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TECHNOLOGY ANALYSIS OF PLASTIC RECYCLING INDUSTRIES & THEIR PERFORMANCE ENHANCEMENT: A CASE STUDY OF KATHMANDU VALLEY

BY:

RIMA PANTHI (075MSESP015)

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN ENERGY SYSTEM PLANNING AND MANAGEMENT

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "TECHNOLOGY ANALYSIS OF PLASTIC RECYCLING INDUSTRIES & THEIR PERFORMANCE ENHANCEMENT: A CASE STUDY OF KATHMANDU VALLEY" submitted by Mrs. Rima Panthi (075MSESP015) in partial fulfillment of the requirements for the degree of Master of Science in ENERGY SYSTEM PLANNING AND MANAGEMENT.

____
Supervisor, Dr. Tri Ratna Bajracharya
Professor
Department of Mechanical and Aerospace Engineering
IOE, Pulchowk Campus

____
External Examiner, Er. Sanjiv Paudel
Mechanical Engineer
Managing Director
Machine Hub Nepal Pvt. Ltd.

____
M.Sc. Coordinator, Dr. Nawraj Bhattrai
Associate Professor
Department of Mechanical and Aerospace Engineering
IOE, Pulchowk Campus

____
HOD, Dr. Sudip Bhattrai
Assistant Professor
Department of Mechanical and Aerospace Engineering
IOE, Pulchowk Campus

Date:

ABSTRACT

This thesis presents the comprehensive study of the current plastic recycling technologies employed in the industries of Kathmandu valley. The research identified a technological gap that required improvement. To fulfill this gap machines that are being used in plastic recycling industries, with a focus on HDPE, were redesigned as per engineering calculations and then fabricated. Numerical verification of redesigned machines revealed subsequent improvement. It showed that for granulator machine by using the suitable bearing type, the dynamic and static load bearing capacity was increased by 2.13 times and 2.64 times respectively compared to the existing design. Similarly, for dryer machine, using double support instead of single increased critical loading by 1.48 times and combined loading decreased by 1.63 times. Likewise, the mixture machine also achieved significant enhancement, with critical loading increased by 2.53 times and combined loading decreased by 2.95 times. Those newly fabricated machines were then operated on a factory in normal conditions. Detail comparison of the performance of updated machines were then made with the existing ones. Due to the design changes, the production capacity of factory was increased while decreasing the maintenance cost. The machines were locally manufactured, resulting in the lowest manufacturing cost compared to other factories. In addition, the maintenance cost incurred throughout the year on upgraded machines was compared with the existing ones which showed the minimum value on the former case. Furthermore, financial analysis was done to check the feasibility of the factory. For this, Benefit Cost Ratio, Internal Rate of Return (IRR) and Payback period is calculated. In the first one NPV of cost and benefit was duly calculated with reference to the data of miscellaneous costs incurred in the industry. From the result obtained benefit cost ratio is 1.11 which is clearly greater than 1, which confidently shows that the project is feasible. Also, the IRR is obtained to be 18% with a payback period of four years.

ACKNOWLEDGEMENT

Preparing this case report on Technology analysis of plastic recycling industries and energy conservation opportunities in Nepal wouldn't be possible without the support and contributions of several individuals and organizations.

I express my sincere gratitude to *G.R.I.T PLASTICS* for providing valuable data and information about the plastic recycling industry. I would also like to thank my supervisor Mr. Tri Ratna Bajracharya Sir for his priceless guidance and help throughout the research process.

I also extend my thanks to my colleagues and peers who provided helpful insights and feedback on the report. My appreciation goes to all those who have directly or indirectly contributed to the completion of this report. I would also like to acknowledge the support of my family and friends, who have motivated and supported me throughout the preparation of this report.

To conclude, I am grateful for the opportunity to research this critical topic and contribute to the persistent efforts to improve the plastic recycling industry in Nepal.

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LIST OF ABBREVIATIONS

PET = Polyethylene Terephthalate

HDPE = High Density Polyethylene

LDPE = Low Density Polyethylene

NPV= Net Present Value

IRR= Internal Rate of Return

CHAPTER ONE

INTRODUCTION

1.1 Background

Plastic is a versatile and durable material used in various products, from packaging and consumer goods to construction materials and medical devices. Plastics are typically made in industries. Most modern plastics are extracted from fossil fuel-based chemicals; however current industrial practices use variants made from renewable materials such as corn or cotton. (American Chemistry, 2023) Plastic is regularly used in our everyday activities. It has its usage from the early milk packed in a plastic bag and ends with the storage of food wrapped in plastic to store in our fridge for the next day.

Plastic was first fully synthesized as Bakelite in the year 1907 (Landmarks., 2023), and became widely produced and used in the mid-20th century. The development of new technologies and processes made it possible to produce plastic in large quantities at a low cost, making it an attractive material for manufacturers. There are seven types of plastic generally used throughout the world. They are Polyethylene Terephthalate (PETE), High-density Polyethylene (HDPE), Polyvinyl Chloride (PVC-U), Low-Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene or Styrofoam (PS) and some others. Among these, PETE and HDPE are widely recycled. LDPE is mainly reused, but we can recycle them if they are more than 50 microns. They are neither decomposed nor can be burnt easily.

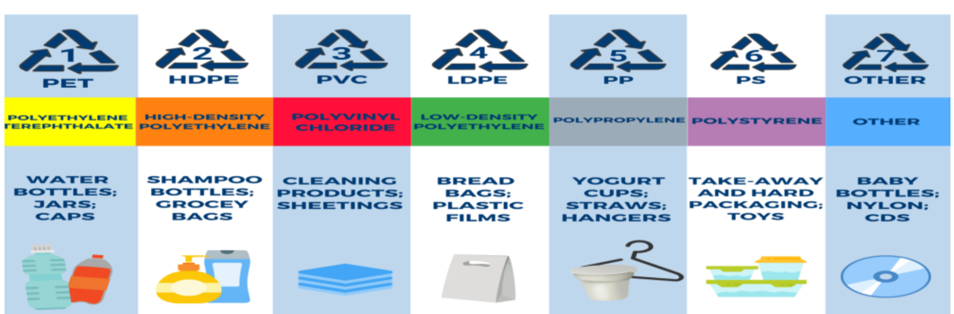

Figure 1 Types of plastics

Plastic waste has been a biggest issue in today's world. They are found to pollute the tallest mountain in the world to the deepest ocean found. They can destroy ecosystem, affect human health and also life of animals and marine species. This problem has soared up in the recent decades. Global plastic production has doubled and reached 400 metric tons per year in 2021. Plastic products may have the life of five to seven years but the plastic may take up to 500 years for decomposition.

1.1.1 Plastic Recycling

Plastic recycling refers to retrieving plastic waste and turning it into new derivatives. Plastic recycling helps to preserve natural resources, reduce energy consumption, and decrease the amount of plastic waste in the environment. We can do plastic recycling through a variety of methods, including mechanical recycling, chemical recycling, and energy recovery.

Chemical recycling is a process where plastic waste is broken down into chemical building blocks, which can then be used to create new plastic products. This method is still in development and has yet to be widely used. Finally, energy recovery is used to burn plastic waste to generate electricity or heat. This method is under question because it can release pollutants into the air, and the energy produced is less efficient than other forms of energy. Mechanical recycling is the most common form of plastic recycling. It involves grinding plastic waste into small pellets or flakes, which can then be used to make new products. Industries can use this process to recycle a wide variety of plastic materials, including polyethylene, polypropylene, and polystyrene.

Recycling plastics is not only an environmental issue but also an entrepreneurial one. There are several benefits to recycling plastics. Some are:

1. Conservation of resources: Recycling plastic reduces the need for virgin materials, such as petroleum, which is used in the production of plastic. By recycling, we can conserve natural resources and reduce the energy required for manufacturing new plastic products.

2. Waste reduction: Plastic waste often ends up in landfills or pollutes the environment, causing harm to wildlife and ecosystems. Recycling helps divert plastic waste from these disposal sites, reducing the amount of plastic pollution.

3. Energy savings: The recycling process generally consumes less energy compared to the production of new plastic from raw materials. Recycling plastic can contribute to energy savings and reduce greenhouse gas emissions associated with plastic production.

4. Economic opportunities: Plastic recycling can create job opportunities in the waste management and recycling industry. It can also stimulate the development of new businesses and industries centered on recycling and reusing plastic materials.

Similarly, in Nepal, plastic recycling is widely practiced these days. Plastic recycling is helpful for our environment, but it may or may not be economically feasible. As plastic is produced as a byproduct during the extraction and refining of petroleum products, in some scenarios, it is financially better to use new plastic rather than recycle it. Hence, we need to find out more efficient recycling methods which can be implemented in recycling plants which will also boost the economic beneficiary factors.

1.2 Problem Statement

Plastic is commonly used in our regular lifestyle. Tons of plastics are produced and thrown as garbage every day. Plastics are not organically decomposable to nature. Hence, they pollute the environment. Plastic waste pollution has been a worldwide crisis that draws vast attention everywhere. Plastic recycling is an option that minimizes this worldwide crisis. Plastic recycling has a wide array of machines used for the process that has varying ranges of capacities. Developed nations are found to have fully automated recycling industries, where significant advancements have been made to refine these machines. In contrast, Nepal primarily relies on small scale recycling machines which are imported from neighboring countries such as India and China. However, these imported machines face different issues that has a scope of further research and enhancement. As the machines are used continuously, frequent break down on the machineries have been a common issue.

And in most of the scenarios it is difficult to invite the technician which results on ending those machines life on scrap value. To address this problem, we plan on improvising and fabricating the machine in our own yard with higher quality to reduce breakdown time and increase production capability and efficiency of the machines.

1.3 Objectives

1.3.1 Main Objective

- To upgrade technologies used in present recycling factories in Kathmandu Valley.

1.3.2 Specific Objectives

- To design machineries used in plastic recycling industries that can be manufactured locally
- To fabricate the plastic recycling machineries
- To check the performance of individual machineries
- To provide modifications ideas on these machineries.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of plastic waste in the world

According to the data in 2022 from UNEP (United Nations Environment Program), almost 400 million tons of plastic are generated yearly. The World Economic Forum predicts that this will double again in 20 years and quadruple by 2050. (UNEP, 2022) Among these, 36 percent are used in packaging, including single-use plastic products for food and beverage containers. If global trends on plastic demand continue, it is estimated that by 2050 annual global plastic production will reach over 1,100 million tons. (UNEP, 2021) Eighty-five percent of plastic waste reaches landfills and needs to be processed. Only 10 percent of plastic produced to date is recycled. We can imagine the pollution this plastic waste has caused to the environment. Most single-use plastic waste is produced as a byproduct while extracting fossil fuel. Limited use of fossil fuels indirectly controls plastic production and plastic wastage. According to ICIMOD, 2.7 tons of daily plastic garbage is produced in Nepal. (ICIMOD, 2018) Among them, only a certain percentage is recycled, and others are landfilled or incinerated.

Plastic waste is particularly harmful when it accumulates in aquatic environments. Plastic debris can block drains in towns and cities creating breeding grounds for harmful waterborne diseases. Aquatic wildlife can consume plastic materials, causing suffocation and particles to build up in their digestive systems, along with plastic molecules in their muscles. Once plastic enters the food chain it can create significant hazards to human and ecological health. The World Economic Forum reported that the best research currently estimates that enter over 150 million tons of plastic waste in the oceans today with at least 8 million tons of plastic leaking into the ocean annually.

2.2 Types of plastic recycling methods and effectiveness

There are many plastic recycling methods used worldwide. The most widely researched is the mechanical recycling. Every waste management system should be properly inspected when designing mechanical recycling process. We must have better control over material life cycle of the plastics and importance must be given to solutions that can maintain value of products over repeated uses. This will lead to improved recycling rates and increase recycled plastic products (Zoé O. G. Schyns, 2020).

Another important method is the chemical recycling of plastics. Chemical recycling helps in overcoming the obvious limitations of mechanical recycling. It helps in enabling production of high value industrial products and reducing the dependency on fossil fuels. One important advantage of chemical recycling is that the contribution of chemical recycling on climate change and fossil fuel shortage are shown to be relatively unconcerned with the energy mix (Voss, 2022).

Biological recycling has emerged as a new player in plastic recycling in recent years. The research and investment in this process is still in its infancy. To overcome challenges, the biopolymer production costs must be reduced and the mechanical ability of biopolymer must be improved. (Lamberti, 2020) Better waste collection and sorting routes also must be established.

2.2.1 Mechanical plastic recycling

In order to recycle plastic, a number of steps must be taken, including gathering, sorting, and processing the plastic so that it can be used in new products (British Plastics Federation, 2023):

- Collection: Users put plastic waste into a recycling bin for collection.
- Sorting: Facilities for sorting separate plastic from other materials and into various types of plastic.
- Reprocessing: Plastic is cleaned, powdered into flakes, heated, and extruded into fresh pellets during reprocessing.

Now this process is further explained in detail:

- Collection: The first stage of plastic recycling starts from collection of plastics from various places. The materials could be collected under local government or by a private waste management contractor. There are various collection opportunities such as homes, schools, market, hotels, stores, etc.

- Sorting: The stage followed by collection is sorting the retrieved material. First the collection undergoes plastic retrieval since the material collected may have non-plastic wastes too. The most prevalent way of sorting plastics is manual picking. Manual labor is used to segregate recyclable plastic as it is simple to do and more efficient. However, there are other ways for sorting such as Segregating using trommel drums, OCC screening, ballistic separator, magnetic separator and much more depending upon the budget.
- Washing: It is important to decontaminate the plastic as it is going to be recycled. It is also done to remove adhesives. It also helps remove food materials, rot and other bio-degradable contaminants. There are various methods of washing plastic such as friction washer, pressure washing but even more common is simple detergent washing. The plastics are filled in a tank with rotating drum with water and detergent mixed. The drum is rotated and the content is cleaned and then dried.

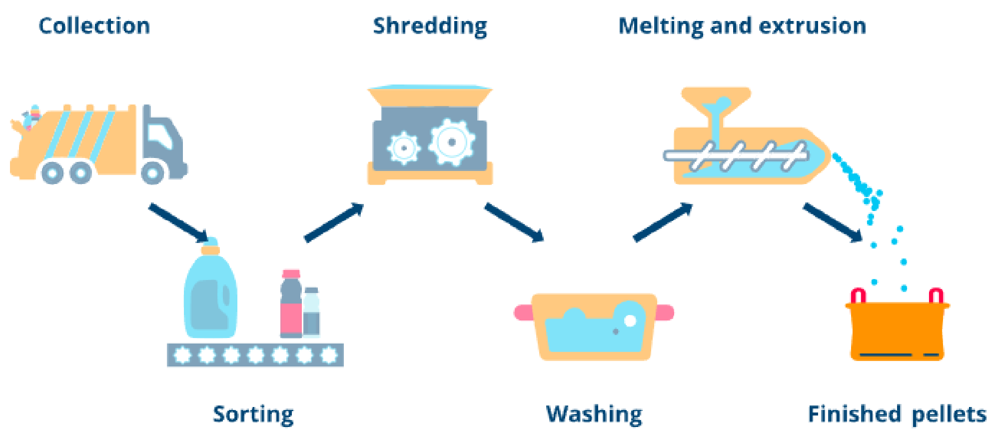

Figure 2 Mechanical Plastic Recycling Process

- Shredding/Grinding: One of the major steps in plastic recycling is shredding and grinding. While it may seem unimportant at first but to be able to recycle plastics, they need to be reduced in size. This is important in later stage of extrusion. Shredders using double blade granulators, single blade granulators or other machines are used. Blades are attached to a rotating shaft that cuts the plastic pieces as it rotates and pulverizes.

The size of plastic bits can be determined by the gap between rotating blades and stationary blade as well as the speed of rotation.

- Extrusion: This process finally prepares plastic pellets fully to be recycled. It is a complete process of melting down plastic and forcing it through an extruder. This is the final and the most important part of mechanical plastic recycling as at the end of it, plastic pellets is received. At first, plastic bits are fed from an inlet leading it to a screw-barrel setup. The barrel is surrounded with thermal jackets which provide heat and are maintained at the desirable temperature. Plastic passes through the barrel with the help of a rotating screw which pressurizes the plastic and further heats it melting in the course. The plastic is finally let out from the outlet and desired diameter is fixed using holes of that particular diameter at the outlet. Wire of plastic from extruder is further passed through cool bath and then cut to get desired size of plastic pellets which completes plastic recycling. This pellet can be used for making further plastic products which are not food grade.

2.2.2 Chemical plastic recycling

Chemical recycling is a cutting-edge method of recycling plastic waste that offers a myriad of brand-new opportunities.

Plastic garbage is broken down into its component molecular bits through chemical recycling. When plastic is broken down in this way, the chemistry of its polymers is directly impacted, allowing for their reconstitution back to their original basic components, where they can then be used to make new polymers or petrochemical feedstock.

Chemical recycling is more complex compared to mechanical recycling. There are 3 major types of chemical recycling (Pryme, 2023).

- Dissolution: It involves in treatment of plastic waste in a solvent that removes additives. The plastic dissolves turning into its polymer stage. This opens up big application window as the obtained polymer exist in molecular state and can be used in any kind of plastic application from ground up.

- De-polymerization: This process further breaks down the polymers into monomers which are fed in plastic production.
- Conversion: It uses chemicals, heat and catalytic process in a reactor to turn the plastic in gaseous or liquid, oil like feedstock (Pyrolysis) like refined hydrocarbon compounds.

The steps in chemical processing can vary due to differences in technologies used but in general, following are the steps involved:

1. Feedstock preparation: Plastic waste is collected and sorted to remove contaminants such as dirt, labels, and non-plastic materials. The waste is typically shredded or granulated to increase its surface area and facilitate subsequent processing.

2. De-polymerization: De-polymerization is the process of breaking down the polymer chains in plastic waste into smaller molecules or monomers. Different methods can be used for de-polymerization, including thermal, catalytic, or solvent-based processes. These processes may involve heating the plastic waste to high temperatures, adding catalysts or solvents to facilitate the breakdown, or using other chemical reactions to break the polymer bonds.

3. Purification: After de-polymerization, the resulting mixture contains the desired monomers along with other byproducts, impurities, or unreacted materials. Purification techniques such as distillation, extraction, filtration, or chemical treatments are employed to separate and remove these impurities, isolating the target monomers.

4. Monomer recovery: Once the mixture is purified, the target monomers are recovered. This can involve further separation and purification steps specific to the monomers of interest. The recovered monomers are typically in liquid form and can be used as raw materials for the production of new plastics or other chemical products.

5. Polymerization or chemical conversion: Depending on the intended application, the recovered monomers can undergo polymerization to produce new plastics with properties similar to virgin plastics. Alternatively, the monomers can be further chemically converted

into different chemical compounds or used as feedstock for the production of various chemicals, fuels, or other materials.

6. Product formulation or refining: The final step involves using the recovered polymers or chemical products to formulate new plastic products, fuels, or other materials. This may involve compounding, blending, or further processing to achieve the desired properties and specifications.

It's important to note that the specific processes and technologies used in chemical recycling can vary widely, and ongoing research and development are exploring different approaches and techniques. The aim is to develop efficient, scalable, and economically viable chemical recycling methods that can effectively address plastic waste management challenges while minimizing environmental impacts.

2.2.3 Energy recovery:

Energy recovery in plastic recycling refers to the process of converting non-recyclable or difficult-to-recycle plastic waste into useful energy sources. This is only considered a very sensible way of waste treatment, when material recovery processes fail due to economical constrains (S.M. Al-Salem, 2009).

There are two main methods of energy recovery in plastic recycling:

1. Waste-to-Energy (WtE) or Waste-to-Fuel: In this method, non-recyclable plastic waste is thermally treated in specialized facilities such as incinerators or gasification plants. The heat generated during the combustion process is used to produce steam, which then drives turbines to generate electricity. This electricity can be used to power homes, businesses, or industries. In some cases, the process can also produce a synthetic gas (syngas) that can be further processed into liquid fuels like ethanol or biodiesel.

Process involved in waste-to-energy method are:

The initial step involves the gathering and meticulous categorization of plastic waste sourced from a variety of origins, including households, industries, and commercial establishments. During this phase, meticulous separation eliminates non-plastic elements and segregates distinct plastic types. Subsequently, the arranged plastic waste is subjected to shredding or granulation, breaking it down into smaller fragments to augment its surface area and facilitate efficient burning or conversion.

Following preparation, the treated plastic waste enters either an incinerator or a gasification chamber. Within the incinerator, plastic is incinerated at elevated temperatures with the presence of oxygen, guaranteeing complete combustion. Conversely, in the gasification process, plastic is heated in an oxygen-deprived environment, transforming it into synthetic gas (syngas). Harnessing the energy released from combustion or gasification, steam generation is initiated, propelling turbines to produce electricity. This electricity can be incorporated into the power grid to fulfill energy requirements. To mitigate environmental consequences, modern waste-to-energy facilities integrate advanced emission control technologies such as scrubbers and filters to capture and treat potentially harmful pollutants emitted during the combustion process.

Pyrolysis: Pyrolysis is a thermal decomposition process that converts plastic waste into liquid fuels, gases, and char in the absence of oxygen. The plastic waste is heated to high temperatures, causing it to break down into its constituent components. The resulting products can be used as fuels or chemical feed stocks.

In the initial step, plastic waste is prepared by sorting out contaminants and shredding the plastic into smaller pieces to enhance its surface area for pyrolysis.

Next, the shredded plastic enters a pyrolysis reactor, where it breaks down into gases, liquids, and solid residues due to controlled heat and the absence of oxygen. These components can be refined into valuable products like fuels, solid char, and even electricity generation. The gases and vapors are condensed into liquid fuels, which can be further purified for specific needs.

Graphs showing relationship between climate change and plastic recycling method and ozone formation and plastic recycling method is shown (Jeswani, 2021).

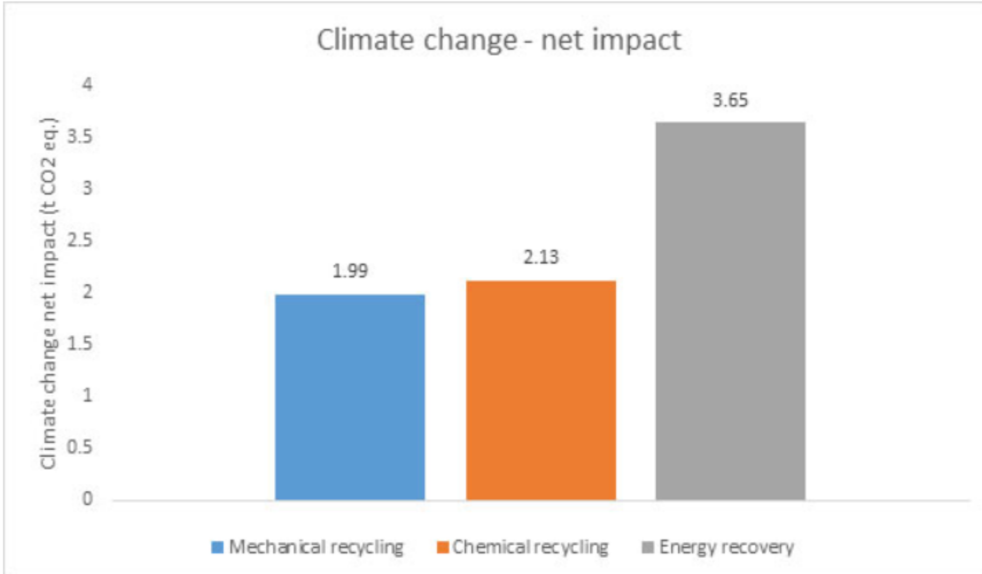

Figure 3 Climate change impact of various plastic recycling methods

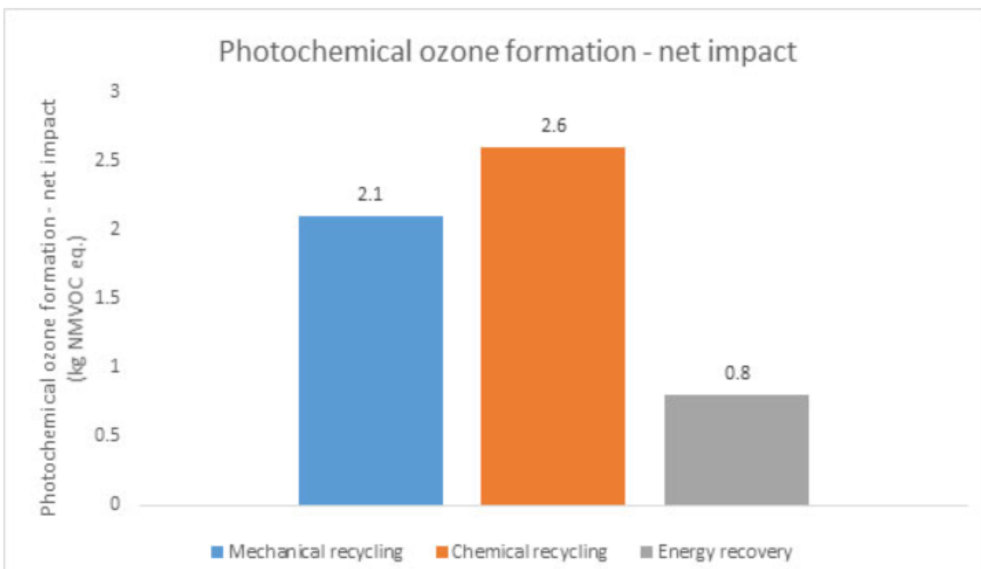

Figure 4 Photo chemical ozone formation impact of varoius plastic recycling methods

From the above graphs it is evident that mechanical plastic recycling has the least the net tons impact of CO_2 on climate change, and second least contributor in net photochemical ozone formation impact. So, it makes mechanical plastic recycling a cleaner method of recycling plastics.

2.3 Plastic Waste Management Efforts in Nepal:

There is no definitive law specifically for plastic waste management but there is a criterion for solid waste management. The Solid Waste Management Act, 2068 of Nepal has made the local governments responsible for the operation and management of infrastructure for collection, treatment and final disposal of the Municipal Solid Waste (MSW). (CBS, 2020) The national policy on solid waste management provides broader framework for the government including local government to manage the solid waste at local level. The main objectives of the policy are:

- To make solid waste management simple and effective
- To minimize environmental pollution caused by the solid wastes and adverse effect and thereof to the public health
- To mobilize the solid wastes as resources
- To privatize the solid waste management
- To obtain public support by increasing public awareness in sanitation works.

The three main methods of waste management adopted by all the municipalities were: i) piling up in landfill site by 48.6% municipalities, ii) burning by 32.1% municipalities, and iii) piling up in the river side by 27.4% municipalities. Among the total municipalities surveyed, 114 (42.0%) municipalities were using the landfilling practices.

Several organizations are working in recycling plastic in an attempt to reduce and clean up the waste while also creating jobs. Creasion, a local company, was founded in 2005 and is working in Chitwan and Kathmandu to recycle PET bottles through segregation and baling before repurposing them. (Nepal Times, 2023) Up to seven plastic types can be found in dumping sites, and the lowest grade plastics reduce the lifespan of the landfill. Of these, PET (polyethylene terephthalate) bottles are the easiest and most recyclable. But Nepal does not have extended producer responsibility to recycle the plastic the factories manufacture. The Recycler Sathi program was started in 2019 and is supported by the Coca-Cola Foundation. Creasion already recycles up to 300 metric tons of PET every month and plans now to move on to other plastic types such as PP (Polypropylene), PVC (Polyvinyl chloride) and MLP (Multi-Layered Plastic).

One of the other areas that has been explored recently in Nepal is on the possibility of plastic roads. In Nepal, Green Road Waste Management Private Limited, a small local organization, has constructed over 100 meters long plastic roads as prototypes for two municipalities. Though these roads are cost-effective and durable, the scaling up is still a challenge due to the lack of proper policies and guidelines at the national and local level. (UNDP, 2023) A new machine named Reverse Vending Machine (RVM) is being used which is a fairly new concept in Nepal.

2.4 Challenges in Plastic Waste Management in Nepal:

Plastic recycling, however righteous and good it may sound, has its own set of challenges. Especially in the case of Nepal where the infrastructures, policies and awareness about plastic recycling is still decades behind, it can be challenging to pursue this venture. Solid waste management in Kathmandu valley of Nepal, especially concerning the siting of landfills, has been a challenge for over a decade (D. Pokhrel, 2005). There are lots of challenges but a few are:

- Contamination: As mentioned earlier, plastic recycling is a very new concept in Nepal. And that is why people are still not used to the whole process. Most of the collectors usually end up collecting mixed or contaminated plastics which produce low grade plastics because the consumers couldn't separate them properly. This will need getting used to, to solve this problem.
- Lack of infrastructure: In Nepal there is no any department of waste and plastics or some special body. The management duties are given to the municipality and they decide however they feel comfortable with. There hasn't been any awareness about plastic recycling until a while ago so there is no infrastructure built to store and manage waste plastics. The wastes are usually directly thrown into the landfill.
- Cost and economics: Plastic recycling venture is an expensive one. It requires a specific plant and assembly line for itself. Which means it requires trained operators and engineers too. This can soar the capital and expenses in a small nation with low plastic usage.
- Politics: Be it mainstream or internal, there has always been a huge political factor in waste management in Nepal. Nepal is a small country with less population but if all of

the waste collection and storage is controlled by few third party bodies, than it can be a huge business. The monopolization in the waste management sector has made it difficult for recycling aspirants to start collecting and distributing. They have to buy the scrape and waste from such third party companies at a high rate and then proceed with recycling.

While these are a few of the problems faced by aspirants, there are a lot more reasons to start recycling plastics. Some of them are:

- Environmental cause: Global warming, over-pollution, deforestation, etc all are real thing and the consequences are real too. From having landfill management issues to having rivers and mountains covered with litters, all of the consequences are coming right back at us. It is perfect time to start applying any and every pollution reduction measures and one of the best ways is recycling.
- Unsaturated business opportunity: Plastic recycling hasn't yet flooded with startups although it could be in a near future. Current time is the most potent time to grow recycling as a business.
- Government and global incentives: As landfill has becoming a huge problem in waste management, government as well as global INGOs are providing incentives and training for plastic recycling.
- Employment opportunities: Waste that could have been dumped over some hill has the potential to generate employment to people.

2.5 Failure analysis of load bearing components in machines

Shafts:

Shafts used in granulator, dryer and mixture machine are subject to similar loads, torsional, axial and buckling. Here are the findings of failure modes of shafts used in rotary machines.

Austin H. Bonnet in his article "Cause, Analysis and prevention of Motor Shaft Failures" (Bonnett, 1998) discussed about cause of shaft failures and the corresponding failure mode. The most common cause of shaft failure is:

Failure mode	Cause
Overload	High impact loading
Fatigue	Excessive rotary bending such as over hung, high torsional load or damage causing stress raisers.
Corrosion	Wear pitting, fretting, cavitation can result in fatigue failure if severe enough.

Its solution or prevention measures can be proper loading, increasing shaft size, using resistant coatings. “Failure analysis of a coupled shaft from a shredder” by Carlos M.S. Vicente et. al. (Carlos M.S. Vicente, 2019) discusses shaft failure in a shredding machine. They incorporated experimental methods of visual inspection, microscopic inspection and hardness tests and theoretical method of stress analysis for their failure analysis. According to their findings, the failure occurred due to fatigue. The shaft fracture surface showed fatigue due to torsion and bending due to high loads. Bending was related to radial misalignment of the shaft which played an important role in the failure of the shaft. As solution to such common problems, the author suggested, increasing the shaft diameter, decrease grinding volume, and changing coupling method from transverse hole to keyseat or flexible coupling. “Fracture failure analysis of gearbox shaft” by V.S. Rocha et al. (V.S. ROCHA, 2012) discusses failure analysis of gearbox shaft of a scrap compressing machine. The shaft was studied using Scanning electron microscopy (SEM), chemical analysis by semi quantitative EDS and optical microscopy (OP). In the conclusion the cause of the failure was due to improper quenching and tempering along with overload during operation. Some ways to reduce the failures are, quality control and increasing shaft size. A work by Yotsakorn Pratumwal et al., “Corrosion Fatigue Cracking in Paper Machine Felt Guide Roll Shafts” (Yotsakorn Pratumwal, 2023)discusses root cause of shaft failure incidents in a paper machine and concludes the root cause to be corrosion fatigue and overloading. Techniques such as chemical composition analysis by emission spectroscopy, fracture surface analysis, OM and SEM were used to determine the conclusion. Prevention measures can be increasing shaft size and using resistant coatings. To summarize, most common cause of the failure in shafts in rotating applications happen due to overload and has been a matter of concern for all industrial applications. Other modes of failures are misalignment, corrosion etc.

Bearing:

“Rolling element bearing failure analysis: A case study” by R.K. Upadhyay and et al. discusses on industrial bearing failure by rolling contact failure. It concludes that RCF occurs due to cyclic stress. Other failures are fretting and brinelling. Overload being the major cause behind brinelling (R.K. Upadhyay, 2013). To decrease the damages, the loading can be decreased or the support can be increased. Similarly, a review on "Fault detection analysis in rolling element bearing” (Pankaj Gupta, 2017) and "Predictive maintenance through the monitoring and diagnostics of rolling element bearings.” (Bently, 1989) conclude that 90% of total rolling contact bearing faults involve damage in bearings due to localized defects, more specifically, spalling due to fatigue failure. Its measures to failure are reducing loading and increasing the number of supports. A review paper, “A Review of Rolling Contact Fatigue” (Sadeghi, 2009) with 38 individual research paper comparison and analysis concluded that, RCF is the most unavoidable mode of failure of ball and rolling element bearings. There are two most dominant mechanisms for RCF, i.e., the subsurface originated spalling and surface originated pitting. The ways to reduce the damage is to use proper loading and use appropriate loading for specific tasks. From these studies it can be concluded that the major fatigue failure mode in bearings used in motor applications are spalling due to fatigue and overloading. Designing shafts and bearings keeping fatigue and overloading in priority can reduce damages and subsequently reduce breakdown times in plastic recycling equipment helping increasing productions.

CHAPTER THREE

METHODOLOGY

We proceeded with our methodology in dividing the task into sub-divisions and proceeded accordingly. This figure below includes the methods we will be going through step by step during our research.

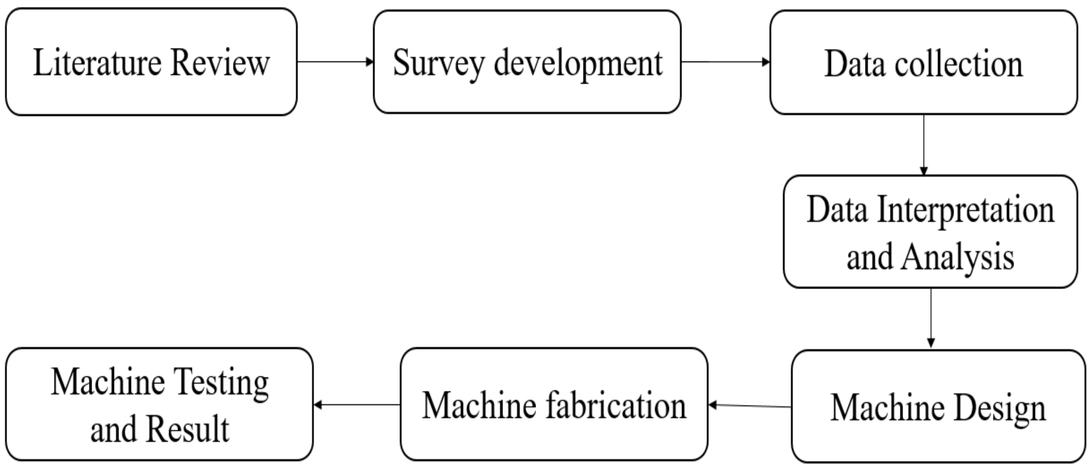

Figure 5 Methodology Flow Diagram

In the beginning, a detail steps plan is done for the whole process. The methodology steps are described below.

3.1 Literature Review

It is the first step to any research after the identification of objective. We performed a comprehensive literature review to grasp the understanding of the present scenario involved in plastic recycling. The present statistics around the globe and in Nepal was searched and analyzed. The different plastic recycling methods such as mechanical recycling, chemical recycling, biological recycling, etc. were studied and their effectiveness as well as their shortcomings were analyzed with solutions as well. Then, the efforts of the government as well as the private sector in the practical recycling of plastic waste was found out and the line of recommendations with trends throughout the world was observed. So, extensive study about the procedures involved and the technological implications were grasped.

The literature reveals that the failure modes of shafts and bearings in rotary machines and industrial equipment are primarily attributed to overload and fatigue. Overload induced failures result from high impact loading and excessive rotary bending, while fatigue related failures often stem from factors such as high torsional loads, misalignment, and corrosive wear. Various studies emphasize the significance of proper loading, increasing shaft or bearing size, and employing resistant coatings as effective preventive measures. Additionally, localized defects, specially spalling due to fatigue, emerge as a prevalent issue in rolling element bearings, with recommendations focused on reducing loading and increasing support. These findings underscore the critical importance of designing and maintaining shafts and bearings with fatigue and overloading considerations to minimize equipment breakdowns and enhance production efficiency in plastic recycling machinery.

Throughout the machines and equipment, the most damage prone components were shafts, bearings and other supports which experience constant loading and movement. Among many types of loads, the ones most impactful and quantifiable are bending and buckling load. The most common solutions to this problem are:

- Increasing the material strength
- Larger cross-sectional area
- Addition of support and reinforcement
- Proper design geometry
- Load redistribution
- Heat treatment and surface hardening

In our research we will be focusing on addition of support and reinforcement. Also, on proper design and geometry. This includes avoiding sharp corners, reducing length to thickness ratio, and use of appropriate shapes.

3.2 Survey Development

For the technology analysis of recycling plant, the present scenario of actively operating industries must be analyzed. A detail survey was carried out. Three factories within the Kathmandu valley were chosen. To obtain the required data from the factories a questionnaire was prepared. After that, by visiting the individual factories and interviewing the authorized persons the answer to the questions were obtained.

3.2.1 Balaju Plastic Udyog

This factory processed recycling plastics to form concreting sheets. In the initial stage they used Granulator machine to cut the used plastic materials. Then for washing the plastics they used conveyer system. This made washing easier and also reduced labor’s time. After that they carried out centrifugal drying. In addition to this, they further dried the plastics using heater. This process increased the energy consumption but prevented extra time than of sun drying. As they processed LDPE plastics, they used agglomerator machine before entering the plastics to mixture machine. The extruder they used was of superior quality. It was completely enclosed and required precise temperature control. They used new technology of hydraulic to change the filter in the machine for time conservation. Overall, the factory used varieties of technology to increase the processing speed.

Problems:

1. Labor-intensive cutting process: Initially, the Granulator machine was used to cut the used plastic materials, which likely required a significant amount of manual labor.

2. Inefficient washing process: The initial washing process might have been time-consuming and labor-intensive before they implemented the conveyor system.

3. High energy consumption for drying: The combination of centrifugal drying and heater drying increased energy consumption.

4. Precise temperature control: Maintaining precise temperature control for the enclosed extruder could be a complex task.

5. Time-consuming filter change: The process of changing the filter in the machine might have taken considerable time.

Solutions

1. Conveyor system for washing: Implementing the conveyor system made washing easier and reduced labor's time.

2. Centrifugal drying: The introduction of centrifugal drying likely improved the drying efficiency compared to traditional methods.

3. Heater drying: Although it increased energy consumption, heater drying was faster than sun drying, potentially reducing overall processing time.

4. Use of a high-quality enclosed extruder: The superior quality enclosed extruder likely enhanced processing efficiency and product quality.

5. Hydraulic technology for filter change: The new hydraulic technology used for changing the filter in the machine aimed to save time during this process.

Overall, the factory employed various technological solutions to increase processing speed and improve the efficiency of plastic recycling.

3.2.2 Pepsicola Plastic Industries

This factory, situated in Pepsicola, Nepal, stood out among all recycling factories for its impressive workforce, boasting a considerably larger number of unskilled laborers. They involved manual cutting process before feeding the plastic into the granulator machine. To further streamline their recycling process, the factory had a vast washing pond adjacent to the granulation area. The pond served as a reservoir to hold the granulated plastics, allowing them to be thoroughly cleaned and get rid of any residual impurities. The factory had invested on a small capacity dryer machine that used 5 HP motor. This limited the capacity of whole output. The factory employed sun-drying method as well. This removed any remaining moisture from the washed plastic, ensuring the material to be completely dry. As the dried plastic pellets were ready for the final transformation, the factory used mixture and extruder machine simultaneously. Mixture machine allowed to add various additives and colorants to the plastic, tailoring the end product to meet specific customer requirements. The cutting machine further shaped the plastic into precisely sized pellets, ensuring uniformity and consistency in their final output.

Problems:

1. The machine arrangement was very haphazard. This caused unnecessary manpower loss.
2. The granulator machine did not contain flywheel, which caused often breaking of main shaft and frequent bearing damage due to impact loading.

Solutions:

1. Since the factory is product oriented the owner could arrange the factory as per product or line layout where all processing equipment are placed as per the sequence of operation.
2. Cutting the plastic into pieces causes impact loading in the shaft, hence it would be better if flywheel could be attached to the shaft. This will prevent the breakage of shaft and also increases the efficiency of machine.

3.2.3 Hattiban Plastic Factory

This factory produced both LDPE and HDPE plastics. Their recycling process began with a granulator, breaking down the plastics like other facilities. Notably, the granulated plastic directly flowed into a linear pond leading to a 20 KG capacity dryer machine, powered by a 5 HP motor. After thorough drying, a mixture machine and a small-capacity extruder, driven by a 10 HP motor, shaped the plastic into uniform pellets. The factory's efficient and innovative approach enabled them to contribute significantly to sustainable plastic recycling process.

Problems:

1. The factory used small dryer causing high run time to obtain the required output.
2. Bearing in mixture machine was placed only on one side which made the cantilever loading in the shaft with increased belt tension.

Solution:

1. The capacity of the drier machine could be increased hence the machine operation time would decrease and prevent the manpower loss.
2. Bearings could be added on both side of the mixture increasing the efficiency of the machine.

The table provides detailed information about three different factories - Balaju, Pepsicola, and Hattiban, and the maintenance costs and machine utilization for their respective equipment.

Table 1 Cost incurred on regular and breakdown maintenance

S.N.	Name of Factory	Machine	Regular Maintenance cost (per Month)	Machine idle time (per month in hours)	Breakdown Maintenance Cost (per year)
		Granulator	6000	20	15000
		Dryer	2500	8	5000
		Mixture	4500	10	10000
		Extruder	5000	200	10000
		Granulator	10000	30	13000
		Dryer	3000	8	6000
		Mixture	4500	14	10000
		Extruder	6000	150	15000
		Granulator	7000	45	12000
		Dryer	2500	10	6000
		Mixture	5000	14	12000
		Extruder	5500	150	18000

Each factory has multiple machines, including Granulator, Dryer, Mixture, and Extruder, with varying regular maintenance costs, machine idle times, and breakdown maintenance costs.

- Balaju operates a Granulator machine specifically used for LDPE (Low-Density Polyethylene) processing. The regular maintenance cost for this Granulator is 6000 Rupees per month. The machine remains idle for about 20 hours per month, which could be due to planned breaks or non-operational periods. In the case of a breakdown, the maintenance cost amounts to 15000 Rupees per year. Additionally, Balaju operates a Dryer, incurring a monthly maintenance cost of 2500 Rupees. The Dryer remains idle for around 8 hours each month. Breakdown maintenance for the Dryer costs 5000 Rupees annually. Furthermore, Balaju operates a Mixture with a monthly maintenance cost of 4500 Rupees and an idle time of approximately 10 hours per month. The annual breakdown maintenance cost for the Mixture is 10000 Rupees. Lastly, Balaju operates an Extruder, incurring a maintenance cost of 5000 Rupees per month. The Extruder experiences a significant idle time of 200 hours each month. The annual breakdown maintenance cost for the Extruder is 10000 Rupees. This data suggests that Balaju faces relatively longer idle times for the Extruder, and the maintenance costs for breakdowns can be significant, requiring more attention to optimize the equipment's reliability and operational efficiency.

- Pepsicola's Granulator is used exclusively for HDPE (High-Density Polyethylene) processing. The regular maintenance cost for this machine is 10000 Rupees per month, which is higher than Balaju's Granulator maintenance cost. The machine has an idle time of about 30 hours per month. In the case of a breakdown, the Granulator's maintenance cost is 13000 Rupees per year. Pepsicola also operates a Dryer with a monthly maintenance cost of 3000 Rupees and an idle time of 8 hours per month. The Dryer's breakdown maintenance cost amounts to 6000 Rupees annually. Additionally, Pepsicola operates a Mixture with a maintenance cost of 4500 Rupees per month and an idle time of around 14 hours per month. The annual breakdown maintenance cost for the Mixture is 10000 Rupees. Furthermore, Pepsicola operates an Extruder with a monthly maintenance cost of 6000 Rupees and an idle time of 150 hours per month. The annual breakdown maintenance cost for the Extruder is 15000 Rupees. This data indicates that Pepsicola invests significantly more in regular maintenance for their Granulator, aiming to ensure the optimal performance of their HDPE processing, and they also face relatively longer idle times for the Extruder.
- Hattiban operates a Granulator that processes both HDPE and LDPE. The regular maintenance cost for this Granulator is 7000 Rupees per month, which is higher than Balaju's and Pepsicola's Granulator maintenance costs. The machine has an idle time of about 45 hours per month, which is relatively longer than the other two factories. In the case of a breakdown, the Granulator's maintenance cost is 12000 Rupees per year. Hattiban also operates a Dryer with a monthly maintenance cost of 2500 Rupees and

an idle time of 10 hours per month. The Dryer's breakdown maintenance cost amounts to 6000 Rupees annually. Additionally, Hattiban operates a Mixture with a maintenance cost of 5000 Rupees per month and an idle time of around 14 hours per month. The annual breakdown maintenance cost for the Mixture is 12000 Rupees. Furthermore, Hattiban operates an Extruder with a monthly maintenance cost of 5500 Rupees and an idle time of 150 hours per month. The annual breakdown maintenance cost for the Extruder is 18000 Rupees. This data indicates that Hattiban faces relatively longer idle times for both the Granulator and the Extruder and invests more in regular maintenance for their equipment, which might contribute to reducing breakdown occurrences.

In conclusion, the table provides valuable insights into the maintenance practices and costs of three factories - Balaju, Pepsicola, and Hattiban. Each factory operates various machines with different regular maintenance costs, idle times, and breakdown maintenance costs. Analyzing this data allows factory management to identify areas for improvement in maintenance strategies, optimize idle times, and minimize breakdown occurrences, ultimately enhancing production efficiency and cost-effectiveness.

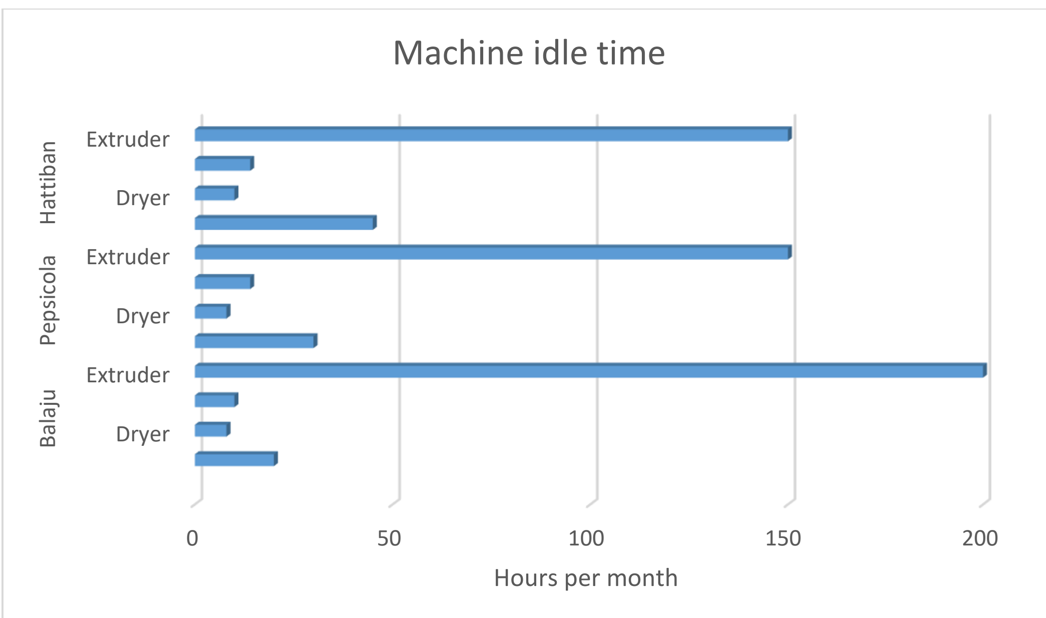

Figure 6 Machine idle time of various equipment

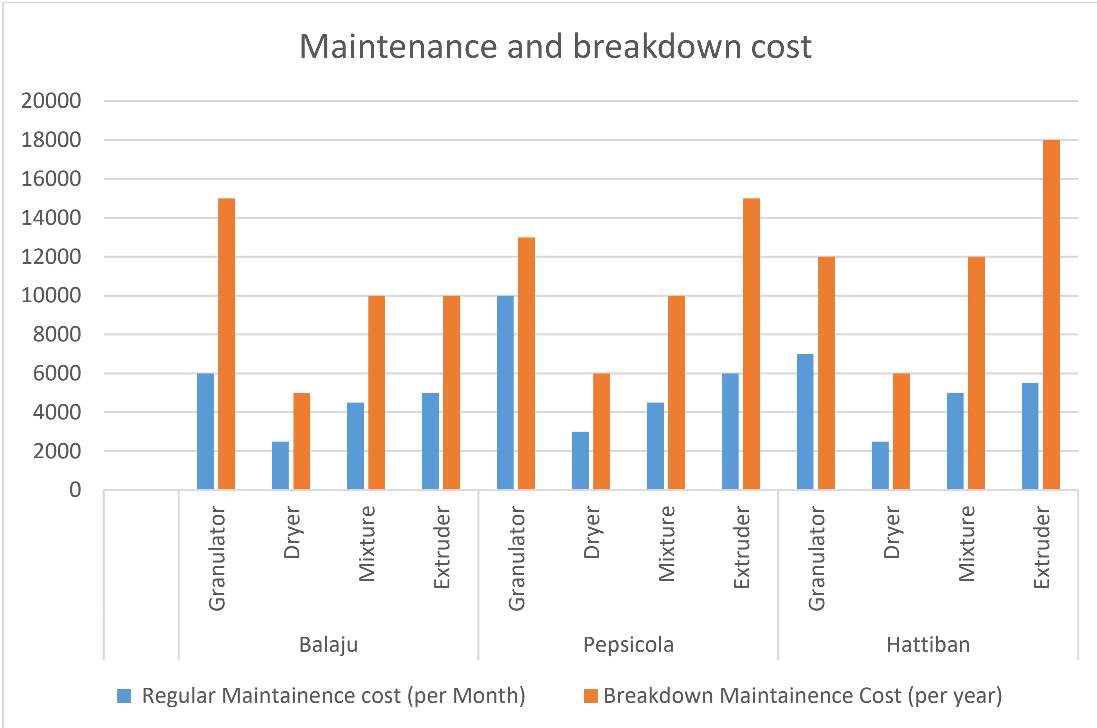

Figure 7 Maintenance and breakdown cost

CHAPTER FOUR
DESIGN AND DEVELOPMENT

Plastic waste collected undergo various stages to again be usable as a new one. For this we require various machineries. In the beginning all the waste collected are segregated manually as per the plastic types.

4.1 Granulator

Segregated plastics are fed into a granulator machine which cuts the plastic to form small chips. Instead of single shaft double blade granulator, double shaft shredding machine can also be used. But we have chosen granulator because of the low cost and ease of fabrication. Two types of granulators that are commonly used in recycling factories, one is 14-inch double blade granulator which is used for harder plastic chunks but productivity is low and next is 18-inch double blade granulator which is used for normal plastic bottles and productivity is high as compared to 14-inch blade. We have chosen single shaft 18-inch double blade granulator for our factory as our production requirement is high.

A. Specifications of Granulator

The machine uses 15 HP motor. There is a pulley belt reduction system with a reduction of 2.5: 1 We have used tapered roller bearing of internal diameter 70 mm for the smooth operation of the machines. There is a flywheel placed on the other side of the main shaft to balance out the weight of a pulley on the next side and to maintain the constant momentum on the rotating blades. If the shaft is not balanced and left with load on only one end, it will tend to bend and the rotation will be eccentric leading to the decreased life of shaft. Once the raw plastics are entered from the hopper, they reach the blade area where they get cut into pieces by the blades. After that, the cut pieces pass through a strainer which are drilled to let only the chips below 20 mm to enter. These chips then fall to an outlet tray. Because of the vibration of machine, the output tray tends to release the cut pieces continuously.

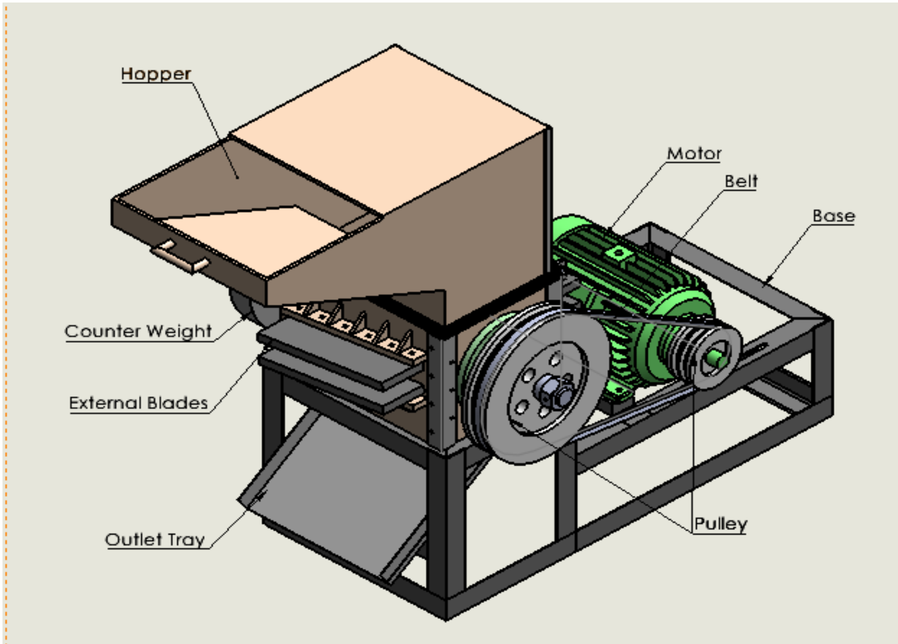

Figure 8 3D design of granulator machine

Granulator:

- Shaft: 90mm shaft with step of 70mm for bearing
- Pulley Reduction: 2.667: 1 (Pulley: C type 2 groove)
- Motor: 15HP
- Blades: 4 fixed blades with 2 rotating blades connected to the shaft
- Capacity: 100 KG per Hour
- Flywheel: 88 KG

B. Design and manufacture of blade of granulator

Blades are the core of granulator machine and the most difficult part within the machine to manufacture. There are four blades attached to the external part of the machine which are fixed with the help of bolts.

And there are two blades that are attached to a shaft inside the machine which rotates when the machine starts its operation. The gap between the internal and external blades can be

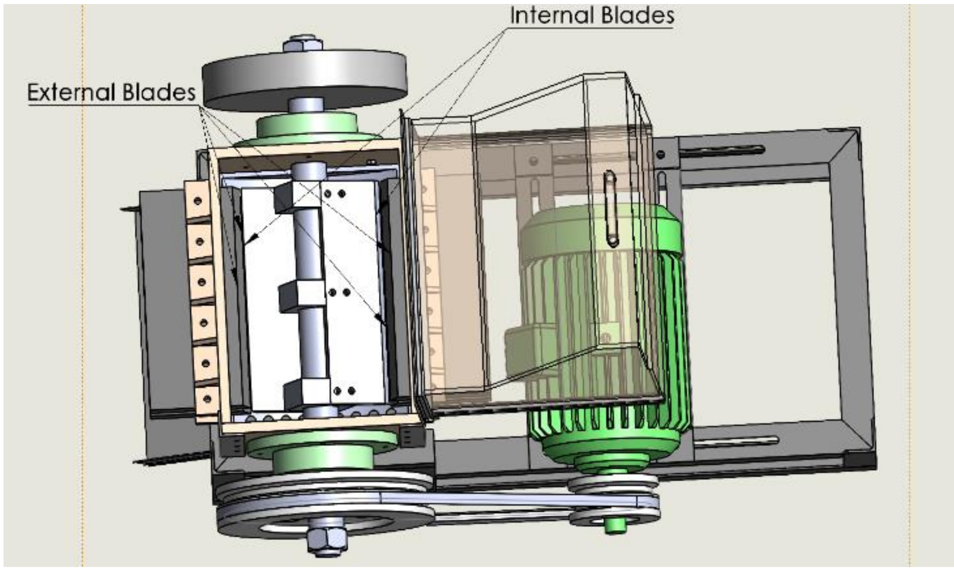

Figure 9 Blade position on 3D design of granulator

adjusted as we have designed slots on the external blades. By adjusting the gap between blades, cutting can be made efficient.

C. Modifications carried out on Granulator Machine

1. The major change is done in the strainer as flat strainers are commonly used in market and we modified the strainer to be curved as per the diameter of the rotation of the blades which increased the production rate.
2. Ball Bearings are normally used in machines available in market. As axial force is developed in the shaft while cutting the plastic, ball bearings cannot withstand the load and are easily damaged. So, we replaced the ball bearings with tapered roller bearings to sustain the axial force. For regular ball bearing the equivalent load is just radial load as it cannot handle axial load.
3. Equal weight fly wheel is placed at the opposite end of the shaft and pulley to provide inertia that eases load on the motor and also balances the center of weight. The shaft and tapered roller bearings are overdesigned to withstand the radial as well as axial load from the weight and vibrations.
4. Shaft is designed with clockwise and anticlockwise thread system on two ends such that pulley and flywheel can be adjusted properly with the use of check nut. Also, bearing cover is designed with cover to press the cup of tapered roller bearing.

D. Numerical analysis

For deep groove ball bearing

P = Fr

The rated loading capacity for deep groove ball bearing of 90mm shaft diameter are:

Dynamic loading capacity = 74040N

Static loading capacity = 60800N

Tapered roller bearing are more suited for axial loading compared to ball bearing. The loading capacity incorporates equivalent load combining radial and axial load.

P = X.Fr + Y.Fa

The rated loading capacity for tapered roller bearing for 90mm shaft are:

Dynamic loading: 158080N

Static loading: 160730N

$$L_{10} = \frac{(C/P)^e x 10^6}{60xN}$$

Where,

C = Specific load bearing capacity of the bearing

P = Equivalent total load

N = Number of revolutions per minute

4.2 Dryer

Dryer machine has a concept similar to washing machine. After the plastics are granulated to small chips they need to be cleaned well. For this the chips are added to larger container with water and detergent. They are cleaned there and the wet plastics are then entered to the dryer machine. The machine after its operation provides dry pieces of plastics as an output. There are two kinds of dryer used in plastic recycling industries. They are Thermal dryer and mechanical dryer. Thermal dryer uses heat to dry the plastics whereas mechanical dryer uses centrifugal force. Most of the factories I visited within the Kathmandu valley used mechanical dryer. It is because of the low energy consumption and low cost. We also used a mechanical dryer.

A. Specifications of Dryer

Dryer consists of two cylinders. One external cylinder that remains still and next is the internal cylinder that rotates along the rotation of shaft. A drainage system has to be provided for the dryer machine to let the excess water flow outside at the process. Since there is a chance of outgo of plastics along the water, we have to use filter such that it blocks the outgo of plastic and does not get clogged. For my design I have used motor drive of 5 HP along with belt and pulley reduction of 3:1. I designed the size of dryer as per the requirement. It can process up to 30 KG of plastic at a time.

Dryer:

- Shaft: 70mm shaft with 70mm bearing
- Inner Cylinder: Tapered both ends
- Pulley Reduction: 3:1 (Pulley: C type 2 groove)
- Motor: 5HP
- Capacity: 30 KG per Batch

B. Design and Manufacture of Inner cylinder

Inner cylinder of a dryer is the most challenging part to design and fabricate. In this model we used stainless steel to make the part. A stainless-steel plate was folded to make a cylinder. It was then drilled all over so that the water will run outside the cylinder when rotating due to the centrifugal force. The cylinder is directly attached to the shaft that rotates as soon as the machine starts. We have used two bearings for bearing the load in the shaft. The shaft has threaded end such that after the assembly of bearing and pulley nut is applied which keeps everything in position.

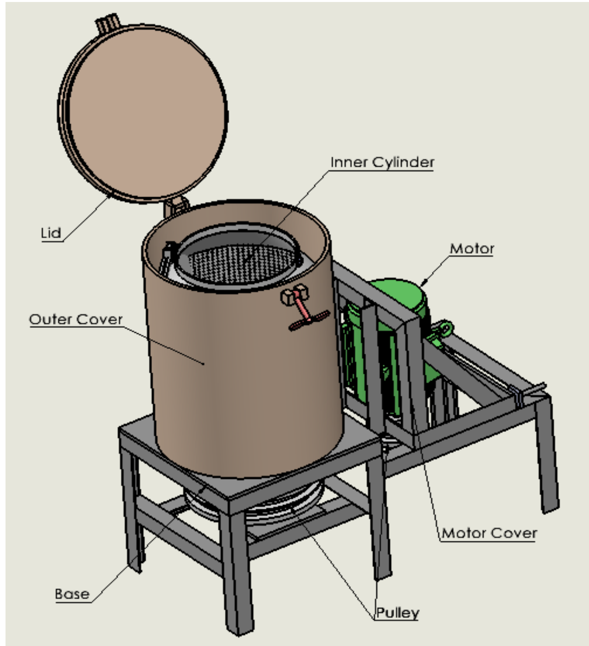

Figure 10 3D model of dryer

C. Modifications on Dryer Machine

1. Dryer machines that are available in market, use only single bearing in the shaft above pulley. This caused break down of shaft and the life of bearing was also reduced drastically. So, I have modified the design such that bearings are kept on both side of the pulley.
2. Normal dryer used in other factory are of less capacity i.e. 10 KG. These dryers have removable cylinder such that plastic could be taken out at once. But to reduce the process time we increased the capacity of dryer to 35 KG. The only difference was that the cylinder was fixed and plastic could not be taken out at once as the weight is very huge. In larger factories we can recommend that a hoist system be used to pull out the cylinder and pour the plastic at once.
3. The bottom edge of the inner cylinder of dryer machine is tapered i.e., chamfered. While rotating the cylinder in high speed the weld line in the base tends to tear down because of the excessive centrifugal force developed. After being chamfered the stress is distributed which reduces the chance of welding being tear down.
4. The Mild Steel base is changed to stainless steel base to protect the corrosion.

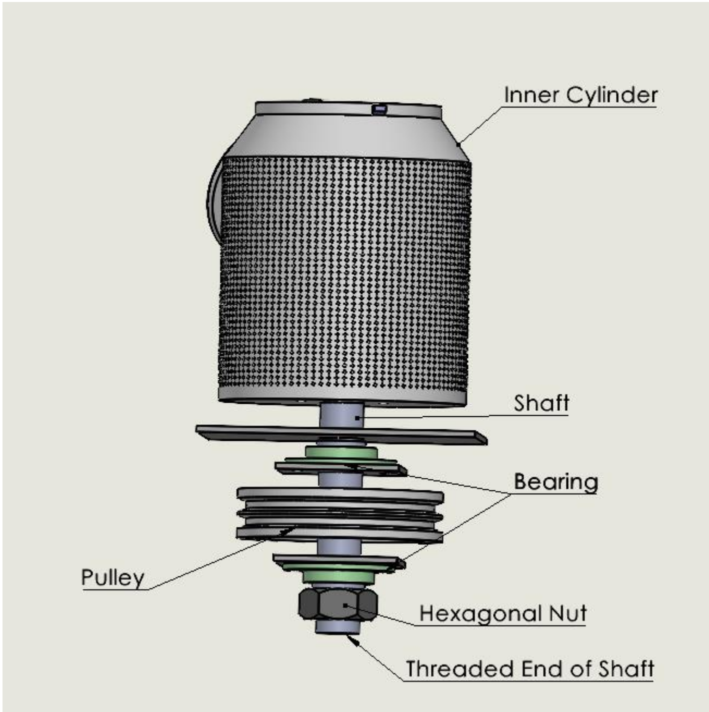

Figure 11 Modified cylinder design

Figure 12 Shaft assembly and inner cylinder of Dryer Machine

D. Numerical Analysis of modification

Here we calculated the difference in torsion, bending moment and a combined impact in addition with axial loading. Usually, the shafts are supported by just one bearing. It results in untimely or frequent maintenance and sometimes even damage. To minimize this occurrence, two bearing reducing effective length of the shaft for bending was used. All of the data and relations are taken from Design Data Handbook by K. Mahadevan and K. Balaveera Reddy.

First torsion was compared.

The material of the shaft is 1040 Steel.

The dryer is run by a motor with power 3.7285kW

P = 3.7285kW

RPM n = 1440 rpm

Torsion T $=\frac{9.74 \text{ x } 10^6 \text{ x P}}{n}$

T = $\frac{9.74 \text{ x } 10^6 \text{ x } 3.7285}{1440}$

T = 50,430 Nmm. with FOS = 8

T = 4, 03,440 Nmm^2

Now for allowable torsion,

T = $\frac{\pi \text{ x } \tau_d \text{ x } d^3}{16} (\frac{1}{1-k^4})$

Where,

τ_d = Design shear stress

k = Ratio of inside and outside diameter of a hollow shaft.

K = 0 for solid shaft.

For τ_d, calculation,

$\tau_d = \frac{\tau_e \text{ x B}}{R}$

Where, τ_e is the shear stress at

Elastic limit i.e. 180 Nmm^2.

R is the reliability factor, R = 2.

B is the size factor, B = 1.

τ_d = 90 Nmm^2

Finally, allowable twisting moment T_c is,

$T_c = \frac{\pi \text{ x } \tau_d \text{ x } d^3}{16}$

For M, calculation,

For a shaft with support at one end,

M = $\frac{WxL}{2}$

M = 68,683.05 Nmm^2

With FOS = 8,

M = 5, 49,464.4 Nmm^2

For σ_d, calculation,

$\sigma_d = \frac{\sigma_e \text{ x B}}{R}$

Where σ_d is the stress due to bending at the elastic limit i.e. 310 Nmm^2.

σ_d = 155 Nmm^2

For allowable bending moment,

M = $\frac{\pi \text{ x } \sigma_d \text{ x } d^3}{32}$

M = 52, 19,461 Nmm^2

T_c = 60, 61, 310 Nmm^2

Now, with the combined loading of bending moment, torsion and axial load, according to maximum shear stress theory a new diameter is,

$$d = \left[\frac{16}{\pi \times \tau_{max}}\left(\sqrt{\left((CmM + \frac{\alpha \times F \times d}{8}\right)^2 + (Ct \; x \; T)^2}\right)\right]^{\frac{1}{3}}$$

Where Cm = 1.5

Ct = 1.0

F is the axial load

τ_{max} = 55 Nmm^2

Finally, the diameter d of the shaft with combined loading is,

d = 44 mm

With this design diameter, the dryer failed frequently due to its bending and axial load. The calculated diameter is less than the design diameter so it can be inferred that the problem cannot be solved by increasing the diameter but by increasing the supports on the shaft.

Substituting the design diameter for bending moment and buckling,

Combined load for buckling and bending,

$$P_{combined} = \sqrt{\left(\frac{M^2}{\frac{4E}{D}}\right) + (P_{crit})^2}$$

Where,

Pcrit is critical bucking loading.

Pcrit = $\pi^2 \times E \times I / L^2$ I = $\pi D^4 / 64$

So,

Pcrit = 4423.57N

Pcombined = 29531.68N

Now adding two supports at the distance of, 194mm d = 39.61 mm

M = $\frac{WxL}{2}$

M = 44,194.073 Nmm^2

With FOS = 8,

M = 3, 53,552.584 Nmm^2

$P_{combined}$ = $\sqrt{\left(\frac{M^2}{\frac{4E}{D}}\right) + (P_{crit})^2}$

Where,

Pcrit is critical bucking loading.

Pcrit = $\pi^2 \times E \times I / L^2$ I = $\pi D^4 / 64$

So,

Pcrit = 6559.27N

Pcombined = 18140.84N

From the results we can see that the combined buckling and bending load of the shaft by adding just two supports has decreased by 38.57%.

Modification on Dryer for Decreased Breakdown Time:

Issue: Dryers in the market experience frequent bending and buckling, requiring maintenance every 3 months.

Objective: Decrease breakdown time by reducing buckling and bending without altering the shaft and gear profile. This will be achieved by adding a strategically placed bearing support.

Calculation Approach:

1. Torsion of the rotating shaft due to the motor-pulley setup is determined.

2. Treating the shaft as one end pinned and applying the force at the center to calculate the maximum bending moment.

3. A factor of safety of 8 (appropriate for moderate machineries) is applied, obtained from the design databook.

4. Further numerical analysis follows to calculate the combined load of bending moment and buckling with one bearing support and double bearing support.

Result: The modifications will help to achieve a more stable and reliable dryer, reducing maintenance frequency and improving overall efficiency.

4.3 Mixture Machine

The dried Plastic chips are now processed towards Mixture Machine. This machine creates the proportion of color, density on plastics before entering it to the extruder machine. It preheats the plastic chips.

A. Specification of the Mixture machine

The machine consists of outer cylinder where all the plastics are poured. The part does not rotate during the operation. Inside the cylinder is the blade. We have designed four blades that are welded to the blade shaft which is coupled to the main shaft. On the operation of machine, the blade rotates and the friction created heats the plastics inside.

Mixture:

- Shaft: 70mm
- Blade: 4 rotating blades connected to the shaft
- Motor: 15 HP
- Pulley Reduction: 2:1 (Pulley: C type 3 groove)
- Capacity: 45 KG per Batch
- Batch per hour

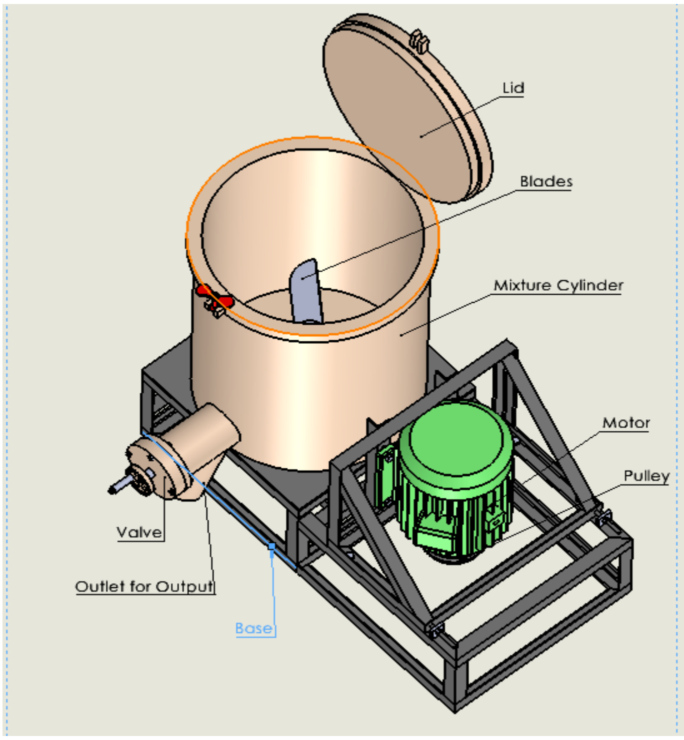

Figure 13 3D model of Mixture machine assembly

B. Design and Manufacturing of Blade

There are four blades attached to the shaft of the machine. The shaft is hollow inside consisting of key groove which is coupled to the main shaft of the machine.

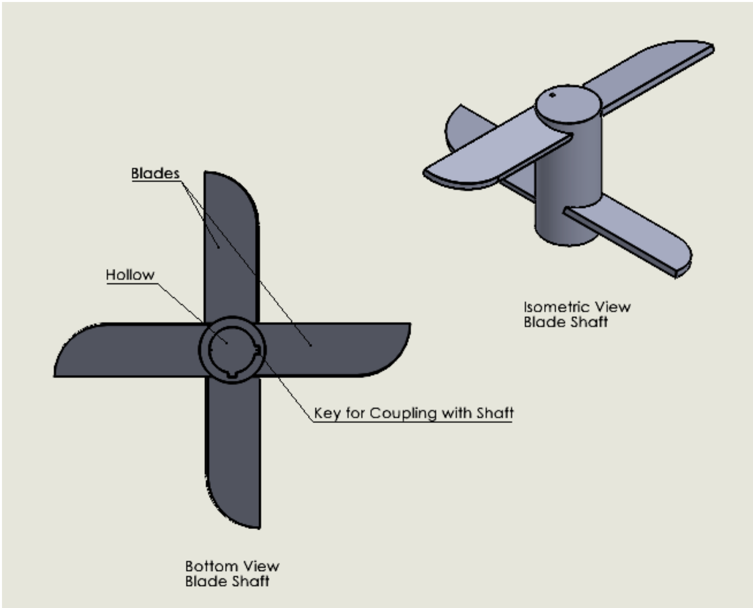

Figure 14 Blade assembly

C. Modifications on Mixture machine:

1. Mixture machines that are available in market, use only single bearing in the shaft above pulley. This caused break down of shaft and the life of bearing was also reduced drastically. So, I have modified the design such that bearings are kept on both side of the pulley.
2. Normal machine contains only two blades in this machine. But I have added the blade and designed with four blades. This helped to increase the heating speed. But along with this the power consumption would increase so I used 15 HP motor. Whereas only 10 HP motor are used in machine that are available in the market.
3. We found that the outer cylinder of the mixture machine being used in other factory used 12 mm plate rolled to the size. But the problem of thinning of plate was very high. As a solution the factory owner thickened the cylinder by adding plates from inside. So to minimize the problem, I designed the cylinder with 16mm plate.

D. Numerical Analysis of modification

Here we calculated the difference in torsion, bending moment and a combined impact in addition with axial loading. The problem with mixer was similar to the dryer.. To minimize this occurrence, two bearing reducing effective length of the shaft for bending was used. All of the data and relations are taken from Design Data Handbook by K. Mahadevan and K. Balaveera Reddy.

First torsion was compared.

The material of the shaft is 1040 Steel.

The dryer is run by a motor with power 11.1855kW

P = 11.1855 kW

RPM n = 1440 rpm

Torsion T = $\frac{9.74 \text{ x } 10^6 \text{ x P}}{n}$

T = $\frac{9.74 \text{ x } 10^6 \text{ x } 11.1855}{1440}$

T = 15,131.49 Nmm. with FOS = 8

T = 12, 10,510 Nmm^2

Now for allowable torsion,

T = $\frac{\pi \text{ x } \tau_d \text{ x } d^3}{16} (\frac{1}{1-k^4})$

Where,

τ_d = Design shear stress

k = Ratio of inside and outside diameter of a hollow shaft.

K = 0 for solid shaft.

For σ_d, calculation,

For a shaft with support at one end,

M = $\frac{WxL}{2}$

M = 1, 45,009.79 Nmm^2

With FOS = 8,

M = 11, 60,078.332 Nmm^2

For τ_d, calculation,

$\tau_d = \frac{\tau_e \text{ x B}}{R}$

Where, τ_e is the shear stress at

Elastic limit ie 180 Nmm^2.

R is the reliability factor, R = 2.

B is the size factor, B = 1.

τ_d = 90 Nmm^2

Finally, allowable twisting moment T_c is,

For σ_d, calculation,

$\sigma_d = \frac{\sigma_e \text{ x B}}{R}$

Where σ_d is the stress due to bending at the elastic limit ie 310 Nmm^2.

σ_d = 155 Nmm^2

For allowable bending moment,

M = $\frac{\pi \text{ x } \sigma_d \text{ x } d^3}{32}$

M = 52, 19,461 Nmm^2

$T_c = \frac{\pi \text{ x } \tau_d \text{ x } d^3}{16}$

T_c = 60, 61, 310 Nmm^2

Now, with the combined loading of bending moment, torsion and axial load, according to maximum shear stress theory a new diameter is,

$$d = \left[\frac{16}{\pi \text{ x } \tau_{max}}\left(\sqrt{\left((CmM + \frac{\alpha \text{ x F x d}}{8}\right)^2 + (Ct\ x\ T)^2}\right)\right]^{\frac{1}{3}}$$

Where Cm = 1.5

Ct = 1.0

F is the axial load

τ_{max} = 55 Nmm^2

Finally, the diameter d of the shaft is,

d = 53mm

Substituting the design diameter for bending moment and bukling,

Combined load for buckling and bending,

$$P_{combined} = \sqrt{\left(\frac{M^2}{\frac{4E}{D}}\right) + (P_{crit})^2}$$

Where,

Pcrit is critical bucking loading.

Pcrit = $\pi^2 \times E \times I / L^2$ I = $\pi D^4 / 64$

So,

Pcrit = 3813.07N

Pcombined = 74354.09N

Now adding two supports at the distance of, 180mm

M = $\frac{WxL}{2}$

M = 57,303.54 Nmm^2

With FOS = 8,

M = 4, 58,428.32 Nmm^2

d = 42mm

$P_{combined}$ = $\sqrt{\left(\frac{M^2}{\frac{4E}{D}}\right) + (P_{crit})^2}$

Where,

Pcrit is critical bucking loading.

Pcrit = $\pi^2 \times E \times I / L^2$ I = $\pi D^4 / 64$

So,

Pcrit = 9631.46N

Pcombined = 25169.31N

From the results we can see that the combined buckling and bending load of the shaft by adding just two supports has decreased by 66.14%.

Modification on Mixer to Reduce Breakdown Time:

Issue: Mixers in the market often experience bending and buckling issues, leading to frequent maintenance every 3 months.

Objective: The goal is to decrease breakdown time by minimizing bending and buckling without altering the shaft and gear profile. This will be achieved by strategically adding a bearing support.

Calculation Approach:

1. The first step involves determining the torsion of the rotating shaft due to the motor-pulley setup.

2. Next, the shaft is treated as one end pinned, and the force is applied at the center to calculate the maximum bending moment.

3. To ensure safety, a factor of 8 (appropriate for moderate machineries) is applied, as specified in the data book.

4. Further numerical analysis follows to calculate the combined load of bending moment and buckling with one bearing support and double bearing support.

Result: These modifications aim to create a more stable and reliable mixer, significantly reducing maintenance frequency and improving overall efficiency. The same calculation procedure applied to the dryer was followed for the mixer modification, ensuring consistency and reliability in both design improvements.

4.4 Extruder

Extruders for plastic are a typical type of plastic machinery that are extensively employed in the plastic processing sector. It primarily uses high temperatures and high pressure to transform solid plastics into a molten state, which is subsequently used to make plastic items in molds. All of the aforementioned procedures are carried out by the plastic extruder machine through a barrel with a screw and spiral channel. The screw rotates while pressing and shearing the waste plastic and constantly squeezes the plastic in the barrel. The rotating screw then melts the solid plastic into a uniform melt and moves the melt to the next step in the process. On the outside of the barrel, there is a heating tube that can heat the plastic and quicken its melting.

There are various types of extruders based on the number of screws.

- Single screw extruder
- Double screw extruder
- Multi-screw extruder

The one that was modified is a single screw extruder as it is the most widely used one. Designing and modifying screw and barrel is a very meticulous process and requires high precision which is not accessible to all. And modifications on such parts can turn out to be costlier than intended due to failures. Some failures that may arise in extruder due to imprecision are:

- Over pressurization in the barrel.
- Improper melting of plastics and lump formation
- In the worst case, the barrel may blast due to extreme pressure.

The plastic recycling extruder has 3 major systems, transmission system, heating system and the extrusion system.

- Transmission system: It is composed of a motor, a feeding screw, a reducer and a transmission screw. The motor provides torque and speed for the extrusion process. The power rating is usually determined by the size of the plastics. Even the same extruder setup can vary in power consumption for different materials.
- Heating system: This is the most crucial system of a extruder. Electric heaters are widely used for extruders where heating bands or jackets are covered over the barrel to heat the plastics inside by raising the temperature to the desired melting point. The heating is done in such way that the melting process is uniform and consistent extrusion which is the final process. The modification is done in the heating system. Usually a heating setup and temperature control panel can cost anywhere between 2 Lakhs to 5 Lakhs. The thermal system developed here costs only about 25 thousand Rupees.
- Extrusion: The extrusion process encompasses the hopper, barrel and the screw. Another important component of the extrusion process is a screen mesh that prevents the plastic from forming lumps and gives a uniform flow. The plastic granules are fed from the hopper which sends it to the barrel. The screw pushes while simultaneously heating the plastic and melting. The melted plastic slowly moves forward and is ejected from the end of the barrel. Various shapes can be given by substituting the head. This extrudes long wires of plastic which is then

dipped in a water vat and then cut to desired size of the pellets completing the extrusion process and plastic recycling as a whole.

Here are the specifications of the major components used for extruder:

- Screw: 110mm dia. and 2400mm length
- Barrel: 110mm
- Pulley Reduction: 4.8: 1 (Pulley: C type 3 groove)
- Heater: 8 pieces with 1500 W each
- Capacity: 90 KG per hour
- Motor: 20 HP
- Gearbox: 1:20 oil feed spur gearbox

Modifications on the Extruder:

Aim: Reduce machine cost and breakdown time.

- Extruder machine operation: Starts at 190°C to 225°C, energy-efficient for continuous shifts.

- Current thermal setup: Expensive, reliable but becomes useless when breakdown occurs.

- Challenges with current setup: Requires specific engineers, high maintenance costs, long waiting time for repairs.

- Modified thermal system: Made it easier and quicker to repair after damage.

- Filter replacement: Time-consuming and tedious if operated continuously for over 8 hours.

- Attempted solution: Automatic hydraulic system to shift the head, using a single cylinder with 50mm bore and 250mm stroke.

- Issue faced: More than 15% leakage during operation despite trying various setups to minimize it.

- Changed approach: Switched to a manual head for the hydraulic setup.

- Overall goal: Minimize downtime and improve machine efficiency for plastic recycling procedure.

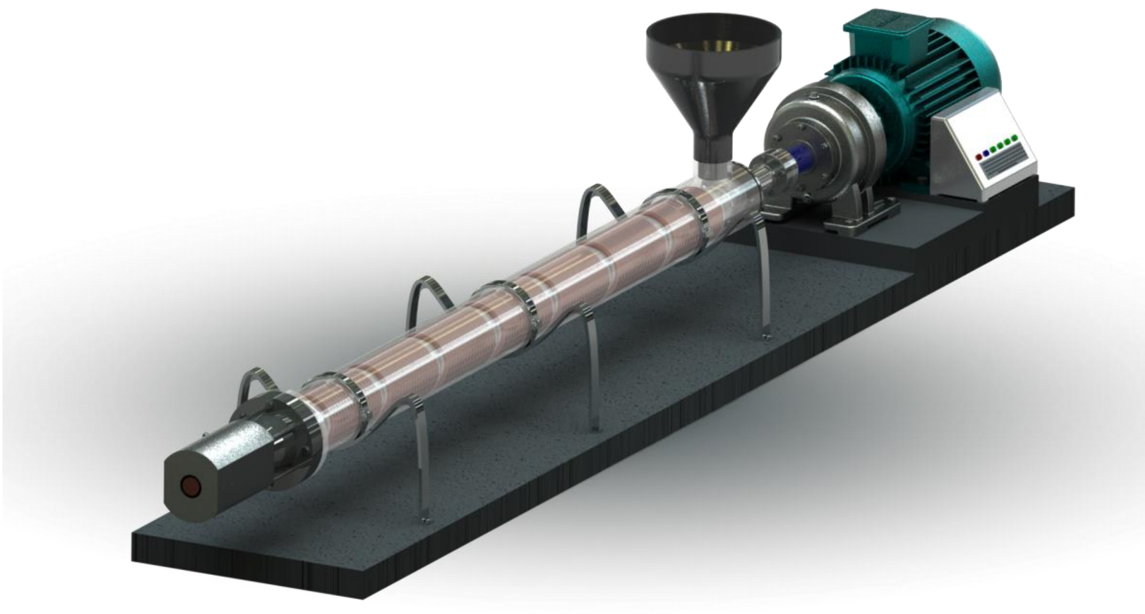

Figure 15Rendered 3D model of an extruder assembly

Above is the picture showing the leakage done due to automation on the head using hydraulics. While the idea was to reduce maintenance of the barrel but it backfired as it resulted in more than 15% leakage of the recycled plastics reducing efficiency.

CHAPTER FIVE

RESULTS AND ANALYSIS

5.1 Calculation and Analysis

In the following section, the results of the comprehensive investigation conducted in this thesis will be presented and meticulously analyzed. The primary objective of this study was to delve into technology study of different plastic recycling industries with a multifaceted approach, aiming to uncover novel insights and contribute to the existing body of knowledge in this field. The ensuing discourse encapsulates a synthesis of empirical findings, numerical findings, and qualitative assessments, all meticulously curated to unveil a comprehensive overview of the intricate interplay within the realms of plastic recycling. Through rigorous data collection, systematic analysis, and rigorous validation, this section illuminates the culmination of dedicated research endeavors, paving the way for an in-depth comprehension of the phenomena under scrutiny.

5.1.1 Load bearing analysis

For granulator:

The rated loading capacity for deep groove ball bearing of 90mm shaft diameter are:

Dynamic loading capacity = 74040N

Static loading capacity = 60800N

The rated loading capacity for tapered roller bearing for 90mm shaft are:

Dynamic loading: 158080N

Static loading: 160730N

By changing the type of ball bearing the dynamic and static load bearing capacity of the support that is the bearing was increased by 2.13 times and 2.64 times. This is a significant increase in load bearing capacity. Similarly, due to vibrations and operation, the granulator shaft was experiencing residual axial load which damaged the deep groove ball bearings frequently. Using tapered roller bearing countered the axial load increasing the life of the shaft and reducing the breakdown time.

For dryer:

The table below presents load scenarios and their respective magnitudes for two different support configurations: single support and double support. The values represent forces applied to a structure, and they are divided into two categories: critical loading and combined loading.

1. Single Support Configuration:

-Critical Loading (4423.57N): In a single support setup, when the structure is subjected to its most critical loading condition, the force applied is 4423.57 Newtons (N). This represents the maximum force that the structure can sustain without failure under this specific loading scenario.

-Combined loading (29531.7N): In the same single support configuration, when multiple types of loads act simultaneously (combined loading), the structure can endure a total force of 29531.7 N. This includes various loads working together on the structure.

2. Double Support Configuration:

- Critical Loading (6559.27N): When the structure has support at two points (double support), the critical loading force is 6559.27 N. This indicates the maximum force the structure can handle without failing under the most critical loading condition for this setup.

-Combined loading (18140.8N): In the double support configuration with combined loading, the structure can withstand a combined force of 18140.8 N. This value accounts for the interaction of multiple loads acting simultaneously on the structure.

Table 2 Critical and combined loading for single and double support for dryer

Loads		
	Critical loading	Combined loading
Single support	4423.57N	29531.7N
Double support	6559.27N	18140.8N

The combined loads on the shaft, discussed in the methodology, is reduced by 1.63 times just by adding a support bearing on the other side of the pulley.

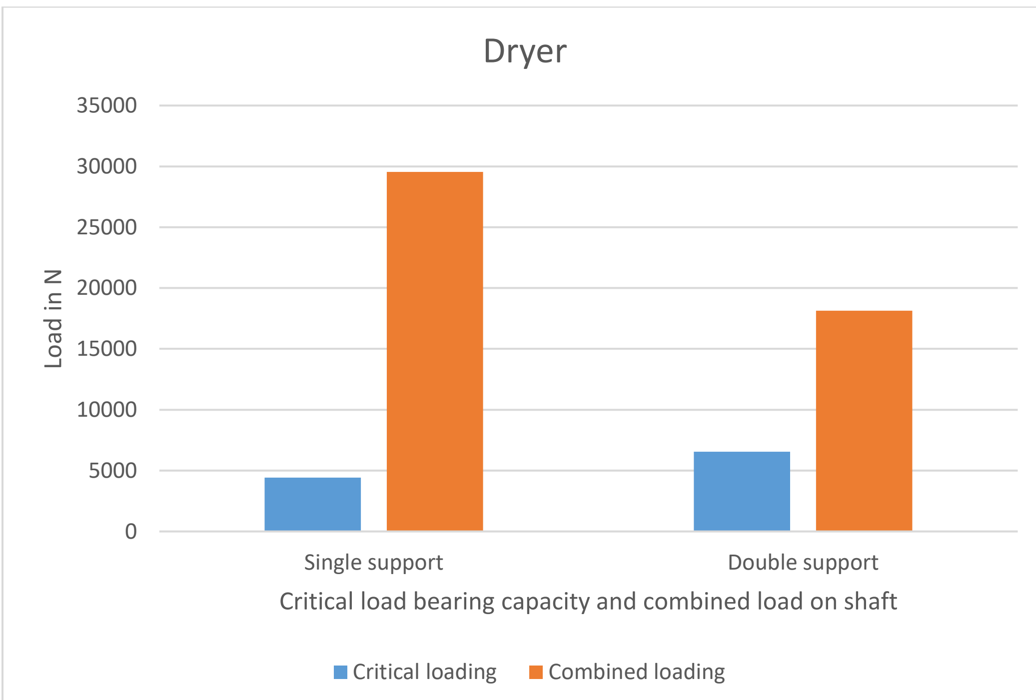

Figure 16 Load comparison on dryer

This higher critical load and lower combined loading suggests a potentially more robust structural response, indicating that the presence of an additional support system contributes to enhanced load distribution and resistance against bending and buckling-induced stresses.

For mixture machine:

The table below illustrates different load scenarios and their corresponding magnitudes for two distinct support configurations: single support and double support. The values in the table represent forces applied to a structure, categorized into two types: critical loading and combined loading.

1. Single Support Configuration:

- Critical Loading (3813.07N): In a single support configuration, when the structure is subjected to its most critical loading condition, the force applied is 3813.07 Newtons (N). This indicates the maximum force that the structure can withstand without experiencing failure under this specific loading scenario.

- Combined loading (74354.1N): In the single support configuration with combined loading, the structure is capable of enduring a cumulative force of 74354.1 N. This value accounts for the interaction of multiple loads acting simultaneously on the structure.

2. Double Support Configuration:

- Critical Loading (9631.46N): When the structure is supported at two points (double support), the critical loading force is 9631.46 N. This represents the maximum force the structure can bear without failing under the most critical loading condition for this particular setup.

- Combined loading (25169.3N): In the double support configuration with combined loading, the structure has the ability to withstand a combined force of 25169.3 N. This value encompasses the synergy of various loads acting concurrently on the structure.

From the results we can see that the combined buckling and bending load of the shaft by adding just two supports has decreased by 66.14%.

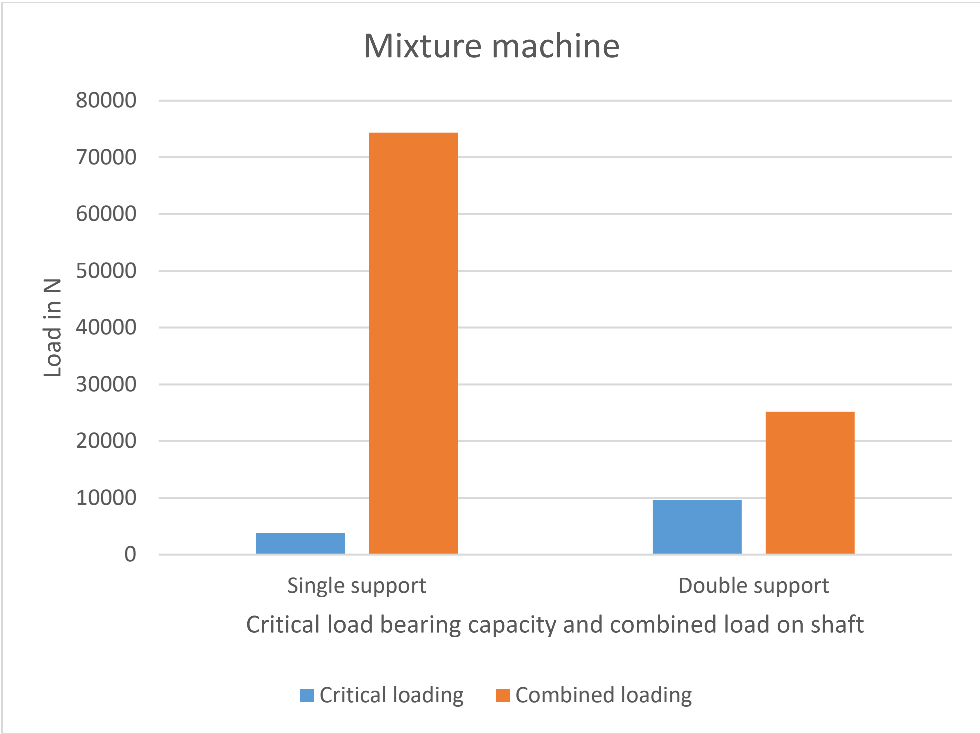

Figure 17 Load comparison on mixture machine

This higher critical load and lower combined loading suggests a potentially more robust structural response, indicating that the presence of an additional support system contributes to enhanced load distribution and resistance against bending and buckling-induced stresses.

5.1.2 Cost and Production capacities of different factories

This table below provides an overview of the production capacities of different industries, specifically detailing the amount of product (in kilograms) each industry produces per month. The "Production per Month" column reflects the total output of each industry over a month.

1. Balaju: This industry has a monthly production capacity of 5000 KG. It utilizes an extruder that operates once every three days, generating 500 KG of product per operation.

2. Pepsicola: Pepsicola's monthly production capacity is 10000 KG. They employ an extruder that runs once every three days, producing 1000 KG per operation.

Notably, this extruder operates for an extended period of 17 to 18 hours during each operation.

3. Hattiban: The monthly production capacity of Hattiban is 8000 KG. Similar to Balaju, they use an extruder that operates once every three days, resulting in a production output of 800 KG per operation.

4. GRIT: This industry boasts a monthly production capacity of 12750 KG. Their extruder operates once every two days, generating 850 KG per operation. Additionally, the machine operates for 10 hours during each cycle.

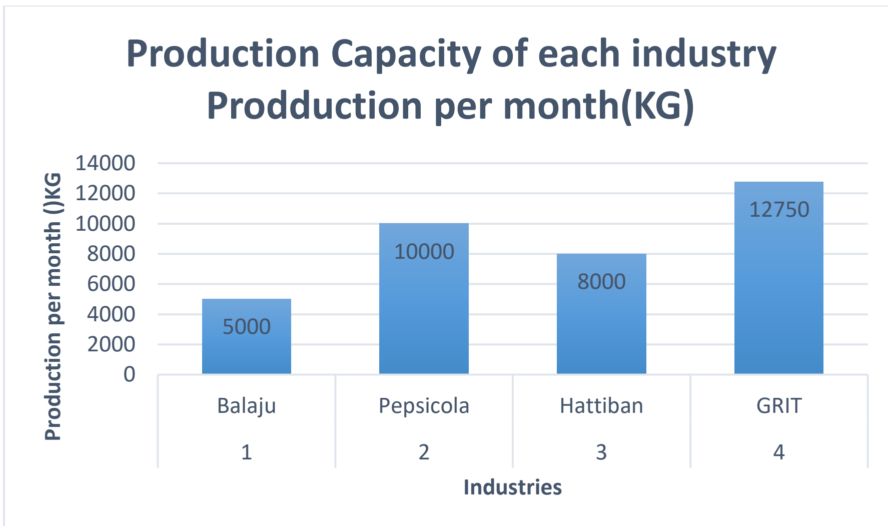

Figure 18 Total production capacity of each industry

Table 3 Total cost incurred in fabrication of machines

Cost of GRIT plastics Machines			
S.N.	Machine	Cost	Capacity
1	Granulator	225000	100 KG/HR
2	Dryer	175000	30 KG/BATCH
3	Mixture	225000	90 KG/HR
4	Extruder	1200000	90 KG/HR

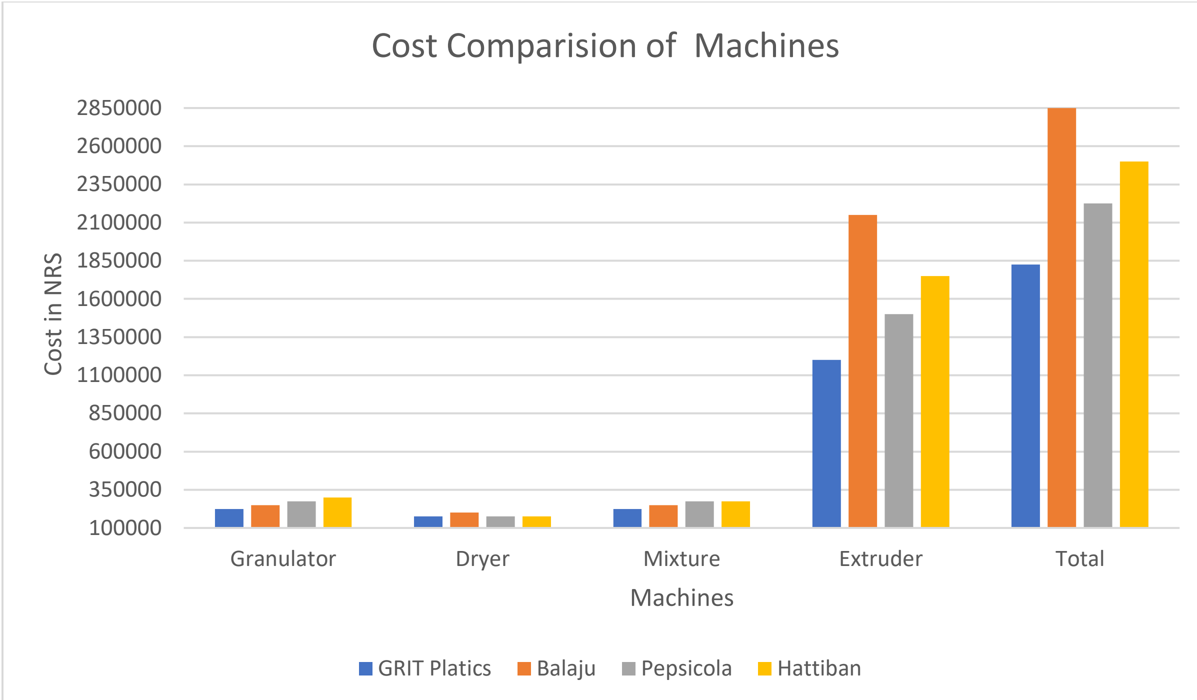

Figure 19 Cost comparison of machines

In the graph on figure 28, it can be observed that, in terms of granulator capacity (KG/HR), GRIT Plastics leads the pack with the highest capacity at 100 KG/HR, followed by Pepsicola Plastics and Hattiban Plastics, both at 70 KG/HR. Balaju Plastics offers a slightly lower granulator capacity of 50 KG/HR. When it comes to dryer capacity (KG/HR), GRIT Plastics and Balaju Plastics share the highest capacity at 30 KG/HR, while Pepsicola Plastics and Hattiban Plastics have a dryer capacity of 20 KG/HR. For mixture capacity (KG/HR), Pepsicola Plastics takes the lead with 100 KG/HR, while GRIT Plastics, Balaju Plastics, and Hattiban Plastics all provide a mixture capacity of 90 KG/HR. Finally, for extruder capacity (KG/HR), Pepsicola Plastics offers the highest capacity at 100 KG/HR, and the other three facilities, GRIT Plastics, Balaju Plastics, and Hattiban Plastics, all have an extruder capacity of 90 KG/HR. From this analysis is can be inferred that GRIT plastics have a competitive production capacity compared to the contemporary giant plastic manufacturers currently in the market.

Similarly, in the graph on figure 29, in terms of total cost (in Rs), GRIT Plastics emerges as the most cost-effective option, with a total expenditure of 1,825,000 Rs. This makes

GRIT Plastics an attractive choice for those looking to optimize their budget. Conversely, Balaju Plastics incurs the highest total cost among the four facilities, standing at 2,850,000 Rs, which may be less economical for those with budget constraints. Pepsicola Plastics and Hattiban Plastics fall in between, with total costs of 2,225,000 Rs and 2,500,000 Rs, respectively. It can be inferred that despite the cost being lowest, GRIT plastics has among the highest production capacity.

Table 4 Maintenance comparison in machines across factories

S.N.	Name of Factory	Machine	Regular Maintenance cost (per Month)	Breakdown Maintenance Cost (per year)	Machine idle time (per month in hours)
		Granulator	6000	15000	20
		Dryer	2500	5000	8
		Mixture	4500	10000	10
		Extruder	5000	10000	200
		Granulator	10000	13000	30
		Dryer	3000	6000	8
		Mixture	4500	10000	14
		Extruder	6000	15000	150
		Granulator	7000	12000	45
		Dryer	2500	6000	10
		Mixture	5000	12000	14
		Extruder	5500	18000	150
		Granulator	5000	8000	20
		Dryer	500	2500	3
		Mixture	2000	8000	8
		Extruder	2000	12000	125

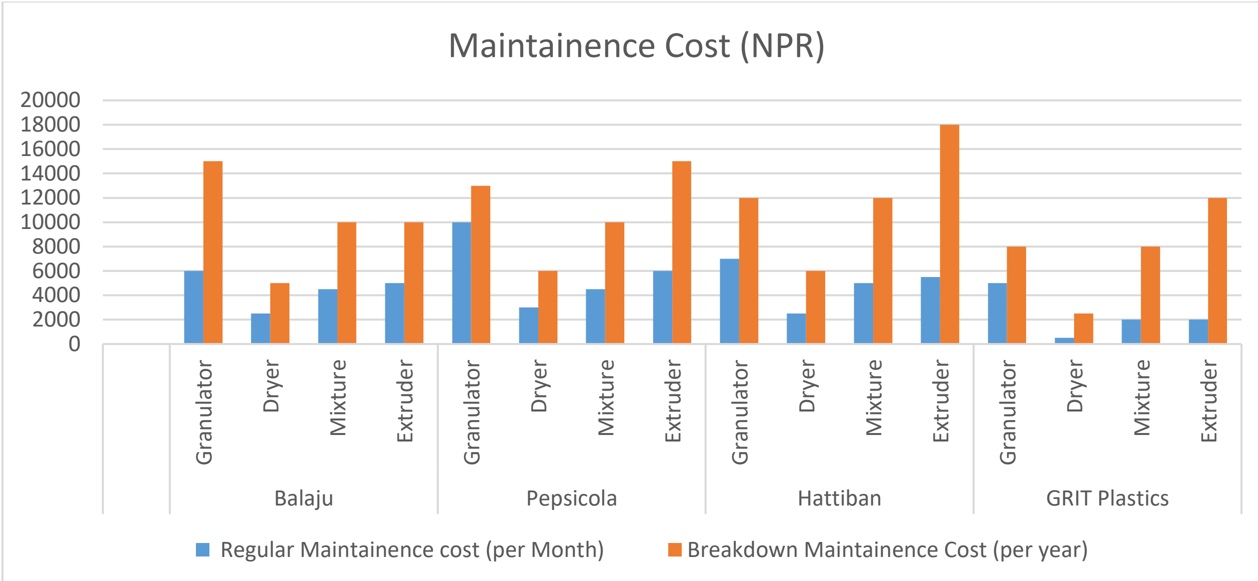

Figure 20 Maintenance cost comparison

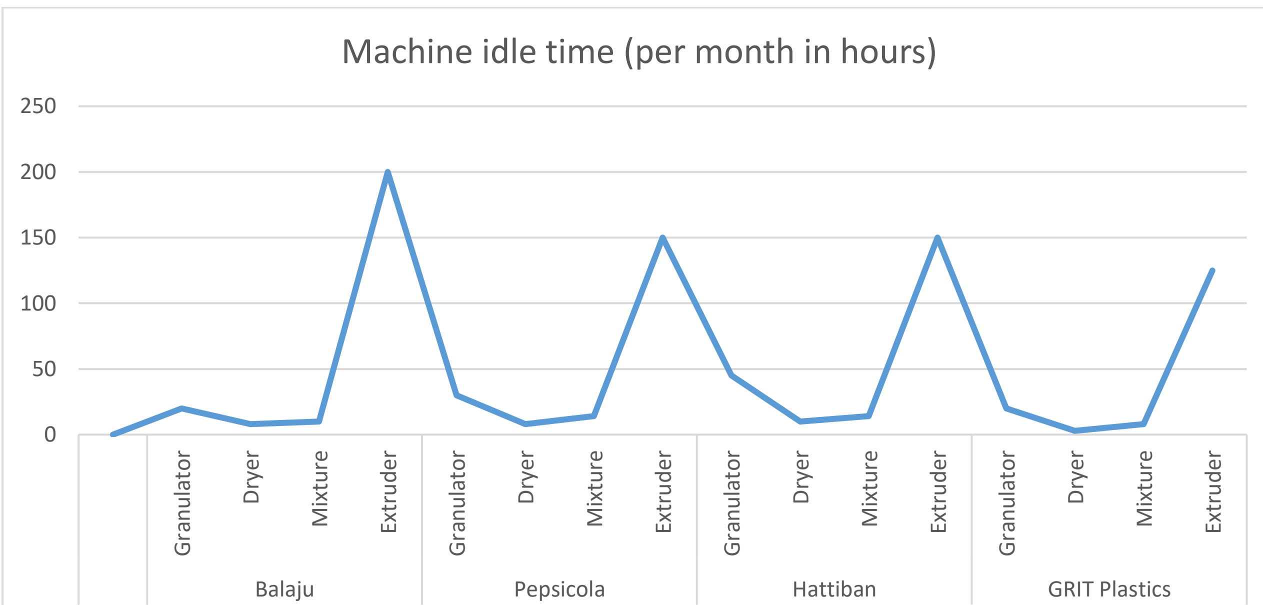

Figure 21 Machine idle time comparison

When examining maintenance costs across various machines in different factories, notable patterns emerge. In terms of Granulator maintenance, Pepsicola consistently incurs the highest monthly and annual expenses, followed by Hattiban and Balaju. Balaju generally maintains relatively lower costs for most machines, while GRIT Plastics consistently displays lower monthly and annual maintenance costs across several machines. For Dryer maintenance, Balaju and Hattiban share similar monthly expenses, with GRIT Plastics having notably lower costs. In Mixture maintenance, Balaju and Pepsicola's monthly and annual expenditures match closely, while Hattiban's costs are slightly higher, and GRIT Plastics maintains lower expenses.

In Extruder maintenance, Pepsicola faces higher monthly and annual costs, followed by Hattiban and Balaju, while GRIT Plastics exhibits lower costs. These variations in maintenance expenses underscore the significance of cost considerations when making decisions about factory operations, complementing capacity evaluations for a comprehensive assessment. GRIT plastics consistently shows lower maintenance cost in various machines involved in plastic recycling.

When the machine idle times were examined across these factories, a clear pattern emerges. GRIT Plastics consistently stands out for its efficient use of various machines, particularly the Granulator, Dryer, and Mixture machines. This means that GRIT Plastics manages to keep these machines active and productive for more hours each month compared to the other factories. It reflects their effective production scheduling and resource management in these areas, potentially resulting in higher overall production output and cost savings.

On the other hand, Balaju faces a significant challenge with its Extruder machine, which experiences the highest idle time among all the factories. This extended downtime can lead to production delays, resource underutilization, and increased operational costs. In contrast, GRIT Plastics demonstrates the most efficient utilization of the Extruder, ensuring that it remains operational for more hours each month than its counterparts.

These findings underscore the critical importance of optimizing production schedules and resource management practices within each factory. Efficient machine utilization not only enhances manufacturing productivity but also plays a crucial role in controlling costs and meeting production demands effectively. As such, factories should closely monitor and adjust their production schedules and maintenance routines to minimize idle time and maximize operational efficiency.

5.2 Financial Analysis

5.2.1 Cost Benefit Analysis

The data collected was used to perform a cost benefit analysis. Simple formulas were used to calculate deliverables and calculation was performed on MS-Excel. The data of costs obtained from the industry is presented below:

Table 5 Variable costs incurred

Capital Cost	Rs. 65,00,000(One-time only)
Electricity Cost	38,500+13500(Demand Charge) = Rs. 52,000
Labor Cost	Rs. 1,70,000
Raw Material Cost	Rs. 9,62,500
Land Lease	Rs. 18,000
Water	Rs. 12,500
Machine Maintenance	Rs. 10,000
Liquid Detergent	Rs. 25,000
Packing Cost	Rs. 6,250
Transportation Cost	Rs.12, 500

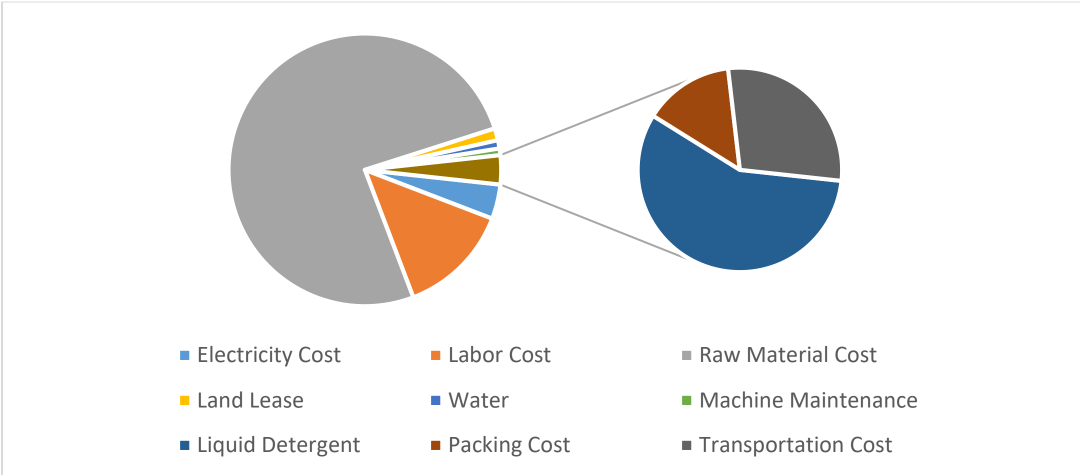

Figure 22: Pie chart depicting percentage of each costs incurred monthly

Calculation of Benefit Cost ratio:

Then we proceeded to calculate the benefit cost ratio. The sum total of costs per month was listed and then it was calculated for an annual basis. Then Net Present Value (NPV) analysis was done to find cost and benefit for the period of 2022-2027. The calculations were performed in MS-Excel.

With the discount rate of 13%, Net present Value for Cost From 2022- 2027 is,

NPV of Cost= Rs. 62,321,340

NPV of Benefit = Rs. 69,715,398

Benefit Cost Ratio = (Present value of future Benefits)/ (Present value of future Cost)

= 1.11 > 1

Hence, Cost Benefit Analysis calculation shows the project is feasible.

5.2.2 IRR

IRR is a financial measure used to calculate the attractiveness of the project. It is usually evaluated before investing. IRR value in this case is calculated in MS-Excel using the formula,

= IRR (Values (yearly cash flow))

The obtained value is 18%. Which is a very good result for a company. This value states that the investment made in the factory should yield an 18% return, annually, over the time we hold it.

5.2.3 Payback Period

Payback period is also a measure used for financial analysis of an investment. With the capital cost of 6,500,000 and yearly income of 1,925,000, the payback period is calculated to be 3.37. This shows that the payback period for the investment is 4 years.

CHAPTER SIX
CONCLUSION

Plastic is one of the essential commodities in our current lives. Its demand and usage have been skyrocketing as time goes by. However, plastic, being non-biodegradable, is a massive challenge for the environment. The plastic recycling industry can be a crucial part of reducing plastic waste and protecting the environment. This case report provides an overview of the current state of the plastic recycling industries in Kathmandu valley. Three different factories located within the Kathmandu valley were studied in detail. The machines that are being used and the problems faced in these recycling industries were observed. Because of the use of under designed mechanical components and weak technology, the machines encountered frequent breakdown causing huge amount of time and money loss.

The break down pattern of individual machines were taken into account. After detailed research, the machines were redesigned. In reference to the existing machines, the component that were prone to damage like shaft and bearings were calculated using the engineering formulae. Some upgrades were done to make the function of the machines easier like changing the shape of strainer in granulator machine, threading the shaft for easier assembly process, increase in production capacity of dryer etc.

After the machines were redesigned, numerical evaluation was conducted. The evaluation showed that after changing the type of bearing (i.e., ball bearing to tapered roller bearing), the dynamic and static load bearing capacity was increased by 2.13 times and 2.64 times respectively in comparison to existing machines. Furthermore, in the dryer machine, the addition of additional bearing support increased critical loading by 1.48 times while decreasing combine loading by 1.63 times. Similarly, in mixture machine critical loading was improved by 2.53 times and combined loading decreased by 2.95 times.

As per the 3D design of the machines, they were fabricated in a manufacturing yard. The fabricated machines were then operated in normal conditions and compared to the performance of existing machines. This showed significant reduction in breakdown frequency and maintenance cost. Additionally, the production capacity of the end product obtained from these machines were also in the highest numbers. Also being manufactured locally, the manufacturing cost of the machines were low. The results of comparative analysis of regular maintenance cost, machine idle and breakdown maintenance cost highlights the efficacy of redesigned plastic recycling machines.

To assess the feasibility of the project, a financial analysis was conducted. Benefit-Cost Ratio, IRR and Payback Period were calculated. The Benefit-Cost Ratio was found to be 1.11, indicating that the project is economically viable. The Internal Rate of Return reached 18%, and the Payback Period was a mere four years.

This research not only addresses critical technological gaps in the plastic recycling industry but also provides a robust economic case for the adoption of the proposed improvements. It serves as a valuable resource for policymakers, industry stakeholders, and researchers seeking sustainable solutions in plastic recycling.

CHAPTER SEVEN

RECOMMENDATIONS

The findings and conclusions received from the comprehensive research suggests a series of recommendations that could be implemented to enhance the operational efficiency, sustainability and environmental responsibility of recycling industries. By implementing these recommendations recycling sectors could strive toward energy conservation reducing waste and resource consumption.

- Improve manufacturing process to reduce hydraulic head leaks in extruder machine, thus improving the overall efficiency and sustainability of the operation.
- Perform analysis through energy audit in recycling industries aiming to identify energy conservation opportunities. This can include optimizing machineries and improving insulation. This will result low energy consumption with reduced environmental impact.
- Partake an environmental analysis that evaluates the ecological impact of the recycling operation, assessing compliance with regulations, and identifying potential risks to the environment.

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APPENDIX

A. IMAGES FROM SITE SURVEY

Figure 23 Granulator of Balaju plastic industries

Figure 24 Conveyer washing system

Figure 25 Detachable small capacity dryer machine

B. IMAGES OF FABRICATED MACHINES

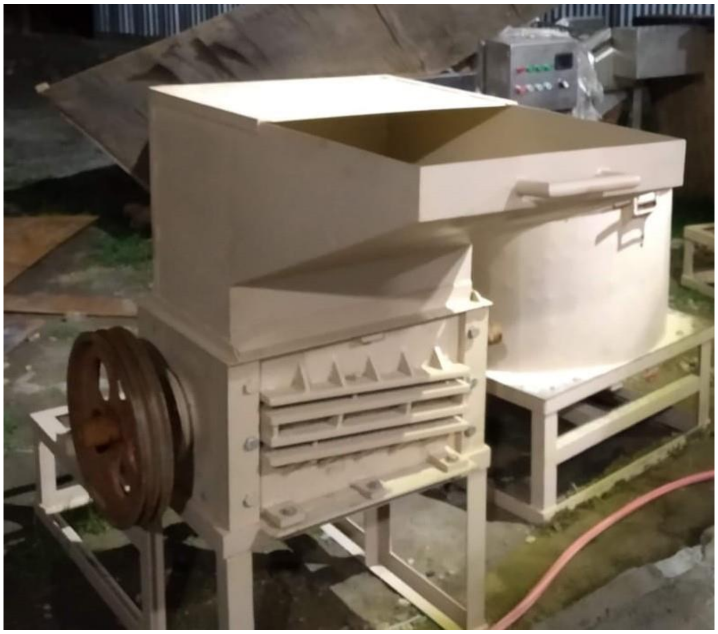

Figure 26 Fabricated granulator machine

Figure 27 Inner cylinder fabrication

Figure 28 assembly of inner cylinder

Figure 29 Mixture blades during fabrication

Figure 30 Extruder along with hydraulic head setup

Figure 31 Leakage in hydraulic head system