COMPARATIVE SUSTAINIBILTY EVALUATION ON REGENERATED INDUSTRIAL NICKEL-CADMIUM BATTERY BASED ON LIFE-CYCLE ASSESSMENT METHOD

MARILYN PAYA MARTIN

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ABSTRACT

Nowadays, rapid growth of used rechargeable batteries such as Nickel-Cadmium (Ni-Cd) battery in industries has its own prominent role in certain niche applications. Examples of such applications are in emergency backup, telecommunications and electrical vehicles (EV). Therefore, the evaluation on the performance characteristics of Ni-Cd battery using regeneration method is discussed in this study. Meanwhile, the evaluation on the battery waste management using Life Cycle Assessment (LCA) method and Life Cycle Cost Assessment (LCCA) method on Ni-Cd battery for environmental impact analysis is presented in this study. Principally, the performance of the Ni-Cd battery deteriorates with time due to the process of charging and discharging during the usage of the Ni-Cd battery where crystalline formed on the surface of the battery plate. Hence, high current pulses technique is selected as battery regeneration process (de-crystallization) to break the formed crystalline to recover back the capacity loss and enhanced the performance of Ni-Cd battery. The results show that, the capacity of the Ni-Cd battery increased up to 22% of its capacity after the de-crystallization take place by injecting high current pulses. For Ni-Cd battery waste management, recycling method and battery regeneration method are selected as ways to dispose Ni-Cd battery waste. Therefore, the impact of the selected method for used Ni-Cd battery waste disposal in terms of percentage carbon footprint and cost involved using LCA and LCCA method respectively is evaluated by using SimaPro software. The selected system boundary for the study is gate to gate. Based on the obtained results, it is shown that battery regeneration method is more environmental friendly and economic which produce 24% of carbon footprint and can save up to 87% of process cost and environmental cost than recycle method. Lastly, this study also presented a proposal on the management of the battery waste in order to improve the current way of the battery disposal management and guidance for future works.

ABSTRAK

Pada masa kini, pertumbuhan pesat bateri boleh dicas semula terpakai seperti bateri Nikel-Kadmium (Ni-Cd) dalam industri mempunyai peranan tersendiri dalam aplikasi tertentu. Contoh aplikasi tersebut adalah dalam sokongan kecemasan, telekomunikasi dan kenderaan elektrik (EV). Oleh itu, penilaian terhadap ciri-ciri prestasi bateri Ni-Cd dengan menggunakan kaedah penjanaan semula telah dibincangkan dalam kajian ini. Manakala, penilaian terhadap pengurusan sisa bateri menggunakan kaedah penilaian kitaran hidup (LCA) dan penilaian kos kitaran hidup (LCCA) terhadap bateri Ni-Cd bagi menganalisis kesan alam sekitar telah dibentangkan dalam kajian ini. Pada prinsipnya, prestasi bateri Ni-Cd semakin merosot mengikut edaran masa disebabkan oleh proses pengecasan dan nyah cas semasa penggunaan bateri Ni-Cd di mana terhasilnya kristal pada permukaan plat bateri. Oleh itu, teknik denyutan arus tinggi dipilih sebagai proses penjanaan semula bateri (nyah-penghabluran) untuk memecahkan kristal yang terbentuk bagi memulihkan semula kehilangan kapasiti dan meningkatkan prestasi bateri Ni-Cd. Keputusan menunjukkan bahawa, kapasiti bateri Ni-Cd meningkat sehingga 22% daripada kapasitinya selepas penyah-habluran berlaku dengan menyuntik denyutan arus tinggi. Untuk pelupusan sisa bateri Ni-Cd, kaedah kitar semula dan kaedah penjanaan semula bateri telah dipilih sebagai cara untuk melupuskan sisa bateri Ni-Cd. Oleh itu, kesan kaedah yang dipilih untuk pelupusan sisa bateri Ni-Cd terpakai dari segi peratusan jejak karbon dan kos yang terlibat dengan menggunakan kaedah LCA dan LCCA telah dinilai dengan menggunakan perisian SimaPro. Sempadan sistem yang dipilih untuk kajian adalah get ke get. Berdasarkan keputusan yang diperoleh, kaedah penjanaan semula bateri telah menunjukkan lebih mesra alam dan ekonomi di mana telah menghasilkan 24% jejak karbon dan jimat sehingga 87% kos proses dan kos alam sekitar berbanding dengan kaedah kitar semula. Akhir sekali, kajian ini juga membentangkan cadangan pengurusan sisa bateri bagi menambah baik cara pengurusan pelupusan bateri semasa dan panduan untuk masa hadapan.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	–	Ampere
AH	–	Ampere Hour
Cd	–	Cadmium
$Cd(OH)_2$	–	Cadmium Hydroxide
CO_2	–	Carbon Dioxide
DOE	–	Departmental of Environment
E	–	Energy
ε	–	Electro Magnetic Field
e-waste	–	electronic-waste
GHG	–	Green House Gases
GWP	–	Global Warming Potential
I	–	unit for current
LCA	–	Life Cycle Assessment
LCCA	–	Life Cycle Cost Assessment
LCIA	–	Life Cycle Impact Assessment
Ni	–	Nickel
$Ni(OH)_2$	–	Nickel Hydroxide
NiOOH	–	Nickel Hydroxyl-Oxide
Q	–	unit for charge
R	–	Resistance
SLI	–	Starting, Lighting and Ignition
UPS	–	Uninterruptible Power Supply
V	–	Voltage
W	–	Watt
Wh	–	Watt Hour
Ω	–	Ohm

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CHAPTER 1

INTRODUCTION

1.1 Project background

The development of devices using power sources in the form of rechargeable batteries is increasing annually because of the usage of the rechargeable batteries for various applications are critical. Ni-Cd batteries is one of the secondary batteries that have used in massive applications in different industrial area especially in hybrid power generation and telecommunication as backup power supply due to their high performance and able to recharge rapidly [1]. Moreover, the Ni-Cd battery have high energy density. Compared to other dominant types of rechargeable batteries that have been used in as backup power supply which are lithium-ion battery, lead-acid battery and Ni-MH battery, Ni-Cd battery is more reliable as it has long life. The normal lifetime of a Ni-Cd battery, in a typically harsh environment back-up power application, is in the range of 15 to 20 years [2-3].

According to the Global Market Insights and Projections [4], it is reported that the trend of the global consumer battery market especially Ni-Cd battery is increase which is shown as in Figure 1.1. In 2018, the Ni-Cd battery size was 40 billion US dollar which then forecast to reach 70 billion US dollar. The global battery consumption is anticipated to increase five-fold in the next ten years [4].

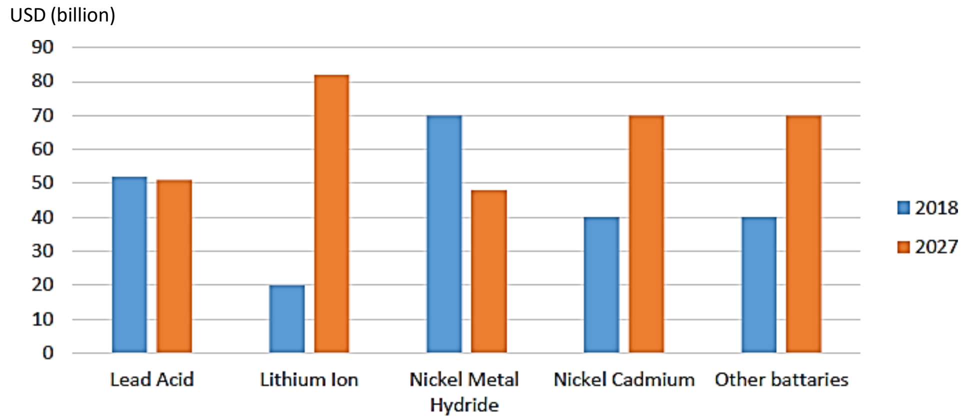

Figure 1.1: Statistic of battery global market. [4]

Battery is a technology that capable to transform chemical energy to electrical energy. The energy stored in the battery is used through the process of oxidation-reduction where the movement of the electron produced an electromotive force which also known as voltage [5]. Primary and secondary batteries are the two types of batteries. As the active components are depleted when the cell discharges, primary batteries can only be used once and discarded once it has been totally depleted. Meanwhile, secondary batteries can be recharged multiple times since the chemical reaction that produces electrical energy can be reversed.

However, the performance of the Ni-Cd batteries degraded over period after undergo charging and discharging process due to the formation of crystalline [5-8]. Formation of crystalline is main factor [5-8] that caused the Ni-Cd battery performance degraded. Others issues which are internal resistance, battery plates corrosion, increment of battery temperature, memory effect are effected by the formation of crystalline. Crystallization is an electrochemical reaction that occurs when the Ni-Cd battery in discharge state that build gradually on the battery cell plates [12-13]. During the discharging process, the Nickel-Hydroxide in state of liquid is transform into solid crystalline and formed on the plate surface of the battery [9-10]. As the formation of the crystalline builds, it caused the surface area of the battery plate is reduced and act as insulator. This condition prevent the Ni-Cd battery to deliver the current effectively and thus result the internal resistance of the Ni-Cd battery rises. As a consequence, the battery temperature increased [11-14]. The Ni-Cd battery's capacity was reduced as a result of this condition, as well as its life expectancy was shortened as a result [15-17]. The formation of the crystalline also contribute as factor that cause the memory effect in the Ni-Cd battery [18-19] as the battery is recharged repeatedly after being only partially discharged.

When the lifetime of the used Ni-Cd battery will reach to its end after a long period of time and defined as dead battery where the condition of the battery unable to deliver electricity. These dead batteries will be discarded and categorized as one of the electronic waste or e-waste. According to the Malaysian e-waste inventory project [20], the amount of e-waste is growing at a rate of 14% every year, and by 2020, 1.17 billion units or 21.38 million tons of e-waste would have been generated. Currently, most of these dead batteries will be recycled although that recycling process has great negative impact to the environment where it can contribute to air pollution. During the recycling process of dead batteries, large amount of smoke is emitted into the air due to the burning huge portion of the metals in an open furnace. This condition contributes to high content of dioxin and cause air pollution. In recycling process, it is estimated 35.45% - 77.85% of reusable and recyclable materials can be obtained from the repair or reassembling processes, 50% - 92.65% can be obtained from the dismantling process while 70.3% to 99.92% from the recovery process [20]. Non- hazardous residues from the repair or reassembling process, dismantling process, and recovery process are disposed in municipal landfills or other methods, whereas hazardous residues are disposed by the registered scheduled waste contractors licensedby the Department of the Environment (DOE). The materials recovered are sold as raw materials to be reprocessed into new components.

Although there has been a significant improvement in the efficiency of rechargeable battery recycling, there is still factors that need to concern throughout the process on the environmental impact [21-24]. The current scenario indicates that spent and dead Ni-Cd batteries will be recycled, despite the fact that the recycling process has a substantial environmental impact. Year after year, the practice of recycling batteries has grown, contributing to the planet's dying factor such as Global Warming Potential (GWP), water pollution, land pollution and damaged to the ecosystem. Therefore, the preferred approach to evaluate the environmental impact of product systems by implementing life-cycle assessment (LCA). LCA is an analysis technique to assess environmental impacts associated with all the stages of a product's life cycle, which is from raw material extraction through materials processing, manufacture, distribution, and use until to waste treatment [45]. This tool could analyse the complete life cycle for multiple scopes, such as cradle to gate, or it can focus on a specific section, such as gate-to-gate. LCA applications include product benchmarking, making a comparison for a specific good or service, environmental labelling, and many others [43]. LCA analysis using current software such as SimaPro can generate a report on global warming potential (GWP) and life cycle impact assessment (LCIA).

The idea of carbon dioxide equivalent, CO^2-equivalent, is used in GWP to standardize carbon dioxide and other GHG emissions from human activities [46]. This method represents different GHGs relative to carbon dioxide such that they can be measured using the same unit of measurement [27]. Issues on GHGs has become popular topic among the researcher as Asia has become the world largest source of GHG emissions, which are linked to global warming and climate change. Figure 1.2 shows the GHGs emission intensity per capita in which China is the largest GHG emitter in Asia.

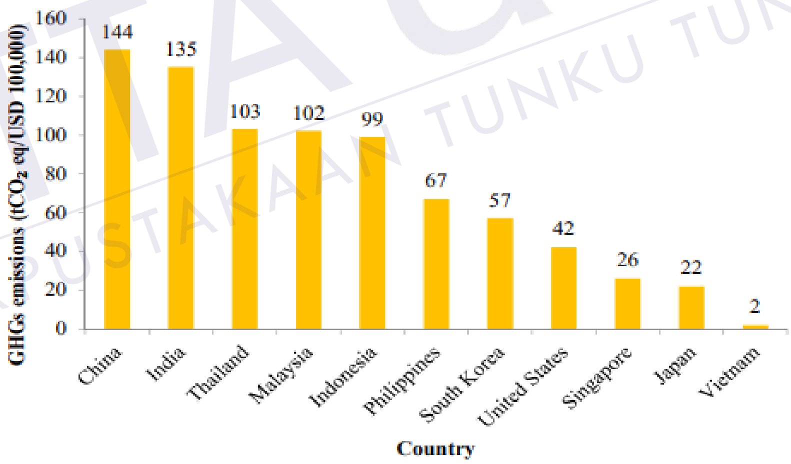

Figure 1.2: GHGs emissions intensity per capita in Asia countries [28].

Therefore, this study focused on enhancement of Ni-Cd battery performance by using regeneration technology where the formed crystalline is break by using principle of high current pulses. Besides performing analysis on the performance of the Ni-Cd battery, this study also focused on the life cycle assessment on the selected disposal method of waste dead Ni-Cd battery which are through conventional recycling process and regeneration process. Life cycle assessment comparison between these two methods is evaluated and discussed in this study.

1.2 Problem statement

The performance of Ni-Cd battery decrease over period of time due to the formation of crystalline on the surface of the battery plate during the process of charging and discharging occurred. This condition will lead to the efficiency of the current and voltage transfer in Ni-Cd battery decrease and shorten the life span of the Ni-Cd battery. Moreover, the crystallization condition also may cause the Ni-Cd battery to have memory effect. Therefore, the process of de-crystallization is required. One of the ways is using the conventional way where additives such as carbon powder, carbon nanotubes, titanium dioxide, glass fibres, silicon dioxide, aluminium oxide and boric acid [28-32] is added. However, one of the disadvantages of this conventional way is it may give negative impact to the environment and human as involved the usage of chemical substances. Other than that, the application of low current and high current pulses method to restore the capacity of the batteries is also possible [33-34]. However, these methods have own merits and demerits in terms of the effectiveness of the technique. Therefore, in this study, de-crystallization with technique of high current pulses is chosen as study focus where the injected high current pulses force the electrons at the battery plate move and chemical reaction occurs. Besides, technique of high current pulses able to break soft and hard crystalline. However, one of the demerits of this technique is it may cause the risen of the battery temperature during the de-crystallization process. To generate high current pulses during de-crystallization, a power converter [43] [44] is considered to generate DC pulses as the main power supply from the main grid in AC state.

As the rapid growth of used of the Ni-Cd battery in the industries, it is important to have good battery management system in order to avoid escalating of waste battery disposal which can cause negative impact to the environment. Exampleof negative environmental impact that caused by disposal of waste battery are river pollution, land-disturbing pollution and air pollution. For Ni-Cd battery waste disposal, recycling method and battery regeneration method is selected as way to dispose Ni-Cd battery waste. Therefore, the impact of the selected method for used Ni- Cd battery waste disposal in terms of percentage carbon footprint and cost involved byusing method Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA) respectively is evaluated by using SimaPro software. The selected system boundary for the study is gate to gate.

1.3 Hypothesis

Based on the objectives, the first hypothesis of the research is as the performance of the Ni-Cd battery in terms of battery cell voltage, battery cell current, battery capacity degraded, the battery discharged time taken become longer. The second hypothesis of this research is as the amount of greenhouse gases (GHG) is high on the selected method for used Ni-Cd battery waste disposal, the percentage of carbon footprint produced is higher. The third hypothesis of this research is as the consumption of electricity on the selected method for used Ni-Cd battery waste disposal is high, the impact on the process cost and environmental cost is increase.

1.4 Aim

The aim of this research is to evaluate and compare the performance of the Ni-Cd battery in terms of battery cell voltage, battery cell current, battery capacity and battery discharged time during before and after it undergo regeneration process. Besides, the aim of this research is to evaluate the environmental impact on the selected method for used Ni-Cd battery waste disposal in terms of carbon footprint where low carbon footprint impact will help reduce the involved process cost and environmental cost on Ni-Cd battery waste disposal. This research also proposed propose battery waste management policy to help reduce disposal of waste Ni-Cd battery.

1.5 Objectives of study

The objectives of this study is listed as following:

1. To design and evaluate the performance characteristics of Ni-Cd battery in terms of battery cell voltage, battery cell current, battery capacity with high current pulses battery regeneration technology.

2. To analyze and compare the impact of carbon footprint on Ni-Cd battery waste management which are through conventional recycling process and regeneration process based on Life Cycle Assessment (LCA) method.

3. To analyze and compare the involved cost which are process cost and environmental cost on the Ni-Cd battery waste management based on Life Cycle Cost Assessment (LCCA) method and propose battery waste management policy.

1.6 Scope of study

The scope of the study is listed as following:

1. The design circuit is simulated by using MATLAB simulator for both charging and discharging process according to the specifications of Ni-Cd battery in datasheet.

2. The study is focus on the characteristic performance of Ni-Cd battery during the process of charging and discharging. The main parameters to be observe are battery cell voltage, battery state of charge and battery current.

3. The parameters which are battery cell voltage, battery discharged time and battery capacity are selected to obtain the result of the regenerated Ni-Cd battery.

4. The model of the involved machine during the regeneration process are RNC48100(charger machine), RCL4830 (discharger machine) and MACBATEC Midi (regenerator machine).

5. The technique of high current pulses (maximum current is 450 A) is chosen for the capacity restoration of the Ni-Cd battery.

6. For evaluation of the life cycle assessment and life cycle cost assessment of disposal method of waste Ni-Cd battery, the selected functional unit is 700kg Ni-Cd batteries and chosen system boundary is gate to gate.

7. SimaPro simulator is used for the Ni-Cd waste battery environmental impact in terms of carbon footprint to determine the Global Warming Potential (GWP)

8. The selected applied database in SimaPro simulator is Ecoinvent 3.7.1.

9. (GWP) index to identify the level of impact on the environment caused by each method.

10. For the Life cycle impact assessment (LCIA), method ReCiPe is chosen to analyse the environmental impact by the Ni-Cd waste battery.

1.7 Thesis Outline

This written report contains six chapters. The first chapter of this report is the introduction which includes the project background, problem statements and the objectives of this project. The scope of study and report outline is also incorporated in this chapter.

The second chapter of this report is literature review which emphases on studying mentioned researches or works that relates to the scope of this study. This chapter discussed on the characteristics of the Ni-Cd battery and its performance, background on the applied life cycle assessment (LCA) and life cycle cost assessment (LCCA).

The third chapter of this report is the methodology of this study. It will go into detail of the concept of battery regeneration and process of implementation of life cycle assessment (LCA) and life cycle cost assessment (LCCA).

The fourth chapter of this report is on results and discussions. This chapter deliberates about the performance of the Ni-Cd battery during before and after its undergo regeneration process. Besides, the outcome on the life cycle assessment (LCA) and life cycle cost assessment (LCCA) of the study also discussed.

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APPENDIX F

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APPENDIX G

VITA

The author was born in March, 1996, in Sarawak, Malaysia. She went to Sekolah Menengah Sains, Miri, Sarawak, Malaysia for her secondary school. Then, she pursued her study at Labuan Matriculation College (KML) in Labuan, Malaysia. She holds a Bachelor Degree in Electrical Engineering with honours in 2019 from University Tun Hussein Onn Malaysia (UTHM), which is located in Batu Pahat, Johor. She then enrolled again at the University Tun Hussein Onn Malaysia in the Department of Electrical Power under the Faculty of Electrical and Electronic Engineering (FKEE) as a Graduate Research Assistant (GRA). Her current research includes power electronics in management of battery which aims for enhance life spent of rechargeable batteries.