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"GATE TO GATE" LIFE CYCLE ANALYSIS OF BABEL LEAD ACID BATTERY

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ABSTRACT: - Life Cycle Analysis "LCA" of Babel Lead acid battery of 135 (Amp/hr) capacity is investigated according to International Organization for Standardization (ISO)14040 framework for LCA, to identify the four major contributors to the environmental impacts; Eutrophication, Global Warming, Human Toxicity, Acidification. "Gate to Gate" approach were employed, data from the production processes for 2012 were collected. Results of the inventory analysis phase are calculated employing Chain Management Life Cycle Assessment (CMLCA) software and the results from impact assessment phase analyzed using the CML method. Results show that the environmental impact spreads over the production processes and every process has a certain impact, however, the largest environmental impact relates to Formation and Assembly processes, the Formation process impact on Eutrophication is of (71%) and on Global Warming is of (26%) contribution. Were the Assembly process impact both for Human Toxicity and Acidification contribution about (59%) and (50%) respectively.
Keywords: *LCA, ISO- (14040-43), Gate to Gate, Lead Acid Battery, CML method, Functional unit, Environmental Impact, Eutrophication, Global Warming, Human Toxicity, Acidification.*

1- INTRODUCTION

Due to the increasing awareness of environmental protection and the possible impacts associated with product systems, industries are looking at new approaches to design and manufacture products to include environmental requirements together with the traditional requirements of product function, quality, and cost (1).

LCA is decision-making process that provides better understanding of the human health and environmental impacts that are not traditionally considered when selecting a product or process, and provides method to account for the full impact of decisions, and where they are occurring (locally, regionally, or globally)(2) .LCA is employed in manufacturing to help in reducing the overall environmental burdens across the whole product life cycle starting from raw material extraction through production, use, end of life treatment, recycling and final disposal (1) with the aim of contributing towards sustainable product (3,4).

2- LCA System Boundaries

LCA can systematically evaluate the environmental consequences of products and processes to make those products, and quantify the environmental releases from each process [5]. Due to The complex nature of life cycle analysis, it may not include all of the life cycle stages, different system boundaries can be defined according to the life-cycle [6,7&8], the system boundaries are :

i. **Cradle to Grave**: Estimated for the product full Life Cycle: as "cradle" from extraction stage, manufacturing to use and disposal stage also called "grave", meaning starting at the upstream cradle of raw material extracted from earth and ending at the product grave of life cycle disposal or product end-of-life.

ii. **Cradle to Gate**: Consider partial product life cycle from manufacture "cradle" to the factory "gate" focuses on the manufacturing or production stage of the system life cycle where the use and disposal stages has not included.

iii. **Cradle to Cradle**: Where products have reused or recycled instead of being disposed of in landfills making the system basically waste free. The term cradle-to-cradle has often implied that the product under analysis has substantially recycled, thus reducing the impact by using the product in the first place.

iv. **Gate to Gate**: The "gate to gate" approach ignores all steps before and after the factory gate; some of the LCA approaches [9] is shown in Fig. (1).

3- LCA Methodological Framework

The methodological framework of LCA is based on ISO standards (14040-43), according to ISO standards consist of four interrelated phases[10], starting from Goal and Scope Definition, followed by Inventory Analysis, Impact Assessment and Interpretation Phase.as shown below:

3-1 LCA Theory and Application

i. **Goal and Scope Definition Phase**: Stating the purpose of the life cycle analysis and the Functional unit which has "quantified performance of a product system for use as a reference unit" in life cycle analysis studies.

ii. **Inventory Analysis Phase:** The energy and raw materials used in the processes, and their emissions to atmosphere, water, and soil have quantified for each step in the process, then combined in the process flow chart related back to the Functional unit. An inventory of all inputs to, and outputs from the production system has prepared as part of the inventory analysis [11,12]. Equation (1) has used to calculate the amount of output (the emissions) of each process:

a. $\mathbf{S = A^{-1} \times \mathit{f}}$ .... (1)

b. Where,

A (the technology matrix): Represents the input and output for both material and energy.

f (functional unit): Is the output amounts aggregated over product life cycle of all processes.

S (scaling factor): Describe how much of each process output has used in total.

The life cycle emissions are calculated in further step, by multiplying **S** with the so-called emission matrix **B**.

i. $\mathbf{g = B \times S}$ …………………… (2)

In order to calculate the aggregated emission over the life cycle of all processes, the emission matrix (**B)** has multiplied by the scaling factor (**S)**. Form that a demand vector (**g)** has resultant and represents life cycle inventory.

iii. Impact Assessment Phase: The results of the inventory analysis have used to determine the effects on environment and human health. To understand its impact, the effects of used resources (raw materials and energy) and generated emissions have grouped and quantified into a limited number of categories. The impacts assessment aggregates and quantifies, the process of impact calculations have follows the equation[13]:

iv. $\mathbf{h= Q \times g}$ ……………………. (3)

Where,

h**:** Impact indicator.

Q: Characterization factor (based on the impact assessment method used).

g: Inventory result (as aggregated emission over the life cycle).

The results of Life Cycle Inventory Analysis "LCIA" can be determined which product / process causes more impact (e.g global warming potential) [2,14].

Based on the method used, the emissions of hazardous substances and extractions of natural resources have to convert to certain indicators named "Impact Category Indicators" so as to find its impacts on environment. Some of the impact assessment methods are, "CML method", "Eco indicator 95 method" and "Eco indicator 99 method", etc. (15, 16). "CML method" has been chosen for this purpose and it is described below:-

The CML Method or (Centre of Environmental Studies) method; is developed by the University of Leiden in Germany, and it is used in the ecological product development and improvement in industry. The method focuses on a series of environmental impact categories expressed in a terms of emissions to the environment. The impacts for "Global warming" and "Ozone layer depletion" has based on Intergovernmental Panel on Climate Change (IPCC) equivalency factors, impact category indicators have usually rather abstract units. For example, the unit of Global warming has (kg CO_2 equivalent) and the unit for Acidification has (Kg SO_2 equivalent) (17,18).

v. **Interpretation Phase**: The objective of this phase has to interpret the results of the life cycle analysis to determine which process has the overall least impact on human health and the environment, and/or one or more specific areas of concern as defined by the goal and scope of the study(2).

4- LITERATURE REVIEW

A literature review is conducted and it has been directed towards the researches conducted on LCA of batteries across the world to reveal the current interest of research towards these products (batteries) and the environmental impact of different types and sizes. For instant, **Carl and Magnus (2002)**(19) had assessed the environmental impact of recycling portable Nickel–Cadmium (NiCd) batteries. Their result had revealed that the battery manufactured from recycled Cadmium and Nickel has (16%) lower primary energy requirements than if only virgin metals have used. The recycled Cadmium and Nickel requires (46%), and (75%) less primary energy respectively comparing with extraction and refining of virgin metals. More studies done by **Van den Bossche, et al (2005)** (20), they studied and compared five different types of batteries; (Lead–acid, Nickel–Cadmium, Nickel-metal hydride, Lithium-ion and Sodium–nickel chloride). The study had employed ECO 99 method and had considered complete battery life cycle. They have found that Lead acid battery have gotten the highest environmental impact as (282), followed by Nickel Cadmium of (241), Lithium-ion of (189), Nickel–metal hydride of (168) and Sodium–Nickel Chloride of (112) as environmental points respectively. While **Sullivanv and Gaines (2010)** (21) have investigated five battery technologies of; Lead-acid, Nickel–Cadmium, and Nickel-metal hydride, Sodium-Sulfur, and Lithium-ion batteries. Cradle-to-Gate approach was employed for this study, focusing on the energy used and Greenhouse Gas (GHG) emissions. They have observed that the production energy of Lead acid batteries had the lowest among the five batteries reviewed where Nickel–Cadmium has the next lowest, with the remaining batteries sensibly tied.

5- EXPERIMENTAL WORK

LCA methodology has applied to Lead acid battery produced in Babel factory according to ISO 14040 standard, the LCA phases starts from defining the goal and scope, followed by inventory analysis, and finally the impact assessment, employing CMLCA software for calculating matrix equations in the inventory analysis phase by relating the data of emissions (from processes) to the functional unit, the flow chart of the CMLCA software (22) is shown in Fig (2). The LCA phases of Bable battery is applied as follows:-

i. Goal and Scope Definition of Babel Battery

The goal of the study has to explore the potential environmental impact of Babel Lead acid battery and highlight the processes where the hotspots of environmental impact occur, while scope definition involves specifying the Functional Unit (FU), which has "delivering electricity throughout a chemical reaction with an energy storage capacity of 135 (Amp/hr) and correspond to the weight of (29.207) Kg".

ii. Inventory Analysis of Babel Battery

The inventory phase has performed by following these steps:-

- Developing Process Flow Diagram:- A process flow has constructed within the specified system boundaries to combine all processes, and form a life cycle analysis picture, as shown in Fig.(3).
- Collecting Data form Process:- The data has quantified, including values for the inputs to and outputs from each process which has included the data of material, energy and emission rates, and the inventory calculations from different processes [22].
- Creating Environmental Data:- After collecting the data, calculations have been made in order to generate the inventory list, so the CMLCA software has employed for this purpose, using equations (1 and 2) of the inventory analysis which has built in the software to calculate the environmental loads from each process related to the functional unit.

iii. Impact Assessment of Babel Battery: Relevant environmental impact categories have selected, based on the inventory analysis results generated according to the eq. (3) using CMLCA software.

6- RESULTS AND DISCUSSION

According to CML method, the environmental impact categories of (Global Warming, Acidification, Eutrophication, and Human Toxicity have considered). The inventory analysis result from Babel battery production is depicted in Table (1). And the results of potential environmental impacts are listed in Table (2) reveals that these processes have at least one impact potential related has described in the following paragraphs:

- **Global Warming Potential (GWP):** All processes has contribute to this impact category since they consume fuel as shown in Fig.(4), however, the highest contribution to GWP has generated from formation process of (26%) due to high energy consumption while the process of charging the plates, followed by Lead oxide production process (22%) and PVC sintering process (19%), respectively. The impact to GWP of these processes is regarded as indirect impact (since it is not generated at the production site itself / at AL-Doura refinery power plant). It has noticed that low GWP impact potential has correlated to grid casting and small parts casting processes (2%) and (1%) respectively, where GWP related to these processes has regarded as (direct impacts) due to consumption of Liquefied Petroleum Gas or (LPG) at the production site.
- **Acidification:** Referring to Table (2) it has found that three processes cause air acidification; assembly, pasting and formation processes, as shown in Fig (5). As the emissions (SO_2 equivalents) have generated from these processes. Assembly process represents the most significant impact on acidification and it has contributed by (50%) this impact has occurs due to stacking and movement of the plates to form the cells, while the pasting process has a contribution of (33%) and the formation process contribution is (17%).
- **Eutrophication:** Two processes pose a potential source of impact on eutrophication potential as the rest of processes do not cause waste water discharge. Formation process has contribution of (71%), followed by pasting process of contribution (29%) as shown in fig. (6).
- **Human Toxicity:** Human toxicity involves the release of pollutants that have uncontrolled, except for paste mixing process where wet scrubber has available. This impact category varies from process to another and almost negligible in plastic manufacturing. The dominating process has holded a major contribution to human

toxicity is the assembly process and contributes about (59%) followed by pasting (14%) then grid casting process (12%), as shown from Fig.(7).

7- CONCLUSIONS

The conclusions have drawn from this study as:

1. It has found that the environmental impact of Babel battery production processes spreads over the production processes and every process has a certain impact.
2. The highest contribution to GWP have generated from: formation process (26%) due to high energy consumption while charging the plates, followed by Lead oxide production process (22%) and PVC sintering (19%), respectively.
3. Assembly process represents most significant impact on acidification and it contributes by (50%), while the pasting process has a contribution of (33%) and the formation process contribution is (17%).
4. Formation that has contribution of (71%) on eutrophication followed by pasting process and has contribution of (29%).
5. The dominating process has holded a major contribution to human toxicity is the assembly process and contributes about (59%) followed by pasting (14%) then grid casting process (12%).
6. The results of the study can be summed up to show that the formation has an impact on global warming (26%) followed by impact on eutrophication (71%), while the assembly process impacts on both acidification and human toxicity by (50%) and (59%) respectively.

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Table (1): Inventory Analysis Phase Result (Emissions per Functional Unit) Generated By CMLCA Software

Processes	Inventory analysis result (g)	Lead oxide production	Grid casting	Paste mixing	Pasting	Formation	Box Injection Molding	Cover Injection Molding	Plugs Injection Molding	Sintering PVC	Small Parts Casting	Assembly
Emission to air (Kg)	PM_{10}	0.000388	0.00551	0.00228	0.0261	0	0.000134	4.00E-05	7.54E-05	0	0.000349	0.19
	Pb	0.000193	0.00155	0.00132	0.00128	0	0	0	0	0	0.000193	0.00303
	CO_2	29.8	2.63	9.47	9.47	35.1	8.29	3.55	3.55	25.6	0.788	5.92
	SO_3	0	0	0	0.0876	0	0	0	0	0	0	0.134
	H_2SO_4	0	0	0	0	0.0571	0	0	0	0	0	0
	VOC	0	0	0	0	0	6.13E-05	1.84E-05	4.47E-06	0.0067	0	0
Emission to water (Kg)	COD	0	0	0	0.027	0.0675	0	0	0	0	0	0
	BOD	0	0	0	0.018	0.0451	0	0	0	0	0	0
	SO4	0	0	0	0.0223	0.14	0	0	0	0	0	0
	Pb	0	0	0	2.31E-05	0.00185	0	0	0	0	0	0
	Oil and Grease	0	0	0	0.0259	0.000617	0	0	0	0	0	0
	TDS	0	0	0	0.317	0.674	0	0	0	0	0	0
	TSS	0	0	0	0.0324	0.172	0	0	0	0	0	0
	CL	0	0	0	0.0363	0.04	0	0	0	0	0	0

Table (2): Potential Impacts Resulting From Babel Battery Production

Battery production processes	Global Warming potential (kg CO_2 eq.)	Acidification potential (kg SO_2 eq.)	Eutrophication potential (kg PO_4 eq.)	Human Toxicity potential (kg 1,4 BD eq.)
Lead oxide production	29.8	_	_	0.005918
Grid casting	2.63	_	_	0.04962
Paste mixing	9.47	_	_	0.04007
Pasting	9.47	0.0701	0.000594	0.05882
Formation	35.1	0.0371	0.00149	0.00963
Box molding	8.29	_	_	0.00011
Cover molding	3.55	_	_	3.28E-05
Plugs molding	3.55	_	_	6.19E-05
PVC sintering	25.6	_	_	_
Small parts casting	0.788	_	_	0.005886
Assembly	5.92	0.108	_	0.244
Total impact	134	0.215	0.00208	0.414

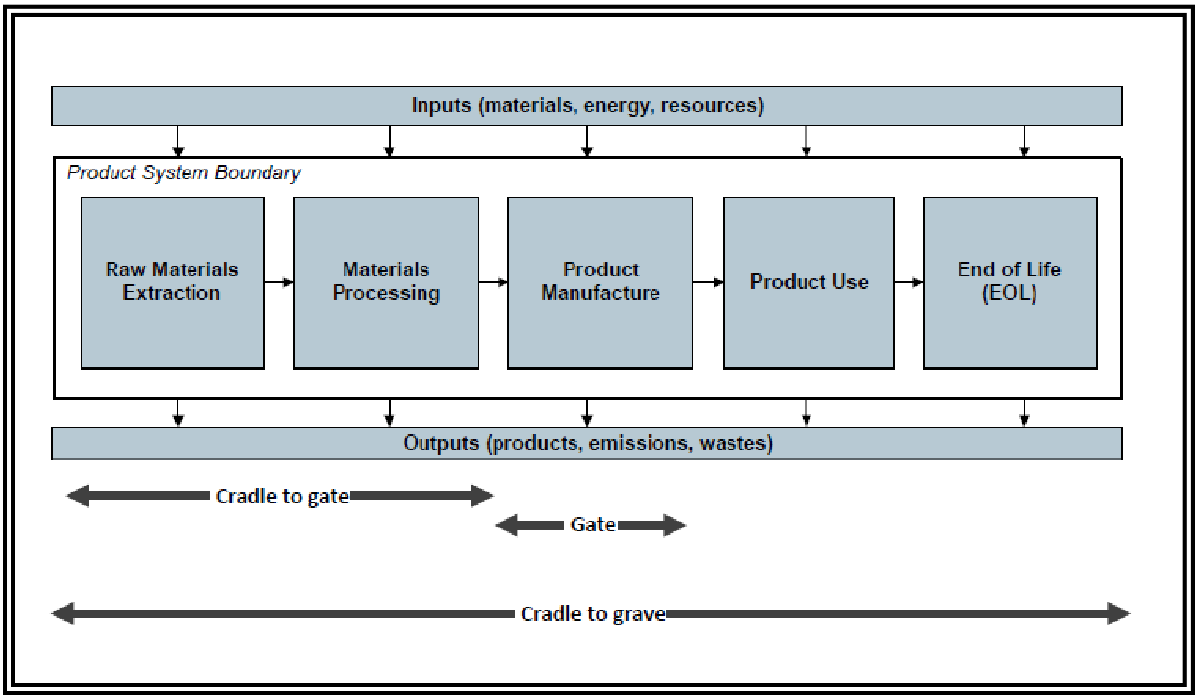

Figure (1): Some of the Approaches to Life Cycle Analysis

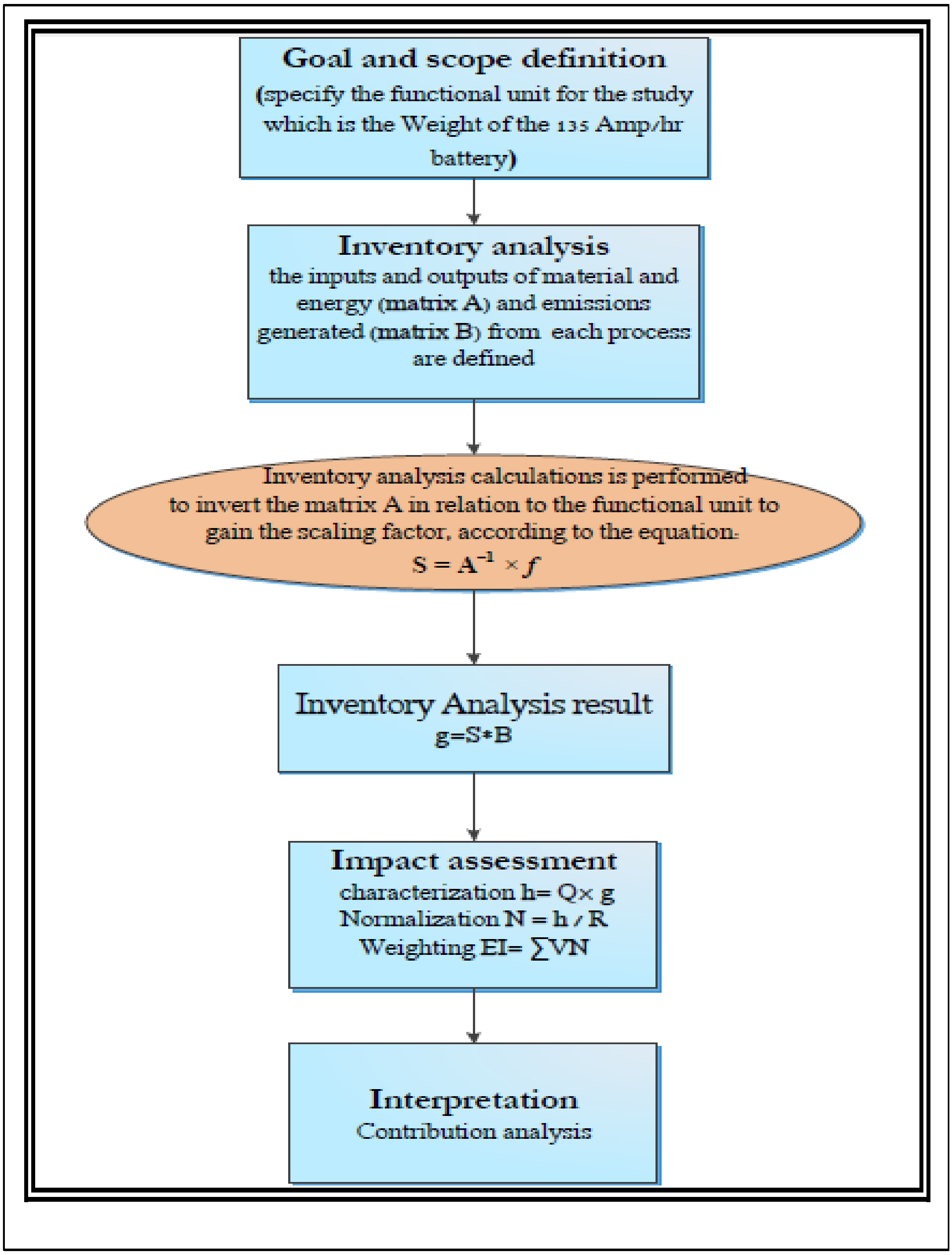

Figure (2): Flow chart of the CMLCA software employed in the study

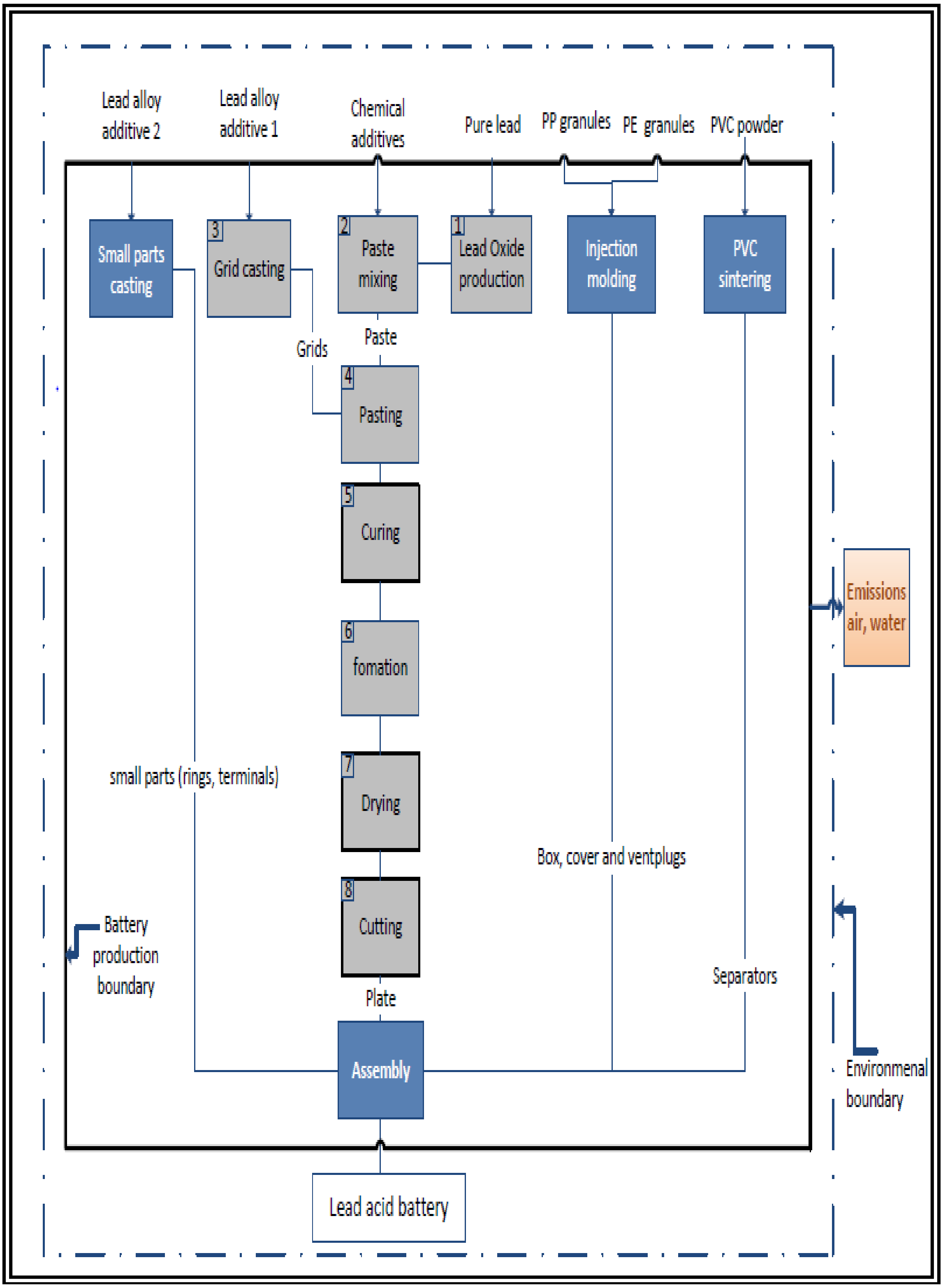

Figure (3): Babel Battery Process Flow Chart

*Solid line represents the boundary of the study (gate to gate).
*Dotted line represents the environmental boundary.
*Bold boxes indicate excluded processes.

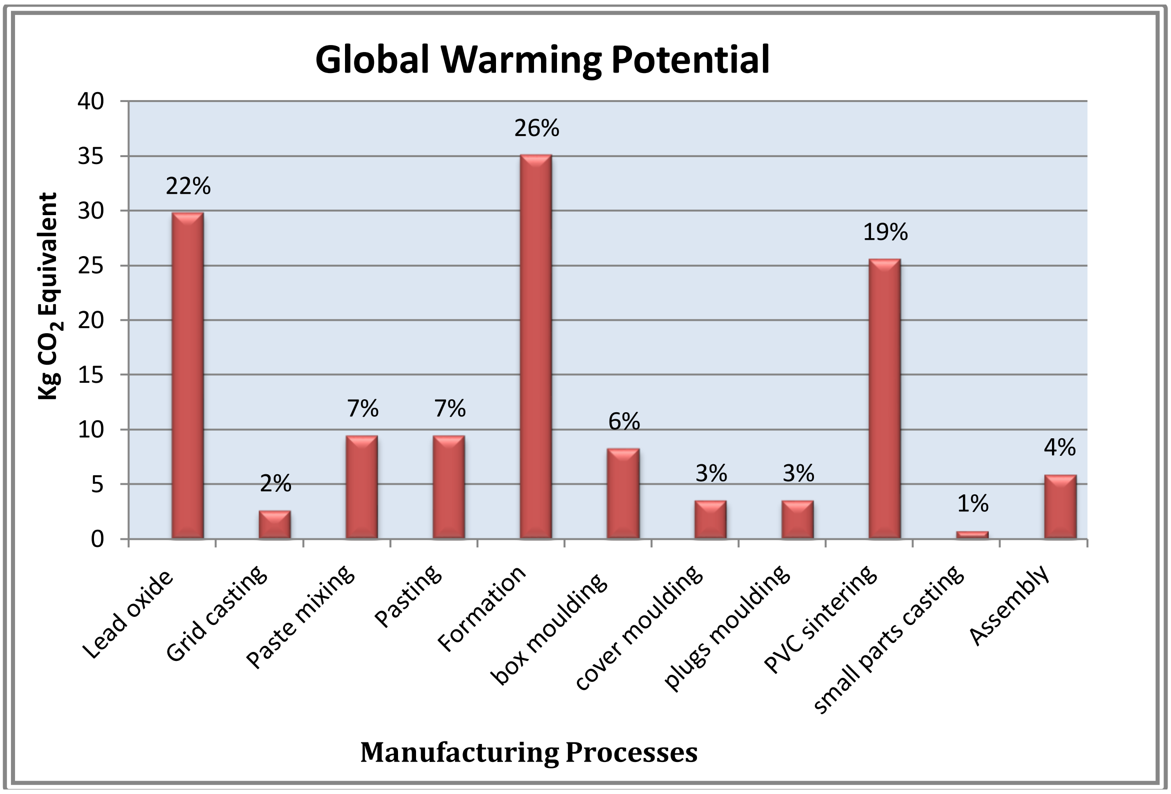

Figure (4): Global Warming Potential Impact per Functional Unit

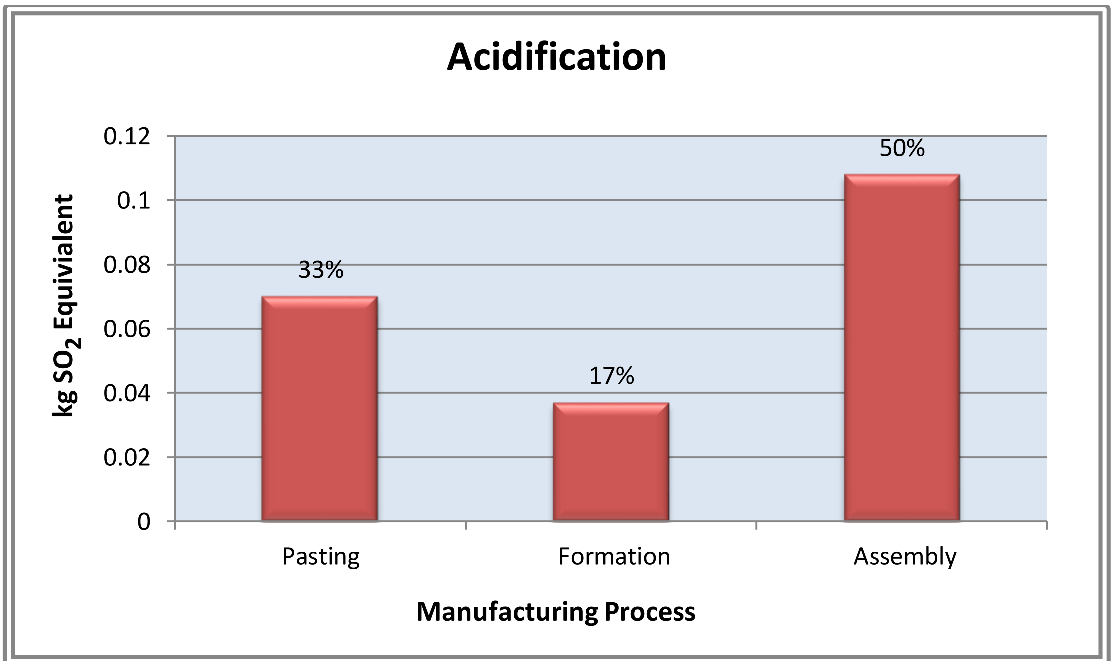

Figure (5): Acidification Potential Impact per Functional Unit

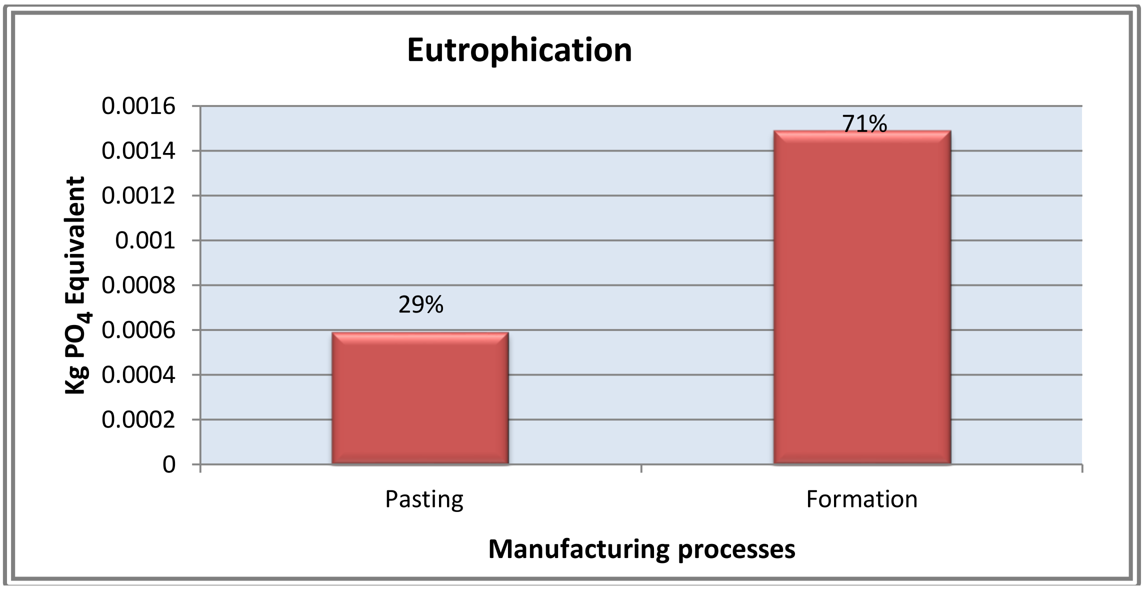

Figure (6): Eutrophication Potential Impact per Functional Unit

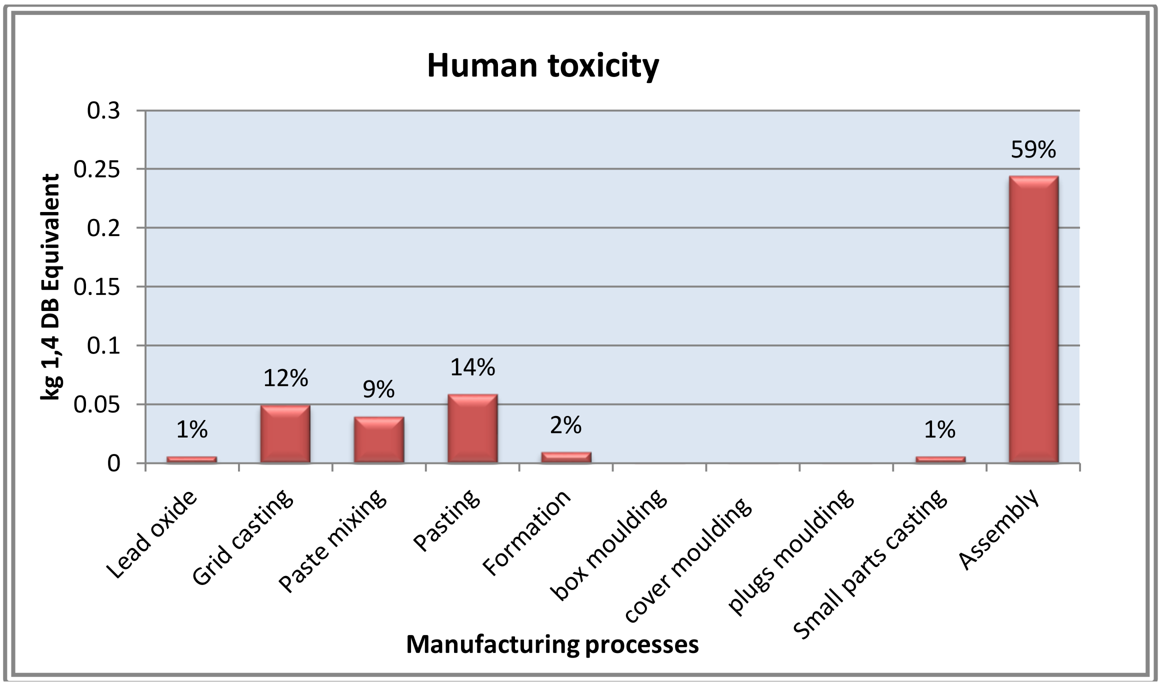

Figure (7): Human Toxicity Impact per Functional Unit

تحليل دورة الحياة من "بوابة الى بوابة" لبطارية بابل الرصاص الحامضية

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الخلاصة

تم تحليل دورة حياة بطارية بابل الرصاص الحامضية سعة 135 (امبير/ساعة) وفقاً لهيكلية المنظمة العالمية للتقييس (الايزو) 14040 . وظفت المقاربة "بوابة الى بوابة" حيث تم استخدام البيانات الخاصة بالعمليات الانتاجية لعام 2012. أستخدم برنامج Chain Management Life Cycle Assessment (CMLCA) لحساب نتائج مرحلة تحليل الخزين , و أستخدمت طريقة (CML method) في مرحلة تحليل و تقييم الاثر البيئي. حيث بينت نتائج الدراسة ان التأثير البيئي المرتبط بتصنيع بطارية بابل منتشر خلال العمليات التصنيعية وهذا التأثير يختلف من عملية الى اخرى. غير ان اعلى نسب للتأثير البيئي ناتج من عمليتي الشحن والتجميع, حيث وجد ان عملية شحن الواح الرصاص تؤثر بنسبة (71%) لفئة الاثراء الغذائي (Eutrophication) و بنسبة (26%) لفئة الاحتباس الحراري (Global warming potential) وكذلك تؤثر عملية التجميع على فئة سمية الانسان (Human toxicity) و فئة الامطار الحامضية (Acidification) حوالي (59٪) و (50٪) على التوالي.

الكلمات المفتاحية: تخمين دورة حياة , من بوابة الى البوابة, بطارية الرصاص الحامضية, ايزو(14040-43) , طريقة CML, التأثيرات البيئية, الوحدة الوظيفية , الاثراء الغذائي , الاحتباس الحراري, سمية الانسان, الامطار الحامضية