DESIGN AND FABRICATION OF POLYMER MELTING AND PELETIZING MACHINE

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SUPERVISOR: ENGR, N.O IGBINOMWANHIA

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CERTIFICATION

I hereby certify that this project work was carried out by USIOSEFE EMWANTA VICTOR, UWANDI CHIBUIKEM GOODNESS, EHIDIAMENTOR UGBOGBO, UCHE STEPHEN, MICHAEL OYAREKUA,……………………..in the Department of Materials and Metallurgical Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

This project work is dedicated to Almighty God, our Lord and creator, to our loving parents, our project supervisor, Engr, N.O Igbinomwanhia, and to all our lecturers in the department for making the journey seems easy and for all their immeasurable support and contributions in our lives.

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First and foremost, I offer my deepest gratitude to Almighty God for His unwavering guidance, strength, and blessings throughout the duration of this project. Without His grace, this endeavor would not have been possible.

I extend my sincere appreciation to my esteemed project supervisor, **Engr, N.O Igbinomwanhia** for his invaluable guidance, expertise, and unwavering support. His insightful feedback, constructive criticism, and patient mentorship were instrumental in shaping the direction and success of this project. I am truly grateful for their dedication and commitment to my academic growth.

My heartfelt thanks go to my beloved family, whose unconditional love, encouragement, and sacrifices provided me with the motivation and resilience needed to overcome challenges. Their unwavering belief in my abilities served as a constant source of inspiration.

Finally, I would like to express my sincere gratitude to my friends, whose unwavering support, understanding, and camaraderie made this journey more enjoyable and manageable. Their encouragement and willingness to lend a helping hand were invaluable throughout the project.

This project is a testament to the collective support and guidance I have received, and I am deeply grateful to everyone who contributed to its completion**.**

ABSTRACT

This project report presents the design, implementation, and performance evaluation of an innovative plastic pelletizing machine engineered to address the escalating challenge of plastic waste management. The core advancement of this machine lies in its hybrid preheating system, which synergistically combines a high-efficiency gas burner for rapid initial temperature elevation and a precision electric heater for sustained, uniform heat distribution.

This dual approach significantly enhances the machine's ability to process a wide spectrum of waste plastics (PPT), optimizing melt homogeneity and minimizing thermal degradation. A detailed analysis of the machine's key components, including the automated feeding hopper, optimized extrusion barrel and screw design, multi-stage filtration system, precision pelletizing unit, and efficient cooling mechanism, is provided. Emphasis is placed on the dual preheating system's ability to achieve significant energy savings by leveraging the rapid heating capabilities of the gas burner and the precise control of the electric heater.

The operational procedures, including material preparation, preheating, extrusion, pelletizing, and cooling, are outlined, along with critical safety considerations and maintenance protocols. The project concludes with a comprehensive assessment of the machine's potential applications in plastic recycling facilities and manufacturing industries, highlighting its contribution to sustainable plastic recycling practices through the production of high-quality, reusable pellets and its role in fostering a circular economy.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Raw materials employed in engineering and technology can be classified as either natural (derived from renewable and abundant sources) or synthetic (produced through subsequent transformation) (Alaba and Nicole, 2016). Natural materials, such as rubber sourced from the latex of rubber trees, have historically played a significant role in the manufacturing of polymer-based products including chairs, kitchenware, automobile tires, and various accessories. Recent advancements in recycling technology have facilitated the reclamation of numerous household and industrial polymer products, thereby reducing reliance on natural rubber plantations, which have been adversely impacted by deforestation and other anthropogenic and environmental factors

Polymeric waste derived from utilized polymeric commodities such as aqueous and beverage polyethylene terephthalate containers, automotive components, polymeric carrying bags, among others, serves as the foundational material for the recycling process into novel products. The utilization of rubber encompasses over 40,000 consumer goods, which includes in excess of 400 medical apparatuses, attributable to its distinctive characteristics, such as resilience, elasticity, resistance to abrasion and impact, effective thermal dissipation, and malleability at low temperatures (Cornish, 2001). Nonetheless, polymeric products have also played a significant role in the exacerbation of environmental degradation due to their indiscriminate disposal in drainage systems and public locales across numerous urban areas globally, particularly in regions such as Nigeria, where the presence of polymeric waste in various environments is a prevalent occurrence, as illustrated in Figure 2.1.

Figure 1.1 Waste polymer bottles

It is projected that as of the year 2015, an estimated 6300 Mt of plastic waste was produced, with approximately 9% of this quantity being subjected to recycling, 12% incinerated, and 79% accumulating in landfills or the broader natural environment. Should this trend persist, it is anticipated that by the year 2050, nearly 12,000 Mt of plastic waste will reside in landfills or within the natural environment. (Osifo, 2021). This scenario will, in turn, exert significant consequences on both human and environmental systems. In light of this reality, it has become imperative to establish effective methodologies for the recycling of polymers. The current investigation is directed towards the creation of a thermal polymer pelletizing apparatus capable of converting polymer waste through thermal processes into diminutive materials that can be readily utilized as raw inputs for the fabrication of various finished goods. The process of melting polymers, such as rubber and plastic, necessitates the application of heat to the polymer substance at temperatures that meet or exceed their melting points, thereby transforming them into a liquid state that can subsequently be poured and extruded through a die to produce pellets. The pellets generated from this process serve as raw materials for additional processing into valuable and economically relevant polymer products, including polyethylene bags, polymer footwear, automotive components, as well as domestic and industrial facilities and equipment.

1.2 Statement of the problem

The application of polymers represents a significant financial commitment globally, particularly in light of the substantial waste generated from polymer materials, which possess the potential for reprocessing (recycling) into novel products. Contemporary recycling methodologies have facilitated the capacity to reclaim considerable quantities of waste polymer items, including plastic PET bottles. This advancement has yielded a beneficial effect in mitigating extensive polymer waste, particularly in developed nations; however, the same cannot be asserted for Nigeria, where plastic materials continue to produce significant volumes of waste within communities. Consequently, it has become imperative, through rigorous research and development, to investigate small-scale recycling initiatives aimed at the transformation of plastic waste into economically valuable products. This transformation can be achieved through the deployment of small-scale plastic melting and pelletizing machinery, which is capable of converting waste plastics into pellets that can serve as raw materials for subsequent processing into new polymer products.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this project is to design and fabricate a small scale plastic recycling machine that can be used for the melting and pelletizing of plastic waste in the Department of Materials and Metallurgical engineering, University of Benin, Benin city.

1.3.2 Objectives

The objectives of this project are;

i. To carry out conceptual designs of plastic melting and pelletizing machine.
ii. To fabricate a plastic melting and pelletizing machine prototype.
iii. To test and carry out performance evaluation of the machine.

1.4 Significance of study

There exists a substantial quantity of plastic waste in Nigeria, which presents a significant financial opportunity for potential investors in the recycling of polymer waste into economically viable products. Recent governmental policies have culminated in restrictions on the importation of foreign goods; thus, the imperative for the cultivation and reliance on indigenous raw materials and products, utilizing locally developed technology, such as the fabrication of recycling machinery, is of paramount importance. The initiative to enhance local content in Nigeria necessitates an augmentation through the investigation of indigenous natural resources and technical expertise. This objective will be significantly bolstered through the domestic production of machinery, including devices for plastic melting and pelletizing. The current study aims to investigate and elucidate areas requiring substantial enhancement in plastic recycling within Nigeria, utilizing the Department of Materials and Metallurgical Engineering as a case study to promote the generation of economically viable raw materials and polymer products via thermal decomposition and pelletizing.

1.5 Methodology

The method adopted to achieve the aim and objectives of this research are as follows.

i. Design of experiment.

ii. Conceptual design.

iii. Detail design

iv. Fabrication of prototype.

v. Testing and evaluation of prototype.

1.6 Scope of study

The scope of the present work is limited to the selection of plastic wastes that can be easily melted and pelletized to meet small scale plastic recycling. Though there are various types of polymers, the present project will be focussed on the recycling of plastic wastes found around in the Nigeria environment and which can be easily melted and pelletized as raw materials or converted into other economically viable finished products.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Concept of Polymer

The history of natural rubber production in Nigeria began in 1894 with the exploitation of Funtumia elastic, indigenous wild rubber (Owen, (2013), The wild trees that yielded rubber were, however, ruined by poor tapping systems, and the export of wild rubber dropped sharply. In search for sources of natural rubber to supply the demand of a rapidly expanding automobile industry, Heavea brasiliensis (Muell Arg.) was found to be the best source of the plant because of its singular ability to renew its bark and thus ensure a sustained harvest.

The annual worldwide polymer production from natural rubber production is estimated to be close to 8,800,000 tons virtually all of which are from one biological source, the Brazilian rubber tree (*Hevea brasiliensis*) which produces latex. Malaysia, Indonesia, and Thailand together produce nearly 80% of the world supply of natural rubber. (Jan, 2006). The yield of rubber varies from 500 kg ha-1 y-1 in smallholder plots to more than 1500 kg ha-1 y-1 in large plantations (Balsiger *et al.*, 2000). Figure 2.1 shows a graphical view of natural rubber tree and the rubber latex.

Figure 2.1 Rubber tree and the latex

Rubber was introduced into Nigeria from Kew Gardens, England around 1895 with the first rubber estate planted at Sapele in 1903 and a second one at Nkisi in the then eastern region in 1912. By 1925, some 1,000 hectares of European owned estates existed in Southwestern Nigeria (Uraih, 1980). Rubber is grown in Edo, Delta, Ondo, Ogun, Abia, Anambra, Akwa Ibom, Cross River, Rivers, Ebonyi, and Bayelsa States where the amount of rainfall is between 1,800 mm and 2,000 mm per annum (Aigbekaen, Imarhiagbe, & Omokhafe, 2000).. In 1909, a team headed by Fritz Hofmann, working at the Bayer laboratory in Elberfeld, Germany, succeeded in polymerizing isoprene, making the first synthetic rubber. (Desmond et al, 2011). Rubber is used in over 40,000 consumer products, including more than 400 medical devices, due to its unique properties, which include resilience, elasticity, abrasion- and impact-resistance, efficient heat dispersion, and malleability at cold temperatures (Cornish, 2001).

Many decades of industrial research have not produced synthetic rubbers with similar qualities. While the amount of synthetic rubber produced has reached a plateau, natural rubber production is steadily increasing.

In a few years from now, natural rubber production could in fact exceed the synthetic rubber market share, which is currently put at 60%. Another issue is that synthetic rubbers are derived from petroleum, a non-renewable resource. A decline in global oil production may begin within the next 10 to 20 years (Hirsch *et al.*, 2006), leading to sharply increasing prices of synthetic rubbers. With respect to all these, there is the need to produce useful domestic and commercial products from natural rubber for the creation of wealth and satisfaction of human wants using viable, cheap and local methods of processing and conversion.

2.2 Rubber types

Rubber used today generally falls into two main categories: natural and synthetic rubber. Natural rubber is derived from the rubber tree (Hevea brasiliensis). When the tree reaches maturity, typically around six or seven years of age, latex is harvested by making a diagonal cut in the trunk.

2.2.1 Natural Rubber

Natural rubber, sourced from Hevea brasiliensis, can only be cultivated in regions that share the climate of the Amazon rainforest—specifically within 15 to 20 degrees north or south of the equator. Rubber trees require 5 to 8 years to grow to a suitable size for tapping, after which they have an economic lifespan of 20 to 30 years. Once their productive life ends, the trees yield rubber wood, a useful medium-density tropical hardwood.

Rubber is harvested in the form of latex—a white, milky fluid stored in cells within the inner bark. The extraction process, called tapping, involves carefully removing a thin layer of bark in a series of half-spiral cuts using a specialized knife, without harming the tree's growing tissue. This allows latex to slowly flow into collection cups for several hours, until it begins to coagulate and stops flowing.

After collection, the latex, which consists of about 70% water, is transported to a processing facility. There, it is sieved to eliminate impurities, blended, coagulated, rolled into sheets, and finally dried in smokehouses to create what is known as ribbed smoked sheets (RSS).

2.2.2 Synthetic Rubber

There are more than 200 types of synthetic rubber, each with distinct components and properties. Despite these differences, all are created through the process of polymerization, where monomers chemically bond to form polymers. This process transforms monomers—typically in liquid or gaseous form—into materials like rubber, plastic, or fiber, depending on their chemical composition.

A common example is styrene-butadiene rubber (SBR), which represents about 37% of global solid synthetic rubber production. SBR is produced from two monomers: styrene (a liquid) and butadiene (a gas), both primarily derived from petroleum. Styrene is typically synthesized from ethylbenzene, which can either be extracted from petroleum streams or produced from ethylene and benzene. Butadiene is sourced through various methods, often from refinery gases or by cracking larger hydrocarbon molecules using heat and catalysts.

The polymerization of styrene and butadiene also uses a catalyst and can occur via two main methods: emulsion polymerization (where monomers are dispersed in water) or solution polymerization (in an organic solvent). Any unreacted monomers are recovered. The resulting polymer, initially in latex form, is coagulated into crumbs, then screened, washed, and filtered. Finally, the crumbs are dried in a hot-air dryer, baled, and packed in polythene bags for distribution.

2.3 Plastic

The term "plastic" originates from the Greek word plastikos, meaning "capable of being shaped or molded." It refers to a broad range of synthetic or semi-synthetic materials based on polymers—large molecules composed of repeating monomer units (Threadingham et al., 2011). These polymers give plastics their well-known flexibility and moldability.

The characteristics of various plastics are determined by polymer chemistry; differences in monomer types, chain length, and molecular structure result in materials with distinct properties such as strength, flexibility, and heat resistance (Crawford, 1998). Plastics are generally divided into two main categories: thermoplastics, which can be repeatedly melted and reshaped, and thermosets, which permanently harden after curing due to irreversible chemical changes.

Plastics have their origins in natural polymers like rubber and shellac (Cornish, 2001). The first semi-synthetic plastic, Parkesine, was developed by Alexander Parkes in 1862, and was followed by John Wesley Hyatt's celluloid in 1870. The invention of Bakelite by Leo Baekeland in 1907 marked the beginning of fully synthetic plastics, notable for their durability and electrical insulation (Desmond et al., 2011). Throughout the 20th century, plastic innovation expanded rapidly, with materials such as PVC, polystyrene, polyethylene, nylon, and Teflon becoming widely used across various industries (Ugoamadi and Ihesiulor, 2011).

During World War II, plastic production surged due to the need for alternatives to scarce natural materials in military applications (Osifo, 2021). In the post-war era, plastics became ubiquitous in consumer products, favored for their affordability and ease of mass production. However, their resilience has contributed to a global environmental issue: plastics now accumulate in landfills and oceans, threatening ecosystems. Microplastics have infiltrated the environment and food chain, raising public health concerns (Bruvoll, 2001). Additionally, the heavy reliance on fossil fuels in plastic manufacturing intensifies natural resource depletion and greenhouse gas emissions (Hirsch et al., 2006).

Although recycling presents a possible remedy for plastic waste, the diverse composition of plastics and insufficient recycling infrastructure continue to hinder its effectiveness (Okiy et al., 2018). In response to mounting environmental concerns, efforts are intensifying to develop sustainable alternatives, such as biodegradable and bio-based plastics, and to support a circular economy that emphasizes reuse and recycling (Balsiger et al., 2000). Emerging technologies like chemical recycling—which can decompose plastics back into their original monomers—offer promising solutions (Spilka et al., 2008).

At the same time, a global shift in consumer behavior is underway, with governments and businesses enacting bans on single-use plastics and advocating for more responsible consumption habits (Cointreau-Levine and U.M. Program, 1994). The root of plastic's versatility lies in its name—derived from the Greek plastikos, meaning "moldable" (Threadingham et al., 2011). This moldability is made possible by its polymer-based structure, composed of long chains of repeating monomers. Differences in polymer structure—such as the type of monomers used, chain length, and molecular arrangement—determine a plastic's characteristics, from rigidity to flexibility and from heat resistance to meltability (Crawford, 1998).

Plastics fall into two main groups: thermoplastics, which can be melted and reshaped multiple times, and thermosets, which harden permanently after curing and cannot be remelted. Human interaction with plastics began with naturally occurring polymers, like those found in rubber and shellac (Cornish, 2001). The era of synthetic plastics began with Alexander Parkes's invention of Parkesine in 1862, followed by John Wesley Hyatt's development of celluloid in 1870. The creation of Bakelite by Leo Baekeland in 1907 marked the first entirely synthetic plastic, known for its durability and insulating properties (Desmond et al., 2011).

The 20th century brought rapid advancements in plastic technology, leading to the creation of materials such as PVC, polystyrene, polyethylene, nylon, and Teflon—all of which became integral across multiple industries (Ugoamadi and Ihesiulor, 2011). World War II significantly boosted plastic production as synthetic alternatives were needed to replace limited natural resources for military use (Osifo, 2021). In the post-war period, plastics became deeply embedded in consumer culture due to their affordability, adaptability, and ease of mass production.

However, the same durability that made plastics so useful has created a global waste issue. Plastic debris now clogs landfills and pollutes oceans, endangering wildlife and ecosystems (Bruvoll, 2001). Microplastics are now widespread in the environment, raising alarms about their potential entry into the human food chain and the implications for health. The fossil fuel-intensive nature of plastic production also contributes to environmental degradation through resource depletion and greenhouse gas emissions (Hirsch et al., 2006).

Although recycling can mitigate some of these problems, current systems face obstacles due to the complexity of plastic types and limited processing capabilities (Okiy et al., 2018). Growing awareness of plastic's environmental toll has spurred the development of greener materials—like biodegradable plastics from renewable sources—and stronger efforts to promote a circular economy (Balsiger et al., 2000). Innovations like chemical recycling add to the arsenal of solutions by allowing plastics to be broken down and reused at a molecular level (Spilka et al., 2008).

Equally crucial is the societal shift toward more sustainable behavior, with increasing bans on single-use plastics and encouragement of eco-conscious consumer choices (Cointreau-Levine and U.M. Program, 1994). Tackling plastic pollution requires an integrated strategy—one that unites technological progress, regulatory reforms, and individual action to reduce environmental damage and build a more sustainable future.

2.3.1 Types and Properties

Plastic is not a singular material but a vast family of polymers, each with unique properties determined by its molecular structure. These properties dictate their suitability for specific applications.

Thermoplastics: These plastics can be repeatedly melted and remolded, making them recyclable.

- **Polyethylene Terephthalate (PET or PETE):**

Properties: Clear, strong, lightweight, good barrier properties.

Applications: Beverage bottles, food containers, synthetic fibers (polyester).

Pros: Widely recyclable, good strength-to-weight ratio.

Cons: Potential for leaching with repeated use, derived from fossil fuels.

- **High-Density Polyethylene (HDPE):**

Properties: Rigid, durable, chemical-resistant, high tensile strength.

Applications: Milk jugs, detergent bottles, pipes, toys.

Pros: Recyclable, resistant to chemicals, durable.

Cons: Derived from fossil fuels.

- Polyvinyl Chloride (PVC or Vinyl):

Properties: Versatile, can be rigid or flexible, durable, weather-resistant.

Applications: Pipes, window frames, flooring, cables, medical tubing.

Pros: Durable, versatile, low cost.

Cons: Contains chlorine, releases dioxins when burned, often contains phthalates (plasticizers).

- **Low-Density Polyethylene (LDPE):**

Properties: Flexible, soft, transparent, low melting point.

Applications: Plastic bags, cling wrap, squeeze bottles.

Pros: Flexible, low cost, easy to process.

Cons: Difficult to recycle due to thinness, derived from fossil fuels.

- **Polypropylene (PP):**

Properties: Strong, heat-resistant, chemical-resistant, fatigue-resistant.

Applications: Food containers, bottle caps, automotive parts, textiles.

Pros: Recyclable, durable, heat-resistant.

Cons: Derived from fossil fuels, can become brittle at low temperatures.

- **Polystyrene (PS):**

Properties: Rigid, brittle, lightweight, good insulation properties.

Applications: Disposable cups, plates, packaging foam (Styrofoam).

Pros: Low cost, good insulation.

Cons: Difficult to recycle, releases harmful chemicals when heated, brittle.

Thermosets: These plastics undergo irreversible chemical changes during curing, making them non-recyclable.

- **Polyurethane (PU):**

Properties: Versatile, can be rigid or flexible, good insulation properties.

Applications: Foam insulation, furniture cushions, automotive parts, coatings.

Pros: Versatile, good insulation.

Cons: Difficult to recycle, releases toxic fumes when burned.

- **Epoxy Resins:**

Properties: Strong, adhesive, chemical-resistant, durable.

Applications: Adhesives, coatings, composites, electronics.

Pros: Strong, durable, excellent adhesive properties.

Cons: difficult to recycle, and can contain harmful chemicals.

- **Bakelite (Phenolic Resins):**

Properties: Rigid, heat resistant, electrical insulating.

Applications: Electrical components, handles, knobs.

Pros: Heat resistant, good electrical insulator.

Cons: brittle, and difficult to recycle.

2.3.2 Applications of Plastics

The diverse properties of plastics have led to their widespread adoption in numerous industries:

1. Packaging: Food packaging, beverage bottles, films, and containers.
2. Construction: Pipes, windows, insulation, roofing materials.
3. Automotive: Interior and exterior components, dashboards, bumpers.
4. Electronics: Computer housings, circuit boards, cables.
5. Medical: Syringes, tubing, implants, prosthetics.
6. Consumer Goods: Toys, furniture, appliances, clothing.
7. Agriculture: Mulch films, irrigation pipes, greenhouse covers.

The Environmental Impact of Plastics

The very properties that make plastics so useful also contribute to their environmental problems:

Plastic Waste Accumulation: The durability of plastics means they persist in the environment for centuries, leading to the accumulation of plastic waste in landfills, oceans, and other ecosystems.

Marine Pollution: Plastic debris in oceans poses a severe threat to marine life through entanglement, ingestion, and habitat destruction. Microplastics, tiny plastic particles, are now pervasive in marine ecosystems, entering the food chain and potentially impacting human health.

Land Pollution: Plastic waste contaminates soil, affecting plant growth and potentially leaching harmful chemicals into groundwater.

Air Pollution: Incineration of plastic waste releases toxic fumes, including dioxins, furans, and heavy metals, contributing to air pollution and health problems.

Resource Depletion: Most plastics are derived from fossil fuels, contributing to the depletion of non-renewable resources and greenhouse gas emissions.

Microplastics: The breakdown of plastics into microplastics has caused contamination in almost every environment on earth, and has been found within the human body.

2.3.3 Sustainable Alternatives and Solutions

Addressing the plastic crisis requires a multi-pronged approach:

Reduce: Minimizing plastic consumption, particularly single-use plastics, through behavioral changes and policy interventions.

Reuse: Encouraging the reuse of plastic containers and products to extend their lifespan.

Recycle: Improving recycling infrastructure and technologies to increase recycling rates and reduce plastic waste.

Replace: Developing and promoting sustainable alternatives to traditional plastics:

Bioplastics: Plastics derived from renewable resources, such as cornstarch, sugarcane, and cellulose.

Polylactic Acid (PLA): Biodegradable plastic derived from cornstarch or sugarcane.

Polyhydroxyalkanoates (PHAs): Biodegradable plastics produced by microorganisms.

Paper and Cardboard: Biodegradable and recyclable packaging materials.

Glass and Metal: Durable and recyclable materials for containers and packaging.

Compostable Materials: Materials that break down into nutrient-rich compost under specific conditions.

Redesign: Implementing circular economy principles to design products for reuse, repair, and recycling.

Innovation: Investing in research and development of new sustainable materials and technologies.

Policy and Regulation: Implementing policies to reduce plastic production and consumption, promote recycling, and hold producers accountable.

Education and Awareness: Raising public awareness about the environmental impact of plastics and promoting sustainable consumption habits.

Extended Producer Responsibility (EPR): Making producers responsible for the end-of-life management of their plastic products.

Chemical Recycling: Technologies that break down plastic waste into its constituent

2.3.4 Polymer plastic recycling

Nigeria produces approximately 32 million tonnes of waste annually, with plastic waste accounting for about 2.5 million tonnes. However, the country’s waste disposal, recycling, and management infrastructure remains largely ineffective—around 70% of both plastic and non-plastic waste ends up in landfills, waterways, sewers, and along coastlines.

As Africa’s leading oil exporter, Nigeria has traditionally depended on oil revenues to drive its GDP and economic growth strategy (Iwapele, 2015). But with the decline in global oil prices and the rising volume of plastic waste, there is a growing global shift toward sustainable energy and development. This highlights an urgent need for Nigeria to embrace plastic waste recycling—not only as a means of environmental protection but also as a viable opportunity for wealth creation and economic diversification.

The recycling process of plastics entails various process stages which include the followings;

2.3.5 Collection of waste plastic material

This involves collection of plastics from wastes bins, eateries, restaurants etc. This process involves gathering waste plastic products (material) in a secluded place or enclosure such as waste bins or bags as shown in Figure 2.3.

Figure 2.2 Collected waste plastic

At this stage in the recycling chain, waste plastic products are gathered by employees or volunteers from various sources, including homes, offices, and public areas. In some communities, designated collection points are provided for plastic waste disposal. To simplify the collection process, some recycling organizations place special recycling bins in public spaces, residential neighborhoods, and industrial areas. These bins are specifically designated for plastics and are kept separate from general waste containers.

Once filled, the bins are collected and transported to recycling facilities for further processing. A common type of plastic involved in this process is PET (Polyethylene Terephthalate), which is widely used to package about 70% of carbonated drinks, juices, dilutable beverages, and bottled water. PET is considered a "safe" plastic, as it does not contain Bisphenol-A (BPA)—a chemical linked to health concerns when consumed in large amounts—making it ideal for use in food and beverage packaging.

As of 2022, large-scale collection efforts primarily focus on PET bottles. The primary drivers behind this recycling push include cost savings during spikes in oil prices and increasing pressure from regulations and public expectations for sustainability in retail packaging. While more PET is now being recycled back into new bottles, a significant portion is repurposed into fibers, plastic film, thermoformed packaging, and strapping materials.

After collection, the bottles undergo sorting, washing, and grinding to produce bottle flake. This flake is then subjected to either basic or physical recycling processes, depending on the intended end use.

2.4.2 Sorting of plastic into categories.

Once collected, the gathered plastic waste is transported to specialized facilities where it is sorted according to type. Since plastics vary widely in terms of size, color, thickness, and intended use, this sorting process is a crucial step. Plastics are typically categorized based on material properties, with color and resin content being key criteria used by recyclers.

Proper sorting is essential because it determines the specific recycling method suitable for each type of plastic. By accurately identifying the material composition, recyclers can ensure the plastic is processed effectively, improving the quality of the recycled product and the efficiency of the recycling operation.

2.3.3 Washing to remove impurities.

Following the sorting stage, the plastic materials are thoroughly washed to eliminate any impurities. These impurities can include paper labels, dirt, adhesive residues, and other foreign particles. Washing also helps remove residual chemicals that may be present on the plastic surfaces.

This cleaning process is vital because contaminants can compromise the quality of the recycled plastic and may even damage the machinery used in later stages of processing. Additionally, since these impurities are not plastic themselves, they are often non-recyclable and must be removed to ensure the integrity and safety of the final recycled product.

2.3.5 Shredding and grinding.

The next step after washing plastics is shredding. Recycling plastic is more efficient when it is in a shredded form, so the materials need to be resized into smaller, manageable pieces that can be easily processed further. During this stage, the plastics are fed into a shredder or grinding machine, which breaks them down into fragments or flakes, as illustrated in Figure 2.4

Figure 2.3 Shreded plastic

2.3.6 Compounding.

Compounding is the final stage in the plastic recycling process. During this phase, the shredded plastic fragments are melted and compressed to form small, uniform pellets. These pellets serve as raw material for manufacturing new plastic products. This process, also known as extrusion, transforms the recycled plastic into a usable form for further production. Notably, compounding is the most time- and energy-intensive step in the recycling chain.

2.3.7 Review of related Literatures

Okiy et al, (2018) carried out the design and construction of a pelletizing machine shown in Figure 2.5 which was used for recycling process of polymer by reducing the size and bulk density of waste polythene materials for ease of transportation and processing in the industry.

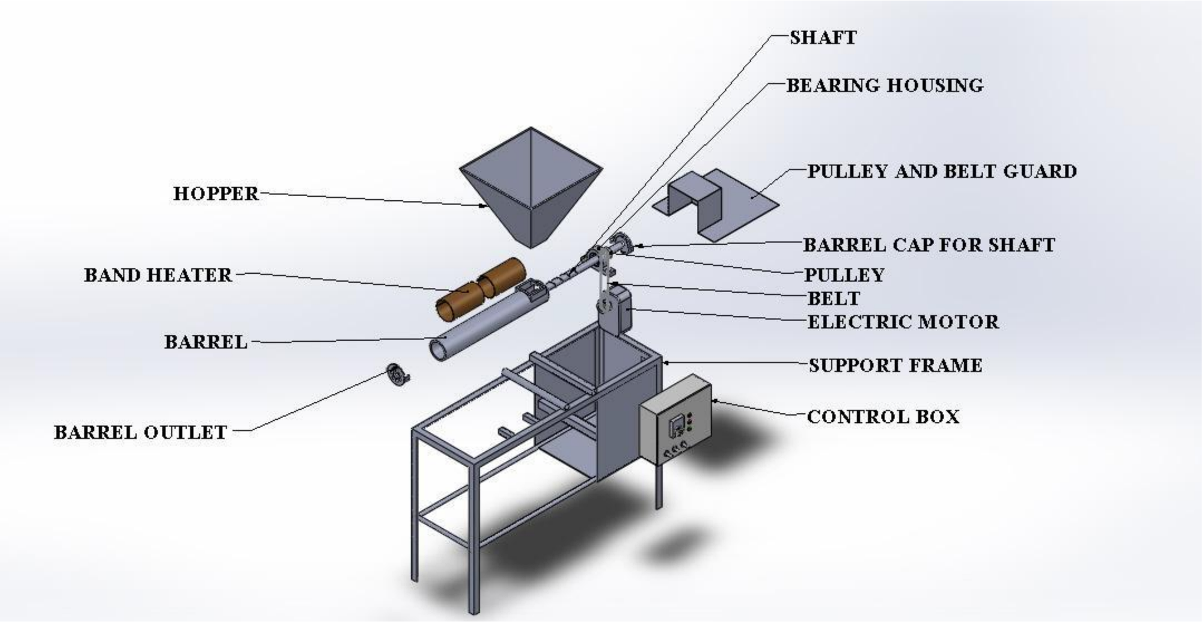

Figure 2.4 Okiy et al, plastic pelletizing machine

The pelletizing machine was designed and built with a screw-thread conveyor housed inside a barrel to transport molded polythene. The screw thread is powered by a belt drive system. The barrel is engineered to heat and shear low-density polyethylene (LDPE) at around 80°C. Waste polythene is fed into the machine through a feed hopper and then extruded through a die.

The output produced serves as valuable raw material for plastic industries. According to the authors, this machine is effective for managing polythene waste in urban areas of Nigeria. The pelletized material not only generates income by supplying raw materials to polythene manufacturers but also creates employment opportunities for local youth.

The main components of the pelletizing machine include the feed hopper, screw thread, barrel and feed throat, heating elements, skid (stand), die, DC motor, thrust bearing assembly, and a temperature controller equipped with a sensor.

Rauwendaal (2011) emphasized that the core part of a plastic pelletizing machine is the extruder screw, which is designed using a feed-forward technique to aid in heating the waste polythene. The screw is a cylindrical rod with a consistent outside diameter that rotates inside the hardened liner of the barrel. The ratio of the circular allowance to the screw diameter is approximately 0.001. As the screw turns, it pushes the resin forward through the channel, where it is heated, melted, and compressed out of the barrel.

The screw conveyor of a polymer pelletizer is divided into three zones:

- The feed zone, which pushes the polythene materials into the barrel,

- The melting zone, where the polymer melts, and

- The metering or conveying zone, which mixes the melted plastic to achieve a uniform temperature and composition.

Ugoamadi and Ihesiulor (2011) conducted optimization work on the development of a plastic recycling machine, the schematic of which is shown in Figure 2.6.

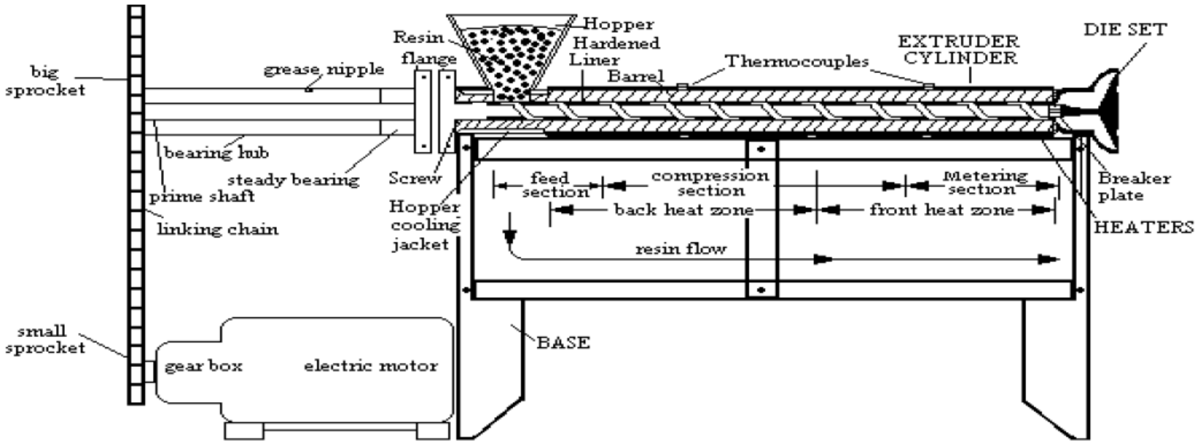

Figure 2.5 Ugoamadi and Ihesiulor (2011) plastic pelletizing machine

The research focused on designing and building a plastic recycling machine that overcomes the limitations of existing imported pelletizing machines while promoting efficient waste management. Experimental results showed that melting the plastic fed into the hopper required a temperature of around 200°C. The machine operates on the principles of conveying and heating to shred and melt the plastic materials and can be operated by just two people.

Constructed using locally sourced materials, the machine is affordable, easy to maintain, and simple to repair. Performance tests revealed that the machine runs effectively at a speed of 268 rpm. It achieved a high recycling efficiency of 97%, processing each batch of plastic in about 2 minutes, with a throughput capacity of approximately 265 kg per hour. Additionally, the machine is cost-effective and energy-efficient, consuming around 30.23 kJ of mechanical energy per kilogram of recycled plastic.

Naveenbala et al. (2017) conducted a study on a granulator designed for recycling plastics and glass fiber. The authors highlighted the significant environmental challenge posed by plastic waste due to its low biodegradability. Despite widespread plastic use, waste management remains poor, with many people resorting to open burning, which releases harmful toxins like dioxins into the atmosphere.

To address this issue, the researchers developed a plastic granulator or shredder. The machine consists of four primary parts: the feeding unit, shredding unit, power unit, and machine frame. The feeding unit is constructed from 16-gauge galvanized mild steel, with a thickness of 2 mm and dimensions of 200 mm by 550 mm, through which waste plastic is fed into the shredder.

The shredding unit is where the plastic is cut into smaller pieces. It features a shaft 50 mm in length, made from a 30 mm mild steel rod, and a cylinder measuring 55 mm long and 200 mm in diameter. Attached to the shaft are cutters made of 12 mm mild steel, each with nine serrated teeth welded 2 mm apart. The cylinder also holds similar cutters with sharp edges to effectively shred the plastic waste. Below the shredding area is an outlet, made from galvanized mild steel, where the shredded material is discharged.

The machine is powered by an electric motor, which drives the shredding mechanism through a belt and pulley system.

2.4.1 Related work done

Stanley et al. (2017) designed and built a polythene pelletizing machine for urban communities. Their machine featured a screw-thread conveyor inside a barrel to transport molded polythene, with the screw driven by a belt drive. The barrel was designed to shear low-density polyethylene (LDPE) at a temperature of 80°C. The resulting output served as valuable raw material for the plastic industry.

Jassim et al. (2016) worked on the design and fabrication of a plastic recycling system that combined a shredder/crusher and an extruder, processing plastic waste into smaller pieces roughly 0.5 to 1 cm in size.

Paul et al. (2019) developed a fish feed pelletizing machine powered by a 1.5 hp three-phase electric motor, with a 1500W heating element attached to the barrel surface. Performance tests showed the pelletizer had a throughput capacity of 17 kg/h and an efficiency of 90.9%, with mechanical damage kept low at 9.10%. The machine produced cylindrical pellets ranging from 2 to 8 mm in diameter, making them suitable for use in fish and poultry farming.

2.4.2 Comparison of Different Pelletizing Technologies

Plastic pelletizing technologies have advanced over time, with various methods developed to improve efficiency, lower energy use, and enhance pellet quality. The three main pelletizing techniques are melt extrusion-based pelletizing, cold granulation-based pelletizing, and hybrid pelletizing systems.

Melt extrusion-based pelletizing is the most widely used, especially in large-scale recycling operations. In this method, shredded plastic is melted and pushed through a die, forming continuous strands that are then cut into pellets. This approach reliably produces uniform pellets with consistent quality, making it well-suited for industrial applications. However, it consumes a lot of energy and requires careful temperature control to avoid polymer degradation. Research such as that by Desmond et al. (2011) has worked on optimizing extrusion parameters to reduce waste and boost efficiency. Despite these benefits, melt extrusion isn’t suitable for all plastics—particularly heat-sensitive or thermosetting types.

Cold granulation-based pelletizing provides an alternative by mechanically cutting plastics into small granules without melting. This process uses significantly less energy and avoids thermal damage to the materials. It is especially effective for thermoplastics that maintain their properties after mechanical processing. However, a key challenge with cold granulation is producing pellets of uniform size, as the mechanical cutting often results in variable particle dimensions. Balsiger et al. (2000) studied cold granulation of polyethylene terephthalate (PET), demonstrating its promise as an energy-efficient recycling method while also pointing out the difficulty in achieving precise pellet sizes.

Hybrid pelletizing systems combine both melting and mechanical cutting techniques, striking a balance between energy efficiency and the production of high-quality pellets. These systems offer greater versatility in handling various types of plastics while improving pellet size uniformity. For example, Okiy et al. (2018) designed a hybrid pelletizing machine featuring automated controls for temperature and cutting speed, which boosted operational efficiency and reduced waste. However, hybrid systems are generally more complex and costly to implement than standalone extrusion or granulation methods, requiring careful calibration to maintain the ideal balance between melting and mechanical processing.

Each pelletizing technology has its own strengths and drawbacks, and selecting the best approach depends on factors like the plastic type, energy resources, cost considerations, and the quality requirements for the pellets. While melt extrusion-based pelletizing remains the industry standard due to its efficiency and scalability, cold granulation and hybrid methods present practical alternatives, particularly in settings where energy conservation is critical. Ongoing research continues to focus on developing more energy-efficient and environmentally sustainable pelletizing technologies, aiming to optimize resource use and reduce environmental impacts.

2.4.3 Identified Challenges in Existing Systems

Despite progress in plastic pelletizing technology, existing systems still face several challenges that impact efficiency, cost, and environmental sustainability. These include high energy use, compatibility issues with different materials, operational inefficiencies, environmental impacts, and limited automation. Tackling these problems is essential to improve plastic recycling and to make pelletizing technology more accessible, especially in resource-constrained regions.

A significant challenge is the high energy demand of melt extrusion pelletizing systems, which require large amounts of electricity or gas to heat plastics to their melting point before extrusion. In places with unreliable power or expensive energy, operating these machines can be financially and practically difficult. Research like Stanley et al. (2017) shows that excessive energy use can make small-scale pelletizing uneconomical. Optimizing energy efficiency through better heating elements and variable-speed motors can help reduce this burden.

Material compatibility is another concern, as many machines are designed to handle specific plastic types. Mixed plastic waste poses a problem, often requiring pre-sorting, which increases labor and processing times. Thermosetting plastics cannot be remelted and reshaped like thermoplastics, limiting their recyclability. Jassim et al. (2016) emphasize that varying melting points and material properties in mixed waste can cause defects in pellets. Improving multi-material processing and sorting methods could increase system flexibility.

Operational inefficiencies also lead to increased waste and higher costs. Variations in feed rate, temperature instability, and reliance on manual adjustments often result in inconsistent pellet size and quality. Poorly controlled conditions can cause over- or under-melting and extruder clogging, shortening machine life. Okiy et al. (2018) studied the use of automated controls to stabilize temperature and feed, improving pellet consistency. Nevertheless, many small or locally made machines still depend on manual operation, limiting precision.

Environmental concerns are another significant challenge in plastic pelletizing. The process often produces excess plastic waste, such as off-spec pellets and processing residue. Additionally, reliance on fossil fuel-based heating methods contributes to carbon emissions. Hirsch et al. (2006) discussed the environmental footprint of plastic processing, emphasizing the need for cleaner, more sustainable recycling methods. Solutions such as using renewable energy sources, adopting closed-loop recycling systems, and minimizing scrap generation can help reduce the environmental impact of pelletizing operations.

Lastly**,** limitations in automation and control systems hinder the efficiency and scalability of existing pelletizing machines. Many traditional systems lack real-time monitoring and feedback mechanisms, requiring constant manual supervision. This increases the likelihood of errors and inefficiencies**.** Paul et al**. (2019)** proposed the use of programmable logic controllers (PLCs) and microcontrollers to automate critical aspects of the pelletizing process, including temperature regulation, speed adjustment, and fault detection. However, implementing such advanced control systems requires additional investment and technical expertise, which may not be readily available in small-scale recycling operations.

To address these challenges, future research and development efforts should focus on optimizing energy efficiency, enhancing multi-material processing capabilities, integrating automation technologies, and adopting sustainable practices. By overcoming these limitations, plastic pelletizing systems can become more efficient, cost-effective, and environmentally friendly, supporting a more circular economy in plastic waste management.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Conceptual Designs

Following review of typical extruders two concepts were considered for production. These include the followings; are mainly desired for commercial activities.

3.1.1 Concept 1. The Archimedes screw auger

The Archimedes screw auger shown in Figure 3.1 consist of evenly spaced or pitched threads much like a thread in a power screw shaft. The rotating auger is used to move bulk material while pressing it against the internal walls of an encasing barrel. The bulk material such as molten polymer is forced out through a die nozzle. The Archimedes auger can be manually operated or motorised. The concept 1 will consist of a hopper, screw auger, heating chamber and a die for extrusion. A heat generating element is incorporated to heat and melt the plastic material to molten form soft enough to be extruded at low pressure through the die nozzles. Other additional components will include a cooling chamber where the pellets are cooled down to further enhance its solidification process.

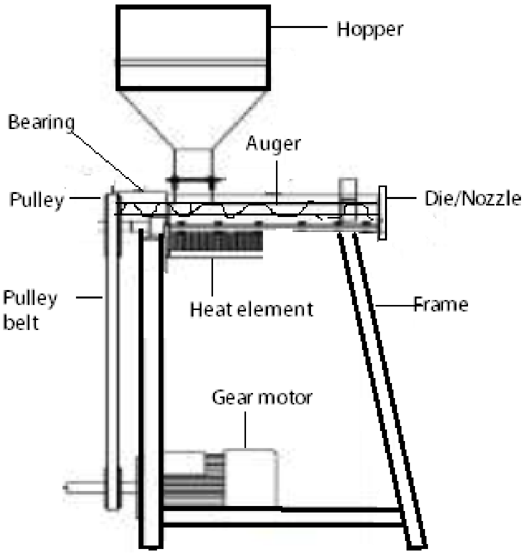

Figure 3.1 Concept 1 Archimedes screw extruder

3.1.2 Concept 2. Piston powered extruder

The concept 2 is a piston power extruder which involves the use of a plunger actuated by fluid or mechanical power as shown in Figure 3.2. The concept consists of a hydraulic or pneumatic actuated piston, motor, fluid pump and reservoir, pressure hose, die and barrel. The plunger pushes the molten polymer or plastic under pressure and forces them through the die nozzle.

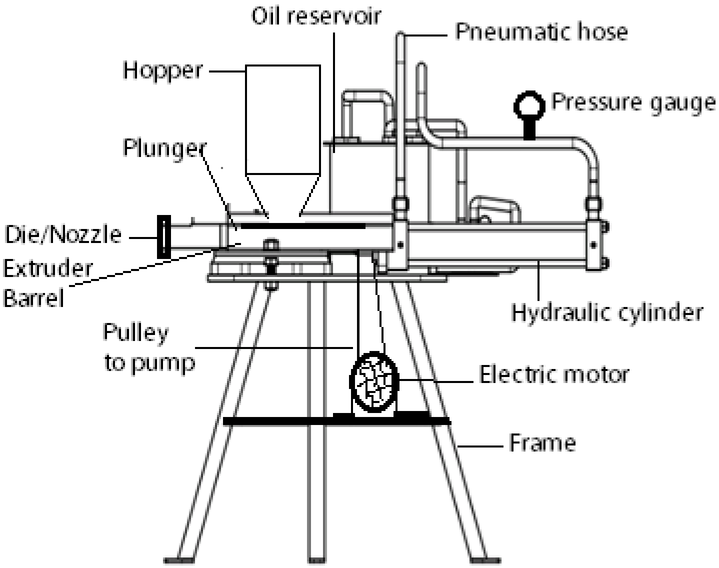

Figure 3.2 Hydraulic powered plastic extruder

3.2 Selection of concept using a decision matrix.

The proposed concept found suitable for further design and production was decided using a decision matrix as shown in Table 3.1 The considerations for selection were selected with higher score of 2 given to the concept most favoured by the design variable.

Table 3.2.1 Decision Matrix table for plastic extruder concept selection

Design Specification	Concept 1	Concept 2
Cost of production	2	1
Weight	2	1
Susceptibility to wear	1	2
Simplicity	2	1

TOTAL	7	5

From the decision matrix Table, it was observed that the concept 1 (Archimedes screw auger) extruder had the highest score based on the design considerations. It had a total aggregate score of 9 compared to the concept 2 with aggregate score of 6.

3.2.3 Detailed design

The components of the selected design of plastic extruder include the following;

Hopper

The funnel-shaped container at the top where raw plastic material (flakes, granules) is fed into the machine

Figure 3.3 hopper

Cylindrical barrel

The heated chamber where the plastic is melted and processed

Figure 3.4 Melting chamber

Screw threaded shaft

A rotating screw inside the barrel that conveys, melts, and mixes the plastic.

Figure 3.5 screw shaft

Die with nozzles

A plate with small holes at the end of the barrel that shapes the molten plastic into strands.

Figure 3.6 Die

Electric motor

The power source that drives the screw shaft.

Figure 3.7 Electric motor

Gas cylinder

A container of gas for the heating of the barrel. (alternative to electric heating)

Figure 3.8 Gas Cylinder

Bearings

The primary function of bearings is to minimize friction between moving parts, particularly the rotating screw shaft within the cylindrical barrel. This allows for smoother operation and reduces wear and tear.

Figure 3.9 Bearings

Electrical elements.

Electric coils or bands that surround the barrel, providing the necessary heat to melt the plastic.

Figure 3.10 Control panel

Hose

A flexible tube that connects the gas cylinder to the gas burner.

Figure 3.11 hose

Gas Burner

A device that mixes gas with air and ignites it to produce a flame for heating the barrel.

Figure 3.12 Gas Head

Heating system

Electric coils or bands that surround the barrel, providing the necessary heat to melt the plastic.

Figure 3.13 heating System

Circuit breaker

Their function is to protect the machine's electrical system from over currents or short circuits.

Figure 3.14 Circuit Breaker

3.2.4 Design considerations

- Material to be extruded: low density polythene (LDPE)
- Melting temperature: 105°C and 150°C
- Production type; Batch production
- Feed mode: Manual feed via hopper

3.3 Cylindrical Hopper and Barrel design

The cylindrical barrel is considered as a cylindrical shell, computed on the assumption that the stress is uniform throughout the wall thickness. Its diameter depends on the amount of material that passes through it per operation/time. The volume of the barrel is expressed as

$V = \pi r^2 h$ ……………………………………………………….3.1

Where; r = radius of the cylinder, h = length of the cylinder

The sheet material required for the production of the cylindrical barrel is expressed as the total surface area of the cylinder expressed as;

$TSA = 2\pi r (r + h)$ …………………………………………………..3.2

Where; TSA = total surface area, r = radius of the cylinder and h = height or length of the cylinder

The torque T (in Nm) transmitted by wave action of the screw auger and the angular speed (in rad/s) is given by

$\omega = \frac{2\pi N}{60}$……………… ………………………………………….. 3.3

$\Gamma = p/\omega = \frac{60P}{2\pi N}$……………………………………………………….. 3.4

Where

P = power transmitted by the auger motion (W)

N = No. of rev/min of wave action (rev/min)

The speed N is related to the pulley diameter by the speed ratio thus

$\frac{N_1}{N2} = \frac{D_1}{D_2}$

I.e $N_1D_2 = N_2D_1$…………………………………………….. .... 3.5

3.3.1 Hoop Stress

The cylindrical barrel where the plastic material is conveyed before extrusion is subject to internal forces as shown in the schematic in Figure 3. A ring or hoop from the cylindrical barrel is isolated from the rest of the cylinder. The free body is obtained by cutting the hoop on the line of the diameter. The moment equilibrium is satisfied about the hoop center. The force equilibrium in the x-direction is satisfied as a result of the symmetry, and thus to ensure equilibrium, force balance in the direction is considered.

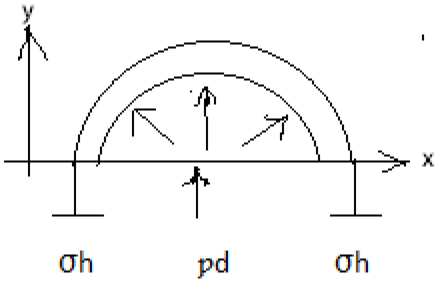

Figure 3.15 cross section of the barrel

Upward forces F_y = Pressure x Area

= P x 1 x d……………………………………………………………3.6

If balanced by downward force f_T which is stress x Area

$F_y = P(D_1) - 2f_T = 0$

But $f_T = \sigma_H \times 2\ (1 \times t)$ ……………………………………………..3.7

And $D_1 = 2rl$

Replacing f_t in equ 5 by equation 6

$F_y = P(2rl) - 2(\sigma_H(tl) = 0$

Making σ subject of the formula we have

$\sigma_H = 2Prl/\ (2tl) = Pr/(t)$

i.e

$\sigma_H = \frac{PD}{2t}$

Where P = operating pressure

D = diameter of the cylinder

t = thickness of the cylinder

Thus, thickness of the cylinder can be calculated

$t = \frac{PD}{2t\sigma}$ ………………………………………………………..3.8

3.3.2 Hoper material selection and design

The material holding capacity of the cylindrical hopper as well as its total amount in square area of metal sheet required to fabricate the hopper is determined thus;

Material holding capacity of hopper in volume per batch =

$v = 2\pi r$ ……………………………………………………………3.9

where;

r = radius of the cylindrical hopper

Total Surface Area (TSA) of the hopper is expressed as

$TSA = \ 2\pi r\ (r + h)$ …………………………………………..…..3.10

This is the expression for the minimum amount in area of sheet metal required to fabricate the hopper.

3.3.3 Belt design and selection

i. length of pulley belt

The length (L) of the pulley belt for the power transmission is given thus

$L = 2C + \frac{\pi}{2}(D_1 + D_2) - \frac{D1 + D2}{4C}$ ……………………………………….3.11

Where C = Centre distance and it is expressed as

$C = A + [(A^2 + B^2)^{1/2}]$

Where $A = [LP/4 - \pi/8 (D_1 - D_2)]$ and $B = [(D_1 - D_2)^2/2]$

L = Length of belt

Diameter of machine pulley (D_1) = 60mm

Diameter of electric motor pulley (D_2) = 30mm

A = 363.22 mm, B = 112.50 mm

Therefore, C = 743.46 mm

ii. Determination of included angle (β), angle of wraps (α) and belt tensions of the pulley belt

The angle of wraps $\alpha_1 = [180 - \beta]$ and $\alpha_2 = [180 + \beta]$……………… 3.12

$\cos \theta/2 = [(D_1 - D_2)/C]$, and $\theta = 175.40$

$\sin \beta = [(D_1 - D_2)/C]$ and $\beta = 2.310$

D_1 and D_2 are the diameter of the small and big pulleys respectively

The tensions in the belt are T_1 and T_2 which are tensions in the tight and slack side respectively

$T_1/T_2 = [\varrho u\theta]$ ……………………………………………………….3.13

But $P = [(T_1 - T_2) u]$

u = coefficient of friction of the belt material (convass stitched) as selected based on availability.

$Tc = [T1/3]$

$(T_1 - Tc)/(T_2 - Tc) = [(\varrho u\theta/\sin\theta/2)]$

Therefore, $T_1 = 337.50$ and $T_2 = 230.72$

And the combined tension = 568.22

3.3.4 Analysis of the Shaft design

The screwed shaft may be designed on the basis of strength, or rigidity and stiffness as considered for most shaft members. If these are to be considered as necessitated in our work, one or all of the followings has to be put into consideration

a. If the shaft is subjected to twisting moment or torque only

b. If it is subjected to bending moment only

c. If it is subjected to fluctuating loads

d. If it is subjected to combined twisting and bending moments

e. If it is subjected to axial loads in addition to combined torsion and bending loads

In view of the nature of our project, the shaft is designed for fluctuating loads since it is subjected to fluctuating bending moment as a result of the variable weight bearing from the groundnut movement and also fluctuating torque due to its rotation about its neutral axis. Let us recall from first principles,

The Torsion equation for shafts

$$\frac{T}{J} = \frac{\tau}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.14$$

Where T = Twisting moment or torque acting upon the shaft

τ = Torsion shear stress and r= Distance from neutral axis to the outermost fibre and it is given by the expression d/2, where d is the diameter of the shaft

J=Polar moment of inertia of the shaft about the axis of rotation and for our shaft selection which is a round solid shaft, and

$$J = \frac{\pi}{32} x\ d^4$$

The equation (17) from substitution of the above expressions can now be written as

$\frac{T}{\frac{\pi d^4}{32}} = \frac{\tau}{\frac{d}{2}}$ or $T = \frac{\pi}{16} x\ \tau\ x\ d^3$

Therefore; $T = \frac{\pi}{16} x\ \tau\ x\ d^3$…………………………………………... 3.15

For the mild steel shaft material in focus, τ =440mpa=440N/mm^2, and d = 20mm

Equation () may be used to determine the diameter of the round solid shaft assuming it is subjected to twisting moment only and no solid or molten plastic materials is contained in the barrel.

Also if the shaft is subject to bending moment only, with no plastic in the hopper and barrel, then the diameter can be determined as follows from first principle,

$M/I = \sigma_b/y$………………………………………………………3.16

Where M = bending moment, I= moment of inertia of cross sectional area of the shaft about the axis of rotation, σ = bending stress and y = distance from neutral axis to the outer most fibre.

Thus for round solid shaft, $I = \frac{\pi}{64} x\ d^4$and y = d/2, Hence substituting these values into equation () we have

$\frac{M}{\frac{\pi d^4}{64}} = \frac{\sigma_b}{\frac{d}{2}}$ or $M = \frac{\pi}{32} x\ \sigma_b\ x\ d^3$

Therefore; $M = \frac{\pi}{32} x\ \sigma_b\ x\ d^3$ ……………………………………….3.17

However, as stated earlier, the shaft is assumed to be subjected to fluctuating loads therefore, a fluctuating torque and bending moment, therefore the combined shock and fatigue factors are taken into account to compute the twisting moment (T) and bending moment (M).

For the combined bending and torsion, the equivalent twisting moment,

$T_e = \sqrt{}\ \{(K_m\ x\ M)^2 + (K_t\ x\ T)^2\}$…………………………….………..3.18

And the equivalent bending moment is given as

$M_e = \frac{1}{2}[K_m\ x\ M + \sqrt{}\ (K_m\ x\ M)^2 + (K_t\ x\ T)\ ^2$……….…………………………...3.19

where:

K_m = Combined shock and fatigue factor for bending

K_t = Combined shock and fatigue factor for torsion

M = Bending moment, and T = Twisting moment or Torque

For recommended values for K_m and K_t see appendix one of this literature.

The forces acting on the shaft are listed below:

a. Weight of bulk plastic material inside hopper acting within a length of the barrel.

b. Weight of shaft and the screw

c. Weight of pulley

3.3.5 Torsional rigidity of the screw shaft

The permissible angle of twist θ; 0.3 is lesser than or equal to θ which is lesser than or equal to 3.0 depending on the application for solid circular shaft

The angular deflection of a torsion solid shaft can be expressed as

$\theta = 584 M_t L / G d^4$ ……………………………………………………..3.20

Where

θ = angular shaft deflection (degrees)

L = length of shaft (m)

G = torsional modulus of elasticity, (N/m2) = 7.30 GN/m^2 of the shaft material

D = diameter of shaft

3.3.6 Bearing selection

Intensive evaluation of some governing conditions guided the selection of the bearings used for supporting the rotating screw shaft. The conditions evaluated includes the followings

a) First was the selection of rolling contact bearings over sliding contact bearings due to the former's advantages that were closely desired for the nature of the machine crucial amongst which included; Its low starting and running friction within the desired low speed, its ability to withstand momentary shock loads, accuracy of shaft alignment and low cost of maintenance.

b)The desired speed to be transmitted from the shaft as supplied from the motor is desired to be low and far less than 2000rpm

c) The bearings required needed to have ability to bear load at this speed

d) The minimum static and dynamic load rating of the bearing has to exceed the bearing load of the shaft.

The above information alongside other conditions as coefficient of friction and bore diameter of the bearing, which are calculated and or matched from reference and manufacturers manual gives a better selection from series of potential bearing for the nature of machine. Though for purpose of studies, the mathematical analysis of the above mentioned parameters are elaborated. The alternative method of reading off from reference manual as shown in the appendix six of this material was adopted for this work for reason of timely completion of the project.

From reference literatures, the appropriate bearing is selected based on output speed, bore size, static load, and dynamic loads and bearing load of shaft.

3.3.7 Dynamic equivalent load for rolling contact bearings (DEL)

This is the constant stationary radial load (in case of radial ball or roller bearings) or axial load (in case of thrust ball or roller bearings) which, if applied to a bearing with rotating inner ring and stationary outer ring, would give the same life as that which the bearing will attain under the actual condition of load and rotation [Khurmi et al 2005]

Denoted by W and for the radial and angular contact bearings under combined constant radial load W_R and constant axial or thrust load W_A is given by the expression below

$W = X.V.W_R + Y.W_A$ ……………………………………………………3.21

Where;

V = A rotation factor = 1 for all types of bearings when the inner race is rotating

And the values of radial load factor X and axial or thrust factor Y for the dynamically loaded bearings may be taken from references or appendix two of this literature.

3.3.8 Dynamic load rating for rolling contact bearings under variable loads DLR

This is denoted by C, is the constant stationary load (in case of radial ball or roller bearings) or constant axial load (in case of thrust ball or roller bearings) which a group of apparently identical bearings with stationary outer ring can endure for a rating life of one million revolutions (which is equivalent to 500 hours of operation at 33.3 rpm) with only 10 percent failure. [Khurmi et al, 2005]

The expression for C is given as

$C = W (L / 10^6)^{1/k}$ ………………………………………………………. 3.22

Where

W= equivalent dynamic load

L= service life rating of the ball or roller bearing

The relationship between the life in revolution L and the life in working hours L_H is given by

$L = 60N.L_H$ revolutions where N I the speed in rpm

k = 3, for ball bearings and 10/3 for roller bearings

Having evaluated all factors from calculated, working condition and references, appropriate ball bearings were found suitable and used for the machine.

In selecting the most suitable ball bearing, the basic dynamic radial load was multiplied by a service factor (K_s) to get the design basic dynamic radial load capacity. The service factor for the ball bearings is shown from references or appendix three of this literature. After determining the design basic dynamic radial load capacity, the selection of bearing was made from literature and manufacturers reference catalogue. Find reference in appendix three of this literature for the basic static and dynamic capacities of various types of ball bearings.

3.3.9 Material and Energy Balance

A. material balance

For the proper bulk material transfer and operation of the machine, it is assumed that the amount of bulk material in mass or volume fed into the hopper and extruded should be equal to the total mass of extrudate John and Turner (2012) i.e

$M_{(in)} = M_{(out)}$ ……………………………………………………….3.23

Where M = mass

However, if losses resulting from adhesion to barrel internal walls, the shaft body, nozzles and dead ends of the barrel are considered, equation 22 may be written thus;

$M_{in} = M_{out} + M_{losses}$………………………………………………… ...3.24

If equations 22 and 23 are expressed with respect to volume, then $V_{in} + V_{out}$

B Energy Balance

The energy coming into a unit operation can be balanced with the energy coming out and the energy stored. This is given by the expression

Energy In = Energy Out + Energy Stored i.e

$\Sigma E_R = \Sigma E_P + \Sigma E_W + \Sigma E_L + \Sigma E_{S.}$ ……………………………………….3.25

Where;

$\Sigma E_R = E_{R1} + E_{R2} + E_{R3} +$ ……. = Total Energy Entering

$\Sigma E_p = E_{P1} + E_{P2} + E_{P3} +$ ……. = Total Energy Leaving with Products

$\Sigma E_W = E_{W1} + E_{W2} + E_{W3} +$ … = Total Energy Leaving with Waste Materials

$\Sigma E_L = E_{L1} + E_{L2} + E_{L3} +$ ……. = Total Energy Lost to Surroundings

$\Sigma E_S = E_{S1} + E_{S2} + E_{S3} +$ ……. = Total Energy Stored

Energy balances are often complicated because forms of energy can be inter-converted, for example mechanical energy to heat energy, but overall the quantities must balance.

3.4 Extruder Efficiency

The extruder efficiency η is evaluated by determining parameters like the extrusion capacity and functional/extrusion efficiency of the machine from data observed Kabri et al, (2006)

The extrusion capacity is given as;

EC = $\frac{M_e}{T}$ (kg/min) …………………………………………………… ..3.26

Where;

M_e = mean mass of the pellets for each treatment (Kg),

T = mean time taken for the extrusion (min).

Extrusion/functional efficiency is calculated as the ratios in percentage of the pellets to the initial mass of materials fed into the machine.

This is represented mathematically as:

RE = $\frac{M_e}{M_i}$ x 100……………………………………………………… 3.27

Where;

RE = extrusion efficiency (%)

M_e = mean mass of extrudates (Kg)

M_i = mean initial mass of ingredients (kg) Kabri et al, (2006).

3.3.10 Heat propagation in the barrel.

The cylindrical barrel is heated by the heat element hence the heat propagation through it can be analysed by the heat governing equations in a cylindrical coordinate as shown in Figure 3.4

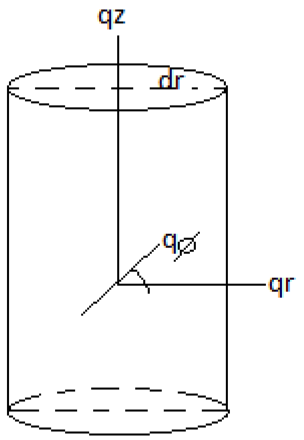

Figure 3.16 Cylindrical coordinate

Considering heat flow in the radial ө , axial z and tangential r directions of the barrel, the heat conduction equation is expressed as;

$$k\left[\frac{d^2t}{dr^2}+\frac{1}{r}.\frac{dt}{dr}+\frac{1}{r^w}.\frac{d^2t}{dØ^2}+\frac{d^2t}{dz^2}\right]+\frac{q_g}{k}=\frac{PC}{K}=\frac{1}{\alpha}.\frac{dt}{d\tau}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.28$$

Where α= k/pc is the thermal diffusivity and the larger it is, the faster will the heat diffuse through the material. The heat from the element is used to heat the polymer and melts it into molten fluid emission of gases. Hence there is also heat propagation through convection and radiation in the barrel expressed respectively as;

$Q = 23.46 \text{ x } A \text{ x } dt \text{ x } V^{0.78} \text{ x } d$ …………………………………………………… 3.29

Where Q= rate of convection heat transfer (kJ/h)

A = Area of heat transfer (m^2), dt = Temperature differential between solid and fluid (^0C)

V = air velocity (m/s) taken as $10W/m^2.k$ for free or forced low speed air over surface, d = gas density in (kg/m^3)

$Q = F\sigma A\ [T_1^4 - T_2^4]$ …………………………………………………………..3.30

Where Q = rate of radiation heat transfer (kJ/h), T_1, T_2 = Absolute temperatures of hot and cold bodies respectively, σ = Stefan-Boltzmann constant = $5.67x10^{-8}W/m^2K^4$, F= factor depending on surface geometry, emissivity and properties.

3.5 Source of heat

The heat is supplied by a propane powered gas due to its ability to easily reach melting temperature of the polymer and to conserve energy by not using electric heaters, utilizing both an electric heater and a gas burner to optimize the preheating process before the plastic enters the extrusion barrel. This dual approach aims to enhance efficiency and handle a broader range of plastic materials.

Figure 3.17 Gas burner

The pelletizing machine operates on the following general principles:

- **Feeding:** Waste plastic materials are fed into a hopper.
- **Preheating:** The plastic is preheated using a combination of an electric heater and a gas burner.
- **Extrusion:** The preheated plastic is fed into an extrusion barrel, where it is melted and homogenized by a screw.
- **Pelletizing:** The filtered plastic is extruded through a die, forming strands that are then cut into pellets.
- **Cooling:** The pellets are cooled, typically using air or water.

3.6 Dual Preheating System Analysis:

The incorporation of both an electric heater and a gas burner for preheating offers several advantages:

- **Flexibility:** Different plastic types require varying preheating temperatures. The dual system allows for precise temperature control, accommodating a wider range of materials. The gas burner can provide rapid initial heating, while the electric heater can maintain a stable and consistent temperature.

- **Energy Efficiency:** The gas burner can be used for the initial rapid heating phase, which is often more efficient than relying solely on electric heating for large temperature increases. The electric heater can then maintain the desired temperature, minimizing gas consumption.
- **Faster Processing:** The combined heating power leads to faster preheating, reducing cycle times and increasing throughput.
- **Adaptability to varying conditions:** In areas where electricity supply is unreliable or expensive, or where gas is readily and cheaply available, this hybrid system provides a valuable level of operational redundancy.

The extrusion barrel utilizes a screw to melt and homogenize the preheated plastic, the screw design and speed are critical for achieving consistent melt quality. Filtration systems remove contaminants, ensuring high-quality pellets. The die and cutting system determine the size and shape of the pellets. Cooling systems prevent clumping and deformation of the pellets.

The polymer extruder machine as designed characteristics are shown in the Table 3.2.

Table 3.3 Design specification of polymer melting and extruding machine.

S/N	Component	Specification
1	Barrel	40mm dia by 350mm
2	Hopper	200mm dia by 300mm
3	Heat element	700W
4	Die/nozzle diameter	45mm/5mm
5	Gear motor	0.5kw
6	Shaft diameter	25mm

3.7 Bill of Engineering materials and evaluation (BEME)

The bill of engineering materials and evaluation for the Plastic pelletizing machine is given in table 3.3

Table 3.4 Bill of Engineering Materials and Evaluation

Item	Specification	Quantity	Unit cost	Total
Mild steel sheet	1.5 mm thickness,	2m^2	10000	10000
Electric element	700watts	1	20000	20000
Mild steel pipe	pipe Φ 40 mm, thickness 15 mm, length 500 mm	1	9000	9000
Mild steel coupling bolt	Φ 22.5 mm, Φ 40 mm 1	bulk		5000
Mild steel angle iron	iron 50 x 50mm x 4, standard length	7000		14000
Bearings	Φ 40 mm	2	6000	12000
Cast iron pulley	Φ 260 mm	1	6000	6000
Cast iron pulley	Φ 58 mm	1	5000	5000
V – belt	B 65	1	2000	2000
Bolts and nuts		Lump sum		7000
Nozzle milling	5mm,	3	2000	6000
Welding electrode Gauge		Lump sum	12000	12000

Electric gear motor	0.5kw	1	35000	35000
Electrical wiring and plug		sum	4000	4000
Paint	Blue	1can	7000	7000
Workmanship, logistics and miscellaneous	sum	sum	50000	50000
Gas Cylinder, Hose, Gas burner	2kg, 3 feet long hose, Industrial Burner	sum	20000	20000
TOTAL =				224000

Figure 3.18 Polymer Pelletizing Machine

The fabricated machine is shown above. drawing and picture of the fabricated machine are shown in Figures 3.5 and 3.6 respectively.

CHAPTER FOUR

TEST, RESULTS AND DISCUSSION

4.0 Test Procedure

The machine put to test after fabrication. The bulk plastic materials gotten from waste cut into pieces and lowered into the hopper for onward transfer to the heating extruder barrel. The plastic melted under heat and was transferred by the rotating auger towards the die for onward extrusion into pellets through die nozzle. The mass of the polymer was weighed prior to extrusion and the pellets were also weighed after extrusion. The heating temperature was set at 260^0C enough to heat and melt the PET plastic.

4.1 Result

The results from test carried out was recorded as shown in Tables 4.1, 4.2 and 4.3.

Table 4.1 Test results for the operated polymer pellets production machine

Runs	Weight of polymer feed before extruding(kg)	Weight of extruded pellets in (kg)	Size of extrudate (mm)	Time to extrude (mins)
1st run	10	9.7	5	3
2nd run	10	9.8	4.98	2.30
3rd run	10	10.1	4.99	2.29
Average	10	9.9	4.99	2.33

4.2 Discussion of Results

From the Table 4.1 the amount of load un-extruded feed fed into the machine was set at 10kg and three different runs of extrusion was carried out with the machine. It was observed that, for the first run, there was increased extrusion load as there was friction between the feed paste and the internal walls of the extruder cylinder. As the extrusion operation continued with subsequent runs, friction was reduced due to some polymer paste sticking to the internal wall of the cylinder and acting as a lubricant for subsequent incoming paste. This was evident from the slight variation in sizes (ranging between 20mm and 19.8mm) of the extruded pellets. The average load output was 9.8kg. A plot of the load (un-extruded feed) input against extruded feed was plotted as shown in Figure 4.1.

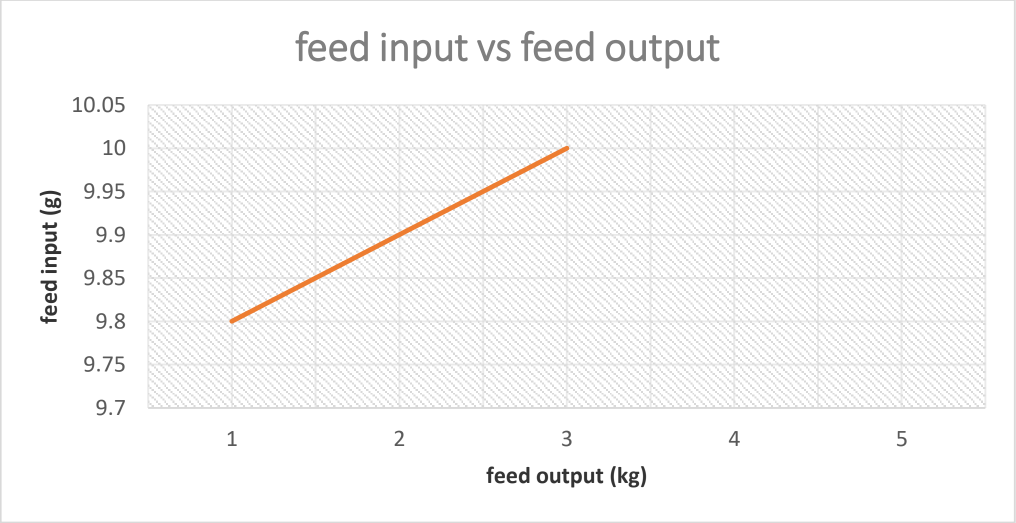

Figure 4.1 graph of load input against load output for dog feed

From the graph in Figure 4.1 it was observed that the load output of the pellets was increasing from the first run up to the third run. This may have been due to decreased friction in the extrusion barrel due to feed which stock to the barrel internal walls. During the first run, friction which inhibited free flow of the feed caused the feed to be extruded in much time and was later reduced as the friction reduced due to the feed clogs acting as lubricant inside the barrel internal walls, however; hot incoming molten polymer carried along polymer already clogged to the internal wall of the barrel from the previous extrude.

The molten polymer also stuck to the barrel causing a slight reduction in size of the pellets as a narrow channel of passage was allowed due to the mass of polymer clogged to the barrel die nozzle. This can be prevented by regular cleaning before and after operation.

Also from the Table of results in Table 4.1 it was observed that as the extrusion load increases, the time to extrude the corresponding pellets load also increased. However; on average it took 2min and 33 seconds to extrude a given amount of 10kg of the feed stock. The extruder throughput and efficiency were calculated thus;

Extruder machine capacity (kg/hr) = $\frac{\text{Average mass of feed extruded (kg)}}{average\ time\ taken\ to\ extrude\ (hr)}$……………………4.1

Average pellets extruded = 9.9kg in 2.33mins

Therefore; in 1hr, machine will extrude 60/2.33 (9.9) kg = 254kg

Therefore extruder machine capacity = $\frac{119kg}{1hr}$ = 254kg/h

Extruder efficiency = load output $\frac{Average\ load\ output\ (kg)}{Load\ input\ in\ (kg)}$ x 10 …………………………4.2

Where;

Load input = 10kg

Average load output = 9.9kg

Therefore efficiency of the polymer extruder = $\frac{9.9}{10}$ x 100 = 99%

Also, the accuracy of the pellets sizes extruded by the machine may be used to evaluate the performance of the die or extrusion ratio

The extrusion ratio = $\frac{croess\ sectional\ area\ of\ die}{average\ size\ of\ feed\ output}$ = 1.008

4.3Where; Cross sectional area of die nozzle = 5mm, Average size of the pellet output = 4.98m

CHAPTER FIVE

RECOMMENDATION AND CONCLUSION

5.1 CONCLUSION

Pellets made from polymer (PET plastics) are raw materials for further processing into new plastic products such as beverage cans, chairs, plastic table and bag etc. the polymer pelletizing machine was designed using locally sourced materials with consideration of appropriate design variables such as cost, functionality, simplicity amongst others. The machine is a viable machine suitable for use in Nigeria with a growing demand for finished polymer products. The machine was tested and found to have an operational efficiency above 90%.

The development and implementation of a plastic pelletizing machine with a dual preheating system represent a significant stride towards more efficient and sustainable plastic recycling. By integrating a gas burner for rapid initial heating with an electric heater for precise temperature control, this machine addresses the limitations of conventional preheating methods, enabling the processing of a wider range of waste plastics (PPT) with enhanced energy efficiency.

The detailed analysis presented in this report highlights the machine's robust design, advanced control systems, and operational advantages. The ability to achieve consistent melt quality, high throughput, and superior pellet production underscores its potential to contribute significantly to the circular economy.

This project demonstrates the feasibility of incorporating advanced heating technologies to optimize plastic recycling processes. The successful integration of the dual preheating system highlights the importance of innovative solutions in addressing the global challenge of plastic waste. The machine's design and operational capabilities offer a viable pathway for recycling facilities and manufacturing industries to reduce their environmental footprint and promote sustainable practices.

Moving forward, further research and development should focus on optimizing the machine's performance, exploring the integration of advanced automation and AI-driven control systems, and investigating the potential for processing even more diverse waste plastic streams. By continually refining and improving plastic recycling technologies, we can move closer to a future where plastic waste is effectively managed and repurposed, minimizing its impact on the environment.

5.2 RECOMMENDATION

Following the success of the research work and the operation of the machine, the following recommendations are made;

I. Further research work should be done to optimize operational efficiencies of screw extruders.

II. Further research on the design of polymer extruders for high density polymers should be carried out to ascertain the operational efficiency as against that achieved from the present research.

III. The present work has the potential of giving more insight into the production and commercialization of indigenously made products, hence further works in this area is highly recommended.

IV. Waste reduction and process optimization should be prioritized by implementing advanced filtration systems to remove contaminants before processing and introducing a reprocessing unit for off-spec pellets to maximize material utilization.

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