LIFE CYCLE ASSESSMENT OF AN ELECTROLESS NICKEL PLATING WASTEWATER TREATMENT PLANT

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This entire research is dedicated with deepest love to my dearest parents, sisters, family, and Izad.
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May Allah give you the best reward and may the blessings of Allah be upon you.

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ABSTRACT

Electroless nickel plating industry has been a well-known industry compared to other types of electroplating industry. This method of coating practice yields better coating properties. Life Cycle Assessment (LCA) is being proposed to assess and quantify the environmental impacts of the treatment processes which include physical, chemical and biological treatments to identify the hotspot (weak point) in the treatment processes. The methodology of this study followed the basis of International Organization for Standardization (ISO) 14040 - series framework. Life Cycle Inventory (LCI) table was completed by data collection from a plant and added with chemical analysis. The assessment was conducted using GaBi software and Life Cycle Impact Assessment (LCIA) method is referred to ReCiPe method (RIVM, Radboud University, CML and Pré Consultants). Both problem-oriented and damage-oriented methods were assessed and chemical treatment process showed higher impacts in important categories like climate change, acidification and human toxicity. This caused the process to be the hotspot in this wastewater treatment plant. The results for problem-oriented are 1553 kg CO_2 equivalent, 5.8 kg SO_2 equivalent, and 5.4 kg 1,4 dichlorobenzene (1,4-DB) equivalent respectively and results for damage-oriented are 2.17 x 10^{-3} DALY (Disability Adjusted Life Years), 3.36 x 10^{-8} species.yr and 3.80 x 10^{-6} DALY respectively when compared to the other treatment processes. This was due to the usage of chemicals in the chemical treatment which is significantly higher than in other processes. Hence, two different scenarios were suggested and assessed in order to reduce the environmental impacts of this conventional wastewater treatment. The scenarios include using the chitosan in chemical treatment process and replacing the chemical treatment process with wet air oxidation process. Both processes showed less environmental impacts than the conventional chemical treatment process in the wastewater treatment plant.

ABSTRAK

Industri penyaduran nikel secara tanpa elektrik merupakan industri yang terkenal berbanding industri penyaduran elektrik yang lain. Kaedah penyaduran ini menghasilkan ciri-ciri saduran yang lebih bagus. Penilaian Kitar Hayat (LCA) dicadangkan untuk menilai dan mengukur kuantiti impak alam sekitar kepada proses rawatan termasuklah rawatan fizikal, kimia dan biologi untuk mengenalpasti titik panas (titik lemah) dalam proses rawatan. Cara kerja untuk kajian ini mengikuti asas Organisasi Antarabangsa untuk Piawaian (ISO) 14040 – rangka siri. Jadual Inventori Kitar Hayat (LCI) dilengkapkan dengan pengumpulan data daripada loji dan ditambah dengan analisis kimia. Penilaian ini dijalankan menggunakan perisian GaBi dan kaedah Penilaian Impak Kitar Hayat merujuk kaedah ReCiPe (RIVM, Universiti Radboud, CML dan Perunding Pré). Kedua-dua kaedah orientasi-masalah dan orientasi-kerosakan dinilai dan didapati proses rawatan kimia menunjukkan impak yang paling tinggi dalam kategori yang penting seperti perubahan iklim, keasidan dan ketoksikan manusia. Ini menyebabkan proses rawatan tersebut merupakan titik panas dalam loji rawatan air sisa ini. Keputusan untuk orientasi-masalah masing-masing adalah 1553 kg CO_2 setara, 5.8 kg SO_2 setara, dan 5.4 kg 1,4 diklorobenzena (1,4-DB) setara dan keputusan untuk orientasi-kerosakan masing-masing adalah 2.17 x 10^{-3} DALY (kecacatan terlaras tahun hayat), 3.36 x 10^{-8} spesies.tahun dan 3.80 x 10^{-6} DALY bila dibandingkan dengan proses rawatan yang lain. Ini disebabkan oleh penggunaan bahan kimia dalam proses rawatan kimia yang mana lebih tinggi dengan ketaranya berbanding proses yang lain. Oleh itu, dua senario yang berbeza dicadangkan dan dinilai untuk mengurangkan impak alam sekitar dari rawatan air sisa lazim ini. Senario-senario tersebut termasuklah menggunakan kitosan dalam proses rawatan kimia dan menggantikan proses rawatan kimia dengan proses pengoksidaan udara basah. Kedua-dua proses menunjukkan impak alam sekitar yang kurang berbanding proses rawatan kimia lazim dalam loji rawatan air sisa.

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LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile Butadiene Styrene
ACF	-	Activated Carbon Filtration
BOD	-	Biochemical Oxygen Demand
CAS	-	Conventional Activated Sludge System
COD	-	Chemical Oxygen Demand
EN	-	Electroless Nickel
EQ	-	Equalizer
HME	-	Heavy Metal Exchange
ISO	-	International Organization of Standardization
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Inventory Assessment
LMNS	-	Low Metal Nickel Solid
MMF	-	Membrane Filtration
OS	-	Organic Solid
POTW	-	Publicly Owned Treatment Works
SI	-	International System of Units
WAO	-	Wet Air Oxidation

LIST OF SYMBOLS

Cd	-	Cadmium
CN	-	Copernicium
Cr	-	Chromium
d	-	day
h	-	hour
kJ	-	kilo Joule
L	-	litre
mg	-	milligram
m^3	-	cubic metre
N	-	Nitrogen
P	-	Phosphorus
Pb	-	Lead
S	-	Sulphur
Se	-	Selenium
Te	-	Tellurium

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Industrial wastewater treatment has given an attention by governments worldwide and Malaysia is not an exception as well. Common types of waste being produced from industries are liquid waste, solid waste, and air pollutant. The focus of this research is on treatment processes of wastewater from electroless nickel plating industry.

Wastewater can be defined as liquid waste that is released from many sources such as commercial properties, domestic residences, industry, and agriculture. These comprise a wide range of contaminants and concentrations. Rapid growth of the industries and urbanisation during the past two decades has contributed to the increased quantity and diversity of toxic and hazardous wastes (Abdullah, 1995). The wastewater should be treated since the industrial effluents have been estimated amounting to nearly 380 000 cubic meters per year, comprising both organic and inorganic materials of varying chemical compositions. By applying this treatment, the environment and human health can be protected since Malaysia now is moving towards manufacturing and finishing industries.

The volume and strength of industrial wastewaters are usually defined in terms of units of production, for example, cubic meters per tonne of water and the variation in characteristic as described by a statistical distribution (Englande *et al.*, 2009). Each industry has its own undesirable constituents in wastewater and it depends on the type of industry itself. All the undesirable constituents should be discharged according to the required limits approved by the government. Examples of constituents are heavy metals, soluble organics causing depletion of dissolved oxygen, suspended solids, priority pollutants such as phenol and other organics discharged in industrial wastes which can give tastes and odours in the water, and oil and floating materials.

There are many types of industries such as food, refinery, petrochemistry, chemistry, steel, electroplating, extractive, and pulp and paper. They produce varieties of wastewaters for instance, electroplating and metal surface treatment process generate significant quantities of wastewaters containing heavy metals such as cadmium, zinc, lead, chromium, nickel, copper, vanadium, platinum, silver, and titanium from a variety of application. These include electroplating, electroless depositions, conversion-coating, anodizing-cleaning, milling, and etching (Barakat, 2010). This study is focused specifically on electroless nickel plating wastewater treatment plant.

Electroless nickel (EN) plating is an auto-catalytic chemical process which is important in depositing a layer of nickel on a solid work piece such as metal or plastic. The formulation and operating condition of the electroless nickel plating bath will affect the chemical and physical properties of an electroless nickel coating. The constituents of the electroless nickel solution are a source of nickel ions, a reducing agent, suitable complexing agents, stabilizers, and energy.

Electroless nickel plating is different from electroplating in process of deposit. There is no need to pass an electric current through the solution to form a deposit unlike electroplating. However, the wastewater from electroless nickel plating contains heavy metal such as nickel. Thus, number of approaches is being used to manage the heavy metals ion which are adsorption, catalytic reduction, chemical coagulation, electrolysis, and ion exchange (Shih *et al*., 2013). An assessment called Life Cycle Assessment (LCA) has been proposed to assess the treatment processes that are involved in this wastewater treatment plant within respective system boundary in order to determine the potential environmental impacts from the processes.

Life Cycle Assessment (LCA) is a tool to assess the potential environmental impacts and resources used throughout a product's life cycle for example from raw material acquisition, via production and use phases, to waste management (ISO, 2006a). LCA is a comprehensive assessment and considers all attributes or aspects of natural environment, human health, and resources (ISO, 2006a).

In this Life Cycle Assessment, there are four main elements that are functional unit, system boundary, inputs and outputs, and impact assessment. Functional unit is the basis in LCA as it is the calculation of environmental impacts for the delivery of specific functions. All the functional units must be the same in the same case study. For example, the functional unit that will be used in this study is environmental impacts per m^3 of treated wastewater from electroless nickel plating industry.

System boundary is set up in order to recognise which part should be assessed and to differentiate one part to the other part of the system. If there is a system being analysed, then there must be boundaries to that system. The system boundary normally conceptually framed in terms of the life cycle stages included in this study (Horne *et al*., 2009). That means there will be more than one system boundaries in one system where it could be hundreds which are totally dependent on the system itself.

Inputs and outputs are the most crucial information that needs to be known before assessment. Life Cycle Assessment is constructed through the calculation of inputs and outputs required or arising as a consequence of the delivery of the functional unit (Horne *et al*., 2009). That is why LCA can be assessed quantitatively and qualitatively where there will be numbers that need to be compared. Final element is impact assessment which can be done after all the data is collected and a model of life cycle is created. However, there is a need to have an indicator. It act as a guide to assess the impacts and it will be easier to choose the scope of the study whether to consider all the environment impacts or choose some of the impacts instead. The examples of these impacts are global warming, acidification, and eutrophication.

This study focuses on electroless nickel plating industry wastewater treatment plant. A software called GaBi 4 that is one of the Life Cycle Assessment tools is used as computer aided method in order to create a model for analysis purposes. Thus, the environmental impacts are interpreted from the model.

1.2 Problem statement

Numerous case studies on Life Cycle Assessment (LCA) for wastewater had been done for years. Basically, the study did comparisons between several wastewater treatment plants (WWTP) in order to get the one WWTP that has less potential environmental impacts. Besides that, the study intended to prove that there is a need for wastewater treatment plant in order to reduce the impacts from raw wastewater to human and ecosystem. The heavy metals in the wastewater such as nickel, copper, lead, and zinc that causes ecotoxicity can be reduced by the treatment plant (Halleux *et. al*., 2006). Malaysia is one of the developing countries which has an increasing number of heavy metal industries namely fertilizer industries, metal plating industries, batteries, and others. These industries produces both direct or indirect discharged of heavy metal wastewaters which requires LCA study (Fu and Wang, 2011). Besides, the heavy metals are soluble in water and can be absorbed by living organisms. The main concern is when the heavy metals may also being absorbed by human body and cause serious health disorders. Several treatment processes need to be applied before the wastewater being discharge to river in Skudai, Johor. This study is aimed to analyse the life cycle of electroless nickel plating wastewater treatment plant. The purpose was to find out the potential environmental impact produced from the treatment processes which consist of physical, chemical, and biological treatment in that wastewater treatment plant respectively.

1.3 Objectives of the study

The objectives of this study are:

a) to do inventory of inputs and outputs for related system boundary which consists of physical, chemical, and biological treatment processes of electroless nickel plating wastewater treatment plant.
b) to assess the potential environmental impacts for the wastewater treatment plant consisting physical, chemical, and biological treatment processes by using Life Cycle Assessment (LCA) approach.
c) to identify hotspots and suggest alternatives scenarios for the treatment which produce much lower potential environmental impacts of the wastewater treatment plant to the environment.

1.4 Scope of the study

The scopes of this study are:

a) Specify system boundary of physical, biological, and chemical treatment of the wastewater treatment plant for the assessment.
b) Collect sufficient data on feed and product yields from case study of electroless nickel plating wastewater treatment plant in Skudai in order to complete Life Cycle Inventory (LCI) table.
c) Using GaBi 4 a Life Cycle Assessment software to analyse the life cycle of electroless nickel plating industry wastewater once LCI table is completed.
d) Developing assessment models consists of physical, chemical, and biological treatment system respectively in GaBi software for the methodology of Life Cycle Assessment
e) Assessment involving midpoint and end point based indicators for potential environmental impacts from the respective treatment processes of the wastewater.
f) Proposing alternative scenarios that have less potential environmental impacts to environment.

1.5 Significance of the study

Treatment systems of wastewater from electroless nickel plating industry contribute to low environmental impacts. Steps toward reducing environmental problems should be taken since this industry keeps growing as the demands are really high in Malaysia nowadays. Thus, this study was conducted to give an insight of potential environmental impacts where the industries can take precaution to reduce the upcoming environmental impacts. The three most critical treatment in industrial wastewater consisting of physical, chemical, and biological treatment will be assessed and hotspots for each treatment being identified. The best scenarios has been proposed in order to reduce the hotspots in treatment that has higher number of hotspots. With that proposed scenarios, this industry can continue to develop without emitting much pollutants to the environment.

1.6 Layout of thesis

In Chapter 1, there is a research background which explains the basic contents of this study. Besides that, problem statements, objectives, scope, and significance of the study are also included in this chapter.

In Chapter 2, literature review had been done on these topics – industrial wastewater treatment, and Life Cycle Assessment. The industrial wastewater treatment processes were included under the topic of industrial wastewater treatment. In this topic of Life Cycle Assessment which is the core of this study, basic introduction is included. Then, there are reviews on Life Cycle Inventory, Life Cycle Impact Assessment, advantages of Life Cycle Assessment, Life Cycle Assessment tools, and Life Cycle Assessment on wastewater treatment in this chapter too.

In Chapter 3, a complete method that was used to conduct this study is being explained in details in this chapter. The sequences are research design, treatment identification, setting up system boundaries, data collections, develop assessment model using GaBi 4 software, Life Cycle Assessment (Goal and Scope, Functional Unit, System Boundary, and GaBi 4 Analysis) and alternative scenarios.

In Chapter 4, the results and discussions are included. The results are based on the findings from this study. In order to understand the results, discussion in this chapter consists of the interpretation of the results, assumptions used in the study, and justification to the assumptions will be included.

In Chapter 5, conclusion is made based on the final findings of the study. Beside that, the recommendations had been suggested in this chapter in order to improve the study in the future.

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