DESIGN AND DEVELOPMENT OF A LOW DENSITY POLYETHYLENE RECYCLING MACHINE

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DEPARTMENT OF AGRICULTURAL AND BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA,

DECEMBER, 2010.

DESIGN AND DEVELOPMENT OF A LOW DENSITY POLYETHYLENE RECYCLING MACHINE

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BEING A FINAL YEAR PROJECT SUBMITTED IN PARTIAL FULFILLMENT 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

DECEMBER, 2010.

DECLARATION

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degree or diploma or certificate at any university or institution derived from personal communications, published and unpublished work were duly referenced in the text.

....

Ekweh, Kenechukwu Anthony Date

CERTIFICATION

This is to certify that the project entitled "Design and Development of a Low Density Polyethylene Recycling Machine" by Ekweh, Kenechukwu Anthony 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

Supervisor

Date

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

Engr. Dr. A.A. Balami

Head of Department

Date

.... 8/12/2010 ....

External Examiner

Date

DEDICATION

This project work is solely dedicated to the Author and Finisher of my soul, the Almighty God and to my late Father Mr. Jonas Ekweh, my lovely mother Mrs. Roseline Ekweh, my siblings also to my mentor, Rev.Fr. Nelson G. Onuh.

ACKNOWLEDGEMENTS

Firstly, my study would not have been successful without God Almighty, to whom I am most grateful for His strength, love, and guidance through my study period.

My special thanks go to my supervisor, Engr. Dr. O. Chukwu for his professional supervision and advice which have been fruitful and indelible, making sure that this project work was successfully completed. I immensely appreciate the effort of Dr. Gbabo Agidi for his timely corrections.

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My special appreciation and gratitude goes to my late father Mr. Jonas U. Ekweh and Mrs. Roseline Ekweh for setting me on the regrettable path of knowledge and for their moral, financial and Spiritual support. I will make you proud!

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Rev. Fr. Nelson G. Onuh- Believe in yourself and your dreams. You are my good book and can't get tired reading you.

I acknowledge Mr. Clement for the brotherly role he played throughout my study period. I also wish to thank all the members of Teaching Ministry and CCRN FUT minna for their spiritual backup.

Finally, my thanks go to all my classmates and project group mates for all the care they showed during our stay in school and for all the wonderful times we have shared together, "see you at the top".

ABSTRACT

In this study, a low density polyethylene recycling machine (LDPE) was designed, developed and tested. Following standard engineering principles the machine was designed and developed. Due to the environmental pollution resulting from the indiscriminate dumping of the used "pure water sachets" in Nigeria, the machine was developed to proffer solution to the problem caused by the low density polyethylene. The recycling process of the machine follows the principle of agglomeration which involves heating the LDPE at a temperature ranging from (105°C-115°C), the melted material is cooled into lump with the aid of water as coolant and the reduction in size of the lump is done by the machine through the process of cutting of the lump to form pellets. A successful performance evaluation test was carried out and the time taken for the whole process was put at 1 hour 43mins.The theoretical time required for both melting and cooling is 45mins and 22mins respectively. The machine is developed with an input capacity of 5kg and output capacity of 3.6kg with power requirement of 2kW, at a shaft cutting speed of 1450rpm. The machine has a melting efficiency of 81%, cooling efficiency of 52% and cutting efficiency of 72%. The product from this machine could be used as a raw material in bottling companies and other polymer processing industries. The machine can be employed to reduce environmental pollution by enhancing the process of recycling of low density polyethylene. The efficiency of the cooling chamber could be increased, if connected to a continuous flow of water source that will enhance faster cooling.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Polyethylene or polythene (IUPAC name polyethene) is the most widely used plastic with the annual production of approximately 80 million metric tons (Piringer and Baner, 2008). Polyethylene is created through polymerization of ethane. It can be produced through radical polymerization and anionic 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. Polyethylene is a waxy, translucent, flexible thermoplastic. It is one of the lightest plastics having a specific gravity of 0.92 - 0.93. Below 60°C, polyethylene is insoluble in all solvents and is resistant to the action of most chemicals other than strong oxidizing acids. However, above 115°C, the polymer changes from a clean solid to a low viscosity melt. At this temperature and above, exposure to air causes relatively extensive oxidative degradation, unless antioxidants are included in the polymer (Encyclopaedia of Polymer Science and Technology, 1992). A number of factors can initiate the degradation of polyethylene, such as ultra-violet light, heat, oxygen and film stress (such as pulling and tearing) (Scott, 1999). Polyethylene is probably the polymer seen most in the world. This is because polyethylene is cheap, safe, harmless, and stable in most environments and easily processed (Ojo, 2007).

1.2 Uses of Polyethylene

The use to which polyethylene is put depends on whether it is low-density or high-density type. Low-density polyethylene is used as kitchen utility ware, in the manufacture of toys, process tank liners, closure packages, sealing rings and battery parts. Other uses are as squeeze bottles for packaging and containers for drugs. The film is used as wrapping materials for food, fruits and clothes (Efiuwevwere and Oyelade, 1991; Nwacchukwu et al., 2008).

Polyethylene is also used in covering wires and cables because of its high insulating properties. It is also moulded into pipes used in transporting chemicals, natural gas and water for various uses. High density polyethylene is used in making refrigerator parts, pipes, defrosters, heater ducts, sterilizable house wire and hospital equipment and hoops. This is attributed to its higher resistance to high temperature (Ojo, 2007).

1.3 Statement of the Problem

In Nigeria, waste disposal is very poor. Most of Nigerian polyethylene wastes originate from consumption of products packaged in polyethylene sachets, bags or other containers. Indiscriminate dumping of the so called 'pure water sachets' on roads, and drainage channels in Nigeria cause blockage of such channels and flooding of the environment during rainy season. Dumping of polyethylene waste materials constitutes a greater part of environmental pollution with many green house effects. This project intends to proffer solution to the above problems by converting used "pure water sachets" of into another form of industrial raw material.

1.4 Objectives of the Study

1. To design a low density polyethylene (LDPE) recycling machine.
2. To develop the designed low density polyethylene recycling machine.
3. To carry out performance evaluation of the low density recycling machine.

1.5 Justification of the Study

Plastics degrade very slowly in nature because of their intermolecular bonds. Some plastics may persist in the environment for thousands of years. Because of their low density, they also tend to float in water. Hence plastics discarded in water shed areas, which invariably all areas of human settlement are, get collected in the rain water sewers. Sometimes, due to prolonged intervals of retrieval, they choke these rain water outlets. The uses of thinner plastic bags have increased the risk of sewer blockages. In Lagos, it has been the reason for exacerbated flooding during the rainy season (Wallace, 1985).This explains why they end up in landfills and dumpsites as recalcitrant pollutants. Therefore, there is a need to develop an efficient and affordable low density polyethylene recycling machine which will help clean up the environment and reduce environmental pollution.

1.6 Scope of the Study

The scope is to design, develop and carryout performance evaluation of the developed low density polyethylene recycling machine. The machine is designed for LDPE materials such as "pure water sachets" and therefore will not be tested with HDPE materials.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 History of Plastics

Plastics have been around for a long time now. It has been said that even before Alexander Parke's major pioneering contribution to the development of plastics from cellulose nitrate in the 1850s, plastic-like materials have been in use by mankind for centuries. However, in the current era life without plastics cannot be imagined. Almost every article of day to day use that we may lay hands on is either a plastic or has plastic component in it (Zaman, 2009).

Because of the immensely versatile nature of plastics to be made into products of varying strength and flexibility, we find plastic products ranging from car bodies, home and office furniture, computers, water bodies and as package materials for almost everything that needs transportation and storage. Besides since plastics are mostly made from the by-products of the petroleum manufacturing processes, they are very inexpensive. The increasing prevalence of plastic use has also resulted in it being incrementally adding to the Municipal Solid Waste (MSW). According to the Environment Protection Agency (EPA) (Zaman, 2009) the contribution of plastics to MSW in 2008 in the US was 30 million tons which is nearly 12% of the total. When we compare this to the plastic content of MSW in 1960 we find that it contributed only to 1% then. Of the 30 million tons of plastic waste in the US in 2008, 13million tons were single-use plastics. Single-use plastic are essentially the plastic products used for packing purposes of almost all manufacture products from the most high-tech equipment like computers to the most basic ones like drinking water.

In general, the major groups of plastics and their areas of application are listed as under in Table 2.1

Types of plastics	Applications
High-Density Polyethylene (HDPE)	Milk jugs
Low-Density Polyethylene (LDPE)	Plastic bags
Linear Low-Density Polyethylene	Plastic bags, sheets, stretch sheets
Polyethylene Terephthalate (PET)	Soda bottle
Polypropylene (PP)	Long underwear
Polystyrene (PS)	Disposable razors, CD case, Packing foam
Polyvinyl Chloride (PVC)	Pipes

Zaman, (2009).

Based on the usage, we may further classify plastics as durable (e.g. plastic furniture, appliances), non-durable (e.g. plastic utensils, diapers, trash bags and medical equipment) or packaging/ container plastics (e.g. plastic bottles, shopping bags). Single-use plastics belong to the non-durable and packaging group. In this study emphasis will be focused on the packaging and container plastics. Plastics are manufactured from petroleum products and currently account for 4% of the petroleum consumption with additional 4% in terms of energy used in the manufacturing process. One third of petroleum products go on to be used in packaging materials which get discarded after their use as the single used plastics (Thompson, 2009).

2.2 Types of Plastics

The virgin plastic material is produced using fossil fuel as raw material. According to chemical physics, plastic is defined as a polymer. Polymer is developed by combining a large number of similar chemical units known as monomers. Depending on the chemical composition and the arrangement of the monomers the characteristics of the polymers vary. Therefore, the types of plastics can be categorised based on their chemical properties. Broadly, plastics can be categorised into two types based on their physical and chemical properties.

2.3 Physical Properties

Hard plastics (relatively large and thick solids such as cans, bowls) and Sheet plastics (thin sheets such as polythene, shopping bags).

2.4 Chemical Properties

However, based on the chemical properties, there are different types of plastics. In plastic recycling the segregation of the waste plastics into both of these categories are important. The reactions for different chemicals such as acids and physical conditions such as temperature and impact vary with the type of plastic.

Things to be composted and excluded from composting bin are listed as under in Table 2.2

Name and Standard Symbol	General Use	Special Features	Identification
High Density Polyethylene (HDPE)  HDPE Unpigmented HPPE Pigmented	Used in packaging of low shelf- life products such as Milk bottles, Vinegar bottles. Detergent bottles Vehicle oil cans Saline bottles Grocery bags shells, coconut husk, komba. Fats/cooking oils Hazardous material like batteries, bulbs, electronic components and chemicals	Good chemical and moisture resistance. It is used for packaging many household and industrial chemicals such as detergents and bleach good barrier properties and stiffness Pigmented HDPE bottles have better stress crack resistance than unpigmented HDPE bottles.	Slightly waxy to the touch; semi-rigid to flexible; does not crack when bent; scratches to some degree; floats in water. Unpigmented Opaque matte finish (not shiny) Pigmented – Translucent matte finish (not shiny)

Polyvinyl Chloride (PVC) 3 PV C	Plastic tiles, Pipes, fittings Wire, cable insulation, and synthetic leather products, Pharmaceutical bottles, medical tubes Can be broadly divided into rigid and flexible	Excellent chemical resistance, good weather ability, flow characteristics and stable electrical properties	Tough; very smooth surface; forms opaque white line when bent; semi-rigid; scratches easily; sinks in water bottles have seems Clear bottles sometimes have faint blue tint; bottom has blow-moulding smile.
Low Density Polyethylene (LDPE). 4 LDPE	Flexible film bags for dry cleaning, bread, produce, trash. Rigid items such as food storage containers, squeezable bottles and flexible lids .	Ease of processing, strength, toughness, flexibility, ease of sealing, barrier to moisture. Used predominately in film applications due to its toughness, flexibility and relative	Slightly waxy to the touch; flexible; stretches before tearing when pulled; easily scratched; floats in water. Can be nearly transparent (for example dry cleaning bags) or

		transparency, making it popular for use in applications where heat sealing is necessary.	opaque: can be coloured; low to high gloss.
Polypropylene 5 PP	yogurt containers and margarine tubs, medicine bottles,. Battery cases	Strength, toughness, resistance to heat, chemicals, grease and oil, versatile, barrier to moisture.	Smooth surfaces; semi- rigid; tough; cannot be scratched; floats in water. Transparent, translucent, or opaque; clear or coloured; can have shiny or low gloss finish.
Polystyrene (PS) 6 PS	Heat resistant containers, Disposable lunch boxes, foam packing, foam	Lightweight; heat resistant; buoyant, relatively low melting point	Smooth surface; cracks easily when bent; lightweight and fluffy; easily scratched; floats in

	plates, cups, utensils		water. Opaque only; smooth to grainy finish; foamed, thick walled
	Depends on the product	Use of this code indicates that the package in question is made with a resin other than the six listed above, or is made of more than one resin listed above, and used in a multi-layer combination.	Varies on the product

Practical Action, (2009).

2.5 Thermoplastics

Thermoplastic are supplied fully polymerized and remain permanently fusible, melting when exposed to sufficient heat, and potentially they can be recycled and reused. Thermoplastic refer to plastics which are linear and branched bonding in their structure. These plastics can be reformed due to the fact that the simple structure of their molecules can be heated, remoulded and covalently bonded several times. Thermoplastics are generally carbon containing polymers synthesized by addition or condensation polymerization. Thermoplastics can have a crystalline microstructure; this process forms strong covalent bonds within the chain and weaker secondary Van der Waals bonds between the chains. Usually these secondary forces can be easily overcome by thermal energy (resulting in plastic deforming); making thermoplastics mouldable set high temperatures (there is a specific temperature at which the material will start to distort). Thermoplastics will also retain their newly reformed shape after cooling. This cycle of softening by heating and solidifying by cooling can be repeated more or less indefinitely and is the basis of most processing methods for these materials. Examples of thermoplastics are polyethylene, poly (vinyl chloride), polystyrene, nylon and cellulose acetate.

2.6 Thermosets

The cross linked polymers mentioned above develop into plastics which are known as thermosets. Thermosets are plastics which cannot be re-moulded after initially being created. This is due to the fact that the bonds which are cross linked will have difficulty in recombining themselves. A thermosets material is produced by a chemical reaction which has two stages. The first results in the formation of long chain-like molecules similar to those present in thermoplastics, but still capable of further reaction. This second stage of inter-linking the long molecules takes place at the point of use and often under the application of heat and pressure. They also have a stronger linkage to other chains. Strong covalent bonds chemically hold different chains together in a thermosets material. The chain may be directly bonded to each other or be bonded through other molecules. This "cross-linking" between the chains allows the materials to resist softening upon heating. These types of plastics can only be made once and cannot be setup for recycling. Examples of thermosets are phenol formaldehyde, melamine formaldehyde, urea formaldehyde, epoxies (glues), automobile body parts, adhesives for plywood and particle board, and matrix for composites in boat hulls and tanks. Although thermosets are difficult to reform, they have many distinct advantages in engineering design applications including high thermal stability and insulating properties.

2.7 Occurrence and recalcitrance of polyethylene bag waste in Nigerian soils

Nwacchukwu and Odocha,(2010) of the Department of Botany and Microbiology University of Lagos. Attempts to biodegrade polyethylene bag wastes (pure water sachets) weighing 25.2 g each were made by burying them in the soil and subjecting them to acid treatment (0.5 M HNO3) and alkaline treatment (0.5 M NaOH) over a 24 week study period. The experimental polyethylene bags Experimental Design 1 (ED1) were inoculated with a strain of Pseudomonas spp. isolated from a refuse dump and by inorganic nutrient supplementation to facilitate biodegradation. Samples without inorganic nutrient supplementation and Pseudomonas spp. inoculation served as first Control Design (CD1), while those placed on a slab on the surface of the soil served as second Control Design (CD2) to evaluate the roles played by microorganisms and physical degradation, respectively. ED1 showed a slight reduction in weight to 24.9 g at week 16 after the acid treatment for 5 days and further reduced to 24.7 g at the end of the study after the alkaline treatment. CD1 reflected no variations in weight, while CD2 reduced to 25.1 g. The study showed that recycling of used pure water sachets which yielded useful products such as water seal, polyethylene bags and jerry can covers, appears to be the only option of checking environmental pollution caused by this product as microbial degradation proved ineffective.

2.8 Types of Recycling

Recycling of plastics will definitely reduce the waste material at waste disposal while reducing the piling up of plastic virgin material on the earth. At the same time it will reduce the energy and water consumption and emission of toxic gases and chemicals in the virgin material production process. When all these factors are taken into account the overall impact of waste plastic recycling would be very high. In plastic recycling, the end product can be replaced for virgin material and will generate the above mentioned environ-economic benefits. Plastic recycling can be done in following ways namely, materials recycling, mechanical recycling and chemical or feedstock recycling.

2.9 Material Recycling

This practice of recycling post- manufacturing waste has been in vogue since many years. But problems are encountered in case of post consumer waste such as great in homogeneity of different polymers present such as Polypropylene, Polystyrene and Polyvinyl Chloride. Further the incompatibility of the components mixed, inferior material properties and chemically different polymers present pose difficulties in processing. It is therefore necessary to separate various polymers to boost their value. Separation work based on the principle of sorting by a centrifugal force field and using density difference of the various polymers is one possible solution. Prior to separation, it will be necessary to clean the polymer waste to remove contamination like dirt, food leftovers, and papers.

2.10 Chemical Recycling

This is converting polymers back into short chain chemicals for re-use in polymerization or Chemical recycling is the breaking down of the plastic polymers again into monomers and rearranging them to produce new material using different technologies. Chemical recycling is very capital intensive and needs large quantities of plastics to make it a financially viable process. Other petrol-chemical processes such as cracking, gasification, hydrogenation and pyrolysis.

2.11 Mechanical Recycling

Consists of melting the plastics under controlled conditions, reshaping, shredding and granulating the waste plastics. Simple and comparatively low cost technologies can be used in the mechanical recycling process and it is this process which is explained in Fig below.

Steps in Mechanical Recycling

The steps in mechanical waste plastic recycling are shown in the flow chart in Figure 2.1.

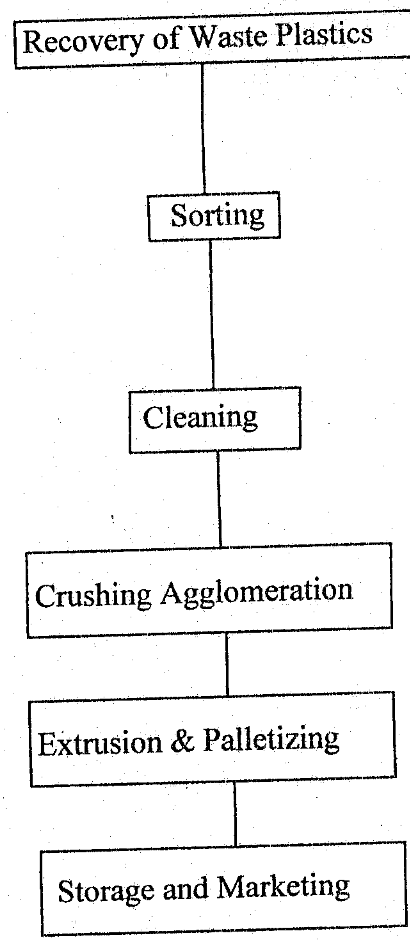


Fig.2.1: Flow of mechanical waste plastic recycling Source: Practical Action, (2009).

2.12 Recycling of Polyethylene

Polyethylene waste (pure water sachets) were picked from different sources, rinsed and ground in a grinding machine. The product was then loaded into a hopper (bin were the material is collected) from where it was fed gradually into a mechanical system comprising of a melting zone, compression zone and a feeding zone. The materials got melted at about 150^0c onto a molten form and were passed into the compressing zone where air was applied and then made into a mould. The material assumed the stage of the mould and was cooled by an inbuilt water-cooling system. On cooling pressure was applied hydraulically and a finished product emerged. The investigation showed that polyethylene waste recycling method can be established easily with no adverse effect on the environment (Noritake et al., 2008).

2.13 Recovery of Plastic

In the normal waste stream the plastics are mixed with other waste. This hinders the extraction of plastics for recycling purposes. The plastics need to be recovered from the main waste stream. It is highly desirable to recover plastics at their source. Promotion of source separation of waste would be beneficial at this point. Collection systems are also important in the recovery stage as the lack of waste material would hinder the continuation of the process. It is advisable that a target group is identified and their awareness be raised on source separation and plastic recycling prior to initiating plastic recycling.

2.14 Initial Upgrading

Once plastics have been collected, they have to be cleaned and sorted. The technique used will depend on the scale of the operation and the type of plastic waste collected. But at the simplest level it will involve hand washing and sorting of the plastics into the required groups. More sophisticated mechanical washers and solar drying can be used for larger operations. Sorting of plastics can be into polymer type (thermosets or thermoplastic), by product (bottles, plastic sheeting) and by colour (Lardinios, 1995). A typical waste plastic reprocessing stream in a low-income country is shown in Figure 2.2.

- **Sorting**

Sorting needs to be done based on the physical and chemical properties of the plastics. Hand-sorting can be done by skilled or unskilled labour. For unskilled labourers, the skill of identifying plastics and polythene can be learned within a very short period of time. Hand sorting can be done based on the physical and chemical properties of the plastics.

a. First the waste plastics needs to be sorted into two broad categories as plastic (cans, large pieces, boxes) and polythene (sheet/film types).

b. Each category needs to be sorted into other sub-types based on their chemical properties. Identification of polythene and plastic types, and segregation into colours are helpful to maintain final quality. The chemical properties needs to be identified in the following ways:

- **The standard symbol**

In most plastic products the relevant standard symbol is printed /embossed.

- **Flexibility**

High density polyethylene plastics are relatively flexible and

without breaking

- **Sound**

The sound created when crushing film plastics vary with the type. For example crushing of the High density polyethylene films gives a unique sound (like the sound emitted when crushing a normal grocery bag). Such identification can be done with

- **Reaction to fire**

Polyvinyl Chloride burns with a greenish blue colour flame without dropping

- **Floating in water**

Some materials float on water while some sink. However, with little experience, even a lay person can identify the type of plastic very quickly by its look and feel.

2.15 Cleaning of Plastics

This is the most important stage in the mechanical waste plastic recycling process. The value of the recycled plastic relies greatly on its purity. Even small dust particles can reduce the quality of the material drastically as it will disturb the polymer arrangement and later the quality of the final product. Therefore, thorough washing of the plastic material and drying should be done prior to processing. In washing, a diluted detergent can be used and precautions should be taken to remove the detergent from the material on completion of the process. Oil contaminants should be removed using an appropriate solvent, followed by a detergent and water. Maintaining a clean working environment is an important aspect of the process. Maximum care should be taken to prevent sand and dust coming into the processing plant. Dust and sand particles can easily come in contact with the recycled plastic pellets which reduces the quality of plastic products. The behaviour of the workers in the recycling plant should be adjusted accordingly such as to maintain a clean work area, for example be wearing clean shoes. A considerable quantity of water will be required for the washing of raw material (waste plastics). Therefore, water treatment and reusing is important to reduce the cost of production and environmental pollution. Moisture in the raw material should be removed prior to the processing of plastics and therefore, reserving area for drying is equally important (Vest, 2000).

2.16 Crushing

The large particles of plastic need to be broken down into small pieces to reduce storage and transportation space requirement. Such broken down High density poly and

Low density polyethylene plastics can be sold as raw material for plastic production without any further processing. On the other hand, it can be re-extruded to produce pellets for plastic manufacturing. Crushing can also be done to reduce the storage space requirement and easy transportation for further processing. A crusher should be used for this purpose and the resultant broken pieces of plastics should be the size of 2– 0.5 cm. It is important to prevent mixing of plastic types to maintain the quality and value of the plastic. Mixed crushed plastics can be used only for low value and low quality products such as junction boxes used in electrical work or plastic lumbers. The crusher should comprise of a rotating set of blades, feeding hopper, and motor. The size of the feeder depends on the maximum size of plastic that needs to be crushed. Operating a crusher is easy and the sorted and cleaned plastics can be fed into the feeding hopper manually and the crushed material should be collected and stored to prevent contamination with sand, dust, and moisture (Vest, 2000).

Note:

The operator of the crusher and helpers should wear ear plugs to protect their ears as the crusher creates a high noise level. Exposure to such noise levels over a long period can create hearing impairments. It is also advisable to use gloves when handling plastics.

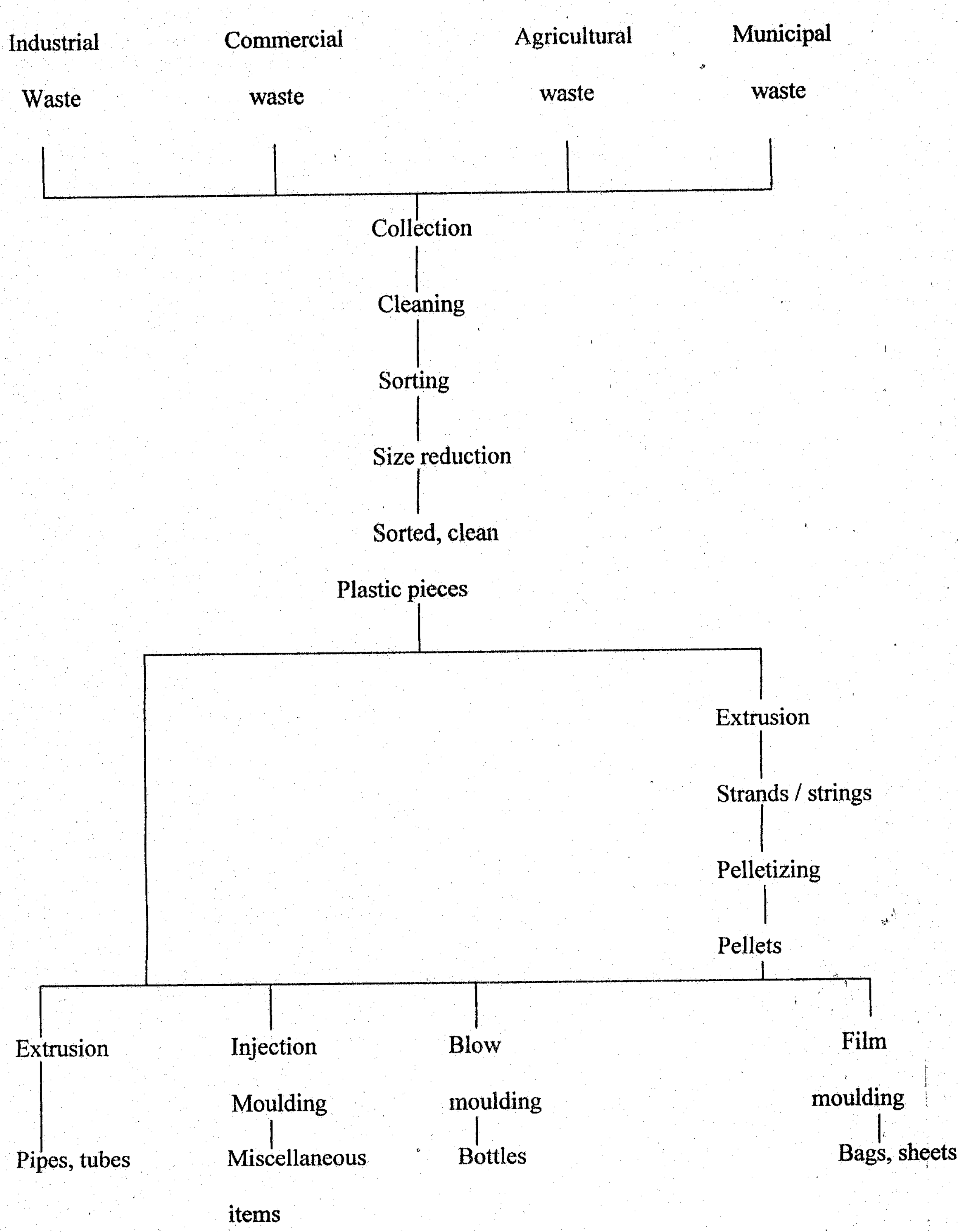


Fig. 2.2: Flow of a typical waste plastic reprocessing stream sin a low-income country Tool, (1995).

2.17 Agglomeration

The term 'agglomeration' itself provides an idea of forming a crumb out of smaller material. Agglomeration is done for film plastics (polythene) instead of crushing. Film plastics cannot be crushed due to its properties. Agglomeration can be performed on Low density polyethylene and Polypropylene type film plastics. An equipment call the "Agglomerator" is used for agglomeration. The Agglomerator is simply a metal drum in which a set of blades are rotating at high rpm (rotations per minute). When the film plastics are fed into the agglomerator it cuts into small pieces by the blades inside. Consequently the heat generated due to the high rotation speed, it makes the pieces of film partially melt and bind into a small crumb. This crumb can be fed to the extruder to ensure smooth functioning in extrusion. Operating of an agglomerator should be done with caution. First, a small quantity of film plastics (about 3 kg) needs to be put in and machine switched on. Then feeding should be done gradually until the drum filled up to 2/3rds of its capacity. The first batch needs more time to get agglomerated as the drum gets heated slowly. In a 100Kg capacity agglomerate the first batch takes 45 minutes for processing, while the following batches take only 25 minutes. The agglomerated film plastics (polythene) should be taken out quickly and allowed cool. The optimum time of agglomeration is when approximately 50% of the particles are in crumbs with 0.5 – 1cm diameter. Over agglomeration (long time in agglomerator) can melt the films too much and can result in pieces of film binding into larger particles. In addition, the rotation of the blades can be disrupted due to over- molten polythene blocking the rotating shafts. Over melting will also make manual handling of the material difficult due to high heat and stickiness of the material (Practical Action, 2009).

Note:

Agglomeration can be performed only with Low density polyethylene and Polypropylene films. To agglomerate High density polyethylene films, higher temperatures should be achieved within the agglomerator if not the films may block the rotating blades. Under high temperatures Low density polyethylene and Polypropylene film cannot be agglomerated as the melting points of these plastics are lower than that of High density polyethylene. Therefore, a special agglomerator should be designed to agglomerate High density polyethylene with heat elements and insulators (Vest, 2000). A typical agglomerator used in Germany shown in Figure 2.3.

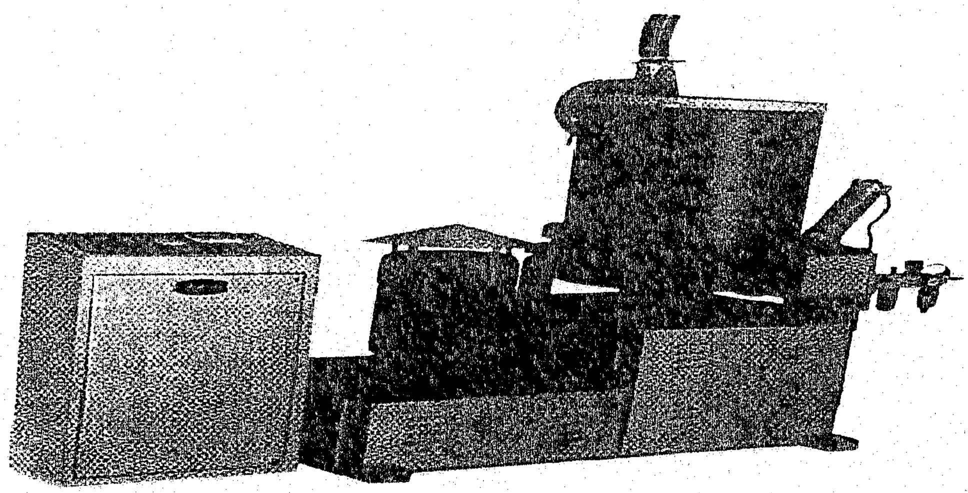


Fig.2.3: A typical agglomerator used in Germany for recycling of low density polyethylene Vest, (2000).

2.18 Plastic Pellet

Plastic (resin) pellets are the raw material that are melted and moulded to create plastic products. Plastic may be formed into pellets of various shapes e.g. spherical, ovoid and cylindrical; size range (1 to 5mm diameter), and colour (most commonly clear, white, or off-white). The wide variety of plastic products produced internationally has created a demand for many different polymers or resins. An estimated 60 billion pounds of resin, most of which are formed into pellets, are manufactured annually in the United States (Battelle Ocean Sciences, 1992). The most commonly produced resins include polyethylene, polypropylene, and polystyrene. After they are formed, the pellets are packaged and transported to processors for moulding into plastic products.

Vest, (2000) in his published Small Scale Recycling of Plastic Waste in Germany said for many purposes it is recommended to convert plastic chips or agglomerate into pellets before further processing. During pelletizing (re-melting in an extruder and production of "spaghettis" which are subsequently chopped into pellets), the recycled plastic can be homogenised, blended, degassed, coloured or stabilised. A typical agglomerator used in Germany shown in Figure 2.4.

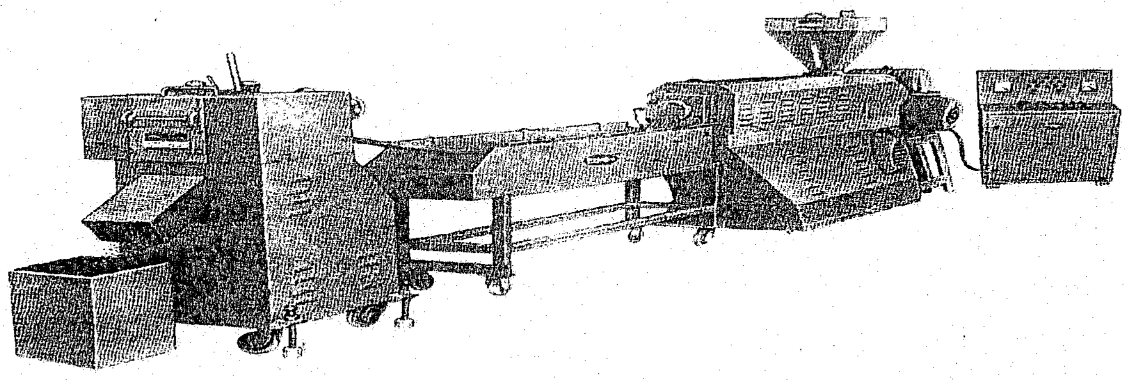


Fig. 2.4: A typical pelletizes used in Germany for recycling of low density polyethylene: Vest, (2000).

2.19 Extrusion of Pipes or Profiles

Chips, agglomerate or pellets from recycled PE and PVC can be used to produce pipes or profiles. Since recycling material is never homogenous tests should be carried out to determine the correct mixture (e.g. of LDPE and HDPE) to achieve a product with the desired physical properties. Pipe or profiles are extruded continuously. The plastic is melted in the extruder and pressed through the extrusion tool. To preserve the desired shape until the plastic has solidified water cooled calibration tools are used. Finally the pipes or profiles are cut to length or are coiled (pipes). Since this technology is quite simple and easy to control, it is an option for small scale production of final products in developing countries. Figure 2.5 shows the general set-up of a pipe extrusion plant. Practical Action, (2009).

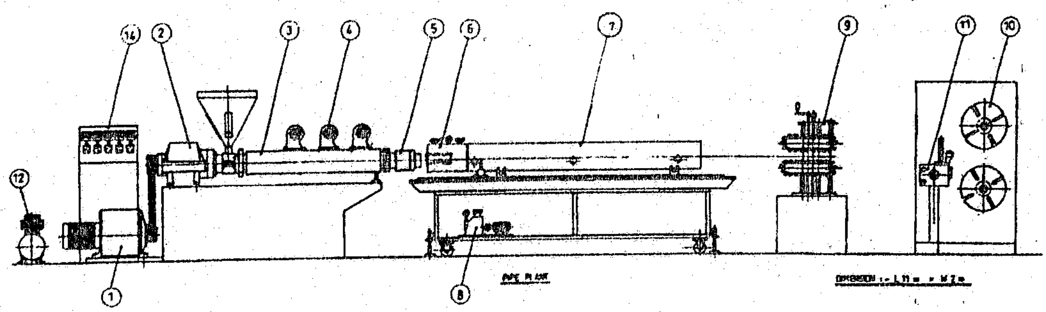


Fig. 2.5: Set-up of pipe extrusion plant : Vest, (2000).

2.20 Injection Moulding

For injection moulding pellets, chips or agglomerate are melted in an extruder. The molten plastic is intermediately stored in a supply chamber at the front of the extruder. In certain intervals the molten material is injected into a mould. After solidifying the produced item is removed from the mould. In the meantime a new supply of molten plastic has been built up, ready for the next injection "shot". To operate this process extensive control mechanism are required. Therefore, automatically operating injection moulding machines are sophisticated and expensive.

1. Eddy current coupling drive
2. Helical gearbox
3. Extruder

4. Blower

5. Extruder head and pipe die

6. Vacuum chamber

7. Water cooling tank

8. Vacuum pump

9. Haul off

10. Coiler

11. Traverse unit

12. Compressor

14. Control panel

For small scale use in developing countries manual operated injection moulding machines have been developed for example in India and Egypt. Figure 3.6 shows a simple manual operated injection moulding machine. In this type of device injection moulded items of up to 50 g can be produce. A single worker is able to produce up to 150 pieces in an hour.

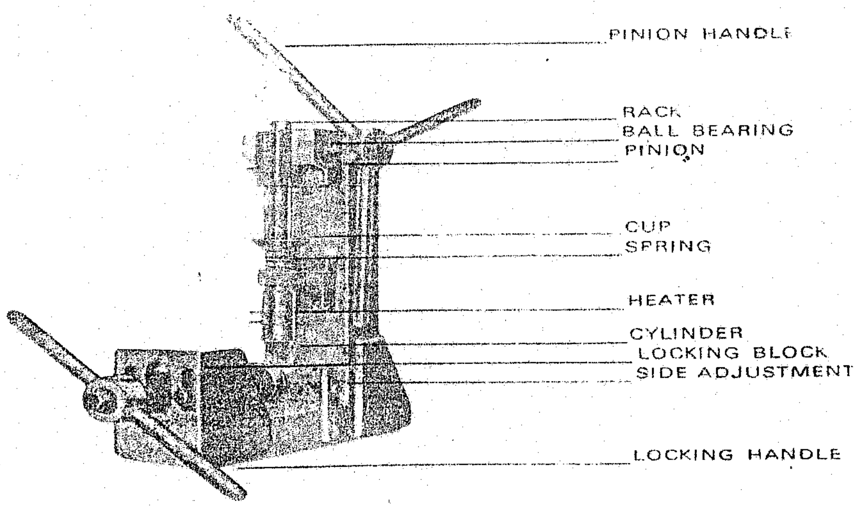


Fig. 3.6: Hand operated injection moulding machine Vest, (2000).

2.21 Water Supply

Water is required for cleaning waste plastics, cooling the extruder machine parts and cooling the extruded plastic strands. The water used in cooling the tank and as coolant in the extruder machine needs to cool. It can then be reused. A simplified cooling tower can be used to reuse this water. A simple water treatment unit can be used to reuse water using in cleaning.

2.22 Storage Facilities

Storage facilities are required to store waste plastics, cleaned plastics and recycled plastics. To ensure continuous operations the continuous supply of raw material is important and storage space should be available in order to store different types of waste plastics in adequate quantities. During rainy periods the drying of washed waste plastic will be a problem. Therefore, storage facilities should be available to store standby stocks of cleaned and dried waste plastic material. After production the products also need to be stored before marketing. In this case, special containers are required to store recycled plastics to protect them from contamination, moisture and pests.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Material Selection

During the materials selections, materials that meet design specifications which were obtained from the calculation, to avoid failure of the machine components were selected. Also relatively cheap materials when compared to other standard engineering materials that meet the design constraints were considered during selection. Factors considered were:

Health: Materials known to be dangerous to health were avoided.

Materials Properties: The materials selected must possess values of maximum stress equal to or greater than those derived analysis and calculations.

Deteriorative Properties: Such as resistance to oxidation, corrosion or weathering were also considered and are taken care of by painting of the finished work.

Manufacturing Characteristics: This includes the materials ability to be welded and machined, as most joints are to be made by welding.

Cost: Material cost and manufacturing cost were considered.

Availability and Aesthetics: The availability of materials and finished parts in the local market the ability to accept special finishes such as painting.

3.2 Design Theory

If the cutting shaft is subjected to twisting moment only,

$$\frac{\tau}{r} = \frac{\tau}{J} \tag{3.1}$$

$$J = \frac{\pi D^4 - d^4}{64} \tag{3.2}$$

$$\tau = \frac{\tau r}{J} = \frac{\tau D}{2J} \tag{3.3}$$

$$\tau = \frac{16DT}{\pi(D^4 - d^4)} \tag{3.4}$$

$$\frac{M}{J} = \frac{\sigma}{y} \tag{3.5}$$

Where,

M = bending moment

σ = bending

J = moment of inertia

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

$$M = \frac{\pi\sigma(D^4 - d^4)}{32D} \tag{3.6}$$

$$\therefore \sigma = \frac{32M}{\pi(D^4 - d^4)} \tag{3.7}$$

Maximum shear stress = $S_{max} = \frac{1}{2}\sqrt{(\sigma^2 + 4\sigma^2)}$ (3.8)

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

$$= \frac{16D\sqrt{M^2 + 4T^2}}{\pi(D^4 - d^4)} \quad (3.9)$$

For cutting blade,

$$S = \frac{M}{Z} \quad (3.10)$$

Where,

M = bending moment

Z = section modulus

Maximum stress

$$\sigma_{Max} = \frac{1}{2}\sqrt{S^2 + 4\sigma^2} \quad (3.11)$$

$$= \frac{1}{2}\sqrt{\left(\frac{M}{Z}\right)^2 + \left(\frac{F}{A}\right)^2} \quad (3.12)$$

(Oluboji, 2004)

3.3 Design of Hopper

An appropriate hopper design is very crucial in all engineering applications that utilize a hopper. In hopper designing, an important consideration is to achieve mass out-flow of material out of the hopper thereby minimizing arching (i.e. where no flow occurs) and funnelling (i.e. where flow may be reduced). 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. The cross-sectional view of the hopper is shown in figure 3.1

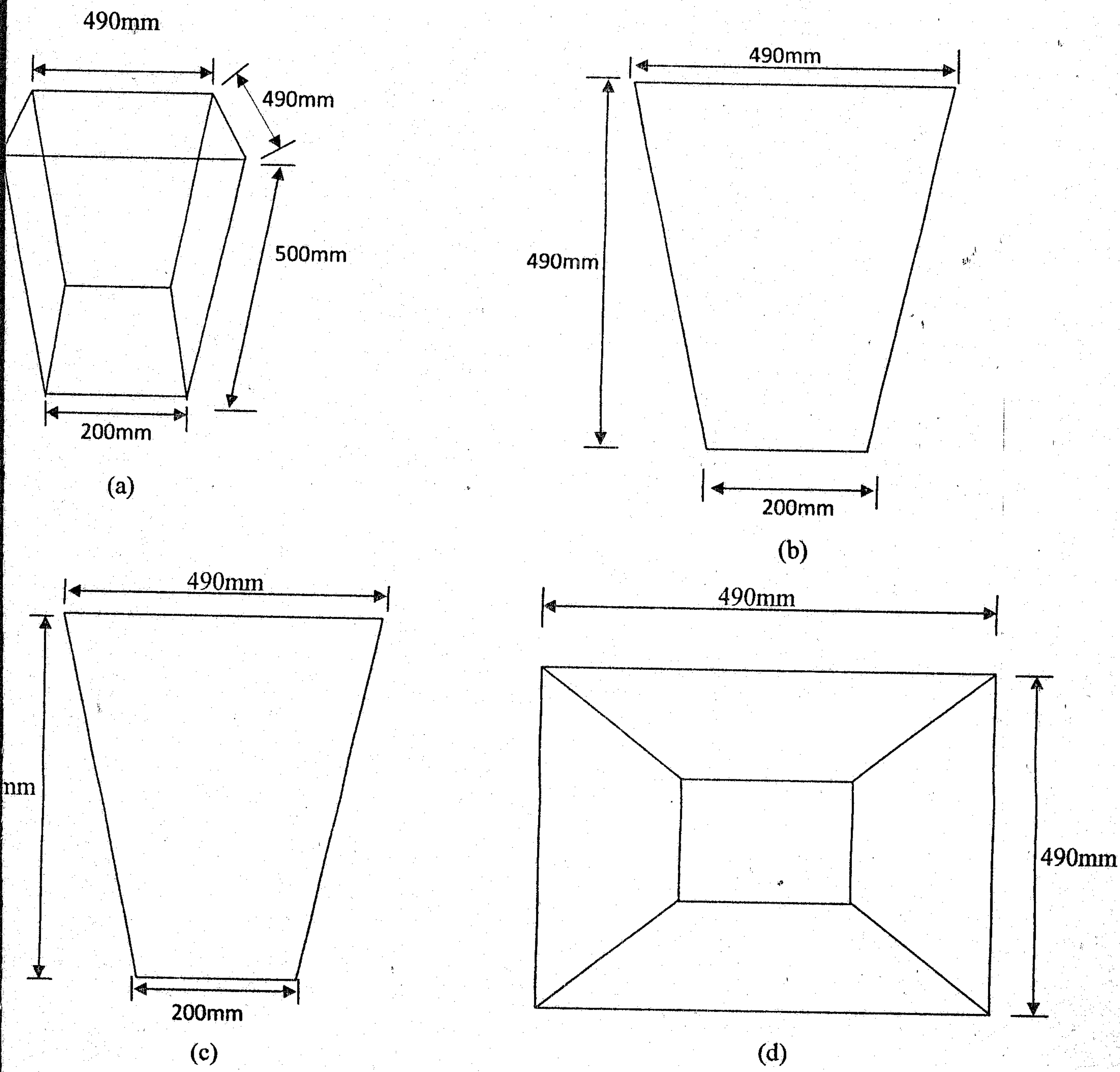


Fig. 3.1: A cross-sectional view of the hopper

Assuming that the volume of the hopper into the cylinder is fully loaded with polyethylene. The weight of polyethylene to be fed inside the hopper will be:-

$$\therefore \text{the mass of one piece of polyethlene} = 2.32g = 2.32 \times 10^{-3}kg$$

$$\therefore \text{for one piece}$$

$$\text{Mass} = mg \qquad (3.13)$$

$$\text{Where } g = 9.81$$

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

$$\text{Then, the weight of } 220 \text{ packs} = 5.00kg$$

3.4 Hopper Capacity

In determining the capacity of the hopper, the volume of the hopper is considered. Beyer, 1987 gave an expression for calculating volume of hopper as the volume of a pyramidal frustum from the Cavalieri's theorem which state "the fact that volume of any pyramid, regardless of the shape of the base, whether circular as in the case of a cone, or square in the case of the Egyptian pyramids or any other shape.

$$\text{Volume} = {}^{1}/_{3}\, h\left(A_1 + A_2 + \sqrt{A_1 A_2}\right) \qquad (3.14)$$

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

$Area\ of\ the\ top, A1 = 0.49 \times 0.49 = 0.2401m^2$

Area of the bottom

$A2 = 0.2 \times 0.2 = 0.04\ m^2$

Substituting in equation (3.14), these values,

Volume of hopper = Volume = $^1/_3\, h(A_1 + A_2 + \sqrt{A_1A_2})$

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

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

$= {}^1/_3\,(0.18905)$

$= 0.06301666m^3 = 0.06302m^3$

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

$= \frac{20}{100} \times 0.06302 = 0.012604m^3$

This is the capacity of the hopper = $0.012604 + 0.06302 = 0.075624m^3$

3.5 Quantity of Heat Require to Melt the Material

Mass of material to be recycled (m) = 0.116kg

Expressing the value of (m) in volume

From density $(\rho) = {}^m/_v$ (3.15)

$$V = {}^{m}/_{\rho} \qquad (3.16)$$

Where ρ = density of the material (LDPE)

ρ =920kg/m^3 (Martienssesen W. (Eds.); H .Warlimort, 2005).

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

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

Using 20% factor of safety

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

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

$$= 1086.905435 m^3 = 1086.91 m^3$$

Melting point of the material (low density polyethylene) $=$ 115°C

Therefore quantity of heat required to melt 0.116kg of the material,

$$Q = MC\Delta T \qquad (3.17)$$

That is $Q = \text{MC}\Delta\text{T}$

Where m = 5kg, C = 2.302kJ/KgK, T_2 = 25°C or 298K,

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

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

$$Q = 1035.9\text{kJ}$$

Therefore,

Wattage $= W = Q/T$ (3.18)

$W = 1035.9KJ/5 \times 60 = 3.453$Kw

3.6 Cooling Chamber

The cooling chamber is shaped in form of tank. The tank is of length 49cm, breadth of 49cm and height of 10cm

Volume of a tank = Length × Breadth × Height (3.19)

= 49cm × 49cm × 10cm

=24010cm = $0.02401m^3$

3.7 Mould Design

The mould is in the form of a frustum with the following dimensions

Diameter of the top = 3.6cm = 0.036m

Diameter of the bottom = 4.0cm = 0.04m

Height of the frustum = 10cm = 0.1m

3.8 Volume of Mould

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

Volume of a frustum V

$$V = \frac{\pi}{3} h (R^2 + r^2 + R \times r) \quad (3.20)$$

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

$$=\frac{\pi}{3}\,0.1\,(4\times 10^{-4}+3.24\times 10^{-4}+3.6\times 10^{-4})$$

$$=\frac{\pi}{3}\,0.1\,(1.084\times 10^{-3})$$

$$=\frac{\pi}{3}(1.084\times 10^{-4})=1.135\times 10^{-4}m^3$$

Total Volume = (volume of a frustum × Total number of frustum) (3.21)

$$V = 1.135\times 10^{-4}\times 9 = 1.0215\times 10^{-3}m^3$$

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

Total volume of water = volume of a cuboids – total volume of the frustum

Total volume of water = $(0.02401 - 1.0215\times 10^{-3})\ m^3 = 2.298\times 10^{-2}m^3$

3.9 Heat loss

$$\text{Retention time} = \frac{\text{heat loss}}{\text{time}} \qquad (3.22)$$

$$= MC\Delta T$$

where $\Delta T = T_2 - T_1$ (3.23)

$$T_2 = 0°C \text{ or } 273K$$

$$T_1 = 115°C \text{ or } 388K$$

$$\Delta T = 273 - 388$$

$$\Delta T = -155°C$$

$$\therefore = 5kg \times 2.302 \times 155°C$$

$$\text{Heat loss} = 1784.05kJ$$

3.10 Rate of cooling

$$\text{Rate of cooling} = \frac{\text{heat loss}}{\text{time}} \quad (3.24)$$

The retention time for the cooling is 45minutes

$$= \frac{1784.05kJ}{60 \times 45} = 0.6608kJ/sec$$

3.11 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 with height

$$H = 12.5cm \sin 60 = 10.8253cm \quad (3.25)$$

Diameter = 4cm

$$\text{Volume of each cutting blade} = nr^2 \quad (3.26)$$

Where: $n = 12.5cm$

$r = 2cm$

$$= 2^2 \times 12.5 = 50cm$$

$$\text{Mass of each cutting blade} = \text{Volume} \times \text{Density} \quad (3.27)$$

$= 50 \times 7850 = 329500Kg$

3.12 Determination of Weight on Cutting Blade

Area of each rod $= \frac{\pi d^2}{4} = \frac{3.142\,(0.04)^2}{4} = 1.2568 \times 10^{-3}m^2$ (3.28)

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

Area $= \frac{\pi(D^2 - d^2)}{4}$ (3.30)

D = 49.5cm = 0.495m

d = 44.5cm = 0.445m

Area = A $= \frac{3.142(0.495^2 - 0.445^2)}{4} = 0.0369185$

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

V = 49cm = 0.49m

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

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

Weight (W) = $\rho v g$ (3.31)

$= 1222.56N$

Weight of Low Density Polyethylene (LDPE)

For a fed rate of $5 Kg/hr$

Amount broken per second

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

Breaking Force F = 3.9943wgRN (3.32)

wg = weight of grain (Kg) (3.33)

R = panicle radius (m)

N = Breaking speed (*rpm*)

(Khurmi and Gupta, 2008)

$F = 3.9943 \times 1.388 \times 1.8 \times 10^{-2} \times 1450 = 144.70Kg$

Total cutter weight = 174.212 + 1222.56 + 1447.0

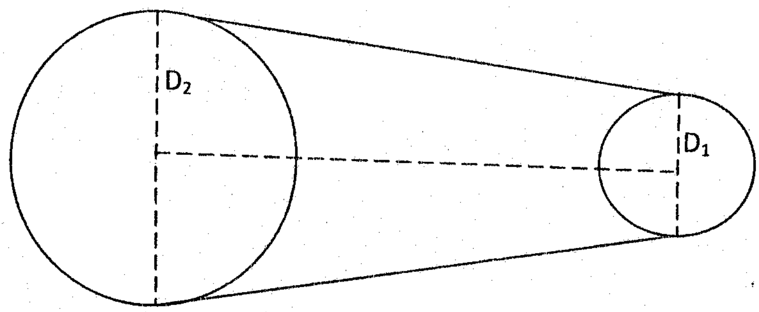
F = 2843.772N

3.13 Belt Selection

V – Belt (based on the usual load of drive 0.75 – 5kw power). These belts are moulded to a trapezoidal shape and are made endless which are particularly suitable for short drives. The angle for v-belt is usually from 30° to 40°, the power is transmitted by the wedging action between the belt and the v-groove in the pulley or sheave. The v-belt is made of fabric and cords moulded in rubber and normally covered with fabric and rubber.

3.14 Determination of Length of Belts

A cross-section of a motor –shaft belt is shown in figure 3.8



Shaft pulley　　　　　Motor pulley

Fig.3.2: Motor- Shaft Belt

D_2 = diameter of the shaft pulley = 12cm

D_1 = diameter of the motor pulley = 8cm

C = Centre to centre distances, minimum =100mm = 0.1m

Nominal Pitch Length,

$$L = 2C + \frac{x}{2}(D_1 + D_2) + \left[\frac{(D1 + D2)^2}{4C}\right] \quad (3.34)$$

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

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

$$= 200 + 3299.1 + 225 = 3724.1\text{mm (max)}$$

3.15 Determination of the Maximum Power of Belt

A cross-section of v-belts is shown in figure 3.3

Calculating the speed of the belt

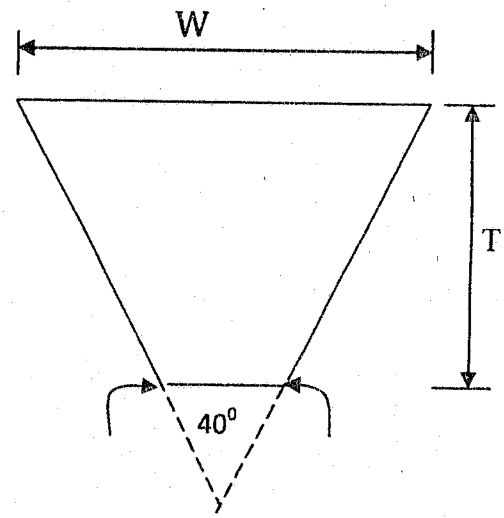


Fig.3.3 cross-section of a v-belt

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 = πdpN_1 (3.35)

Required shaft speed = 2000rpm (Khurmi and Gupta, 2008)

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

Required motor speed = 1450 rpm

Speed ratio; $Vs = \frac{n_1}{n_2} = \frac{1450}{2000} = 0.725$ (3.36)

3.16 Angular Velocity of Motor-cylinder Belt

$W_2 = \frac{2 \times \pi \times 1450}{60} = 151.863$ rad/s (3.37)

$W_1 = \frac{2 \times \pi \times 2000}{60} = 209.467$ rad/s (3.38)

3.17 Power on Motor-cylinder Belt

Power = torque × angular velocity = τw (3.39)

Torque on motor - pulley to accelerate the cylinder = $tmw_2 = w_2 r_2$ (3.40)

r_2 = radius of motor-pulley

Hence,

Power = $tm\, w_2 = w_2^2 r_2$

Therefore, power delivered by the motor

$Pm = (151.863)^3 \times \frac{0.12}{2} = 1383.742$ watts

For efficiency of 95%

$= \frac{95}{100} \times 1383.742 = 1314.555$ watts (3.41)

Power required driving the shaft,

$P_S = w_1^2 r_1$ (3.42)

Where,

r_1 = radius of shaft of pulley

$P_2 = (209.467)^2 \times \frac{9}{2} = 197443.908$ watts

3.18 Determination of Weight of Pulley

Cross-section of V-groove Belt is shown in Figure 3.4

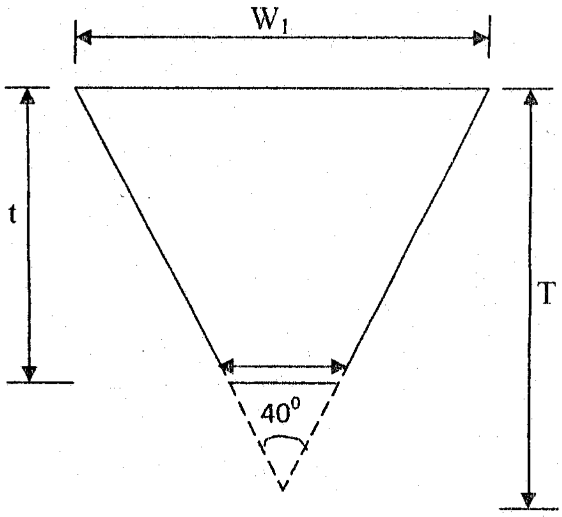


Fig.3.4: Cross-section of V-groove Belt

Width of the belt; w_1 = 13mm

Nominal depth of the belt; t = 8mm

Sleeve groove angle = 40 ^{0}

Density of the leather belt = ρ = 970Kg/m^3

From the above,

$$\beta = \left(\frac{180-40}{2}\right) = 70^0 \tag{3.43}$$

Actual depth of the belt, $T = \frac{1}{2} \times 13 \times \tan 70$ (3.44)

T = 17.859mm

$$w_2 = \frac{t \times w_1}{T} = \frac{8 \times 13}{17.854} = 5.83\text{mm} \tag{3.45}$$

The cross-sectional area of the belt can be calculated as;

$$A = \left[\frac{w_1 + w_2}{2}\right]t \tag{3.46}$$

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

$$= 9.415 \times 8 = 75.32\text{mm}^2 = 75.32 \times 10^{-6}\ \text{mm}^2$$

$$M = P \times A = 970 \times 75.32 \times 10^{-6} = 73060.4 \times 10^{-6} = 0.730604\text{Kg/mm}^2 \tag{3.47}$$

3.19 Centre-distance of Motor-shaft Pulley

The centre-distance is obtained from the relation CD = max (2R, 3r + R) (3.48)

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

$Ø_S$ = Angle of contact of small pulley = $\pi - 2\sin^{-1}\frac{(D-d)}{2CD}$ (3.50)

$$= \pi - 2\sin^{-1}\frac{(120-90)}{2(195)} = -5.681°$$

3.21 Motor-cylinder Design Calculation

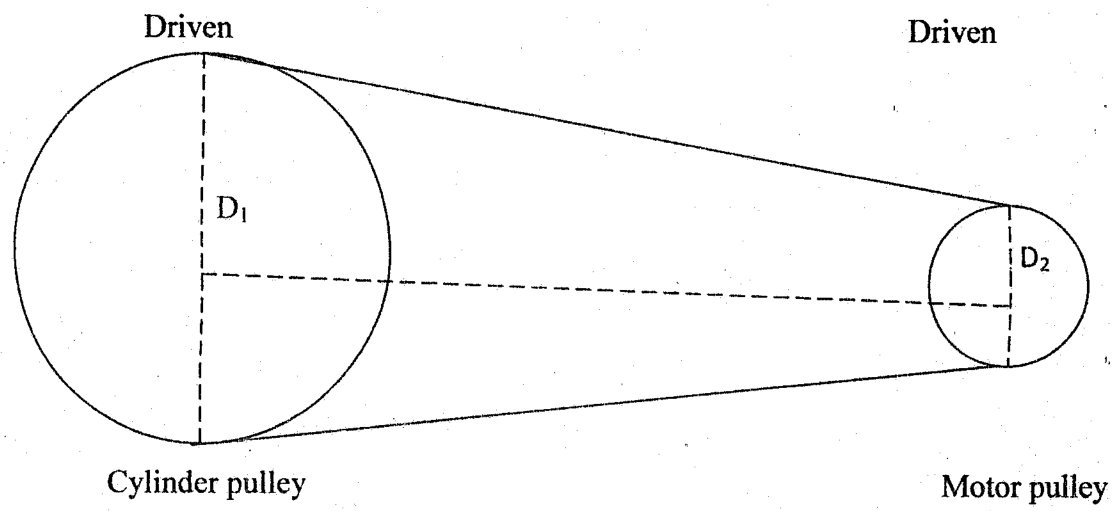


Fig.3.5: Motor-cylinder Pulley Belt Arrangement

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.

3.20 Angle of Contact of Motor-shaft Pulley

$Ø_L$ = Angle of contact of large pulley = $\pi + 2\sin^{-1}\frac{(D-d)}{2CD}$ (3.49)

$= \pi + 2\sin^{-1}\frac{(120-90)}{2(195)}m = 11.965°$

$$\frac{D_1}{D_2} = \frac{N_1}{N_2} \tag{3.51}$$

Where,

D_1= diameter of motor pulley = 12cm

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;

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

$$D_1 N_2 = D_2 N_1$$

$$D_2 = \frac{D_1 N_2}{N_1} = \frac{12 \times 1450}{2000} \tag{3.52}$$

$$= \frac{17400}{2000} = 8.7\text{cm} = 9.0\text{cm}$$

If the diameter of the shaft driven pulley is 9cm

$$\text{Speed of Shaft} = \frac{\pi \times 0.09 \times 1450}{4} = 410.031\text{m/s} \tag{3.53}$$

3.22 Determination of Stress on Cutting Blade

$$\text{Torque (T)} = Fr \tag{3.54}$$

Where,

r = distance to the neutral axis = 0.018

$$T = 2843.772 \times 0.018 = 51.1879Nm$$

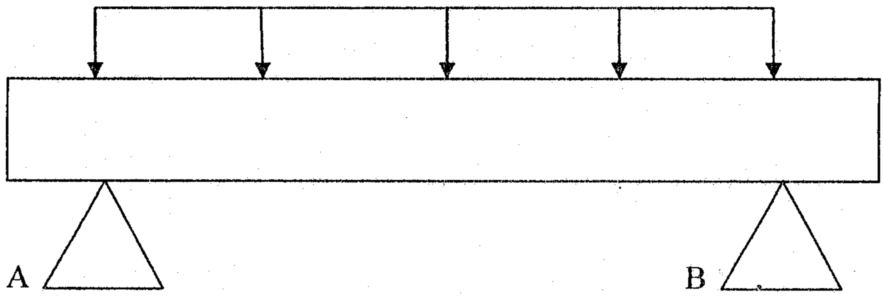


Fig.3.6: Beam diagram of shaft

$$R_A = R_B = \frac{2843.772}{2} = 1421.886 \quad (3.55)$$

$$W = \frac{2843.772}{0.49} = 5803.616N/m \quad (3.56)$$

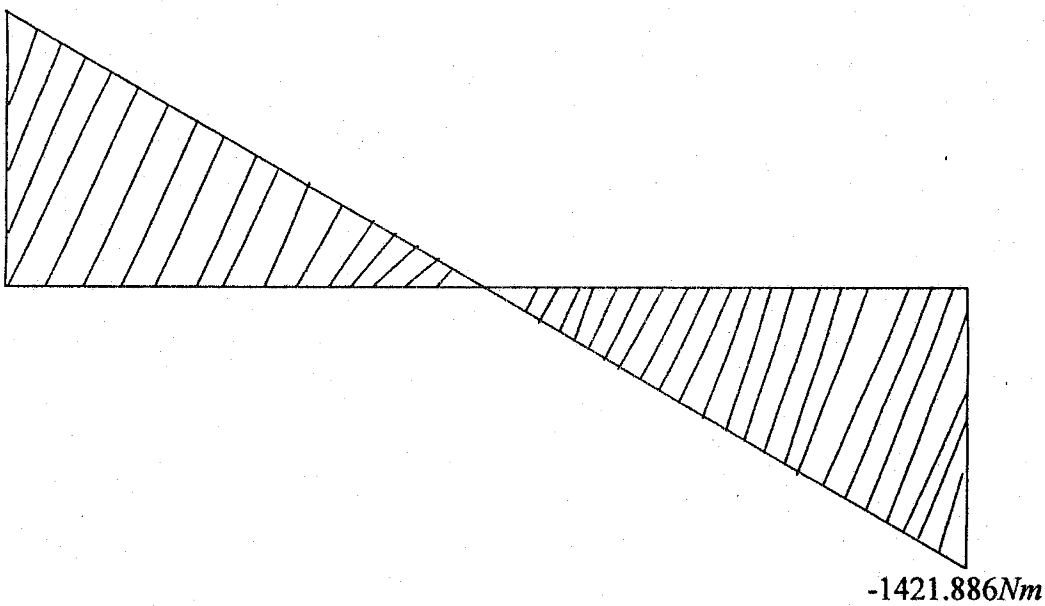


Fig.3.7: Shear force diagram of cutting shaft

$$S.F = \frac{wl}{2} - wx \quad (3.57)$$

Maximum shear force at B

$$\frac{wl}{2} = \frac{5.803.616 \times 0.49}{2} = 1421.886\text{Nm} \quad (3.58)$$

Maximum shear force at A

$$-\frac{wl}{2} = \frac{-5.803.616 \times 0.49}{2} = -1421.886\text{Nm} \quad (3.59)$$

3.23 Bending Moment of Shaft

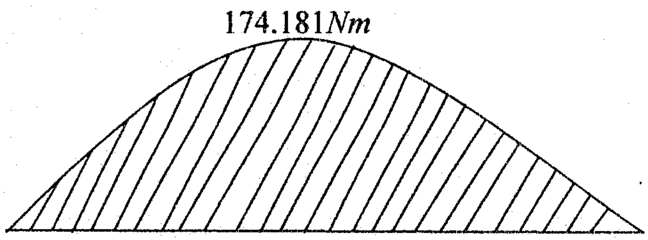


Fig.3.8: Bending moment diagram of the cutting shaft

$$M = \frac{wl^2}{8} = \frac{5803.616 \times 0.49^2}{8} = 174.181\text{Nm} \quad (3.60)$$

Maximum shear on shaft

$$S = 16 \times 0.495 \sqrt{\frac{174.181^2 + 4(0.989)^2}{\pi(0.495^2 - 0.445^2)}} = 3590.06\text{Nm} \quad (3.61)$$

3.24 Power Demand at Shaft

$$P = \tau\omega \quad (3.62)$$

$$\omega = \frac{2\pi N}{60} \quad (3.63)$$

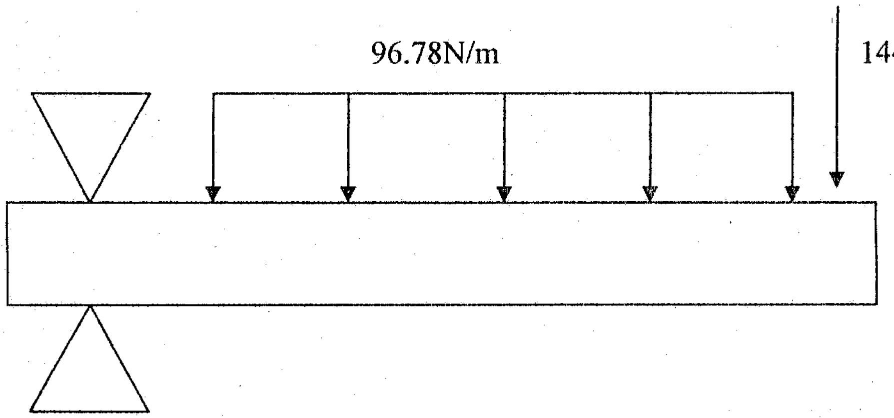
$\omega = \frac{2 \times 3.142 \times 1450}{60} = 151.86$

P = 51.1879 × 151.86 = 7773.565W

For the cutting blade

W = 1447N

$W = {}^{9.678}/_{0.1} = 96.78N/m$ (3.64)

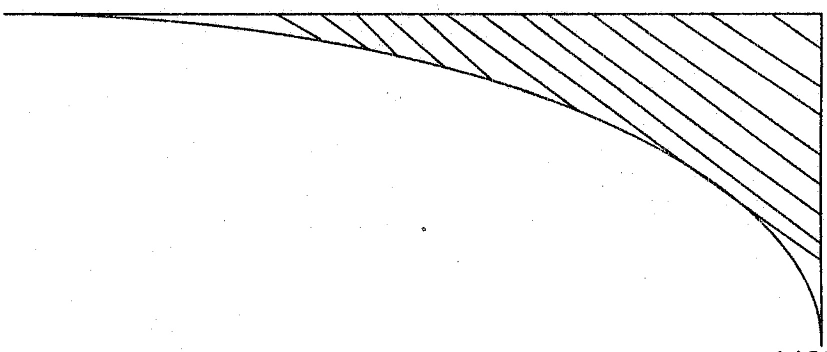


A Fig.3.9: Uniform load on a beam

Shear force

S.F. = -W – wx (3.65)

= - 1447 – 96.78 × 0.045 = - 1451.36N



Bending moment

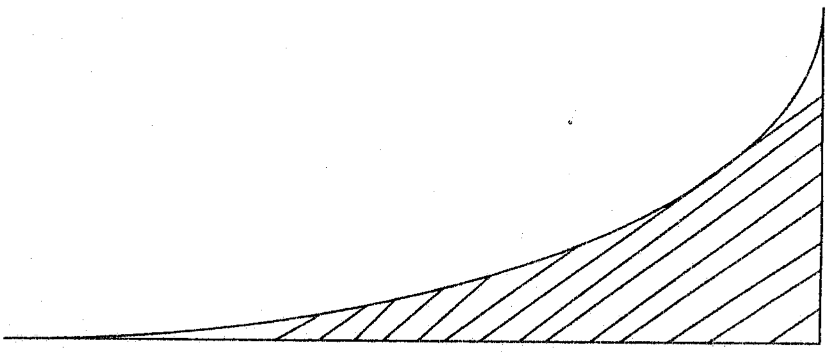


Fig.3.10: maximum bending moment

$$M = Wx + \frac{wx^2}{2} \tag{3.66}$$

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

$$M = 65.1247\text{Nm}$$

$$Z = \frac{\pi d^3}{32} \tag{3.67}$$

$$= \frac{3.142 \times 0.045^3}{32} = 8.9473 \times 10^{-6}$$

Shear stress

$$S = \frac{F}{A} \tag{3.68}$$

$$S = \frac{1451.36}{1.2568 \times 10^{-3}} = 1154805.856\text{N/m}^2$$

Maximum stress

$$S_{Max} = \frac{1}{2}\sqrt{\left(\frac{65.1247}{8.9473 \times 10^{-6}}\right)^2 + (1154805.856)^2} = 1.3335 \times 10^{12}\ \text{N/m}^2 \tag{3.69}$$

3.25 Description of machine

The low density polyethylene recycling machine consists of the following major components.

1. The heating chamber
    - Hopper
    - The heating element
    - Sieve
    - Insulator
    - Thermostat
    - Stopper tray
2. The cooling chamber
    - The mould
    - The water box
    - The stopper tray
3. The size reduction chamber
    - The shaft
    - The blade
    - The electric motor
    - The v-belt
    - The concave
    - The collector
    - Frame

In the design of this low density polyethylene machine, the cost and availability of required materials were first considered after which strength and its ability to resist heat were considered, which the needed design process. All these considerations and materials specifications led to the selection of mild steel, which is the most available and easy to work. Paint was used to reduce the action of rusting with time, as well as beautify the work.

1. **The heating chamber:**

Hopper: The hopper is essentially the component that aids the introduction of the polyethylene to be heated up, so that it can be melted. The construction of the hopper is made from mild steel sheet and weld to the cooling unit. It is a square at the top and bottom of dimensions 49cm by 49cm and 20cm by 20cm respectively with a height of 50cm.

1. **Heating Element:** This device is used as a source of heat generators for melting.

Sieve: This materials is used for the separations of solid and liquid polyethylene, 33cm by 33cm is used for this design.

Insulators: A material or device that prevents or reduces the passage of heat.

Thermostat: This is a device that regulates the temperature within the hopper.

Stopper tray: the stopper tray is used to hold back the melted polyethylene before it follows into the cooling unit.

a. **The cooling chamber:**

Mould: The was constructed in form of a frustum with a small diameter at the top and larger diameter at the bottom

Water Box: The box was with and inlet and outlet with a dimension of 49cm by 49cm and a height of 10cm.

Stopper tray: the stopper tray is used to hold back the melted polyethylene before it follows into the breaking chamber.

b. The size reduction chamber:

Shaft: A shaft is a rotating machine element which is used to transmit power from one place to another. The pelletizing unit comprises of 18 spikes mounted on a rotating cylinder encased in a housing and surrounded 180^0 by the concave rod which is done having space in between like a perforated metal sheet. This is where the breaking action takes places.

The Blade: the flat sharp-edged cutting part of a tool.

Electric Motor: This used to supply power to the shaft.

V-belt: A strip of material worm around the pulley.

The Concave: Curved inward like the inner surface of a bowl or sphere.

The Frame: The frame is the component of the machine on which all other components of the machine are mounted. Therefore the frame provides support for the machine when during operation. The frame is made from angular-bar of size 45mm by 45mm which is welded together to the frame. The frame consists of legs of height 49m, length of top frame 55cm and width 55cm.

3.26 Sources of Heat Loss

There are various ways in which the heat is lost. These include

1. Heat loss due to conduction through the wall of the hopper.
2. Heat loss due to convention through the wall of the frustum.

3.27 Mode of Operation

The basic component of the machine is a single shaft with uniform loading which rotates at 1450 rpm. The machine is powered by an electric motor through a v-belt in order to transfer the speed of the electric motor to the speed of the shaft. The polyethylene is fed through the hopper which forms the opening through which the materials enter the recycling machine. The heating elements incorporated in the hopper complement each other such that when the heating element is connected to power source, heat is conducted in the hopper to a temperature of about 115^0C which melt the polyethylene material to a liquid form.

For a complete melting of materials and enhanced efficiency, the heating unit is enhanced with a stopper to assist in proper melting of materials to a soluble state. The stopper is remove and the melted material flow through the hopper to the cooling chamber into the mould. Water is passed directly around the mould through the process of convention to help cool the melted polyethylene to solid state. The solidify polyethylene fall into the size reduction chamber when the second stopper is removed. The cutting process of the lumps of the low density polyethylene into smaller pellets with the help of the cutting blade attached to the shaft drive by the electric motor. This machine is simple to operate while maintenance and adjustment require little specialist attention.

3.28 Safety equipment

Safety should be a prime concern in plastic recycling as in any other industry. The workers in the factory should have adequate protection in handling material and operating machines. Gloves should use in handling material all the time. Heat resistant gloves are required for the handling of agglomerated film plastics and extruded plastics. Ear plugs and ear protectors should be used in crushing and agglomeration areas to protect ears from high noise levels. Goggles should use when feeding material into crushers, the agglometator and the extruder. Masks with gas filters should be worn when working at the agglomerator, extruder and when cleaning waste plastics. It is recommended that all the workers should wear protective boots when working in the factory.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Performance Evaluation

Performance evaluation is simply a measure of how well the machine accomplishes its designed functions. The performance evaluation of the machine is analysed using such parameters as practical pellet yield and efficiency.

4.2 Presentation of Results

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

Time (mint)	Stages	Form
0 – 30mint	Melting	Semi solid
30 – 55mint	Melting	Liquid
55 – 1h 38mint	Cooling	Solid (lumps)
1h 35mint – 1hr 43mint	Cutting	Solid (pellet)

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

4.3 Melting Efficiency

$$\text{Efficiency} = \frac{Tr}{Ta} \tag{4.1}$$

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

T_a = actual time used in melting

Since T_r = 45minute

T_a = 55minute

Therefore $\frac{45}{55} \times 100$ =81.8181 = 82%

4.4 Cooling Efficiency

Janssen (2009) Cooling takes 50% period of melting

C_r = cooling rate

C_a = actual time used in cooling

Therefore (4.2)

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

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

=52.32558 = 52%

4.5 Cutting Efficiency

Since the material fed into the hopper is 5kg

The output after grinding is 3.21kg (4.3)

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

$$\text{Efficiency} = \left(\frac{3.6kg}{5kg}\right) \times 100 = 72\%$$

4.6 Discussion of Results

After cleaning and sorting of the materials, melting process takes place. At initial melting, a longer melting period was observed due to the fact that heat from the heating element has not circulated to the area of the hopper. The melting time was 55minute before it turns to total liquid. Though the time required is 45minute for the first process Janssen (2009). Also the time required for cooling by (Janssen 2009) "the optimum time of agglomeration is approximately 50% of the melting process" but due to the cooling chamber design, in the early stages of cooling when water was supply, the cooling rate was faster but due to the fact that the water was flowing, there was a change in temperature of the water which increases the cooling period and reduce cooling rate. Therefore it took about 43minute to solidify. After the material was cooled, it then drop to the cutting chamber were the size was reduce to pellet form by the 12.5cm blade, powered by 2hp motor.

4.7 Cost Analysis

In the design of this low density polyethylene recycling machine, cost effectiveness was one of the major considerations having the Nigeria economic in mind. In this section, the cost of the equipment shall be analysed under the following headings:

a) Materials cost

b) Labour cost

c) Overhead cost

4.8 Material Cost

In the course of fabrication, all the materials used were bought locally. Table 4.2 shows the cost of each material, the quantity bought and the unit price of the materials used in the construction. The cost of each material is added up to give the total cost of all materials used for the constructions.

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
	Angle iron	2 inch	3	1600	3200
	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.

4.9 Labour Cost

In the construction of the machine, direct labour was used; hence direct labour cost was incurred. It took the period of six weeks to complete the construction of the machine. Labour cost involves the cost of cutting, machining, welding and painting. It takes about 23.42% of the material cost.

Therefore,

Labour cost = $\frac{23.42}{100} \times 172000$ = 40282.4 =N= 40282 (4.4)

4.10 Over Head Cost

This is the cost incurred during the production, which is not directly related to the production. They include transportation and other petty expenses. This involves the cost of transportation and other miscellaneous. It takes about 10.34% of the material cost.

Over head Cost = $\frac{10.34}{100} \times 172000$ = 17200 =N= 17200 (4.5)

Total cost = Material Cost + Labour Cost + Overhead Cost (4.6)

= 172000 + 40282 + 17200 =N= 229482

4.11 Benefits of Polyethylene Recycling

Recycling in the context of solid waste may be defined as the reclamation of material and its reuse which could include repair, remanufacture and conversion of materials, parts and products. In developed countries recovery of material from solid wastes is affected more scientifically at central collection and processing stations. Reclamation of material from solid wastes helps the community economically, environmentally, socially and ecologically, as described by (Kaseva and Gupta, 1996).

4.12 Economical Advantage of Polyethylene Recycling

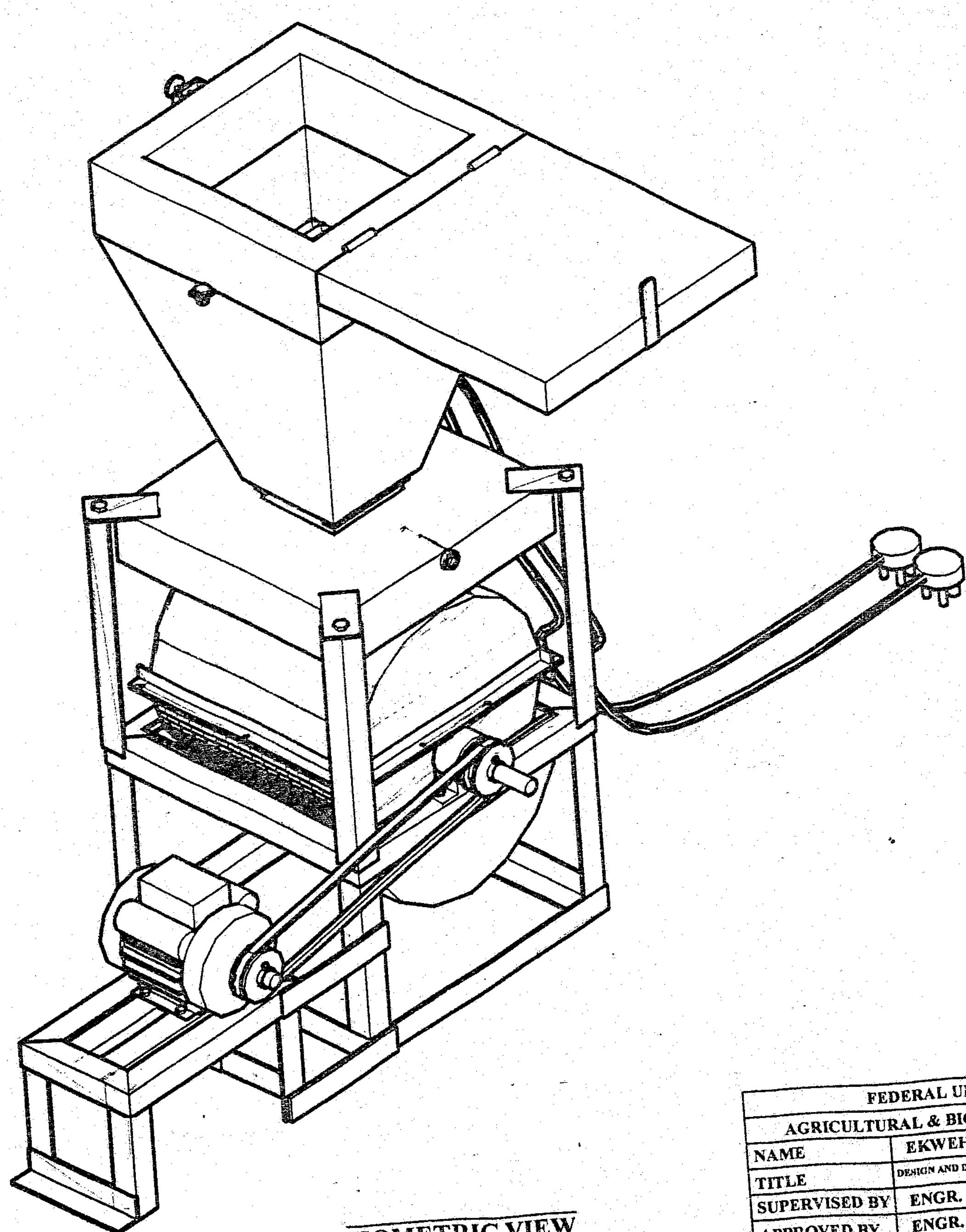
1. Recovered materials use less energy in the process plant compared to that needed for products shaped from virgin raw materials. This results in the saving of energy in terms of electricity or fuel.

2. Reuse of recovered material may reduce importation costs in the case of developing countries. So, recycling could be considered as aids the balance of payments as we import less material for our needs and recycling reduces pressure on virgin resources.

4.13 Economic Analysis of the LDPE Recycling Machine

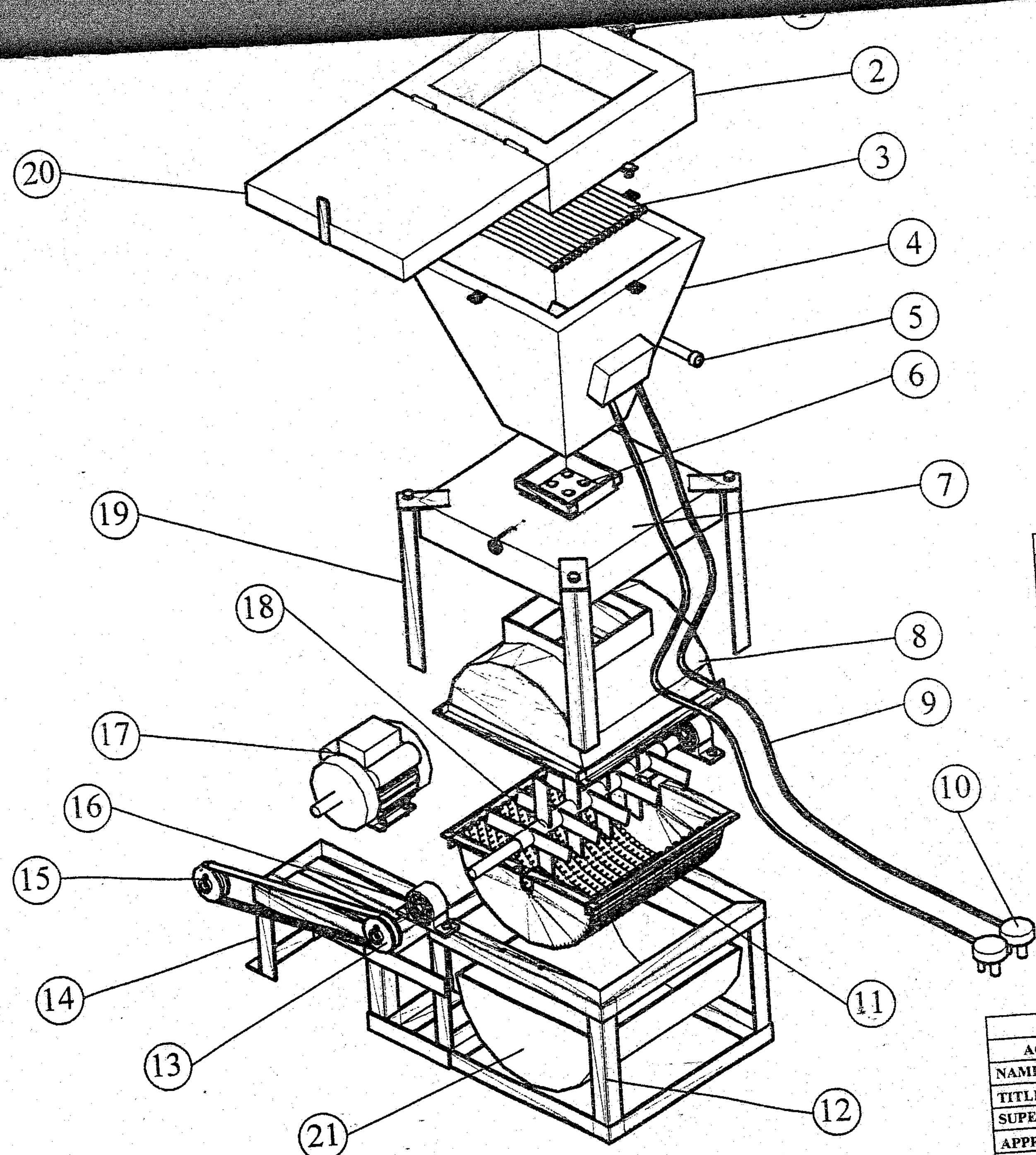
In analyzing any investment economically, the true worth of the investment is regarded as how much income it will generate and how soon after the original capital outlay (Chukwu, 1987). Therefore, it is desirable that any investment generates large share of total income in the early years of its life. 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	EKWEH, KENECHUKWU ANTHONY	2005/21595EA	
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 201[illegible]



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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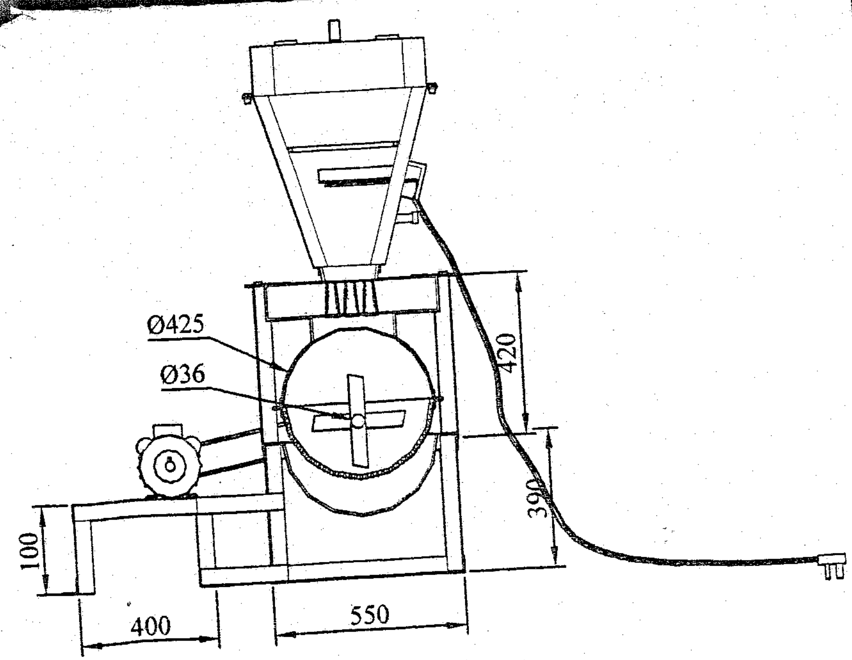
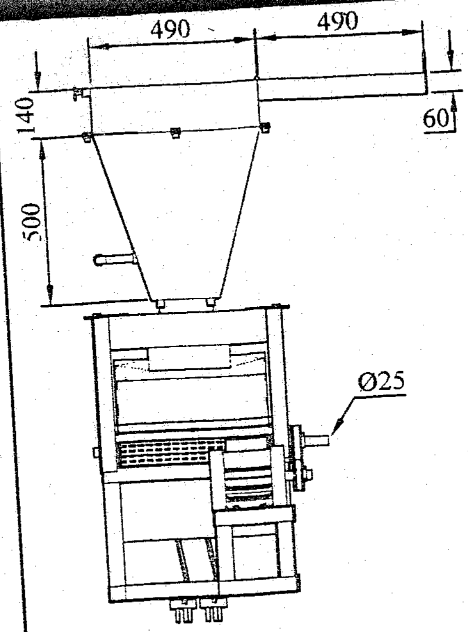
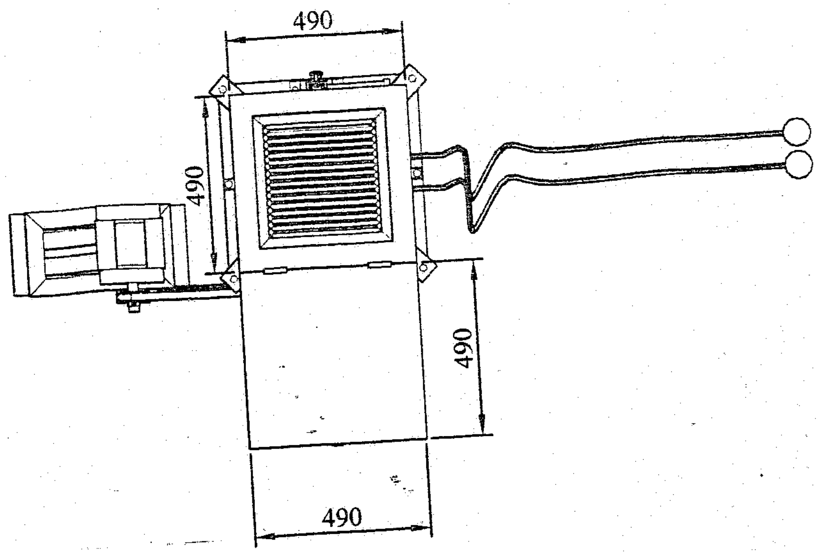
SCALE	1:5	DATE:	DECEMBER 2010







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CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Plastic recycling is a newly emerging industry and it has already been identified that there is a good potential to this sector. The recycled plastics can be shared with both small and large scale industries to produce new plastic items. Further, recycled plastics can replace pure material being imported from other countries and this will create many job opportunities amongst the people. Recycling of plastics therefore, is a resource that one could obtain maximum benefit out of it and helps minimise environmental degradation. Therefore, plastic material should not be disposed or buried without a proper disposal mechanism.

The objectives of this project is to design, development and carry out performance evaluation of a low density polyethylene recycling machine (LDPE) from melting to cooling and size reduction to form pellets. The following could be computed from the recycling experiment results of the recycling machine. It has a designed shaft speed of 1450, the minimum power required for operating the recycling machine is 2kW, the melting efficiency is 81%, cooling efficiency is 52% and grinding efficiency is 72%. On a large scale, the machine can be employed to reduce environmental pollution by enhancing the processing of recycling of low density polyethylene.

5.2 Recommendations

Following the construction and testing of this machine, the following recommendation is made to enhance further development.

The cooling chamber should be connected to an inlet and outlet to water source that will enhance fast cooling and increase its efficiency.

Increase in number of blade will increase the chances of cutting more materials.

The use of stainless steel is highly required for all internal component of the machine to increase the efficiency.

For a faster rate of melting the number of heating elements could be increased and for efficient heating there should be proper supply of power.

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