DESIGN AND DEVELOPMENT OF LOW DENSITY POLYETHYLENE RECYCLING MACHINE

BY

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MATRIC. NO: 2005/21596EA

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BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN AGRICULTURAL AND BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE, NIGERIA

DECEMBER, 2010.

DECLARATION

I hereby declare that this project is a record of a research work done and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished works of others were duly referenced in the text.

.... 13/12/2010 ....

EKWENUGO, VICTOR ARINZE Date

CERTIFICATION

This Project entitled "Design and Development of Low Density Polyethylene Recycling Machine" by Ekwenugo, Victor Arinze meets the regulations governing the award of the degree of Bachelor of Engineering (B. ENG.) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

.... 13/12/10

Engr. Dr. O. Chukwu — Date

Supervisor

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Head of Department

.... 8/12/2010

External Examiner — Date

DEDICATION

This Project work is dedicated to Almighty God and my parents Mr. and Mrs. D.O. Ekwenugo

ACKNOWLEDGEMENTS

I give thanks to Almighty God for sparing my life and seeing me through the difficult times during my study at Federal University of Technology, Minna.

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ABSTRACT

Based on standard engineering design principles, a low density polyethylene (LDPE) recycling machine was designed and developed. The machine is mainly composed of mild steel. According to the design, the machine is composed of three chambers, namely; heating chamber, cooling chamber and the size reduction chamber. All these chambers are connected directly to each other. The general function of the designed machine is to melt LDPE with the aid of a heating element (which uses electric power) with respect to its melting temperature which is in the range of 105^0C to 115^0C. At this temperature, it is in molten state. It is then cooled in the cooling chamber with the aid of water which acts as a coolant to a temperature of 0^0C. The final chamber which is the size reduction chamber is then responsible for cutting cooled solid from the cooling chamber. The end result of the whole process is in the form of pellets. A successful performance evaluation test was carried out and the time taken for the whole process was put at 1hr 43mins. The theoretical time required for both melting and cooling is 45mins and 22.5mins respectively. The actual time taken for melting and cooling was put at 55mins and 43mins respectively. In relation to the theoretical time, the efficiencies for the three chambers were calculated on 81%, 52% and 72% respectively. For a more efficient performance, adequate quantity of electric energy which is 220volts must be supplied to the heating element. A thermostat should be incorporated in the heating chamber to regulate the quantity of heat used in the melting process. Also in the cooling chamber, a means of circulation of water must be provided in order to increase the cooling efficiency of the machine.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The substance polymer which in derived from the Greek word Poly- meaning "Many" and Meros meaning parts; a Polymer is a large molecule composed of repeating structural units typically connected by Covalent Bonds. Polymeric materials are either natural or synthetic in nature and both with wide variety properties. Plastic are also derived from polymers. Natural polymeric materials are shellac, amber, and natural rubber. Synthetic polymers include Synthetic Rubber, Bakelite, Polyethylene, Nylon, PVC and many more.

Polyethylene or Ployethene however, in the widely used plastic in the world. It is used to package food item and lots more. it is a Thermoplastic Polymer consisting of long chains of the monomer ethylene. The name can be abbreviated to PE. There are different classes of PE with respect to density and molecular weight of which low density polyethylene is one. LDPE is one amongst the classes that is commonly used in the industries for the purpose of packaging.

Since LDPE is used mainly for packaging, it is necessary to device a proper means of disposal and also in means of recycling of waste product.

1.2 Statement of Problem

For years, the government of Nigeria has faced a menace cause by all sorts of polymer littering the environment. The government has thereby embarked on different of environmental sanitation to eliminate these polymers from the environment. This exercise has proven ineffective due to improper orientation to the people waste especially of polymer kind still on the ground.

Another fault by the environmental exercise introduced by the government is how this wastes derived from the exercise is being managed. Sometimes these wastes are disposed on unspecified lands leaving the land owners to bear the damages. The land owners may have the intention to erect houses or turning into farm lands.

Due to constant disposer of waste as polymer, it may become buried in the earth thereby preventing infiltration of water. Now, even if these wastes are not polymer –like they may cause the land its fertility. They can also cause a lot of environmental hazards to the immediate surrounding when the chemical contained in the waste are exposed to the air.

Most polymers especially LDPE are not biodegradable in nature. They are not affected by the acidity or alkalinity of any soil and so remain in the soil for years. It therefore means that for the land to be used for farm land, all forms of polymers must be excavated. This excavation can cause lot of energy, time and money.

1.3 Objective Of Study

The major aim of the study of polymers is as follows:

i. Elimination of polymer-like waste from the farm land.

ii. Identification of different type of polymer

iii. Designing and developing a low density polyethylene recycling machine

1.4 Justification of the Study

The purpose for embarking on this study is mainly on the recycling of polyethylene derived from the farm lands which cause lot of nuisance.

Another reason for embarking on this study is the creation of wealth derived from the sale of recycled product.

1.5 Scope of the Study

The course of this study is to objectively observe and understand polyethylene as a type of polymer used for packing of items. This study also covers the design and development of a low density polyethylene recycling machine.

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

2.1 Waste Management

Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials. The term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each.

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial producers. Management for non-hazardous residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator.

2.1.1 Methods of Disposal

Incineration

Incineration is a disposal method that involves combustion of waste material. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam and ash.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants.

Recycling

The popular meaning of 'recycling' in most developed countries refers to the widespread collection and reuse of everyday waste materials such as empty beverage cont separately from general waste using dedicated bins and collection vehicles, or sorted directly from mixed waste streams.

The most common consumer products recycled include aluminum beverage cans, steel food and aerosol cans, HDPE and PET bottles, glass bottles and jars, paperboard cartons, newspapers, magazines, and corrugated fiberboard boxes.

PVC, LDPE, PP, and PS (see resin identification code) are also recyclable, although these are not commonly collected. These items are usually composed of a single type of material, making them relatively easy to recycle into new products. The recycling of complex products (such as computers and electronic equipment) is more difficult, due to the additional dismantling and separation required.

2.1.3 Sustainability

The management of waste is a key component in a business' ability to maintaining ISO14001 accreditations. Companies are encouraged to improve their environmental efficiencies each year. One way to do this is by improving a company's waste management with a new recycling service (such as recycling: glass, food waste, paper and cardboard, plastic bottles etc.).

2.2 Plastic Recycling

Plastic recycling is the process of recovering scrap or waste plastics and reprocessing the material into useful products, sometimes completely different in form from their original state. For instance, this could mean melting down soft drink bottles and then casting them as plastic chairs and tables. Typically a plastic is not recycled into the same type of plastic, and products made from recycled plastics are often not recyclable

2.2.1 Challenges

When compared to other materials like glass and metal materials, plastic polymers require greater processing to be recycled. Plastics have low entropy of mixing, which is due to the high molecular weight of their large polymer chains. A macromolecule interacts with its environment along its entire length, so its enthalpy of mixing is large compared to that of an organic molecule with a similar structure. Heating alone is not enough to dissolve such a large molecule; because of this, plastics must often be of nearly identical composition in order to mix efficiently (Thompson, 2009).

When different types of plastics are melted together they tend to phase-separate, like oil and water, and set in these layers. The phase boundaries cause structural weakness in the resulting material, meaning that polymer blends are only useful in limited applications.

Another barrier to recycling is the widespread use of dyes, fillers, and other additives in plastics. The polymer is generally too viscous to economically remove fillers, and would be damaged by many of the processes that could cheaply remove the added dyes. Additives are less widely used in beverage containers and plastic bags, allowing them to be recycled more frequently.

The use of biodegradable plastics is increasing. If some of these get mixed in the other plastics for recycling, the reclaimed plastic is not recyclable because the variance in properties and melt temperatures (Financial Times, May 15, 2009).

The table below shows the different plastic identification code;

Plastic Identification Code	Type of Plastic Polymer	Properties	Common Packaging Applications
01 PET	Polyethylene terephthalate (PET, PETE)	Clarity, strength, toughness, barrier to gas and moisture.	Soft drink, water and salad dressing bottles; peanut
02 PE-HD	High-density polyethylene (HDPE)	Stiffness, strength, toughness, resistance to moisture, permeability to gas.	Water pipes, Hula-Hoop (children's game) rings, Milk, Juice and water bottles; the occasional shampoo/toiletry bottle
03 PVC	Polyvinyl chloride (PVC)	Versatility, clarity, ease of blending, strength, toughness.	Juice bottles; cling films; PVC piping
04 PE-LD	Low-density polyethylene (LDPE)	Ease of processing, strength, toughness, flexibility, ease of sealing, barrier to moisture	Frozen food bags; squeezable bottles, e.g. honey, mustard; cling films; flexible container lids.
05 PP	Polypropylene (PP)	Strength, toughness, resistance to heat, chemicals, grease and oil, versatile, barrier to moisture	Reusable microwaveable ware; kitchenware, yogurt containers; margarine tubs; microwaveable disposable take-away containers; disposable cups; plates.

06 PS	Polystryrene (PS)	Versatility, clarity, easily formed	Egg cartons; packing peanuts; disposable cups, plates, trays and cutlery; disposable take-away containers;
07 O	Other (often polycarbonate or ABS)	Dependent on polymers or combination of polymers	Beverage bottles; baby milk bottles; electronic casing.

Table 2.2.1 (Vest, 2000).

2.2.2 Processes of recycling

Before recycling, plastics are sorted according to their resin identification code, a method of categorization of polymer types, which was developed by the Society of the Plastics Industry in 1988. Polyethylene terephthalate, commonly referred to as PET, for instance, has a resin code of 1. They are also often separated by color. The plastic recyclables are then shredded. These shredded fragments then undergo processes to eliminate impurities like paper labels. This material is melted and often extruded into the form of pellets which are then used to manufacture other products (Vest, 2000).

2.3 Polyethylene

Polyethylene or **polythene** (IUPAC name **polyethene** or **poly(methylene)**) is the most widely used plastic, with an annual production of approximately 80 million metric tons. Its primary use is within packaging (notably the plastic shopping bag).

2.3.1 Description

Polyethylene is a thermoplastic polymer consisting of long chains of the monomer ethylene (IUPAC name ethene). The recommended scientific name *polyethene* is systematically derived from the scientific name of the monomer. In certain circumstances it is useful to use a structure-based nomenclature; in such cases IUPAC recommends *poly(methylene)* (poly(methanediyl) is an non-preferred alternative). The difference in names between the two systems is due to the *opening up* of the monomer's double bond upon polymerization.

The name is abbreviated to **PE** in a manner similar to that by which other polymers like polypropylene and polystyrene are shortened to PP and PS respectively. In the United Kingdom the polymer is commonly called **polythene**, although this is not recognized scientifically (Piringer and Baner, 2008).

The ethene molecule (known almost universally by its common name ethylene) C_2H_4 is $CH_2{=}CH_2$, Two CH_2 groups connected by a double bond, thus: Polyethylene contains the chemical elements carbon and hydrogen.

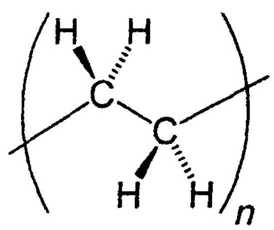


Fig 2.3: Structural Diagram of Polyethylene

Polyethylene is created through polymerization of ethene. It can be produced through radical polymerization, anionic addition polymerization, ion coordination polymerization or cationic addition polymerization. This is because ethene does not have any substituent groups that influence the stability of the propagation head of the polymer. Each of these methods results in a different type of polyethylene.

2.3.2 Classification

Polyethylene is classified into several different categories based mostly on its density and branching. The mechanical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight. With regard to sold volumes, the most important polyethylene grades are HDPE, LLDPE and LDPE. (Kahovec, Fox and Hatada, 2002).

- Ultra high molecular weight polyethylene (UHMWPE)
- Ultra low molecular weight polyethylene (ULMWPE or PE-WAX)
- High molecular weight polyethylene (HMWPE)
- High density polyethylene (HDPE)
- High density cross-linked polyethylene (HDXLPE)
- Cross-linked polyethylene (PEX or XLPE)
- Medium density polyethylene (MDPE)
- Linear low density polyethylene (LLDPE)
- Low density polyethylene (LDPE)
- Very low density polyethylene (VLDPE)

- **UHMWPE:** Is polyethylene with a molecular weight numbering in the millions, usually between 3.1 and 5.67 million. The high molecular weight makes it a very tough material, but results in less efficient packing of the chains into the crystal structure as evidenced by densities of less than high density polyethylene (for example, 0.930–0.935 g/cm^3). UHMWPE can be made through any catalyst technology, although

Ziegler catalysts are most common. Because of its outstanding toughness and its cut, wear and excellent chemical resistance, UHMWPE is used in a diverse range of applications. These include can and bottle handling machine parts, moving parts on weaving machines, bearings, gears, artificial joints, edge protection on ice rinks and butchers' chopping boards. It competes with Aramid in bulletproof vests, under the tradenames Spectra and Dyneema, and is commonly used for the construction of articular portions of implants used for hip and knee replacements.

- **HDPE:** Is defined by a density of greater or equal to 0.941 g/cm^3. HDPE has a low degree of branching and thus stronger intermolecular forces and tensile strength. HDPE can be produced by chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts. The lack of branching is ensured by an appropriate choice of catalyst (for example, chromium catalysts or Ziegler-Natta catalysts) and reaction conditions. HDPE is used in products and packaging such as milk jugs, detergent bottles, margarine tubs, garbage containers and water pipes. One third of all toys are manufactured from HDPE. In 2007 the global HDPE consumption reached a volume of more than 30 million tons.
- **PEX:** Is a medium- to high-density polyethylene containing cross-link bonds introduced into the polymer structure, changing the thermoplast into an elastomer. The high-temperature properties of the polymer are improved, its flow is reduced and its chemical resistance is enhanced. PEX is used in some potable-water plumbing systems because tubes made of the material can be expanded to fit over a metal nipple and it will slowly return to its original shape, forming a permanent, water-tight, connection.
- **MDPE:** Is defined by a density range of 0.926–0.940 g/cm^3. MDPE can be produced by chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts. MDPE

has good shock and drop resistance properties. It also is less notch sensitive than HDPE, stress cracking resistance is better than HDPE. MDPE is typically used in gas pipes and fittings, sacks, shrink film, packaging film, carrier bags and screw closures.

- **LLDPE:** Is defined by a density range of 0.915–0.925 g/cm^3. LLDPE is a substantially linear polymer with significant numbers of short branches, commonly made by copolymerization of ethylene with short-chain alpha-olefins (for example, 1-butene, 1-hexene and 1-octene). LLDPE has higher tensile strength than LDPE, it exhibits higher impact and puncture resistance than LDPE. Lower thickness (gauge) films can be blown, compared with LDPE, with better environmental stress cracking resistance but is not as easy to process. LLDPE is used in packaging, particularly film for bags and sheets. Lower thickness may be used compared to LDPE. Cable covering, toys, lids, buckets, containers and pipe. While other applications are available, LLDPE is used predominantly in film applications due to its toughness, flexibility and relative transparency. Product examples range from agricultural films, saran wrap, and bubble wrap, to multilayer and composite films. In 2009 the world LLDPE market reached a volume of almost 24 billion US-dollars (17 billion Euro).
- **LDPE:** Is defined by a density range of 0.910–0.940 g/cm^3. LDPE has a high degree of short and long chain branching, which means that the chains do not pack into the crystal structure as well. It has, therefore, less strong intermolecular forces as the instantaneous-dipole induced-dipole attraction is less. This results in a lower tensile strength and increased ductility. LDPE is created by free radical polymerization. The high degree of branching with long chains gives molten LDPE unique and desirable flow properties. LDPE is used for both rigid containers and plastic film applications

such as plastic bags and film wrap. In 2009 the global LDPE market had a volume of circa 22.2 billion US-dollars (15.9 billion Euro).

- **VLDPE:** Is defined by a density range of 0.880–0.915 g/cm^3. VLDPE is a substantially linear polymer with high levels of short-chain branches, commonly made by copolymerization of ethylene with short-chain alpha-olefins (for example, 1-butene, 1-hexene and 1-octene). VLDPE is most commonly produced using metallocene catalysts due to the greater co-monomer incorporation exhibited by these catalysts. VLDPEs are used for hose and tubing, ice and frozen food bags, food packaging and stretch wrap as well as impact modifiers when blended with other polymers.

Recently much research activity has focused on the nature and distribution of long chain branches in polyethylene. In HDPE a relatively small number of these branches, perhaps 1 in 100 or 1,000 branches per backbone carbon, can significantly affect the rheological properties of the polymer.

2.3.4 History

Polyethylene was first synthesized by the German chemist Hans von Pechmann who prepared it by accident in 1898 while heating diazomethane. When his colleagues Eugen Bamberger and Friedrich Tschirner characterized the white, waxy, substance that he had created they recognized that it contained long -CH_2- chains and termed it *polymethylene*.

The first industrially practical polyethylene synthesis was discovered (again by accident) in 1933 by Eric Fawcett and Reginald Gibson at the ICI works in Northwich, England. Upon applying extremely high pressure (several hundred atmospheres) to a mixture of ethylene and benzaldehyde they again produced a white, waxy, material. Because the reaction had been initiated by trace oxygen contamination in their apparatus, the experiment was, at first, difficult to reproduce. It was not until 1935 that another ICI chemist, Michael Perrin, developed this accident into a reproducible high-pressure synthesis for polyethylene that became the basis for industrial LDPE production beginning in 1939.

Subsequent landmarks in polyethylene synthesis have revolved around the development of several types of catalyst that promote ethylene polymerization at more mild temperatures and pressures. The first of these was a chromium trioxide-based catalyst discovered in 1951 by Robert Banks and J. Paul Hogan at Phillips Petroleum. In 1953 the German chemist Karl Ziegler developed a catalytic system based on titanium halides and organoaluminium compounds that worked at even milder conditions than the Phillips catalyst. The Phillips catalyst is less expensive and easier to work with, however, and both methods are used in industrial practice.

By the end of the 1950s both the Phillips- and Ziegler-type catalysts were being used for HDPE production. Phillips initially had difficulties producing a HDPE product of uniform quality and filled warehouses with off-specification plastic. However, financial ruin was unexpectedly averted in 1957 when the hula hoop, a toy consisting of a circular polyethylene tube, became a fad among youth in the United States.

A third type of catalytic system, one based on metallocenes, was discovered in 1976 in Germany by Walter Kaminsky and Hansjörg Sinn. The Ziegler and metallocene catalyst families have since proven to be very flexible at copolymerizing ethylene with other olefins and have become the basis for the wide range of polyethylene resins available today, including very low-density polyethylene and linear low-density polyethylene. Such resins, in the form of fibers like Dyneema, have (as of 2005) begun to replace aramids in many high-strength applications.

Until recently the metallocenes were the most active single-site catalysts for ethylene polymerisation known-new catalysts are typically compared to zirconocene dichloride. Much effort is currently being exerted on developing new, single-site (so-called post-metallocene) catalysts that may allow greater tuning of the polymer structure than is possible with metallocenes. Recently work by Fujita at the Mitsui corporation (amongst others) has demonstrated that certain salicylaldimine complexes of Group 4 metals show substantially higher activity than the metallocenes.

2.3.5 Physical Properties

Depending on the crystallinity and molecular weight, a melting point and glass transition may or may not be observable. The temperature at which these occur varies strongly with the type of polyethylene. For common commercial grades of medium- and high-density polyethylene the melting point is typically in the range 120 to 130 °C (248 to 266 °F). The melting point for average, commercial, low-density polyethylene is typically 105 to 115 °C (221 to 239 °F).

Most LDPE, MDPE and HDPE grades have excellent chemical resistance and do not dissolve at room temperature because of their crystallinity. Polyethylene (other than cross-linked polyethylene) usually can be dissolved at elevated temperatures in aromatic hydrocarbons such as toluene or xylene, or in chlorinated solvents such as trichloroethane or trichlorobenzene.

When incinerated, polyethylene burns slowly with a blue flame having a yellow tip and gives off an odour of paraffin. The material continues burning on removal of the flame source and produces a drip.

2.3.6 Environmental Issue

Although polyethylene can be recycled, most of the commercial polyethylene ends up in landfills, and in the oceans such as the Great Pacific Garbage Patch (Thompson, 2009). Polyethylene is not considered biodegradable, because, except when it is exposed to UV from sunlight, it takes several centuries until it is efficiently degraded. In May 2008, Daniel Burd, a 16-year-old Canadian, won the Canada-Wide Science Fair in Ottawa after discovering that *Sphingomonas*, a type of bacteria, can degrade over 40% of the weight of plastic bags in less than three months. Researchers are yet to find a practical application for this finding, however.

2.4 Thermoplastics and Thermosets

Thermoplastics and thermosetting plastics are terms that describe how a polymer reacts to heat. All plastics, whether made by addition or condensation polymerization, can be divided into two groups: thermoplastics and thermosetting plastics. Thermoplastics can be repeatedly softened by heating and hardened by cooling. Thermosetting plastics, on the other hand, harden permanently after being heated once.

The difference - weak van der waal forces The reason for the difference in response to heat between thermoplastics and thermosetting plastics lies in the chemical structures of the plastics. Thermoplastic molecules, which are linear or slightly branched, do not chemically bond with each other when heated. Instead, thermoplastic chains are held together by weak van der Waal forces (weak attractions between the molecules) that cause the long molecular chains to clump together like piles of entangled spaghetti. Thermoplastics can be heated and cooled, and consequently softened and hardened, repeatedly, like candle wax. For this reason, thermoplastics can be remolded and reused almost indefinitely.

2.4.1 Thermosetting Plastics

Thermosetting plastics consist of chain molecules that chemically bond, or cross-link, with each other when heated. When thermosetting plastics cross-link, the molecules create a permanent, three-dimensional network that can be considered one giant molecule. Once cured, thermosetting plastics cannot be remelted, in the same way that cured concrete cannot be reset. Consequently, thermosetting plastics are often used to make heat-resistant products, because these plastics can be heated to temperatures of 260 °C (500 °F) without melting.

2.4.2 Thermoplastics

The different molecular structures of thermoplastics and thermosetting plastics allow manufacturers to customize the properties of commercial plastics for specific applications. Because thermoplastic materials consist of individual molecules, properties of thermoplastics are largely influenced by molecular weight. For instance, increasing the molecular weight of a thermoplastic material increases its tensile strength, impact strength, and fatigue strength (ability of a material to withstand constant stress). Conversely, because thermosetting plastics consist of a single molecular network, molecular weight does not significantly influence the properties of these plastics. Instead, many properties of thermosetting plastics are determined by adding different types and amounts of fillers and reinforcements, such as glass fibers.

2.4.3 The Processes of Making Plastics

The process of forming plastic resins into plastic products is the basis of the plastics industry. Many different processes are used to make plastic products, and in each process, the plastic resin must be softened or sufficiently liquefied to be shaped. Although some processes are used to manufacture both thermoplastics and thermosetting plastics, certain processes are specific to forming thermoplastics.

shut off and the melt temperature maintained by pressure and friction alone inside the barrel. In most extruders, cooling fans are present to keep the temperature below a set value if too much heat is generated. If forced air cooling proves insufficient then cast-in heater jackets are employed, and they generally use a closed loop of distilled water in heat exchange with tower or city water.

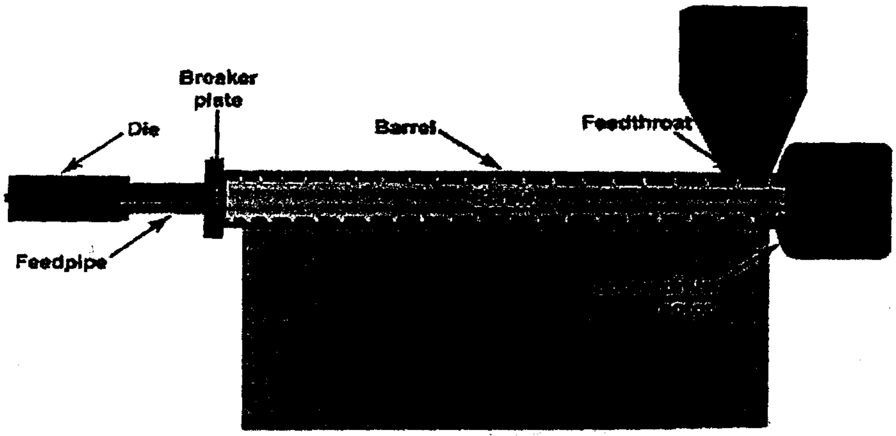


Fig 2.5.1: Plastic Extruder Cut in Half to Show the Components

At the front of the barrel, the molten plastic leaves the screw and travels through a screen pack to remove any contaminants in the melt. The screens are reinforced by a breaker plate (a thick metal puck with many holes drilled through it) since the pressure at this point can exceed 5000 psi (34 MPa). The screen pack/breaker plate assembly also serves to create back pressure in the barrel. Back pressure is required for uniform melting and proper mixing of the polymer, and how much pressure is generated can be 'tweaked' by varying screen pack composition (the number of screens, their wire weave size, and other parameters). This breaker plate and screen pack combination also does the function of converting "rotational memory" of the molten plastic into "longitudinal memory".

After passing through the breaker plate molten plastic enters the die. The die is what gives the final product its profile and must be designed so that the molten plastic evenly flows from a cylindrical profile, to the product's profile shape. Uneven flow at this stage would produce a product with unwanted stresses at certain points in the profile. These stresses can cause warping upon cooling. Almost any shape imaginable can be created so long as it is a continuous profile.

The product must now be cooled and this is usually achieved by pulling the extrudate through a water bath. Plastics are very good thermal insulators and are therefore difficult to cool quickly. Compared with steel, plastic conducts its heat away 2000 times more slowly. In a tube or pipe extrusion line, a sealed water bath is acted upon by a carefully controlled vacuum to keep the newly formed and still molten tube or pipe from collapsing. For products such as plastic sheeting, the cooling is achieved by pulling through a set of cooling rolls.

Sometimes on the same line a secondary process may occur before the product has finished its run. In the manufacture of adhesive tape, a second extruder melts adhesive and applies this to the plastic sheet while it's still hot. Once the product has cooled, it can be spooled, or cut into lengths for later use.

Screw design

There are five possible zones in a thermoplastic screw. Since terminology is not standardized in the industry, different names may refer to these zones. Different types of polymer will have differing screw designs, some not incorporating all of the possible zones.

Fig 2.5.2: A Simple Plastic Extrusion Screw

Most screws have these three zones:

coated paper or foil, monofilaments and textile fibers, flat sheet (anything over 0.010 inch (0.25 mm)), wire and cable covering, and a great variety of profiles such as window frames, gaskets and channels, and house siding. The products can be cut to length or rolled up as needed.(Todd, Allen & Alting 1994)

2.5.3 Typical extrusion materials

Typical plastic materials that are used in extrusion include but are not limited to: polyethylene, polypropylene, acetal, acrylic, nylon (polyamides), polystyrene, acrylonitrile butadiene styrene (ABS) and polycarbonate.(Todd, Allen & Alting 1994)

2.5.4 Blow extrusion of plastic film

For products such as plastic sheet or film, the cooling is achieved by pulling through a set of cooling rolls (calender or "chill" rolls), usually 3 or 4 in number. Running too fast creates an undesirable condition called "nerve"- basically, inadequate contact time is allowed to dissipate the heat present in the extruded plastic. In sheet extrusion, these rolls not only deliver the necessary cooling but also determine sheet thickness and surface texture (in case of structured rolls; i.e. smooth, levant, haircell, etc.).

Often co-extrusion is used to apply one or more layers to obtain specific properties such as UV-absorption, soft touch or "grip", matte surface, or energy reflection.

A common post-extrusion process for plastic sheet stock is thermoforming, where the sheet is heated until soft (plastic), and formed via a mold into a new shape. When vacuum is used, this is often described as vacuum forming. Orientation (i.e. ability/ available density of the sheet to be drawn to the mold which can vary in depths from 1 to 36 inches typically) is highly important and greatly affects forming cycle times.

Thermoforming can go from line bended pieces (e.g. displays) to complex shapes (computer housings), which often look like they've been injection moulded, thanks to the various possibilities in thermoforming, such as inserts, undercuts, divided moulds.

Plastic extrusion onto paper is the basis of the liquid packaging industry (juice cartons, wine boxes...); usually an aluminum layer is present as well. In food packaging plastic film is sometimes metallised, see metallised film.

Blown film extrusion

The manufacture of plastic film for products such as shopping bags is achieved using a blown film line.

This process is the same as a regular extrusion process up until the die. The die is an upright cylinder with a circular opening similar to a pipe die. The diameter can be a few centimetres to more than three metres across. The molten plastic is pulled upwards from the die by a pair of nip rolls high above the die (4 metres to 20 metres or more depending on the amount of cooling required). Changing the speed of these nip rollers will change the gauge (wall thickness) of the film. Around the die sits an air-ring. The air-ring cools the film as it travels upwards. In the centre of the die is an air outlet from which compressed air can be forced into the centre of the extruded circular profile, creating a bubble. This expands the extruded circular cross section by some ratio (a multiple of the die diameter). This ratio, called the "blow-up ratio" can be just a few percent to more than 200 percent of the original diameter. The nip rolls flatten the bubble into a double layer of film whose width (called the "layflat") is equal to ½ the circumference of the bubble. This film can then be spooled or printed on, cut into shapes, and heat sealed into bags or other items.

An advantage of blown film extrusion over traditional film extrusion is that in the latter there are edges where there can be quality (thickness,...) variations.

Overjacketing extrusion

In a wire coating process, bare wire (or bundles of jacketed wires, filaments, etc.) is pulled through the center of a die similar to a tubing die. Many different materials are used for this purpose depending on the application. Essentially, an insulated wire is a thin walled tube which has been formed around a bare wire.

There are two different types of extrusion tooling used for coating over a wire. They are referred to as either "pressure" or "jacketing" tooling. The selection criteria for choosing which type of tooling to use is based on whether the particular application requires intimate contact or adhesion of the polymer to the wire or not. If intimate contact or adhesion is required, pressure tooling is used. If it is not desired, jacketing tooling is chosen.

The main difference in jacketing and pressure tooling is the position of the pin with respect to the die. For jacketing tooling, the pin will extend all the way flush with the die. When the bare wire is fed through the pin, it does not come in direct contact with the molten polymer until it leaves the die. For pressure tooling, the end of the pin is retracted inside the crosshead, where it comes in contact with the polymer at a much higher pressure.

Tubing extrusion

Extruded tubing process, such as drinking straws and medical tubing, is manufactured the same as a regular extrusion process up until the die. Hollow sections are usually extruded by placing a pin or mandrel inside of the die, and in most cases positive pressure is applied to the internal cavities through the pin.

Tubing with multiple lumens (holes) must be made for specialty applications. For these applications, the tooling is made by placing more than one pin in the center of the die, to produce the number of lumens necessary. In most cases, these pins are supplied with air pressure from different sources. In this way, the individual lumen sizes can be adjusted by adjusting the pressure to the individual pins.

Co extrusion

Co extrusion is the extrusion of multiple layers of material simultaneously. This type of extrusion utilizes two or more extruders to melt and deliver a steady volumetric throughput of different viscous plastics to a single extrusion head (die) which will extrude the materials in the desired form. This technology is used on any of the processes described above (blown film, over jacketing, tubing, sheet). The layer thicknesses are controlled by the relative speeds and sizes of the individual extruders delivering the materials.

There are a variety of reasons a manufacturer may choose co extrusion over single layer extrusion. One example is in the vinyl fencing industry, where co extrusion is used to tailor the layers based on whether they are exposed to the weather or not. Usually a thin layer of compound that contains expensive weather resistant additives are extruded on the outside while the inside has an additive package that is more suited for impact resistance and structural performance.

Extrusion coating

Extrusion coating is using a blown or cast film process to coat an additional layer onto an existing rollstock of paper, foil or film. For example, this process can be used to improve the characteristics of paper by coating it with polyethylene to make it more resistant to water. The extruded layer can also be used as an adhesive to bring two other materials together. A famous product that uses this technology is tetrapak.

Compound extrusions

Compounding extrusion is a process that mixes one or more polymers with additives to give plastic compounds. The feeds may be pellets, powder and/or liquids, but the product is usually in pellet form, to be used in other plastic-forming processes such as extrusion and injection molding. Machine size varies from tiny lab machines to the biggest extruders in the industry, running as much as 20 tons per hour, as used by the chemical companies that make the base resins. Usually twin-screw extruders are preferred because they give better mixing at lower melt temperatures. Most of these have screws and barrels made up of smaller segments (mixing, conveying, venting and additive feeding) so that the design can be changed to meet the production and product needs. Single-screw extruders can be used for compounding as well, especially with appropriate screw design and static mixers after the screw. Selection of the components to be mixed (viscosities, additive carriers) is as important as the equipment (Eldridge, 2005).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Design Considerations

The low density polyethylene (LDPE) recycling machine to be developed will mainly be compose of metallic materials. It will consists of three chambers namely; heating chamber, cooling chamber and size reduction chamber. These chambers will work collectively to achieve the end result.

The calculation below is aimed at evaluating the necessary parameters to be used for the different components that make up the above listed chambers. The results of this analysis will be incorporated in the design calculation to prevent the possibility of under design or over design of parts for the fabrication.

Heating chamber

The components found in the heating chamber are as follows;

i. **Hopper:** This is where the LDPE is housed as melting takes place. It is made up of 2.5mm thick mild steel to withstand the heat that is being generated.

ii. **Electric Heating Element:** This is found inside the hopper, it serves as source of heat for the heating chamber. Each of the heating element is 1kW

iii. **Insulator:** This is found behind the hopper (heating chamber) where the heating takes place. It prevents heat loss from the heating chamber .It is made of Rock wool.

iv. **Screen:** This is found at the lower part of the hopper, it allows the liquid or low density polyethylene melt to pass through to the cooling chamber. It doesn't allow melted LDPE to pass through.

v. **Stopper:** This is located at the bottom of the hopper .It is usually closed when the melting is still taking place to enable proper heating of the whole material before flowing to the cooling chamber.

Cooling Chamber

i. **Mould:** These are found in the water tank, they are frustum in shape with the smaller end on top and the larger end below. For easy dissipation of heat to the surrounding and increase in the surface area the moulds are nine in number, it is also made of mild steel.

ii. **Water Tank:** This is found below the hopper after the screen beneath the hopper. It encloses the mould. Water that is used as the medium for cooling is stored here.

iii. **Stopper:** this is located at the bottom of the tank, it closes the bottom of the frustums to ensure proper cooling of the melt, before it is allowed to enter the size reduction chamber.

Size Reduction Chamber

The cooling chamber is made up of the following components;

i. **Electric motor**: This is used to supply power which drives the shaft.

ii. **Shaft:** This cuts across through the central axis of the shredding chamber. It rotates with the power of the motor and carries the blade that shreds the already cooled LDPE.

iii. **Cutting Blade:** This is located at intervals on the rotating shaft. It shreds the LDPE to pellets.

iv. **Screen:** This is found at the lower end of the size reduction chamber. It allows the LDPE that has been reduced to a particular size to pass through and be collected.

rication of the machine hence would minimize unnecessary cost.

3.2 Hopper Design

In hopper designing, an important consideration to make is for the hopper to be able to contain the input and allow easy passage of raw material into the next chamber. Also the hopper's strength and capacity are taken into consideration. In designing a hopper, it is recommended that the angle of inclination of the sides of the hopper to the horizontal must be greater than the angle of friction between the hopper wall and the material.

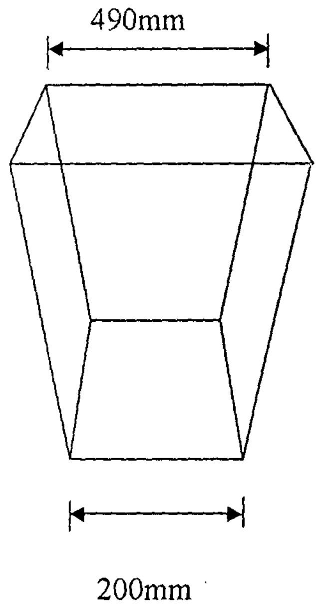
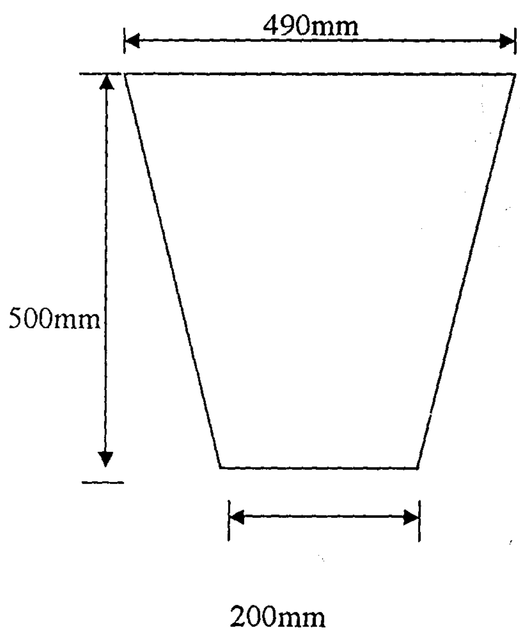
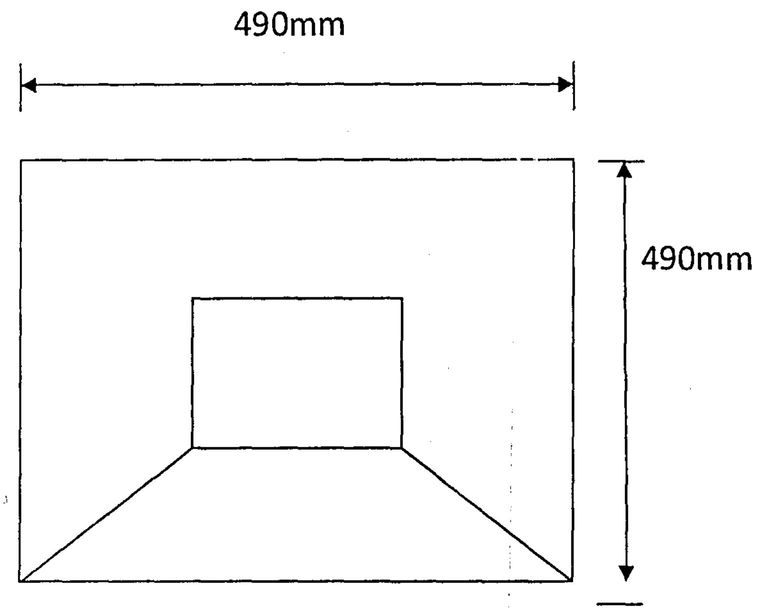


Figure 3.1 (a) Cross-section of the hopper



(b): Dimensions of the hopper



(c) Top view of the hopper

Assuming the volume of the hopper is fully loaded with LDPE. The weight of LDPE to be fed inside the hopper will be calculated as follows:-

The mass of one sample of polyethylene=2.32g = 2.32×10^{-3} kg

Weight of one sample, where g= 9.81m/s

Weight= mg = $2.32\times 10^{-3} \times 9.81 = 0.0227592$kg

Then, the weight of 220 packs = 220×0.0227592

= 5.00kg

3.2.1 Hopper Capacity

In determining the capacity of the hopper, the volume of the hopper is considered, and Oyedepo, 1998 gave an expression for calculating volume of hopper as;

$$\text{Volume} = {}^{1}/_{3}\left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right)h \qquad 3.1$$

Where; A_1 = Area of the top

A_2 = Area of the bottom

h = Height of the hopper

Considering the following dimension;

Length of the top = 0.49m

Breadth of the top = 0.49m

Length of the bottom = 0.2m

Breadth of the bottom = 0.2m

Height of the hopper = 0.5m

Therefore;

Area of top, $A_1 = 0.49 \times 0.49$

$= 0.2401\text{m}^2$

Area of the bottom, $A_2 = 0.2 \times 0.2$

$= 0.04\text{m}^2$

Substituting in equation (1), these values,

Volume of hopper = $\text{Volume} = {}^{1}/_{3}\left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right)h$

$= {}^{1}/_{3}\left[(0.2401 + 0.04) + \sqrt{0.2401 \times 0.04}\right]0.5$

$= {}^{1}/_{3}\,(0.2801 + \sqrt{0.009604})0.5$

$= {}^{1}/_{3}\,(0.2801 + 0.098)0.5$

$= {}^{1}/_{3}\,(0.3781)0.5$

$= 0.0630m^3$

For 20% factor of safety for the capacity of the hopper

$= \frac{20}{100}0.0630$

$= 0.0126m^3$

This is the capacity of the hopper

$= 0.0630 + 0.0126$

$= 0.0756m^3$

3.2.2 Quantity of Heat Required to Melt the Material (LDPE)

Mass of material to be recycled (m) = 5kg

Expressing the value of (m) in volume

From density $(\rho) = {}^{m}/_{V}$ 3.2

$V = m/\rho$

Where ρ = density of the material (i.e. LDPE)

$\rho = 920kg/m^3$ (Martienssen W. (Eds.); H.Warlimort, 2005)

Using the mass, the volume of the material to be recycled

$$(V) = \frac{5kg}{920kg/m^3} = 5.435 \times 10^{-3}m^3$$

3.2.3 Cooling Chamber

Volume of Tank

In calculating the volume of the Tank, it is taken that, the tank is a cuboid in shape

Volume of a Tank = Length × Breadth × Height 3.5

= 0.49m × 0.49m × 0.1m

=$0.02401m^3$

Volume of Mould

The size of the mould (frustum) will be as follow or considering the following dimension;

Diameter of the top = 3.6cm = 0.036m

Radius of the top, r = 1.8cm = 0.018m

Diameter of the bottom = 4cm = 0.04m

Radius of the bottom, R = 2cm = 0.02m

Height of the mould, H = 10cm = 0.1m

The total number of moulds (frustum) in the cooling chamber is nine (9).

Volume of the mould V;

$$V = \frac{\pi}{3} h\,(R^2 + r^2 + R \times r) \quad 3.6$$

$$= \frac{\pi}{3} 0.1(0.02^2 + 0.018^2 + 0.02 \times 0.018)$$

$$= \frac{\pi}{3} 0.1(0.0004 + 0.000324 + 0.00036)$$

$= \frac{\pi}{3}\, 0.1(0.001084)$

$= 0.000113516$

$V = 1.135 \times 10^{-4} m^3$

Total Volume = (volume of a mould × Total number of moulds)

$V = 1.135 \times 10^{-4} \times 9$

$= 1.0215 \times 10^{-3}\ m^3$

Therefore; to determine the amount of water in the cooling chamber

Total volume of water = volume of a tank – total volume of the moulds

Total volume of water = $(0.02401 - 1.0215 \times 10^{-3})\ m^3$

$= 2.298 \times 10^{-2} m^3$

Heat Loss from the Cooling Chamber

Heat loss $= MC_P\, \Delta T$

$C_p = 2.302 (kJ/kgK)$ (Martienssen W. (Eds.); H.Warlimort, 2005)

Where change in temperature, $\Delta T = T_2 - T_1$

$T_2 = 0°C\ or\ 273K$

$T_1 = 115°C\ or\ 388K$

$\Delta T = 273 - 388$

$\Delta T = -155\text{K (cooling)}$

Heat loss =5kg ×2.302(kJ/kgK)× 155K

Heat loss= 1784.05kJ

Cooling Rate of the Cooling Chamber

$$\text{Rate of cooling} = \frac{\text{heat loss}}{\text{time}} \qquad 3.7$$

For 22.5 minutes (Janssen 2009);

$$= \frac{1784.05}{(60 \times 22.5)}$$

=1.3215kJ/sec

Size reduction Chamber

Cutting Blades on the Rotating Shaft

Ahuja and Shama, 1989 establish blade spacing for his manually operated shredding machine at 30 to 50mm. most existing shredders have one legged blade. In this design, one legged blade of 10cm × 10cm spacing is used.

The cutting blade is made of mild steel.

Radius r = 12.5cm

Height H = rsinθ

=12.5cm sin 60 = 10.8253cm

Diameter = 4cm

Volume of each cutting blade = πr^2 (length)

$$=\frac{4^2}{2}\times 12.5$$

$$= 8 \times 12.5$$

$$=100\ cm^3$$

$$=1.0m^3$$

Mass of each cutting blade = Volume × Density of mild steel

$$= 1.0 \times 7850kg/m^3$$

$$= 78.5kg$$

Belt Selection:

A V – Belt (based on the usual load of drive 0.75 – 5kw power)

Determination of the Maximum Power of Belt

Calculation of the belt speed

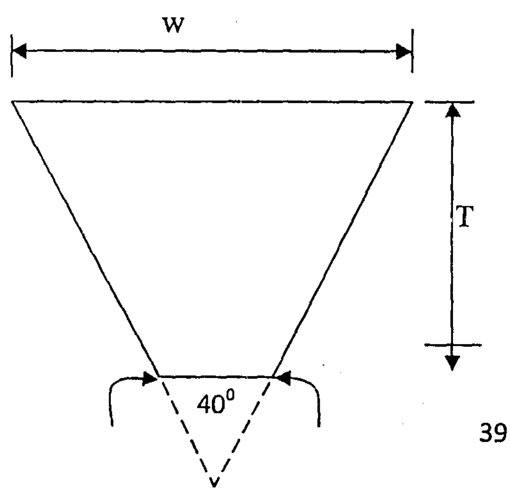


Figure 3.2: Crossection of V groove belt

For V – belt A, the following are the data of the sections:-

Usual load of drive = 0.75 – 5kw

Recommended minimum pulley pitch diameter, d = 0.09m, N1 = 1450m

Normal thickness, T = 8mm

Weight per meter = 0.100kg

Belt speed, $S = \pi dpN_1$ 3.8

Required shaft speed = 2000rpm (selected)

Belt speed, $S = \pi dpN_1$

$$S = \frac{\pi(0.09 \times 1450)}{60} = 6.833 m/s$$

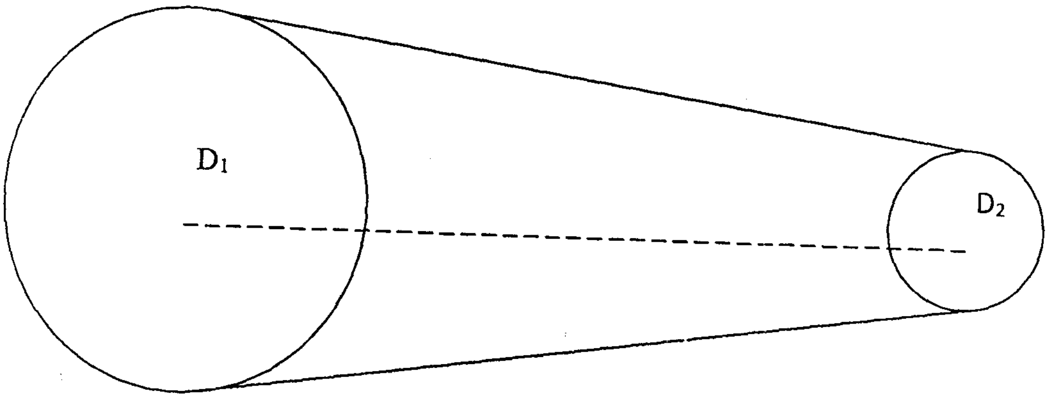
Required motor speed = 1450 rpm

Speed ratio; $Vs = \frac{n_1}{n_2} = \frac{1450}{2000} = 0.725$

Motor-Cylinder Design Calculation

Driven

Driven



Motor pulley

Shaft pulley

Figure 3.3: Motor-Cylinder Pulley Belt Arrangement

$$\frac{D_1}{D_2} = \frac{N_1}{N_2} \qquad 3.9$$

Where,

D_1= diameter of motor pulley = 12cm

D_2 = diameter of the shaft driven pulley =?

N_1 = Speed of electric motor = 1450rpm

N_2 = Speed of rotating shaft = 2000rpm

From the equation;

$$\frac{D_1}{D_2} = \frac{N_1}{N_2}$$

$D_1 N_2 = D_2 N_1$

$D_2 = \frac{D_1 N_2}{N_1}$

$= \frac{12 \times 1450}{2000}$

$= \frac{17400}{2000}$

$=8.7cm$

$= 9.0cm$

If the diameter of the shaft driven pulley is 9cm

Speed of Shaft = $\frac{\pi \times 0.09 \times 1450}{4}$

$= 410.031 m/s$

Angular Velocity of Motor-Cylinder Belt

$$\omega = \frac{2\pi N}{60} \qquad 3.10$$

Angular Velocity of Motor, ω_2

$\omega_2 = \frac{2 \times \pi \times 1450}{60} = 151.863$ rad/s

Angular Velocity of shaft, ω_1

$\omega_1 = \frac{2 \times \pi \times 2000}{60} = 209.467$ rad/s

Power on Motor-Cylinder Belt

Power = torque × angular velocity

$$=T\omega \qquad 3.11$$

Torque on motor-pulley to accelerate the cylinder = $t_m = w_2 r_2$

r_2 = radius of motor-pulley

Hence,

Power = tm $w_2 = w_2^2 r_2$

Therefore, power delivered by the motor

$Pm = (151.863)^3 \times \frac{0.12}{2}$

$= 1383.742$ W

For efficiency of 95%

$= \frac{95}{100} \times 1383.742$

$= 1314.555$ W

Power required to drive the shaft,

$$P_S = \omega_1^2 r_1 \qquad 3.12$$

Where,

r_1 = radius of shaft of pulley

$P_2 = (209.467)^2 \times \frac{9}{2}$

$= 197443.908$ W

Centre-Distance of Motor-Shaft Pulley

The centre-distance is obtained from the relation CD = max (2R, 3r + R) 3.13

Where, CD = Centre distance

R = Radius of large pulley

r = Radius of small pulley

From the equation above, two centre distances will be obtained, but the larger is chosen.

That is $CD = \max\left(\frac{2\times1.12}{2}, \frac{3(0.09)}{2} + \frac{0.12}{2}\right)$

CD = max (0.120, 0.195)

CD = 195mm (which is equal to the larger centre distance)

Note: the centre-distance should not be greater than three times the sum of the sheave diameters or less than the diameter of the larger pulley.

Angle of Contact of Motor-Shaft Pulley

$\emptyset_L$ = Angle of contact of large pulley = $\pi + 2\sin^{-1}\frac{(D-d)}{2CD}$ 3.14

$= \pi + 2\sin^{-1}\frac{(120-90)}{2(195)}$

$= 11.965$ □

$\emptyset_S$= Angle of contact of small pulley = $\pi - 2\sin^{-1}\frac{(D-d)}{2CD}$ 3.15

$= \pi - 2\sin^{-1}\frac{(120-90)}{2(195)}$

$= -5.681$ □

Length of Motor-Shaft Pulley

Length of belt, $L = \frac{\pi}{2}(D_1 + D_2) + 2CD + \frac{(D_1 - D_2)}{4CD}$ 3.16

According to Khurmi and Gupta (2005)

$= \frac{3.142}{2}(120 + 90) + 2 \times 195 + \frac{(120-90)^2}{4 \times 195}$

$L = 438.28mm$

The length correction factor $K_L = 0.84$ (Khrumi and Grupta)

$L = 438.28 \times 0.84$

$L = 368.158mm$

Determination of Weight of Pulley

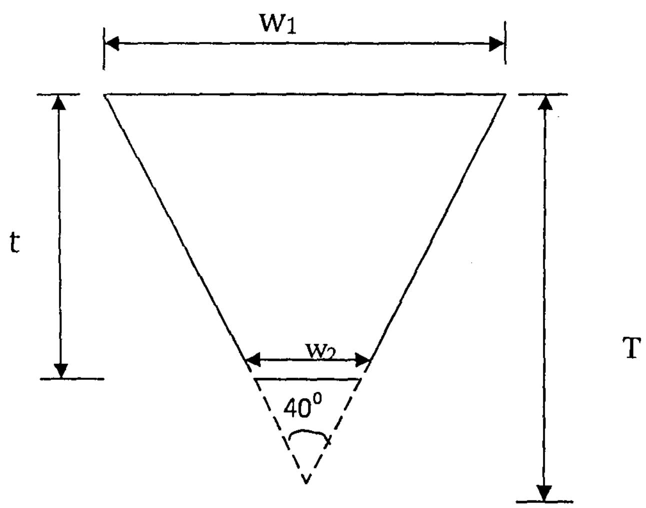


Figure 3.4: Cross-Section of V-groove Belt

Large Width of the belt; $w_1 = 13mm$

Smaller width of the belt, w_2

Nominal depth of the belt; $t = 8mm$

Sleeve groove angle = 40^0

Density of the leather belt = $\rho = 970kg/m^3$

(Shaun series)

From the above,

$\beta = \left(\frac{180-40}{2}\right) = 70^0$

Actual depth of the belt, $T = \frac{1}{2} \times 13 \times \tan 70$

$T = 17.859mm$

$w_2 = \frac{t \times w_1}{T}$

$= \frac{8 \times 13}{17.854}$

$w_2 = 5.83mm$

The cross-sectional area of the belt is calculated as;

$$A = \left[\frac{w_1 + w_2}{2}\right]t \qquad 3.17$$

$= \left[\frac{13+5.83}{2}\right]8$

$= 9.415 \times 8$

$= 75.32mm^2$

$= 73.32 \times 10^{-6}$ m

$M = P \times A = 970 \times 75.32 \times 10^{-6} = 73060.4 \times 10^{-6}$

M = 0.730604kg/m

Determination of Length of Belts

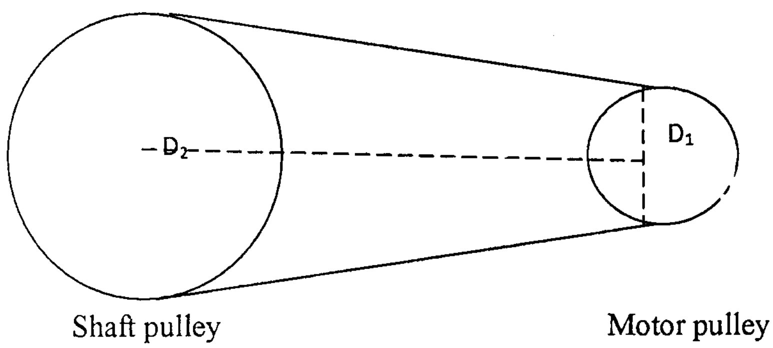


Figure 3.5: Motor- Shaft Belt

D_2 = diameter of the shaft pulley

= 12cm

D_1 = diameter of the motor pulley

= 8cm

Centre to centre distances, C = minimum

100mm = 0.1m

Nominal Pitch Length,

$$L = 2C + \frac{x}{2}(D_1 + D_2) + \left[\frac{(D1 + D2)^2}{4C}\right] \qquad 3.18$$

$$L = 2 \times 100 \times \frac{\pi}{2}(120 + 900) + \left[\frac{(120-900)^2}{4\times100}\right]$$

$$= 200 \times \frac{2100\pi}{2} + \frac{90000}{400}$$

$$= 200 + 3299.1 + 225$$

$$= 3724.1\text{mm (max)}$$

Design Theory of Cutting Shaft

If the cutting shaft is subjected to twisting moment only,

$$\frac{\tau}{r} = \frac{\tau}{J} \qquad 3.19$$

$$J = \frac{\pi D^4 - d^4}{64} \qquad 3.20$$

$$\tau = \frac{\tau r}{J} = \frac{\tau D}{2J}$$

$$\tau = \frac{16DT}{\pi(D^4 - d^4)} \qquad 3.21$$

$$\frac{M}{J} = \frac{\sigma}{y} \qquad 3.22$$

Where,

M = bending moment

σ = bending

J = moment of inertia

y = distance from neutral axis to shaft diameter = $\frac{D}{2}$

$$M = \frac{\pi\sigma(D^4 - d^4)}{32D}$$

$$\therefore \sigma = \frac{32M}{\pi(D^4 - d^4)} \qquad 3.23$$

Maximum shear stress = $S_{max} = \frac{1}{2}\sqrt{(\sigma^2 + 4\sigma^2)}$ 3.24

$$S_{max} = \frac{1}{2}\sqrt{\left\{\left[\frac{32MD}{\pi(D^4 - d^4)}\right]\right\} + 4\left[\frac{16DT}{\pi(D^4 - d^4)}\right]^2}$$

$$= \frac{16D\sqrt{M^2} + 4T^2}{\pi(D^4 - d^4)} \qquad 3.25$$

For cutting blade,

$$S = \frac{M}{Z} \qquad 3.26$$

Where,

M = bending moment

Z = section modulus

Maximum stress

$$\sigma_{Max} = \frac{1}{2}\sqrt{S^2 + 4\sigma^2} \qquad 3.27$$

$$= \frac{1}{2}\sqrt{\left(\frac{M}{Z}\right)^2 + \left(\frac{F}{A}\right)^2} \qquad 3.28$$

(Oluboji, 2004)

Determination of Weight of Cutting Blade

Area of each rod $= \frac{\pi d^2}{4} = \frac{3.142\ (0.04)^2}{4}$

$= 1.2568 \times 10^{-3} m^2$

Length of the blade = 12.5cm = 0.125m

Volume of the blade = $1.2568 \times 10^{-4} m^3$

Weight of blade = (W) = ρvg 3.29

$= 7850 \times 1.2568 \times 10^{-4} \times 9.81$

= 9.678N

For 18 cutting blade

$W = 18 \times 9.678$

$= 174.212N$

Weight of cylinder (shredding chamber)

Area $= \frac{\pi(D^2 - d^2)}{4}$

D = 49.5cm = 0.495m

$d = 44.5cm = 0.445m$

Area, $A = \frac{3.142(0.495^2 - 0.445^2)}{4}$

$= 0.0369185$

$A = 3.692 \times 10^{-2} m^3$

$V = 49cm = 0.49m$

$V = Al = 3.692 \times 10^{-2} \times 0.43$

$V = 1.58756 \times 10^{-2} m^3$

Weight (W) = ρvg

$= 1222.56N$

Weight of low density polyethylene (LDPE) for a feed rate of 5kg/hr

Amount broken per second

$= \frac{5}{3600} = 1.388kg$

Breaking Force $F = 3.9943 W_g RN$

W_g = weight of LDPE pellets (kg)

R = panicle radius (m)

N = Breaking speed (*rpm*)

(Khurmi and Gupta, 2008)

$F = 3.9943 \times 1.388 \times 1.8 \times 10^{-2} \times 1450$

$= 144.70N$

Total cutter weight = 174.212 + 1222.56 + 1447.0

$F = 2843.772N$

Determination of Stress of Cutting Blade on Shaft

The beam and shear force diagram for the shaft as shown in figure 3.6 and 3.7 are being computed for as follows;

$$\text{Torque } (T) = Fr \qquad 3.30$$

Where,

r = distance to the neutral axis = 0.018

F= force exerted by the blade on the shaft

$T = 2843.772 \times 0.018$

$= 51.1879Nm$

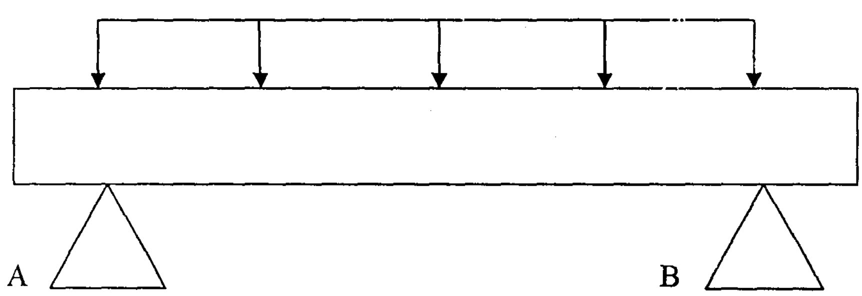


Figure 3.6: Beam diagram of shaft

$R_A = R_B = \frac{2843.772}{2} = 1421.886$

$W = \frac{2843.772}{0.49} = 5803.616 N/m$

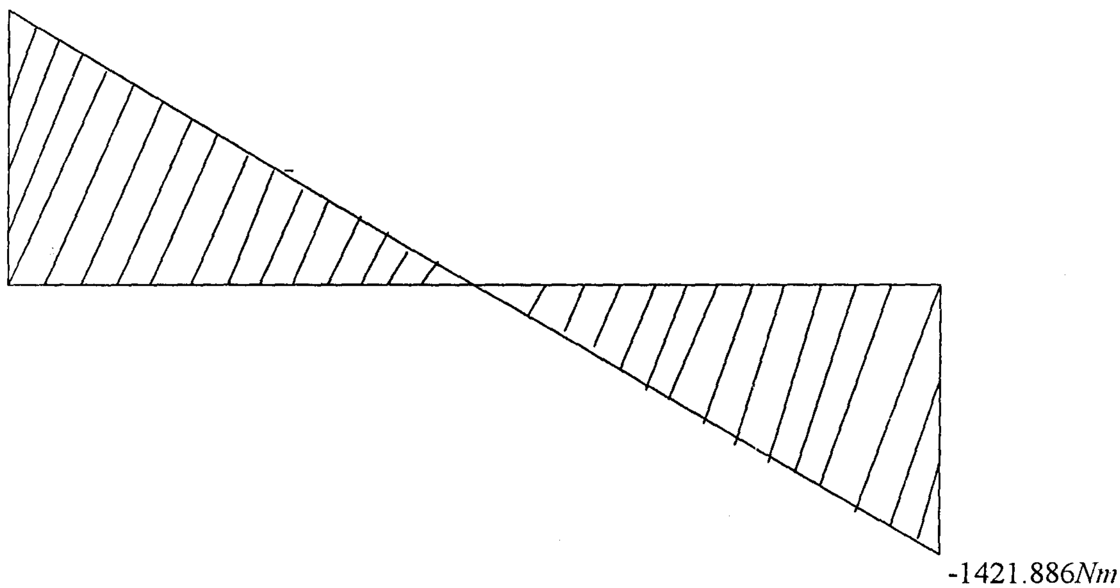


Figure 3.7: Shear force diagram of rotating shaft

$$S.F = \frac{wl}{2} - wx \qquad 3.31$$

Maximum shear force at B

$\frac{wl}{2} = \frac{5.803.616 \times 0.49}{2} = 1421.886 Nm$

Maximum shear force at A

$-\frac{wl}{2} = \frac{-5.803.616 \times 0.49}{2} = -1421.886 Nm$

Bending Moment of Shaft

The bending moment diagram is as shown in figure 3.8 for the rotating shaft

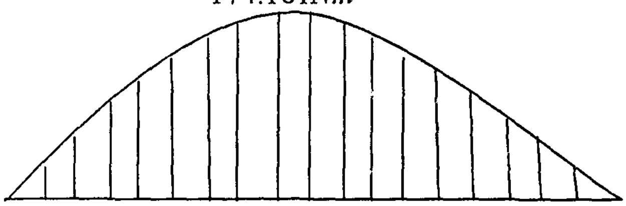


Figure 3.8: Bending moment diagram of the rotating shaft

$M = \frac{wl^2}{8} = \frac{5803.616 \times 0.49^2}{8}$

M = 174.181*Nm*

Maximum shear on shaft

$S = 16\times 0.495 \sqrt{\frac{174.181^2 + 4(0.989)^2}{\pi(0.495^2 - 0.445^2)}}$

S = 3590.06*Nm*

Power Demand at Shaft

$P = \tau\omega$ 3.32

From equation 3.10 $\omega = \frac{2\pi N}{60}$

$\omega = \frac{2 \times 3.142 \times 1450}{60}$

$\omega = 151.86$

$P = 51.1879 \times 151.86$

$P = 7773.565W$

For the cutting blade

$W = 1447N$

$W = {}^{9.678}/_{0.1}$

$W = 96.78N/m$

The shear force diagram is shown in figure 3.9

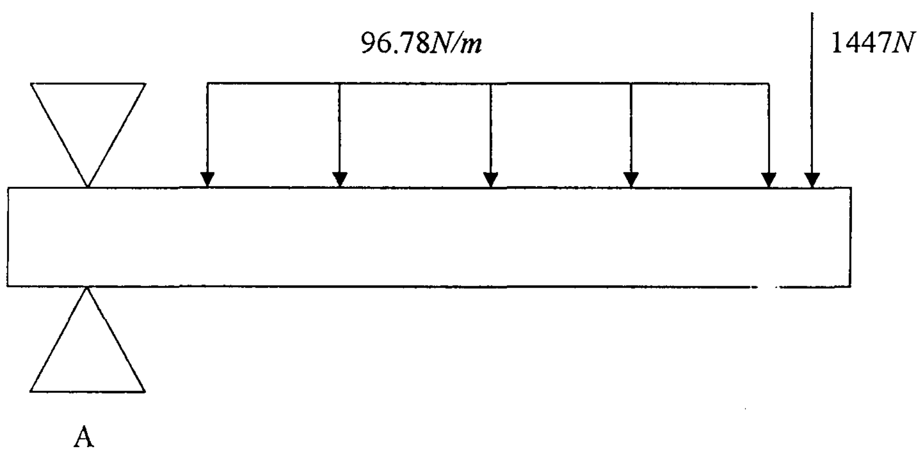


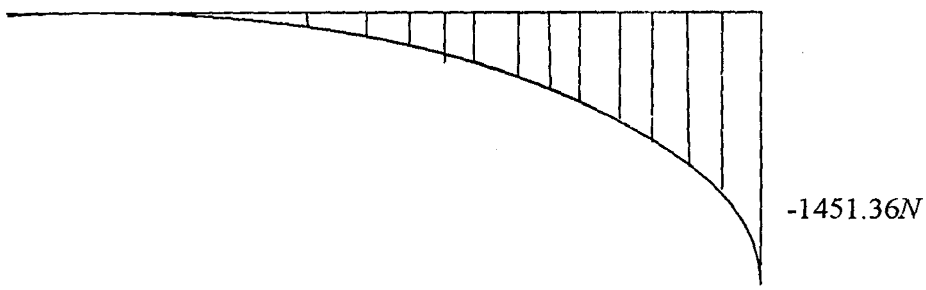
Figure 3.9: Shear force diagram of shaft

$S.F. = -W - wx$ 3.34

$= -1447 - 96.78 \times 0.045$

$= -1451.36$

The bending moment diagram is shown in figure 3.10



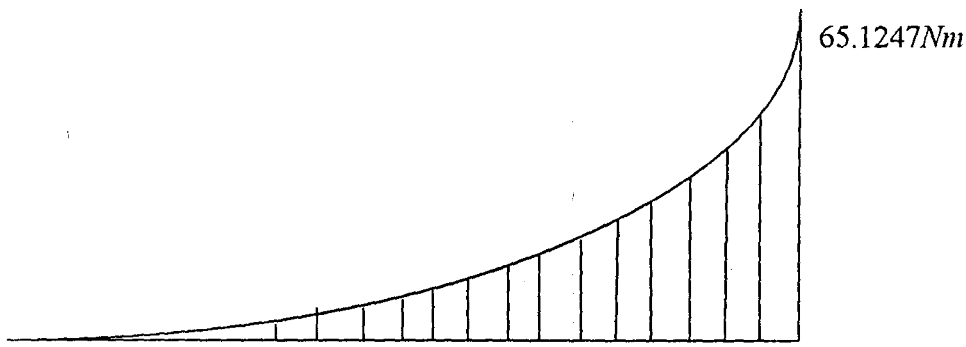


Figure 3.10:Bending moment diagram of shaft

$$M = Wx + \frac{wx^2}{2} \quad 3.35$$

$$M = 1447 \times 0.045 + \frac{9.678 \times 0.045^2}{2}$$

$$M = 65.1247Nm$$

$$Z = \frac{\pi d^3}{32}$$

$$= \frac{3.142 \times 0.045^3}{32}$$

$$= 8.9473 \times 10^{-6}$$

Shear stress

$$S = \frac{F}{A} \qquad 3.36$$

$$S = \frac{1451.36}{1.2568 \times 10^{-3}}$$

$$= 1154805.856 N/m^2$$

Maximum stress

$$S_{Max} = \frac{1}{2}\sqrt{\left(\frac{65.1247}{8.9473 \times 10^{-6}}\right)^2 + (1154805.856)^2}$$

$$= 1.3335 \times 10^{12}\ N/m^2$$

3.3 Materials for Development

The materials for the development of the low density polyethylene machine are;

i) **Mild Steel Sheet**: This is used for the outside and inside walls of the recycling machine. It is also used for the pipes in the cooling chamber.

ii) **Mild Steel Rod**: This is used as the shaft that is in the shredding compartment .

iii) **Rock Wool**: this used as the insulating material to prevent heat losses from the heating chamber.

iv) **Stainless steel**: this material is used in the hopper to avoid sticking of the material and to enhance cooling in the tank.

v) **Half-Cut Rod:** This is used for the screen in the melting and shredding section of the machine.

vi) **Angle iron:** This is used to create a frame for the stopper to slide and as a frame for the shredder. it is also used as the stand for the machine.

vii) **Flat bar:** This is used as the blade on the shaft in the shredding section.

3.4 Components of the LDPE Recycling Machine

The components of the low density polyethylene recycling machine are composed of three stages;

- Heating chamber
- Cooling chamber
- Size Reduction chamber

3.4.1 Heating chamber

The components found in the heating chamber are as follows;

vi. **Hopper:** This is where the LDPE is housed as melting takes place. It is made up of 2.5mm thick mild steel to withstand the heat that is being generated.

vii. **Electric Heating Element:** This is found inside the hopper, it serves as source of heat for the heating chamber. Each of the heating element is 1kW

viii. **Insulator:** This is found behind the hopper (heating chamber) where the heating takes place. It prevents heat loss from the heating chamber .It is made of Rock wool.

ix. **Screen:** This is found at the lower part of the hopper, it allows the liquid or low density polyethylene melt to pass through to the cooling chamber. It doesn't allow melted LDPE to pass through.

x. **Stopper:** This is located at the bottom of the hopper .It is usually closed when the melting is still taking place to enable proper heating of the whole material before flowing to the cooling chamber.

3.4.2 Cooling Chamber

iv. **Mould:** These are found in the water tank, they are frustum in shape with the smaller end on top and the larger end below. For easy dissipation of heat to the surrounding and increase in the surface area the moulds are nine in number, it is also made of mild steel.

v. **Water Tank:** This is found below the hopper after the screen beneath the hopper. It encloses the mould. Water that is used as the medium for cooling is stored here.

vi. **Stopper:** this is located at the bottom of the tank, it closes the bottom of the frustums to ensure proper cooling of the melt, before it is allowed to enter the size reduction chamber.

3.4.3 Size Reduction Chamber

The cooling chamber is made up of the following components;

v. **Electric motor**: This is used to supply power which drives the shaft.

vi. **Shaft:** This cuts across through the central axis of the shredding chamber. It rotates with the power of the motor and carries the blade that shreds the already cooled LDPE.

vii. **Cutting Blade:** This is located at intervals on the rotating shaft. It shreds the LDPE to pellets.

viii. **Screen:** This is found at the lower end of the size reduction chamber. It allows the LDPE that has been reduced to a particular size to pass through and be collected.

3.5 Description of the LDPE Recycling Machine

The recycling process in this machine comprises of three stages, known as;

- The Heating
- The Cooling and
- The Size Reduction

These three processes could also be called agglomeration. The LDPE gotten in their waste form are collected and put inside the hopper where 1035.9kJ of heat is applied through conduction to increase the LDPE temperature to its melting point of 115°C During the melting process the stopper below the hopper is closed to ensure proper heating before the melt begins to flow down to the cooling chamber. When these LDPE are melted the stopper is opened and allows the melt to pass through the screen to the cooling chamber.

At the cooling chamber the melt from the heating chamber flows through frustum pipes that are surrounded by water that is in continuous flow in and out of the mold and the inner water tank. Beneath the water tank there is a stopper which is closed while the cooling takes place, to ensure that no melt passes to the size reduction chamber without proper cooling. When the cooling is complete the stopper is opened and the solid LDPE falls in the shredding section where the size reduction takes place.

The size reduction takes place when the shaft powered by an electric motor of 1450rpm and 2hp is used to rotate 18 blades that cut the solid LDPE into reduced sizes or flakes. These tiny flakes are then collected beneath the screen. The screen only allows a particular range of sizes not more than 2mm of the LDPE to pass through.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 PRESENTATION OF RESULTS

Table 4.1 shows the stages and conditions of materials during the recycling process.

Time (min)	Stages	Form
0 – 30min	Melting	Semi solid
30 – 55min	Melting	Liquid
55 – 1hr 38min	Cooling	Solid (lumps)
1h 38min– 1hr 43min	Cutting	Solid (pellet)

The total time taking for the recycling process was 1hour 43minutes.

4.2 MELTING EFFICIENCY

Efficiency $=\frac{Tr}{Ta}$

Were, T_r = theoretical time required for melting (Janssen. 2009)

T_a = actual time used in melting

Since T_r= 45minute

T_a = 55minutes

Therefore $\frac{45}{55} \times 100$

=81.8181

=81%

4.3 COOLING EFFICIENCY

Janssen (2009) Cooling takes 50% period of melting

C_r = cooling rate

C_a = actual time used in cooling

Therefore

$\frac{Cr}{Ca} \times 100$

$= \frac{22.5}{43} \times 100$

=52.32558

= 52%

4.4 CUTTING EFFICIENCY

Since the material feed into the hopper is 5kg

The output after grinding is 3.21kg

Efficiency = $\left(\frac{output}{input}\right) \times 100$

Efficiency = $\left(\frac{3.6kg}{5kg}\right) \times 100$

=72%

4.5 DISCUSSION OF RESULT

The process began by inputting the adequate quantity of raw material which was LDPE (locally used to package water) into the hopper. Electric energy was then supplied to the heating element which was the beginning of the melting process. The melted input then flowed into the cooling chamber.

The cooling chamber comprises of a mold that has nine frustums in which the melted LDPE flowed into. The cooling was made possible with the use of water contained in a rectangular tank in which the mold is attached. The mold is also perforated to ensure adequate cooling. A stopper is placed below the cooling chamber in order to prevent semi-solid material from getting to the size reduction chamber.

The size reduction chamber is made up of eighteen cutting blades attached to a shaft. The shaft is joined to a bearing which is also joined to a pulley. The shaft rotates with the aid of an electric motor. The stopper was then removed to allow the cooled solid to go into the size reduction to be reduced.

4.6 COST ANALYSIS

The cost analysis for this project is carried out and was locally sourced for the conditions of various machine parts are subjected to give rise to the important of material selection. It is not enough to use a material but that the material should withstand service conditions. In the design of this project, strength, cost of material, serviceability of parts and most especially availability of material were considered through as at compiling this write up, not all materials were available for costing due to variation in market prices. These considerations and material specification led to the selection of mild steel, which was the most available and easily machined. Finally, the painting of the machine was essential in order to reduce rusting.

The cost of producing this LDPE recycling machine is categories into

1. Material Cost
2. Labour Cost
3. Over head Cost

4.7 MATERIAL COST

The table 4.2 below shows the various materials purchased and used for the project work based on their present market value

s/No.	Materials	Specification	Quantity	Amount=N=	Price=n=
1	Mild steel sheet	Gauge 16	4	5500	22,000
2	Heating element	2000watt	2	1000	2,000
3	Solid shaft	3.5cm	1	4000	4000
4	Electrode	8mm metal	3 packet	900	1800
5	Paint	Enamel grey green	4 litre	2500	5000
6	Angle iron	$1^1/_2$ inch	2 length	1500	3000
7	Sheet	Gauge 14	3	5100	15,300
8	Angle iron	2 inch	3	1600	3200
9	Stainless steel electrode	8mm metal	2	1300	2600
10	Wires	2.5mm	4 yards	400	1600
11	Plug	13 amps	3	100	300
12	Rock wool	-	1 carton	18000	18000
13	Angle iron	1 inch	2	1300	2600
14	Iron rod	10mm	2	1000	2000
15	Quarter rod	2.5mm	5	800	4000
16	Connector	-	2	200	400
17	Stainless steel	Gauge 14 thick	Quarter	21,300	21,300
18	Pulley	12mm	2	500	1000
19	Belt	-	1	800	800
20	Electric Motor	2hp	1	23000	23000
21	Ball bearing	3.65B	2	400	800

22	Silicon oil	-	1	2000	2000
23	Transportation	-	-	-	21530
24	Miscellaneous	-	-	-	13770

The table 4.2 shows the cost of materials for the development of the low density polyethylene recycling machine, it is necessary to mention here that the prices were valid as at the time of costing and fabrication, and it is subjected to change depending on the market trend and periodic inflation rate.

4.8 LABOUR COST

Labour cost involves the cost of cutting, machining, welding and painting. It takes about 23.42% of the material cost.

Therefore,

Labour cost $= \frac{23.42}{100} \times 134700$

$= 31546.74$

=N= 31546

4.9 OVER HEAD COST

This involves the cost of transportation and other miscellaneous. It takes about 10% of the material cost.

Over head Cost $= \frac{10.34}{100} \times 134700$

$= 13927.98$

=N= 13927

Total cost = Material Cost + Labour Cost + Overhead Cost

= 134700 + 31546 + 13927

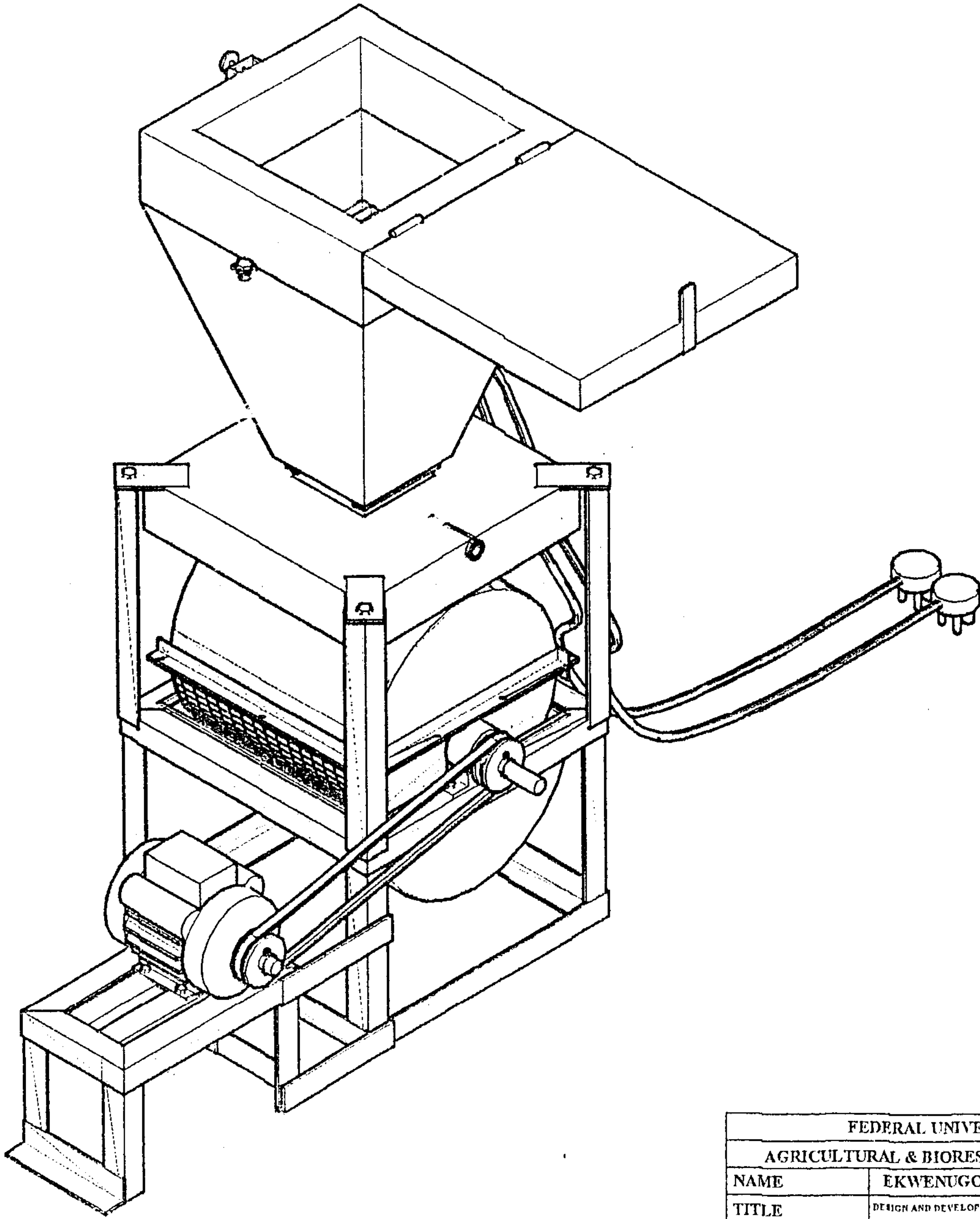
=N= 180,173

4.10 ECONOMIC ANALYSIS OF THE LDPE RECYCLING MACHINE

In analyzing any investment economically, the true worth of the investment is regarded as how much income it will generate and how soon after the original capital outlay (Chukwu, 1987).

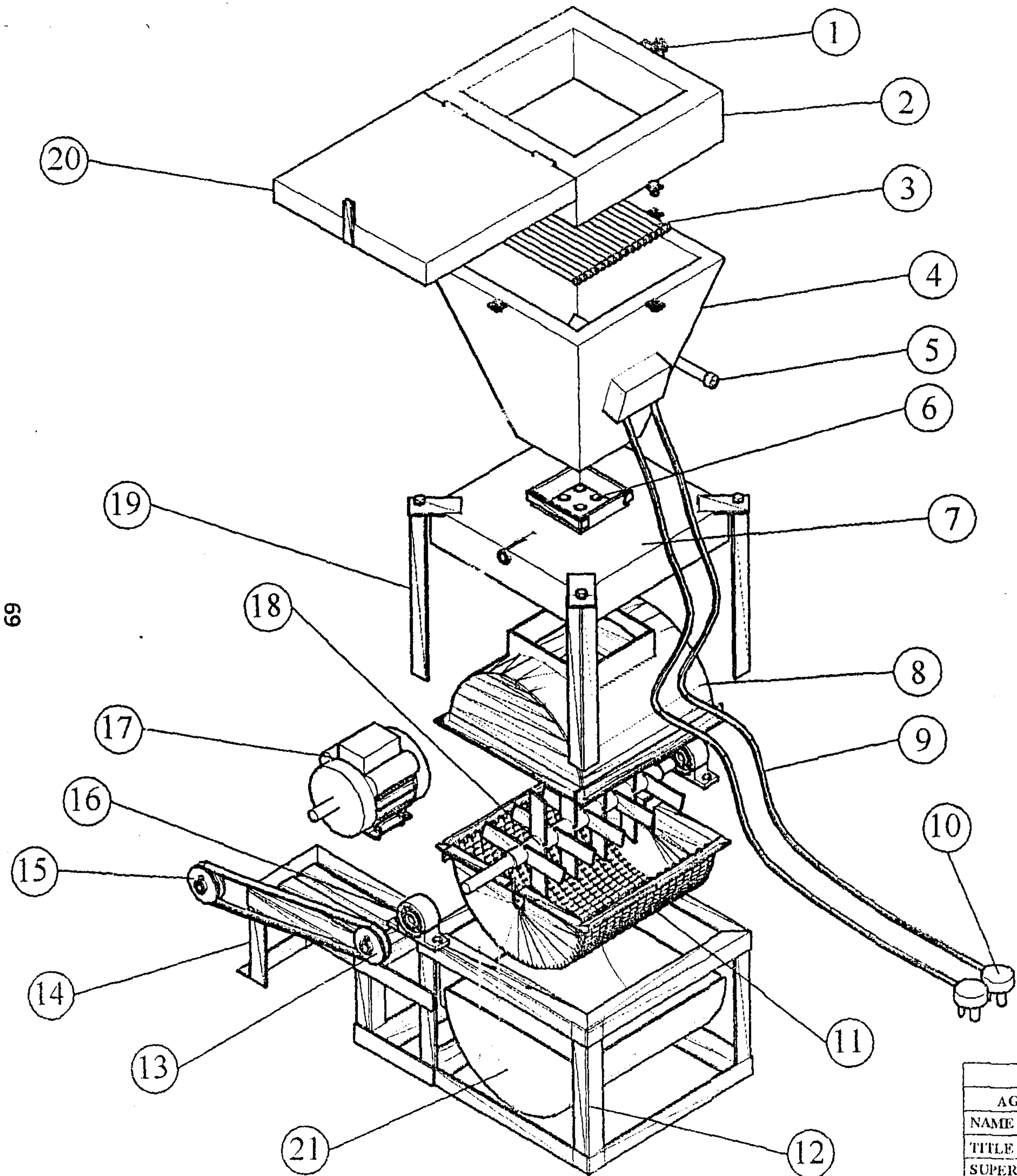
The design and development of this LDPE recycling machine is aimed at generating wealth through the sale of the output of this machine which is in pellet form. These pellets are used in plastic manufacturing industries to produce plastics with the use of machines like plastic extruders.

Also, this machine if adopted by local farmers or local waste management agencies will help reduce the nuisance caused by the littering of LDPE.



ISOMETRIC VIEW

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA			
AGRICULTURAL & BIORESOURCES ENGINEERING DEPARTMENT			
NAME	EKWENUGO VICTOR ARINZE		2005/21596EA
TITLE	DESIGN AND DEVELOPMENT OF LOW DENSITY POLYETHYLENE (LDPE) RECYCLING MACHINE		
SUPERVISED BY	ENGR. DR. O. CHUKWU	SIGN:	
APPROVED BY	ENGR. DR. O. CHUKWU	SIGN:	
SCALE	1:5	DATE:	DECEMBER 2010



ITEM	DESCRIPTION	MATERIAL
21	COLLECTOR	MILD STEEL
20	COVER	MILD STEEL
19	FRAME	MILD STEEL
18	SHAFT	MILD STEEL
17	MOTOR	
16	BEARING	MILD STEEL
15	BELT	RUBBER
14	MOTOR FRAME	MILD STEEL
13	PULLEY	ALUMINUM
12	MACHINE FRAME	MILD STEEL
11	SCREEN	MILD STEEL
10	PLUG	PLASTIC
9	WIRE	COPPER
8	CONCAVE	MILD STEEL
7	COOLING CHAMBER	MILD STEEL
6	MOULD	STAINLESS STEEL
5	STOPPER	MILD STEEL
4	HOPPER (HEATING CHAMBER)	MILD STEEL/STAINLESS STEEL
3	IRON ROD	MILD STEEL
2	HOPPER	MILD STEEL
1	LOCK	MILD STEEL

PARTS LIST

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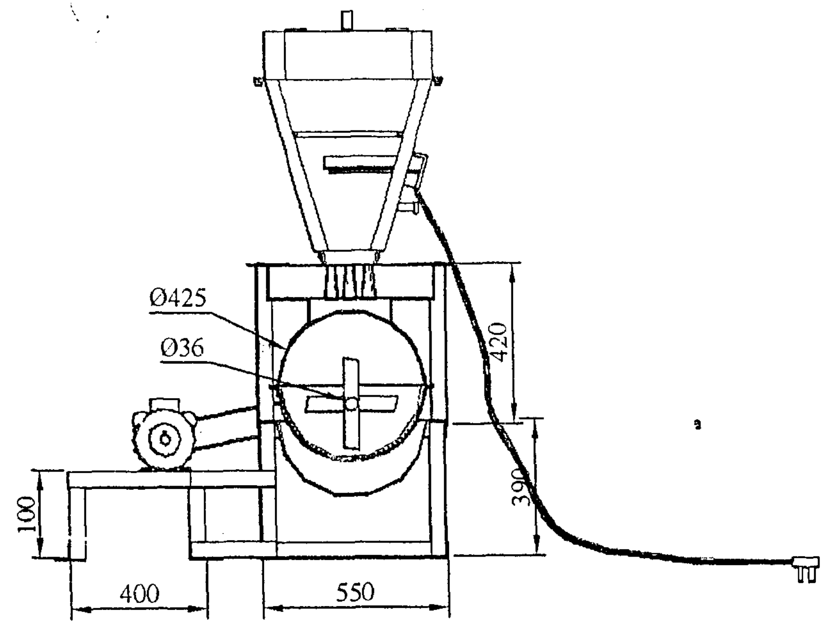

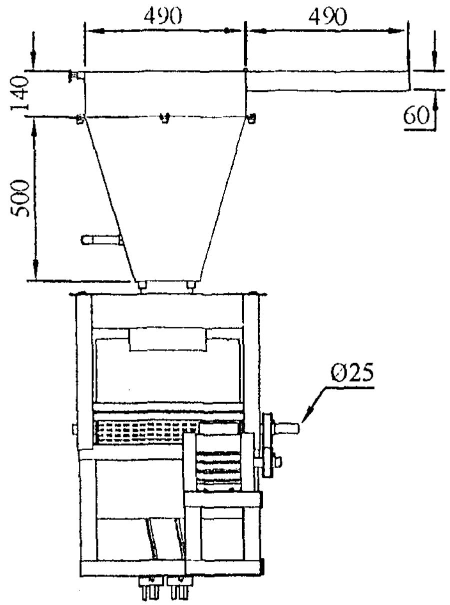

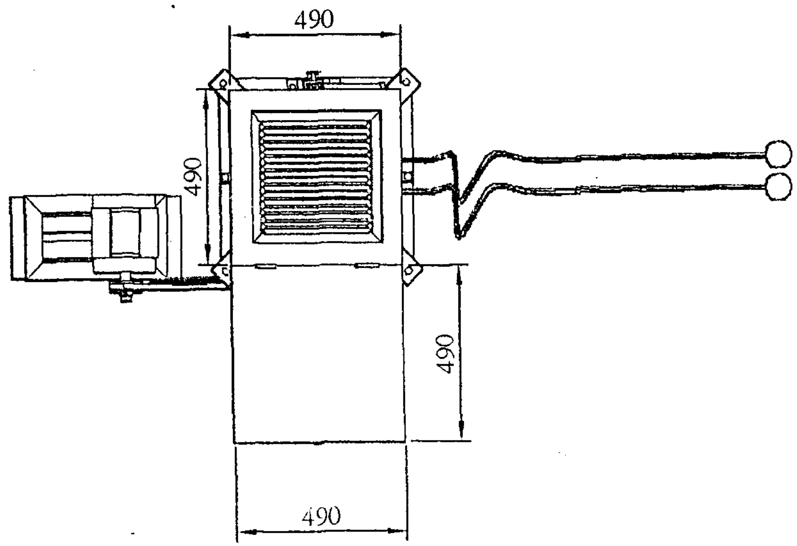

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SCALE	1:5		

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In conclusion, polyethylene as a type of polymer was studied .Also, the design and development of a low density polyethylene recycling machine was successful. As a result of the successful performance test carried out, polymer-like waste especially LDPE can now be eliminated from the farmland using the designed machine. The machine is categorized into three which are the heating chamber, cooling chamber, and the size reduction chamber. The efficiency of the several chambers mentioned above was calculated as, 81%, 52%, and 72% respectively.

The time taken for the raw material which is LDPE, to transform to desire product was put at a range of 1h 38min– 1hr 43min.

5.2 RECOMMENDATIONS

1. A thermostat is to be installed in heating chamber in order to regulate heat used to melt the LDPE
2. In the cooling chamber, an in-flow and out-flow of water should be made continuous for more efficient cooling
3. Stainless steel should be used in the inner chamber of the cooling chamber
4. Optimum supply of electric energy to heating element must be ensured in order for proper melting

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