DESIGN AND DEVELOPMENT OF A LOW DENSITY POLYETHYLENE RECYCLING MACHINE

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DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

JANUARY, 2011

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PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG) DEGREE IN AGRICULTURAL AND BIO-RESOURCES ENGINEERING.

JANUARY, 2011

DECLARATION

I hereby declare that this project is a record of a design work that was undertaken and rewritten 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 Information derived from personal communications, published and unpublished work of others were duly referenced to the text.

Bello, Peter Olusegun E.	25/01/2011 Date

CERTIFICATION

This project entitled “Design and Development of a Low Density Polyethylene Recycling Machine” by Bello Peter, 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.

Engr. Dr. O. Chukwu Project Supervisor	24/01/2011 Date
Dr. A. A. Balami Head of Department	25/01/2011 Date
External Examiner	13/01/2011 Date

DEDICATION

This project is dedicated to the almighty God who is the author and finisher of our faith for his grace and mercy and for a dream come true.

I also dedicate this project to the entire members of the Bello family for their love, understanding and support.

ACKNOWLEDGEMENTS

I give God all the praises and adoration for he is the author and finisher of our faith, the beginning and the end. He alone has made this project successful through thick and thin, his grace and mercies has been my strength and source of inspiration.

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I also wish to thank my parents, Mr. and Mrs. Bello for their immense support both financially, morally and spiritually and also my brother and sisters namely, Mrs. Toyin Odebode, Miss Mojisola Bello, Mr. Adelaja Bello, Mrs. Comfort Olumofin, Miss Tope Bello and my little nephew Oluwanifemi.

I am also grateful to the following people for their help in one way or the other in making sure that this project is a success: my group members; Ekweh Tony, Dahunsi Charles, Ekeh David, Bamisaiye Toyin, Ekwenugo Victor and Elijah Nissi. Also my friends, Adeoye Samson, Igwe Kingsley, Robinson Richards, Abdulkareem Idris and others. All those not mentioned because of constraints of space are also highly appreciated for their concerted effort towards the completion of this project. I love you all.

ABSTRACT

Low Density Polyethylene is a widely used thermoplastic in the world. However, its disposal and recycling process has been of great concern to the general public. A low density polyethylene recycling machine combats the above problem of LDPE. Recycling of LDPE involves melting and cooling sorted LDPE materials, then shredding the cooled material. The LDPE recycling machine consists of three chambers. The heating chamber that melts the material, the cooling chamber that hardens the molten LDPE and the size reduction chamber that beats the material into smaller chunks. The machine is principally made from 2mm mild steel and a solid shaft of 3.6mm diameter with cutting blades joined to it. The hopper and beater are the main components of the machine involved in melting and reducing the material respectively. The insulated hopper has a melting element with a power rating of 2kW embedded in it. The beater is powered by a 1.5kW motor. The performance of the machine was evaluated using 5kg of sorted LDPE with the following results: A melting efficiency of 82%; cooling efficiency of 52%; recovery efficiency of 72% and a throughput capacity of 5kg/hr were obtained. Based on the result, it was recommended that the machine hopper be insulated with moist clay to reduce heat loss and the machine be fabricated with stainless steel to improve its performance.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Study

1.1.1 Plastics

A plastic material is any of a wide range of synthetic or semi-synthetic organic amorphous solids used in the manufacture of industrial products. Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce costs. Monomers of plastic are either natural or synthetic organic compounds. (Goebel, 2001)

The word plastic is derived from the Greek πλαστικός (plastikos) meaning capable of being shaped or molded, from πλαστός (plastos) meaning molded.(Liddell and Scott, 2000). It refers to their malleability, or plasticity during manufacture, that allows them to be cast, pressed, or extruded into a variety of shapes—such as films, fibers, plates, tubes, bottles, boxes, and much more.

The common word plastic should not be confused with the technical adjective plastic, which is applied to any material which undergoes a permanent change of shape (plastic deformation) when strained beyond a certain point. Aluminum which is stamped or forged, for instance, exhibits plasticity in this sense, but is not plastic in the common sense; in contrast, in their finished forms, some plastics will break before deforming and therefore are not plastic in the technical sense.

There are two types of plastics: thermoplastics and thermosetting polymers. Thermoplastics will soften and melt if enough heat is applied; examples are polyethylene, polystyrene, polyvinyl chloride and polytetrafluoroethylene (PTFE) (Kent, 2010). Thermosets can melt and take shape once; after they have solidified, they stay solid.

The raw materials needed to make most plastics come from petroleum and natural gas (Worden, 2005). Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships. They have already displaced many traditional materials, such as wood; stone; horn and bone; leather; paper; metal; glass; and ceramic, in most of their former uses.

1.1.2 Polyethylene

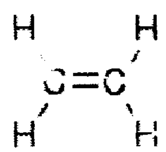
Polyethylene is the most popular plastic in the whole world.It is the most widely used plastic in the world and the most commonly manufactured thermoplastic with an annual production of about 80 million metric tonnes (Piringer and Baner, 2008) notably plastic shopping bags, shampoo bottles, and even bullet proof vests. Its primary use is within packaging.

Polyethylene is highest commodity polymer consumed in the world today, with low density polyethylene accounting for almost 20% of polymer consumption, of which almost 40% is used for packaging applications. (Reddy *et al.*, 2007)

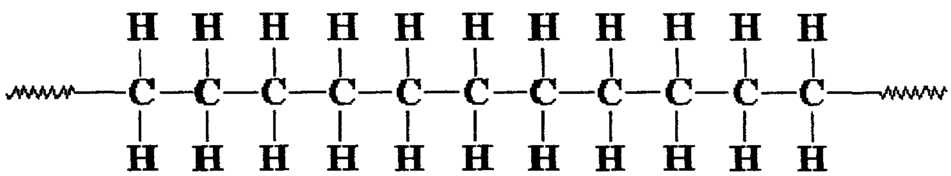
Polyethylene is a thermoplastic polymer consisting of long chains of the monomer ethylene (IUPAC name ethene). The recommended scientific name *Polyethene* is systematically derived from the scientific name of the monomer (Kavohec *et al*, 2002). The name is abbreviated to PE in a manner similar to that 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.

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



Polyethylene film is usually stable and resistant to degradation. Methods have been developed to make it more degradable under certain conditions of sunlight, moisture, oxygen and composting.

Polyolefins (LDPE, HDPE, PP) are a major type of thermoplastic used throughout the world in such applications as bags, toys, containers, pipes (LDPE), house wares, industrial wrappings and film, gas pipes (HDPE), film, battery cases, automotive parts, electrical components (PP). In Western Europe alone approximately 21.37 million tonnes of these three polymers are consumed each year (data of 2003), representing an amount of 56% of the total thermoplastics (Plastics Europe Association, 2007). Addition polymers (like polyethylene) in contrast to condensation polymers (i.e. poly(ethylene terephthalate) (PET)) cannot be easily recycled by simple chemical methods (Karayannidis and Achilias, 2007). Instead, thermochemical recycling techniques like pyrolysis have been proposed as process producing a series of refined petrochemical products and particularly of a liquid fraction similar with that of commercial gasoline (Achilias and Karayannidis, 2004).

1.1.3 History of Polyethylene

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 -CH2- 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 Imperial Chemical Industries (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.

Polyethylene litters can be unsightly and hazardous to wildlife. The easiest and most common plastics to recycle are made of polyethylene terephthalate (PETE). Examples include soda and water bottles, medicine containers and other common consumer products containers. Once it has been processed by a recycling facility, PETE can become fiberfill for winter coats, sleeping bags and life jackets. It can also be used to make bean bags, rope, car bumpers, tennis ball felt, combs, cassette tapes, sails for boats, furniture and of course, other plastic bottles. high density polyethylene plastics are also commonly recycled but are less easier to recycle compared to PETE. HDPE includes containers that hold shampoo.

Recycling is a very important conservation process. It has helped to manage and control wastage of resources. polyethylene bags have been a menace to the environment with the way they litter the surroundings. For this reason, it has been imminent to find a way to eradicate this problem. Polyethylene recycling is a good way to totally eradicate or reduce this bottleneck. This is done by processing the plastic bags into pellets or powdery form so that it can be used to produce a wide range of some other plastic items.

1.2 Statement of Problem

In Nigeria, plastic bags are used virtually in almost every area of the economy. It is used as shopping bags in the market, as paper bags to hold garbage and household waste, as containers for growing seedlings in the nursery and also as containers for bagging table water commonly known as 'Pure Water'. The importance and use of polethylene bags can not be over emphasized. The use, however, has not been reciprocated by proper disposal. Nigerians, generally do not have a decent waste disposal culture. So, as these PEs are used, they are poorly disposed of in the environment. PE which is a stable and resistant compound takes 1000 years for it to decompose completely. For this reason, PE litters continue to accumulate in the society causing an eye sore. Apart from the unsightly effect it projects, it is also harzadous to flora and fauna. Since PE never gets decomposed, it gets buried into the soil as time goes by and remains an impurity in the soil. This in turn reduces the agricultural quality and viability of the soil and hence low plant yield. Another problem is that PE litter is a major cause of blockage in piping and drainage systems. Each year consumers throw millions of tonnes of plastic away. 10.7 percent of municipal waste are plastics. As municipal lanfills reach capacity and additional landfill space diminishes accross the country, it is imperative that alternative methods of reducing and disposing of plastic wastes be explored. Some of the methods include reducing consumption of plastics, using biodegradable plastics, and recycling or incinerating plastic waste.

Low Density Polyethylene (LDPE) commonly known as plastic bags has been a great point of concern to the public and also the government. Its use in making plastic bags, water bags and other products has made it an essential commodity in the area. Because of the improper disposal of the plastic bags by its users, it has littered the environment thus causing an eyesore. Plastic bags are not biodegradable under normal conditions so it remains in the soil for a long period of time. A means has to be made to re-use and utilize the used plastic bags again.

1.3 Justification of the Project

Plastics are used extensively in Nigeria with the Low Density Polyethylene making the bulk of it. LDPE comes in form of shopping bags, pure water bags and several other containers.As a result, it would be sagacious to provide a means of recyling these LDPEs. When the Low Density Polyethylene recycling machine is designed and developed, it would rid the environment of PE litters. The benefits of recycling polyethylene includes:

1. Resource Conservation: Recycling polyethylene conserves natural resources by reducing the need for new material. Thermoplastics of which Polyethylene is a part, can be melted and remoulded instead of producing new sets from its raw material.
2. Energy Conservation: Recycling saves energy by reducing the need to process new plastics , which requires more energy than the recycling process (Grant *et al,*2001).
3. Pollution Reduction: Recycling plastic reduces pollution because recycling the plastic creates less pollution than creating a new one. Litters of plastics which would normally litter the streets would be reduced as they would be recycled into some other products. Foam products such as cups and plates which are manufactured with chlorofluorocarbons (CFCs) when produced with recycled plastics eliminates the creation of harmful CFCs. Many scientists suspect that CFCs harm the atmosphere's protective layer of ozone.
4. Land Conservation: Recycling plastics saves landfill space – land that must be set aside for dumping trash. Furthermore, recycling plastics reduces the amount of plastic waste that would be in the soil.

The Nigerian consumer uses polyethylene products and either incinerates it or dumps it in a garbage bin or public area. Recycling the polyethylene bags will rid the streets of this eyesore that the polyethylene product has caused. Providing low cost and easy to use alternatives would go a long way to combat the indiscriminate disposal of these polyethylene products and improve the general appearance of the environment at large.

Because of the littering effect of Low Density Polyethylene (LDPE), it has become imminent to provide a suitable way to get rid of the used plastic bags from the envirionment and recycle them. This would help reduce wastage of plastic compounds and also control environmental pollution. Furthermore, it would create a clean and dirt-free environment which would in turn improve the living conditions of human beings.

1.4 Objectives of the Project

The general objective of the work is to design and develop an electrically powered low density polyethylene recycling machine.

The specific objectives are:

i. To design, construct and develop a low density polyethylene recycling machine.
ii. To evaluate the performance of the low density polyethylene recycling machine.

1.5 Scope

Design and develop low density polyethylene recycling machine to convert electrical energy into heat energy.

Design cooling mechanism.

Design shredder mechanism to shred cooled plastic pellets.

Combine power source, heater coolant and shredder into single machine.

Improve design ergonomics

Performance testing of machine

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

2.1 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 ean 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 (Dynalab Corporation, 2007).

The low density polyethylene recycling machine has been manufactured as the agglomerator machine and more recently, as the densifier (Roth, 1997). It agglomerates all kinds of plastics from industrial waste of all kind and post consumer waste. Sparke (2002) stated that agglomerators make use of extruders which pushes out the molten plastics into shapes. In modern recycling plants, replacing the force feed of extruder has gained widespread success. In fact, use of the densified product ensures high extruder production since it compacts, dries and homogenizes the product to be reduced, making it similar to a single product with numerous benefits.

The densifier operates in batches and the processing chamber is loaded before and during the process. The high energy blades shred the material and press it under the rotor due to its design; the friction heats the material to the processing temperature. At this temperature, the material becomes highly viscous. Subsequently, cold water is injected into the process which causes the material to densify (Papaspyrides et al., 2005).

2.1.1 Pre-Recycling Operations

Before it can be recycled, plastics have to be collected, sorted and cleaned. Thereafter, pelleting and size reduction constitute the recycling process. The stages the plastic material undergoes are as follows:

Step 1 - Plastic Collection

Plastics for recycling come from two main sources: Post consumer plastics and post industrial plastics. Post consumer plastics are those which have already been used by people. These are the plastics collected in plastics recycling bins and at domestic roadside collections. Post industrial plastics, on the other hand, are rejects from industry — offcuts, damaged batches etc. These plastics are collected either directly from the industry, roadside collection or collected by the local council, squashed into bales and sold to a recycler. The specific sources of plastic wastes, according to Lardinois and Klundert (1995) are:

- **Industrial waste** (or primary waste) can often be obtained from the large plastics processing, manufacturing and packaging industries. Rejected or waste material usually has good characteristics for recycling and will be clean. Although the quantity of material available is sometimes small, the quantities tend to be growing as consumption, and therefore production, increases.
- **Commercial waste** is often available from workshops, craftsmen, shops, supermarkets and wholesalers. A lot of the plastics available from these sources will be PE, often contaminated.
- **Agricultural waste** can be obtained from farms and nursery gardens outside the urban areas. This is usually in the form of packaging (plastic containers or sheets) or construction materials (irrigation or hosepipes).

- **Municipal waste** can be collected from residential areas domestic or household waste), streets, parks, collection depots and waste dumps. In Asian cities this type of waste is common and can either be collected from the streets or can be collected from households by arrangement with the householders.

Step 2 - Sorting

In this stage, unwanted objects like nails an stone are removed. The plastics are then sorted into LDPE and the others types of plastics based on this project. Sorting of plastic can be by polymer type (thermoplastic or thermoset for example), by product (bottles, plastic sheeting etc), by colour etc. In theory, every type of plastic can be recycled. The incoming plastic is manually sorted into LDPE and the other types. Any rocks, nails, metal etc. that is mixed in with the plastic is also manually removed at this stage (Harper *et al.*, 1999).

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 (PACIA, 2008). Polyethylene terephthalate, commonly referred to as PET, for instance, has a resin code of 1 and Low Density Polyethylene, which is our case of study has a resin code of 4. 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.

2.1.1.1 Plastic Identification Code

Seven groups of plastic polymers, (Association of Plastic Manufacturers, 2007) each with specific properties, are used worldwide for packaging applications (see table below).

Each group of plastic polymer can be identified by its Plastic Identification code (PIC) - usually a number or a letter abbreviation. For instance, Low-Density Polyethylene can be identified by the number 4 and/or the letters "LDPE". The PIC appears inside a three-chasing arrow recycling symbol. The symbol is used to indicate whether the plastic can be recycled into new products.

The PIC was introduced by the Society of the Plastics Industry, Inc. which provides a uniform system for the identification of different polymer types and helps recycling companies to separate different plastics for reprocessing. Manufacturers of plastic products are required to use PIC labels in some countries/regions (Holt *et al*, 2006) and can voluntarily mark their products with the PIC where there are no requirements. Based on the PACIA 2008 Plastics Recycling Survey, consumers can identify the plastic types based on the codes usually found at the base or at the side of the plastic products, including food/chemical packaging and containers. The PIC is usually not present on packaging films, as it is not practical to collect and recycle most of this type of waste (PACIA, 2008).

Table 2.1: Showing the Plastic Identification Codes (PIC) and related information (PACIA, 2008)

Plastic Identification Code	**Type of plastic polymer**	**Properties**	**Common packaging applications**	**Percentage of plastic**
	Polyethylene Terephthalate (PET, PETE)	Clarity, strength, toughness, barrier to gas and moisture.	Soft drink, water and salad dressing bottles; peanut butter and jam jars	0.5%

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	21%
03 PVC	Polyvinyl Chloride (PVC)	Versatility, clarity, ease of blending, strength, toughness.	Juice bottles; cling films; PVC piping	6.5%
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.	27%

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.	16%
06 PS	Polystyrene (PS)	Versatility, clarity, easily formed	Egg cartons; packing peanuts; disposable cups, plates, trays and cutlery; disposable take-away containers;	16%
07 O	Other (often polycarbonate or ABS)	Dependent on polymers or combination of polymers	Beverage bottles; baby milk bottles; electronic casing.	8.5%

2.1.1.2 Identification of different types of plastics

There are several simple tests that can be used to distinguish between the common types of polymers so that they may be separated for recycling.

The water test: After adding a few drops of liquid detergent to some water put in a small piece of plastic and see if it floats.

Burning test: Hold a piece of the plastic in a tweezers or on the back of a knife and apply a flame. Does the plastic burn? If so, what colour?

Fingernail test: Can a sample of the plastic be scratched with a fingernail?

Table 2.2: Showing Results of Different Tests on Some Polymers

Test	**PE**	**PP**	**PS**	**PVC***
Water	Floats	Floats	Sinks	Sinks
Burning	Blue flame with yellow tip, melts and drips	Yellow flame with blue base.	Yellow, sooty flame – drips.	Yellow, sooty smoke. Does not continue to burn if flame is removed
Smell after burning	Like candle wax.	Like candle wax – less strong than PE	Sweet.	Hydrochloric acid.
Scratch	Yes	No	No	No

*To confirm PVC, touch the sample with a red-hot piece of copper wire and then hold the wire to the flame. A green flame from the presence of chlorine confirms that it is PVC. Source: Vogler. 1984

Step 3 - Cleaning

This stage removes contaminants such as paper labels, dirt and remnants of the product originally contained in the plastic. The sorted plastics are washed to remove glue, paper labels, dirt and any remnants of the product they once contained. LDPE (which has a much lower melting point) must be washed below 40°C to prevent discolouration. The wash solution consists of an alkaline detergent in water, which removes dirt and grease and degrades protein. The detergent used is an alkaline, cationic detergent (i.e. an alkaline solution containing a cationic surfactant).

Step 4 - Pelleting

This is done by melting the chips and extruding them out first through a fine grill to remove any solid dirt or metal particles that have made it through the treatment thus far and then through a die of small holes. If the plastic was simply allowed to extrude from these holes it would come out as spaghetti-like strings and quickly tangle together. However, it is sprayed with water as it comes out (to prevent the plastic from sticking together) and cut off by rotating knives to give small, oval pellets.

Step 5 - Size Reduction

This is done to break the hard LDPE pellets into smaller pieces or chunks. It prepares the LDPE material for another manufacturing process.

Size Reduction Techniques: Size reduction is required for several reasons; to reduce larger LDPE material to a size manageable for small machines, to make the material denser for storage and transportation, or to produce a product which is suitable for further processing. There are several techniques commonly used for size reduction of plastics;

• **Cutting** is usually carried out for initial size reduction of large objects. It can be carried out with scissors, shears, saw, etc.

• **Shredding** is suitable for smaller pieces. A typical shredder has a series of rotating blades driven by an electric motor, some form of grid for size grading and a collection bin. Materials are fed into the shredder via a hopper which is sited above the blade rotor. The product of shredding is a pile of coarse irregularly shaped plastic flakes which can then be further processed.

• **Agglomeration** is the process of pre-plasticising soft plastic by heating, rapid cooling to solidify the material and finally cutting into small pieces. This is usually carried out in a single machine. The product is coarse, irregular grain, often called crumbs.

According to Achilias *et al* (2007), the approaches that have been proposed for recycling waste polymers include *Primary Recycling* referring to the in-plant recycle of the scrap material of controlled history. *Mechanical Recycling,* where the polymer is separated from its associated contaminants and it is reprocessed by melt extrusion. *Chemical Recycling,* leading in total depolymerization to the monomers or partial degradation to other secondary valuable materials.

The different methods of processing plastics includes:

1. Monomer recycling
2. Thermal depolymerization
3. Heat compression

1. Monomer Recycling:This is a process in which a condensation polymer essentially undergoes the inverse of the polymerization reaction used to manufacture it. Many recycling challenges can be resolved by using this elaborate monomer recycling process. This yields the same mix of chemicals that formed the original polymer, which can be purified and used to synthesize new polymer chains of the same type. Du Pont opened a pilot plant of this type in Cape Fear, North Carolina, USA, to

recycle PET by a process of methanolysis, but it closed the plant due to economic pressures (Kinnane, 2002).

2. Thermal Depolymerization: This process involves the conversion of assorted polymers into petroleum by a much less precise thermal depolymerization process. Such a process would be able to accept almost any polymer or mix of polymers, including thermoset materials such as vulcanized rubber tires and the biopolymers in feathers and other agricultural waste. Like natural petroleum, the chemicals produced can be made into fuels as well as polymers. A pilot plant of this type exists in Carthage, Missouri, USA, using turkey waste as input material. Gasification is a similar process, but is not technically recycling since polymers are not likely to become the result.
3. Heat Compression: This is yet another process that is gaining ground with startup companies (especially in Australia, United States and Japan). The heat compression process takes all unsorted, cleaned plastic in all forms, from soft plastic bags to hard industrial waste, and mixes the load in tumblers (large rotating drums resembling giant clothes dryers). The most obvious benefit to this method is the fact that all plastic is recyclable, not just matching forms. However, criticism rises from the energy costs of rotating the drums, and heating the post-melt pipes.

2.2 Classes of Polyethylene Plastics

Polyethylene is classified into several different categories based mostly on its density and branching. The mechanical properties of PE depends significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight. The classes of polyethylene are as follows:

1. Ultra high molecular Weight polyethylene (UHMWPE)
2. Ultra-low molecularWeight Polyethylene (ULMWPE or PE-WAX)
3. High molecularWeight polyethylene (HMWPE)
4. High density polyethylene (HDPE)
5. High Density Cross-linked Ppolyethylene (HDXLPE)
6. Cross-Linked Polyethylene (PEX or XLPE)
7. Medium Density Polyethylene (MDPE)
8. Linear Low Density Polyethylene (LLDPE)
9. Low Density Polyethylene (LDPE)
10. Very LowDensity Polyethylene (VLDPE)

2.2.1 Ultra High MolecularWeight Polyethylene (UHMWPE): This 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 structureas 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 bottlehandling machine parts, moving parts on weaving machines, bearings, gears, artificial joints, edge protection on ice rinks and butchers' chopping boards. It competes with Aramidin bulletproof vests, under the trade names Spectra and Dyneema, and is commonly used for the construction of articular portions of implants used for hip and knee replacements.

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. (All measurements in mm).

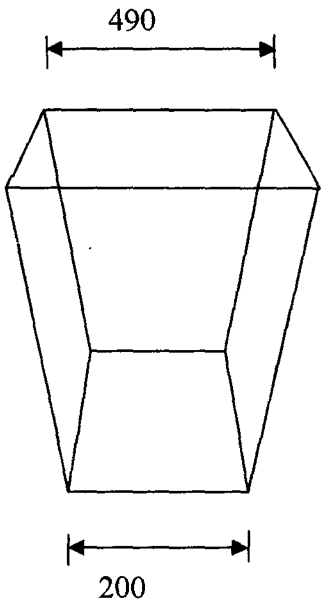
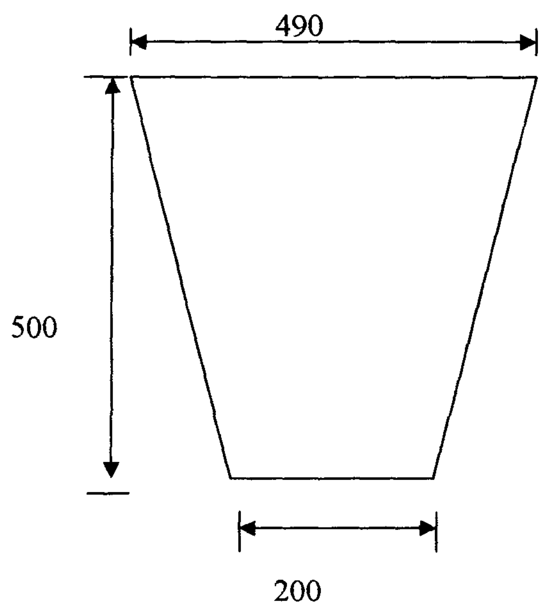
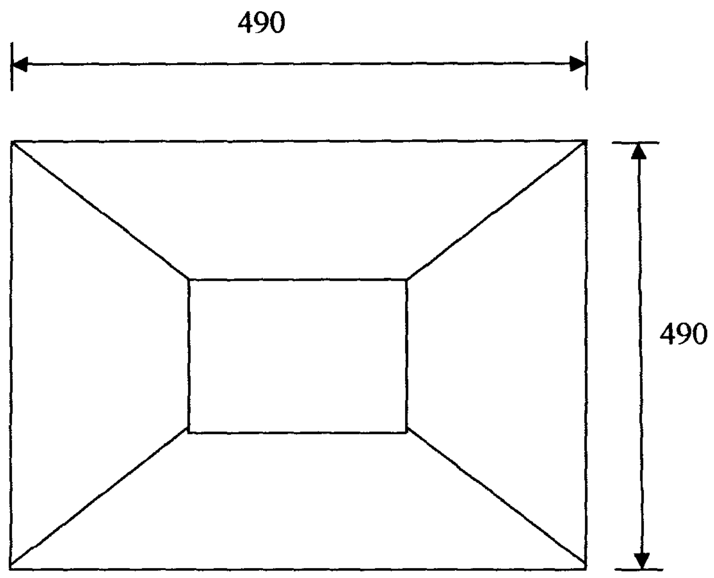


Figure 3.1 (a) Cross-section of the hopper



(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=2.32 g = 2.32×10^{-3} kg

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

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

Then, the weight of 220 packs = 220×0.0227592

= 5.00 kg

3.4.1.2 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 = 0.49 m

Breadth of the top = 0.49 m

Length of the bottom = 0.2 m

Breadth of the bottom = 0.2 m

Height of the hopper = 0.5 m

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 = Volume $= {}^1/_3 \left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right)h$

$= {}^1/_3 \left[(0.2401 + 0.04) + \sqrt{0.2401 \times 0.04}\right]0.5$

$= {}^1/_3 \left(0.2801 + \sqrt{0.009604}\right)0.5$

$= {}^1/_3 (0.2801 + 0.098)0.5$

$= {}^1/_3 (0.3781)0.5$

$= 0.0630 \text{ m}^3$

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

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

$= 0.0126\ m^3$

This is the capacity of the hopper

$= 0.0630 + 0.0126$

$= 0.0756\ m^3$

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

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

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)

$\rho = 920 kg/m^3$ (Martienssen and Warlimort, 2005)

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

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

Taking factor of safety to be 20%

$$V = \frac{20}{100} \times 5.435 \times 10^{-3} m^3 = 1.0869 \times 10^{-3}\ m^3$$

Total Volume (V) $= (5.435 \times 10^{-3} m^3 + 1.0869 \times 10^{-3})$

$= 1086.905435\ m^3$

$\approx 1086.91\ m^3$

Melting point of LDPE = 115°C (Martienssen and Warlimort, 2005)

Therefore quantity of heat required to melt 5 kg of the material,

$Q=MC_p\Delta T$ 3.3

Where $m = 5kg, C = \frac{2.302kJ}{kgK}, T_1 = 25°C$ or 298 K,

$T2 = 115°C$ *or* 388 *K* (T_1 = room temperature, T_2 = melting temperature)

$Q = 5\,kg \times 2.302 \times (115 - 25)$

$Q = 1035.9\,kJ$

Therefore,

Wattage =*W* = *Q* /T 3.4

Wattage = 1035.9 kJ/5 × 60

= 3.453 kW

3.4.2 Cooling Chamber

3.4.2.1 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

= 0.49 m × 0.49 m × 0.1 m

=0.02401 m^3

3.4.2.2 Volume of Mould

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

Diameter of the top = 3.6 cm = 0.036 m

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

Diameter of the bottom = 4 cm = 0.04 m

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

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

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

Volume of the mould V;

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

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

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

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

$$= 0.000113516$$

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

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 = $(0.02401 - 1.0215 \times 10^{-3})\ m^3$

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

3.4.2.3 Heat Loss from the Cooling Chamber

Heat loss $=MC_P \Delta T$

C_p=2.302 kJ/kgK (Martienssen and Warlimort, 2005)

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

$T_2 = 0°C \; or \; 273 \; K$

$T_1 = 115°C \; or \; 388 \; K$

$\Delta T = 273 - 388$

$\Delta T = -155K$ (cooling)

Heat loss =5 kg ×2.302 kJ/kgK× 155 K

Heat loss= 1784.05 kJ

3.4.2.4 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);

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

=1.3215 kJ/sec

3.4.3 Size reduction Chamber

3.4.3.1 Cutting Blades on the Rotating Shaft

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

The cutting blade is made of mild steel.

Radius r = 12.5 cm

Height H = rsinθ

$= 12.5 \text{ cm} \sin 60 = 10.8253\text{cm}$

Diameter = 4 cm

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

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

$$= 8 \times 12.5$$

$$= 100 \text{ cm}^3$$

$$= 1.0 \text{ m}^3$$

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

$$= 1.0 \times 7850 \text{ kg/m}^3$$

$$= 78.5 \text{ kg}$$

3.4.3.2Belt Selection:

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

3.4.3.3 Determination of the Maximum Power of Belt

Calculation of the belt speed

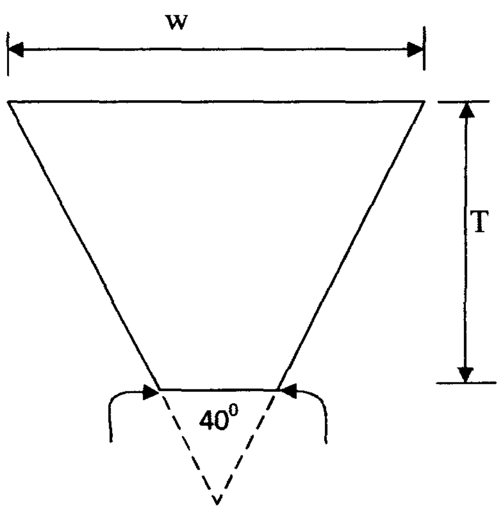


Figure 3.2: Cross-section of V groove belt

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

Usual load of drive = 0.75 – 5 kw

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

Normal thickness, T = 8 mm

Weight per meter = 0.100 kg

Belt speed, $S = \pi dpN_1$ 3.8

Required shaft speed = 2000 rpm (selected)

Belt speed, $S = \pi d_p N_1$

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

Required motor speed = 1450 rpm

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

3.4.3.4 Motor-Cylinder Design Calculation

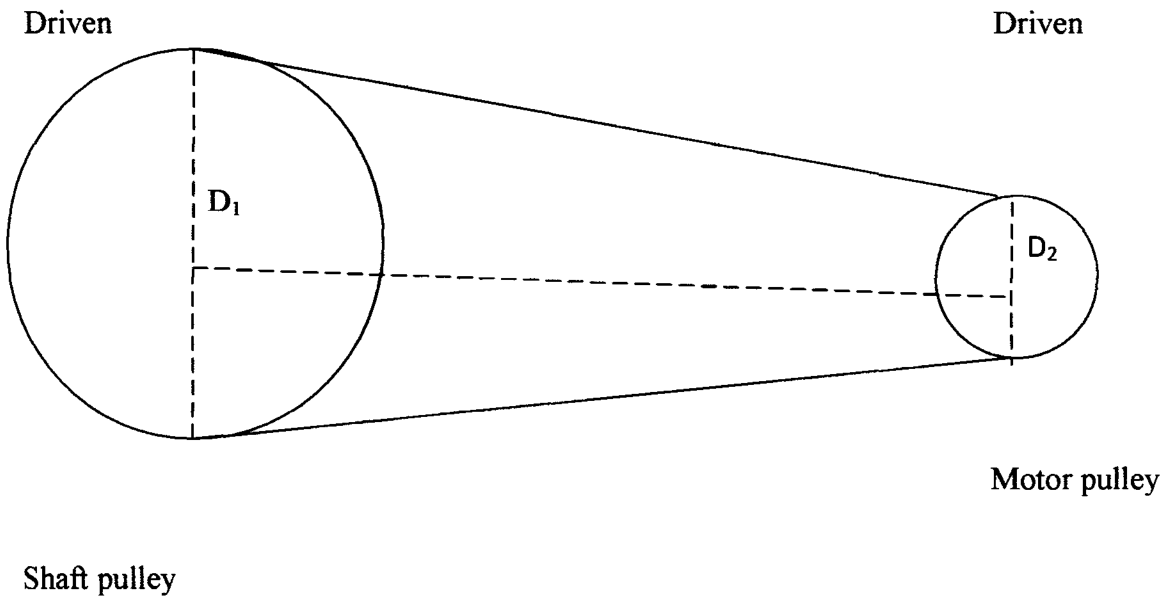


Figure 3.3: Motor-Cylinder Pulley Belt Arrangement

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

Where,

D_1 = diameter of motor pulley = 12 cm

D_2 = diameter of the shaft driven pulley =?

N_1 = Speed of electric motor = 1450 rpm

N_2 = Speed of rotating shaft = 2000 rpm

From the equation;

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

$D_1 N_2 = D_2 N_1$

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

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

$$= \frac{17400}{2000}$$

$$= 8.7 \text{ cm}$$

$$= 9.0 \text{ cm}$$

If the diameter of the shaft driven pulley is 9 cm

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

$$= 410.031 \text{ m/s}$$

3.4.3.5 Angular Velocity of Motor-Cylinder Belt

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

Angular Velocity of Motor, ω_2

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

Angular Velocity of shaft, ω_1

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

3.4.3.6 Power on Motor-Cylinder Belt

Power = torque × angular velocity

$= T\omega$ 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,

$P_S = \omega_1^2 r_1$ 3.12

Where,

r_1 = radius of shaft of pulley

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

$= 197443.908$ W

3.4.3.7 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 $\left(\frac{2\times 1.12}{2}, \frac{3(0.09)}{2} + \frac{0.12}{2}\right)$

CD = max (0.120, 0.195)

CD = 195 mm (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.

3.4.3.8 Angle of Contact of Motor-Shaft Pulley

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

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

$= 11.965°$

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

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

$= -5.681^{\circ}$

3.4.3.9 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)

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

$L = 438.28$ mm

The length correction factor $K_L = 0.84$ (Khurmi and Grupta, 2005)

$L = 438.28 \times 0.84$

$L = 368.158$ mm

3.4.3.10 Determination of Weight of Pulley

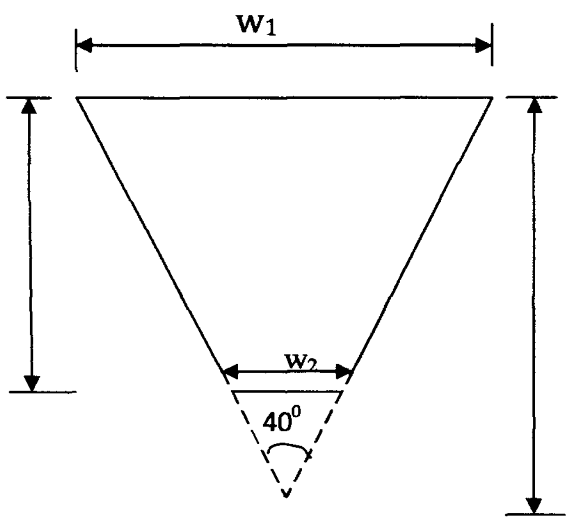


Figure 3.4: Cross-Section of V-groove Belt

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

Smaller width of the belt, w_2

Nominal depth of the belt; t = 8 mm

Sleeve groove angle = 40 ^{0}

Density of the leather belt = ρ = 970 kg/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 = 17.859 mm

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

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

$w_2 = 5.83$ mm

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

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

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

$= 9.415 \times 8$

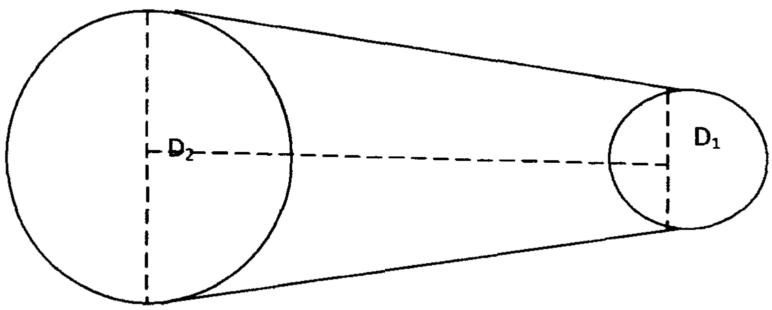
$= 75.32$ mm^2

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

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

$M = 0.730604$ kg/m

3.4.3.11 Determination of Length of Belts



Shaft pulley Motor pulley

Figure 3.5: Motor- Shaft Belt

D_2 = diameter of the shaft pulley

= 12 cm

D_1 = diameter of the motor pulley

= 8 cm

Centre to centre distances, C = minimum

100mm = 0.1 m

Nominal Pitch Length,

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

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

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

$= 200 + 3299.1 + 225$

$= 3724.1$ mm (max)

3.4.3.12 Design Theory of Cutting Shaft

If the cutting shaft is subjected to twisting moment only,

$$\frac{\tau}{r} = \frac{T}{J} \quad 3.19$$

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

$$\tau = \frac{Tr}{J} = \frac{TD}{2J}$$

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

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

Where,

M = bending moment

σ = bending

J = moment of inertia

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

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

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

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

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

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

For cutting blade,

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

Where,

M = bending moment

Z = section modulus

Maximum stress

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

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

(Oluboji, 2004)

3.4.3.13 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 = 0.125 m

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

Weight of blade = (W) = ρvg 3.29

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

$= 9.678$ N

For 18 cutting blade

$W = 18 \times 9.678$

$= 174.212\, N$

Weight of cylinder (shredding chamber)

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

D = 49.5 cm = 0.495 m

d = 44.5 cm = 0.445 m

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

$= 0.0369185$

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

V = 49 cm = 0.49 m

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

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

Weight (W) = ρvg

$= 1222.56\, N$

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

Amount broken per second

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

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)

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

$= 144.70$ N

Total cutter weight = 174.212 + 1222.56 + 1447.0

F = 2843.772 N

3.4.3.14 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;

Torque (T) = Fr 3.30

Where,

r = distance to the neutral axis = 0.018

F= force exerted by the blade on the shaft

$T = 2843.772 \times 0.018$

$= 51.1879\ Nm$

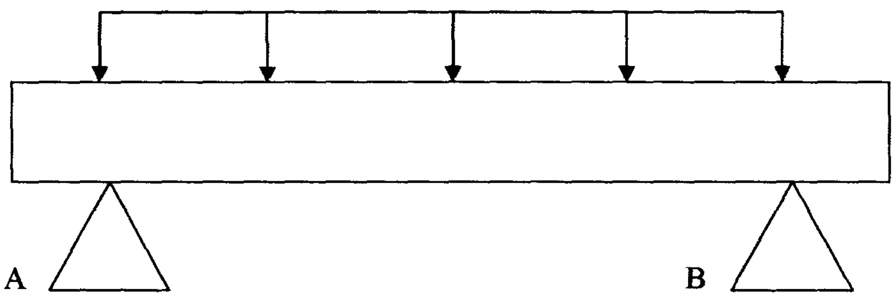


Figure 3.6: Beam diagram of shaft

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

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

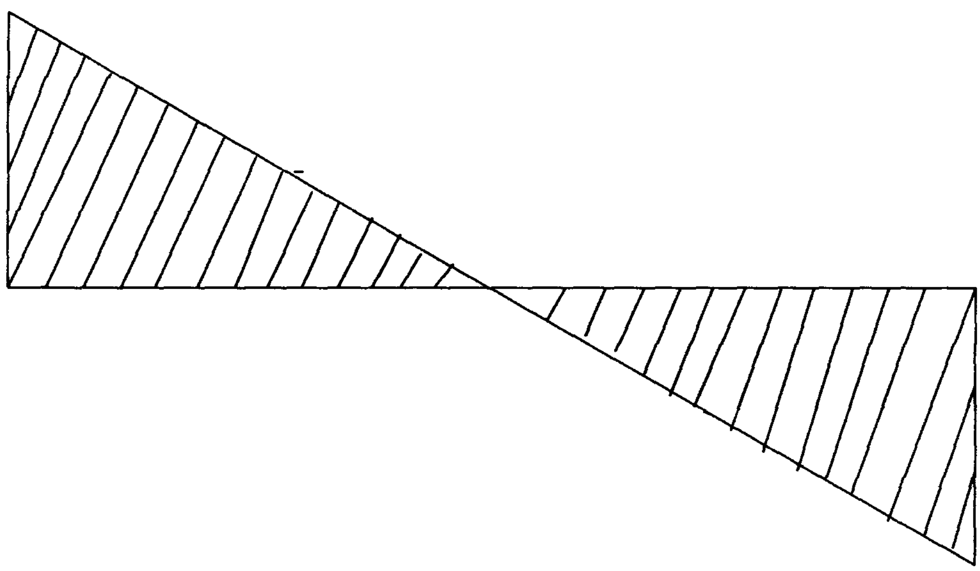


Figure 3.7: Shear force diagram of rotating shaft

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

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

3.4.3.15 Bending Moment of Shaft

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

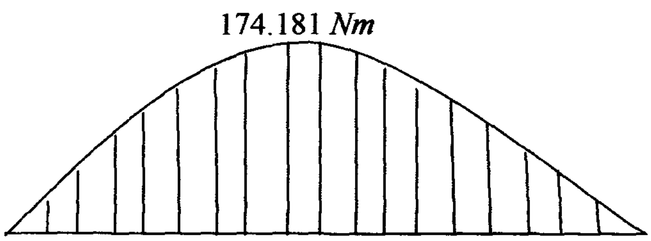


Figure 3.8: Bending moment diagram of the rotating shaft

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

$M = 174.181\ Nm$

Maximum shear on shaft

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

$S = 3590.06\ Nm$

3.4.3.16 Power Demand at Shaft

$P = \tau\omega$ 3.32

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

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

$\omega = 151.86$

$P = 51.1879 \times 151.86$

$P = 7773.565$ W

For the cutting blade

$W = 1447$ N

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

$W = 96.78$ N/m

The shear force diagram is shown in figure 3.9

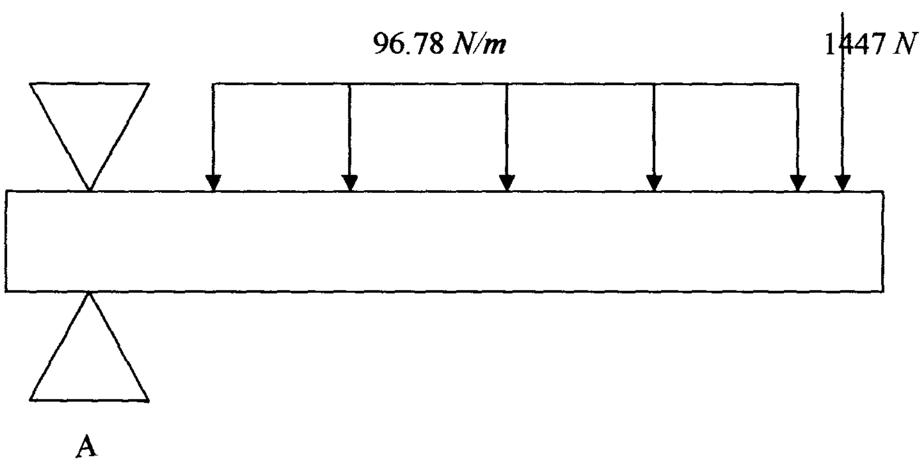


Figure 3.9: Shear force diagram of shaft

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

$= -1447 - 96.78 \times 0.045$

$= - 1451.36$

The bending moment diagram is shown in figure 3.10

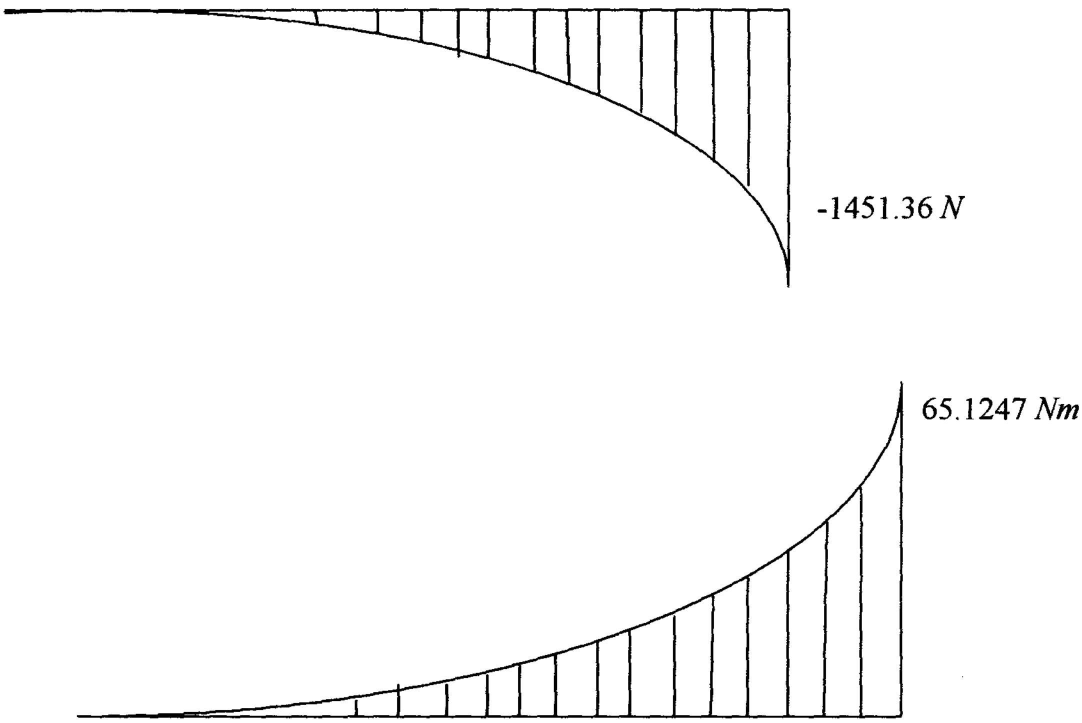


Figure 3.10:Bending moment diagram of shaft

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

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

$$M = 65.1247\ Nm$$

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

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

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

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

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

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

3.5 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.

3.6 Machine Operational Mechanism

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 $=\frac{Tr}{Ta}$ 4.1

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

$$\frac{Cr}{Ca} \times 100 \qquad 4.2$$

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

=52.32558

= 52%

4.4 Recovery Efficiency

Since the material feed into the hopper is 5 kg

The output after grinding is 3.6 kg

$$\text{Efficiency} = \left(\frac{output}{input}\right) \times 100 \qquad 4.3$$

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

=72%

4.5 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

4.6 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 (₦)	Price (₦)
1	Mild steel sheet	Gauge 16	4	5500	22,000
2	Heating	2000watt	2	1000	2,000
3	element	3.5cm	1	4000	4000

	Solid shaft				
4	Electrode	8mm metal	3 packet	900	1800
5	Paint	Enamel grey green	2 liter	1500	3000
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

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.

4.7 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 $= \frac{23.42}{100} \times 134700$

$= 31546.74$

₦ 31546

4.8 Over Head Cost

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

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

$= 13927.98$

₦ 13927

Total cost = Material Cost + Labour Cost + Overhead Cost

= 134700 + 31546 + 13927

₦ 180,173

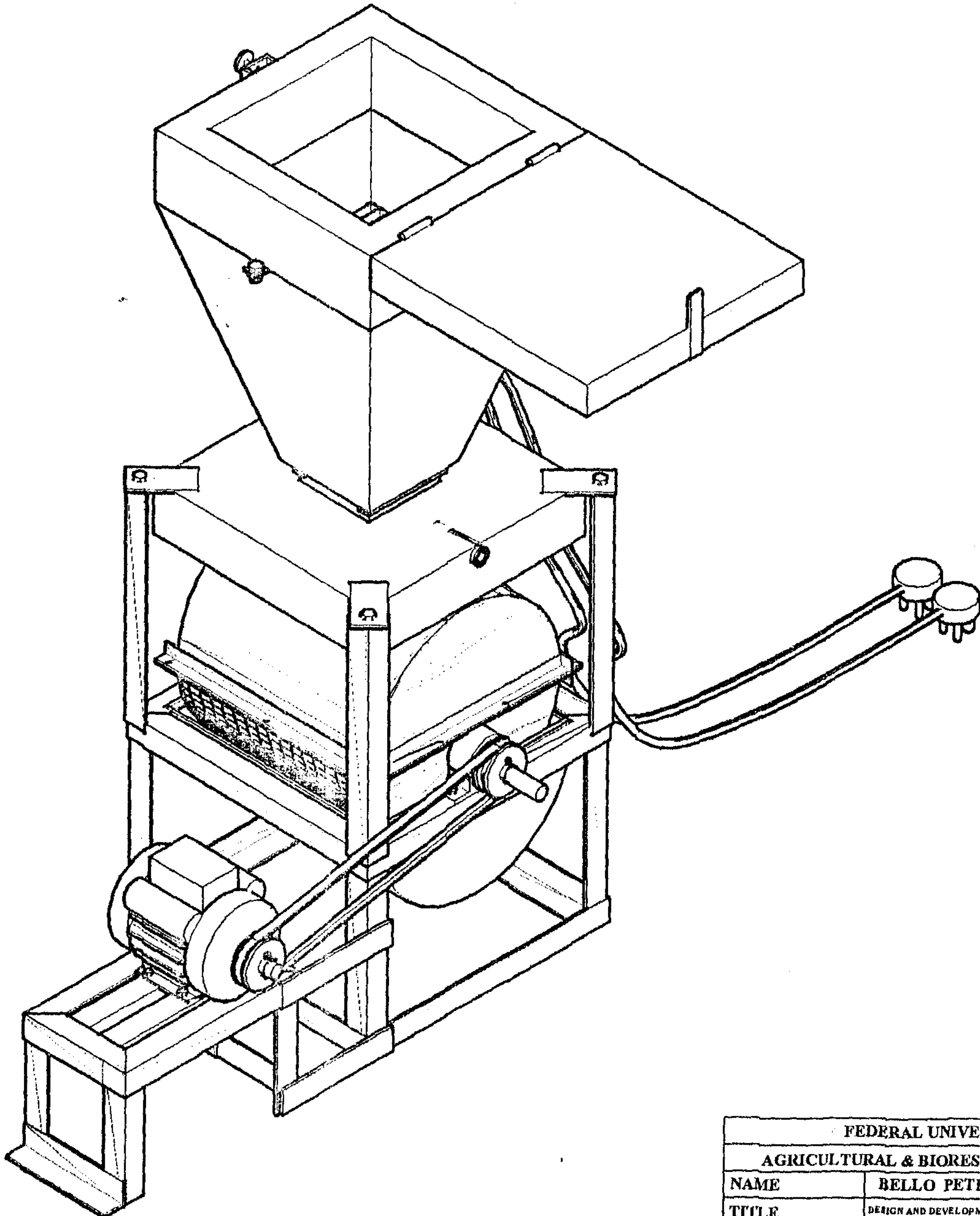
4.9 Economic analysis of the LDPE recycling machine

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).

Therefore, it is desirable that any investment generates large share of total income in the early years of its life.

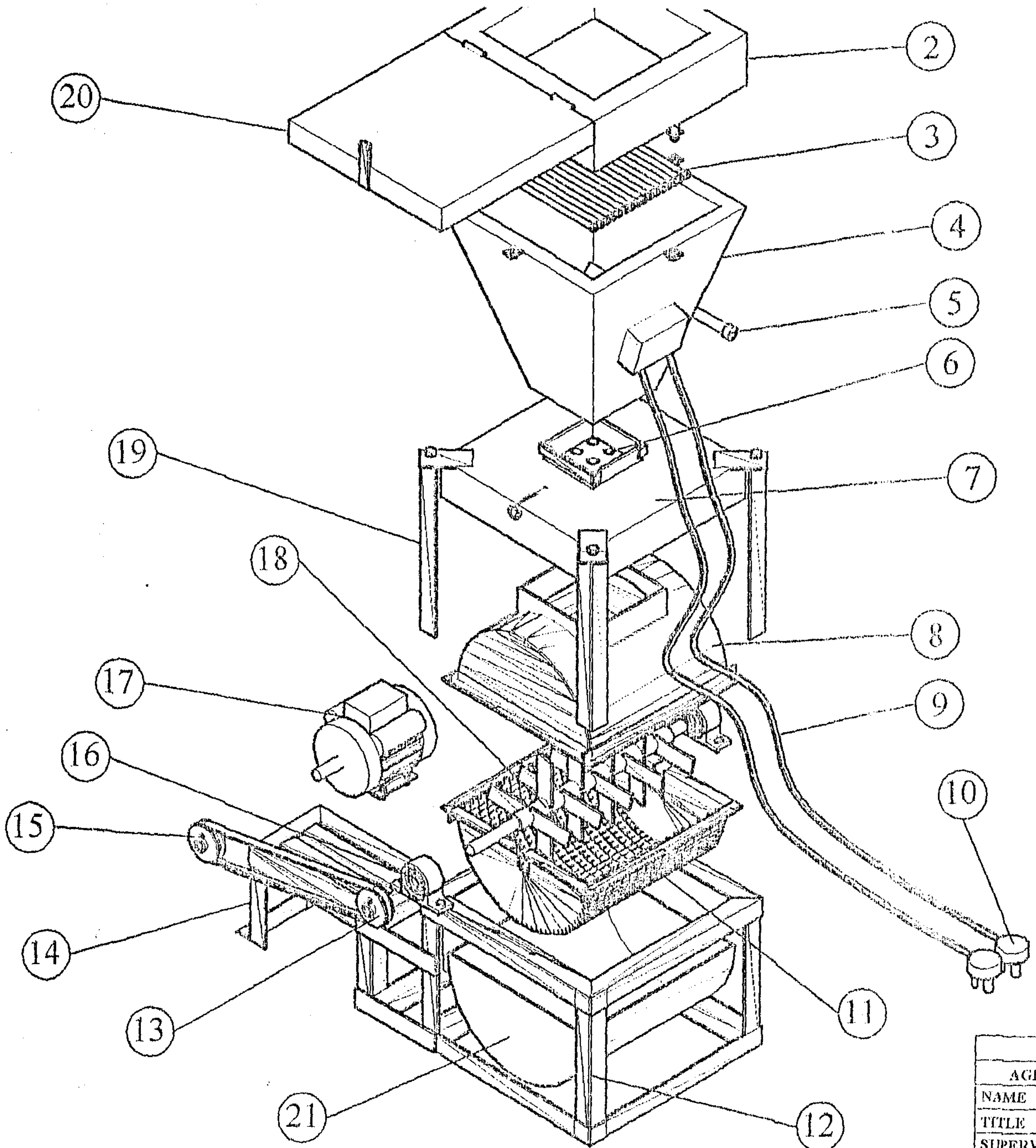
For the LDPE recycling machine, the income is viewed as producing a new product and reducing environmental pollution.

Within the limit of time and the completion time of this project work, a full economic analysis could not be made but it is assumed it is more economical as it saves and reduces environmental pollution.



ISOMETRIC VIEW

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA			
AGRICULTURAL & BIORESOURCES ENGINEERING DEPARTMENT			
NAME	BELLO PETER OLUSEGUN E.	2005/21591EA	
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

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA			
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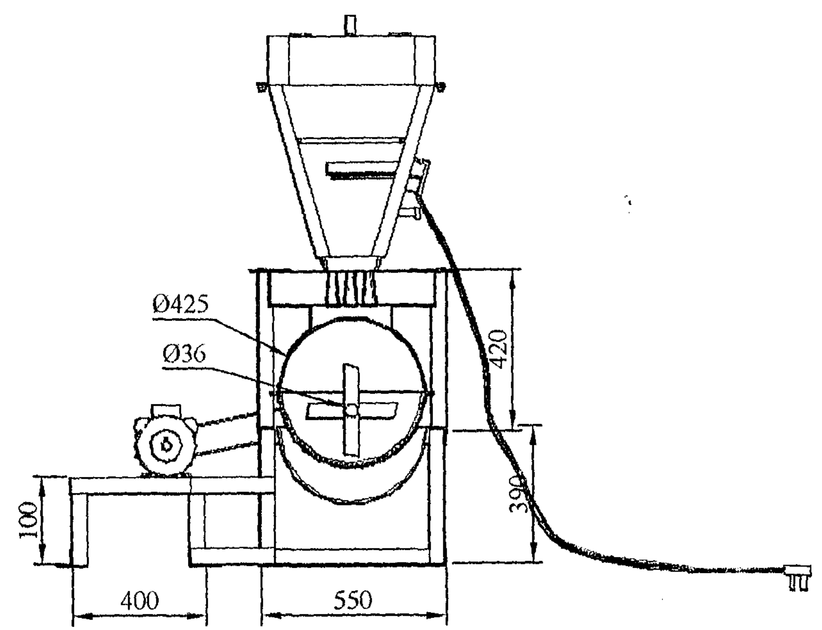

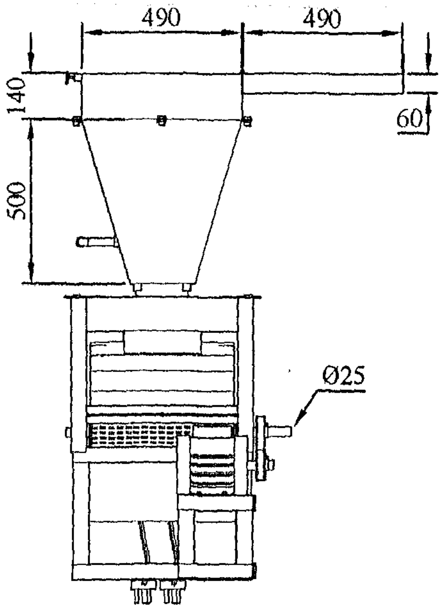

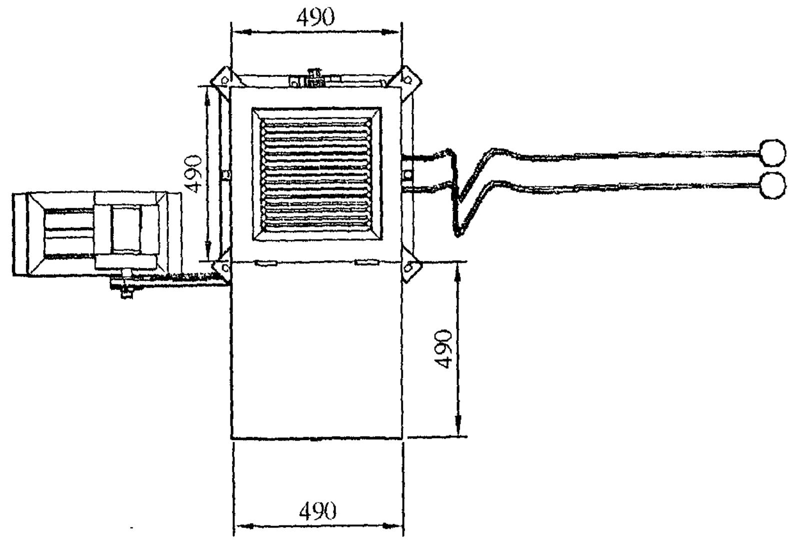

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FEDERAL UNIVERSITY OF TECHNOLOGY MINNA			
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CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The low density polyethylene recycling machine was designed and developed using locally available mild steel material, which makes it affordable to the environmentalist and industrialist at a moderate cost.

The performance of the low density polyethylene recycling machine was evaluated successfully. A good recycling output was actually obtained after testing, owing to the ability of the cooling chamber to effectively cool the molten LDPE and convey it to the size reduction chamber. The size reduction process was fairly good with the given speed. The performance of the machine was evaluated using 5kg of sorted LDPE with the following results: A melting efficiency of 82%; cooling efficiency of 52%; recovery efficiency of 72% and a throughput capacity of 5kg/hr were obtained.

However, improvements could still be made to the design ergonomics to achieve a better efficiency than 72%. This will be recommended upon

5.2 Recommendations

During and upon the completion of the development of the low density polyethylene recycling machine, there were various challenges that were not overcome due to the fact that they were not visible during the fabrication and cannot be changed after completion due to time constraints of the project. These shortcomings will be recommended upon for future modification and improvement. They are given below:

- The used cooling water should be passed to a mesh to drip into a tank with the purpose of it to get cooled in a short time. The water can then be re-used to minimize wastage.
- The machine walls should be fabricated with stainless steel as this improves the performance of the machine.
- The hopper should be insulated with moist clay as this insulated better than foam material.
- A control mechanism should be provided to put on the size reduction mechanism only when material gets into it so as to save electrical power.
- The frame of the machine should be provided with roller at the legs to ease transportability of the machine.
- The machine ergonomics should be improved to enable operators of shorter height be able to use the machine conveniently.

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