Life–Cycle Assessment (LCA) Study Adopted in Cement Industry for Sustainable Development

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Abstract

Sustainable development is thought of as seeking a balance between economic prosperity, environmental quality and social progress. Cement industry can contribute significantly to society by operating in a sustainable manner by adopting conservation measures for natural resources, energy and modifying in-plant practices to achieve global efforts in reducing Green House Gases (GHG) impact in climate change. Sustainability requires life–cycle thinking amongst scientists, plant engineers and managers who are committed to adopt a holistic view of the embedded in large systems from limestone mining to dispatch of cement. While adopting an integrated environmental management approach, Life Cycle Assessment (LCA) “Cradle-to-Gate” has identified energy intensive units and emission sources. The paper highlights an LCA study encompassing major raw materials, thermal and electrical energy and emissions, in terms of input and output; of Indian cement industry for achieving the goal for shaping the environment on a sustainable basis on account of climate change.

1.0 INTRODUCTION

Indian cement industry ranking second in the world cement production is currently in search of competitive advantages for continuous improvement on the environmental front. The cement manufacturing has mainly three areas of environmental concern - the ecological degradation of mined out areas of raw materials, air pollution due to both fugitive and stack dust, and Green House Gas(GHG) emissions. Hence, in order to improve the environment one needs to reduce both thermal and electrical consumption, which has a direct bearing on the environment. There is an urgent need to adopt a holistic integrated approach like Life Cycle Assessment (LCA) to identify weaker sub-units of the processes to deal both in terms of energy consumption i.e. cost as well as environmental front like dust and GHG emissions. It is true that, growing awareness of the environmental problems and cost effective compulsion has led cement plants to adopt advanced technology in mining, crushing, grinding, pyroprocessing technology along with environmental operational control and process optimization measures.

2.0 INDIAN CEMENT INDUSTRY

Today's Indian cement industry is on the threshold of a new era of energy efficient and pollution-free activities. The depleting energy resources clubbed with rising cost of energy have compelled the industry to develop and up-grade modern techniques and methodologies on a continuous basis. However some genuine difficulties exist for the implementation of advanced available technologies. Most of cement plants have up graded their technology but few have barriers for adoption of the efficient technologies due to two broad reasons - economical barriers and technical barriers due to limitation for retrofitting in the existing system and/or low priority for environment amongst stakeholders may be one of the major deterrents in technical as well as environment friendly category on longer terms for few of the cement plants. The time has come for every cement plant to improve both their energy consumption as well as environmental aspects for their own survival. For India to be a global player in cement manufacturing it needs to adopt various environmental tools like LCA for its sustainability.

At present in India there are 130 major cement plants in the country. There are three major types of cement product like OPC, PPC and PSC. But over the years the blended cement production has increased to many folds in last one decade. Fig-1 and 2 show the capacity, production and product profile of Indian cement industry.

Fig-1 Installed Capacity Vs Production Capacity for Indian Cement Plants

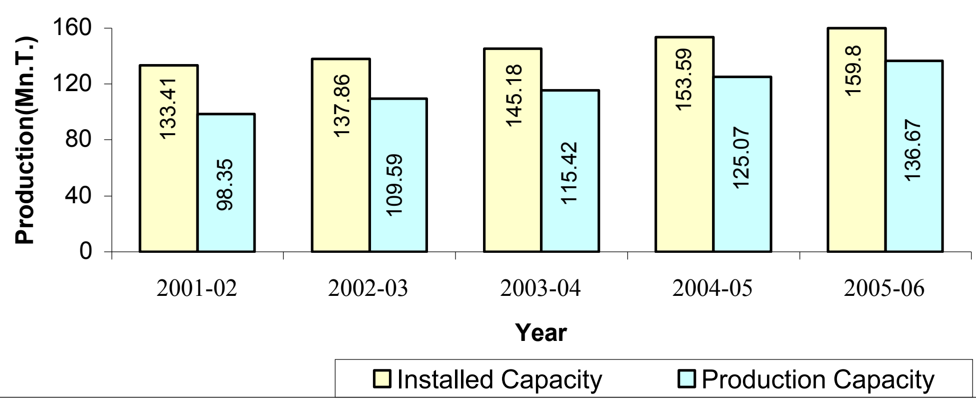
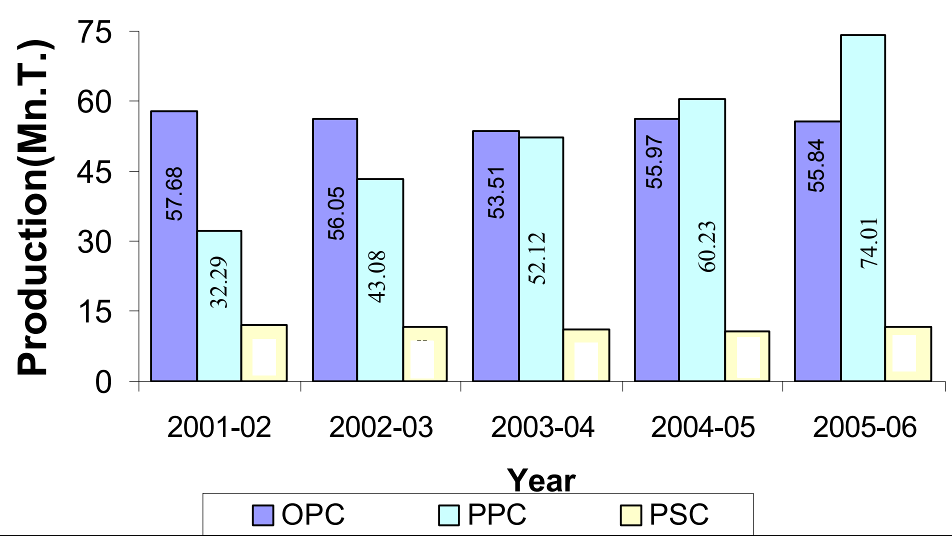


Fig-2 Variethywise Cement Production for Indain Cement Plants



3.0 LIFE CYCLE ASSESSMENT (LCA)

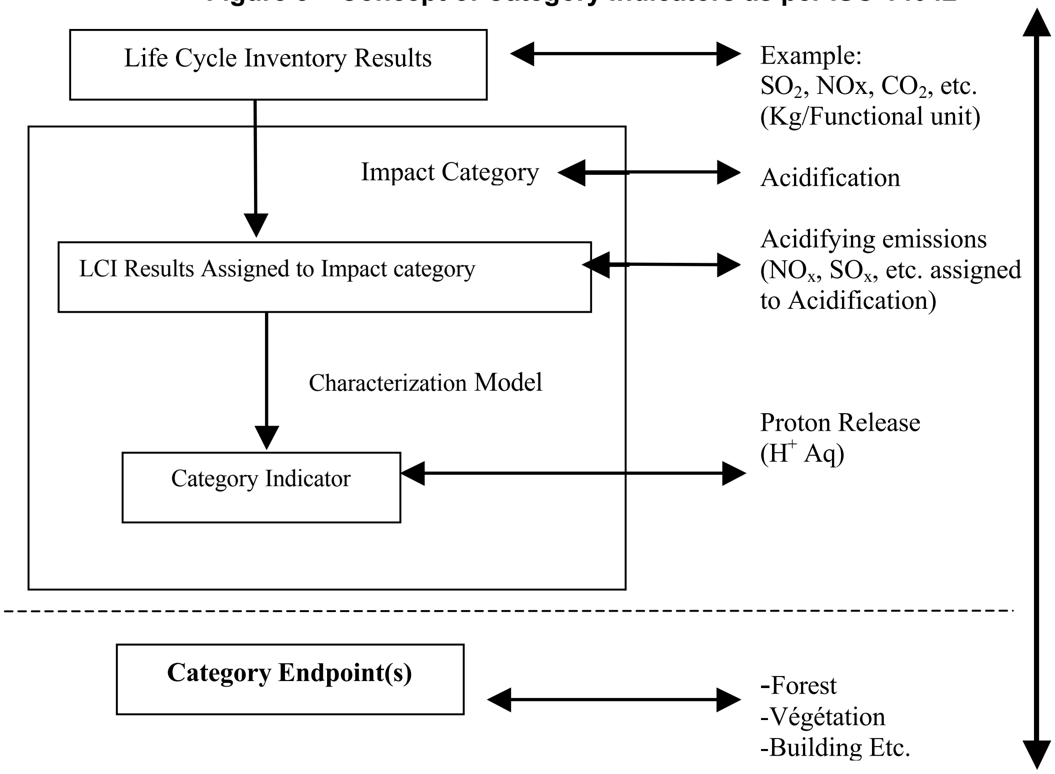
Life Cycle Assessment (LCA) has been witnessed world over with keen interest as a method for evaluating total environmental load in order to realize the sustainable development. The standardization of these methods were promoted by both International Standardization Organization (ISO) and Society of Environmental Toxicology and Chemistry (SETAC). Within LCA study the Life Cycle Impact Assessment (LCIA) is the third stage of study, after goal, scope and life cycle inventorization (LCI). LCIA is to examine the product or process system for an environmental prospective using various impact categories and their indicators connected with the LCI results. Conceptually in LCIA there are five phases like selection of impact categories, classification, characterization, normalization and weighting. In this paper, we will discuss on impact categories along with data-quality and source its limitations, uncertainties aspects in general while carrying out life cycle assessment study for any product or process keeping the target of sustainability.

Life Cycle Impact Assessment (LCIA) evaluates the possible environmental impact associated with measured environmental inputs and outputs of a product or process. It is important to note that LCA is not single-issue tool; rather, the analysis encompasses numerous environmental issues like energy consumption, global warming, acidification, photochemical smog, ecotoxicity etc. Conceptually, there are five major phases of LCIA like selection of categories, classification, characterization, normalisation and weighting. In ISO there is an exception that between normalisation and weighting there is also another phase-grouping. Grouping is the assigning of impact categories into one or more sets without weighting. The ISO14042 considers selection of categories, classification and characterization to be mandatory elements of LCIA, whereas valuation in terms of normalization and weighting are optional elements to be considered depending on the goals and scope of any LCA study. LCIA enables us to interpret the results of the inventory and furthermore to draw the correct conclusions concerning improvement approaches.

The consideration of environmental effects as a consequence of environmental interventions provides additional information, which is not covered by inventory step. In LCIA the values of environmental interventions assessed in the inventory analysis are interpreted on the basis of their potential contribution to the environmental impact. This is due to the facts that information or data on time and spatial detail in LCIA is very limited and it is time taking process to assess the local (one kilometer to some tens of kilometers) as well as long term effects (time period). Hence LCA is commonly considered as a tool for global and regional environmental problems because of its inability to describe local effects on the basis of the “less-is-better” approach. Different LCIA methods differ from each other on the basis of areas of protection related to impact categories like: natural resources, human health, natural environment and man-made environment. The method applied in LCIA is that the determinations of characterization factors can be based on past, present and the future load situation with spatial and temporal details so that impact category indicators will be continuously more end point oriented.

Figure 3 shows basic elements of LCIA and depicts the concept of category indicators as per ISO 14042. One inventory item may have multiple properties and therefore would have multiple impacts. For example, CO_2 and NOx are both responsible for global warming but CO_2 has prominent role for global warming; where as NOx has the potential to create acidification also. Output inventory items from a process may have varying dispositions, such as direct release (to air, water or land), treatment or recycle/ reuse. Outputs with direct release dispositions are classified into impact categories for which impacts will be calculated in the characterization phase of the LCIA. Outputs sent to treatment are considered inputs to a treatment process and impacts are not calculated until direct releases from that process occur. Outputs to recycle/reuse are considered inputs to previous processes and impacts are not directly calculated for outputs that go to recycle/reuse. A product is also an output of a process; however, product outputs are not used to calculate any impacts. Once impact categories for each inventory item are classified, life – cycle impact category indicators are quantitatively estimated through the characterization step.

Figure 3 – Concept of Category Indicators as per ISO 14042



4.0 DISCUSSIONS

The objective of this paper is to provide an overview of the environmental aspects of four of the major cement plants in line with the essential character of the LCA tool. It also aims at being a starting point for further initiatives by this sector, on the road to sustainable production patterns in Indian cement industry. After defining goal and scope of the study, as per ISO 14041, LCI is the second stage of LCA involving compilation of all the input and output in terms of raw materials, thermal energy, electrical energy, and emissions along with product. Four cement plants input & output data were collected for the period of three years. Inventory was prepared for 1000 kg, which is used as a functional unit with in defined boundary. A comprehensive inventories of four cement plants were prepared for major raw material and both thermal and electrical consumption per tonne of clinker then cement to distinguish clarity with different products like, OPC, PPC, PSC depending on specific plants. Input and output data for each kiln separately were compiled also, if plant has more than one kiln. Out of four selected plants there are three, having more than one kiln except one plant having one kiln.

4.1 USE OF LCA SOFTWARE (LCAiT) FOR IMPACT ASSESSMENT OF CEMENT PLANTS

LCAiT software (Sweden) is used to analyze impact assessment for Global warming and acidification potentials for cement industry. Table 1 & 2 show the global warming and acidification potential of four cement plants having capacity more than 2.5 million tonnes per annum. For each cement plant GWP and AP varies differently depending on their source of power and the type of fuel used and other inputs including the technology adopted. CO_2,, CO and NOx emissions due to DG set for power supply reflects the higher GWP and AP for plant A in comparison with B, C and D. It reflects also in acidification potential. The product variation is also having significant role to play in various impact categories.

4.2 GLOBAL WARMING

Global warming, or the “Greenhouse Effect,” is defined as the changes in the Earth’s climate caused by a changed heat balance in the Earth’s atmosphere. After water vapor, CO_2 is the most important greenhouse gas. Normally, billions of tonnes of carbon in the form of CO_2 are absorbed by the oceans and vegetation and are emitted to the atmosphere annually through natural processes. When at equilibrium, the changes between absorption and emission are roughly balanced. The additional anthropogenic sources of greenhouse gases (GHG’s) present in the atmosphere may have shifted that equilibrium, acting as a “thermal blanket” and trapping heat from reflected sunlight that would otherwise pass through the atmosphere. Altering the atmosphere by trapping more heat has been modeled to have a wide variety of effects on the earth’s climate, including longer growing seasons, droughts, floods, increased glaciations, loss of the polar ice caps, sea level rise and other displacements, including direct effects on human health through biological agents. The speeds of these projected effects, coupled with their widespread nature, imply a devastating effect on the entire biosphere. The Intergovernmental Panel on Climate Change (IPCC) global climate change model is used to estimate the potential impacts to the environment from global warming. This model converts quantities of GHG’s into carbon dioxide (CO_2) equivalents using IPCC-defined global warming potential equivalency factors. Global Warming Potential Equivalency Factors (GWP’s) compare the ability of each greenhouse gas to trap heat in the atmosphere relative to the heat-trapping ability of CO_2. GHG data obtained for each LCA stage are multiplied by the relevant GWP100 (over a 100 year lifespan) to produce CO_2 equivalent values. As the equivalency factors are unit less values, any unit of weight can be used, as long as the unit of measurement is stated explicitly and are consistent throughout the calculation. This process is done for each GHG, with the final step being the summation of all CO_2 equivalents. The final sum, known as the Global

Warming Index (GWI), indicates the product's potential contribution to global warming for each life cycle stage. The following equation is used to calculate the GWI: Global Warming Index = $\sum_i$ wi x GWPi, where wi = weight of inventory flow i per functional unit of product GWPi = Global Warming Potential Equivalency Factor evaluated at 100 years = weight of CO_2 with the same heat-trapping potential as a gram of inventory flow. A 100-year lifespan was selected as the most suitable for the goal of this effort, although other bases for calculating potential equivalency are also available.

4.3 ACIDIFICATION POTENTIAL

Acidification, or acid rain as it is commonly known, occurs when emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NOx) react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds. This mixture forms a mild solution of sulfuric acid and nitric acid. Sunlight increases the rate of most of these reactions. These compounds then fall to the earth in either wet form (such as rain, snow, and fog) or dry form (such as gas and particles). About half of the acidity in the atmosphere falls back to earth through dry deposition as gases and dry particles. The wind blows these acidic particles and gases onto buildings, and trees. In some instances, these gases and particles can eat away the things on which they settle. Dry deposited gases and particles are sometimes washed from trees and other surfaces by rainstorms. When that happens, the runoff water adds those acids to the acid rain, making the combination more acidic than the falling rain alone. The combination of acid rain plus dry deposited acid is called acid deposition. Prevailing winds transport the compounds, sometimes hundreds of miles, across state. Acid rain causes acidification of lakes and streams and contributes to damage of trees at high elevations. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. Prior to falling to the earth, SO_2 and NO_x gases and their particulate matter derivatives, sulfates and nitrates, contribute to visibility degradation and impact public health. Calculating the Acidification Indicator Several indicators exist for acidification; the most common reference substances being hydrogen ions and sulfur dioxide. Either can be expressed in terms of the other. Here we use SO_2 as the reference chemical. The method for calculating the Acidification Index (AI) is similar in approach to other impact indicators: the LCI substances that are present in the table below are multiplied by the equivalency factor (AP) to arrive at SO_2 equivalent quantities. The SO_2 equivalents for each life cycle stage are summed to calculate the Acidification Index (AI). The following equation outlines the calculation: Acidification Index = $\sum_i$ wi x APi, where wi = weight of inventory flow i per functional unit of product APi =

Acidification Potential Equivalency Factor = weight of SO_2 with the same potential acidifying effect as a unit weight of inventory flow.

4.4 RESULTS

This study is confined to few environmental parameters and their impact in consonance with scope and goal envisaged. So reader of this paper should not draw any conclusion straight away from following results given in Table – 1 & 2 as there are numerous variables which has not been explained in detail at micro level but it will give idea of macro level to visualize the larger environmental picture, which is indicative in nature to take remedial measures. Not withstanding the complex effect of various factors in cement plant, the total environmental performance has to be kept with in specific impact category like GWP, AP, CO_2, NO_x, SO_2 , Particulate Matter etc. The task of evaluating total environmental performance is more complex than it was conceived, as every plant is an identity by itself due to varied inputs and outputs, wherein, the performance of pollution control technology depends on many factors like physicochemical characteristics of the raw materials, manufacturing process and its technology – age, maintenances, performances and their various products.

However, effort has been made to suggest few major environmental parameters for each plant to enable them to enhance their environmental performance at regional and global level. In order, to explain better and to make understand various figures are given below for different environmental parameters of four cement plants but not for any comparison purpose only to draw a clear and closer picture for visualization. Hence what has been suggested in this paper is only one step forward towards establishing in usage of LCA study to identify and improve the environment in totality starting from mining to dispatch of cement.

Table-1 Impact Characterization of Four Plants (Per Tonne of Cement) 2003 – 04

Cement Plant	Global Warming Potential (kg CO2 equiv.)	Acidification Potential (kg S02 equiv.)	CO2 (kg)	NOx (kg)	SO2 (kg)	Dust (kg)
A	1530	1650	852	2.30	0.036	0.174
B	1180	1050	750	1.46	0.029	0.155
C	1040	866	679	1.22	0.015	0.145
D	2630	2470	1600	3.47	0.039	0.167

Table-2
Increase Blended Cement Production and Its Impact Characterization
(Per Tonne of Product) 2003-04

Cement Plant	GWP (kg CO2 equiv.)	A P (kg S02 equiv.)	CO2 (kg)	NOx (kg)	SO2 (kg)	Dust (kg)
Plant - A (10% PPC Increase)	1,490	1,600	825	2.23	0.0351	0.171
Plant - A (20% PPC Increase)	1,440	1,550	799	2.16	0.0341	0.167
Plant - B (10% PPC Increase)	1,140	1,010	723	1.41	0.0281	0.154
Plant – B (10% PSC Increase)	1,120	995	711	1.38	0.0281	0.153
Plant -C (5% PPC Increase)	1,020	846	664	1.19	0.0147	0.142
Plant -D (10% PPC Increase)	2,540	2,390	1,550	3.36	0.0382	0.165
Plant - D (20% PPC Increase)	2,460	2,310	1,500	3.25	0.0374	0.163

5.0 CONCLUSION

Life Cycle Assessment is an environmental management tool to know the scope of reducing the environmental impacts attributable to associated wastes, emissions and resource consumption during specific process or product. The paper provides a detailed review of LCIA phase. A number of models are available for calculating characterization factors for use by LCIA practitioners. Characterization factors linearly express the relationship between inventory data and impact category indicators. Depending on the selected, available indicators can provide estimates of the marginal changes to cumulative risks and potential impact attributes to different product options. These indicators can be compared across impact categories, like global warming potential, acidification potential which ultimately for the evaluation in the role of effect on climatic change, as the cement industry emits CO_2 and NOx.

The summary of the strategies recommended for all cement plants mainly on environmental like climate change and resource conservation especially on reduction of CO_2 emission by taking various measures like improving the energy efficiency of the plant's facilities, variation in clinker-cement ratio i.e. increasing additive- cement ratio, shifting to a more energy efficient process (VRM, high efficiency cooler, fuzzy logic / expert kiln control system), improvement in the energy (thermal & electrical) efficiency during cement production (better operational control & scale of production and blended cements), more use of secondary fuel, use of mineralises for better burnability, develop sink (green belt) for CO_2 absorption and, capturing CO_2 indirectly reduces CO_2 in the atmosphere.

It is imperative for each plant to adopt LCA in order to achieve environmental excellence in a competitive global environment. National Council for Cement and Building Material (NCB), India on its parts will continue to its efforts to popularise "LCA" approach as part of its objective towards sustainable development.

6.0 ACKNOWLEDGEMENT

The authors have freely drawn upon completed R&D works/status reports and some of the unpublished work of NCB. The paper is being published with the permission of the Director General, NCB.

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