CERTIFICATION OF APPROVAL

Life Cycle Assessment of
Gas District Cooling Plant Absorption Chiller
at Universiti Teknologi Petronas

by

Noor Ilyia Binti Mohd Yusnee

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Approved by,

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(AP Ir. Dr. Mohd Amin Abdul Majid)
Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, which is the original work is my own work except as specified in the references and acknowledgements. The original work contained herein have not been undertaken or done by unspecified sources or persons.

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NOOR ILYIA BINTI MOHD YUSNEE

ABSTRACT

In this project, main components for absorption chillers system were evaluated based on the Life Cycle Assessment (LCA). Materials and manufacturing processes of main components of the chiller were identified. Main components for absorption chiller are high temperature generator, low temperature generator, condenser and absorber while main parts for each of the main component are shell, tube, plate supports and eliminator blade. Shell, tube and eliminator blade are made from stainless steel whereas tubes are made of copper. These materials and manufacturing processes then were analyzed to identify the environmental effect by using GaBi 4 Education software due to the limitation of data. Results of this project identified the elements released from the life cycle of the absorption chiller. The emissions are 6422 kg DCB equivalent, 29 kg phosphate equivalent, 332 kg SO_2 equivalent and 82332 kg CO^2 equivalent. The high CO_2 elements released have contributed to global warming potential, thus resulted on warming effect at the earth surface. Recommendation to reduce the effect to the environment is also discussed, and it is recommended to use steels as the material for tube due to their low embodied energy and the copper scrap should be recycled back to the tube life cycle in order to reduce the carbon dioxide emission.

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LIST OF ABBREVIATIONS

LCA	LIFE CYCLE ASSESSMENT
AC	ABSORPTION CHILLER
CHP	COMBINED HEAT AND POWER

CHAPTER 1

INTRODUCTION

1.1 BACK GROUND OF STUDY

This project assessed double effect steam absorption chiller based on Life Cycle Assessment study. The absorption chiller is installed in Gas District Cooling plant at Universiti Teknologi Petronas in year 1998. The absorption chiller is a double effect absorption cycle, and is driven by steam. It uses pure water as refrigerant and lithium bromide as the absorbent.

An essential problem of the 21st century is the world pollution. Currently, the environment is so much contaminated that urgent measures should be taken to address the effect. Thus, beside major factors such as cost, and design, the environmental impact arise from absorption chiller due to the manufacturing process of the absorption chiller and also at the end of the absorption chiller cycle should also be considered. Environmental impact should be quantified in order to compare the effects of the production of energy and to analyse the possibilities of improvement of the process from that point of view. Thus, the aim of this project is to analyse the environmental impact of absorption chillers, considering the whole life cycle of the absorption chiler system. This can be achieved by applying the life cycle assessment method on the absorption chiller.

The absorption chiller consists of many components of different types. The components are made from different types of materials. However, in this study the focus is only limited to compiling the life cycle inventory (LCI) on the major components and parts of the absorption chiller. The major components of absorption chiller are evaporator, absorber, high stage generator, low stage generator, and absorber.

In the Life Cycle Assessment, there are four stages in performing LCA, namely goal and scope definition, inventory analysis, impact analysis, and interpretation. By undertaking LCA, priority areas for improvement could be identified and then provide means of comparing the environmental impacts of materials, processes and services.

1.2 PROBLEM STATEMENT

Nowadays, in industries, environmental impact is one of the important factors to be considered beside major factors such as cost and design. Thus, there is a need to perform Life Cycle Assessment (LCA) in order to evaluate for environmental impacts and if possible, implement improvement of the product's life cycle. Absorption chiller is an important equipment at Universiti Teknologi Petronas Gas District Cooling plant and it is fabricated from steel and copper. The manufacturing and disposal of these materials have impact to the environment. Hence, the study on LCA of the AC could provide of extent of environmental impacts of the AC to the environment.

1.3 OBJECTIVE

To perform life cycle assessment of steam absorption chiller of Gas District Cooling Plant at Universiti Teknologi PETRONAS.

1.4 SCOPE OF STUDY

In this project, only main components of the absorption chiller were analysed using LCA method. The main components were high temperature generator, low temperature generator, absorber, condenser and evaporator; while the major parts involved were tube, tube sheet, shell and eliminator blade.

CHAPTER 2

LITERATURE REVIEW

2.1 LIFE CYCLE ASSESSMENT

Life cycle assessment is the investigation and evaluation of the environmental impacts of a given product or service. In this project, several LCA studies covering a number of products are discussed.

2.1.1 LIFE CYCLE ASSESSMENT CONCEPT

Life Cycle Assessment (LCA) is to identify and improve the environmental effects and aspects of products at various points in their life cycle. Life cycle assessment consists of four steps, which are goal and scope definition, inventory analysis, impact assessment and interpretation as shown in **Figure 1** [9].

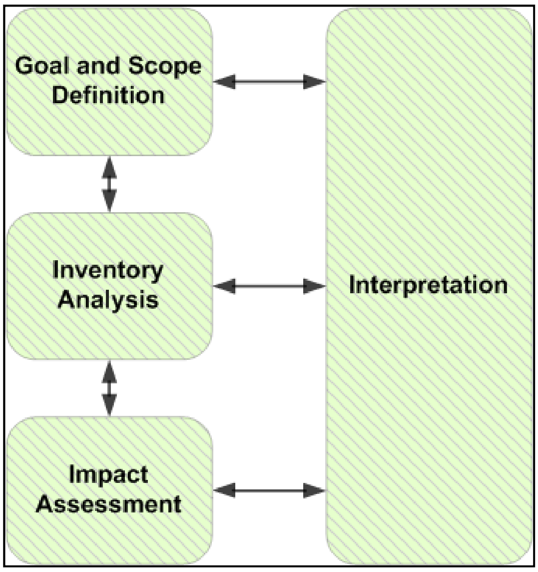

Figure 1: Four Steps in Life Cycle Assessment [9]

- Goal and scope definition: All general decisions for setting up the LCA systems are made. It will be defined clearly and consistently with the intended application [10].
- Inventory analysis: Compilation and quantification of inputs and outputs for a given product system throughout its life cycle. It includes data collection and compilation of data [10].
- Impact assessment: Identifies and evaluates the amount and significance of the potential environmental impacts arising from inventory analysis [10].
- Interpretation: Results are reported in the most informative way possible and the need and opportunities to reduce the impact of the products or services on the environment are systematically evaluated [10].

2.1.2 LIFE CYCLE ASSESSMENT OF A 2-MW RATED POWER WIND TURBINE

In this project, an environmental impact due to the manufacturing process of the wind turbine and the disposal process at the end of the wind turbine life cycle, even though wind power does not produce pollution or emissions during operation. This environmental impact is quantified in order to compare the effects of the production of energy and to analyze the possibilities of improvement of the process from that point of view. The aim of this study is to analyze the environmental impact of wind energy technology considering the whole life cycle of the wind power system.

This wind turbine is analyzed during all the phases of its life cycle, from cradle to grave, by applying LCA methodology, taking into account all the processes related to the wind turbine: the production of its main components (through the incorporation of cut-off criteria), the transport to the wind farm, the subsequent installation, the start-up, the maintenance and the final dismantling and stripping down into waste materials and their treatment.

Within the limits of the system studied, falls the construction of the main components of the turbine, the transportation of the turbine to the wind farm, the assembly, the installation and the start-up, as well as the process of dismantling the wind turbine and the subsequent treatment of generated waste. Outside the limits of the system under study falls the system of distribution of the electricity generated by the wind turbine, that is, the medium-voltage wiring, the transformer substation and the national electrical power network. In this project, the focused is only on the most important components, specifically the foundation, the tower, the nacelle and the rotor. The system boundary of the project is shown in **Figure 2**.

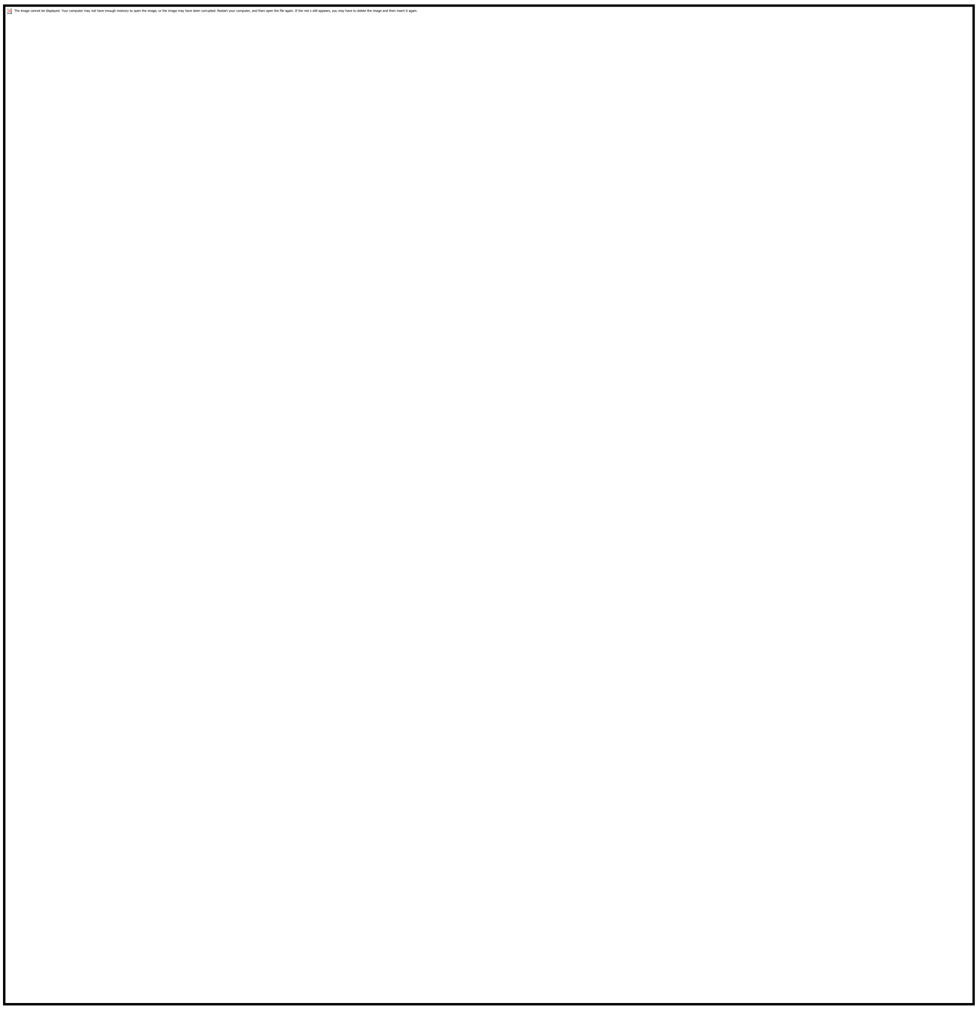

Figure 2: Life Cycle Assessment of Wind Turbine [1]

Throughout this project, the environmental impact generated by a wind turbine has been analyzed. From the results, an important conclusion is the significant impact generated by the turbine blades and, especially, their non-recycling status. Another material that presents a significant impact within the study is the copper present in the nacelle of the turbine but in this case, with the advantage of being a recyclable material [1].

2.1.3 LIFE CYCLE ASSESSMENT OF FORMWAY LIFE CHAIR

Formway furniture, a designer and manufacturer of office furniture products, is a New Zealand-based company that is committed to sustainable development. It manufactures two models of the light, intuitive, flexible and environmental (LIFE) office chair: one with an aluminium base and one with a glass-filled nylon (GFN) base. Thus, in this project, it was decided to undertake a life cycle assessment (LCA) study of these two models in order to:

1. Determine environmental hotspots in the life cycle of the two chairs.
2. Compare the life cycle impacts of the two chairs.
3. Compare alternative potential waste-management scenarios

The LIFE chair models consist of a mix of metal and plastic components manufactured by selected Formway suppliers according to design criteria. Thus, the research methodology included determining the specific material composition of the two chair models and acquisition of manufacturing data from individual suppliers. These data were compiled and used in conjunction with pre-existing data, specifically from the ecoinvent database purchased in conjunction with the SimaPro7 LCA software, to develop the life cycle inventory of the two chair models. The life cycle stages included in the study extended from raw-material extraction through to waste management.

Since the LIFE chair is manufactured from components supplied by numerous suppliers, the LCA study required information on materials and processes to be gathered from within Formway and from suppliers as shown in **Figure 3.** Process information from within Formway was gathered by audits, and questionnaires were used to obtain supplier information. The aim of the study was to include all possible processes from cradle to grave within practical limitations. **Table 1** shows the materials used for the LIFE chair.

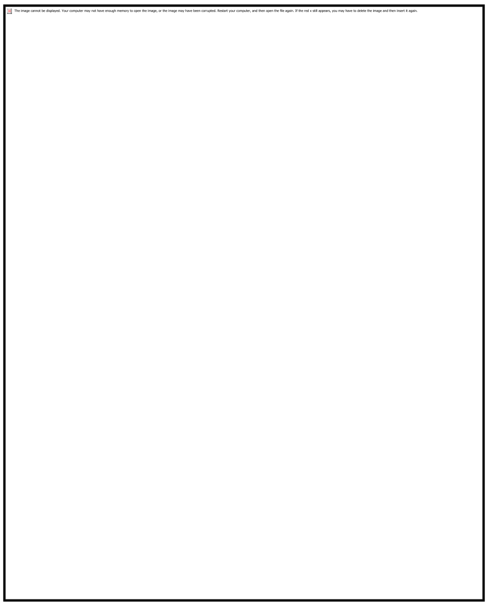

Figure 3: LIFE Chair Material Components [2]

Table 1: Material for LIFE Chair

Component	**Material**
Mesh Back	Polyester
Back Frame	Glass Filled Nylon
Lumbar	ABS
Lumbar Hinge	Nylon
Arm	Aluminium
Arm Pads	Polyurethane foam
Arm Component	Acetal
Seat Cushion	Polyurethane foam
Seat Moulding	Hytrel Crastin (PBT)
Seat Carriage	Aluminium
Mechanism Assembly	Aluminium
Gas Spring Tube	Steel
Base	Aluminium / Nylon
Castors	Nylon
Castors Axle, Spring	Zinc
Springs, Bolts, Pivots	Steel

Figure 4 indicates the processes included in this study.

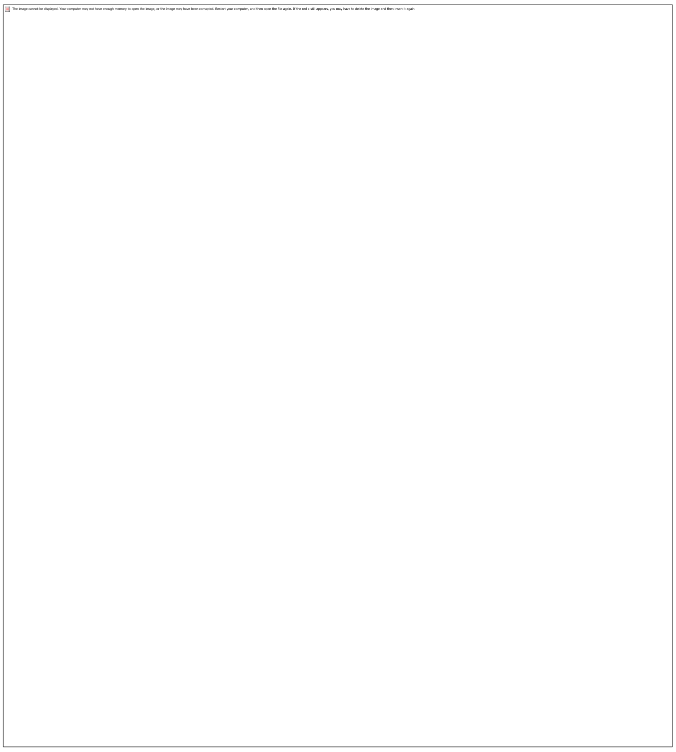

Figure 4: LIFE Life Cycle Assessment System Boundary [2]

Results showed that the main difference between the two LIFE chair models occurs at the raw-material extraction/refinement and component production stages. The difference at the raw material/extraction stage is due to the difference in the material used for the chair's base. Overall, these results highlight the desirability of using recycled aluminium in chair manufacture, using materials that are less energy intensive, and recycling of aluminium at EOL (at least according to the consequential approach). Additionally, the LCA study highlighted limitations pertaining to data availability specific to the New Zealand manufacturing sector. Further research into the relevance of other impact categories (eutrophication, acidification, etc.) for a New Zealand-specific case would also be beneficial in the future [2].

2.2 ABSORPTION CHILLER

Absorption chiller are thermally driven chillers using a liquid refrigerant or sorbent solution and a heat source to provide cooling. These absorption chillers are using heat to provide cooling to building or space required without the use of ozone-depleting chlorofluorocarbons (CFCs). These chillers can be powered by natural gas, steam, or waste heat and they transfer thermal energy from the heat source to the heat sink through an absorbent fluid and a refrigerant [6].

In this absorption chiller, a solution mixture in the absorber absorbs refrigerant vapor from the evaporator. The solution is then pumped to the generator. In the generator, the refrigerant re-vaporizes using a waste steam heat source, this refrigerant returns to the absorber through a throttling device. Two most common refrigerant/absorbent mixtures used in AC are ammonia/water and water/lithium bromide [6].

2.2.1 TYPES OF ABSORPTION CHILLER

Absorption chillers generally are classified as direct- or indirect-fired, and as single, double - or triple effect.

Direct-fired

This system mainly contains natural gas burner. Rejected heat from this chiller can be used to generate desiccant dehumidifiers or provide hot water. It utilize a burner as the heat input for the absorption cooling cycle and most operate using natural gas. However, unlike most steam absorption chillers, the direct-fired absorption chiller applications involve both cooling and heating in the same unit. This can result in a smaller footprint for the boiler room in some situations [3].

Indirect-fired

This type of chiller use steam, steam, hot water or hot gases steam from a boiler, turbine or engine generator, or fuel cell as their primary power input. It can be suited well for integration into CHP system for building. This is done by utilizing the rejected heat from the electric generation process, thereby providing high operating efficiencies through use of otherwise wasted energy [3].

Single Effect

This type of absorption chiller used the single effect 'cycle' that is refers to the transfer of fluids through the four major components of refrigeration machine, which are evaporator, absorber, generator and condenser [3].

Double Effect

This type of absorption chiller (double effect $LiBr/H_2O$ system) is developed due to the desire for higher efficiencies in absorption chiller. This chiller differ from the single effect type due to the equipment involved which are tow condensers and two generators. Both of these equipments allow more refrigerant boil-off from the absorbent solution [3].

Triple Effect

This type of chiller is the improvement of the double effect type. This triple effect type of absorption chiller is still under development, as the next step in the evolution of absorption chiller. In this system, two single effect absorption circuits are combined with heat exchange occurring between a condenser and absorber of a high temperature circuit, and a generator of a low temperature circuit. The evaporators of both the high and low temperature circuits provide cooling to an external heat load [3].

2.3 MAIN COMPONENTS OF ABSORPTION CHILLER

An absorption chiller includes an inner shell that supports a tube bundle, in which combustion occurs, and an outer shell. The two solution flow paths converge after the solution flowing there through has been heated by the combustion occurring in the inner shell. A vapor separator disentrains solution in liquid form from vaporized solution before the vapor exits the generator [4].

Referring to **Figure 5** and **Figure 6**, an absorption apparatus for an absorption chiller includes a series of eliminator blades (vapor-liquid separator) situated between a vaporizing chamber (a generator or an evaporator) and a devaporizing chamber (a condenser or an absorber). In some embodiments, a tube support plate includes a series of holes for not only supporting the tube bundles of two heat exchangers but also for supporting the eliminator blades [4]. **Table 2** shows major components and parts of an absorption chiller.

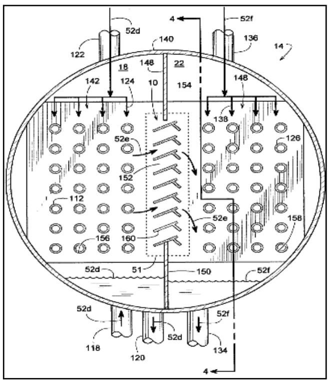

Figure 5: Cross Sectional View of Vaporising Chamber [4]

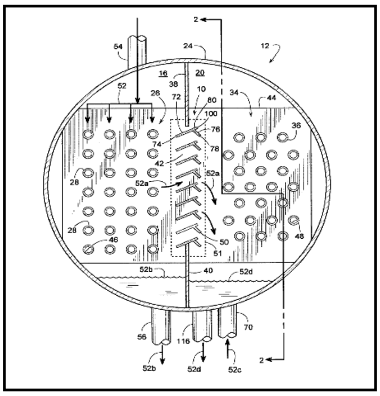

Figure 6: Cross Sectional View of Devaporising Chamber [4]

Table 2: Major Component and Parts of an Absorption Chiller

Major Component	Major Parts
• Evaporator • Condender • High Temperature Generator • Low Temperature Generator • Absorber	• Shell • Tube • Eliminator (Vapour-Liquid Separator) • Plate Support.

2.4 MANUFACTURING PROCESS OF PARTS FOR ABSORPTION CHILLER

An apparatus for manufacturing a tube includes an extruding means for extruding a material perform in the shape of a tube, and a pair of compression rollers for compressing a central portion of the tube, and having a disc-like shape. Tubes are generally manufactured by melting raw materials, refine the material, cast to produce clean bars products, rolling process in order to improved grain structure in the finished product, thermal treatment process to provide the necessary strength and toughness or the optimum hardness and microstructure, straighten process so that the products meet straightness tolerances, and cutting process to meet standard length [5].

Manufacturing an eliminator can be made of two pieces metal sheet. An upstream piece is spot welded to a downstream piece to create an upstream leg, a downstream leg and a deflection tab. The spot welding process couples the sheet metals together at several discrete spots. Eliminator generally is manufactured by melting raw materials, refine the material, cast to produce clean bars products, rolling process in order to obtain sheet metal shape, thermal treatment process to provide the necessary strength and toughness or the optimum hardness and microstructure, straighten process so that the products meet straightness tolerances, cutting process to meet standard length, spot welding, and inspection of the final product [7].

Plate supports are usually made from flat piece of metal with holes drilled for the tube ends in a precise location and pattern relative to one another. Tubes are attached to the plate support by pneumatic or hydraulic pressure or by roller expansion. Tube holes can be drilled and reamed and can be machined with one or more grooves. Welding process will join the tubes and plate supports, and applying a seal weld or strength weld to the joint can further strengthen the tube joint. As for shell, it is constructed from welded plate metal. Plate support and shell are generally manufactured by melting raw materials, refine the material, cast to produce clean bars products, rolling process in order to obtain sheet metal shape, thermal treatment process to provide the necessary strength and toughness or the optimum hardness and microstructure, straighten process so that the products meet straightness tolerances, cutting process to meet standard length, bending process, drilling process, welding process, and inspection of the final product [7]. **Table 3** shows major manufacturing processes for major part of an absorption chiller.

Table 3: Major Manufacturing Processes for Major Part of an Absorption Chiller

Part	**Major manufacturing process involved**
• Tube	• Melting process, casting process, rolling process, and cutting process
• Shell	• Melting process, casting process, rolling process, cutting process and welding process
• Eliminator	• Melting process, casting process, rolling process, cutting process and spot welding process
• Plate support	• Melting process, casting process, rolling process, cutting process, and drilling process

2.5 ENVIRONMENTAL IMPACT CATAGORIES

2.5.1 CATEGORIES

Throughout the world, various types of pollution has interfere with the quality of life for all living creatures and with the natural functioning of the earth's ecological system. Even though some pollution is from natural causes such as toxic materials released from volcanoes, most pollution is caused by human activities. And the greatest caused comes from the industrial community. According to Environmental Protection Agency (EPA), over 2.95 million metric tons of toxic chemicals from about 2000 industrial facilities are annually released to the environment [9].

An industry is a collection of companies that operate in a related of goods and services, which eventually sold to purchasers. Numerous industries work together to produce the necessary goods and products. Generally, industries are divided into several groups; which are [10]:

- Primary industries – Involved in collection, utilizing and harvesting or resources directly produced by physical processes; example such as mining and smelting [10]
- Secondary industries (Manufacturing sector) - Deal with manufacturing as they take raw materials, convert them in various ways and produce tangible good [10]
- Tertiary industries – Produce services for individual and groups [10]

The largest impact from pollution is produces within the secondary industries. Environmental impact categories are an effective way in order to determine the effect of these secondary industries to the environment. There are several types of environmental impact categories as follows:

Global Warming Potential (GWP)

Climate change is caused by the released of greenhouse gases such as carbon dioxide, water vapour, methane, nitrous oxide and ozone. Factors are expressed as Global Warming Potential (GWP), measured in the reference unit, kg CO_2 equivalents [11].

Acidification Potential

Acidic gases such as sulphur dioxide (SO_2) can react with water in atmosphere and will form acid rain, which can cause ecosystem impairment. Acidification Potential (AP) is expressed using the reference unit, kg SO_2 equivalents. The revised method only accounts for acidification caused by SO_2 and NO_x [12].

Eutrophication Potential (EP)

Phosphate and Nitrates are essential for life but as the concentration increases, it will lead to excessive growth of algae, reducing the oxygen within the water and damaging ecosystem. Eutrophication Potential (EP) is expressed using the reference unit, kg PO_4 equivalents [13].

Human Ecotoxity Potential

The emission of some substances can have negative impacts on human health. Characterisation method, expressed as Human Toxicity Potential (HTP) describes fate, exposure and effects of toxic substances for an infinite time horizons. Each toxic substance HTPs is expressed using the reference unit, kg 1,4-dichlorobenzene (1,4-DB) equivalents [14].

2.5.2 CHARACTERISATION FACTOR

Environmental impacts are assessed by looking at appropriate environmental impacts categories. Characterisation measures the level of environmental impact caused by a product or functional unit in a life cycle assessment (LCA). Characterised results are calculated for each impact categories with findings presented in appropriated unit (example: Use of reference substance of kg CO_2 equivalent for climate change) [15].

Impacts in one category can contributed by different substances, and one substance can contribute to several impact categories. Characterisation is where all the different substances contributing to each impact category are assessed relative to one another to give an overall measure of the level of impact in each category [15].

Each impact category has a reference and the contribution of each substance to the impact category is calculated by converting the amount of substance into the equivalent amount of the reference substance or unit. This conversion is done by characterisation method [16].

For example, the most common greenhouse is carbon dioxide. Numerous other gases, however also have greenhouse properties, including methane, nitrous oxide, hydrofluocarbon, perfluorocarbons, and sulphur hexafluoride. These gases each have different ability to absorb heat in atmosphere. For methane, it is 21 times more dangerous than carbon dioxide, so it is considered to have a 'global warming potential' of 21. Thus, for climate change, the reference substance is CO_2. So, the effects of 1 tonne of methane are converted into the amount of CO_2 needed to cause the same effect over 100-year timescale (as methane is 23 times more damaging than CO_2). Below is the list of characterisation factor [16]. **Table 4** shows characterisation factor for each gas element.

Table 4: Characterisation Factors

Gas	Characterisation Factor
Carbon Dioxide	1 (Global Warming Potential)
Methane	23 (Global Warming Potential)
Nitrous Oxide	296 (Global Warming Potential)
HCFC	210 (Global Warming Potential)
Bromo-Methane	2.3 (Ozone Depleting Potential)
CFC-11	1 (Ozone Depleting Potential)
Tetrachloromethane	1.23 (Ozone Depleting Potential)
Trichloroethane	0.45 (Ozone Depleting Potential)
Ammonia	1.6 (Acidification Potential)
Sulphur Oxides	1 (Acidification Potential)
Sulphur Dioxides	1.2 (Acidification Potential)
Nitrogen Oxides	0.5 (Acidification Potential)
Nitrogen Dioxides	0.5 (Acidification Potential)
Ammonia	0.35 (Eutrophication Potential)
Ammonium	0.33 (Eutrophication Potential)
Ammonium Carbonate	0.12 (Eutrophication Potential)
Ammonium Nitrate	0.072 (Eutrophication Potential)
Chemical Oxygen Demand	0.022 (Eutrophication Potential)
Dinitrogen Monoxide	0.13 (Eutrophication Potential)
Nitrate	0.10 (Eutrophication Potential)
Nitric Acid	0.10 (Eutrophication Potential)

CHAPTER 3

METHODOLOGY

There are four steps in conducting this Life Cycle Assessment project as discussed in the following sections. In this study, all the four steps are adhered to the following:

3.1 PROCEDURES

1. Goal and scope definition
    a. Defining of system boundary
    b. In this project, Life Cycle Assessment (LCA) is used. Only main components are assessed in terms of its materials, manufacturing processes, and the disposal of the Absorption Chiller due to the limitation of data obtained
2. Inventory analysis
    a. Technical data gathering to support estimates of energy and raw material requirements, atmospheric emissions, waterborne emissions, solid waste, and other releases for AC life cycle
        i. Main components of absorption chiller are identified which are absorber, condenser, high stage generator, low stage generator and condenser.
        ii. Parts of each of the main component are identified which are tube, shell, plate and eliminator blade. These parts are chosen because they are the most important parts for each of the main components.
        iii. Materials for parts are identified which are
            - Plate (Stainless Steel)
            - Shell (Stainless Steel)
            - Eliminator Blade (Stainless Steel)
            - Tube (Copper)
        iv. Weight for each part is determined after all dimensions for each part are obtained. These dimensions are used to calculate

volume for each part, and from the volume, weight in kilogram is calculated

- Plate (172.4 kg)
- Shell (66800 kg)
- Eliminator Blade (32 kg)
- Tube (128.55)

2. Impact assessment

    a. The effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories, which may then be weighted (in kg equivalent) for importance. This is done by the GaBi software, after data of resources used is entered

        i. Global Warming Potential (82332.786 kg CO_2 equivalent)

        ii. Acidification Potential (332.056 kg SO_2 equivalent)

        iii. Human Toxicity Equivalent (6422.536 kg DCB equivalent)

        iv. Eutrophication Potential (28.862 kg PO_4 equivalent)

3. Interpretation

    a. The results are interpreted

        i. The amount of emission released can be obtained from the impact assessment section and the highest amount of the emission is the most contributing to the environment. From the result obtained, the processes involved in the life cycle of AC is analysed in order to discover how the emissions are released and how to minimize the releases.

CHAPTER 4

RESULTS AND DISCUSSION

In this part, technical data which are major components and parts, materials involved, manufacturing process involved, are gathered and by using GaBi 4 Education software, potential environmental impacts is calculated.

4.1 RESULTS

4.1.1 SYSTEM BOUNDARY

System boundary for the absorption chiller understudy is as shown in **Figure 7**.

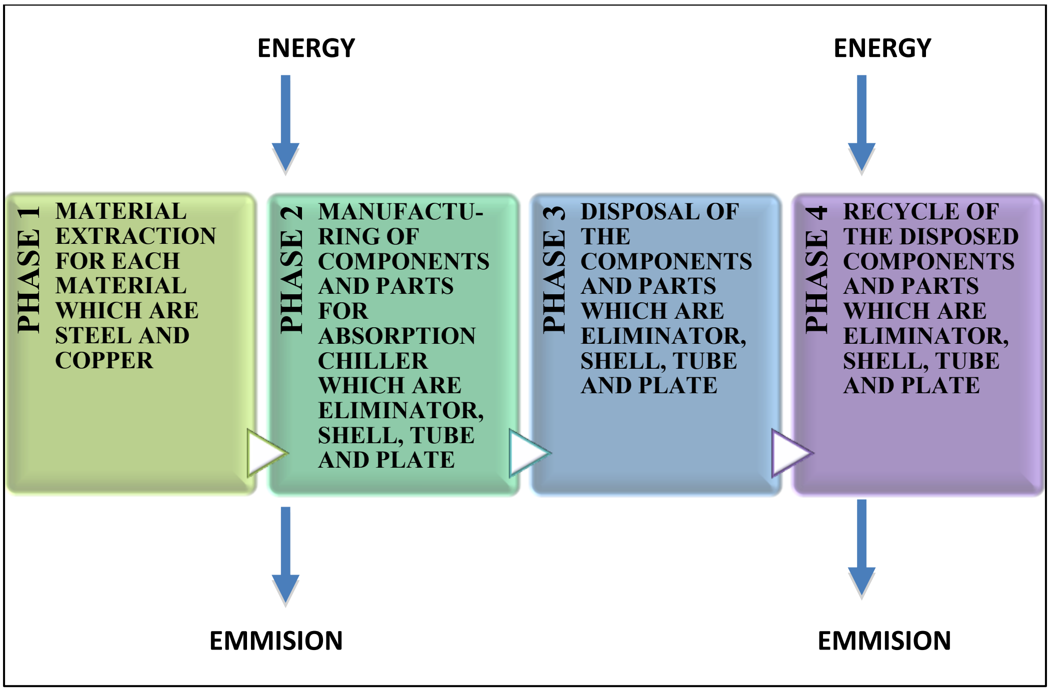

Figure 7: System Boundary of Life Cycle Assessment of Absorption Chiller

4.1.2 INVENTORY OF COMPONENTS AND PARTS OF AC

Figure 5 shows solid model of double effect steam absorption chiller. It shows the main components of the absorption chiller.

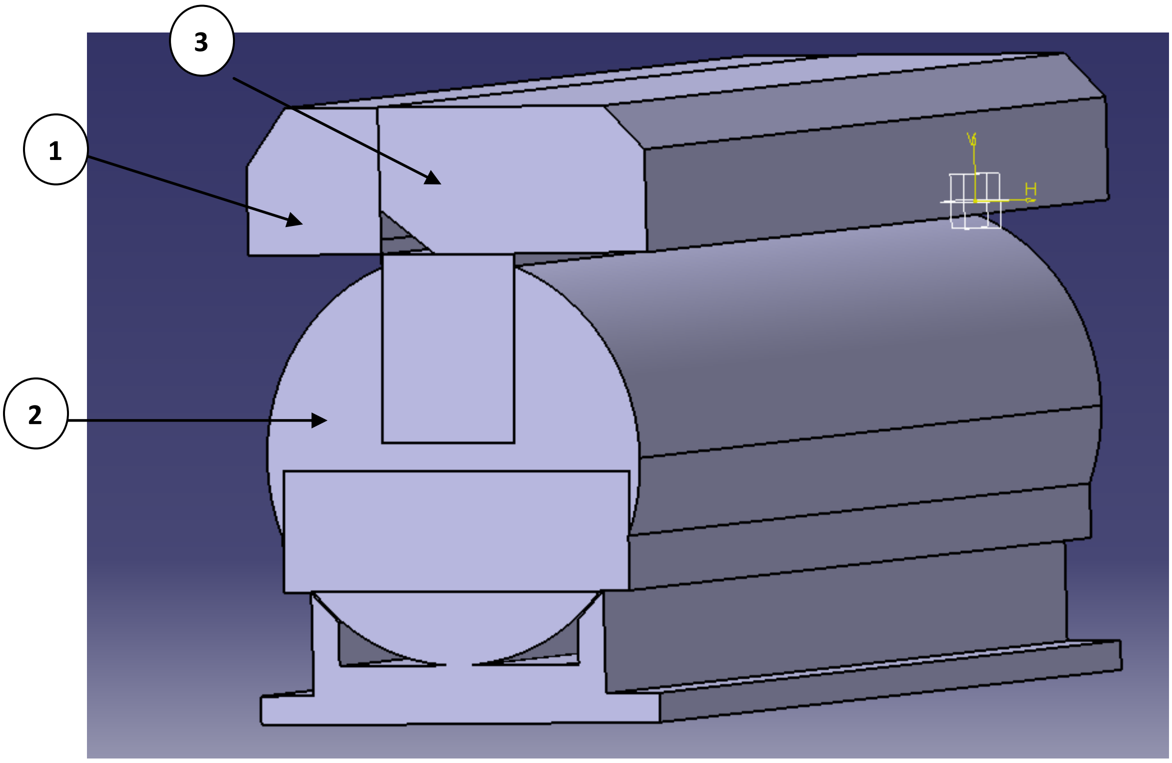

Figure 8: Solid Model of Double Effect Steam Absorption Chiller

Table 5 shows the major components of steam absorption chiller based on the solid model of the chiller.

Table 5: Major Components of Steam Absorption Chiller

Number	Component
1	• High temperature generator
2	• Evaporator and Absorber
3	• Low temperature generator and condenser

Table 6 shows the inventory per component for the absorption chiller

Table 6: Inventory Per Component

COMPONENT	PART	MATERIAL FOR EACH PART
1. High Temperature Generator 2. Low Temperature Generator 3. Evaporator 4. Absorber 5. Condenser	• Tube • Eliminator • Shell • Tube plate	• Copper • Stainless Steel • Stainless Steel • Stainless Steel

4.1.3 MAJOR MANUFACTURING PROCESSES AND WEIGHT FOR MAJOR PARTS

Table 7 shows the major manufacturing processes involved of the absorption chiller.

Table 7: Major Manufacturing Process for Each Major Part

Part	Major Manufacturing Process Involved
Tube	• Melting, Casting, Rolling, Cutting
Eliminator	• Melting, Casting, Rolling, Cutting, Spot Welding
Shell	• Melting, Casting, Rolling, Cutting, Welding
Plate Support	• Melting, Casting, Rolling, Cutting

Figure 9 shows component drawing of steel plate.

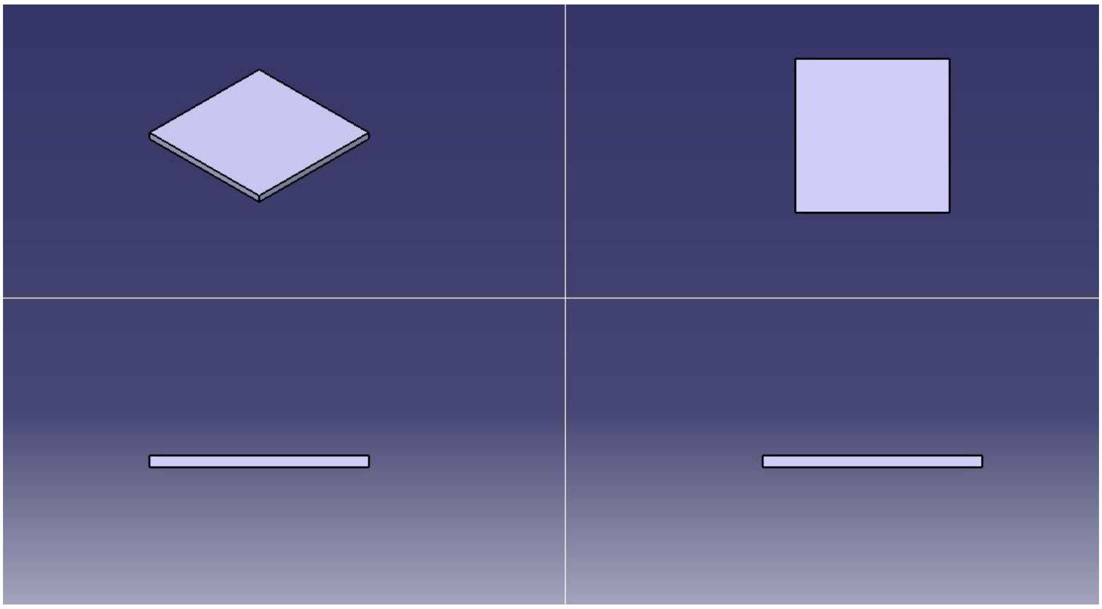

Figure 9: Component Drawing of Steel Plate

Table 8 shows the calculated weight for plate:

Table 8: Calculated Volume in Kilogram for Plate of Absorption Chiller

Component	a(mm)	b(mm)	c(mm)	Amount	Volume (cm^3)
Evaporator	890	900	1.2	4	3844
High Temperature Generator	730	1432	1.2	4	5018
Low Temperature Generator	820	636	1.2	4	2503
Absorber	800	1980	1.2	4	7603
Condenser	820	656	1.2	4	2582

Total Volume = 21550 cm^3

Material = Stainless Steel

Density of Stainless Steel = 8000 kg / m^3

Volume = a x b x c x Amount

Mass = Volume x Density

Total Mass = 0.02155 m^3 x 8000 kg / m^3 = 172.4 kg

Figure 10 shows component drawing of steel plate.

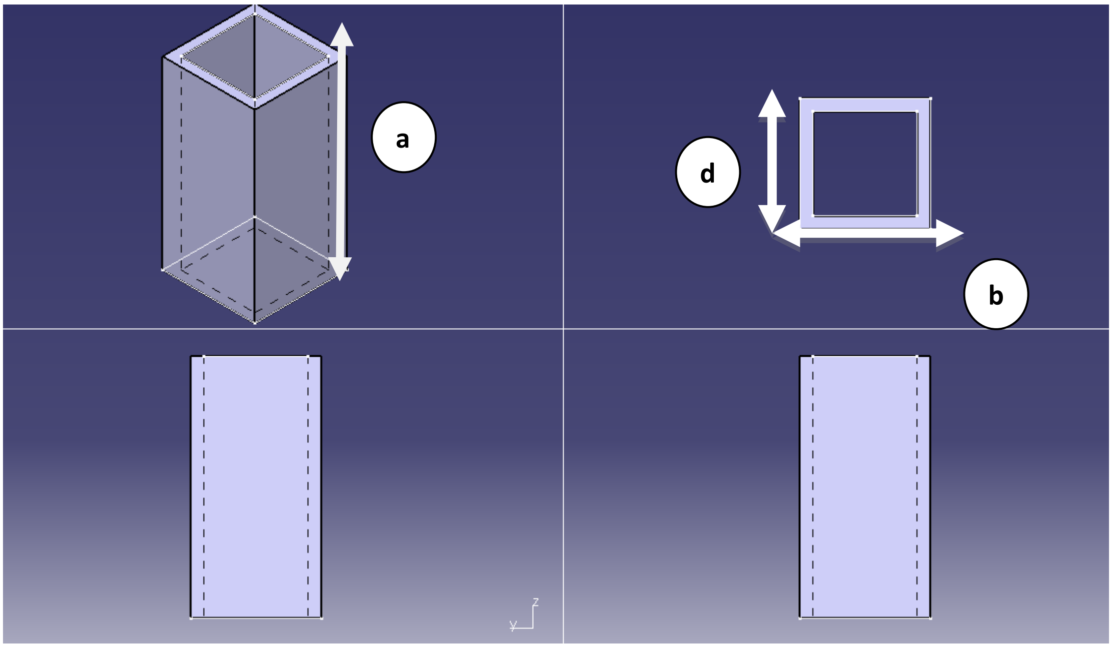

Figure 10: Assembly Drawing of Steel Shell

Table 9 shows the calculated weight for shell:

Table 9: Calculated Volume in Kilogram for Shell of Absorption Chiller

Component	a(mm)	b(mm)	Thick-ness(mm)	d(mm)	Volume(m^3)
Evaporator	7610	50	1090	1100	1.59
High Temperature Generator	7610	50	930	1632	1.87
Low Temperature Generator	7610	50	836	930	1.27
Absorber	7610	50	1000	2180	2.34
Condenser	7610	50	856	930	1.28

Total Volume = 8.35 m^3

Material = Stainless Steel

Density of Stainless Steel = 8000 kg / m^3

Volume = (d x d x a) – (c x c x a)

Mass = Volume x Density

Total Mass = 8.35 m^3 x 8000 kg / m^3 = 66800 kg

Figure 11 shows component drawing of steel plate.

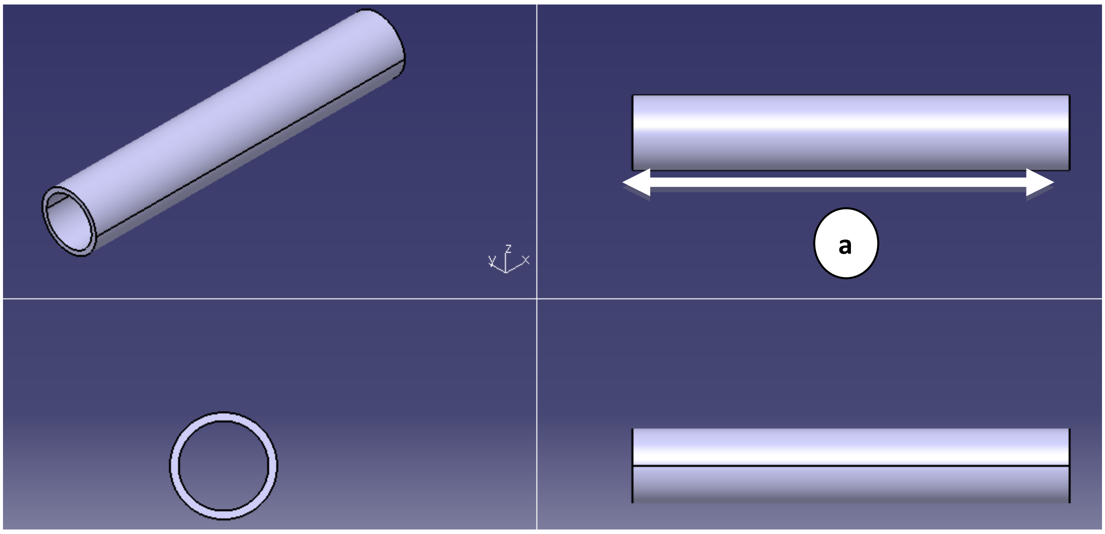

Figure 11: Component Drawing of Tube Copper

Table 10 shows the calculated weight for tube:

Table 10: Calculated Volume in Kilogram for Tube of Absorption Chiller

Component	a(mm)	Outside Radius (mm)	Inside Radius (mm)	Amount	Volume (cm^3)
Evaporator	150	20	18	23	43.354
High Temperature Generator	150	20	18	25	47.124
Low Temperature Generator	150	20	18	27	50.89
Absorber	150	20	18	23	43.354
Condenser	150	20	18	25	47.124

Total Volume = 231.846 cm^3

Material = Copper

Density of Copper = 8.92 g / cm^3

Volume = π x (Outside Diameter – Inside Diameter $)^2$ x a x Amount

Mass = Volume x Density

Total Mass = 231.846 cm^3 x 8.92 g / cm^3 = 2068.07 kg

Figure 12 shows component drawing of steel plate.

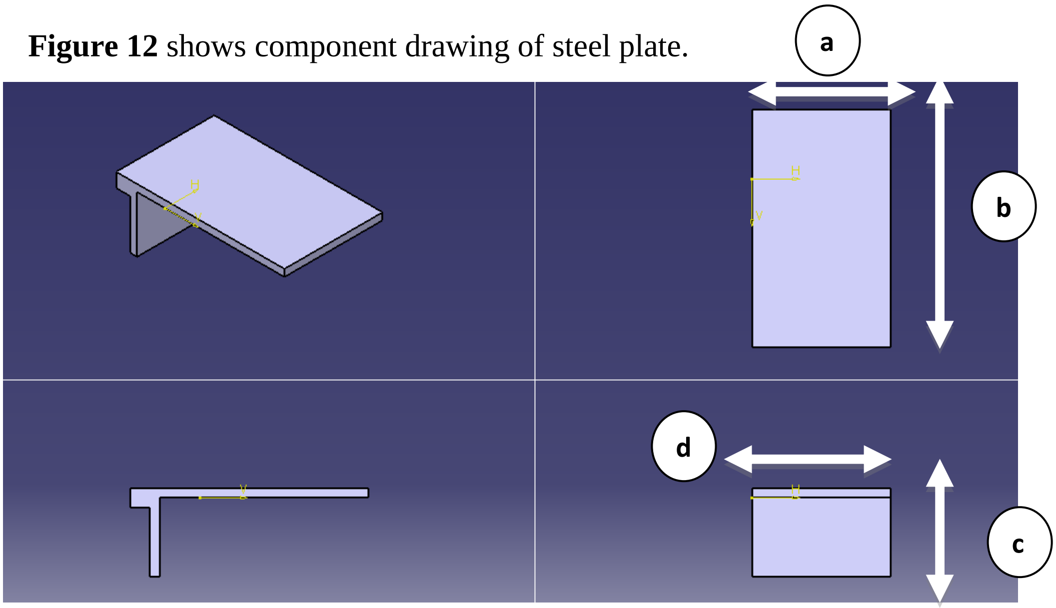

Figure 12: Assembly Drawing of Steel Eliminator Blade

Table 11 shows the calculated weight for eliminator blade:

Table 11: Calculated Volume for Eliminator Blade of Absorption Chiller

Component	a (mm)	b (mm)	c (mm)	d (mm)	Thick -ness	Amount	Vol (cm^3)
Evaporator	50	80	30	40	4	8	166.7
High Temperature Generator	50	80	30	40	4	8	166.7
Low Temperature Generator	50	80	30	40	4	8	166.7
Absorber	50	80	30	40	4	8	166.7
Condenser	50	80	30	40	4	8	166.7

Total Volume = 833.6 cm^3

Material = Stainless Steel

Density of Stainless Steel = 8000 kg / m^3

Volume = [(a x b x thickness) + (c x d x thickness) + 40mm^3] x Amount

Mass = Volume x Density

Total Mass = 833.6 cm^3 x 8000 kg / m^3 = 6.669 kg

4.1.4 LIFE CYCLE ASSESSMENT

Flows for life cycle of plate, shell, eliminator blade and tube of the absorption chiller were evaluated using GaBi 4 Education Software and is shown in **Figure 13**, **Figure 14**, **Figure 15** and **Figure 16** respectively.

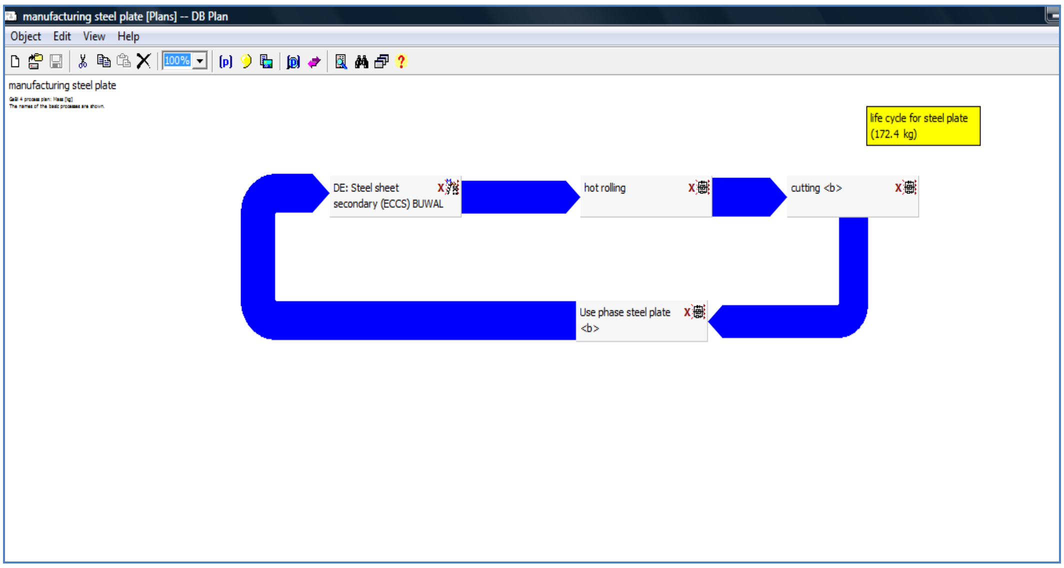

Figure 13: Life Cycle of Steel Plate

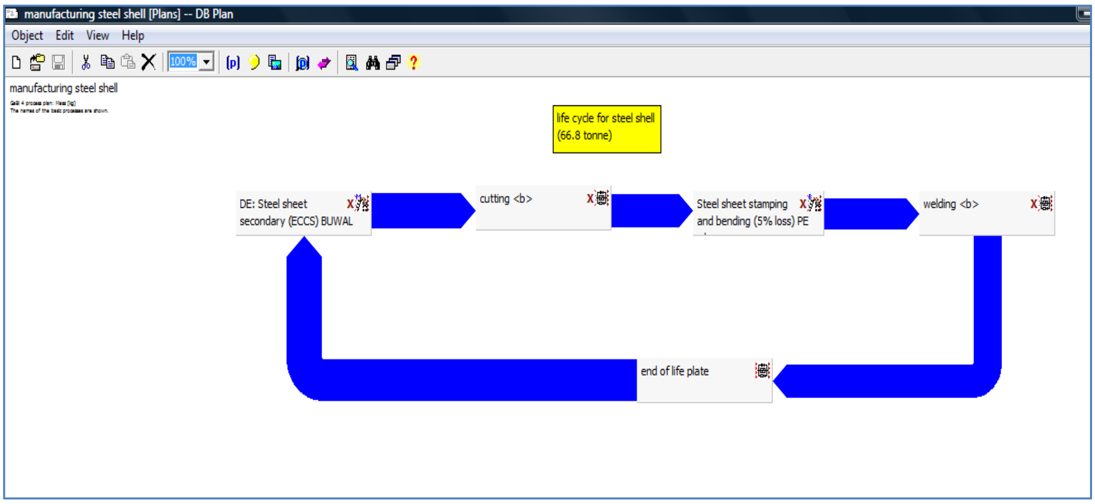

Figure 14: Life Cycle of Steel Shell

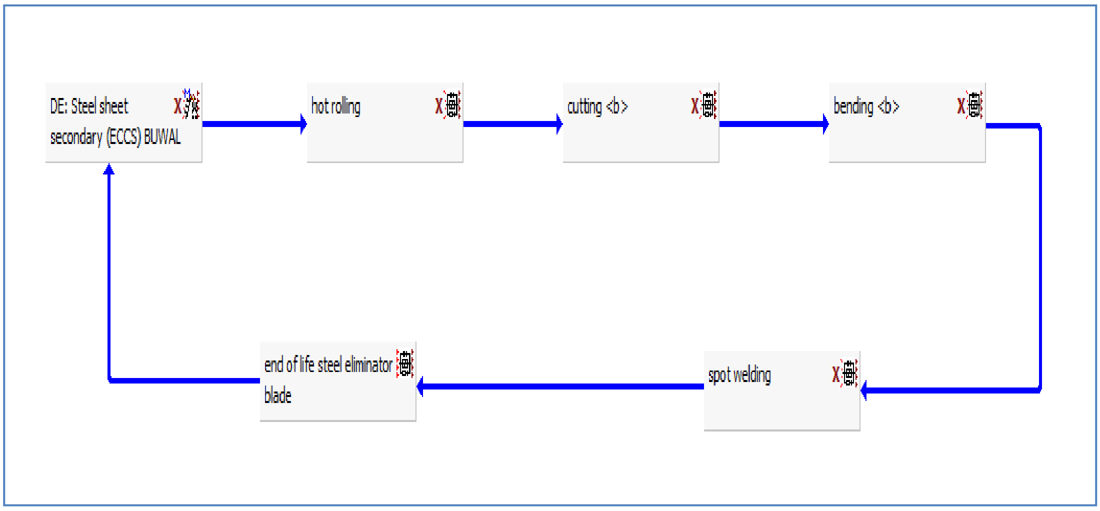

Figure 15: Life Cycle of Eliminator Blade

Figure 16: Life Cycle Assessment of Copper Tube

This GaBi 4 Education software calculated the potential environmental impacts for life cycle of plate, tube, eliminator blade and shell. For this impact assessment, this software used characterisation factors. For example, for climate change, the reference substance is CO_2. So the effects of 1 tonne of methane are converted into the amount of CO_2 needed to cause the same effect to the global warming (as methane is 23 times more damaging than CO_2). This shows that the climate change characterisation factor for methane is 23.

In **Figure 17** below, Sulphur Dioxide, Nitrogen Oxides, Hydrogen Fluorides and Heavy metals to fresh water have been released. Total of all these elements are 8352.52 kg SO_2 equivalent.

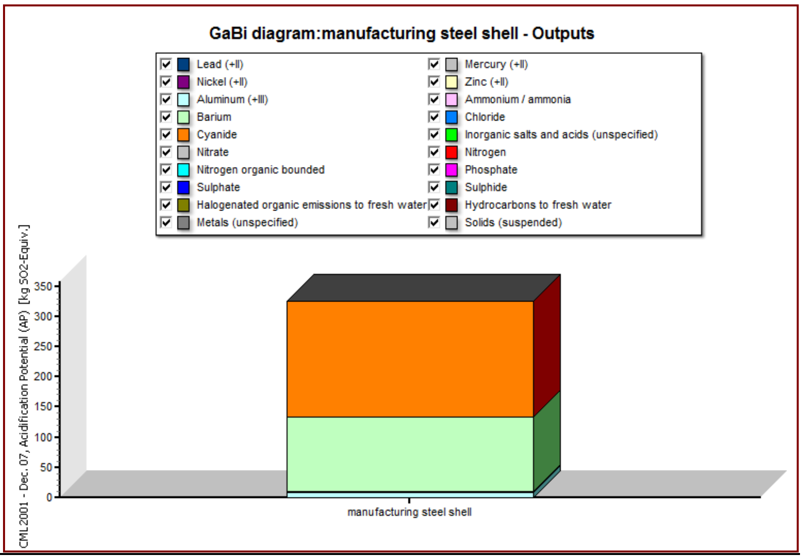

Figure 17: Acidification Potential

In **Figure 18** below, Heavy Metals, Organic Emission (group VOC), Particles and Inorganic Emissions to Air, Heavy metals and Inorganic Emission to Fresh Water have been released. Total of all these elements are 27.94 kg Phosphate equivalent.

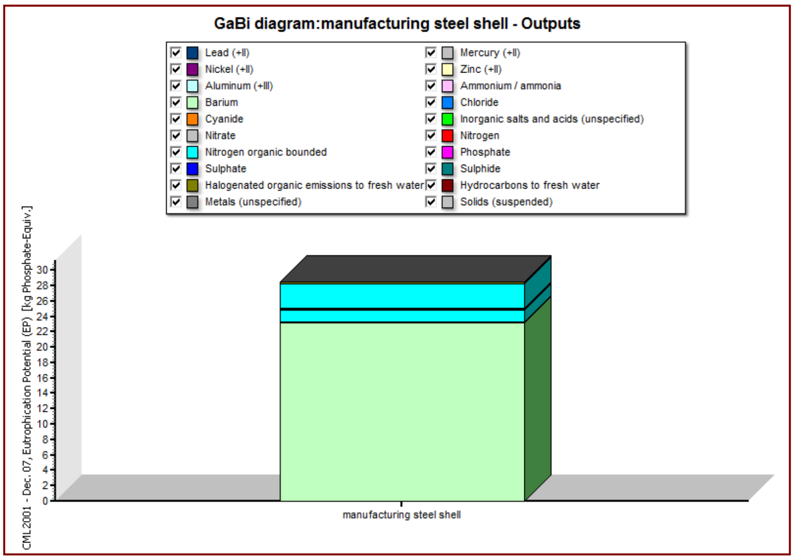

Figure 18: Eutrophication Potential

In **Figure 19** below, Inorganic Emission to air, Analytical measures and Inorganic Emission, Organic Emission to Fresh Water have been released. Total of all these elements are 5409 kg DCB equivalent.

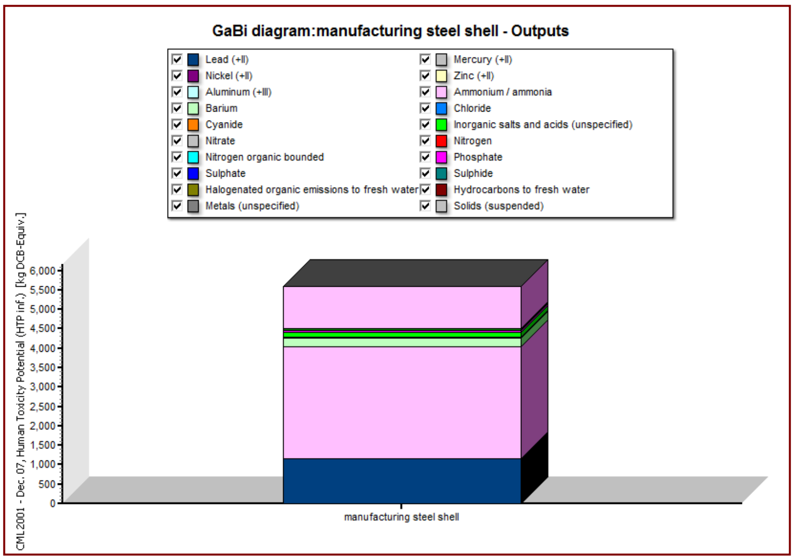

Figure 19: Human Toxicity Potential

In **Figure 20** below, Inorganic Salts and Acids and Nickel have been released. Total of all these elements are 80983 kg CO_2 equivalent.

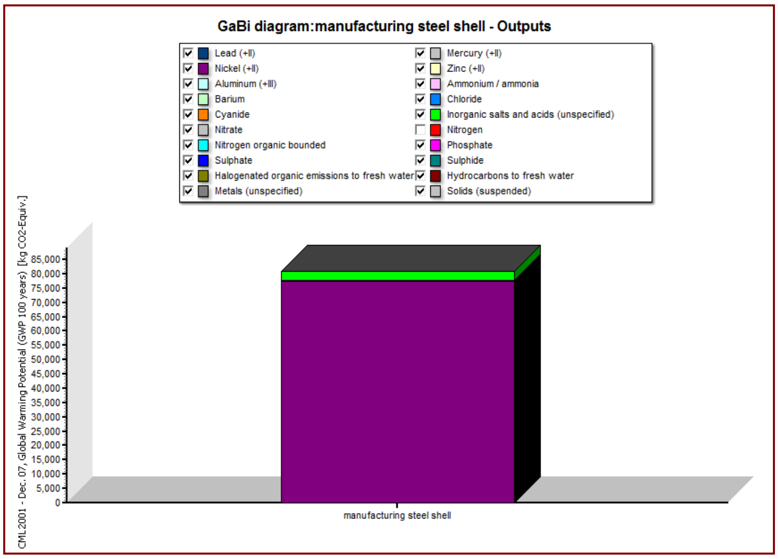

Figure 20: Global Warming Potential

Life cycle Assessment of Steel Plate

In **Figure 21** below, Sulphur Dioxide, Nitrogen Oxides, Hydrogen Chlorides and Particles to fresh water have been released. Total of all these elements are 0.8401 kg SO_2 equivalent.

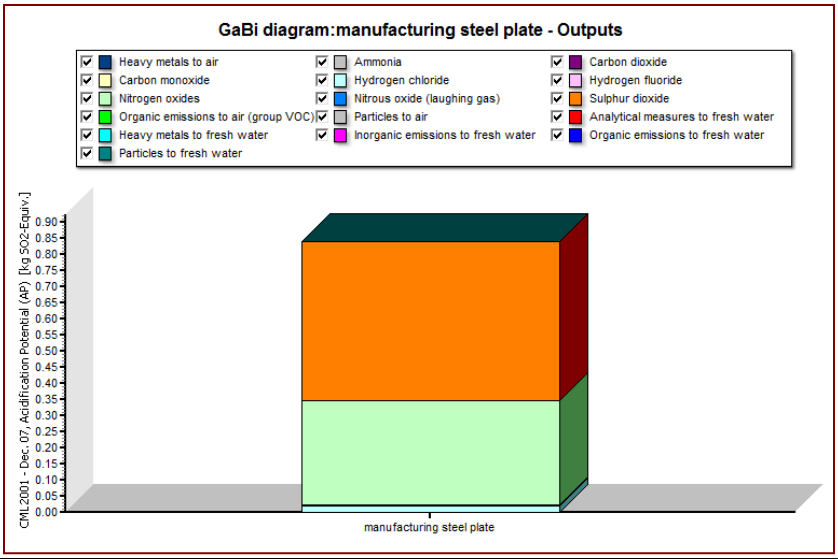

Figure 21: Acidification Potential

In **Figure 22** below, Nitrogen Oxides, Analytical Measures, Inorganic Emission and Particles to Fresh Water have been released. Total of all these elements are 0.496 kg Phosphate equivalent.

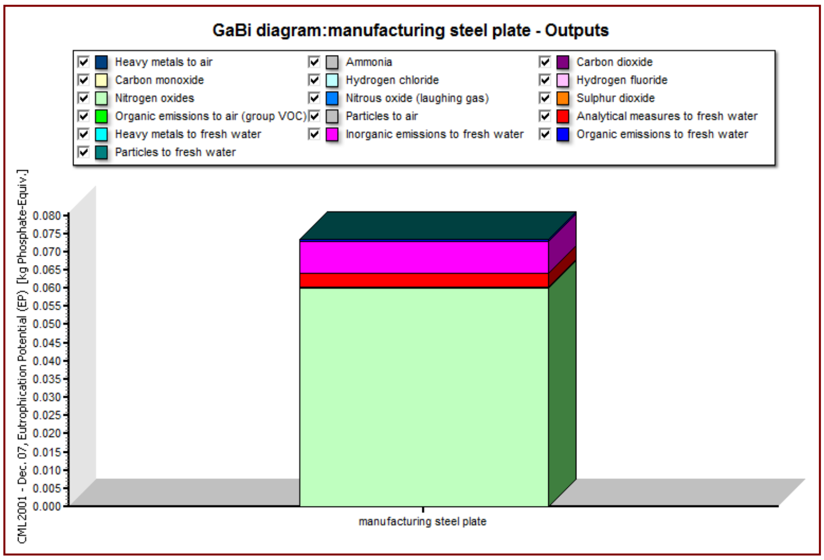

Figure 22: Eutrophication Potential

In **Figure 23** below, Carbon Dioxide, Organic Emission to Air (group VOC) and Particles to Fresh Water have been released. Total of all these elements are 209 kg CO_2 equivalent.

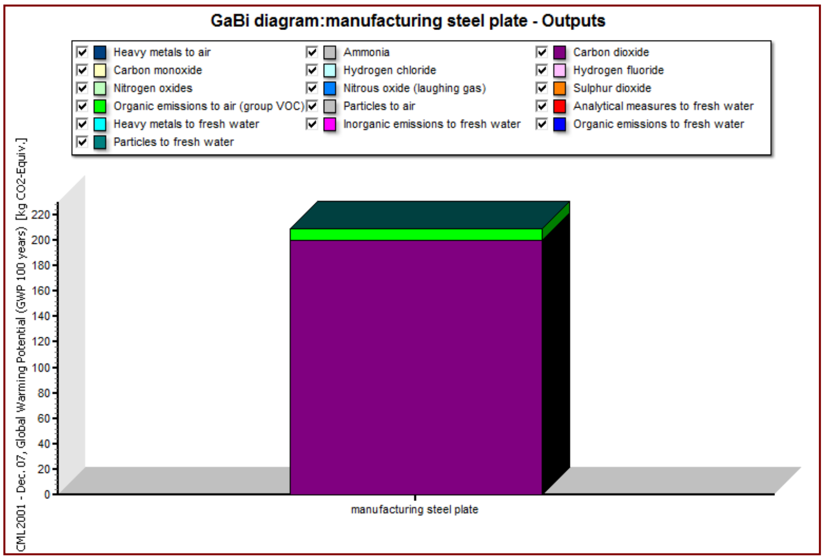

Figure 23: Global Warming Potential

In **Figure 24** below, Nitrous Oxides, Hydrogen Fluoride, Nitrogen Oxides, Organic Emission to Air (group VOC), Particle and Inorganic Emission to Fresh Water have been released. Total of all these elements are 11.21 kg DCB equivalent.

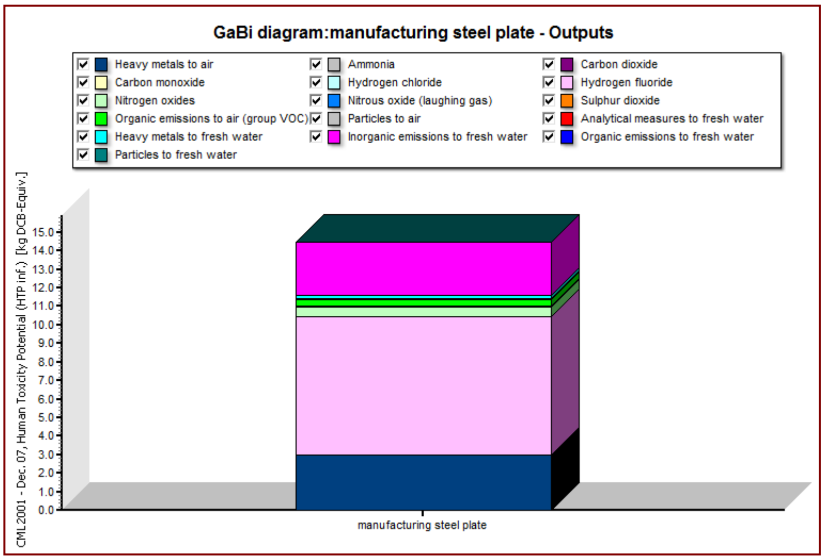

Figure 24: Human Toxicity Potential

In **Figure 25** below, Hydrogen Sulphide, Nitrous Oxides and Organic Emission to Fresh Water have been released. Total of all these elements are 555.72 kg SO_2 equivalent.

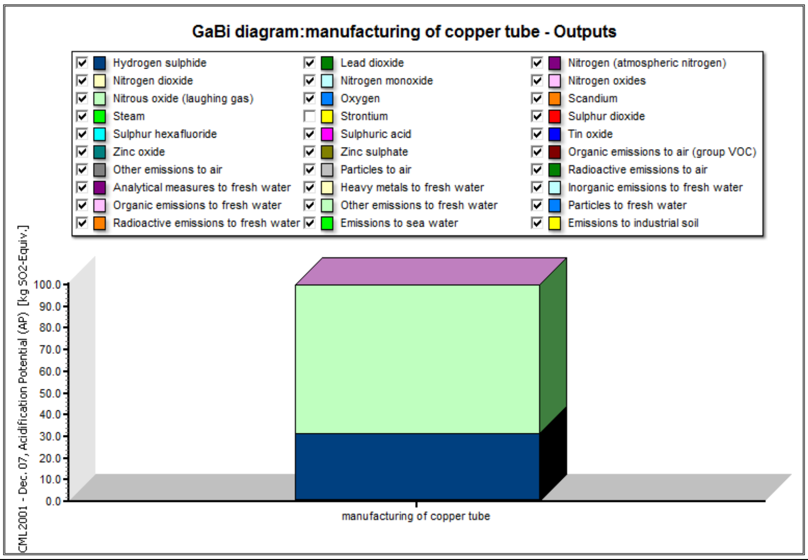

Figure 25: Acidification Potential

In **Figure 26** below, Tin Oxides, Radioactive Emission to Air, Lead Dioxide, and Organic Emission to Fresh Water have been released. Total of all these elements are 105.796 kg Phosphate equivalent.

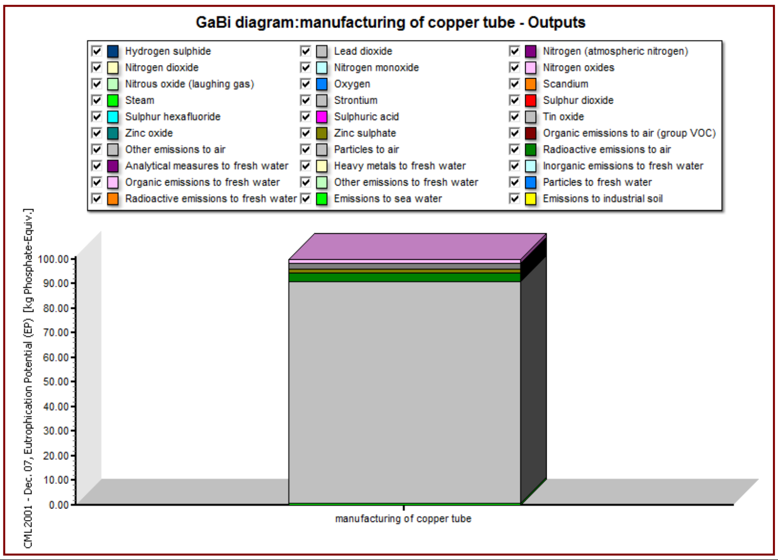

Figure 26: Eutrophication Potential

In **Figure 27** below, Organic Chlorine Compounds, Radioactive Emission to Air, Zinc Sulphite and Tin oxide have been released. Total of all these elements are 1106.3 kg CO_2 equivalent.

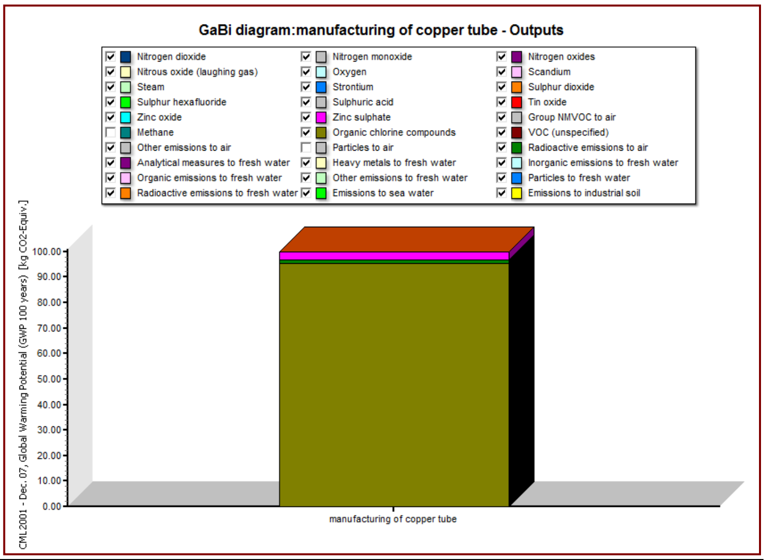

Figure 27: Global Warming Potential

In **Figure 28** below, Heavy Metals to Air, Inorganic Emission to Air and Emission to Industrial Soil have been released. Total of all these elements are 940.9 kg DCB equivalent.

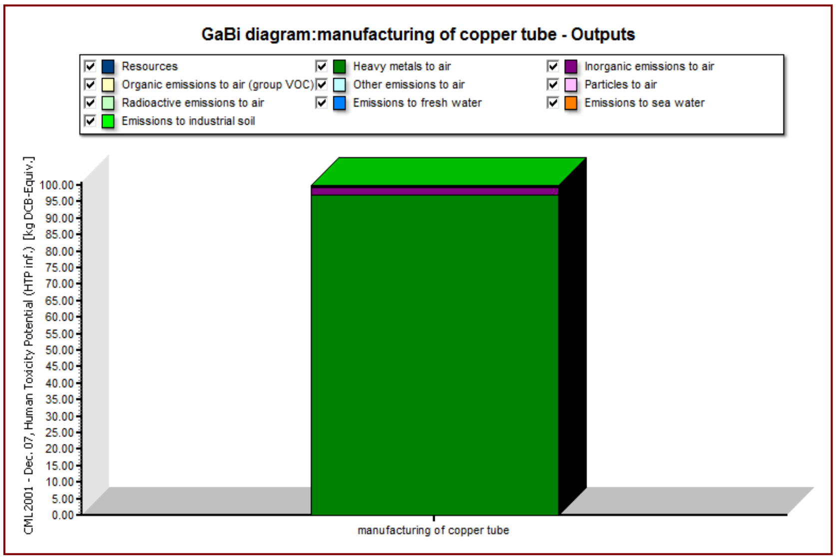

Figure 28: Human Toxicity Potential

In **Figure 29** below, Nitrogen Oxide, Hydrogen Chloride, Sulphur Oxide, and Heavy Metals to Air have been released. Total of all these elements are 108.325 kg CO_2 equivalent.

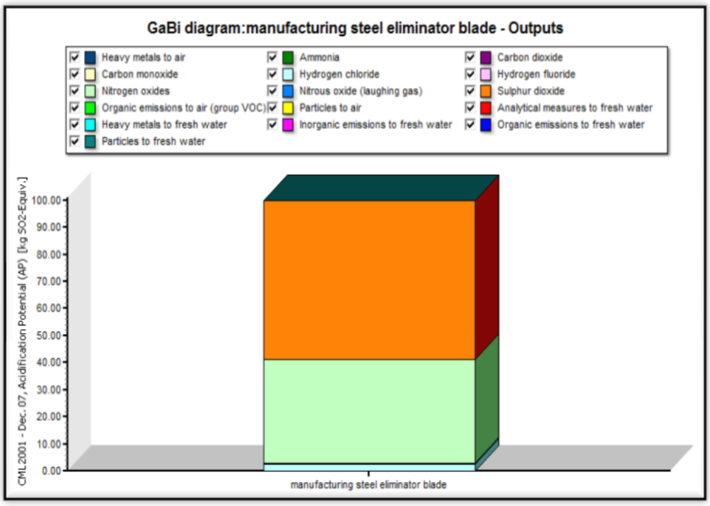

Figure 29: Acidification Potential

In **Figure 30** below, Nitrogen Oxide, Analytical Measure to Fresh Water, Inorganic Emission to Fresh Water and Particle to Fresh Water have been released. Total of all these elements are 109.49 kg Phosphate equivalent.

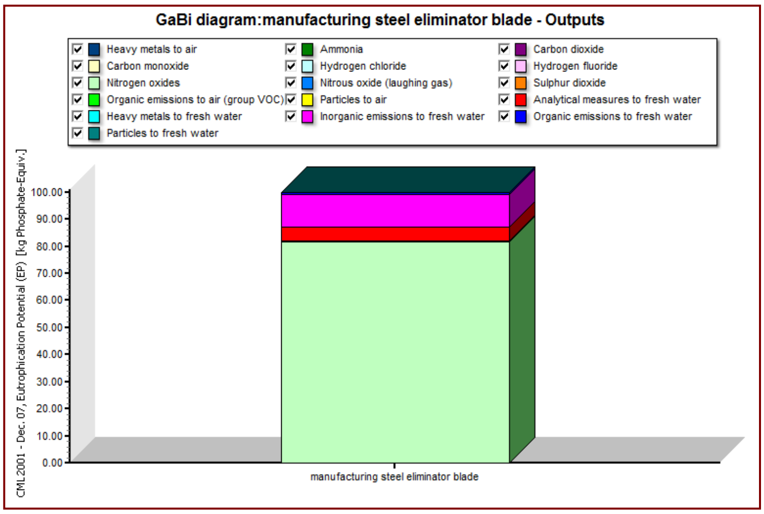

Figure 30: Eutrophication Potential

In **Figure 31** below, Carbon Dioxide, Carbon Monoxide and Particle to Fresh Water have been released. Total of all these elements are 134.39 kg CO_2 equivalent.

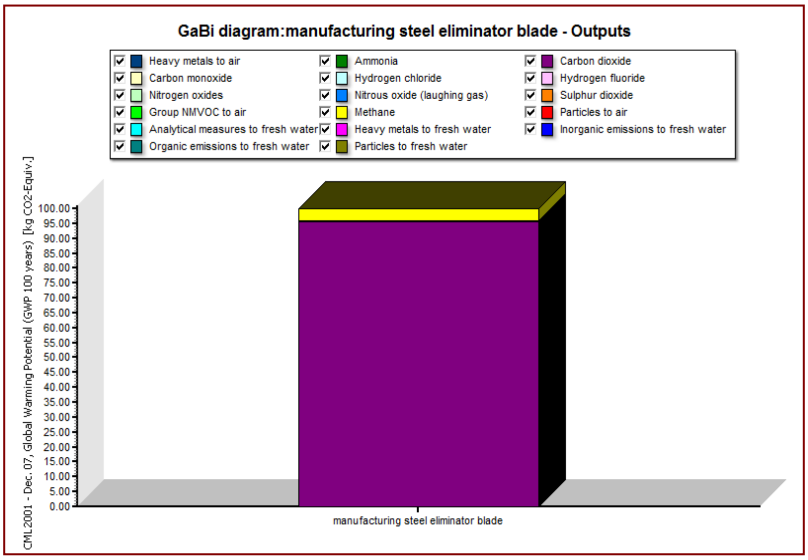

Figure 31: Global Warming Potential

In **Figure 32** below, Heavy Metals to Air, Hydrogen Fluoride, Nitrogen Oxides, Group NMVAC to Air, Heavy Metals and Inorganic Emission to Fresh Water have been released. Total of all these elements are 151.4 kg DCB equivalent.

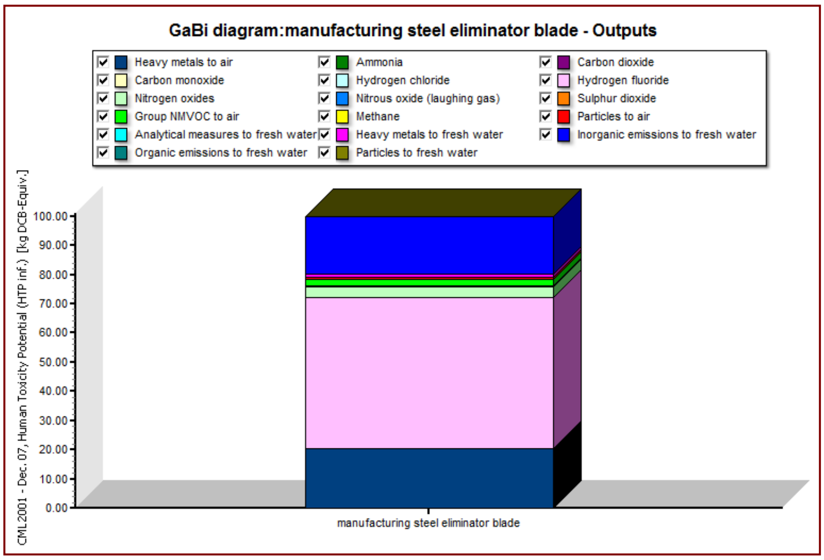

Figure 32: Human Toxicity Potential

Based on all the graphs above, the potential environmental impacts for both life cycles can be summarized as per **Table 12** below:

Table 12: Environmental Impacts for Life Cycle of Absorption Chiller

Potential Environment Impact Categories	Amount Released
Human Toxicity Potential	6422.536 kg DCB equivalent
Eutrophication Potential	28.862 kg PO_4 equivalent
Acidification Potential	332.056 kg SO_2 equivalent
Global Warming Potential	82332.786 kg CO_2 equivalent

4.2 DISCUSSION

All materials contain energy and these energies are used to refine, shape metals, and mine. When the materials are used, the energies used carry an environment penalty; for example CO_2, SO_2, oxides of nitrogen, sulphur compounds, dust and waste heat. Quantity of the elements released can be obtained by the multiplying the emission factor with the energy used. The emission factor depends on the input used such as natural gas, light oil, heavy oil of propane.

From the results, amount of kg CO_2 equivalent released is the highest among of all elements released. This indicates that Life Cycle Assessment of Absorption Chiller is highly contributing to global warming potential compared to other environmental impact categories. This could result in warming effect at the earth surface. The other impact categories are also contributed to the negative impact of environment, eutrophication potential which could lead to acceleration of algae growth (decrease in photosynthesis and less oxygen production), and also enrichment of nitrite, thus could damage the eco-system. While Human Toxicity Potential could lead to negative impacts of a process on human, and Acidification Potential could lead to decrease in the PH-value of rainwater and fog, thus damages the ecosystem.

In steel plate, steel shell and eliminator blade processes, Electric Arc Furnace (EAF) was used for making steel. Raw material used by this EAF were steel scrap which is from the end of life cycle from both plate and shell processes. The environmental impact of the EAF was due to mainly from the carbon monoxide that escaped from the melt, and the particulates that were generated as a result of the gas flows and the transfers of incoming and outgoing materials. Furthermore, the usage of electric power generated nitrogen oxides in the arcing that occurred between the electrodes. Beside nitrogen oxides and carbon monoxides, there were also other gases emissions released which are sulfur oxides, fine particles and volatile organic compounds (VOCs).

In life cycle of steel plate, tube and eliminator blade, hot rolling process was involved. The hot rolling produced hydrocarbon emissions from lubricating oils. Gradual heating and cooling also gave emissions of nitrogen oxides and carbon monoxides. In life cycle of steel shell, welding of stainless steel contributed to emission of hexavalent chromium. While bending process could results to wastes due to lubricants and cleaning of the shell part.

The secondary copper processing in the life cycle assessment of copper tube could produce air emissions include particulates and sulfur dioxide. Particulate air emissions included iron and copper oxides, and also contained other metal oxides, sulfates or sulfuric acid.

The resulting sulfur oxides and nitrogen oxides emissions contributed to the acidification potential, which will damaged ecosystem, whereby forest dieback was the most well known impact. While the resulting air pollutants and wastewater contributed to the eutrophication. This could accelerate algae growth in water, which prevented sunlight from reaching the lower depth. In addition, oxygen was used for the composition of the algae. This could decrease oxygen concentration in water, which leads to fish dying and destruction of the ecosystem.

Nitrogen oxides and volatile organic compounds (VOCs) were substances that have a depleting effect on the ozone. This could result in warming of the earth's surface (global warming potential). Other effects of this depletion were decrease of sea plankton, decrease in harvest crops, and indications of tumors, which are skin cancer and eye disease (human toxicity potential).

The resulting hydrocarbon and hexavalent chromium were contributing to the human toxicity potential. When hydrocarbons combined with NOx and sunlight, ozone is formed. This is a serious form of air pollution and a key component of smog. The brown haze of smog that plagues many urban areas caused irritation and damage to eyes, skin and lungs. It dried out the protective membranes of the nose and throat, interfering with the body's ability to fight infection. These hydrocarbons were considered toxic, and could cause serious health problems such as cancer or death. While hexavalent chromium is a toxic air contaminant that contributed to an increase in mortality or an increase in serious illness, or which may posed a present or potential hazard to human health.

From the results, in can be concluded that the life cycle of steam absorption chiller is contributing to acidification potential, eutrophication potential, human toxicity potential, and global warming potential. It is recommended that instead of using copper as the material for tube, the best materials to be used is steel due to their low embodied energy (low CO_2 emission).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Life cycle assessment (LCA) is an important tool to identify and improve the environmental effects and aspects at various points in a product life cycle. This LCA method is performed on the steam absorption chillers (SAC) in order to evaluate the life cycle effects the environment and also to evaluate the opportunities available to reduce environmental impacts.

The steam absorption chiller consists of many components, which also comprise many sub-components; therefore it is difficult to gather from suppliers the information on all parts that compose the absorption chillers. Thus, this project is focused only on compiling the life cycle inventory (LCI) data on most important components, which are condenser, high temperature generator, low temperature generator, absorber, and evaporator.

From the results, amount of CO_2 released is the highest among of all the elements released. This indicates that life cycle assessment of the absorption chiller is highly contributing to the global warming potential. This resulted in warming effect at the earth surface.

It is recommended that instead of using copper as the material for tube, the best material to be used is steel due to its low embodied energy because the lower the material's embodied energy, the lower their CO_2 emission. It is also recommended to recycle back the copper scrap to the tube life cycle, because by recycling a tonne of copper, it uses 15% of the energy that would be used to mine and extract the same copper. Recycling will conserve the world's supply of fossil fuels and reduce carbon dioxide emissions.

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