations on properties of the batteries.

1.2 Purpose of The Project

1.2.1 To make flexible batteries

1.2.2 To achieve voltage of 1.5 V

1.3 Project Output

At the end of this project, we will be able to make flexible batteries that are small, lightweight, bendable and have same performance as normal batteries.

1.4 Project Outcome

1.5 V batteries are produced

1.5 Scope of The Project

To study effects of electrolyte concentration on performance of flexible batteries

1.6 The Place of Project

This project is carried out in Faculty of Engineering at Naresuan University.

1.7 The Time of Project

This Project will be studied from August, 2016 to April, 2017

1.8 Timeline

Table 1.1 Plan of Progress for Flexible Battery

No	Progress	2016					2017			
		August	September	October	November	December	January	February	March	April
1	Literature Review	↔								
2	Design Experiment		↔							
3	Formulate Anode, Cathode and Electrolytes			←—	—→					
4	Fabricating Flexible Batteries				←—	—→				
5	Characterizing Performance						←—	—→		
6	Summary and Report								←—	—→

Chapter 2

Principles and Theory

A Battery is device that converts chemical energy into electrical energy. This process involves the transfer of electron from one electrode to another electrode through an external electric circuit. In the following section, we will discuss the basic principle and components of batteries. (Figure 2.1)

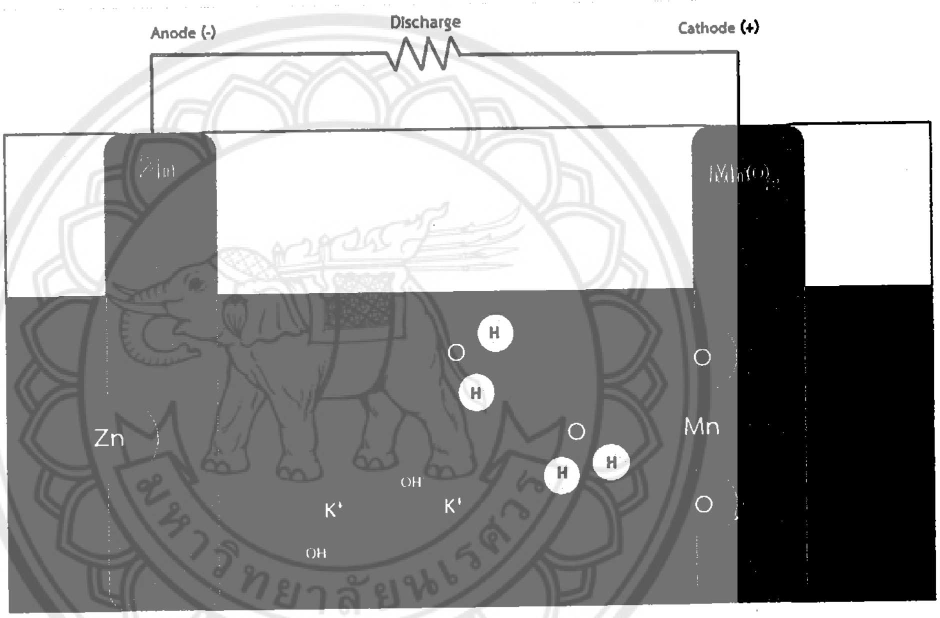


Fig. 2.1 Primary battery

2.1 Types of Battery

There are two types batteries: primary batteries and secondary batteries in primary batteries, reactions are non-reversible, therefore, primary cells are one-time use Batteries, typically, primary batteries have moderate shelf life, high energy density, and low to moderate discharge rates (Figure 2.2). The common primary batteries are cylindrical and flat button batteries or multicell batteries using these component cells. (David linden and Thomas B. Reddy,1995)

In secondary batteries, the reactions can be reversed by an external electrical energy source, therefore, these cells can be recharged by passing electric current and used multiple times. Examples of secondary battery are lead-acid batteries and nickel – cadmium batteries. (David linden and Thomas B. Reddy,1995)

The focus of this project is alkaline batteries, from here on, we will provide an overview concerning on this type of batteries only. (Figure 2.2)

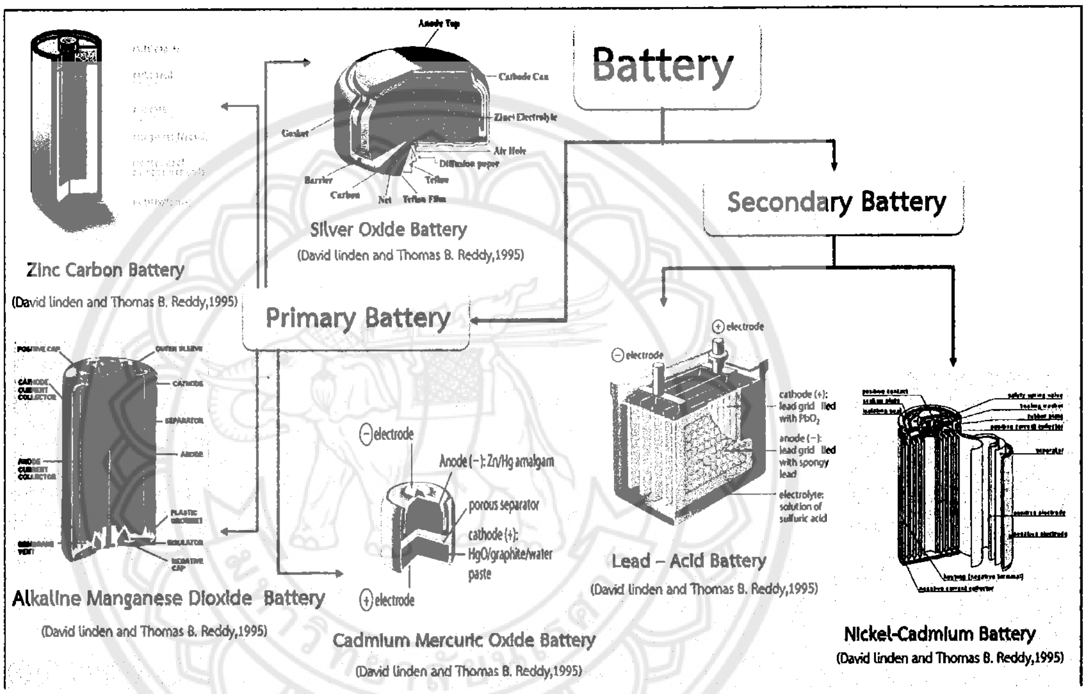


Fig. 2.2 Type of battery

2.2 Alkaline Batteries

Alkaline batteries are primary batteries. Commercially alkaline batteries are available in different sizes such as AAA, AA, C, D, 9V batteries. The major difference between alkaline batteries and zinc-carbon batteries is in the electrolyte. In alkaline batteries, potassium hydroxide (KOH) is used instead of ammonium chloride (NH_4Cl). (David linden and Thomas B. Reddy,1995)

Basic components of batteries are anode, cathode, electrolyte, separator and current collector. Anode donates electrons to cathode. In alkaline batteries, the anode is made of zinc alloys (zinc metal mixes with bismuth, indium, and others). The cathode is a solid mixture of graphite, MnO_2 and binder. Electrolyte functions as a medium for the storage and transport of ions to maintain reactions at anode and cathode surfaces. In alkaline batteries, potassium hydroxide with concentration ranging between 6.0 M to 9.0 M is used as electrolyte. Separator is used to prevent short circuit between anodes and cathodes. The separator must be ionically conductive but electronically insulating; chemically stable in concentrated alkali under both oxidizing and reducing conditions; strong, flexible, and uniform; impurity-free; and rapidly absorptive. Common used separator materials are regenerated cellulose, vinyl polymers, polyolefins, etc. Current collectors are used as electrical contact points to accept and transfer electrons from anode to cathodes. Due to chemical and electrochemical stability, materials used as current collectors for anodes and cathodes are different from each other. Brass is used as current collector for cathode while steel is used for anode. (David linden and Thomas B. Reddy,1995) as shown in Figure 2.3

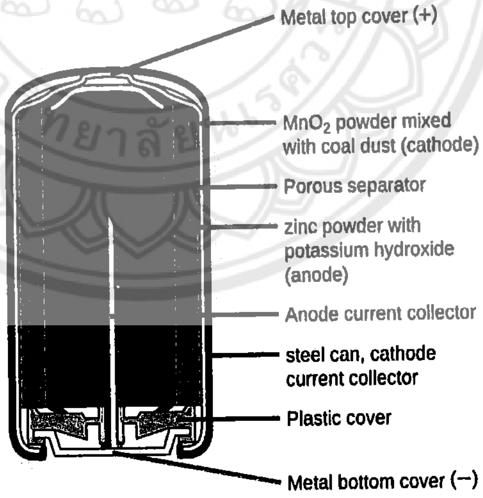


Fig. 2.3 All component battery

Source: www.google.co.th/search?q=component+of+alkaline+battery,1992

2.3 Basic Electrochemistry of Alkaline Battery

Electrochemistry of alkaline battery is based on reactions at anode and cathode. In general, oxidation reaction happens when substance loose its electrons and reduction reaction happens when substance gain electrons. The combination of reduction and oxidation reactions is called redox reactions. In batteries, oxidation reaction occurs at anode and reduction reaction occurs at cathode. (David linden, Thomas B. Reddy,1995)

For instance, an electrochemical cell consists of Zn anode and Cu cathode, their redox reaction is:

$$\text{Anode : } Zn - 2e^{-} \longrightarrow Zn^{2+} \qquad \textbf{(2.1)}$$

$$\text{Cathode : } Cu^{2+} + 2e^{-} \longrightarrow Cu \qquad \textbf{(2.2)}$$

$$\text{Redox Reaction : } Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu \qquad \textbf{(2.3)}$$

In the case of alkaline batteries, the oxidation reaction will happen at zinc anode and reduction reaction will happen at MnO_2 cathode. Under strong alkaline environment, zinc is oxidized to form zincate. The most common used in alkaline battery is MnO_2. (David linden and Thomas B. Reddy,1995)

$$\text{Anode : } Zn + 2(OH)^{-} - 2e^{-} \longrightarrow Zn(OH)_2 \qquad \textbf{(2.4)}$$

$$\text{Cathode : } MnO_2 + 2e^{-} + 2\,H_2O \longrightarrow Mn(OH)_2 + 2(OH)^{-} \qquad \textbf{(2.5)}$$

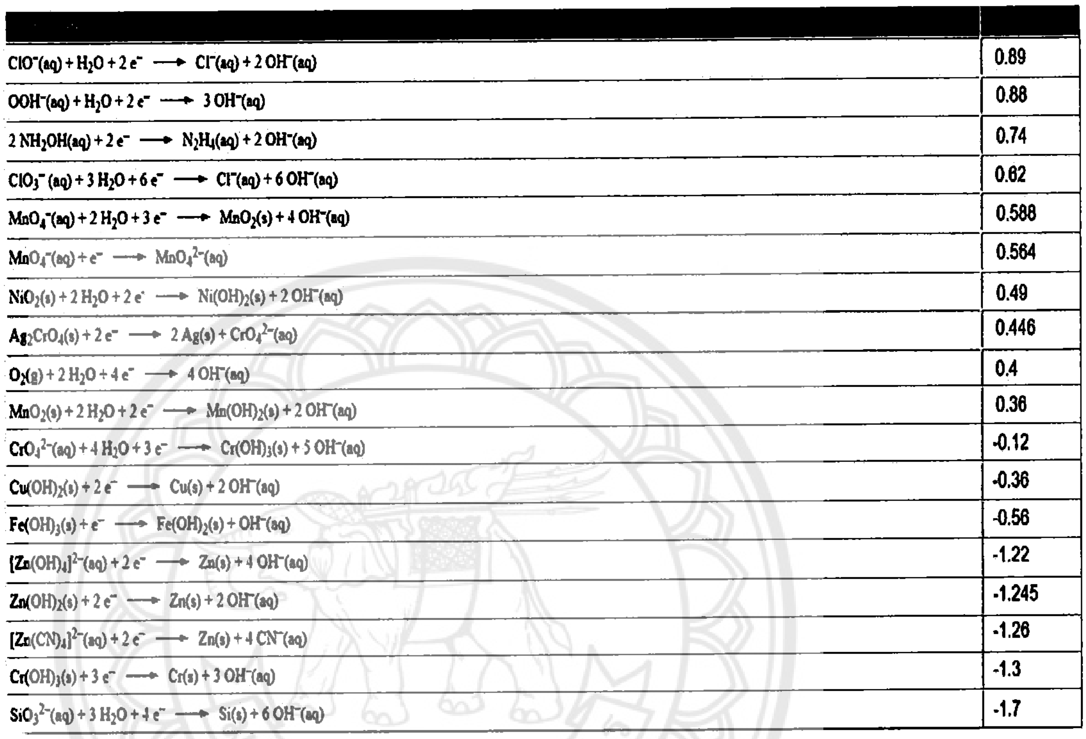
$$\text{Redox Reaction : } Zn + MnO_2 + 2H_2O \longrightarrow Mn(OH)_2 + Zn(OH)_2 \qquad \textbf{(2.6)}$$

2.4 Factors Affect Battery Characteristics

2.4.1 Standard Reduction Potential

In order to choose suitable materials for anode and cathode, it is necessary to know the tendency of a substance to be reduced under standard conditions. The standard cell potential is the potential difference between a material and standard hydrogen electrode when it is in contact with its own salt solution (1M) at 298 K, 1 atmosphere of pressure (atm). (David linden and Thomas B. Reddy,1995)

Standard potential is conventionally reported as reduction potential, hence, reduction reactions have positive potential value while oxidation reactions have negative potential value (Figure 2.4)



$ClO^-(aq) + H_2O + 2e^- \longrightarrow Cl^-(aq) + 2OH^-(aq)$	0.89
$OOH^-(aq) + H_2O + 2e^- \longrightarrow 3OH^-(aq)$	0.88
$2NH_2OH(aq) + 2e^- \longrightarrow N_2H_4(aq) + 2OH^-(aq)$	0.74
$ClO_3^-(aq) + 3H_2O + 6e^- \longrightarrow Cl^-(aq) + 6OH^-(aq)$	0.62
$MnO_4^-(aq) + 2H_2O + 3e^- \longrightarrow MnO_2(s) + 4OH^-(aq)$	0.588
$MnO_4^-(aq) + e^- \longrightarrow MnO_4^{2-}(aq)$	0.564
$NiO_2(s) + 2H_2O + 2e^- \longrightarrow Ni(OH)_2(s) + 2OH^-(aq)$	0.49
$Ag_2CrO_4(s) + 2e^- \longrightarrow 2Ag(s) + CrO_4^{2-}(aq)$	0.446
$O_2(g) + 2H_2O + 4e^- \longrightarrow 4OH^-(aq)$	0.4
$MnO_2(s) + 2H_2O + 2e^- \longrightarrow Mn(OH)_2(s) + 2OH^-(aq)$	0.36
$CrO_4^{2-}(aq) + 4H_2O + 3e^- \longrightarrow Cr(OH)_3(s) + 5OH^-(aq)$	-0.12
$Cu(OH)_2(s) + 2e^- \longrightarrow Cu(s) + 2OH^-(aq)$	-0.36
$Fe(OH)_3(s) + e^- \longrightarrow Fe(OH)_2(s) + OH^-(aq)$	-0.56
$[Zn(OH)_4]^{2-}(aq) + 2e^- \longrightarrow Zn(s) + 4OH^-(aq)$	-1.22
$Zn(OH)_2(s) + 2e^- \longrightarrow Zn(s) + 2OH^-(aq)$	-1.245
$[Zn(CN)_4]^{2-}(aq) + 2e^- \longrightarrow Zn(s) + 4CN^-(aq)$	-1.26
$Cr(OH)_3(s) + 3e^- \longrightarrow Cr(s) + 3OH^-(aq)$	-1.3
$SiO_3^{2-}(aq) + 3H_2O + 4e^- \longrightarrow Si(s) + 6OH^-(aq)$	-1.7

Fig. 2.4 Standard reduction potential

Source: www.chem.libretexts.org/Core/Analytical_Chemistry,1989

2.4.2 Electrode Material Selection

Anode material needs to donate electron via oxidation reaction; therefore, a good anode material should have low standard reduction potential. Cathode material accepts electron via reduction reaction; hence, a good cathode material should have high standard reduction potential. (David linden and Thomas B. Reddy,1995)

The theoretical cell potential or cell voltage can be calculated based on the standard reduction potential of anode and cathode materials use value from above in figure. 2.4

$E^{o} = E^{o}_{Reduction}$ of reaction at cathode – $E^{o}_{\ Oxidation}$ of reaction at anode

$E^{o} = E^{o}_{Reduction} - E^{o}_{Oxidation}$ **(2.7)**

For alkaline battery, the theoretical cell voltage can be calculated based on the standard reduction potential of Zn anode and MnO_2 cathode as follows.

Anode : $Zn + 2(OH)^{-} - 2e^{-} \longrightarrow Zn(OH)_2$, $E^{o} = -1.245$ V **(2.8)**

Cathode : $MnO_2 + 2e^{-} + 2\ H_2O \longrightarrow Mn(OH)_2 + 2(OH)^{-}$, $E^{o} = 0.36$ V **(2.9)**

Redox Reaction : $Zn + MnO_2 + 2H_2O \longrightarrow Mn(OH)_2 + Zn(OH)_2$ **(2.10)**

$$
\begin{aligned}
E^{o}_{t} &= E^{o}_{Reduction} - E^{o}_{Oxidation} \\
&= 0.36\ V - (-1.245\ V) \\
&= 1.605\ V
\end{aligned}
$$

2.4.3 Electrolyte

The theoretical cell voltage is calculated at standard condition. However, the electrochemical cell is often operated under non-standard state. According to Nernst's equation, the cell potential is highly dependent on concentrations of electrolyte. A cell made of the same materials but with different concentrations will produce different potential. (David linden and Thomas B. Reddy,1995)

$$E^{o}_{\ cell} = E^{o} - \frac{RT}{nF}\ell n\left(\frac{[Oxidation]}{[\mathrm{Re}\,ductione]}\right) \qquad \textbf{(2.11)}$$

n = Number of electron transferred during redox reactions

F = Faraday's constant (F = 96,488 C)

Oxidation = Concentration of reaction anode (M)

Reduction = Concentration of reaction cathode (M)

T = Temperature (K)

R = Gas Constant is $8.3144 \frac{J}{mol \times K}$

E° = Standard reaction potential (V)

2.5 The Calculation of Battery

2.5.1 Battery Capacity

Capacity is the amount of charge (Coulomb; C) that can be used under specific time. It can be calculated using Faraday's law. The available capacity (A x h) (David linden, Thomas B. Reddy,1995)

$$\text{Capacity} = \frac{nF}{M.W} \tag{2.12}$$

n = Number of electron transferred during redox reactions
F = Faraday's constant (F = 96,488 C)
MW = Molecular weight of active material (g)

For example, the capacity value per gram for zinc electrodes can be calculated as shown below. (1 C = 1 A x s)

$$\text{Capacity} = \frac{2x96,488C}{65.38g} x \frac{1}{3,600s}$$

$$\text{Capacity} = 0.820\frac{Ah}{g} = 820\frac{mAh}{g}$$

2.5.2 Discharge current

To Measure Battery performance, constant current discharge is used. The rate at which the battery discharge over time is called capacity rate or C-rate. C-rate is defined by the theoretical capacity (Ah)

$$\text{Discharge Current} = \frac{capacity}{time} \tag{2.13}$$

Notation of C rates is nC or C/n, where C is the theoretical capacity and n is the number of hours. 1C means under a constant current setting, the theoretical capacity of the battery would discharge in one hour. C/2 means the theoretical capacity of the battery would discharge in two hours. (David linden, Thomas B. Reddy,1995)

For instance, to discharge a battery made of 0.081g zinc anode over 1 hours (C/1 rate), the discharge current would be:

$$\text{Discharge current} = \frac{820\,\frac{mAh}{g}}{1h}\,x0.081g$$

$$= 66.42 \text{ mA}$$

2.6 Related Research

2.6.1 Flexible Fiber-Type Zinc–Carbon Battery Based on Carbon fiber Electrode

In this paper, zinc-carbon batteries were made using Zn wires as negative electrodes and carbon fibers coated with MnO_2 paste as positive electrodes. The batteries were placed in flexible plastic tubes and filled with ammonium chloride electrolyte. With light weight of carbon fiber and high mechanical strength and high flexibility. Their batteries were able to achieve ~1.4V voltage with the maximum discharge capacity of 0.15mAh/cm. When connecting two fiber batteries in series, they were able to light up a green LED. (Xiao Yu et al.,2013)

2.6.2 Thin, Flexible Secondary Li-Ion Paper Batteries

In this paper, flexible lithium ion batteries were made using carbon nanotubes as current collectors, paper as separators. Carbon nanotubes were used as current collectors because they are lightweight (0.2 mg/cm^2) , low sheet resistance (5Ω/sq) and provide high flexibility. The paper-based battery was about 300 µm in thickness and had a voltage of about 2.5 V and energy density of 108mWh/g. (Liangbing Hu et al.,2010)

Chapter 3

Research Methodology

3.1 Design of Experiment Flowchart

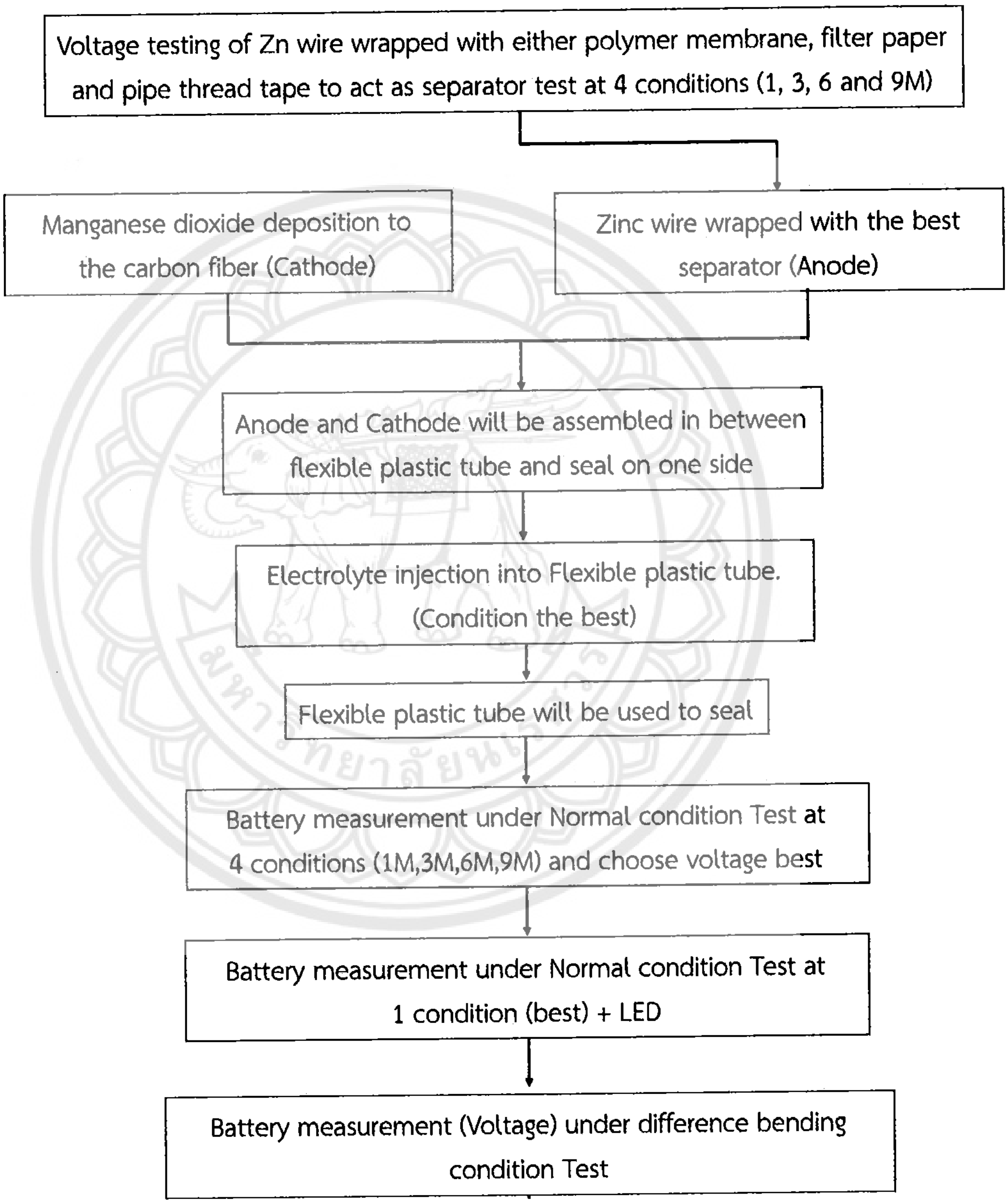


Fig. 3.1 Flow chart

3.1.1 The Design of Flexible Batteries

The flexible batteries consisted carbon fiber current collectors, MnO_2 cathode, Zn thin film anode, KOH electrolyte, material 3 type serving as separator. Flexible plastic tube was used to seal the batteries. Figure 3.2 and 3.3 show design and inside of our batteries. The size of anode, cathode and separator were 9 cm. x 0.068 cm.

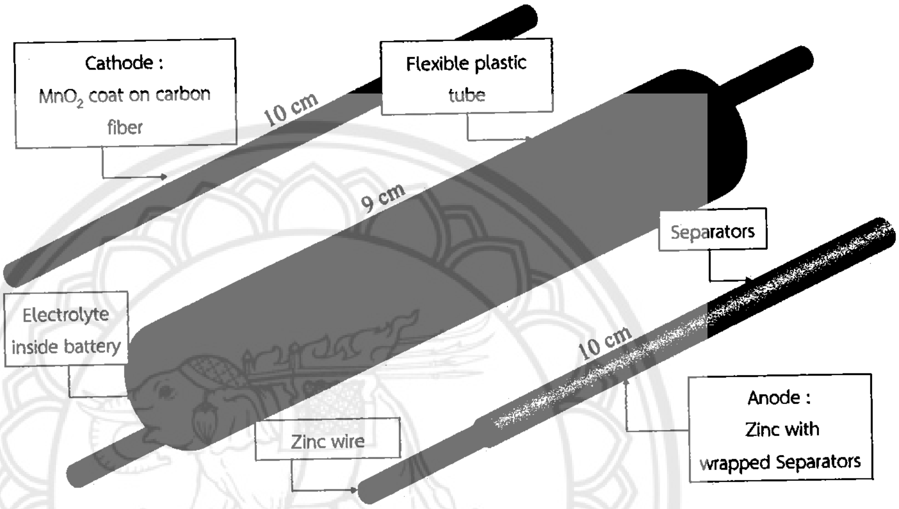


Fig. 3.2 Design of battery

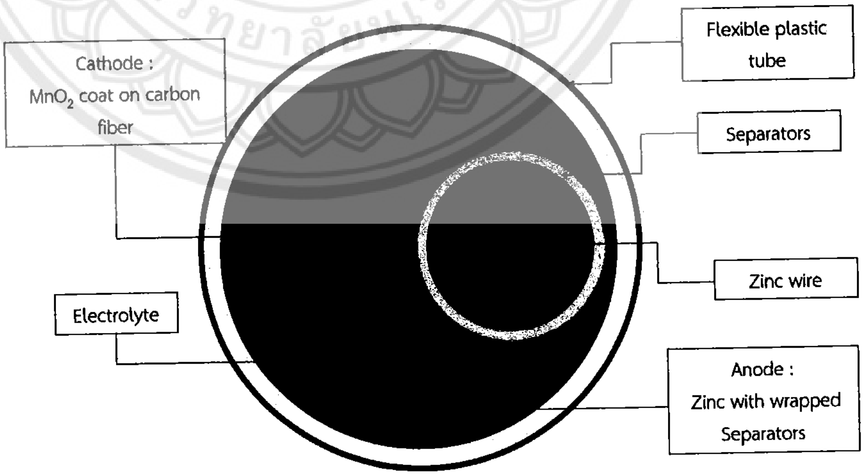


Fig. 3.3 The inside of flexible battery

Table 3.1 Material, size and mass

Materials	**Length (cm)**	**Radius**		**Mass(g)**
		Diameter Outside (cm)	**Diameter Inside (cm)**	
Carbon Fiber	10	0.01	-	0.01
Zinc Wire	10	0.019	-	0.081
MnO_2	10	0.012	0.01	0.004
Heat-shrink Tube	9	0.15	0.13	0.013

The size, material and mass are shown in table 3.1 and 3.2. The separators were soaked in different KOH concentrations (1, 3, 6 and 9M). All components were assembled and sealed in between flexible plastic tube by Epoputty.

Table 3.2 Separators

Materials	Length (cm)	Width (cm)	Thickness(cm)	**Mass(g)**
Polymer membrane	12	0.7	0.010	0.005
filter paper	12	0.7	0.038	0.130
Pipe thread tape	12	0.7	0.025	0.031

3.1.2 Preparation of Electrode

3.1.2.1 Anode electrode

Zinc wire wrapped with a separator was immersed in KOH solution. The weight of Zn is 0.081 g have capacity 0.0656 Ah

3.1.2.2 Cathode Electrode

MnO_2 was coated on carbon fiber by boiled it in $KMnO_4$ (50 ml) at a temperature of 70 °C (2 hr).

3.1.3 Preparation of Electrolyte

Table 3.3 shows the amount of KOH used to prepare different concentrations. 0.3ml of solution was used in each battery.

Table 3.3 Preparation of Electrolyte

Concentration	DI Water (ml)	KOH(g)
1M	2	0.112
3M	2	0.336
6M	2	0.672
9M	2	1.008

3.1.4 Capacity

Capacity is the amount of charge (Coulomb) that can be used under specific time. It can be calculated using Faraday's law. In this experiment, the battery should have a capacity of 0.0656 Ah.

3.2. Materials and Equipment

3.2.1 Materials for Manufacturing

a. Heat-shrink tube
b. Carbon fiber
c. Zinc wire
d. Polymer membrane
e. Filter paper
f. Epoputty
g. Pipe thread tape

3.2.2 Chemical

a. Manganese dioxide
b. Potassium hydroxide

3.2.3 Equipment to Analyze Voltage and Current.

a. Multimeter
b. LED 20 mA

3.2.4 Device for Testing Bending

Bending Machine

3.3 Effects of Separators

Material used as separators affect voltage. We first tested different types of materials (polymer membrane, filter paper, pipe thread tape shown in figure 3.4, 3.5, 3.6) to identify the best candidate, which should yield the highest voltage value. To be used as separator. In this study, polymer membrane, filter paper and pipe thread tape were used at various KOH concentrations ranging from 1 M to 9 M. This experiment was repeated 3 times for each separator. Multimeter was used to read out voltage of the battery. The measurements were carried out for 4 hr.

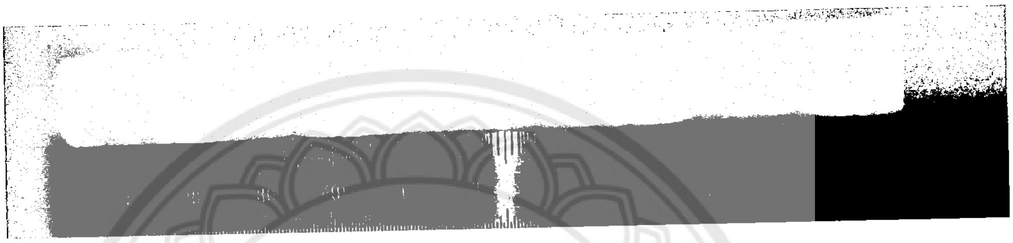


Fig. 3.4 Polymer membrane

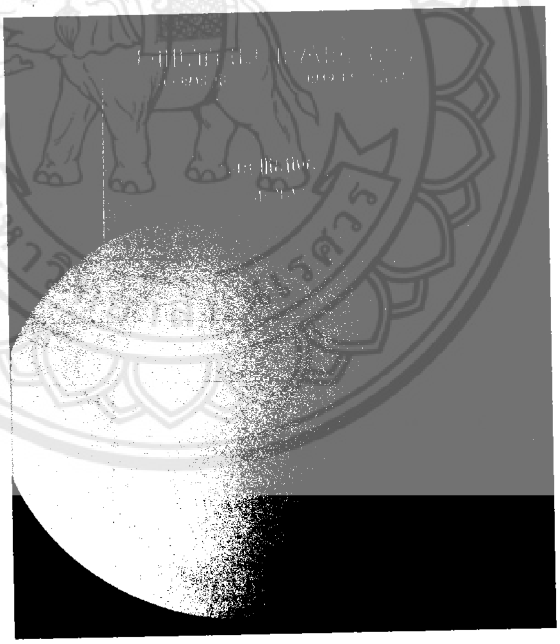


Fig. 3.5 Filter paper

Fig. 3.6 Pipe thread tape

3.4 Effects of KOH Concentration

In this study, the concentration of KOH was varied ranging from 1 M to 9 M. The mass of KOH and volume of water used at each concentration and voltage to the calculations of the equation 2.11 are shown in table 3.4.

Table 3.4 Electrolyte of KOH

Electrolyte	Concentration(M)	ml	Voltage of calculate (V)
KOH	1	0.3	1.605
KOH	3	0.3	1.619
KOH	6	0.3	1.629
KOH	9	0.3	1.633

Multimeter was used to read voltage of the battery every 15 minute for 4 hours. Voltage change with respect to time was plotted.

3.5 Effects of Bending Angle

Bending tests at different angles (0°, 30°, 45°, 60° and 90°) were carried out to analyze the performance of battery. A custom-made set-up as shown in figure 3.7, 3.8, 3.9, 3.10 and 3.11 were used for bending test.

After analyzing the effects of separators at different concentrations, batteries with best performances was chosen for bending test. Voltage readings was recorded every 15 minute for 4 hr. Changes in voltage with respect to time were plotted.

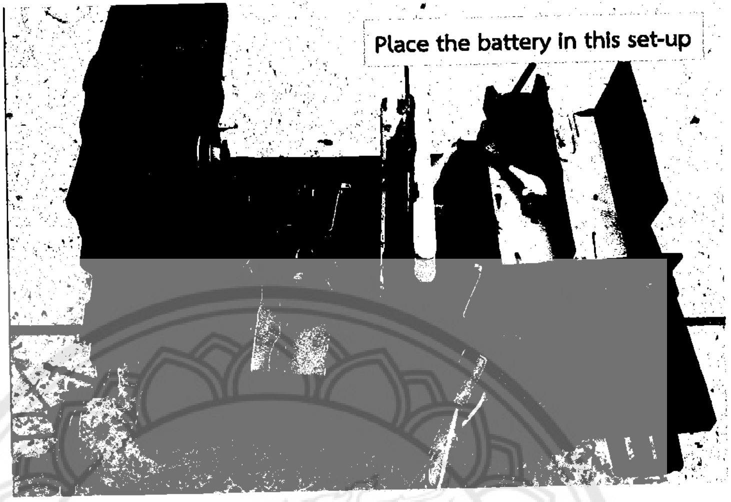


Fig. 3.7 Bending Machine

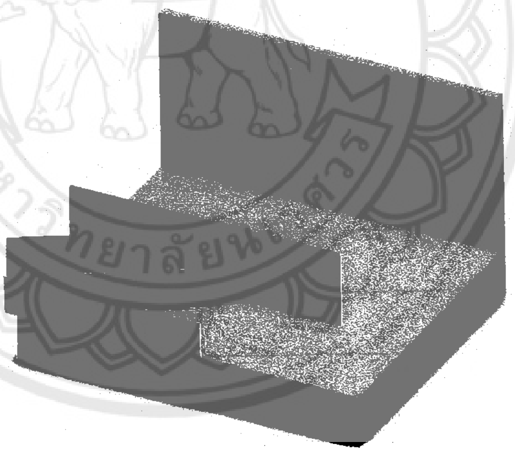


Fig. 3.8 Simulation of the bending 30 degrees.

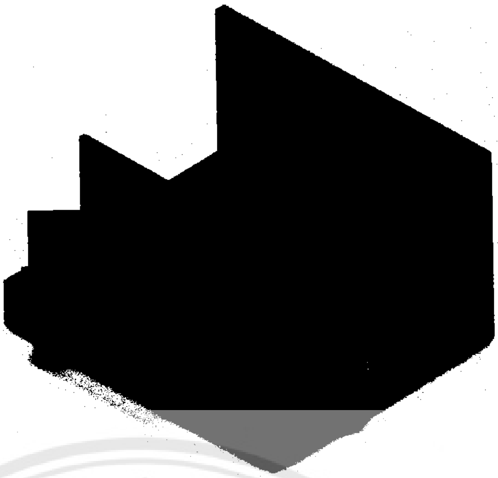


Fig. 3.9 Simulation of the bending 45 degrees.

Fig. 3.10 Simulation of the bending 60 degrees.

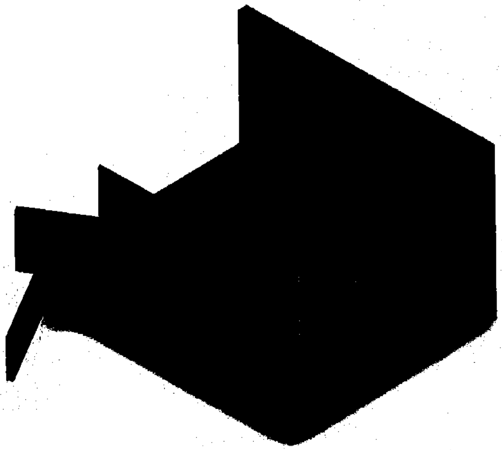


Fig. 3.11 Simulation of the bending 90 degrees.

3.6 Data Collection

3.6.1 Voltage of 3 separators

3.6.2 Voltage of Battery (1, 3, 6 and 9M)

3.6.3 Voltage of Battery (The best) + LED

3.6.4 Voltage of Battery (The best) bending 30 degree

3.6.5 Voltage of Battery (The best) bending 45 degree

3.6.6 Voltage of Battery (The best) bending 60 degree

3.6.7 Voltage of Battery (The best) bending 90 degree

3.7 Analysis and Conclusion

After collecting data from different conditions, voltage and current were analyzed to select the best conditions. Performances of the best batteries under bending test were analyzed and discussed.

Chapter 4

Results and Discussion

4.1 Effects of Separators

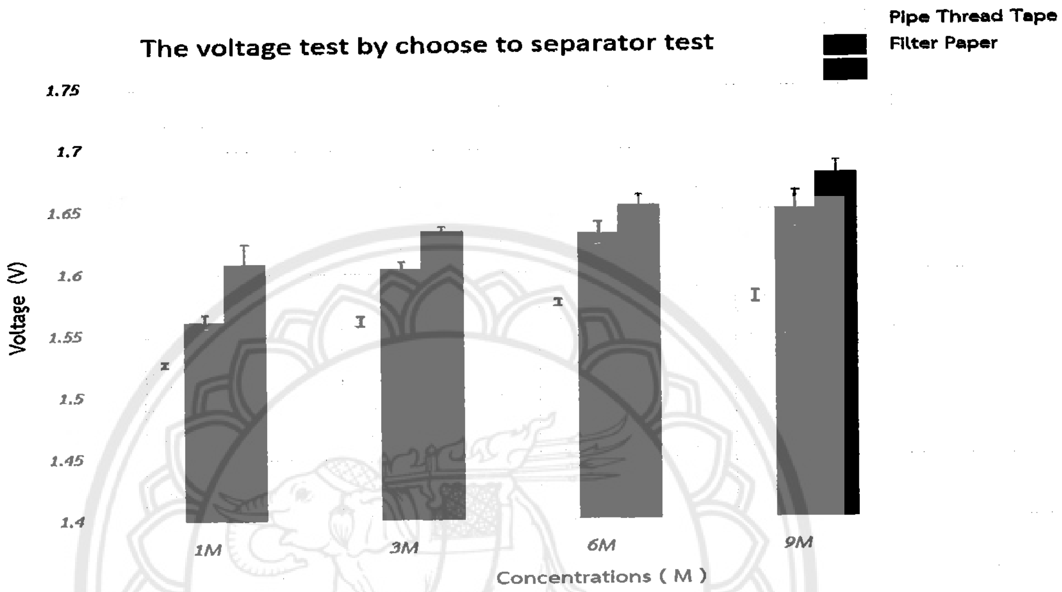


Fig. 4.1 Effects of separators at different KOH concentration on voltage of batteries

Figure 4.1 shows the voltages measured from batteries using different separators at 1, 3, 6 and 9M concentration of KOH. It clearly showed that highest voltage (1.679 V) is from those batteries that were made of polymer membranes at the KOH concentration of 9M. Batteries made of polymer membranes have highest voltage value because the polymer membranes possess the minimum thickness (Figure 4.2), meaning ions can transport better.

4.2 Effects of KOH Concentration

Figure 4.3 shows the effect of KOH at 1, 3, 6 and 9 M on the voltage of flexible batteries. It can be seen that at the concentration of 9 M, the voltage rate of decrease is minimum, and the voltage is stable above 1.5 V during 1 hour of testing.

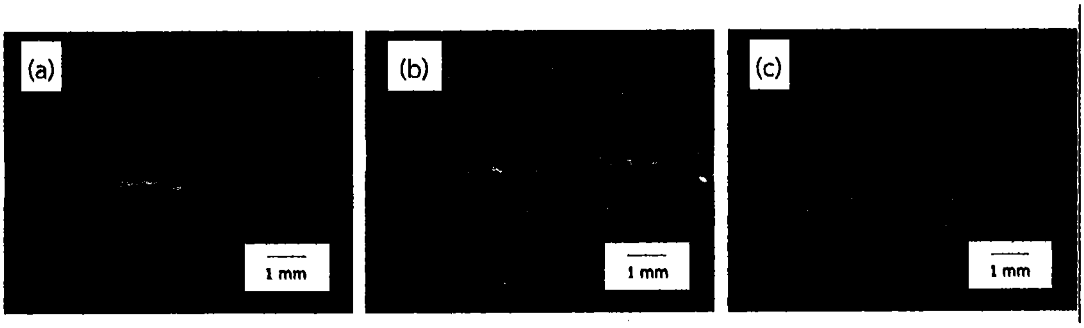


Fig. 4.2 Macrostructure of separators
(a) Polymer membranes
(b) Filter paper
(c) Pipe thread tap

When the KOH concentration decreases, the voltage drops about 0.686% after 15 minute and 3.991% after 30 minutes. While the voltage of batteries using 9 M is steadily decreasing after 120 minutes, the voltage of batteries at other conditions decreases more rapidly. Lower voltages than the high concentration.

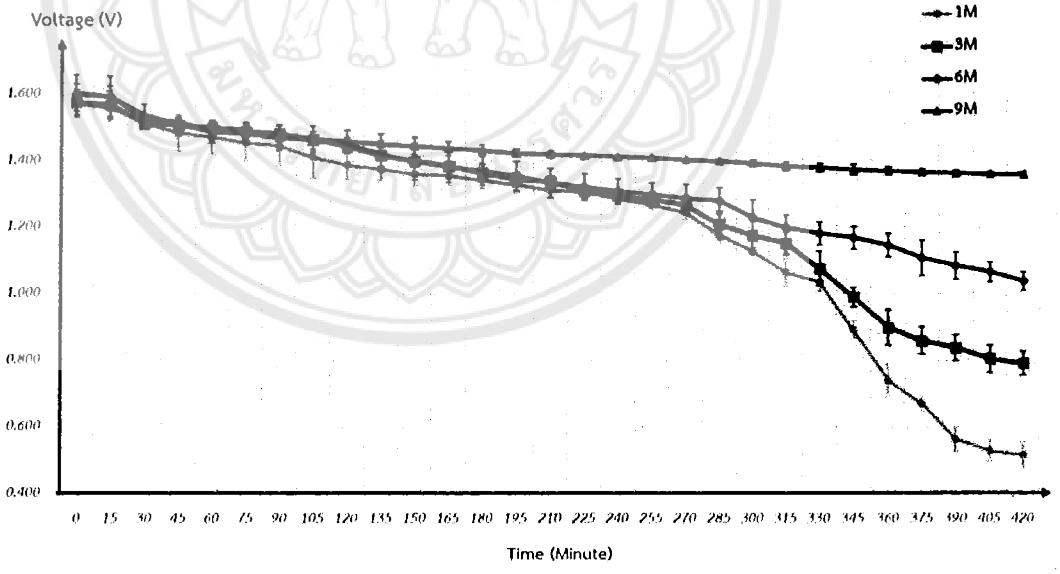


Fig. 4.3 Effects of KOH concentration

When the concentration of electrolyte increases, the amounts of K^+ and OH^- ions available in the solution are also increasing, promoting higher reaction rate and resulting higher voltage at higher electrolyte concentrations.

Table 4.1 voltage of experiment

Concentration (M)	Average experiment (V)
1M	1.560
3M	1.567
6M	1.600
9M	1.604

The measured voltages from our experiments (Table 4.1) are in good agreement with the theoretical calculation shown in table 3.3.

The experimental measured voltages are lower than the calculated ones due to resistance at contacts and intrinsic resistance of electrolyte and separator material.

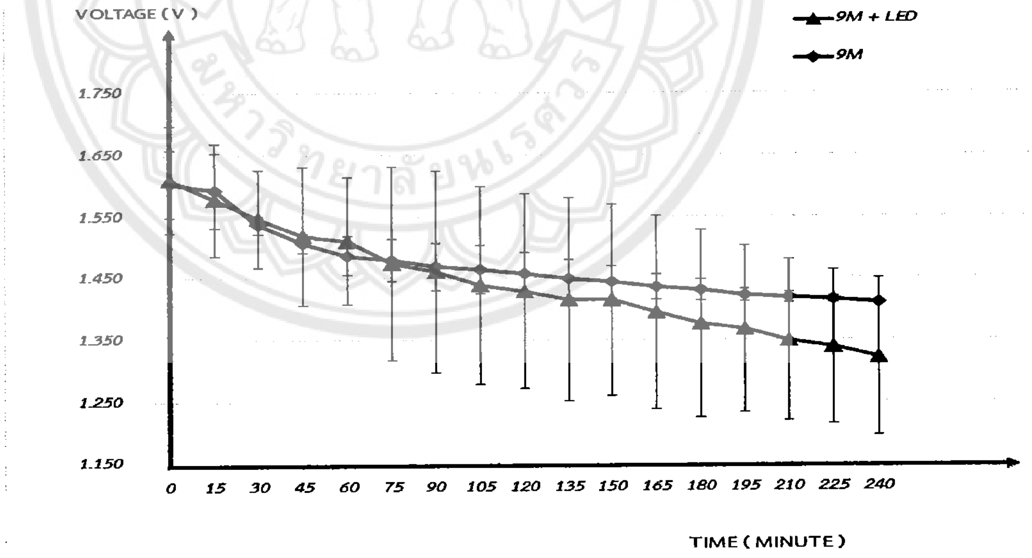


Fig. 4.4 Voltage of Battery 9M+LED

Figure 4.4 shows voltage drop when we connected the 9 M batteries with a 20mA LED. It can be seen that the voltage reduced more rapidly when it is connected to the LED. Without LED, the electrons are accumulated at the two electrodes causing an imbalance between the two poles, which is seen as voltage. But when the LED is connected with a battery, electrons are used to power up the LED, causing decrease in voltage.

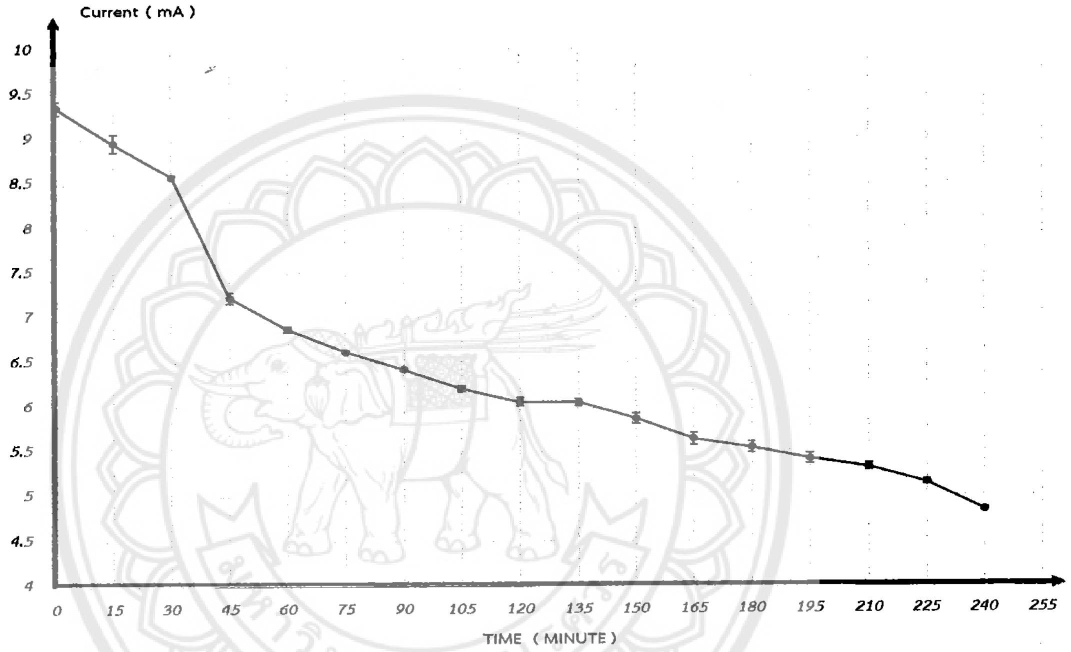


Fig. 4.5 Current of Battery 9+LED

Figure 4.5 shows current drop when we connected the 9 M batteries with a 20mA LED (0.3 watt). In the first 15 minutes, the LED lid up more but when the voltage below 1.585 V LED is lid up less same blackout. The 20 mA LED (0.3 watt) requires a voltage between 1.5 V-1.65 V and a current below or equal 20mA. The battery has a voltage of around 1.5 V-1.6 V and a current of around 9.5 mA

4.3 Effects of Bending Angle

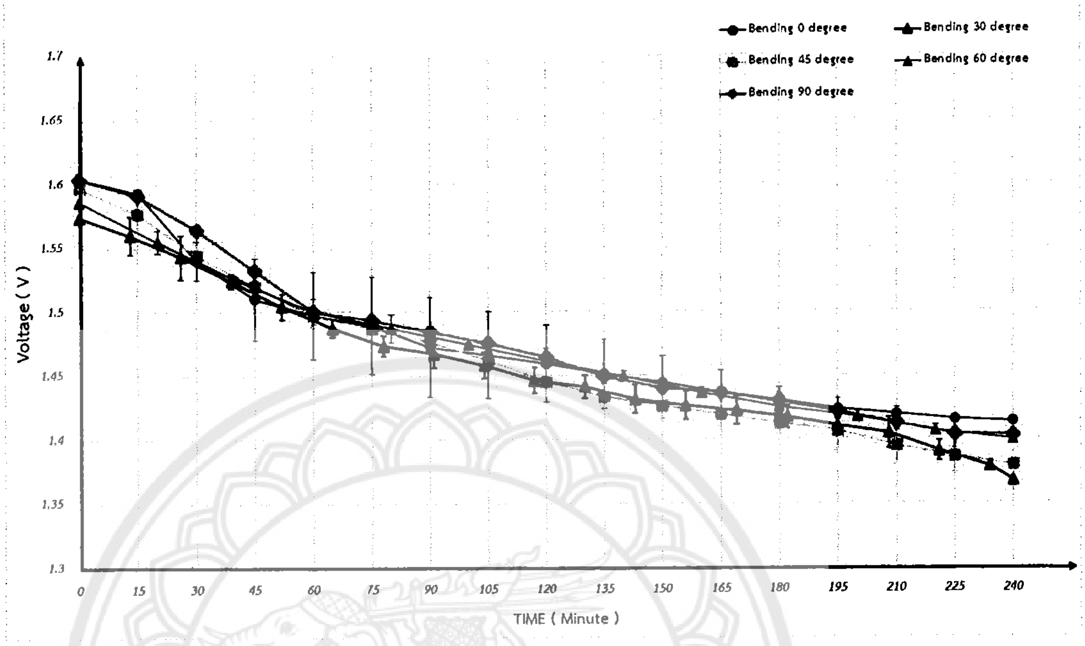


Fig. 4.6 Bending of Battery 9M

Figure 4.6 shows the voltage change at different under bending test at all degree angles at room temperature. It clearly shows that batteries performance does not affect by the bending. The reduction of the voltage during bending is similar to those that are not bending.

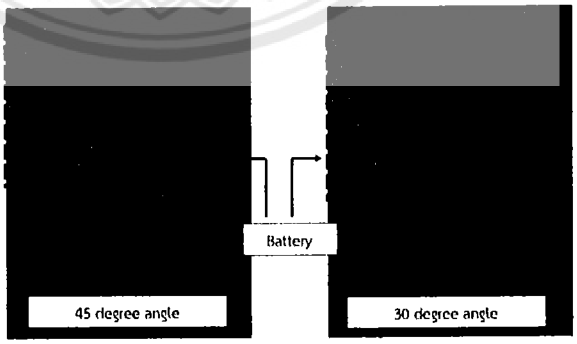


Fig. 4.7 Simulate Bending at 30,45 degrees angle (Top view)

Figure 4.7 and 4.8 shows that the 30° angle set-up could cause damage the most compared to the other three bending angles.

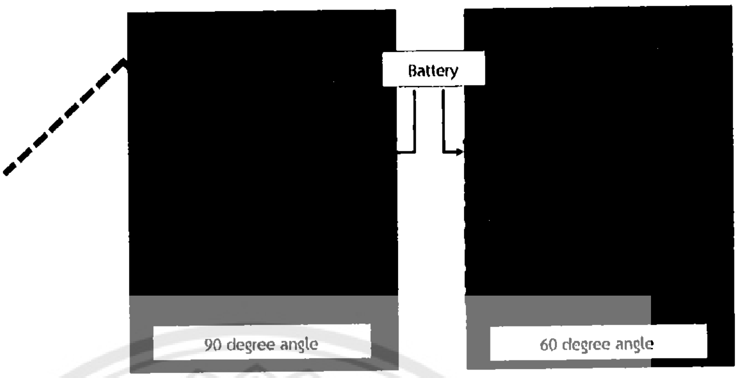


Fig. 4.8 Simulate Bending at 60,90 degrees angle (Top view)

Chapter 5

Conclusion and Recommendation

5.1 Conclusions

In conclusions, we found the batteries with best performances are those made of polymer membrane and 9.0 M potassium hydroxide. The batteries provide a voltage of 1.679 V. Flexible battery at 9M concentrations can be connected to a LED but it is not very bright because of their limited current of 9-10mA while LED requires a current 20mA. We also found that the voltage of flexible batteries is not affected by bending.

5.2 Recommendation

If we had more time on this project, we would like to improve the current of our flexible batteries by adjusting the weight of zinc electrode, and make the battery packaging more attractive. We would also want to improve our homemade bending set-up for better accuracy.

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Appendix A

The choose materials for using separators in all 4 concentrations

Table a.1 The voltage for separator test in all 4 concentrations

Concentrations	Material	Voltage (V)			Voltage Average	Standard Deviation
		1st	2nd	3rd		
1 Molarity	Polymer	1.607	1.592	1.625	1.608	0.017
	Pipe thread tape	1.528	1.525	1.529	1.527	0.002
	Filter paper	1.559	1.56	1.568	1.562	0.005
3 Molarity	Polymer	1.637	1.63	1.634	1.634	0.004
	Pipe thread tape	1.564	1.557	1.563	1.561	0.004
	Filter paper	1.6	1.602	1.61	1.604	0.005
6 Molarity	Polymer	1.66	1.658	1.645	1.654	0.008
	Pipe thread tape	1.578	1.572	1.575	1.575	0.003
	Filter paper	1.623	1.632	1.64	1.632	0.009
9 Molarity	Polymer	1.689	1.678	1.669	1.679	0.010
	Pipe thread tape	1.583	1.581	1.574	1.579	0.005
	Filter paper	1.64	1.644	1.666	1.65	0.014

Appendix B

The voltage test in all 4 concentrations in choose to make flexible battery

Table b.1 The voltage test of concentrations 1M

Concentration1M					
Time (min)	1st	2nd	3rd	1Molarity	Standard deviations
0	1.524	1.597	1.588	1.570	0.040
15	1.513	1.574	1.587	1.558	0.040
30	1.504	1.519	1.513	1.512	0.008
45	1.42	1.517	1.51	1.482	0.054
60	1.412	1.489	1.507	1.469	0.050
75	1.391	1.469	1.501	1.454	0.057
90	1.38	1.458	1.496	1.445	0.059
105	1.347	1.41	1.471	1.409	0.062
120	1.341	1.392	1.426	1.386	0.043
135	1.338	1.376	1.405	1.373	0.034
150	1.324	1.361	1.392	1.359	0.034
165	1.323	1.358	1.381	1.354	0.029
180	1.316	1.337	1.367	1.340	0.026
195	1.312	1.317	1.354	1.328	0.023
210	1.307	1.304	1.32	1.310	0.009
225	1.3	1.297	1.314	1.304	0.009
240	1.286	1.273	1.296	1.285	0.012

Table b.2 The voltage test of concentrations 3M

Concentration3M					
Time (min)	1st	2nd	3rd	3Molarity	Standard deviations
0	1.532	1.591	1.604	1.576	0.038
15	1.52	1.588	1.598	1.569	0.042
30	1.512	1.51	1.514	1.512	0.002
45	1.502	1.507	1.51	1.506	0.004
60	1.489	1.504	1.507	1.500	0.010
75	1.474	1.499	1.492	1.488	0.013
90	1.469	1.487	1.488	1.481	0.011
105	1.457	1.464	1.468	1.463	0.006
120	1.435	1..439	1.449	1.442	0.007
135	1.402	1.418	1.426	1.415	0.012
150	1.379	1.406	1.41	1.398	0.017
165	1.349	1.392	1.408	1.383	0.031
180	1.347	1.348	1.393	1.363	0.026
195	1.345	1.324	1.362	1.344	0.019
210	1.344	1.319	1.345	1.336	0.015
225	1.302	1.299	1.32	1.307	0.011
240	1.294	1.287	1.298	1.293	0.006

Table b.3 The voltage test of concentrations 6M

Concentration 6M					
Time (min)	1st	2nd	3rd	6Molarity	Standard deviations
0	1.564	1.62	1.615	1.600	0.031
15	1.556	1.612	1.61	1.593	0.032
30	1.518	1.534	1.526	1.526	0.008
45	1.501	1.521	1.528	1.517	0.014
60	1.456	1.506	1.502	1.488	0.028
75	1.448	1.498	1.497	1.481	0.029
90	1.439	1.485	1.495	1.473	0.030
105	1.43	1.471	1.478	1.460	0.026
120	1.424	1.458	1.463	1.448	0.021
135	1.378	1.435	1.448	1.420	0.037
150	1.335	1.419	1.437	1.397	0.054
165	1.327	1.398	1.418	1.381	0.048
180	1.323	1.375	1.409	1.369	0.043
195	1.309	1.356	1.396	1.354	0.044
210	1.289	1.331	1.378	1.333	0.045
225	1.278	1.328	1.356	1.321	0.040
240	1.264	1.321	1.335	1.307	0.038

Table b.4 The voltage test of concentrations 9M

Concentration9M					
Time (min)	1st	2nd	3rd	9Molarity	Standard deviations
0	1.54	1.635	1.637	1.604	0.055
15	1.523	1.625	1.632	1.593	0.061
30	1.511	1.545	1.565	1.540	0.027
45	1.497	1.515	1.517	1.510	0.011
60	1.481	1.501	1.509	1.497	0.014
75	1.469	1.499	1.5	1.489	0.018
90	1.437	1.497	1.483	1.472	0.031
105	1.428	1.495	1.476	1.466	0.035
120	1.425	1.484	1.468	1.459	0.031
135	1.421	1.477	1.454	1.451	0.028
150	1.419	1.469	1.443	1.444	0.025
165	1.418	1.457	1.434	1.436	0.020
180	1.416	1.447	1.428	1.430	0.016
195	1.415	1.433	1.421	1.423	0.009
210	1.413	1.427	1.416	1.419	0.007
225	1.412	1.419	1.415	1.415	0.004
240	1.41	1.415	1.414	1.413	0.003

Appendix C

Measurement current flexible battery at concentrations 9M and connection LED

Table c.1 The voltage test of concentrations 9M with LED connection

Concentration 9Molarity + LED				9Molarlity + LED	Standard deviation
Time (min)	1st	2nd	3rd		
0	1.511	1.668	1.654	1.611	0.087
15	1.473	1.632	1.629	1.578	0.091
30	1.455	1.591	1.595	1.547	0.080
45	1.388	1.585	1.582	1.518	0.113
60	1.392	1.571	1.569	1.511	0.103
75	1.294	1.567	1.563	1.475	0.156
90	1.272	1.558	1.554	1.461	0.164
105	1.253	1.536	1.527	1.439	0.161
120	1.247	1.521	1.519	1.429	0.158
135	1.225	1.512	1.508	1.415	0.165
150	1.235	1.507	1.502	1.415	0.156
165	1.213	1.482	1.487	1.394	0.157
180	1.201	1.467	1.460	1.376	0.152
195	1.211	1.449	1.439	1.366	0.135
210	1.198	1.428	1.421	1.349	0.131
225	1.195	1.409	1.411	1.338	0.124
240	1.175	1.387	1.402	1.321	0.127

Appendix D

The bending all 4 degree angle of flexible battery

Table d.1 The bending test at 30 degree angle

TIME (MINUTE)	Bending 30 degree			30 Degree angle	Standard deviation
	1st	2nd	3rd		
0	1.583	1.579	1.561	1.574	0.012
13	1.578	1.564	1.537	1.560	0.021
26	1.558	1.542	1.529	1.543	0.015
39	1.539	1.526	1.506	1.524	0.017
52	1.51	1.504	1.499	1.504	0.006
65	1.498	1.483	1.479	1.487	0.010
78	1.481	1.471	1.468	1.473	0.007
91	1.476	1.464	1.460	1.467	0.008
104	1.468	1.459	1.447	1.458	0.011
117	1.451	1.453	1.435	1.446	0.010
130	1.445	1.448	1.429	1.441	0.010
143	1.43	1.441	1.423	1.431	0.009
156	1.423	1.438	1.417	1.426	0.011
169	1.419	1.434	1.412	1.422	0.011
182	1.415	1.429	1.408	1.417	0.011
195	1.409	1.419	1.401	1.410	0.009
208	1.401	1.413	1.398	1.404	0.008
221	1.395	1.398	1.376	1.390	0.012
234	1.379	1.385	1.369	1.378	0.008
240	1.367	1.371	1.363	1.367	0.004

Table d.2 The bending test at 45 degree angle

TIME (MINUTE)	Bending 45 degree			45 Degree angle	Standard deviation
	1st	2nd	3rd		
0	1.6	1.592	1.599	1.597	0.004
15	1.587	1.568	1.576	1.577	0.010
30	1.553	1.534	1.544	1.544	0.010
45	1.524	1.51	1.526	1.520	0.009
60	1.501	1.491	1.498	1.497	0.005
75	1.496	1.479	1.487	1.487	0.009
90	1.485	1.468	1.476	1.476	0.009
105	1.469	1.456	1.461	1.462	0.007
120	1.448	1.437	1.449	1.445	0.007
135	1.435	1.42	1.443	1.433	0.012
150	1.429	1.415	1.434	1.426	0.010
165	1.423	1.408	1.426	1.419	0.010
180	1.417	1.401	1.417	1.412	0.009
195	1.413	1.395	1.409	1.406	0.009
210	1.406	1.375	1.400	1.394	0.016
225	1.392	1.369	1.397	1.386	0.015
240	1.384	1.364	1.388	1.379	0.013

Table d.3 The bending test at 60 degree angle

Concentration 6M					
Time (min)	1st	2nd	3rd	6Molarity	Standard deviations
0	1.564	1.62	1.615	1.600	0.031
15	1.556	1.612	1.61	1.593	0.032
30	1.518	1.534	1.526	1.526	0.008
45	1.501	1.521	1.528	1.517	0.014
60	1.456	1.506	1.502	1.488	0.028
75	1.448	1.498	1.497	1.481	0.029
90	1.439	1.485	1.495	1.473	0.030
105	1.43	1.471	1.478	1.460	0.026
120	1.424	1.458	1.463	1.448	0.021
135	1.378	1.435	1.448	1.420	0.037
150	1.335	1.419	1.437	1.397	0.054
165	1.327	1.398	1.418	1.381	0.048
180	1.323	1.375	1.409	1.369	0.043
195	1.309	1.356	1.396	1.354	0.044
210	1.289	1.331	1.378	1.333	0.045
225	1.278	1.328	1.356	1.321	0.040
240	1.264	1.321	1.335	1.307	0.038

Table d.4 The bending test at 90 degree angle

TIME (MINUTE)	Bending 90 degree			90 Degree angle	Standard deviation
	1st	2nd	3rd		
0	1.602	1.605	1.604	1.604	0.001
15	1.594	1.587	1.591	1.591	0.004
30	1.563	1.564	1.564	1.564	0.001
45	1.528	1.535	1.532	1.532	0.003
60	1.501	1.498	1.500	1.500	0.001
75	1.497	1.489	1.493	1.493	0.004
90	1.483	1.485	1.484	1.484	0.001
105	1.478	1.471	1.475	1.475	0.003
120	1.464	1.462	1.463	1.463	0.001
135	1.456	1.441	1.449	1.449	0.007
150	1.442	1.437	1.440	1.440	0.002
165	1.439	1.432	1.436	1.436	0.004
180	1.431	1.426	1.429	1.429	0.003
195	1.428	1.413	1.421	1.421	0.007
210	1.417	1.407	1.412	1.412	0.005
225	1.409	1.397	1.403	1.403	0.006
240	1.397	1.395	1.415	1.402	0.011