A

DISSERTATION REPORT

ON

Life Cycle Analysis of Single Row Deep Groove Ball Bearing

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY
IN
INDUSTRIAL ENGINEERING

BY

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MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

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CERTIFICATE

This is to certify that the dissertation entitled **"Life Cycle Analysis of Single Row Deep Groove Ball Bearing"** being submitted by **Rao Pratik (2013PIE5102)** is a bonafide work carried out by him under my supervision and guidance, and hence approved for submission to the **Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur** in partial fulfillment of the requirements for the award of the degree of **Master of Technology (M.Tech.) in Industrial Engineering**. The matter embodied in this dissertation report has not been submitted anywhere else for award of any other degree or diploma.

Prof. (Dr.) G.S. Dangayach
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Place: Jaipur
Dated: June 2015

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled **"Life Cycle Analysis of Single Row Deep Groove Ball Bearing"** in partial fulfillment of the requirements for the award of the degree of **Master of Technology (M.Tech.)** in **Industrial Engineering**, and submitted to the **Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur** is an authentic record of my own work carried out by me during a period of one year from July 2014 to June 2015 under the guidance and supervision of **Prof.** (**Dr.) G.S. Dangayach** of the Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur.

The matter presented in this dissertation embodies the results of my own work and has not been submitted anywhere else for award of any other degree or diploma.

Rao Pratik
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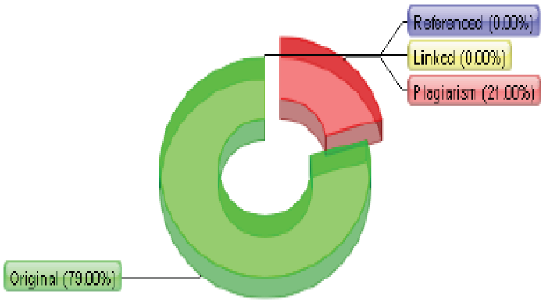

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Abstract

The objective of this report is to investigate the environmental properties of NBC Ball Bearings 6210 and to identify parameters and processes that cause major environmental impact. The increasing environmental concern in today's society puts pressure on the manufacturing companies to have the knowledge of the environmental impacts caused by their products and LCA is a tool for this.

The method used in this project is LCA and the study is performed from gate (beginning of the company) to gate (end of the Company). LCA is a method to assess the potential environmental impacts associated with a specific product or service. All stages in the life cycle are taken into account and use of natural resources, transportation, energy consumption, waste and emissions are considered. LCA can be used for identification of improvement possibilities, decision-making etc. but has also an important application in learning about environmental impacts caused by substances and processes used in the life cycle. This is mainly what is done in this study.

One of the difficulties while performing an LCA is allocating emissions, energy consumption etc. to the product being studied. To investigate the difference the choice of allocation method may have on the study an investigation of three different allocation methods within the National Engineering Industries Jaipur is performed. The results of the inventory analysis are presented for each bearing component.

Differences and similarities are discussed. Manufacturing of various parts of the bearings such as inner rings outer rings and balls are studied, each and every operation is defined along with the energy consumed and waste produced. And after that emission from all the parts are then compared and analysed At last a brief comparison is made in NBC and SKF bearing of same size which shows that which product is more environmental friendly.

The NBC 6210 is a ball bearing within the medium size range and is produced in large scale. The Single Row radial ball bearing has a single row of balls and can take pure radial, loads within its load capacity. The reason for choosing this ball bearing is that it is widely used, have a optimum size, an economical price and it is a representative product of NBC. The total inventory results are also characterised and

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the inventory results are in this way connected to the environmental impact categories they contribute to and the results are discussed.

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ABBRIVATIONS

LCA	Life Cycle Assessment
NBC	National Bearing Company
NEI	National Engineering Industries
GWP	Global Warming Potentials
LCIA	Life Cycle Impact Assessment
CNC	Computer numerical Control
OD	Outside Diameter
OR	Outer Ring
IR	Inner Ring
CRCA	Cold Rolled Close Annealed
NMVOC	Non Methyl Volatile Organic Compounds
AoPs	Areas of Protection

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Chapter -1

Introduction

The increasing environmental concern in today's society puts lot of pressure on the industry to produce less environmental damaging products. At this point, this is principally experienced by industries producing consumer goods but these industries are in their turn increasing the pressure on their suppliers. So far it is in most cases questions about environmental management systems but the nature of the questions are slowly changing and becoming more product-related. Questions about LCA work and performed LCAs are becoming more frequent. With this as a background I decided that it was time to perform an LCA on one of key products of NBC.

In recent years Life Cycle Assessment (LCA) has become one of many useful tools in assessing the environmental aspects and potential impacts associated with a product. In LCA the product is followed from the cradle to the grave, i.e. from raw material acquisition, through production, use and waste disposal. LCA is multidisciplinary and deals with the social system, the technical system, the natural system and their relationships.

The LCA method provides researchers or companies with quantitative data for their current products. By looking at a product's life from the raw material extraction to its disposal, the environmental impact of each process and material can be analysed. The LCA allows analysts to determine and analyse the technological, economic, environmental, and social aspects of a product or process necessary to manage the complete life cycle. With this quantitative data, desired changes can be justified with respect to the cost and environmental impacts of a product or process.

LCA is an increasingly important tool for environmental policy, and even for industry. Analysts are also interested in forecasting future materials/energy fluxes on regional and global scales, as a function of various economic growth and regulatory scenarios. A fundamental tenet of LCA is that every material product must eventually become a waste. To choose the 'greener' of two products or policies it is necessary to take into account its environmental impacts from 'cradle to grave'. This includes not only indirect inputs to the production process, and associated wastes and emissions, but also the future (downstream) fate of a product. The first stage in the analysis is

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quantitative comparisons of materials flows and transformations. Energy fluxes are important insofar as they involve materials (e.g., fuels, combustion products). This can be an extremely valuable exercise, if done carefully. However, the data required to accomplish this first step are not normally available from published sources. Theoretical process descriptions from open sources may not correspond to actual practice.

The purpose of the thesis is to investigate the environmental properties of NBC's ball bearing 6210. This is to be done from the starting of the factory gate to the end gate. The purpose is further to identify parameters and processes that causes major environmental impact. Every product has its impact on the environment depending upon the type of material of that product and the manufacturing techniques used in formation of that product. Resources are consumed in formation of product and to produce those resources human being exploit the natural resources which is having a negative impact on the surrounding and environment.

Through life cycle assessment it is possible to find out that how much amount of wastages or unwanted material has been emitted during the desired manufacturing process. Environment can be effected through many ways such as emission to air, water, land, eutrophication emission of photochemical smog etc. by LCA we are capable of find out the exact amount of wastage that has been produced or emitted out. Apart from this LCA also enables us to find out that which of the environment category is badly effected for e.g. by an chemical forming industry the wastage in water resources is far more than air emission which led to human toxicity and water and land eutrophication. So by LCA we can analyse the level of severity of that particular category and try to find out the required measure to protect the same either by changing the type of material used or by changing the type of energy resource or manufacturing process.

The major objective is to quantify the amount of emission in each environmental category and then to compare it with existing emission data of other company which makes the same product. Through this we will be able to find out that whether the company is environmental friendly or it is emitting more than the required standards. After finding out the hot spots of manufacturing process desired suggestion or

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remedies should be proposed in order to mitigate the unwanted environmental impacts.

The methodology used for fulfilling the purpose of this study is an LCA based on quantitative data. This study deals with the life cycle, from start gate to end gate, of the bearing. Use of natural resources, transportation, energy consumption, waste and emissions to air and water are considered. In the study the production and the use of the bearing takes place in Jaipur. The main production plant for NBC is located in Jaipur but the bearings are sold worldwide. Alternative processes will not be studied.

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Chapter -2

Literature review

2.1 LCA in general

An LCA is a comparison between different stages life cycles or between different parts of the life cycle. LCA has advantage as a categorizing tool to identify major and minor environmental impacts from each other. Thus defining the "hot spots" [1] which means the areas which are creating more impacts as compared to others.

With the use of LCA it is possible to identify which kind of environmental impact will be affected by different choice of alternatives. This can be applied to present situations as well as changes that are to be made to be future. LCA is intended to provide information that may be used for environmental improvements but can also be used to identify processes, substances and systems in a life cycle that are major contributors to environmental impacts [2]. These stages can later be studied in detail with the help of other tools such as economical or technical tools.

The three main stages in an LCA study are shown in Figure 2 below and are also described in the following sections[3].

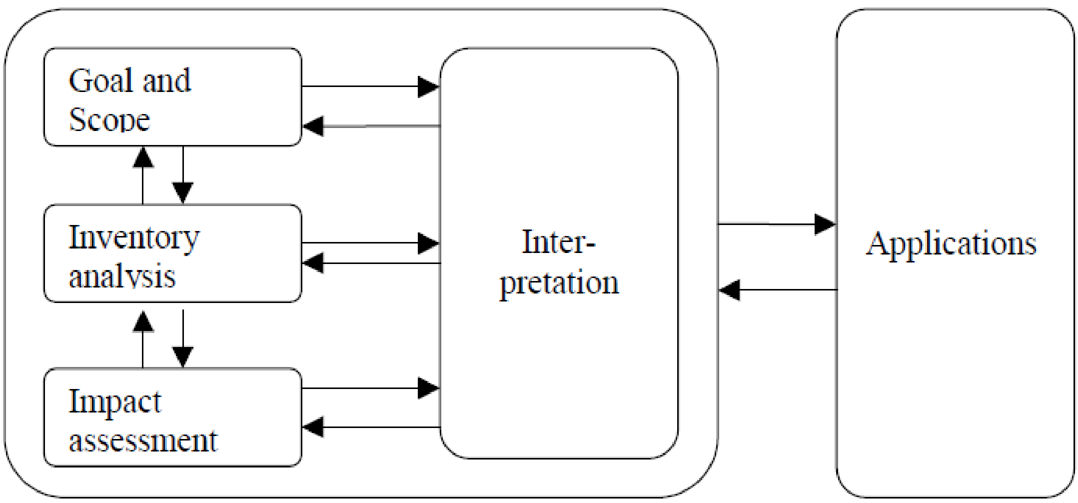

Figure 1: The three main stages in an LCA study according to ISO 14040 *(Soucrce : ISO 14040, 1997)*

The next paragraph shows the key issues of these LCIA parts—starting with an overview of classification and characterisation, discussion of modelling issues, and

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then out show differences compared to other common impact assessment approaches[4]. Summarises the models and associated indicators that currently exist for characterisation for commonly adopted impact categories. Given all the indicators for the different impact categories, outlines how indicator results can be compared, or condensed, across impact categories using social science techniques when direct comparisons using natural science are not feasible or are considered undesirable[5].

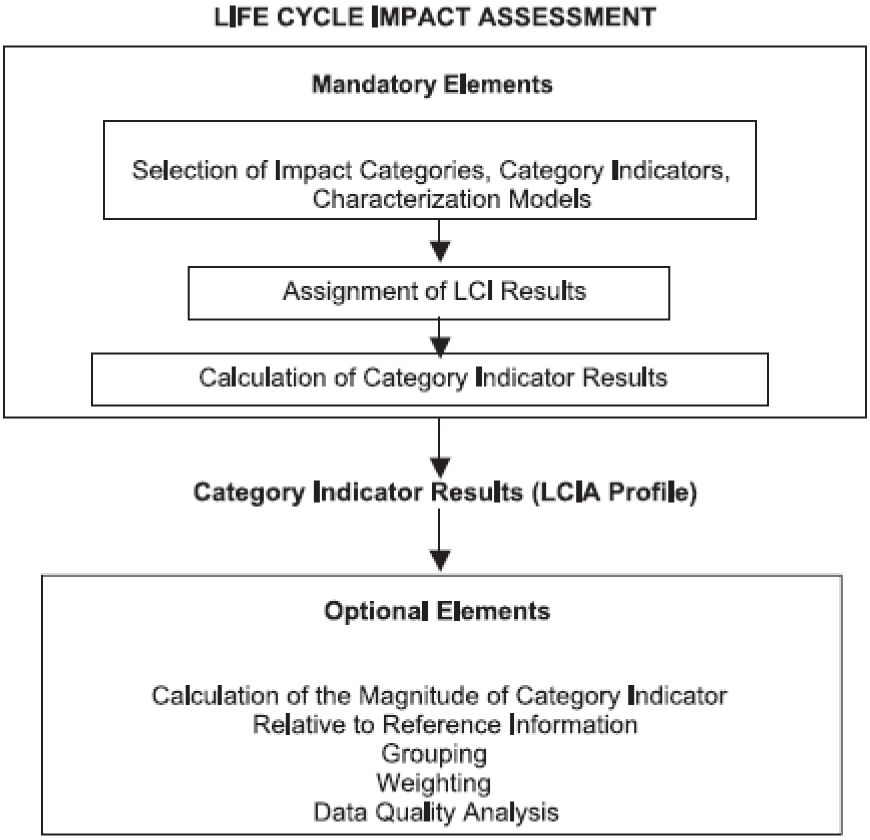

Figure 2: Elements of LCA (*Source: ISO 14042, 2000)*

2.2 Goal and scope definition

Defining the goal of the study includes stating the intended application of the Study, the reasons for carrying it out and to who the results are intended to be communicated. LCA is an iterative process and some choices may have to be made at a later stage in the study, they are however still seen as part of the goal and scope definition.

The goal and scope definition shall include [6][7]:

- Functional unit, which will be used as a reference unit for all data.
- System boundaries, e.g. which processes to include in the analysed system.

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- Types of impacts being considered and thus choice of for which parameters data will be collected in the inventory analysis.
- Level of detail in the study and thus the data requirements.
- Whether or not to perform a critical review and if so of what type.

2.2.1 Functional unit

Since manufactured product needs to be expressed in quantitative terms. This is done by a functional unit. Elaboration and choice of functional unit is one of the most critical activities in first stage. The functional unit shoes the function, benefit, quality and performance of the product. It also made a base in the evaluation and comparison of different alternatives. The functional unit must be clearly defined, measurable and related to input and output data in manufacturing unit.[8][9].

Example: suppose if the purpose of the study is to collate various types of flooring material the function is to protect the floor. One clear difference between various flooring materials is the durability of the material i.e. the time it will last. In this example the functional unit should be: *One square meter of protected floor area*.

2.2.2 System boundaries

To assess the environmental impacts loads from a certain process there are a few things that need to be verified and clearly stated. The environmental loads can vary depending on various parameters. Therefore system boundaries need to be clearly shown [10].the final system boundary is between the technological system and natural world. Theoretically, all the inputs and outputs necessary to the function of a product that should be followed upstream and downstream to flows of energy or material: (a) from natural system to the technological system; and (b) from the technological system to natural system [11][12].

2.2.2.1 Boundaries in relation to natural systems

The starting point of the life cycle is the extraction of raw materials from the nature. Sometimes it is very hard to draw the line between the natural and the technical systems, and thus to decide what to include in the inventory analysis and what to include in the impact assessment[13]. This is one of the reasons why it is difficult to describe the impacts of land use in LCA terms.

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2.2.2.2 Geographical boundaries

Different parts of a products life cycle may occur in different geographical areas and this needs to be specified since the sensitivity to pollutants etc. may vary a lot between these areas. The infrastructure such as electricity production, waste management and transport systems often vary from region to region and if the region which contains the activity is not specified it may have consequences for the result of the study. Are site specific or generic data to be used? If generic data are to be used, which geographic area should they cover? Due to what has been mentioned above the answers to these questions can have an impact on the results [14].

Depending on whether the LCA is done to investigate the environmental load from the production of a product or to investigate the difference between processes average or marginal data can be used. A change in the production is most likely to effect the margin and is therefore probably best estimated by marginal data. If the average data are to be used there are other things to be consider like which type of data is used and it is associated with which process [15].

Example: If the electricity needed for a process is to be estimated with average data the geographic region covered by the data can influence the results considerably. In Sweden electricity mainly originates from water- and nuclear power. The average data for electricity production in Sweden will clearly differ from average data for electricity production in Europe where electricity produced with nuclear power and combustion of fossil fuel is most common. When using weighting methods the indices may be specific for the geographical area. Some methods used today are based on political goals for example reduction targets in the public environmental policy, and are therefore specific for each country[16].

2.2.2.3 Time boundaries

The time boundaries are depending on the goal of the LCA study. If the goal is to investigate what environmental impacts the product can be held responsible for, it can be answered by an LCA with bookkeeping perspective, i.e. retrospective. If the goal instead is to investigate the impacts of changes in material or processes etc. it is probably better achieved by a change-oriented LCA that looks forward in time and tries to find alternative ways of action [17]. The applicability of the results from the

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LCA may depend on the time period represented by the gathered data. If, for example, the production has been changed it is very important to know whether the data are based on production before or after the change was completed. The result can also have a "best before date" if process changes are being planned for the future. Some impact categories or rather methods to calculate potential impacts are time dependent, for example Global Warming Potentials (GWP) and Ozone Depletion Potentials (ODP) [18].

2.2.2.4 Boundaries within the technical system

2.2.2.4.1 Cut-off criteria

While performing an LCA a decision to cut off the life cycle, and not follow a flow further upstream or downstream, may be based on the assumption that the contribution to environmental loads from the excluded processes is negligible in relation to the rest of the life cycle. The decision to cut off the life cycle while performing a change LCA may be based on what is relevant, i.e. what processes will be affected of the changes. Processes that will not be affected need not be included in the LCA[19]. Sometimes the LCA is not done from the cradle to the grave but the system is only studied from cradle-to-gate, gate-to-gate or gate-to-grave. This also means cutting off processes within the life cycle[20].

2.2.2.4.2 Allocation

There are situations when several products share the same process or process chain. If the environmental load is to be expressed in relation to only one of the products an allocation problem arises. There are three basic cases when allocation problems are encountered [21]:

- Processes which have outputs of many products
- Waste treatment processes that have inputs of many different products
- Open loop recycling, i.e. when a product is recycled into a different product.

Allocations can sometimes be avoided through increasing the level of detail of the model or through system expansion. Where allocation cannot be avoided the environmental loads are to be partitioned between the different functions of the system. A good base for this is physical relationships. If the physical relationships cannot be used, relationships, such as economic value between products can be used[22]. One should always be careful when using allocation models because of the differences in result one might get from using different basis for the allocation.

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2.3 Inventory analysis

Inventory analysis is the second stage of the LCA and here a system is built according to the requirements specified in the goal and scope definition. The model may be described as an incomplete mass and energy balance over the system, taking only environmental relevant flows into account.

The inventory analysis should include [23]:

- Construction of a flow model according to the system boundaries – The flow model is usually documented as a flow chart showing the activities included in the analysed system and the product flows between these activities.
- Data collection for all activities in the product system - These data should include inputs and outputs of all activities, i.e.:
  - Raw materials, including energy carriers
  - Products
  - Solid waste and emissions to air, ground and water
- Calculation of environmental loads of the system in relation to the functional unit.

Technical systems and processes often fulfil more than one function, which can make the inventory modelling complicated. In these cases the environmental loads of such a process have to be partitioned i.e. allocated between its different products or functions [24].

2.4 Impact assessment (LCIA)

The life cycle impact assessment (LCIA) phase, focusing on the key attributes of the supporting models and methodologies. These models and methodologies provide LCA practitioners with the factors they need for calculating and cross-comparing indicators of the potential impact contributions associated with the wastes, the emissions and the resources consumed that are attributable to the provision of the product in a study[25].

- Selection of the impact categories of interest, the indicators for each impact category and, although often implicitly considered by practitioners, the underlying models (a procedure also considered in the initial goal and scope phase of an LCA).

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- Assignment of the inventory data to the chosen impact categories (classification).
- Calculation of impact category indicators using characterisation factors (characterisation).
- Calculation of category indicator results relative to reference values(s) (normalisation, optional).
- Grouping and/or weighting the results (optional, weighting not being allowed when following ISO14042 in comparative assertions disclosed to the public).
- Data quality analysis (mandatory in comparative assertions disclosed to the public, according to ISO14042, but receiving little attention in current practice).

2.4.1 Impact Categories and Areas of Protection (AoPs)

LCIA standard, there are three broad groups of impact categories that should be taken into account when defining the scope of an LCA study. Impact categories include climate change, stratospheric ozone depletion, photo oxidant formation (smog), eutrophication, acidification, water use, noise, etc. The three broad groups are commonly referred to as AoPs [26]:

- Resource use
- Human health consequences
- Ecological consequences

In some of the recent proposals [27]. The suggested AoPs are now:

- Natural environment (resources and life support functions—climate regulation, soil fertility)
- Man-made environment (monuments, forest plantations)

2.4.2 Characterization

The Given Equation provides an example for outpouring data of how indicators for each impact category can be willingly calculated from the inventory data of a product using general characterisation factors [28]. Characterisation factors are typically the yield of characterisation models. The factors which are made accessible to practitioners in the literature, in various other form of databases, as well as in available LCA support tools. Similar general equations and data exist for wastes and resource emaciation [29].

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Category Indicator = $\sum_{s} Characterisation\ Factor * Emission\ Inventory$

Where subscript s denotes the type of chemical used.

The emissions inventory data are shown in terms of the mass ransom into the environment such as 1 kg per functional unit. The characterisations factors from above equation therefore are linearly shown the hand out to an impact category of a unit mass (1 kg) of an emission to the environment. As an example, the correlative contributions of different natural goes to climate change are usually compared in terms of carbon dioxide equivalents using Global Warming Potentials (GWPs). A Global warming potential500 of 100 implies that 1 kg of the substance has the same progressive climate change effect as 100 kg of carbon dioxide through, a 500 year time period.

2.4.3 Normalization

The main priority of normalisation is typically two-fold [30] to place Life cycle inventory assessment indicator results into a wider context and to adjust the results to have common units [31].

The addition of each category indicator result is then divided by a reference point,

$N_k = S_k / R_k$

Where k denotes the impact category, N shows normalised indicator, S is the category indicator which comes from the characterisation phase and R is the reference value.

The reference system is usually chosen using overall indicator results for a specific region, for example a nation, and for a specific time (year), such as the annual national US hand out to climate change in terms of GWPs. Space related scale, time related scale, a defined system (e.g. a region or an economic sector) and a per capita basis are all examples of characteristics that could be taken into account while choosing the reference value [32].

2.4.4 Grouping

Grouping is a qualitative, or semi-quantitative, which includes sorting and/or ranking results across various impact categories. Grouping may give result in a broad ranking, or hierarchy family, of impact categories with respect to their importance. Such a

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ranking can provide help in making conclusions on the relative importance of various impact categories [33]. For example, categories could be grouped in terms of high importance, medium importance and very low important issues. Some methods which include grouping are the verbal-argumentative perspective described by [34], as further developed by Schmitz and Paulini, and the ranking method is given by Volkwein.

2.4.5 Weighting

Weighting is also sometimes cited to as ‘‘valuation’ ’in some Life-cycle assessment circles which refers to using numerical factors based on value choices to facilitate differentiation across impact category indicators (or normalised results)[35]. Weighting is usually applied in the form of linear weighting factors[36]:

$$EI = \sum V_K * N_K \text{ or } EI = \sum V_K * S_K$$

where EI is the overall environmental impact indicator, Vk is the weighting factor for given impact category k, N is the normalised indicator and S is the category indicator from the characterisation phase.

Weighting remains a disputable part of LCA, as in other assessments—mainly because it includes social, political and moral value choices [37]. Not only are there values involved when selecting weighting factors, but also when selecting which type of method is to be use, and even in the choice of whether to use a weighting method at all or not. However, every weighting method contains a scientific aspect not only from natural sciences, but also from social and etiquette sciences as well as from economics. For example, techniques, knowledge and theories developed by decision analysis and environmental economics can be manipulate for weighting in Life-cycle assessment [38].

Methods for weighting can be classified in different ways [39]:

(1) A distinction can be made between methods based on impact indicators defined early (at midpoints) or late (e.g. at endpoints or for areas of protection), in the impact chain, as described in Section 5.
(2) A second distinction is between three major groups of methods:

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- Monetisation (here used as an umbrella term for all methods which have a monetary measure involved in the weighting factors)
- Panel (a group of methods where the relative importance of damages, impact categories or interventions is derived from a group of people through surveys)
- Distance to target (where characterisation results are related to target levels)

(3) A third contrast exists between shown preference methods and revealed preference methods. Panel methods, as well as some monetisation methods, are based on expressed preferences. People are asked their preferences (for example, willingness-to-pay). On the other hand, some monetisation methods are based on revealed preferences. These monetised weighting factors are derived from reactions to different situations of individuals and/or organisations, such as insurance payouts, health care expenditures, fines, costs incurred for environmental cleanups and ecotaxes[40]. provided an overview of monetisation in the context of LCA and human health.

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Chapter 3

Research Methodology

3.1 Phase 1: Selection of product and company

As performing a life cycle assessment on a product which is having little number of components and all of that of same material is comparatively easy as compared to material having different components of different material. So after discussion with research supervisor I finally decide to choose ball bearing because it is mostly made up of metal and a life cycle analysis is not performed on this product. The another reason for choosing this product is that it is manufactured by the very know company in Jaipur i.e. national engineering industry which is commonly known as NBC Jaipur, which is one of the biggest bearing manufacturing plant in India.

In NBC Jaipur, the bearing NBC 6210 is chosen for study because of following reasons

- It is produced in large number as compared to others
- It is distributed to many companies in India as well as in aboard
- The size and weight of the bearing is optimum which is suitable for data collection i.e. measurement of weights during various operation.
- Bearing 6210 is one of the most prioritized product in the NBC.Second Phase

3.2 Phase 2: Inventory Analysis or data collection

The next phase is to identify and quantify the materials and emissions crossing system boundary. The input and emission flows are termed environmental burdens or environmental interventions; ISO recommends the term `elemental flows', but this is avoided here because it is potentially confusing. The inventory analysis phase accounts for input and output flows of materials, energy, water and pollutants. Therefore it is necessary to follow the precise standards for data collecting, calculation procedures, allocation rules etc., i.e. SETAC (1993) [41]. Key questions are to be answered:

- What is the system to be assessed (defining systems)?
- What are the system's boundaries?
- Which machining process includes in manufacturing of the product?

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- What are the various input output flows during manufacturing?

Inventory analysis is the one of the most difficult task to perform in LCA study. Gathering the required data with enough accuracy is a time consuming and tedious job. After defining the goal and scope and system boundaries, detailed inventory data should be collected. It includes the various inputs such as raw material, energy requirement etc. and the output such as wastage and emission. Each and every manufacturing process should be studied and data should be collected along with the energy consumption in each stage.

The data is collected in NBC Jaipur plant by personally visiting each workstation and measuring the weights before and after the process while the energy consumption is find out by machine power rating. Interviews with key persons have been performed through discussions on site, if possible. This has proved to be the most efficient method for receiving data immediately.

3.3 Phase 3: Impact assessment

Impact assessment has been done by using the SIMA PRO 8.0 LCA software with the Eco invent 3.2 database. The impacts assessment phase implies the selection of impact categories, classification and characterisation of environmental impacts based on the inventory analysis, regarding goal and scope. The impacts assessment procedure is codified in ISO standard 14042, though the impacts are often context–specific and can thus hardly be generalised [42]. The identification of impact categories depends on the goal of the particular LCA. General impact categories are resources depletion, human health as well as ecological and global impacts. These impacts are operationalized by specific impacts such as global warming, ozone depletion, acidification or eutrophication. In the characterisation phase, the impacts are analysed, quantified and calculated, requiring scientific knowledge about load–response relationships [43]. For that purpose, the inventory data needs to be analysed by modelling approaches, like the use of equivalency factors (e.g. ozone depletion potential) or toxicological data.

3.4 Phase 4: Interpretation or result analysis

The interpretation phase organises the results of the inventory analysis and impact assessment in a comprehensible way in order to handle them by decision makers. The

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findings allow a global view on the lifecycle of products and/or processes. With respect to the goal and scope of the study conclusions and recommendations may be formulated. Interpretation is recognized as the final phase of an LCA. In this phase, the findings of either the inventory analysis or the impact assessment or both are combined in line with the defined goal and scope of the study[44]. The results are used `to effect environmental improvements'.

As a basis for a decision−making processes considering environmental aspects, the LCA results point out various options for improvements and supports other environmental concepts, tools and systems (e.g. Eco labelling, environmental management system).

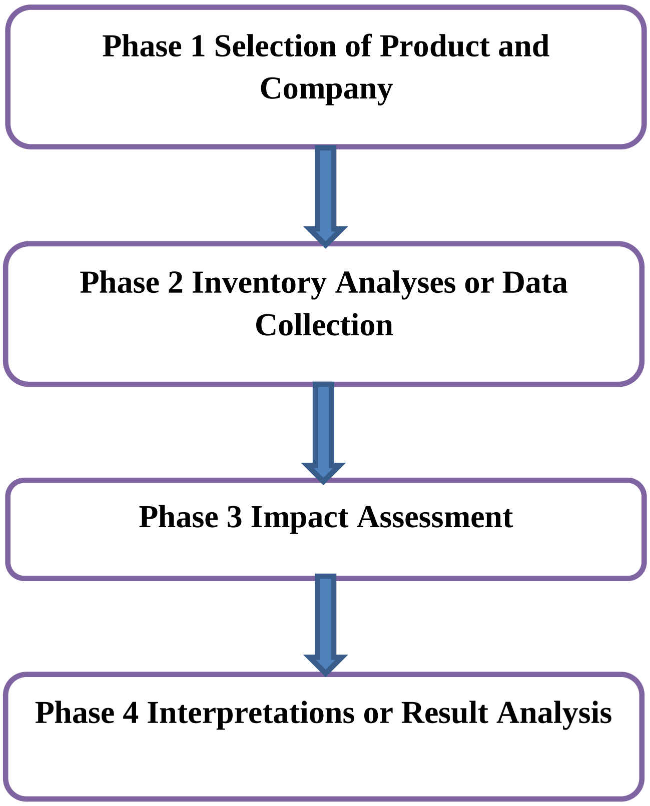

Figure 3 Flow Chart of Methodology

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Chapter 4

About the NBC Jaipur

National Engineering Industries Limited (NEI) is the flagship NBC company of the CK Birla Group, a union with a turnover of US$ 1.6 billion. NEI was founded in 1946 by the eminent industrialist, Shri B M Birla, by the name of 'National Bearing Company Limited'. The company started manufacturing in 1950 with a yearly production of 30,000 bearings in 19 sizes. With increasing activities and endowment of industrial licenses for other important industries and manufacturing, the name of the company was changed in 1958 to 'National Engineering Industries Ltd.' retaining its original trade mark NBC [45].

Over the past 60 years, NBC has grown to be the major and fastest growing bearings brand in India and now produces over 100 million bearings in more than a 1000 sizes. It has the capacity to develop bearings from 10 mm bore to 2000 mm outer diameter. The product range includes ball bearings, tapered roller bearings, and double row angular contact (DRAC) bearings, cylindrical and spherical roller bearings. The company has equipped facilities produce axle boxes for railway applications; cartridge tapered roller bearings, large-diameter bearings for industrial applications and other engineering products.

The first product manufactured at this plant was a ball bearing in the year 1949. At that time there was no ball bearing industry in India so it becomes the oldest ball bearing manufacturing company in the India. In addition to making several types of bearings for automotive and other industrial segments, it makes around 10 varieties for Indian railways. Besides supplying to Indian Railways, the company is also supplying to Brenco, US since it is corroborate by American Association of Rail and Road. Company get the Deming Prize in 2010 the company went for a re-certification audit a couple of years later. It was inspected for the Deming Grand Prize recently. The Jaipur unit has about 25 manufacturing lines. While 19 lines manufacture ball bearings, the rest make other bearings including DRAC (Double Row Angular Contact) bearings, most of which is supplied to Nissan. The lines here are running as single-piece-flow, which means single quality bearings. The company outsources cages and few types of steel balls. All races and other censorious components are manufactured in-house. NBC Bearings are widely used by two and three Wheelers,

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Cars, Trucks, Tractors, Railway wagons, coaches & locomotives, Steel Mills, Heavy Engineering Plants, Bulldozers, Tillers and Thermal Power Plants. The automotive and railway industries form the two biggest client segments.

The industry is spread over 118 acres in Jaipur and 56 acres in Newai. This is the only manufacturing plant in the country manufacturing wide variety & range of bearings such as Ball Bearings, Steel Balls, Tapered Roller Bearings, Cylindrical Roller Bearings & Axle Boxes for Railway Rolling Stock including Spherical Roller Bearings, Cartridge Tapered Roller Bearings and Large Diameter Special Bearings in isolated fully equipped divisions. The development of National Engineering Industries Ltd. was evolve with a theme "Indigenisation & Self-reliance".

NBC has emerged as a leading exporter of bearings from India and its current export foot-print comprises of over 21 countries across 5 continents. Leading customers from US, Germany, Brazil, Japan, and Australia etc. have entrusted NBC with their critical product requirements. NBC serves the Indian aftermarket through a countrywide network of 500 authorized partners[46].The NBC vision is to become a preferred anti-friction bearings supplier in domestic market & focus on select export markets and to enhance our presence in allied engineering products and services. The NBC mission is to grow in the business of anti-friction bearings and other allied engineering products and services, deliver superior value to our customers, suppliers, shareholders, employees and society at large and to pursue excellence through total quality management.

NEI invests in Research and development activities. Recently, the company has developed a low torque bearing that can mitigate friction up to 20%, which results in fuel efficiency. This product was developed as a result of understanding the various torque contributors to the bearing such as grease, seal and internal bearing geometry. The Company spends 1% of its turnover on R & D activities with an eye on growing it to 2% in coming years. The department is staffed by 115 experts and the new facility built in 2006 is in active growth mode. Company made 12 patents applications have successfully last year. The research work is divided into tribology (the lubrication science), advanced materials, advanced manufacturing processes, new product design, virtual simulation and testing for materials. For simulation of actual work conditions there are 35 test rigs, which include four for railways.

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NEI has invested much in automation, specifically automation related to quality improvement and not related to manpower reduction. For instance, the parts from the grinding line are moved to the assembly area by workers. Since it began following single-piece-flow concept, it resorted to conveyors where on-line checking is also done, helping to maintain quality at a much higher level. Poke-yokes technique is used in this plant to ensure that a defective part never goes for further process [47]. Begin from material selection to the finished product is packed the company has made mechanisms to verify for conformity and good quality. All these initiatives have made NEI a name to surmise with in the bearing manufacturing industry.

4.1 Assumptions

- Study of Thin Polyethylene film used in packing of one piece of bearing is not included.
- Environmental impacts made by cages are not considered in the Life Cycle analysis.
- Energy Consumed in cleaning of bearings during various stages and electricity required in Assembly of ball bearing is also not included.
- Since Bearings are transported from one station to another via human help, so transportation is not considered in the study.
- Instead of Raw materials from mines, Forged Rings are considered as raw material which is obtained by the company from various suppliers.
- All the impact factors were calculated from Eco invent Version 3.1 which were according to German Standards not according to Indian Standards.

4.2 Single Row Deep Groove Ball Bearing

The Single Row radial ball bearing has a single row of balls and can take pure radial, loads within its load capacity. It is widely used because it can operate at very high speeds due to its low torque and is cost-effective at an economical price. Single row deep groove ball bearings are adaptable, self-retaining bearings with outer rings, inner rings and ball and cage assemblies. These products, which are of simple design, robust in operation and easy to maintain, are available in unsealed and sealed variants [48]. Due to the raceway geometry and the balls, deep groove ball bearings can support axial forces in both directions as well as radial forces. Due to their low noise

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level and low frictional torque, single row deep groove ball bearings are particularly suitable for electrical machinery, ventilators, washing machines and power tools.

As there is high degree of compliance between balls and raceways, the self-aligning capability of deep groove ball bearings is less. Advantages of deep groove ball bearings are [49]

- Lower noise level due to improved quality of balls, optimised surfaces, cage with higher stability and modified osculation.
- Lower friction due to modified osculation and optimised surfaces, waviness and roundness.
- Improved sealing action due to optimised position of the HRS seal lips, a matched undercut on the inner ring and axial running contact of the seal lip on the inner ring or due to Z seals with a labyrinth function.
- Higher cost-efficiency lower energy costs due to lower friction; longer grease operating life due to reduced strain on lubricant; longer rating life of sealed bearings due to better protection against contamination; reduced grease loss due to better sealing function.

The Ball bearing has four different types of components.

- ***Outer ring*** - which has a spherical raceway and fits into the housing
- ***Inner ring*** - which has two separate raceways, that are inclined at an angle to the bearing axis, and which fits into the shaft
- ***Rollers*** - that are Ball-shaped and incorporated in two rows between the inner and outer rings
- ***Cages*** - that keep the balls separated from each other.

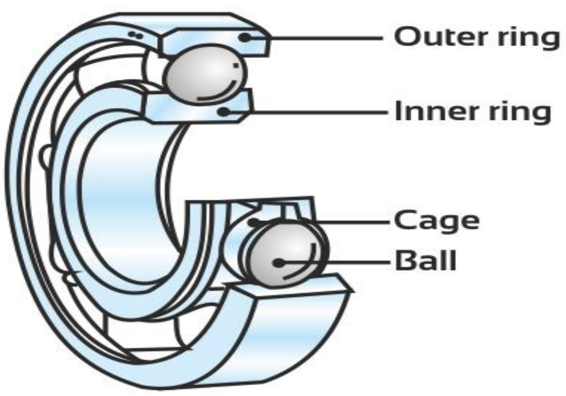

Figure 4: Deep Grove Single Row Ball Bearing

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4.2.1 Bearing materials

The staging and endurance of a dimensionally perfect bearing with ideal internal and external geometries and surfaces, correct mountings, and professional operating conditions are influenced by characteristics of its material. The major criteria to consider for the good performance of bearing including material selection and processing with resultant physical properties [50].

Bearing contains amount of carbon, iron, chromium, manganese, phosphorus, sulphur, silicon etc. Each of these elements plays a role in making final steel suitable for bearings. Chromium and carbon give deep hardening. The mixture of chromium, carbon & iron helps to minimize failure. As they increase the surface resistance to abrasion & wear increase. In short, proper combination of all these elements make final bearing steel which is tough under shocks, heavy loads & strength enough to withstand fatigue. Generally bearings are made from bars. But now a day, many manufacturers are making bearings by forging rings. The latest techniques adopted recently are the "Vacuum Processing". The bearing steel is made through vacuum processing, which assists rod to be clean & free from defects & give lager life.

Table 1: Contents of impurities in a Raw material

ELEMENT	AMOUNT
Manganese	0.25 to 0.35 %
Silicon	0.025 to 0.35 %
Sulphur	0.025 max. %
Phosphorus	0.025 max. %
Nickel	0.025 max. %
Copper	0.35 max.%
Molybdenum	0.10 max. %

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4.2.2 Product specification

The bearing which was chosen is having product number 6210 in the company. The criteria for choosing this particular bearing type have been that the bearing is:

- produced in large scale
- representative for NBC
- sold to more than one customer

Following were the Characteristic of the job [51]

Bearing Number: 6210

Outer Ring Diameter (D): 180 mm

Inner Ring Diameter (d): 100 mm

Width (B): 20mm

Radius of Curvature (r): 1.1 mm

Mass of Complete bearing (approximately): 0.457 Kg

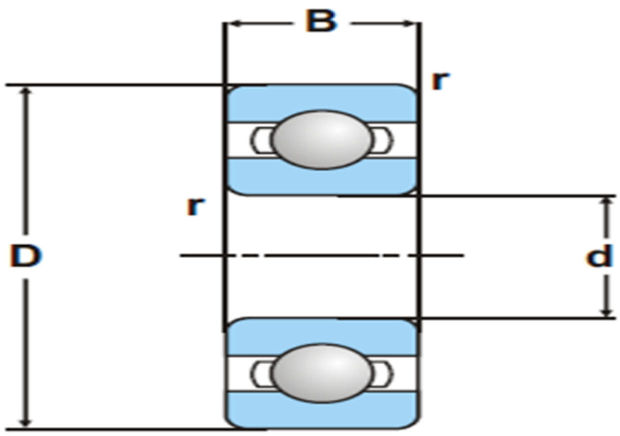

Figure 5: Ball Bearing Line Diagram *(source: NBC product Catalogue)*

4.3 Life cycle Analysis

4.3.1 Goal of the study

The purpose of the study is to investigate the environmental properties of NBC's Ball bearing 6210. The study is to be done from the beginning of factory gate to the end gate. The purpose is further to identify parameters and processes that cause major environmental impact. The environmental impacts caused by the production of each component will be compared.

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The intended application of the study is to increase the knowledge of the potential environmental impacts that can be associated with the life cycle of NBC's ball bearing. The intended audience is mainly employees at NBC.

4.3.2 Functional unit

The functional unit of this study is one ball bearing of type 6210 ready for sale. This signifies one complete bearing; rust treated and packed in a corrugated board box.

4.3.3 Choice of methods for aggregation and evaluation

In the LCIA the characterisation methods used are [52]:

- Acidification (max)
- Eco toxicity, aquatic
- Eutrophication (max)
- Global warming (100 years)
- Human toxicity
- Photochemical oxidant creation (0-4 days high NOx)
- Resource depletion (reserve based)

4.3.4 System boundaries

- The raw material for the bearing steel is Forged outer and inner rings, which is regarded, as a resource not traced back to the cradle.
- The study considers emissions to air and water.
- Waste treatment is not included.

4.3.5 Time boundaries

Almost all of the site-specific data are based on the production in the month of February year 2015. While some of data is collected from the company's profile which is previously being set up as standard for performing operation while manufacturing ball bearings.

4.3.6 Geographical boundaries

The manufacturing of the bearing takes place at the plant in NEI Jaipur, which is the main production unit for NBC. The bearings are sold almost in every part of India and even abroad.

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4.3.7 Boundaries within the technical system

- Real capital like tools, buildings, machinery and infrastructure is not included in this study.
- The allocation methods used in the study vary between the activities but the method most widely used is allocation based on quantity.
- The bearing is packed in flow film and a corrugated board box. The corrugated board box is included in this study while the flow film is not.
- In many of the activities included in the life cycle steel scrap is produced. In this study the steel scrap is not recycled. This assumption is based on statements made by the companies participating in the life cycle. The steel scrap produced NBC Jaipur is transported to recycling process.

4.4 Inventory Analysis

4.4.1 Manufacturing processes of ball bearing

As the NBC procured its various parts from different companies and after having subsequent machining operation they assemble them in a finished product. Firstly NBC got the forged raw material from various suppliers and after inspection, they are sent for further operation in the plant.

Manufacturing of bearings includes various process like Heat treatment, turning, facing, grinding, lapping etc. For heat treatment they either used an air fuel furnace or an electric furnace. And for most of the other process they used CNC machines. There is a separate manufacturing unit for the manufacturing of steel balls of various sizes. Lastly when all the parts are manufactured then are assembled on workstation and finally sent to inspection department for further checking and packaging of the bearings.

The method of manufacturing and assembling a ball bearing which consists in forming uninterrupted, integral inner and outer rings or race ways grooved respectively on the outer and inner circumferential faces to embrace the balls and prevent lateral displacement thereof when assembled, subjecting the body of the outer

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ring to an electric heating current while the working face thereof an the inner ring and balls are maintained at a low temperature [53].

NBC gets forged and roller bearings from their vendors, as there are no separate dept. for forging or rolling. Than they do carburizing or other heat treatment to strengthen the bearing or finally grinding or other finishing operation is performed to make it able to operate in automotive vehicle, railway etc. The processes through which bearing has to go are shown in flow diagram below-

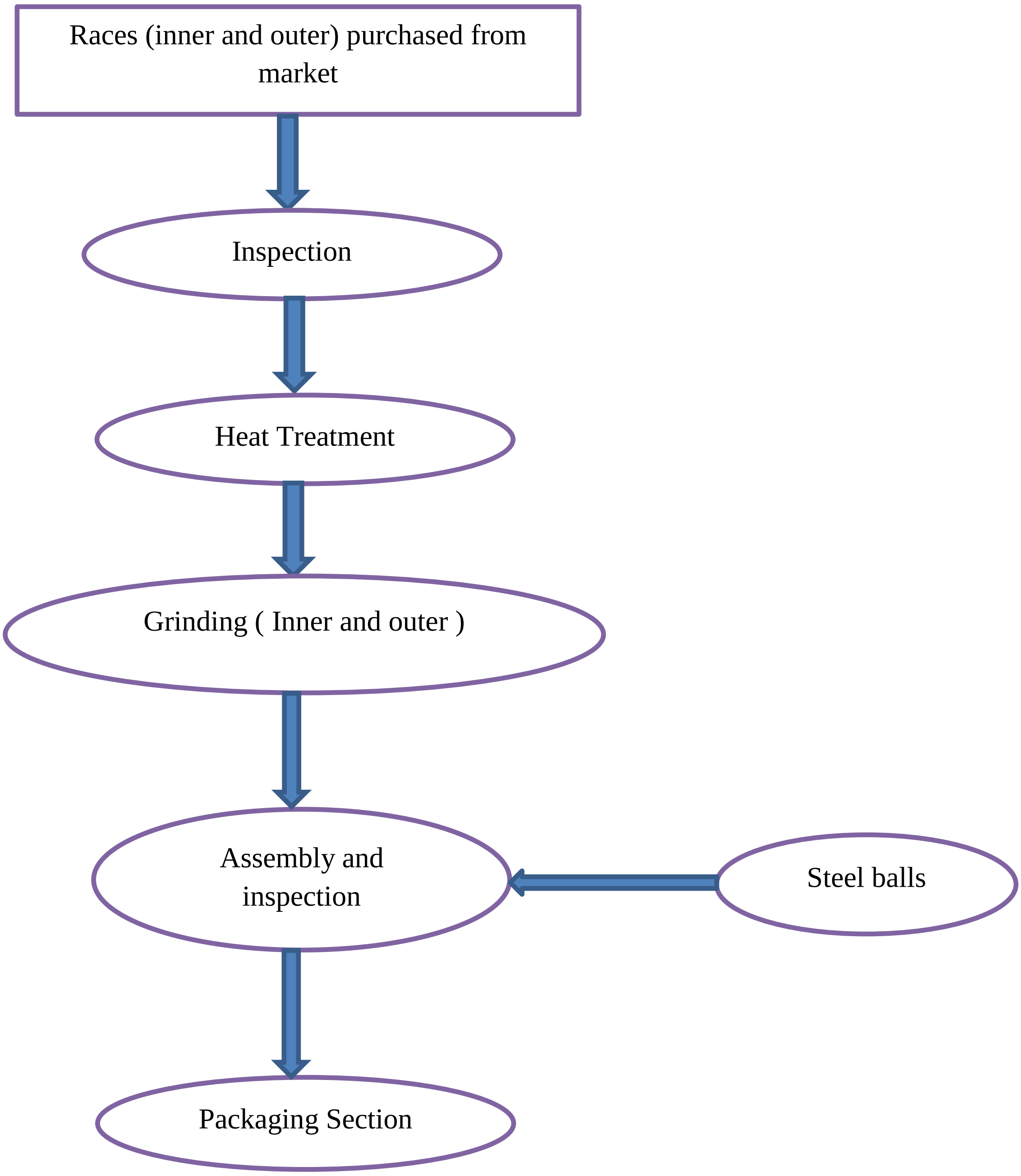

Figure 6: Flow Diagram

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4.4.2 Heat treatment

Heat treatment of bearing steel components necessitates heating and cooling under controlled atmospheric conditions to impact the desired material characteristics and properties such as hardness, a diffused high carbon surface layer, high fracture toughness or ductility, high tensile strength, improved machinability, proper grain size, or reduced stress state[54].

The process of heat treatment started with prewashing the both inner and outer rings in 60°C water and then heating both the rings in hardening furnace at a temperature of 850°C for the duration of 35-45 minutes. The fuel used is liquefied petroleum gas, mixture of LPG and air is fed into big chamber by external blower. After hardening furnace, Quenching is done in an oil tank, which is already at a temperature at 115°C. the Final step is to do tempering.

Steels are not suitable for some bearing applications requiring impact resistance; hence a secondary heat treatment process called tempering is carried out on quenched steel to achieve the necessary toughness and ductility by marginally sacrificing hardness. This process also relives the internal stresses thus improving the ductility. The tempering temperature is about 110°C for 10-15 minutes.

The weights of both inner and outer rings are almost same during the whole heat treatment process. Forged rings which are available as raw materials for heat treatment are having following weights:

Inner Rings: 147.3 gm.
Outer Rings: 204.9 gm.

The heat treatment was done in a LPG furnace in which mixture of air and LPG is used fed to the chamber where both outer and inner races are placed. The rate at which LPG is fed is 22.5 kg/hr. hardening and tempering furnaces both get the fuel from the same supply as the total time taken by 1500 bearing races is approximately one hour in both hardening and tempering furnaces. Therefore the total amount of LPG used for per bearing component is about 15 gm. each.

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Table 2: Resource Table for Heat Treatment

Number of bearing treated per hour	LPG supply per hour	Amount of LPG required per bearing	Total resource required
1500	22.5 kg	15 gm.	30 gm.

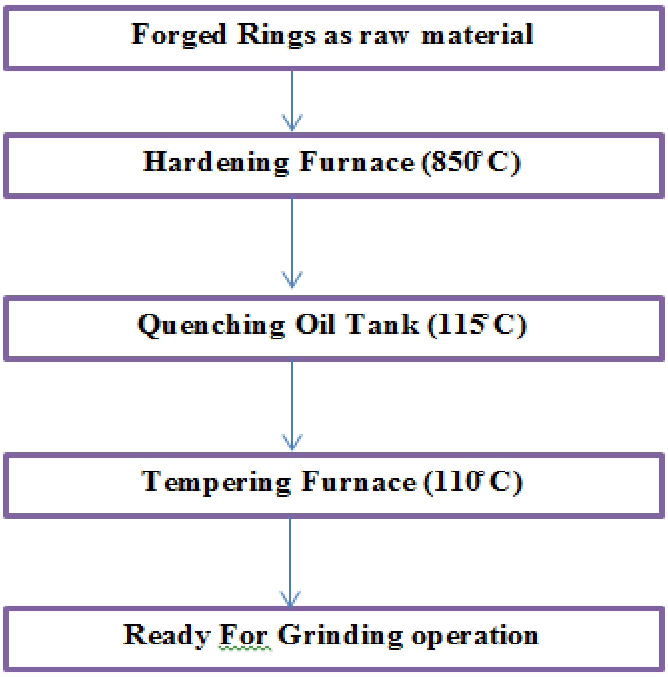

Figure 7: Flow Diagram for Heat treatment

4.4.3 Manufacturing of Rings

The forged rings which were obtained from the supplier are treated here as raw material and the number of operations were performed on these rings to get the desired dimensions and finishing [55]. In case of outer ring the series of operations are given below

- Circumferential or OD grinding
- Face grinding
- OR Track Grinding
- OR Track Honing

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While in case of inner ring the circumferential grinding does not required, apart from this operation it required bore grinding as the bearing has to be assembled to another machine by shaft attachment through bore of inner rings. The numbers of operations for Inner rings are

- Face Grinding
- IR Track Grinding
- Bore Grinding
- IR Track Honing

4.4.3.1 Manufacturing of Outer Rings

4.4.3.1.1 Circumferential or OD grinding

Forged rings which were given heat treatment were now proceeds to circumferential grinding in order to have desired surface finish and dimension. This is done by a grinding machine with power rating of 7.5KWh. It grinds about average of 225 outer rings and the maximum capacity of 400 outer races per hour. While taking the average speed, the amount of electricity required to properly finish one single unit of raw material weight 204.9 gm. to final weight of 190.1 gm. is 33.33 watt.

Table 3: Resource Table for OD grinding

Initial Weight	Final Weight	Wastage	Energy Required
204.9 gm.	190.1 gm.	14.8 gm.	33.33 watt

4.4.3.1.2 Face Grinding

After circumferential grinding the side of the outer rings/ races has to be finished. The finished product from circumferential grinding with weight 190.1 gm. will now be a raw material and the final product will be weight of 186.43 gm. The machine used in face grinding is similar to circumferential grinding so the amount of electricity used is similar to 33.33 Watt

Table 4: Resource Table for Face Grinding

Initial Weight	Final Weight	Wastage	Energy Required
190.1 gm.	186.43 gm.	3.67 gm.	33.33 watt

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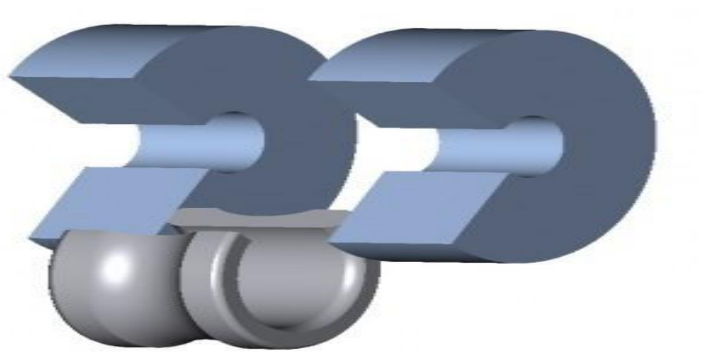

Figure 8: Face Grinding

4.4.3.1.3 OR Track Grinding

Outer ring has an inside track on which steel balls have to slide in order to provide a smooth less friction motion to the inner rings, which is imparts by the rotating shaft or some machine element. So before making the track smooth by honing it is first treated in a CNC machine which grinds the inner surface of the track by abrasive stones. The initial weight of bearing race is about 186.40 gm. which was finally reduced to 184.14 gm. the power rating of the CNC machine was 12 KWh and in order to maintain constant throughput it also machined the inner races at the speed of 250 to 350 races per hour. So the total amount of electricity consumed in OR track grinding operation comes out to be 48 watts.

Table 5: Resource Table for OR Track Grinding

Initial Weight	Final Weight	Wastage	Energy Required
186.43	184.14 gm.	2.29 gm.	48 watt

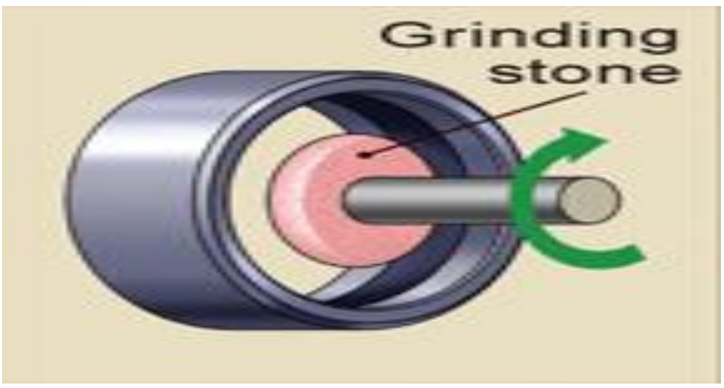

Figure 9: OR Track Grinding

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4.4.3.1.4 OR Track Honing

Track honing is quite similar to track grinding. However the surface finish level achieved in track honing is very high as compared to that of grinding and this is also necessary to have smooth motion of the bearing on the track. The machine used in this operation is quite similar to that of grinding but with different tool attachment, it's a CNC machine with the power rating of 12 KWh and it's also machined the track as in the same rate of track grinding CNC machine. The power used in this operation is also 48 watts (approximately). The final weight of the bearing which is now ready for assembly after cleaning and lubrication is 182.02 gm.

Table 6: Resource Table for OR Track Honing

Initial Weight	Final Weight	Wastage	Energy Required
184.14 gm.	182.02 gm.	2.12 gm.	48 watt

4.4.3.2 Manufacturing of Inner Rings

4.4.3.2.1 Face Grinding

After hardening process the first of grinding is face grinding and this process is done on facing wheel grinding machine by manual feeding of cup and cone. Facing wheel grinding machine grind the face of races at an average speed of 225 races per hour with maximum capacity of 550 races per hour. Facing of outer ring (cup) also takes place between two facing wheel, out of which one wheel is hard and one wheel is soft. Soft wheel used to take into account wear resistance of hard wheel. After facing inspection takes place with the tolerance of 40 micrometres. Flange width also checked with the tolerance of 15 micrometres. As the face grinding of inner rings is done on the same machine with the same rate as of the outer rings so electricity consumed is same and which is equal to 33.33 watt. The initial weight of inner ring which is obtained after heat treatment is 147.3 is reduced to 144.1 gm.

Table 7: Resource Table for Face Grinding

Initial Weight	Final Weight	Wastage	Energy Required
147.3 gm.	144.1 gm.	3.2 gm.	33.33 watt

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4.4.3.2.2 IR Track Grinding

After face grinding, track grinding is performed which is performed on a CNC machine of 12KWh. The initial weight before this operation is 144.1 gm. which was finally reduced to 142.8 gm. the power consumption is 48 watts as the number of parts produced is same as of OR track grinding.

Table 8: Resource Table for IR Track Grinding

Initial Weight	Final Weight	Wastage	Energy Required
144.1 gm.	142.8 gm.	1.3 gm.	48 watt

4.4.3.2.3 Bore Grinding

Bore is the inner circumferential surface of the bearing. The bore should be surface finished since the bearing has to be assembled in machine. Grinding of bores or holes and is probably one of the most difficult types of grinding. Requirements of internal grinding range from very rapid removal of stock to processes capable of generating size and concentricity measured in millionths of an inch. It is obtain in the bore grinding CNC machine. The CNC machine which is used is of 8 KWh power. Weight of inner bearing from 142.8 gm. was reduced to 141.4 gm. the power consumption is 35.55 watts.

Table 9: Resource Table for Bore Grinding

Initial Weight	Final Weight	Wastage	Energy Required
142.8 gm.	141.4 gm.	1.4 gm.	35.55 watt

4.4.3.2.4 IR Track Honing

Honing is an abrasive machining process that produces a precision surface on a metal work piece by scrubbing an abrasive stone against it along a controlled path. Honing is primarily used to improve the geometric form of a surface, but may also improve the surface texture. The final weight of inner rings obtained after this process is 140.63 gm. the power consumption is 48 watts. As steel balls will move on the track

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so the track surface should be super finished so the balls will move smoothly. The finished product after this process is sent for assembly section.

Table 10: Resource Table for IR Track Honing

Initial Weight	Final Weight	Wastage	Energy Required
141.1 gm.	140.63 gm.	.47 gm.	48 watt

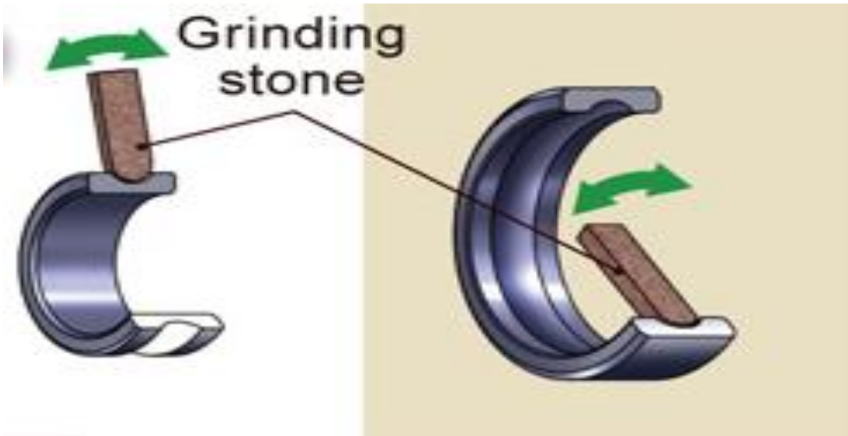

Figure 10: IR track honing

4.4.3.3 Manufacturing of balls

The purpose of balls is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two races to contain the balls and transmit the loads through the balls. In most applications, one race is stationary and the other is attached to the rotating assembly (e.g., a hub or shaft). As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were sliding against each other [56]. As there were number of operations in manufacturing of balls which makes it very tedious job to find out the energy requirement for each and every process, so I find out the total energy consumption of the balls manufacturing unit and divides the equal energy consumption to all operations which were performed during the manufacturing process. The process for manufacturing ball is given below with the flow chart

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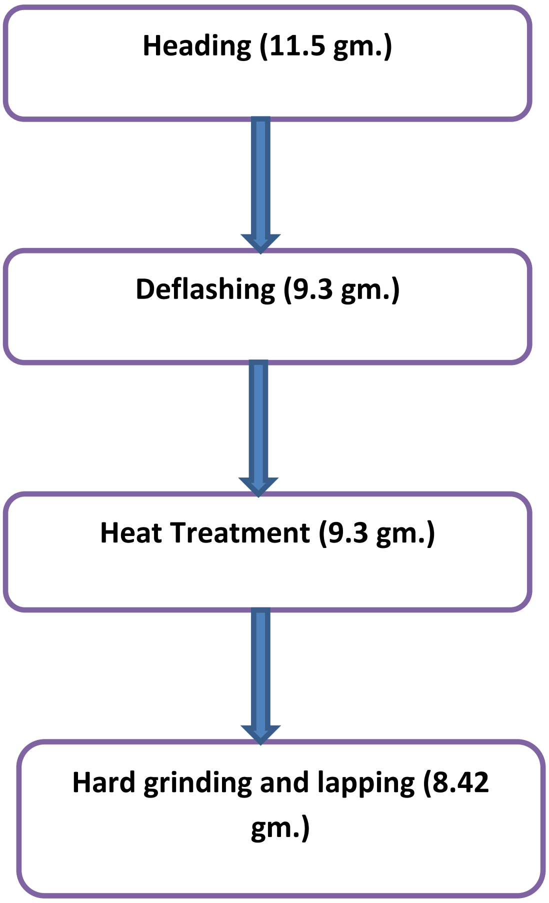

Figure 11: Process flow chart

4.4.3.3.1 Heading

The balls are a little more difficult to make, even though their shape is very simple. Surprisingly, the balls start out as thick wire. This wire is fed from a roll into a machine that cuts off a short piece, and then smashes both ends in toward the middle. This process is called cold heading. Its name comes from the fact that the wire is not very hot.

4.4.3.3.2 Deflashing

The bulge around the middle of the rolling balls is removed in a machining process. The balls are placed in rough grooves between two cast iron discs. One disc rotates while the other one is stationary; the friction removes the flash. From here, the balls are heat treated, ground, and lapped, which leaves the balls with a very smooth finish. Heated before being smashed, and that the original use for the process was to put the heads on nails (which is still how that is done). At any rate, the balls now look like the

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planet Saturn; with a ring around the middle called "flash." his first machining process removes this flash.

The ball bearings are put between the faces of two cast iron disks, where they ride in grooves. The inside of the grooves are rough, which tears the flash off of the balls. One wheel rotates, while the other one stays still. The stationary wheel has holes through it so that the balls can be fed into and taken out of the grooves. A special conveyor feeds balls into one hole; the balls rattle around the groove, and then come out the other hole. They are then fed back into the conveyor for many trips through the wheel grooves, until they have been cut down to being fairly round, almost to the proper size, and the flash is completely gone. Once again, the balls are left oversize so that they can be ground to their finished size after heat treatment. The amount of steel left for finishing is not much; only about 8/1000 of an inch (.02 centimetre), which is about as thick as two sheets of paper.

Table 11: Resource Table for Steel Ball Manufacturing

Operations				**Energy consumed**
Heading	**Deflashing**	**Heat treatment**	**Hard Grinding and Lapping**	
11.3 gm.	9.3 gm.	9.3 gm.	8.42 gm.	60 watt

4.4.3.3.3 Heat Treatment

The heat treatment process for the balls is similar to that used for the rings, since the kind of steel is the same, and it is best to have all the parts wear at about the same rate. Like the races, the balls become hard and tough after heat treating and tempering. Carbon steel balls are next carburized and hardened. Heat treatment imparts the desired hardness and case depth [57]. The heat treatment of balls is done in 110kwh electric furnace and the duration for heat treatment was about 50-55 minutes. The approximate numbers of balls treated in one time process is about 3000 to 4000. Therefore the amount of electricity comes out for per bearing ball is 0.036 Kwh. As we know that in per bearing assembly we have 10 numbers of steel balls are required, so the total electricity consumption for a single functional unit is 0.36 kWh.

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4.4.3.3.4 Hard Grinding and lapping

After heat treatment, the balls are put back into a machine that works the same way as the flash remover, except that the wheels are grinding wheels instead of cutting wheels. These wheels grind the balls down so that they are round and within a few ten thousandths of an inch of their finished size.

After this, the balls are moved to a lapping machine, which has cast iron wheels and uses the same abrasive lapping compound as is used on the races. Here, they will be lapped for 8-10 hours, depending on how precise a bearing they are being made for. Once again, the result is steel that is extremely smooth.

The Final weight of ball which were made after all this process is about 8.42 gm. Each complete assembly of ball bearing consist of one outer race, one inner race, 10 ball and one cages with around 4-6 small rivets and rivets holes. For the period of 6-8 hours the ball manufacturing unit produces about 15000-16000 of steel balls in a shift. During this process the amount of electricity consumption is about 90 units which is equivalent to 90 kWh. So the total electricity consumption for manufacturing 10 steel balls i.e. for one functional unit is 60 watt (approximately).

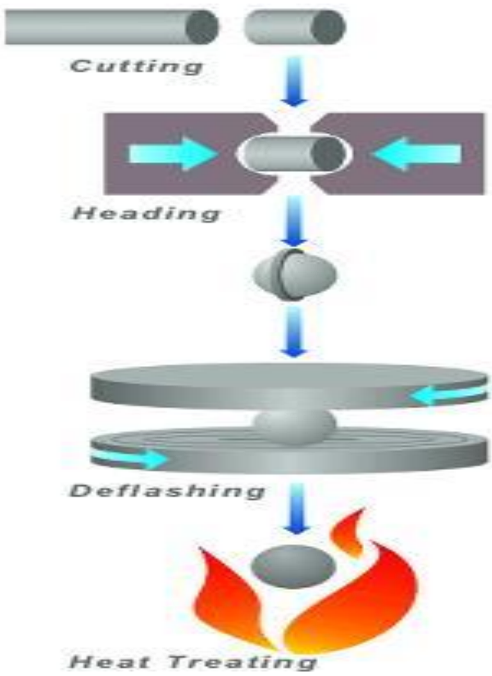

Figure 12 Flow chart for Ball Manufacturing

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4.4.3.4 Manufacturing of Cages

A cage for a roller bearing which is free of fretting and abnormal noise, which can be manufactured at low cost, and which can be easily mounted in the bearing. The cage is formed by bending a metal sheet having pockets into a ring shape, temporarily joining its ends, heat-treating the ring thus formed to remove stress, and separating the temporarily joined portion. Such a cage tends to rotate slower than the raceway members on the driving side of the bearing, making it possible to reduce fretting[58].

The ball bearing cage (also known as a ball bearing retainer or ball separator – these are used interchangeably), is the component in a ball bearing that separates the balls, maintains the balls symmetrical radial spacing, and in most cases, holds the bearings together. Cages can also be utilized in providing lubrication by acting as a reservoir for oils, or by supplying a solid film via the cage material itself or a coating on the cage. The designer's selection of the appropriate cage design for the application is essential in achieving the desired life and performance of the bearing.. They were generally made up of cold rolled close annealed sheets (C R C A). C R C A means that after hot rolling and pickling, the steel is cold rolled to a reduced thickness (which makes it brittle and not too useful), which is then followed by annealing in a closed atmosphere of nitrogen or other non-oxidizing gases (which softens it back up while protecting it from oxidation). However the study of cages is not included in LCA but a brief description on manufacturing is discussed.

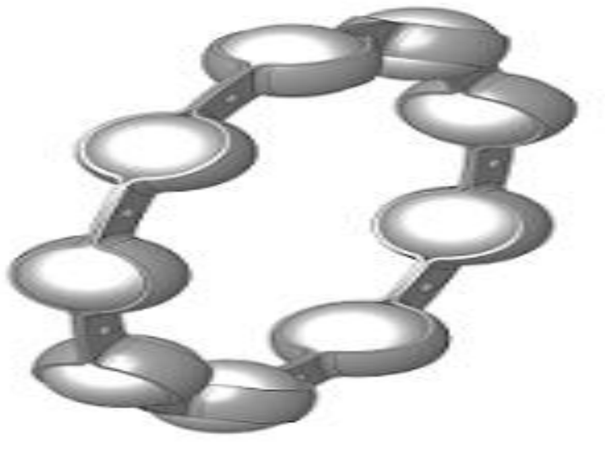

Figure 13: Cages for ball bearing

The cages for various bearings sizes are manufactured from Cold Rolled narrow width sheets IS 4397 cold rolled, cold annealed sheets, and The CR sheet is converted in the cage in Press machines in successive press operations: Blanking, Punching, forming (pocketing) rivet holes and visual inspection is carried for any deformity. Cages are manufactured from cold rolled steel strip. Presses with progressive or, alternatively, transfer tools are used to produce cages halves from the ship. The operational sequence consists of piercing and blanking, forming the ball pockets and piercing the rivet holes. After surface treatment and cleaning, the cage halves are coated with preservative and packed for transport to the assembly plant[59]. Flow chart for manufacturing of cages is given below.

Raw Material (C R C A sheets)

↓

Blanking and Punching

↓

Forming (Pocketing)

↓

Shot Blasting / Vibro machining

↓

Ready for Assembly

Figure 14: Flow Process chart for manufacturing of cages

4.4.3.5 Corrugated Box

Corrugated board is made with a corrugated sheet of paper attached to the facing of flat paper, usually Kraft by adhesives. In our country, it is mostly produced over a single facer machine here two paper reels are run together, one layer of paper becomes corrugated after passing through the heated rolls and the other is brought into contact with it after the former having glued at the tips. Thus both get pasted together and are wound in rolls. The resulting roll is now known as single face/ corrugated roll/board. By cutting this roll with board cutter and then gluing the corrugated side by a pasting machine and placing 3rd ply of paper over it double

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faced or 3-ply corrugated board is produced, this board is kept under pressure in a sheet pressing machines for some time for setting of the wet glued sheets.

A structural corrugated paper board for use in forming boxes which incorporates two fluted layers bonded peak to peak enclosed in two outer liners. By increasing board thickness and concentrating strength in the outer liners and eliminating the inner liner between the fluted layers improved edge compression and overall strength per unit weight is improved [60].

The corrugated box used in packaging of bearing, can carry 30 number of 6210 type of bearing. In order to include corrugated box in the LCA, it is only necessary to define its dimensions and weight. The dimensions of box are 400mm×200mm ×105 mm and which is having weight of 179.14 gm. approximately.

4.5 Results

4.5.1Air emissions

. The discussion below is based on the air emissions reported during the life cycle inventory

4.5.1.1 Emission of CH_4

Air emissions of methane (CH_4) contribute to global warming and photochemical oxidant creation. The component contributing most to the emission of methane to air is the Outer rings. Within process chain of the rings, the production of electricity causes the largest emissions of methane.

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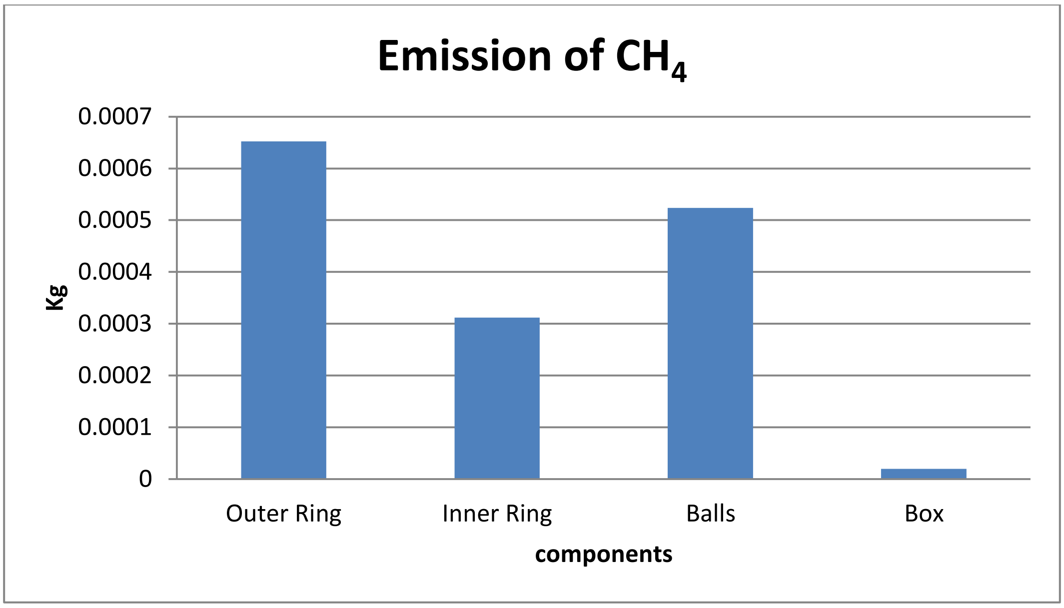

Figure 15: Emissions of CH_4 for each component

4.5.1.1 Emission of CO

Emissions of carbon monoxide (CO) to air will contribute to global warming, human toxicity and photochemical oxidant creation. The emission of carbon monoxide in this study originates mainly from the process of outer and inner rings and balls, in the process chain which furnace is used and the fuel which cannot burn properly will result in the formation of CO [61]. The heat treatment of the rings is also a considerable contributor to the emissions of carbon monoxide.

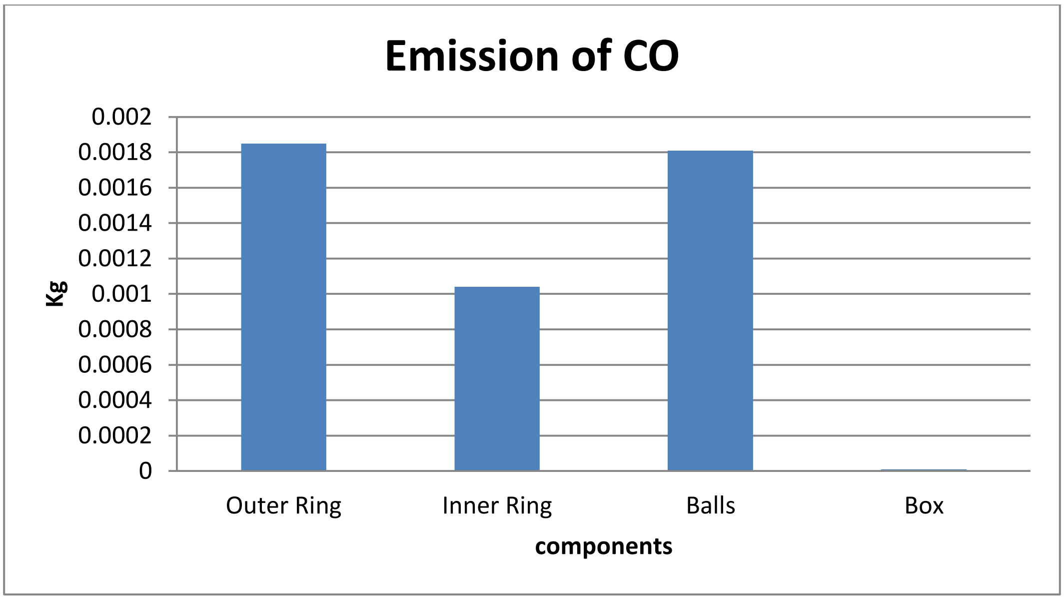

Figure 16: Emissions of CO for each component

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4.5.1.3 Emission of CO_2

Air emissions of carbon dioxide (CO2) contribute to global warming. The component responsible for emitting the largest amount of carbon dioxide is the rings, and the activity with the largest emissions is the electricity production, which in turn includes combustion of fossil fuel. The combustion of fossil fuels to generate electricity is the largest single source of CO_2 emissions. The production and consumption of metals products such as iron and steel also led to the emission of CO2 in the environment. CO_2 is inevitably created by burning fuels like e.g. oil, natural gas, diesel, organic-diesel, petrol, organic-petrol [62].

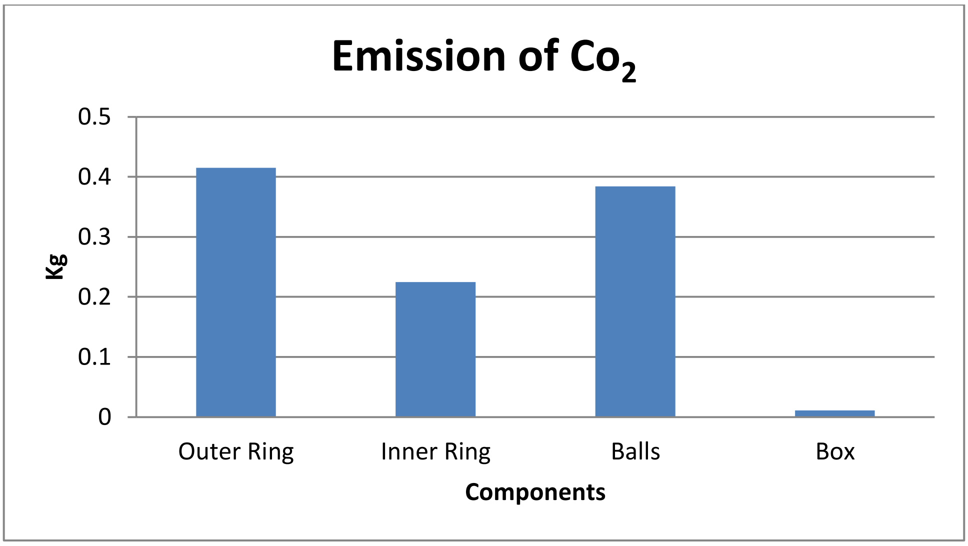

Figure 17: Emissions of CO2 for each component

4.5.1.4 Emission of NMVOC

Emissions of non-methane volatile organic compounds (NMVOC) to air contribute to the photochemical oxidant creation. The emissions originate, within this study, mostly from the production of energy resources. The component making the largest contribution is the rings, and the main source is the production of liquefied petroleum gas (LPG). The LPG is used in the activities for Heat treatment of Inner and Outer rings as well as of Steel balls, as a fuel in the furnaces used to heat the material is the main cause for the emission of NMVOC.

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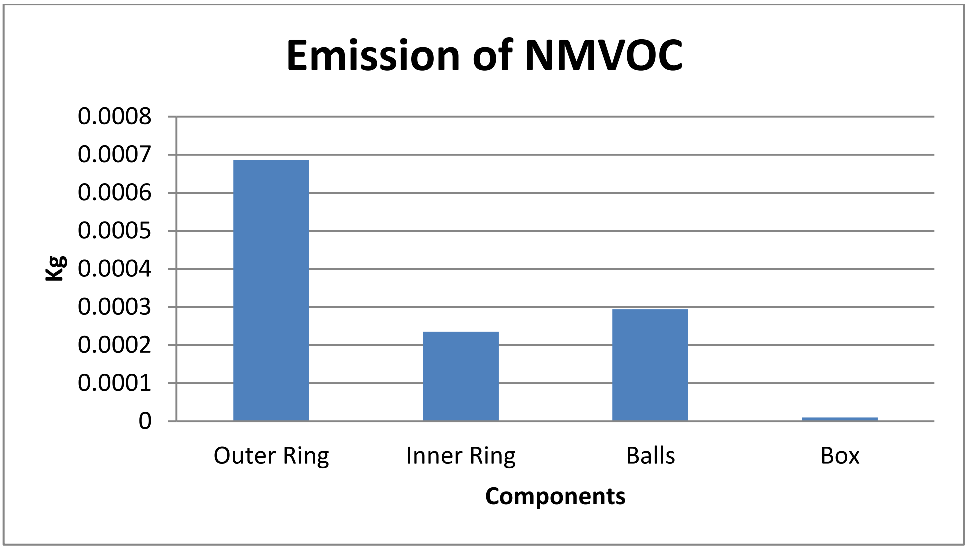

Figure 18: Emissions of NMVOC for each componen

4.5.1.5 Emission of NOx

The emissions of NOx to air contribute to acidification, eutrophication, global warming and human toxicity. Incomplete combustion of fuel at higher temperature will result in formation of NOx.Within this study the emissions originate mostly from the production of electricity, which in turn includes combustion of fossil fuel. The inner and outer rings are the components responsible for the highest emissions.

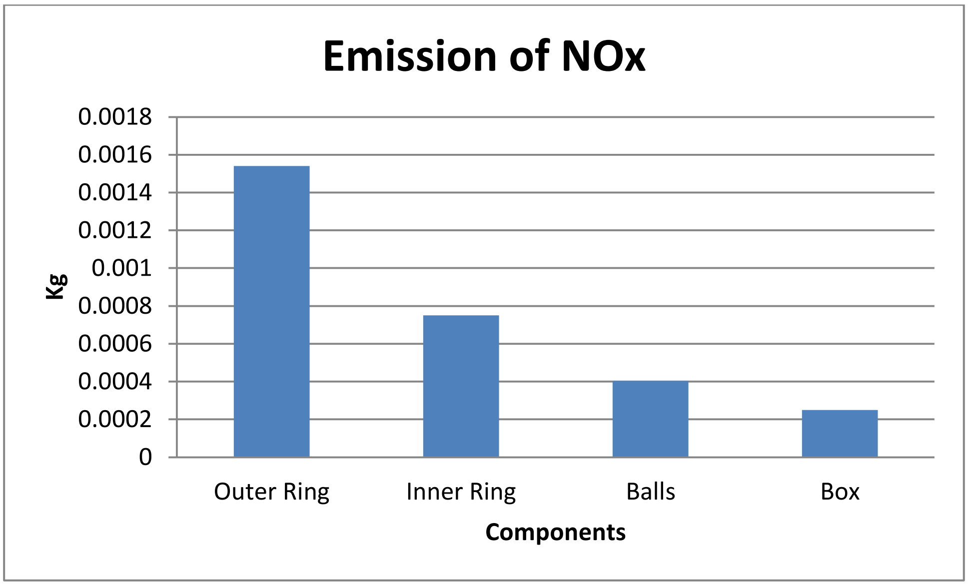

Figure 19: Emissions of NOX for each component

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4.5.1.6 Emission of Particulates

"Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles [63]. The use of LPG gas for the heat treatment of rings and steel balls results in emission of Particulate matter. Within the production chain of the rings quite large amounts of heat is used thereby making the rings the component responsible for the largest emissions of particulates.

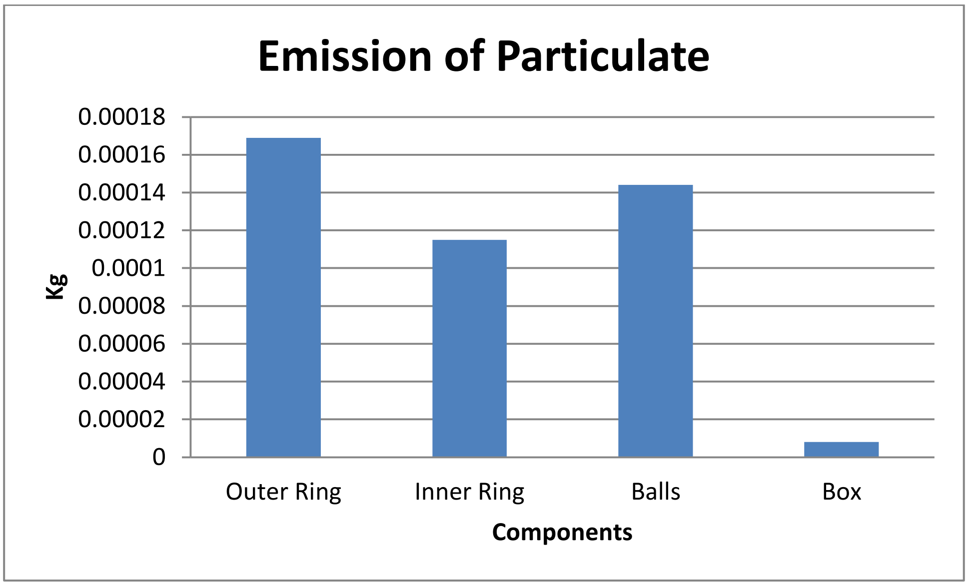

Figure 20: Emissions of Particulate for each component

4.5.1.7 Emission of SO2

Air emissions of sulphur dioxide contribute to acidification and human toxicity and again the rings are responsible for the largest emissions. This is caused by the production of liquefied petroleum gas (LPG). The main source of sulphur dioxide in the air is industrial activity that processes materials that contain sulphur, e.g. the generation of electricity from coal, oil or gas that contains sulphur[62].

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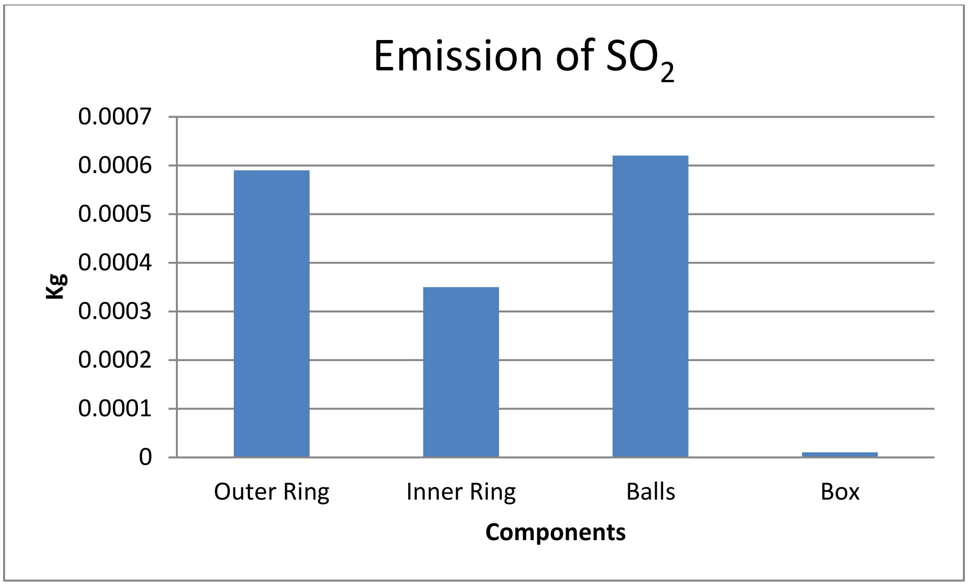

Figure 21: Emissions of SO_2 for each component

Table 12: Environmental category affected

S.No.	Emissions	Environmental category affected
1	Methane (CH_4)	Global Warming, Photochemical Oxidant
2	Carbon Monoxide (CO)	Global Warming, Human Toxicity, Photochemical Oxidant
3	Carbon Dioxide (CO_2)	Global Warming
4	Non-methane Volatile Organic Compounds (NMVOC)	Photochemical Oxidant
5	Nitric Oxide and Nitrogen Dioxide (NO_X)	Acidification, Eutrophication, Global Warming
6	Particulate	Human Toxicity, Eutrophication
7	Sulphur Dioxide	Acidification, Human Toxicity

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4.6 Result Analysis

The results obtained from NBC data by sima pro Eco invent 3.2 databases were then compared by SKF bearing of the same size. The only difference in SKF and the NBC bearing is that NBC's is Ball bearing while the SKF's was spherical roller bearing. So the comparison was made in between the emission made by only the rings which were of approximately same size. Emission in six different categories was compared another major difference between both bearings is that NBC was manufactured in India while the SKF was in Sweden. Since the manufacturing process of outer ring and inner ring is almost same, the only difference is about the energy consumption at different stages of manufacturing. So it's become quite easy that which bearing is more suitable from environment point of view. The following comparison is shown through graphs between both the manufacturing units.

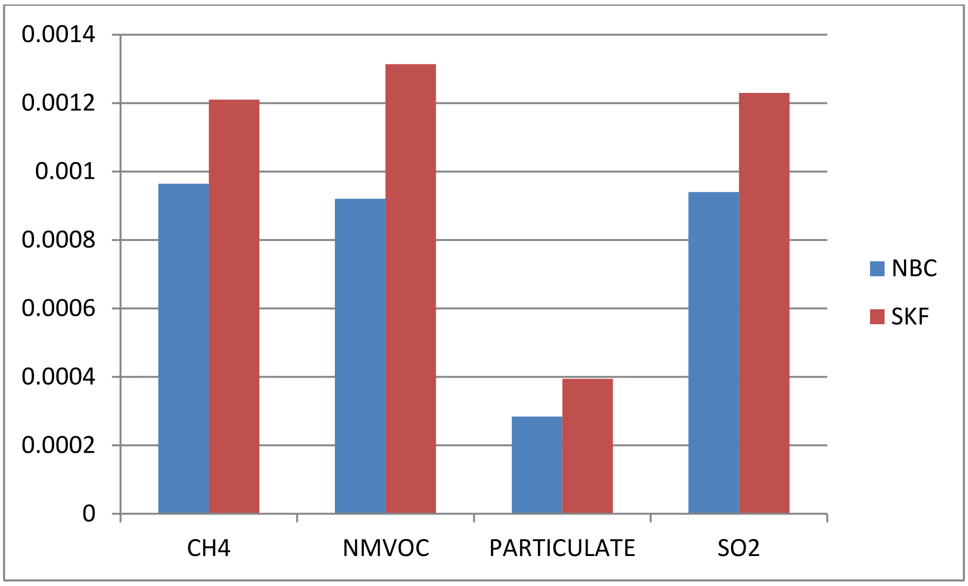

Figure 22: Comparison of Emission in NBC and SKF

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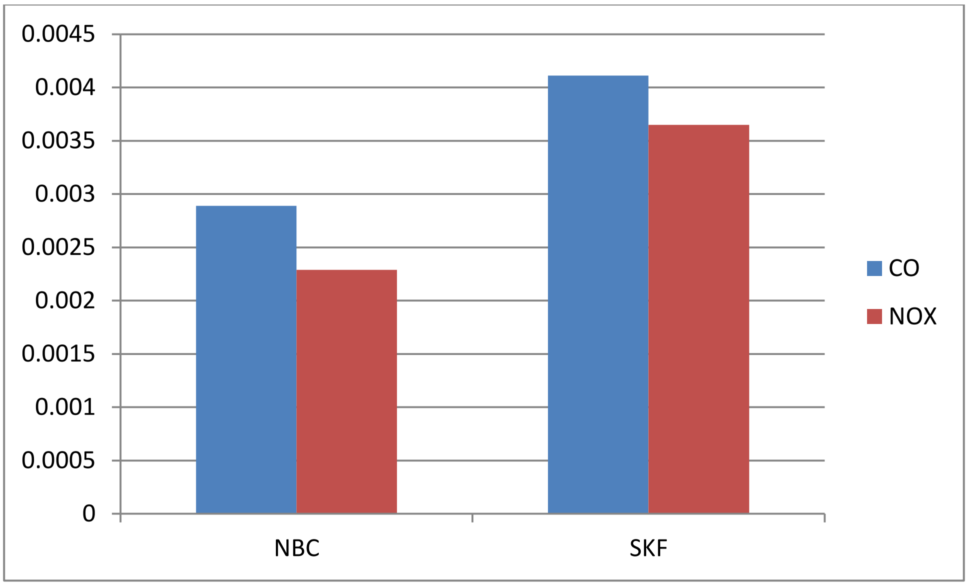

Figure 23: Comparison of Emission in NBC and SKF in CO and NOX

Since from the above result it is clearly visible that emission made by SKF bearing is almost high in every category as compared to NBC. The major factor for increased emission in SKF is due to because that the study performed in SKF is from Cradle to Gate while Study in NBC is from Gate to Gate. This led to significant difference in every category [64].

The cradle to gate study might contain some additional manufacturing process which was not included in gate to gate study. Therefore the energy consumptions and the wastage produced during those processes create the emission difference in both the studies. The best way to make these graphs more reliable is to perform a cradle to cradle study in NBC also and then compare the various environmental impacts.

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Chapter 5

5.1Conclusions

The most important conclusions from an environmental point of view, taken into account all assumptions and limitations made during performance of the LCA, are listed below. We have to stress that this LCIA addresses only those environmental issues that are identified in the goal and scope.

LCA methodologies are very useful to evaluate environmental impacts and food safety of a product or production system. This study revealed that environmental load of a product can be reduced by alternate production, processing, packaging, distribution and consumption patterns. As from the result's obtained it can be seen that a large amount of environmental impacts were made by various parts of bearings, in which the outer rings made the most adverse effects on numerous categories like eutrophication global warming etc. as from the seven environmental categories chosen it is not easy to say which categories has severe effect and which were least effected. As it is clearly visible from the size and weight of outer rings, it is the biggest contributor in making environmental impacts followed by steel balls, inner rings and finally by the corrugated box. The major contribution in effecting these categories were made by the use of electricity in performing various machining operations. The production of electricity itself causes various impacts which includes emission of carbon di oxide, carbon monoxide, methane and oxides of nitrogen

The second most factor which is responsible for impacts is use of liquefied petroleum gas (LPG) for the heat treatment of the bearings components at various stages. Use of LPG causes huge amount of emission of sulphur dioxide, particulate in atmosphere and non-methane volatile organic compounds. The third important factor is wasted produced during the manufacturing of bearing. Every machining process used in this whole study has some wastage at the output which overall lead to the resource depletion of the material used in manufacturing of bearings.

The use of energy has often been employed as an indicator of environmental impact. In the above study the primary energy is electricity while the secondary energy resource is LPG which is second mostly used energy resource. The database used for the calculation of various impacts is Eco invent 3.2 database which is based on

German country standards which may result in slight deviation of emission values as compared to Indian context. The above result may help the company to find out the hot spots or the areas which had severe effect which in turn help in development of finding alternatives to current manufacturing processes and the material used, to reduce the environmental loads and making their product more sustainable.

Many decisions made to improve the environmental performance of products will have positive and negative aspects. It is only with the use of LCA that these can be properly evaluated and the best potential outcome reached. The same holds true for government policies aimed at reducing impacts to the environment. LCA is therefore a powerful and highly valuable tool to all those involved with environmental policymaking and ecodesign. The reality of LCA is that it can be technically challenging, time consuming and costly. These factors can make completing an LCA difficult. Never the less, the information gained from LCA has many applications that will more often than not result in benefits, even for a small business. Effort needs to be made to promote the use of LCA amongst potential users in both public and private sectors. Smaller businesses should make use of tools designed to simplify the LCA process such as those being developed by the 'LCA to go' project. Without the widespread adoption of LCA it will be difficult to fully address environmental issues and successfully implement ecodesign strategies in businesses.

5.2 Future Scope

As this study was performed on single row deep groove ball bearing which is made by steel, this can be helpful in further comparing of another bearing which is of same size or which serve same purpose and made by some other material or by different manufacturing process. The LCA of two different bearing will be helpful in finding out that which product is more environmental friendly and sustainable.

The current study was performed on Gate to Gate basis; it can be performed in a better way by considering the recycling as the option and performing it by Cradle to Cradle basis where the end-of-life disposal step for the product is a recycling process. Or it can be performed cradle to grave i.e. from resource extraction to disposal.

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Chapter 6

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