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Comparison Study of Environmental Impacts between Mid (CML) and End Point (Eco 95) Methods for Babel Lead Acid Battery Production Processes

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Abstract:

In this research, quantitative analysis, comparison of the environmental impacts for Iraqi Babel Lead acid battery (capacity of 135 Amps/hr) throughout the production processes is conducted for 2012 year, according to the ISO (14040-14043) series of standards. Two impact assessment methods employed are; Centre of Environmental Studies (CML–midpoint) and (Eco 95-endpoint). Chain Management Life Cycle Analysis [CMLCA] software is used to process and generate the collected data. In CML (mid-point) method four potential environmental impact categories are; [Global Warming Potential (GWP), Acidification, Eutrophication, and Human toxicity], while Eco 95 (endpoint) method evaluates six categories of environmental impact are; [Global Warming Potential (GWP), Acidification, Eutrophication, Heavy metals, Summer, and Winter Smog]. Results generated according to CML method reveal that formation process as the highest contributor to GWP by (26%), Eco 95 declared contribution to the GWP of the same process by (4%). Through CML (mid-point) the assembly process is identified as having the most significant impact on acidification by (50%), while Eco 95 method quantify acidification for the same process by (4%). Human toxicity is allocated by (60%) contribution in the assembly process by CML method, whereas the same process is identified as the most hazardous process of (93%) contribution heavy metals impact is, and winter smog (3%) according to Eco 95 method. Formation process is the highest contributor to Eutrophication according CML method, while Eutiphication is not of concern, according to (Eco 95) for this process. It is concluded that the environmental impacts of Babel battery spread over the production processes and every process have certain environmental impact category (nerveless the quantifying method). Therefore, it is recommended using both methods to expose all the environmental categories, and to control the environmental aspects of the company, also it is recommended to use new technologies for battery production that have less impact on the environment.

Key words: Environmental impact, Lead Acid Battery, ISO, CML Method, Eco 95, CMLCA, GWP, Acidification, Eutrphication, Heavy metals, winter, Summer, Smog.

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دراسة مقارنة التأثيرات البيئية بين طريقتي النقطة الوسطية والنهائية لبطارية بابل الرصاص الحامضية

الخلاصة

تم في هذا البحث تحليل كمي لمقارنة التاثيرات البيئيه لعمليات تصنيع بطارية الرصاص الحامضيه- بابل (١٣٥ امبير \ساعه) باستعمال طريقتي النقطه الوسطيه (CML) و طريقه النقطه النهائيه (Eco 95) وفقا لهيكله المنظمه العالميه للمعايير (الايزو) ١٤٠٤٠-١٤٠٤٣ وللعام ٢٠١٢. تم استخدام برنامج [CMLCA] لمعالجة واظهار البيانات حيث تعتمد طريقة النقطه الوسطيه (CML) أربعة فئات للتاثيرات البيئيه المحتمله هي (الاحتباس الحراري، الاثراء الغذائي، الامطار الحامضيه، وفئة تسمم الانسان). وتعتمد طريقه النقطه النهائيه (Eco 95) سته فئات هي: (الاحتباس الحراري، الاثراء الغذائي، الامطار الحامضيه، العناصر الثقيله، الضباب الصيفي والضباب الشتوي .

اظهرت نتائج النقطه الوسطيه (CML) ان عملية شحن الواح الرصاص لها اكبر مساهمه وبنسبة ٢٦% في الاحتباس الحراري، ولكن استعمال طريقة النقطه النهائيه (Eco 95) تشير الى ان نفس العمليه تساهم في الاحتباس الحراري بنسبة ٤ % . عند استخدام طريقة النقطه الوسطيه تبين بان عملية التجميع لها تاثير عالي وبنسبة ٥٠% في فئة الامطار الحامضيه بينما اشارت طريقة النقطه النهائيه الى مساهمه نفس العمليه بنسبة ٤% في فئة الامطار الحامضيه .اما بالنسبه لفئه تسمم الانسان فتشير نتائج طريقه النقطه الوسطيه (CML) بان عملية التجميع تساهم بنسبة ٦٠% بينما تشير نتائج الطريقه النهائيه(Eco 95) الى ان عملية التجميع تساهم بنسبة ٩٣% في فئة العناصر الخطره الثقيله و٣% في فئه الضباب الشتوي. اما بالنسبه لفئه الاثراء الغذائي فتشير نتائج طريقه النقطه الوسطيه (CML) الى ان عملية شحن الواح الرصاص تساهم بنسبة ٩٣% بينما لم تحدد طريقه النقطه النهائيه (Eco 95) اي تاثير ذا قيمه بالنسبه لنفس العمليه في فئه الاثراء الغذائي .نستنتج من ذلك بان عمليات تصنيع بطارية الرصاص ذات الاساس الحامضي بصوره عامه تؤثر على البيئه تنتشر على مختلف العمليات التصنيعيه و بنسب متفاوته بغض النظر عن طريقه الاحتساب .ولذلك يوصي الباحثون اعتماد اكثر من طريقه لتغطيه كافة المؤثرات البيئيه وبضروره السيطره على المؤثرات البيئيه في الشركه كماتوصي بضروره اعتماد التكنولوجيا الحديثه في التصنيع ذات الاثر البيئي الاقل على كافة الاصعده .

الكلمات المرشدة: التاثيرات البيئيه، بطارية الرصاص الحامضيه، طريقه النقطه الوسطيه، طريقة النقطه النهائيه، الايزو، الاحتباس الحراري، الامطار الحامضيه، الاثراء الغذائي، تسمم الانسان، العناصر الثقيله، ضباب صيفي، ضباب شتوي.

INTRODUCTION|

Due to the increasing awareness of environmental protection and possible impacts associated with product systems, industries are looking at new approaches to design and manufacture products that include environmental, with the traditional requirements of product function, quality, and cost. Life Cycle Analysis(LCA) takes into consideration the environmental aspects throughout the product life cycle starting from raw material extraction through production, use, end of life treatment, recycling and final disposal [1,2]. LCA seeks to maximize the beneficial environmental impacts and to minimize the adverse ones. Therefore LCA is a central pillar of the environmental product sustainability [3]. In addition to reducing the negative effect on the environment, integration of environmental aspects into industrial operations can generate significant economic benefits [4,5]. Life cycle analysis can be defined as a methodology to evaluate the environmental impacts of products or processes by identifying and quantitatively describing the energy and materials used, and waste released to the environment, then assess the impacts throughout the entire life cycle or from cradle to grave perspective [6,7]. Life cycle analysis/Assessments (LCA) estimate the environmental effects caused by products and processes, and employed in decision-making to provide better understanding of human health and environmental impacts that are not traditionally considered on selecting a product or process. LCA provides the way to describe the full impact of decisions, and where they are occurring (locally, regionally, or globally). Life Cycle Impact Assessment (LCIA) is used to identify significant potential environmental effects. LCIA show relative differences in potential environmental impacts, and could determine which product/ process causes more impact (e.g. global warming potential) [8,9].

LCIA comprises four elements are: classification, characterization (mid_point), normalization and weighting (end_point), the choice of these elements depends on the method employed in LCA [8,10]. Due to The complex nature of life cycle analysis, it may not include all of the product life cycle stages, therefore different system boundaries can be defined according to the life-cycle approach, these approaches are: - Cradle to Grave, Cradle to Gate, Cradle to Cradle, and Gate to Gate [11,12,13]. Many studies are directed toward batteries across the world to reveal the current interest of research towards these products (batteries) and the environmental impact according to their different types and sizes. Van den Bossche et al. (2005) [14] compared five different battery types which are; (Lead–acid, Nickel–Cadmium, Nickel-metal hydride, Lithium-ion and Sodium–nickel chloride) so as to define which type is the most appropriate for electric vehicle applications from an environmental point of view. Olivetti, Gregory and Kirchain (2011) [15] employed life cycle analysis to alkaline batteries in order to provide a comprehensive means for considering the environmental impacts. Whereas Sullivanv and Gaines (2010) [16] investigated five battery technologies which are; Lead-acid, Nickel–Cadmium, and Nickel-metal hydride, Sodium-Sulfur, and Lithium-ion batteries. They employed (cradle-to-gate) approach and focused on the energy use and Greenhouse Gas (GHG) emissions, and included battery manufacturing as the production of materials that make up batteries.

It worth's mentioning that there are studies made in the past on Lead acid battery industry in Iraq, which aimed at recognizing the risk of toxic chemicals or exposing Lead acid battery impacts by streamlined LCA matrix, yet there is no study on quantitative life cycle analysis of Lead acid battery in Iraq [17-19]. The goal of the study is to explore the potential environmental impact of Babel Lead acid battery and highlight the environmental hotspots using Gate to Gate approach. The next paragraph review LCA methodology of Babel battery, according to ISO standards (14040-43), followed by experimental work where data collection, calculations, and analysis according to two impact assessment methods (CML, and Eco95 indicator) is conducted. Results are further discussed to verify different impacts, and the last paragraph exposed basic conclusions, recommendations that are deduced from this research.

LCA Methodology of Babel Battery

The methodological framework of LCA of Babel lead acid battery presented in this study is shown in Fig. (1), where it consists of four interrelated phases are [20]:- Phase one:- Goal and Scope Definition Phase: stating the purpose of the life cycle analysis and the functional unit "quantified performance of a product system for use as a reference unit".

Phase Two (LCI) Phase: The energy and raw materials where emissions to atmosphere, water, and solid are quantified for each step in the production processes shown in Fig. (2) according to Gate to Gate approach, boundaries are indicated by dotted lines in Fig. (2).

Then combined and related to the functional unit, an inventory of all the inputs and outputs to and from the production system as part of the inventory analysis according to the following equations [21,22]:-

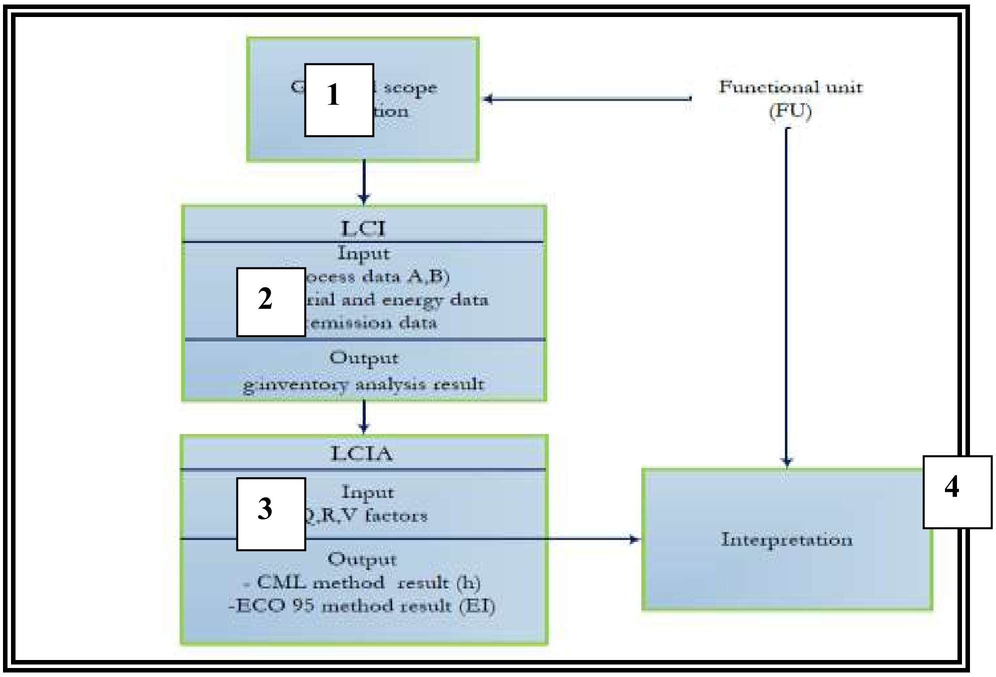

Figure (1). Framework of LCA of the study [19]

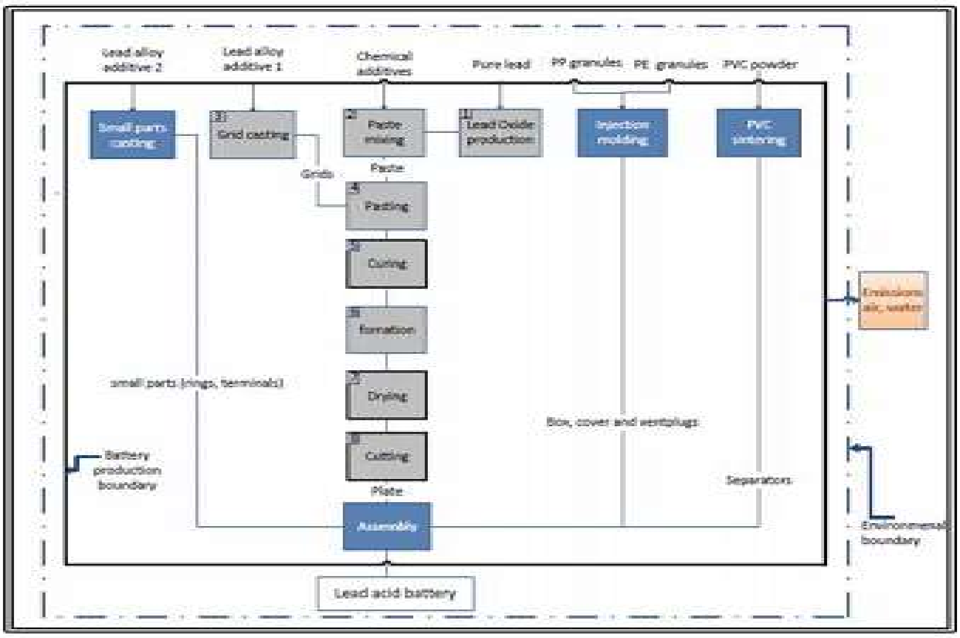

Figure (2). Babel Battery Production Process Flow Diagram [19]

$$S = A^{-1} \times f \qquad (1)$$

Where:

A: (the technology matrix) that represents the input and output material and energy.

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

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

$$g = B \times S \qquad (2)$$

The life cycle emissions are calculated in a further step, by multiplying S with the so-called matrix B [Emission matrix].

The aggregated emission over the life cycle of all processes the (emission matrix B) is multiplied, by the scaling factor S. Form that a demand vector g is the result and represents the life cycle inventory.

Phase Three: (LCIA) In this phase the effect of processes on the environment and human health to understand its impact, effects of the resource use and emissions. The generated results of the inventory analysis are grouped and quantified into a limited number of categories. The Impact Assessment methods are categorized into two groups:-

- The first group uses so called “the midpoint level”, is based on internationally and scientifically accepted approaches such as acidification, climate change and human-toxicity, etc. [23].
- The second group impact category indicators at “endpoint level” are easier since the use of endpoint level in LCIA helps to convey the results to common understanding (such as damage to human health and damage to ecosystem quality [24,25]. Impact assessment phase is divided into (characterization, normalization, weighting), as explained below.

– Characterization [h]: The characterization step in the impact assessment aggregates and quantifies the impact within impact category, according to the following equation [23].

$$h = Q \times g \qquad (3)$$

Where, h: Impact indicator: Characterization factor (based on the impact assessment method used). and g is Inventory result.

– Normalization [N]: Is found by dividing the impact result by reference value [23].

$$N = h / R \qquad (4)$$

Where, N: the normalized result.
h: the impact indicator from the characterization result.
R: the reference value.

– Weighting [EI]: Single indicators of each category are multiplied by weighting factors and summed up in a single number, according to the Eq. (5) below [23].

$$\mathbf{EI} = \sum \mathbf{V\,N} \qquad (5)$$

Where, EI: the overall Environmental Impact indicator.
V: weighting factor.
N: normalized result.

The impact assessment converts emissions of hazardous substances and extractions of natural resources into impact category indicators based on the method used. Some of the impact assessment methods are: CML method, the Eco indicator 95 methods, and the Eco indicator 99 method etc.,

CML Method focuses on a series of environmental impact categories as shown in Fig (3). The impact for global warming and Ozone layer depletion is based on Intergovernmental Panel on Climate Change (IPCC) equivalency factors. For example, the unit of global warming is (kg CO_2 equivalent) and the unit for acidification is (Kg SO_2 equivalent) [9, 26].

ECO Indicator 95 method expresses the total environmental load of a material or process in a single aggregated score, where the impact categories are shown in Fig. (4). Eco-indicator absolute value is relatively meaningless because the indicator is intended solely for comparative purpose. As the score is dimensionless, it can be summed up and then represent the total environmental burden in terms of one Eco-indicator value for each system under investigation [27].

The fourth and last phase (Interpretation Phase): In this Phase results are interpreted to determine which process has the least overall 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 [8].

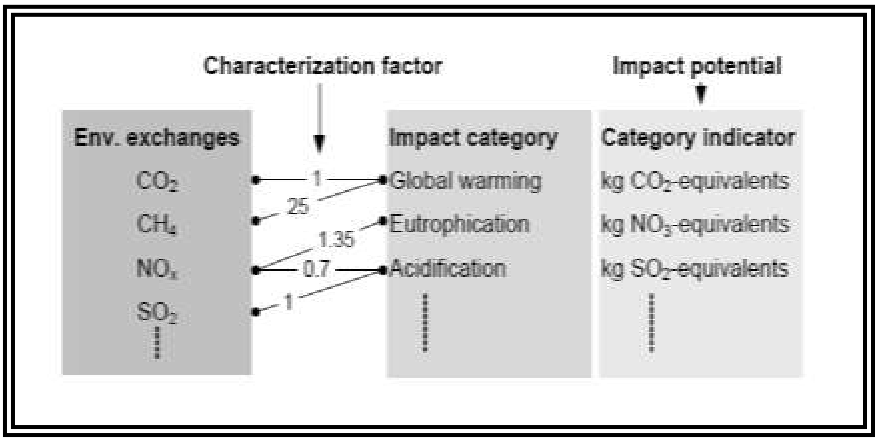

Figure (3). Environmental impact categories in CML Method [28]

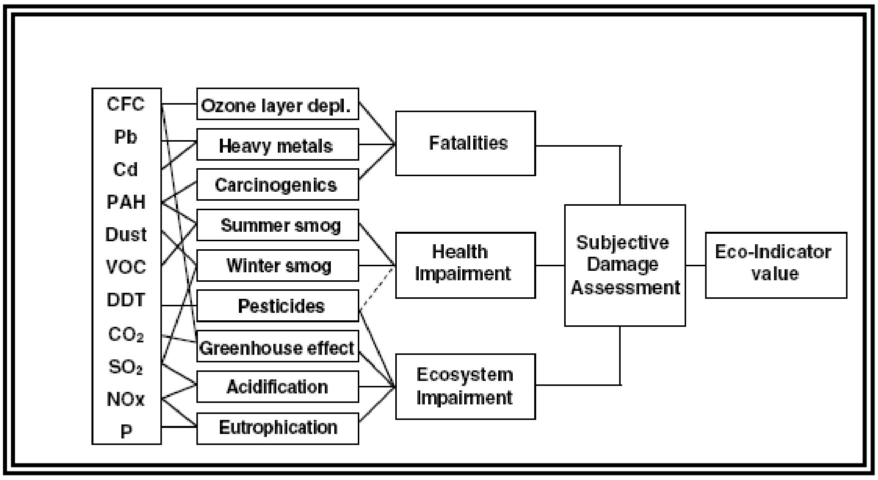

Figure (4). ECO Indicator 95 Method impact categories [29]

Experimental Work

In this research the life cycle analysis of Babel Lead acid battery of (135 Amps./hr) capacity is investigated according to the International Organization for Standardization (ISO)14040-14043 framework for LCA, to identify the major contributors to the environmental impacts that occur in the production processes according to "Gate to Gate" approach. The data are collected and processed for the year 2012, the inventory analysis phase results are calculated employing the Chain Management Life Cycle Assessment (CMLCA) software, using two different quantitative methods are; CML (Mid-point) and ECO 95 (End-point)

LCA phases for lead acid are applied as follows:-

Phase 1: Goal and Scope Definition of Babel Battery

The goal is: to explore the potential environmental impacts of Babel Lead acid battery and highlight environmental impact hotspots that occur throughout production processes, whereas the Scope is: Functional Unit (FU), is "delivering electricity throughout a chemical reaction with an energy storage capacity of 135 (Amps/hr) corresponds to the weight of (29.207) Kg

Phase 2: Inventory Analysis of Babel Battery:

This phase is performed by these steps:-

- Developing production process flow that is shown in Fig. (2),
- Collecting Process Data: The collected data [for the production processes shown in dotted line in Fig. (2) i.e Gate to Gate] are quantified, for the inputs to and outputs from each process; data of material, energy and emission rates, the inventory calculations from different processes; and,
- Creating Environmental Data: calculations are employed using equations (1), and (2) to calculate the environmental impacts (loads) from each process in relation to the functional unit, relevant impact categories are selected based on the inventory analysis results, grouped according to assessment method.

Results and Discussion.

Results generated from inventory analysis are analyzed and classified according to the impact assessment method and related environmental impact categories for comparison purposes. The impact assessment is presented according to Equation. (3), for CML method and Equations. (4), and (5) according to Eco 95 method, all results are processed and generated using Chain Management LCA software [CMLCA].

Results Analysis Based on CML

Table (1) shows potential environmental impact categories for Babel battery production processes of: global warming, acidification, eutrorphication, and human toxicity potentials. These results are the quantified characterized which at least shows one impact potential related to them [30], for:

Global Warming Potential (GWP):

The highest contribution to GWP is from the formation process (26%) due to high energy consumption while charging the plates, followed by Lead oxide production process (22%) and PVC sintering (19%), respectively as shown in Fig(5). Generally the impact to GWP of these processes is regarded as (indirect impacts); when generated outside the processing [at AL-Doura refinery power plant]. Low GWP impact potential is correlated to grid casting and small parts casting processes (2%) and (1%) respectively. This is (direct impacts) since it is generated at the manufacturing site [due to consumption of Liquefied Petroleum Gas or (LPG) fuel].

Acidification: From Table (1) three processes in Lead acid battery manufacturing processes causes air acidification these are; assembly, pasting and formation processes, as shown in Figure (6).The emissions of SO_2 equivalent are generated from these processes. The assembly process represents the most significant impact on acidification it contributes by (50%). This impact occurs due to stacking and movement of the plates to form the cells, while the pasting process contribution of (33%) and the formation process contribution is (17%). The summation of the remaining eight production processes share is negligible as shown in Table (1),and Figure (6).

Eutrophication:

Two processes pose the potential category sources of impact on eutrophication as the rest of processes don't cause a wastewater discharge as depicted in Fig. (7), these processes are; formation of (71%) contribution, followed by pasting process of (29%) contribution [because of the discharge waste water resulted from removing the suspended material in the plates].

Human Toxicity:

This category involves the release of pollutants that are uncontrolled, except for paste mixing processes where wet scrubber is available. This impact varies from process to process and almost negligible in plastic manufacturing process, while other processes have high impact such as the assembly process, as seen from Fig. (8). This process has a major contribution to human toxicity of (59%) followed by pasting (14%) then grid casting (12%) processes.

Table (1). Potential Impacts of Babel Battery Production Processes according CML Method [30]

Battery manufacturing 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

Results Analysis based on ECO 95.

This analysis is performed for Lead acid battery manufacturing processes, since ECO 95 method evaluates six categories; (global warming potential, acidification, Eutrophication, heavy metals, Summer smog, and Winter smog). These results can be used to compare between production processes and impact categories as shown Figure(9).

Figure (9) shows the contribution of each production process according the six categories identified by Eco 95 method. It could be noticed the high contribution in the heavy metals category of the assembly process by (93%), acidification (4%) followed by Winter Smog (3%). Two processes are the major contributor to the heavy metals category are; grid and small part castings as Lead is emitted during these processes (uncontrolled emissions generated) thus it represents (99%) among their other impact categories as seen in Fig. (9). For GWP category four processes are identified as having high values and overall contribution to this category as shown in Fig. (9), these processes are box, cover, and plug molding followed by PVC Sintering and less impact of Lead oxide production process.

Formation process emits Lead into the water of contribution of heavy metals category (96%), but low impact on acidification [about (4%)] the reason behind differences between the two assessment methods is because ECO 95 method does not consider Sulfuric acid as acidification potential, while CML method does. As seen in Fig. (9) Eutrophication is not the main issue thorough the whole Lead acid battery production processes. Furthermore, some emissions generated through production processes do not have characterization factor in both methods either because these methods do not consider these emissions as an origin of environmental impact or the environmental impact is not known yet.

Conclusions

It is found that the environmental impact of Babel battery production processes spreads over all the processes and every process has a certain impact on the environment. The following conclusions are deduced based on comparing two LCA impact assessment methods CML, and Eco 95:

1. CML (mid-point) method signified formation process as the highest contributor to GWP by (26%). While Eco 95 method identified GWP of the same process by (4%) contribution. Eco methods results reveals other process that contributes highly in GWP category are; box, cover, plug molding, and PVC Sintering and less impact value of lead oxide production process.
2. CML (mid-point) identified the assembly process as the process of the highest impact on acidification by (50%), while the Eco 95 method quantifies acidification for the same process by (4%).
3. For human toxicity category CML method results allocated the assembly process by (60%) contribution, whereas Eco 95 method assigned the same process as the most hazardous process by (93%) contribution to heavy metals category.
4. Highest contributor to Eutrophication (71%) is for formation process according to CML, but Eco 95 method reveals that eutrophication is not the main issue through the whole Lead acid battery production processes.
5. Potential impacts in CML (midpoint) method are generally calculated based on differing scales and cannot be directly compared, where in Eco95 method (endpoint) the impacts are comparable due to performing of normalization and weighting steps.

Since production processes of Babel battery cause significant damage to the environment through various impact categories therefore it is recommended:-

_full reconsideration in the design and production of this product should be employed to minimize and optimize this process environmental impacts.

_Employing both assessment methods is important to verify the whole possible threats throughout Babel Lead acid battery production process.

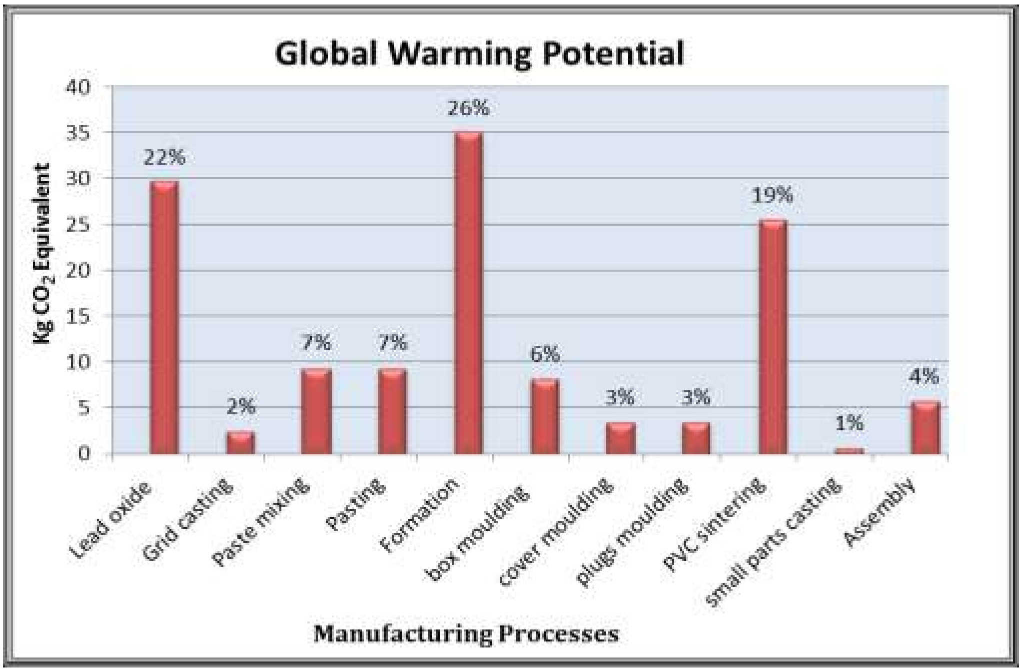

Figure (5). Global Warming Potential Impact per Functional Unit [30]

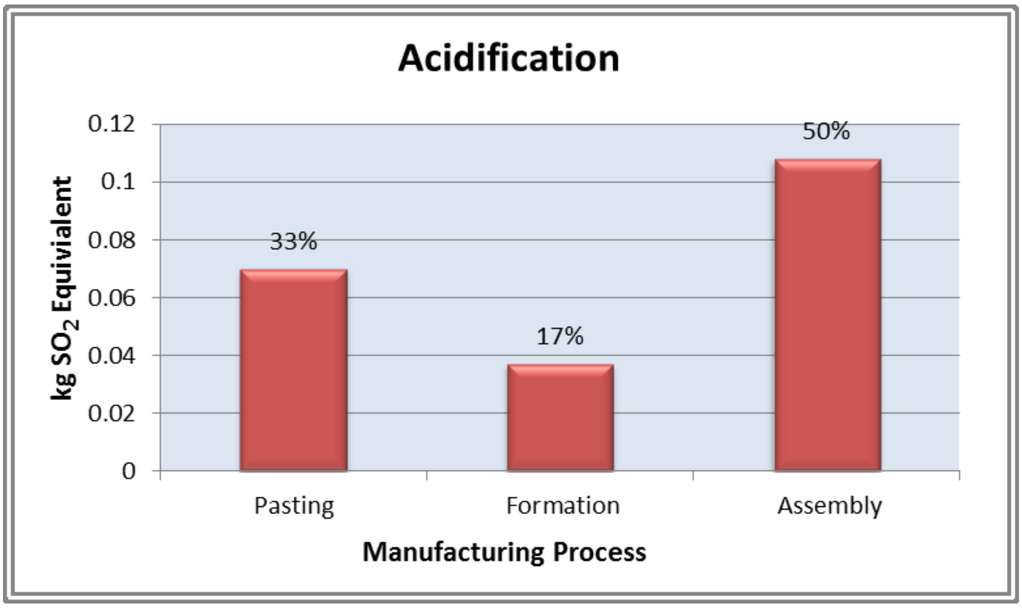

Figure (6). Acidification Potential Impact per Functional Unit [30]

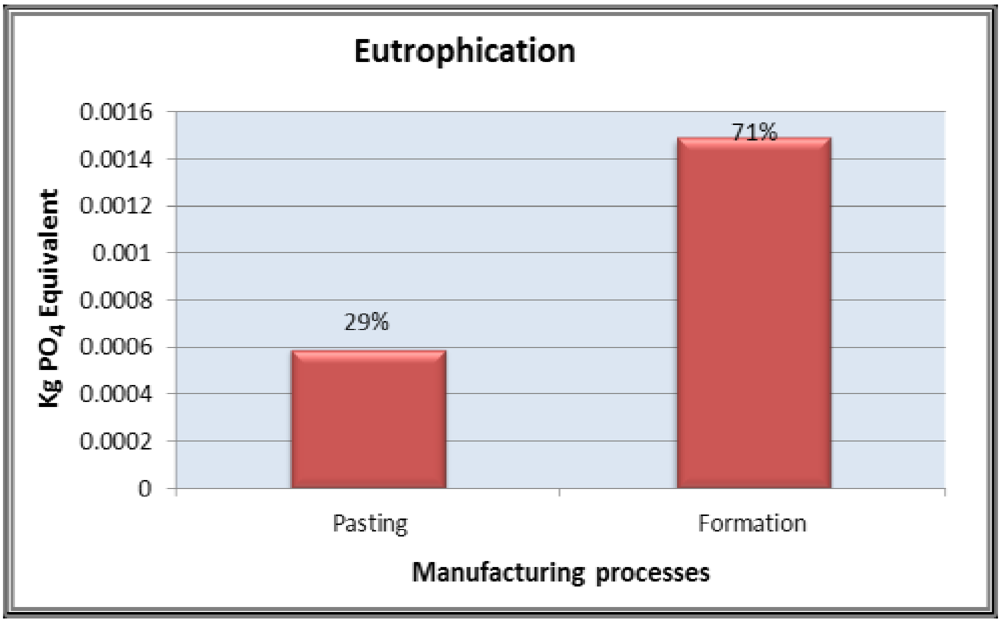

Figure (7). Eutrophication Potential Impact per Functional Unit [30]

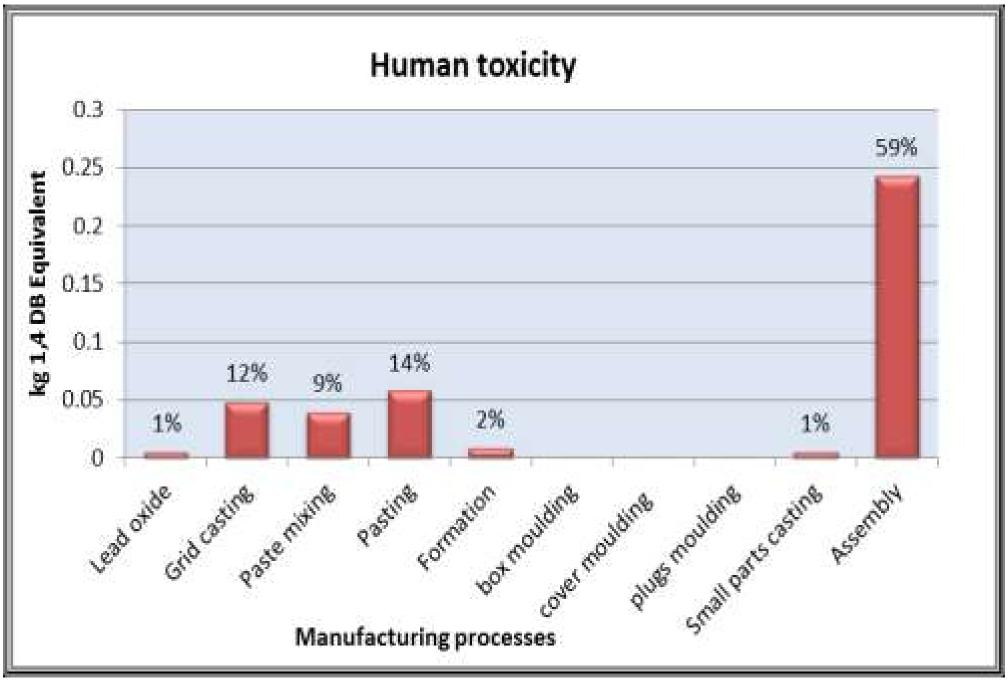

Figure (8). Human Toxicity Impact per Functional Unit [30]

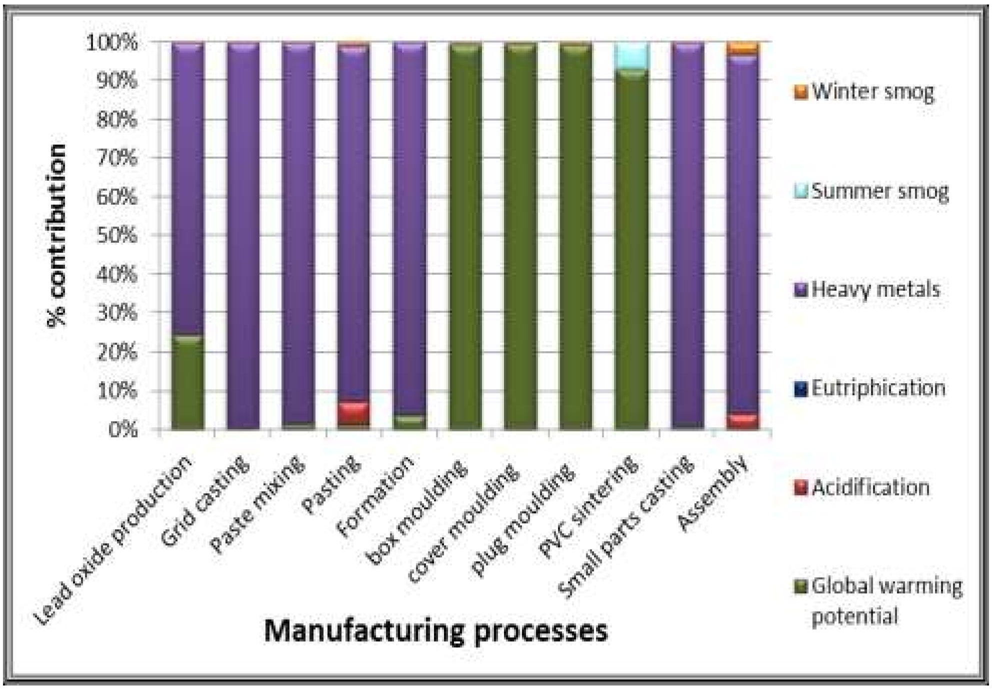

Figure (9). The Contribution of Battery Lead acid production Processes to Environmental Impact per Functional Unit [19]

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