

**DESIGN, CONSTRUCTION AND TESTING OF A THERMOPLASTIC
EXTRUDING MACHINE**

BY

AHMED ABDULSALAM

ENG/11/MEC/00695

ABDULAZIZ MUHAMMAD MUAZU

ENG/12/MEC/00093

JOSEPH ANTEYI

ENG/11/MEC/00756

IDRIS ISHAU

ENG/11/MEC/00716

**SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING,
BAYERO UNIVERSITY KANO. IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE AWARD OF B.ENG DEGREE IN MECHANICAL
ENGINEERING, BAYERO UNIVERSITY, KANO NIGERIA**

DECEMBER, 2016

CERTIFICATION

This is to certify that the project titled “Design, construction and testing of a thermoplastic recycling plant” has been duly presented by GROUP “E” of the department of Mechanical Engineering Bayero University, Kano and has been read and approved for meeting part of the requirement and regulations governing the award of Bachelor of Engineering (Mechanical) degree of Bayero University Kano, Nigeria.

Project supervisor (Chairman)
Prof. A.T Abdullahi

Date

Head of Department
Dr. I.A Yola

Date

External supervisor

Date

DEDICATION

This project is dedicated to our parents and loved ones.

AKNOWLEDGEMENT

All praise be to GOD Almighty the lord of the world, The Most Beneficent, The Most Merciful who gave us the chance and ability to complete this project successfully.

First of all, we want to register our profound appreciation to our project supervisors; Prof. A. T Abdullahi, Dr. M. Makoyo, Dr. A. A. Adamu, Dr. Mu'azu, Mallam Mustapa and Muhammad for their constant supervision and help through the challenges of this project work. We wish also to express our gratitude to the lecturers and staff of the Department of Mechanical Engineering, Bayero University, Kano whom stood in class and impacted knowledge as well as disciple in this noble profession.

Our gratitude also goes to Mustapha Balarabe Dantsoho, Muhammed Rabi, Toyeeb Abdulrahim. For their various roles and encouragement.

In a deep sense of humility, appreciation we will like to tender our appreciation to our parents, family for helping us stand up to the task at hand during these five years.

TABLE OF CONTENT

Title page	-	-	-	-	-	-	-	-	-	-	i
Certification page	-	-	-	-	-	-	-	-	-	-	ii
Dedication	-	-	-	-	-	-	-	-	-	-	iii
Acknowledgment	-	-	-	-	-	-	-	-	-	-	iv
Table of content	-	-	-	-	-	-	-	-	-	-	v
Abstract	-	-	-	-	-	-	-	-	-	-	vii

CHAPTER ONE INTRODUCTION

1.1 Background of the Study	-	-	-	-	-	-	-	-	-	-	1
1.2 Statement of the Problem	-	-	-	-	-	-	-	-	-	-	2
1.3 Significance of the Study	-	-	-	-	-	-	-	-	-	-	3
1.4 Aim and Objectives	-	-	-	-	-	-	-	-	-	-	3
1.5 Scope and Limitation	-	-	-	-	-	-	-	-	-	-	3

CHAPTER TWO LITERATURE RE REVIEW

2.1 Plastics	-	-	-	-	-	-	-	-	-	-	4
2.2 Classification of Plastics	-	-	-	-	-	-	-	-	-	-	4
2.3 Production of Virgin Plastics	-	-	-	-	-	-	-	-	-	-	5
2.4 Recycling of Plastics	-	-	-	-	-	-	-	-	-	-	6
2.5 Methods of Recycling Plastics	-	-	-	-	-	-	-	-	-	-	7
2.6 Plastic Recycling Equipment and Machines	-	-	-	-	-	-	-	-	-	-	10

CHAPTER THREE 3.0 DESIGN

3.1 Sketch of Concept	-	-	-	-	-	-	-	-	-	-	12
3.2 Design Specification	-	-	-	-	-	-	-	-	-	-	13
3.3 Design Factors	-	-	-	-	-	-	-	-	-	-	13
3.4 Design Procedure of an Extruding Machine	-	-	-	-	-	-	-	-	-	-	14
3.4.1 Design of Power Screw	-	-	-	-	-	-	-	-	-	-	14
3.4.1.1 Design For Screw Thread	-	-	-	-	-	-	-	-	-	-	17
3.4.1.2 Design of the Load that can be Conveyed by the Screw	-	-	-	-	-	-	-	-	-	-	19
3.4.1.3 Stress in Thread	-	-	-	-	-	-	-	-	-	-	19
3.4.1.4 Failure Analysis	-	-	-	-	-	-	-	-	-	-	21
3.4.1.5 Design for the Capacity of the Screw Shaft at Feedzone	-	-	-	-	-	-	-	-	-	-	22
3.4.2 Design for Barrel Cage	-	-	-	-	-	-	-	-	-	-	23
3.4.2.1 Stresses in the Barrel Cage	-	-	-	-	-	-	-	-	-	-	24
3.4.3 Design of Belt Drive	-	-	-	-	-	-	-	-	-	-	26
3.4.3.1 Design Of Pulley	-	-	-	-	-	-	-	-	-	-	32
3.4.3.2 Design of Pulley Shaft	-	-	-	-	-	-	-	-	-	-	32
3.4.3.3 Design for Key	-	-	-	-	-	-	-	-	-	-	34
3.4.4 Design of Hopper	-	-	-	-	-	-	-	-	-	-	34
3.4.5 Determining the Heat Required to Melt the Plastic	-	-	-	-	-	-	-	-	-	-	36
3.4.6 Bearing Analysis And Selection	-	-	-	-	-	-	-	-	-	-	39
3.4.6.1 Bearing Analysis	-	-	-	-	-	-	-	-	-	-	41
3.4.7 Gear Train Analysis And Selection	-	-	-	-	-	-	-	-	-	-	43
3.4.7.1 Analysis	-	-	-	-	-	-	-	-	-	-	43
3.4.8 Selection of Die	-	-	-	-	-	-	-	-	-	-	44

3.5 Materials Selection	-	-	-	-	-	-	-	-	-	44
-------------------------	---	---	---	---	---	---	---	---	---	----

CHAPTER FOUR

FABRICATION, ASSEMBLY, COST ANALYSIS AND TESTING OF EXTRUDING

4.1 Fabrication	-	-	-	-	-	-	-	-	-	46
4.1.1 Hopper	-	-	-	-	-	-	-	-	-	46
4.1.2 Extruder Barrel	-	-	-	-	-	-	-	-	-	46
4.1.3 Screw Shafts	-	-	-	-	-	-	-	-	-	47
4.1.4 The Die	-	-	-	-	-	-	-	-	-	47
4.1.5 Frame	-	-	-	-	-	-	-	-	-	48
4.1.6 Bearing	-	-	-	-	-	-	-	-	-	48
4.1.7 The Pulleys	-	-	-	-	-	-	-	-	-	48
4.1.8 Electric Motor	-	-	-	-	-	-	-	-	-	48
4.1.9 Belt	-	-	-	-	-	-	-	-	-	48
4.1.10 Barrel Heaters	-	-	-	-	-	-	-	-	-	48
4.1.11 Reduction Gears	-	-	-	-	-	-	-	-	-	48
4.2 Assembly	-	-	-	-	-	-	-	-	-	49
4.3 Principle of Operations	-	-	-	-	-	-	-	-	-	49
4.4 Testing	-	-	-	-	-	-	-	-	-	50
4.4 Cost Analysis	-	-	-	-	-	-	-	-	-	50
4.5.1 Material Cost	-	-	-	-	-	-	-	-	-	51
4.5.2 Labour Cost	-	-	-	-	-	-	-	-	-	51
4.5.3 Miscellaneous Cost	-	-	-	-	-	-	-	-	-	52
4.6 Safety and Maintenance of the Machine	-	-	-	-	-	-	-	-	-	52

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion	-	-	-	-	-	-	-	-	-	54
5.2 Recommendation	-	-	-	-	-	-	-	-	-	54
References	-	-	-	-	-	-	-	-	-	55
Appendix	-	-	-	-	-	-	-	-	-	57

ABSTRACT

This project presents the design, construction, and testing of a thermoplastic extruding machine intended for the recycling of waste plastic materials into useful products. The study was motivated by the need to provide a locally fabricated and relatively low-cost alternative for small-scale plastic recycling applications. The methodology involved a review of plastic recycling and extrusion processes, engineering design and analysis of the major machine components, selection of suitable construction materials, fabrication, assembly, and experimental testing of the completed machine. The extruder was engineered to possess a nominal processing capability of 20 kg/h and included a hopper, heated barrel, single power screw, electric motor, belt-drive mechanism, bearings, reduction gearing, and die. Locally available materials were used for the fabrication of the major components. During operation, crushed thermoplastic material was introduced through the hopper and conveyed by the rotating screw through the electrically heated barrel, where the material was intended to melt and pass through the die. Testing was conducted under no-load and loaded conditions. The machine was able to provide enough heat to melt the crushed plastic, but it was unable to extrude continuously through the chosen die. The main restrictions found during testing were improper die size and geometry, which limited the flow of the molten material, and insufficient temperature control, which caused the plastic to overheat. The machine cost ₦123,350 to fabricate, including labour, materials, and other expenses. While the test findings show that better temperature control and die redesign are required to accomplish dependable continuous extrusion and enhance the machine's operational efficiency, the study shows that it is feasible to fabricate a thermoplastic extrusion system locally.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Waste are materials that are not prime products (that is products produced for the market) for which the initial user has no further use in terms of his own purposes of production, transformation or consumption, and of which he wants to dispose. Waste may be generated during the process of extraction of raw material, the processing of raw materials into intermediate and final products, the consumption of final products and other human activities. Waste includes all the items that people no longer have any use for, which they either intend to get rid of or they have already discarded. All daily activities, therefore, can give rise to a large variety of different waste flows from different sources. These sources include, for instance waste coming from households (e.g. plastic packaging waste). Commercial activities (e.g. cardboard packaging waste from shops, food waste from restaurants and medical waste from hospitals), industry (e.g. fly ashes from thermal processes of energy generation, textile waste and tanning liquor from clothes manufacturers), agriculture (slurry) etc. A small part of the waste which is generated is hazardous; that is it poses substantial or potential threats to human health or to the environment. (Fillaudeau, et al 2006, Unterstein, 2000).

Every year in The United States, consumers throw millions of tons of plastic away and of the 190 million metric tons of municipal wastes produced annually nine percent are plastics (Andrew and Subramaman, 1992). Plastic have become very popular for industry and household uses leading to an increase in the volume of plastic waste being generated in the society (Wilson, 1981). By the year 2005, annual global demand for plastics is projected to exceed 200 million metric tons. As municipal landfills reach capacity and additional landfill

spaces diminish alternative methods of reducing wastes are being explored. Some of the options include incineration, source reduction, recycling and making plastics biodegradable. Whereas paper, wood and other waste may be burn in incinerators with minimum damage to the environment, incineration of plastics can produce hazardous emission and other pollutant. There is much information on the volume of plastics generated in Nigeria. Nonetheless, the nuisance created may be inferred from various government campaign on de-clogging drainages and dirt abeyance.

In recent times, plastic packaging has increased in the area of table water and soft drinks and has replaced the biodegradable leaves traditionally used in wrapping various foodstuffs in Nigeria. They are very light and are easily thrown away after use and this has increased on the abundance of the plastic waste. In addition they can also be recycled for another usage. Due to ignorance some people do not know about the effect of improper waste disposal. Such people dump the plastic wastes carelessly. Getting these plastics waste off the street is very important. This project is expected to propose ways of cleaning the environment of non-biodegradable waste. Since not much has been done in the area of recycling of these waste in Nigeria. The primary objective of this project is to design and fabricate a plastic recycling machine, using locally available materials, capable of converting the plastic wastes into flakes that can be used in the manufacture of new plastics products.

1.2 Statement of the Problem

- Plastic products are disposed indiscriminately in the environment, and thus increases pollution. Hence this can have to be recycled taking in consideration and environmental concerns.
- Plastics wastes are non-biodegradable, hence they cause pollution to the environment.

1.3 Significance of the Study

Recycling of waste plastic materials will go a long way in curtailing the menace of environmental pollution, provide small scale industries or SME with raw materials and thus, provide job opportunities thereby improve the standard of living.

1.4 Aim and Objectives

Aim

The aim of this project is to design, construct and test a thermoplastic recycling plant which will be used in recycling waste plastic materials into useful products.

Objectives

The objectives are:

- Understanding how the extrusion process works, and gain knowledge about extruders.
- To convert plastic waste into useful raw materials
- To produce plastic pellets.

1.5 Scope and Limitation

The scope of this project is to design, construct and test a plastic extruding machine.

The capacity of the extruder is limited to recycling of 20kg/hr of waste plastic.

CHAPTER TWO

LITERATURE RE REVIEW

2.1 Plastics

Plastic may be defined as organic materials containing a polymer as the major constituent. The polymer being materials of high molecular weight formed by joining together many (poly) small molecules (monomer) that can easily be moulded or shaped by mechanical or chemical action to give non-crystalline substances that are solid at ordinary temperatures. Plastic can also be defined as materials made up of long-chain molecules based on carbon and hydrogen.

“Polymer” is a general term for all plastic materials and means that they are organic , carbon based compounds whose molecules are linked together in long chain patterns.

2.2 Classification of Plastics

Plastics are usually synthetic organic materials, resins in solid form. However there are some inorganic plastics also like phosphorous polymer, cetramoplastics, silicones, glass resins etc.

The plastic may be classified into various ways depending upon their basic raw materials, their distinctive properties and the broad of applications. From engineering point of view they can be divided into two branches, i.e. thermosetting and thermoplastics.

NATURAL PLASTICS – these are naturally occurring materials that can be said to be plastics because they can be shaped and moulded by heat. An example of this is amber, which is a form of fossil led pine tree resin and is often used in jewellery manufacture.

SYNTHETIC PLASTIC- these are materials that are derived from breaking down, or ‘cracking’ carbon based materials usually crude oil, coal or gas so that their molecular structure changes.

This is generally done in petrochemical refineries under heat and pressure, and is the first of the manufacturing process that is required to produce most of the present day plastics.

Synthetic plastics can be further divided into two other categories. These two categories are defined by the ways in which different plastics react when heated.

Thermoplastics:-these are plastics that can be softened and formed using heat, and when cool, will take up the shape that they have been formed into. But if heat is reapplied, they will soften again.

Thermosetting plastics: - these are plastics that soften when heated and can be moulded when soft, and when cool they will set into the moulded shape. But if heat reapplied, they will not soften again, they are permanently in the shape that they have been moulded into.

ELASTOMERS: These are thermosets, with rubber like properties, used for medical masks, gloves etc. Examples of elastomers are: polyurethane, silicones.

2.3 Production of Virgin Plastics

They are made from crude oil and natural gas which are gotten from nature and taking to petroleum refinery to extract propane, ethane, petrol and many other petrochemical products. Ethane and propane are the derivatives of plastics and are mixed under high temperature furnace to produce propylene and ethylene which combine with a catalyst in a reactor to produce fluff (resin) which is a powder material. Fluff is combined with other additives in a blender and further melted in an extruder. When cooled and transform into pellet and then it becomes a virgin plastic.

The plastics 'forward' industry basically consists of plastic producers, converters and machine manufacturers. In the UK, the industry employs about 1.6 million people and many

times more in industries depending on plastics for their business. In 2008, converter in the UK produced approximately 3.7 million tonnes of plastics (1.5% of global total production). The plastics producers and converters also contributed together around € 13 billion in trade surplus to EU27 in 2008. The global production of plastics had been increasing exponentially from 1950 to 2007 and only declined in 2008 due to the financial crisis. The total global production of plastics grew to 245 million tonnes in 2008 from 1.5 million tonnes in 1950 (PlasticEurope, 2009). In 2008, NAFTA produced 23%, China and the rest of Asia produced 15% and 16.5%, and European countries produced 25% of the global plastics. Other producers of plastics include those from the Middle East, Africa, Japan and Latin America (PlasticEurope, 2009).

2.4 Recycling of Plastics

Plastic recycling is the process of recovering scrap or waste plastic and reprocessing the material into useful products. Since plastic is non-biodegradable, recycling it is a part of global efforts to reduce plastics in the waste stream, especially the eight million metric tonnes of waste that enters the earth's ocean every year. This helps to reduce the rate of plastic pollution.

Plastic recycling includes taking any type of plastic, sorting it into different polymers and then chipping it and then melting it down into pellets after this stage it can then be used to make items of any kind such as chairs, tables, bags, toys, automobile parts, shoes etc. As shown in the figure below.

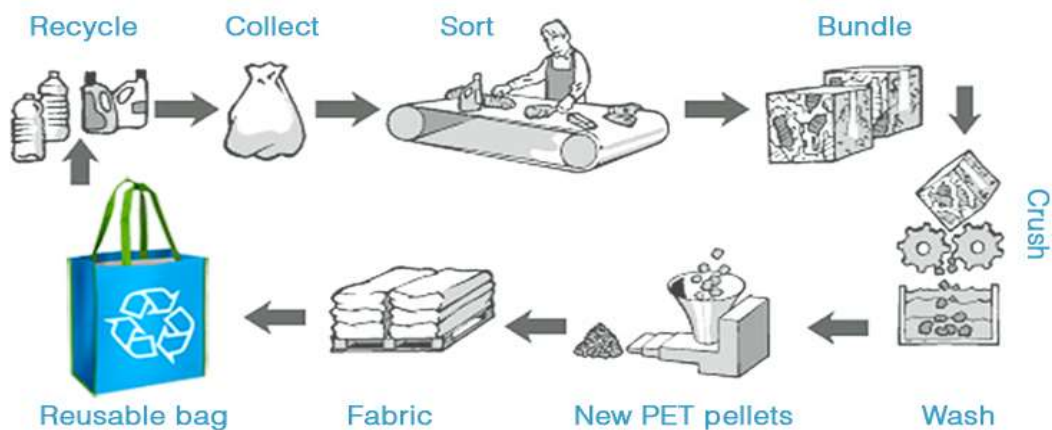


Fig.2.1; Process of recycling plastics

Before recycling, most plastics are sorted according to their resin type. In the past, plastic reclaimers used the resin identification code (RIC), a method of categorization of polymer types. Which was developed by the Society of the plastics industry in 1988.

Polyethylene terephthalate, commonly referred to as PET, for instance, has a resin code of 1. Most plastic reclaimers do not rely on the RIC now; they use automatic sort systems to identify the resin. Ranging from manual sorting and picking of plastic materials, to mechanized automation processes that involve shredding, sieving, separation by rates of density i.e. air, liquid, or magnetic, and complex spectrophotometric distribution technologies e.g. UV/VIS, NIR, laser, etc. some plastic products are also separated by colour before they are recycling.

2.5 Methods of Recycling Plastics

Once the plastic has been collected, it will have to be cleaned and sorted. The technique used will depend on the scale of operation and the type of waste collected, but at the simplest level will involve hand washing and sorting of the plastic into the required groups. More sophisticated mechanical washers and solar drying can be used for larger operations. Sorting

of plastics can be by polymer type (thermoset or thermoplastic for example), by products (bottles, plastic sheeting, etc.), by colour.

SIZE REDUCTION TECHNIQUES:

Size reduction is required for several reasons to reduce larger plastic waste 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: This is usually carried out for initial size reduction of large objects. It can be carried out with scissors, shears, and 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.

FURTHER PROCESSING TECHNIQUES: EXTRUSION AND PALLETISING

The process of extrusion is employed to homogenise the reclaimed polymer and produce a material that is subsequently easy to work. The reclaimed polymer pieces are fed into the extruder, are heated to induce plastic behaviour and then forced through a die to form a plastic “spaghetti” which can then be cooled in a water bath before being palletised. The

palletisation process is used to reduce the “spaghetti” to pellets which can then be used for the manufacture of new products.

Manufacturing Techniques

Extrusion: extrusion is a process that can be compared to squeezing toothpaste out of the tube. Thermoplastic granules are forced through a heated barrel and the fused polymer is then squeezed through a die that is the profile of the extruded component. The extrusion is cooled by water or air as it leaves the die and is finally cut to the required length. The shape of the die can be varied from one simple hole with a centrally supported core to produce tube such as pipes, to very complex sections for curtain tracks or hollow window frames.

Blow moulding: Blow moulding is a simple process where compressed air is introduced underneath a warmed sheet of thermoplastic material forcing the material into a mould cavity, or allowing it to expand freely into the shape of a hemisphere. It is a good way of forming large domes, which when made out of clear acrylic sheet are often used in shop displayed.

Vacuum forming (thermoforming): This is a very common manufacturing process used, for example, to make a range of plastics packaging. Think of the boxes sandwiches come in, or the inner in a chocolate box, or your acrylic bath. It is really the opposite of blow moulding instead of the warmed plastic sheet being forced into mould by air pressure, in vacuum forming the air is drawn out from under the softened plastic sheet, so it is forced over or into a mould by atmospheric pressure. Vacuum forming is a very common and effective way of producing complex shapes in thermoplastic sheeting.

Extrusion blow moulding: This is a combination of extrusion and blow moulding and is often used where the article to be made has a narrow neck, such as bottle. The plastic materials first extruded as a tube shape into an open die. The die is then closed to seal the

ends of tube and air is blown in forcing the plastic tube to take up the shape of the die cavity. As the material is extruded first and then blow moulded, the process is known as extrusion blow moulding.

Injection Moulding: This process is one of the most common of all plastics manufacturing process. The polymer, in granule form, is heated until fused and forced into a closed mould. Because of the viscous nature of the fused polymer, very high pressures are needed to make it flow, which means that the machine and the mould have to be very strong to withstand the forces involved.

A typical industrial injection moulding machine uses a screw to force the granules along a heated barrel, and when the granules become fused the screw is used as a plunger to force the polymer into the mould. The moulds are usually made from high-grade steel to withstand the forces involved and must also be highly polished to produce a very good finish on the product, as any scratches will show up in the mould plastic surface. Because of the ability of the plastic to show even the smallest of marks very fine detail can be cut into the mould, for example, in the form of trademarks, lettering or textures.

Calendaring: this is used to produce plastic sheeting and products such as floor tiles, coated fabrics and coverings for car interiors. Fused thermoplastic is extruded on to heated rotating rollers that squeeze the material into a continuous sheet or film. The film is cooled by jets of air or water before being cut to suitable length or loaded onto rolls.

2.6 Plastic Recycling Equipment and Machines

Machinery for plastic recycling and processing varies in size and sophistication. In most developing countries it is not possible to find new equipment which can be purchased off-the-shelf and machinery will either have to be imported, manufactured locally or improvised.

Within the informal sector, the latter is usually the most common method of procuring equipment and the level of improvisation is often admirable and ingenious.

Some of these machines includes:

- Plastic recycling system
- Plastic recycling plant
- Plastic pelletizer
- Plastic granulating machine

The plastic recycling machine is considered with conveyor, agglomerator, extruder, hydraulic screen changer, cutting system, centrifugal dewater machine, air sending system and silo. Metal detector, roll feeder, degassing system, chiller, vibrating screener are optional devices. It may be provided depending on the property of the material.



Fig. 2.2; Plastic recycling plant

CHAPTER THREE

3.0 DESIGN

The extruding machine is designed in such a way that it is operated electrically. Therefore factors considered in the design are safety, efficiency, cost effectiveness and environmental friendliness.

3.1 Sketch of Concept

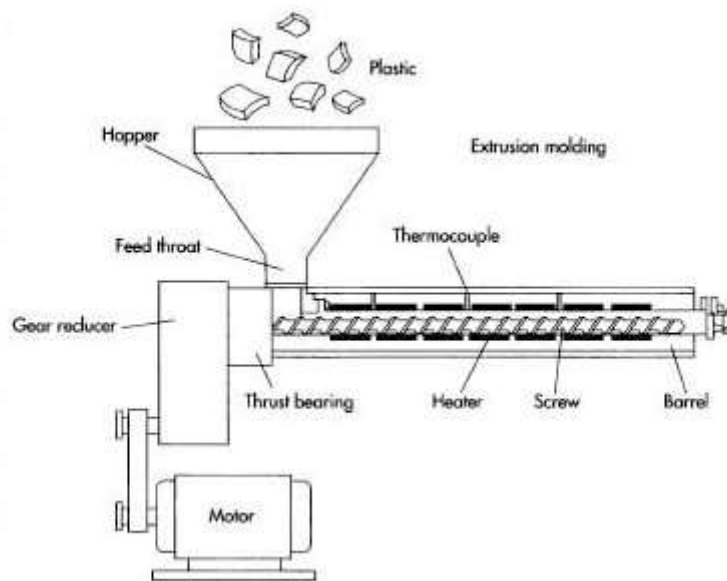


Fig 3.1 extruding machine

The Frame: the frame is used to hold, support and guide the component of the machine.

The Hopper: It is also called the feeder. It is used to feed materials into the machine.

The Barrel: This is where the material fed into the machine pass through from the hopper to the die. This is also where heating and melting takes place.

The Screw Shaft: it is also known as the heart of the machine. It is a long threaded shaft which helps in conveying the raw materials.

The Motor: The machine is powered by an electric motor and connected to the shaft by a mean of belt drive. This is usually a 3 phase AC motor.

The Belt Drive: The belt drive transmits power produced by the motor and transfer it to the shaft.

The Die: It is exit of the machine where the output flows out in form of spaghetti.

3.2 Design Specification

The machine was designed base on the following specifications:

- Taking pressure in the to be 70bar (7N/mm), it ranges from 70-350bar (Paulson plastic, 2016)
- Speed of pressing screw = 100rpm (Paulsonplastics, 2016)
- Input Capacity = 20kg/hr. (from the existing crushing machine).

3.3 Design Factors

The intention was to design an extruding machine that will be electrically operated, efficient and cost effective to produce the desired output. Priority factors were considered for the design, construction and testing of the extruding machine. These factors are as follows:

Temperature: Temperature is a very important factor. It was consider for our purpose so that the extruding machine will produce the required viscos liquid.

Easy to Assembly and Dismantle: As stated in chapter one that there is an existing crusher and subsequently other units of the recycling plant will be designed and constructed. So we considered these so that other unit of the plant will be incorporated to our extruder without any additional labour or cost.

Economy: The target people are lower class and the middle class people in the society who can venture into plastic recycling business, so we considered them and made our machine to be of low cost.

Environmental: the extruding machine is environmentally friendly in terms of operation.

3.4 Design Procedure of an Extruding Machine

3.4.1 Design of Power Screw

The power screw also known as Archimedes screw provides a means for obtaining large mechanical advantage. It also serves as a conveyor which will be used to convey the melted plastic to the die. The one used for this design is the single screw because it has a good pressurization and does not require pre-pelletizing.

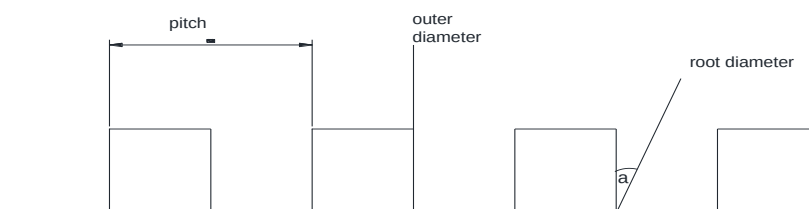


Fig 3.2 screw thread

Pitch (P) is the distance from one point on one thread to the corresponding point in the next adjacent thread.

Lead is the distance the screw advances relative to the nut in one rotation. But for a single thread screw, pitch is equal to lead.

Helix angle (α) is related to the lead and mean radius (r_m) by the equation:

$$\tan\alpha = \frac{\text{lead}}{2\pi r_m} \quad (3.1)$$

The torque (T) required to advance the screw in the direction of load is given by:

$$T = W \tan(\alpha + \phi) \frac{d}{2} \quad (3.2)$$

Where $\tan\phi = \mu$; T=torque; W=Load; r_m = mean radius of thread; α = helix angle;
 μ =coefficient of friction; ϕ =friction angle.

Pitch (lead) was taken to be 70mm. (Conveyor screw catalogue)

Outside diameter (d_o) = 80mm , The screw height (h) can be determined using the relation;

$$h = 0.5P \quad (3.3)$$

$$= 0.5 \times 70$$

$$= 35\text{mm}$$

The screw width (b) can be determined using the relation;

$$b = 0.5487P \quad (3.4)$$

$$= 0.5487 \times 70$$

$$= 38.41\text{mm}, 39 \text{ adopted (for easy machining)}$$

$$\text{The mean screw diameter } d = d_o - h \quad (3.5)$$

$$= 80 - 35$$

$$= 45\text{mm}$$

The diameter of the barrel (d_b) can be obtained using the relationship below:

$$d_b = d_o + 2c \quad (3.6)$$

Assuming the clearance (c) of 3mm, the diameter of the barrel (d_b) is then obtained from equation as:

$$\begin{aligned} d_b &= 80 + (2 \times 3) \\ &= 86 \text{mm} \end{aligned}$$

From equation 3.1, the helix angle (α) is given by;

$$\begin{aligned} \tan \alpha &= \frac{\text{lead}}{\pi d} \\ &= \frac{70}{\pi \times 45} \end{aligned}$$

$$\tan \alpha = 0.4951$$

$$\alpha = 26.42^\circ$$

Friction angle;

$$\phi = \tan^{-1} 0.15$$

$$\phi = 8.53^\circ$$

From equation 3.2, the torque (T) can be determined using the relation;

But force (W) is determined using:

$$W = P \times A \quad (3.7)$$

P is the pressure and A is the area

$$A = \frac{\pi d_b^2}{4} \quad (3.8)$$

$$A = \frac{\pi \times (0.086)^2}{4}$$

$$A = 0.0058m$$

Therefore, from equation 3.8. $W = 7 \times 0.0058$

$$W = 40.6kN$$

So, $Torque (T) = W \tan(\alpha + \phi) \frac{d}{2}$

$$T = 40.6 \times 10^3 \tan(26.42 + 8.53) \frac{45 \times 10^{-3}}{2}$$

$$T = 638.5Nm$$

The efficiency (η) can be obtained using the relation;

$$efficiency (\eta) = 100 \frac{\tan \alpha}{\tan(\alpha + \phi)} \quad (3.9)$$

$$\eta = 100 \frac{\tan 26.42}{\tan(26.42 + 8.53)}$$

$$\eta = 71.09\%$$

3.4.1.1 Design For Screw Thread

The threading of the power screw needs to be increased for a certain distance of the different zones i.e. the feeding zone, transition zone and the metering zone.

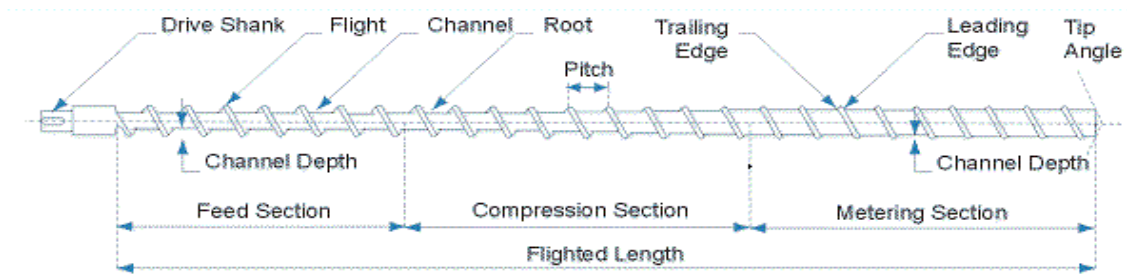


Fig 3.3 Threading zones

Thereby reducing the screw depth using the relation below:

$$u_n = a + (n - 1)d \quad (3.10)$$

u_n = screw depth at discharge end; a = screw depth at feed end; n = number of screw turns;

d = common difference between next successive screw depth.

According to olaniyan et al (2006), the ratio of u_n to $a = \frac{1}{5}$

And n is number of thread to be adopted =7

Therefore we have

$$n = 10, a = h = 35\text{mm}, u_n = 7$$

Substituting values in the above equation

$$7 = 35 + (10 - 1)d$$

$$d = -3.11\text{mm}$$

Therefore, the screw depth would be decreased consistently by 3.11mm from the feed end to the discharge end of the barrel.

The L/D ratio of screws for thermoplastic is 10:1, there for the length for the screw was:

$$L = 10D \quad (3.11)$$

$$L = 10 \times 80$$

$$L = 800\text{mm}$$

$$\text{Length of the feeding zone } (L_f) = 60\% \times L = \frac{60}{100} \times 800 = 480\text{mm}$$

$$\text{Length of the compression zone } (L_c) = 20\% \times L = \frac{20}{100} \times 800 = 160\text{mm}$$

$$\text{Length of the metering zone } (L_m) = 20\% \times L = \frac{20}{100} \times 800 = 160\text{mm}$$

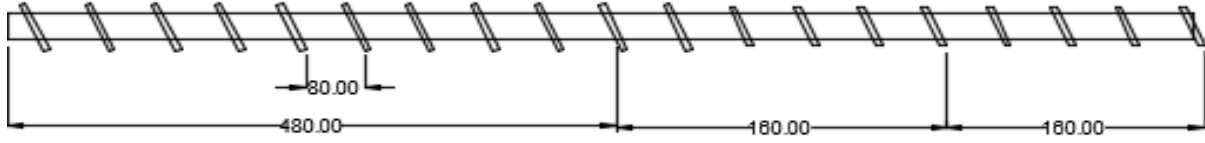


Fig 3.4 sketch of the conveying screw

3.4.1.2 Design of the Load that can be Conveyed by the Screw

The load that can be lifted by the screw was determined from the equations given by;

$$W_e = T \frac{\frac{D_m}{2} \tan \phi + \frac{\mu}{\cos \alpha}}{(1 - \mu \tan \phi \cos \alpha)} \quad (3.12)$$

Where, W_e is the load to be conveyed by the screw; T is the torque transmitted by the screw shaft; D_m is the mean thread diameter; μ is the coefficient of friction; ϕ is the angle of thread angle; α is the helix angle.

Therefore substituting the values into the relation above

$$W_e = 638.5 \times \frac{\frac{0.045}{2} \times \tan 8.53 + \frac{0.15}{\cos 26.42}}{(1 - 0.15 \tan 8.53 \cos 26.42)}$$

$$W_e = 111.3N$$

3.4.1.3 Stress in Thread

Bending stress

The bending stress (S_b) can be determined using the relation;

$$S_b = \frac{3Wh}{\pi db^2} \quad (3.13)$$

$$S_b = \frac{3 \times 111.3 \times 35 \times 10^{-3}}{\pi \times 45 \times 10^{-3} \times (38.41 \times 10^{-3})^2}$$

$$S_b = 56.03 \text{ kN/m}^2$$

Shear stress

Shear stress can be determined using the relation;

$$\tau = \frac{W}{\pi d n b} \quad (3.14)$$

$$\tau = \frac{111.3}{\pi \times 45 \times 10^{-3} \times 38.41 \times 10^{-3}}$$

$$\tau = 20.5 \text{ kN/m}^2$$

The bending pressure (P_b) can be determined using the relation;

$$P_b = \frac{W}{\pi d n h} \quad (3.15)$$

$$P_b = \frac{111.3}{\pi \times 45 \times 10^{-3} \times 35 \times 10^{-3}}$$

$$P_b = 22.49 \text{ kN/m}^2$$

The torsional shear stress S_s can be determined using the relation;

$$S_s = \frac{2T}{\pi (r_1)^2} \quad (3.16)$$

$$S_s = \frac{2 \times 638}{\pi (10 \times 10^{-3})^2}$$

$$S_s = 4.07 \text{ kN/m}^2$$

The bending stress S_b can be calculated using the relation;

$$S_b = \frac{32M}{\pi d^2}$$

Since S_b from the above equation is 56.03 kN/m^2 , therefore the moment (M) is determined by making M subject of formulae;

$$M = \frac{\pi d^2 S_b}{32} \quad (3.17)$$

$$M = \frac{\pi \times (45 \times 10^{-3})^2 \times 56.03 \times 10^3}{32}$$

$$M = 11.39 \text{ Nm}$$

The torsional shear stress (τ) is given in the relation;

$$\tau = \frac{16T}{\pi d^3}$$

Since τ from the above calculation is 20.5 kN/m^2 , therefore T is determined by making T subject of formulae;

$$T = \frac{\tau \pi d^3}{16} \quad (3.18)$$

$$T = \frac{\pi \times 20.5 \times 10^3 \times (45 \times 10^{-3})^3}{16}$$

$$T = 0.367 \text{ Nm}$$

3.4.1.4 Failure Analysis

$$\sigma_{1,2} = \left(\frac{16}{\pi d^3} \right) [M \pm \sqrt{M^2 + T^2}] \quad (3.19)$$

$$\sigma_{1,2} = \left(\frac{16}{\pi \times (45 \times 10^{-3})^3} \right) [11.39 \pm \sqrt{11.39^2 + 0.367^2}]$$

$$\sigma_{1,2} = 636584.84 \pm 11.40$$

$$\sigma_1 = 636.596 \text{ kN/m}^2$$

$$\sigma_2 = 636.573 \text{ kN/m}^2$$

Assuming a factor of safety of 2.5, and a poisson ratio of 0.3. The yield stress of the selected material is;

$$\sigma_1 - \sigma_2 = \frac{\sigma_{yp}}{2} \quad (3.20)$$

Making σ_{yp} subject of formulae;

$$\sigma_{yp} = 2(\sigma_1 - \nu\sigma_2)$$

$$\sigma_{yp} = 2(636.596 - 0.3(636.573))$$

$$\sigma_{yp} = 891.25 \text{ kN/m}^2$$

It is seen that the principal stresses are less than the yield stress, therefore the selected material will support the load having a yield stress of 876.38N/m² and principal stresses of 625.97N/m² and 625.94N/m².

3.4.1.5 Design for the Capacity of the Screw Shaft at Feedzone

Solid flow rate can be obtained from the relationship:

$$Q_f = 60 \times \rho \times \pi^2 \times N \times \eta_f \times H \times D_b(D_b - H) \times \frac{W}{W+W_{flt}} \times \cos \alpha \sin \alpha \quad (3.21)$$

N is the speed =100 rpm; η_f is the efficiency of the screw = 71.09%; H is the depth of feed zone= 11mm; D_b is the barrel diameter= 86mm; W is the channel width=38.41mm; W_{fl} is the flight width=8mm and ρ is the density of polyethylene terephthalate (PET) =1380kg/m³.

$$Q_f = 60 \times 1380 \times \pi^2 \times 100 \times 0.711 \times 0.011 \times 0.086(0.086 - 0.011) \\ \times \frac{0.03841}{0.03841 + 0.008} \times \cos 26.42 \sin 26.42$$

$$Q_f = 2.07kg/hr.$$

Power Required For Moving The Rotating Shaft

The power required for continuously moving and rotating the screw shaft can be estimated using the equation below:

$$P = T \frac{2\pi N}{60} \quad (3.22)$$

$$P = 638.5 \frac{2 \times \pi \times 100}{60}$$

$$P = 6686.35W = 6.686kW$$

Selection of motor is done by multiplying P with the service factor C_s .

3.4.2 Design for Barrel Cage

The barrel cage is a thin or thick wall cylinder. The criterion for a thin or thick wall cylinder is;

If the $(t) < \frac{1}{10}d$ then is it a thin wall, so also if $t > \frac{1}{10}d$ then it is thick wall vessel.

Internal diameter (d_b) = 86mm

Internal pressure (p) = 7N/mm because internal pressure ranges from 70-480 bar (Paulson plastic, 2016), we took 70bar (7N/mm) as the internal pressure for safety.

To show whether it is thin or thick;

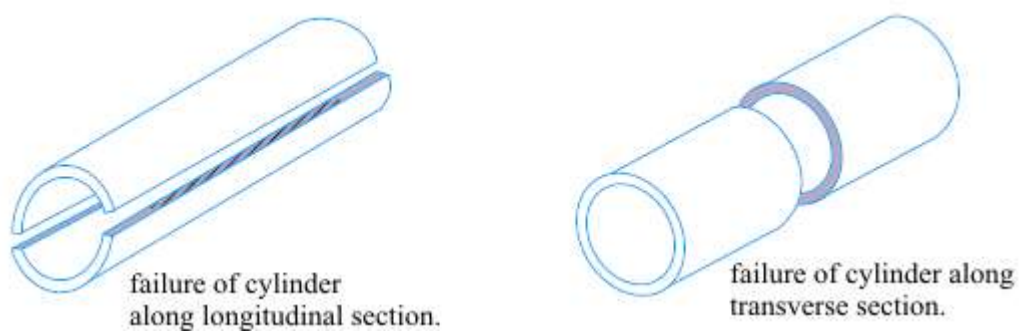
$$= \frac{1}{10} \times 86$$

$$= 8.6mm$$

3.4.2.1 Stresses in the Barrel Cage

The analysis of stresses induced in a thin cylindrical shell are made on the following assumptions:

1. The effect of curvature of the cylinder wall is neglected.
2. The tensile stresses are uniformly distributed over the section of the walls.
3. The effect of the restraining action of the heads at the end of the pressure vessel is neglected. (Gupta and Khurmi, 2005)



Fug 3.5 barrel cage

Circumferential or Hoop Stress

A tensile stress acting in a direction tangential to the circumference is called **circumferential** or **hoop stress**.

$$\sigma_{t1} = \frac{p \times d}{2t} \quad (3.23)$$

The allowable shear stress (σ_t) of steel is $0.27\sigma_y$; σ_y is the yield stress of steel = 220N/mm^2 (IS 1570 (Part I)-1978 (Reaffirmed 1993)).

$$t = \frac{p \times d}{2\sigma_t}$$

$$t = \frac{7 \times 86}{118.8}$$

$$t = 5.08\text{mm}$$

Since $t < \frac{1}{10}d$, the barrel was a thin walled cylinder

Longitudinal stresses

A tensile stress acting in the direction of the axis is called **longitudinal stress**.

$$\sigma_{t2} = \frac{p \times d}{4t} \quad (3.24)$$

$$\sigma_{t2} = \frac{7 \times 86}{4 \times 5.08}$$

$$\sigma_{t2} = 29.63 \text{ N/mm}^2$$

Since the longitudinal stress is half the circumferential stress, therefore the barrel is safe and the design was based on the maximum stress and the barrel can withstand the pressure. The is size of the barrel is;

Length = 800mm,

Thickness = 5.08mm , Inner diameter = 86mm

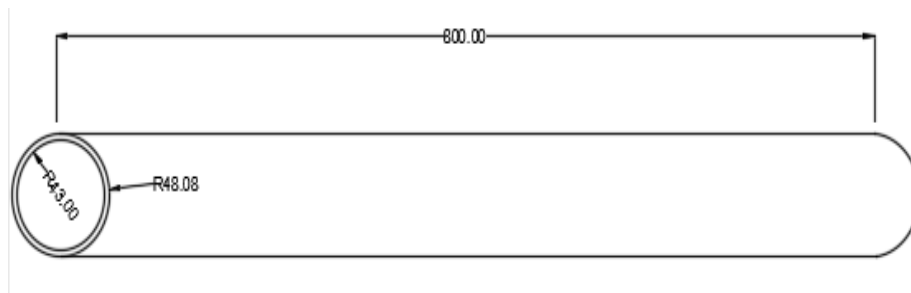


Fig 3.6; Sketch of the barrel cage

3.4.3 Design of Belt Drive

The belts or are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. The amount of power transmitted depends upon the following factors:

1. The velocity of the belt.
2. The tension under which the belt is placed on the pulleys.
3. The arc of contact between the belt and the smaller pulley.
4. The conditions under which the belt is used.

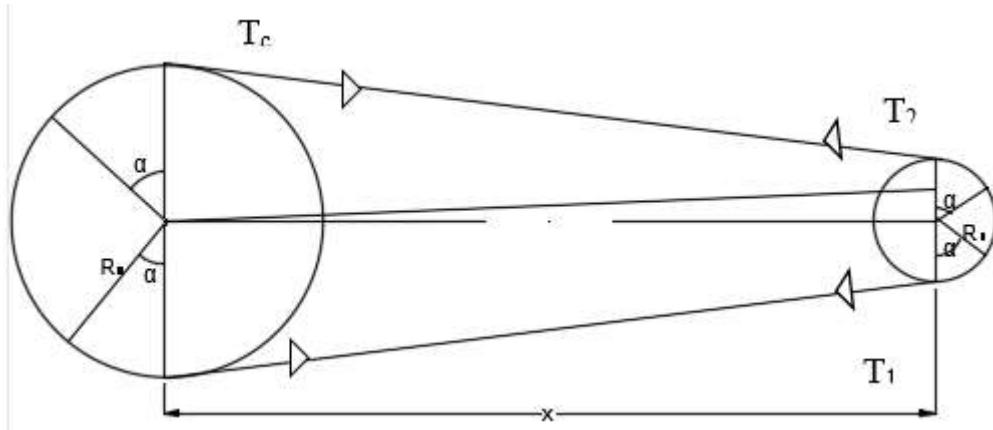


Fig 3.7; Belt drive

- Belt maximum stress (σ) = 2.5MPa
- Diameter of motor pulley (D_1) = 160mm (Saurabhtec, 2016)
- Speed of motor (N_1) = 1400rpm
- Diameter of shaft pulley (D_2) = 800mm (phoenix, 2016)
- Service factor = 1.2 (bando USA)

Note: the driven (shaft) pulley diameter is larger than driving (motor) pulley diameter.

$$\text{Speed of shaft } (N_2) = \frac{D_1 \times N_1}{D_2} \quad (3.25)$$

$$= \frac{160 \times 1400}{800}$$

$$= 280rpm$$

From the above specification, we used the A type V- belt

Belt tension and power

The area of the tension A_b is calculated using the relation;

$$A_b = w_b \times t_b \quad (3.26)$$

Width (w) = 13mm

Thickness (t) = 8mm

Therefore, $A = 13 \times 8$

$$A = 104 \text{ mm}^2$$

For an open belt drive;

$$\sin \alpha = \frac{R_2 - R_1}{2x} \quad (3.27)$$

Where x is the centre distance between the two pulleys = 0.8

R_2 and R_1 are the radii of the shaft and motor pulley respectively.

$$\therefore \sin \alpha = \frac{0.4 - 0.08}{2 \times 0.8}$$

$$\sin \alpha = 0.20$$

$$\alpha = 11.54^\circ$$

Angle of lap on the driving pulley,

$$\theta = 180^\circ - 2\alpha$$

$$\theta = 180 - 2 \times 11.54$$

$$\theta = 156.92^\circ$$

$$\theta = 156.92 \times \frac{\pi}{180}$$

$$\theta = 2.74 \text{ rad}$$

The mass (m_b) of the belt per meter length,

$$m_b = A_b \times X \times \rho \quad (3.28)$$

A_b is area of the belt tension = 104mm^2

X is the centre distance between the pulleys = 800mm

ρ is density of the rubber = 1140kg/m^3 (AZOmaterials,2016)

$$\therefore \text{mass}(m) = 104 \times 10^{-3} \times 0.8 \times 1140$$

$$m = 0.095\text{kg}$$

and velocity (v_b) of the belt,

$$v_b = \frac{\pi D_1 N_1}{60} \quad (3.29)$$

$$v_b = \frac{\pi \times 0.16 \times 1400}{60}$$

$$v_b = 11.72\text{m/s}$$

Centrifugal tension (T_c) of the belt. (Gupta and Khurmi, 2005);

$$T_c = m_b v^2 \quad (3.30)$$

m_b is the mass of the belt per length

v_b is the velocity of the belt

$$T_c = 0.095 \times (11.73)^2$$

$$T_c = 13.07\text{N}$$

Maximum tension (T) in the belt. (Gupta and Khurmi, 2005),

$$T = \sigma \times A_b \quad (3.31)$$

σ is the belt maximum stress = 2.5MPa .

A_b is the area of the belt = 104mm^2

$$T = 2.5 \times 104$$

$$T = 260N$$

Therefore, tension (T_1) in the tight side of the belt, (Gupta and Khurmi, 2005)

$$T_1 = T - T_c \quad (3.32)$$

$$T_1 = 260 - 13.07$$

$$T_1 = 246.93N$$

Tension on the slack side of the belt is determined using;

$$2.3 \log \left(\frac{T_1}{T_2} \right) = \mu \theta \csc \beta \quad (3.33)$$

- T_1 is the tight side of the belt.
- T_2 is the slack side of the belt.
- β is the groove angle.
- θ is the angle of lap.

Where μ is the coefficient of friction between the belt and pulley which is taken to be 0.3,

For A type V-belt, groove angle is 32°

But $2\beta =$ groove angle,

$$\beta = \frac{32}{2}$$

$$\beta = 16^\circ$$

Therefore, $2.3 \log \left(\frac{246.93}{T_2} \right) = 0.3 \times 2.74 \times \csc 16$

$$\log\left(\frac{246.93}{T_2}\right) = \frac{2.9822}{2.3}$$

$$\log\left(\frac{246.93}{T_2}\right) = 1.2966$$

Taking antilog of 0.93696

$$\frac{246.93}{T_2} = 19.80$$

Making T_2 subject of formula, $T_2 = \frac{246.93}{19.80}$

$$T_2 = 12.47N$$

Motor power,

$$P = (T_1 - T_2)v \times \text{service factor} \quad (3.34)$$

$$P = (246.93 - 12.47) \times 11.47 \times 1.2$$

$$P = 3227.11W$$

Number belts (n);

$$n = \frac{\text{design power}}{\text{rated power}} \quad (3.35)$$

$$n = \frac{6686.6}{3227.11}$$

$$n = 2.002 \text{ say } 2 \text{ belt}$$

3.4.3.1 Design Of Pulley

From the table of dimensions of standard V-grooved pulleys according to IS: 2494-1974 for the calculated belt; (Gupta and Khurmi, 2005)

$w = 11\text{mm}$; $d = 12\text{mm}$; $a = 3.3\text{mm}$; $c = 8.7\text{mm}$; $f = 10\text{mm}$; $e = 15\text{mm}$; $n = 1$

$$B (\text{face width of the pulley}) = (n - 1)e + 2f \quad (3.36)$$

$$B = (2 - 1)15 + 2(10)$$

$$B = 35\text{mm}$$

3.4.3.2 Design of Pulley Shaft

The extrusion shaft is the component connecting the pulley to the die, and it should have the following properties;

1. Ability to be machined.
2. High strength.
3. High wear resistant.

For ordinary shafts, the material used is carbon steel.

Torque transmitted by the pulley (T) is given as;

$$T = \frac{\text{power} \times 60}{2\pi N_2} \quad (3.37)$$

N_2 is the speed of the screw shaft = 100rpm

$$T = \frac{3227.11 \times 60}{2\pi \times 100}$$

$$T = 308.17\text{Nm}$$

Bending moment of the shaft due belt tension (M);

$$M = (T_1 + T_2 + 2T_c)n \quad (3.38)$$

T_1 (tension at the tight side of the belt) = 246.93N; T_2 (tension of the belt on slack side) = 12.47N; T_c (centrifugal tension of the belt) = 13.07N

$$M = (246.93 + 12.47 + 2 \times 13.07)2$$

$$M = 571.08 \text{ Nmm}$$

Equivalent twisting (T_e) moment;

$$T_e = \sqrt{T^2 + M^2} \quad (3.39)$$

T is the torque transmitted by the pulley; M is the bending moment of the shaft due to belt tension.

$$T_e = (308.17^2 + 571.08^2)^{1/2}$$

$$T_e = 648.92 \text{ Nmm}$$

To calculate the diameter of the shafts;

$$d_s = \frac{16T}{0.27\pi\delta} \quad (3.40)$$

Where T is the torque and δ is the yield stress. Given that T is 600.49Nmm and δ is 432.33N/mm².

Therefore

$$d_s = \frac{16 \times 648.92}{0.27 \times \pi \times 432.33}$$

$$d_s = 28.31 \text{ mm}$$

Say 30mm shaft diameter is adopted.

3.4.3.3 Design for Key

A key is a piece of mild steel which is inserted between a shaft and the boss of a pulley. A parallel sunk key is used for this design purpose because it was used to key the shaft to the pulley. According to the standard to IS: 2292 and 2293-1974 (Reaffirmed 1992). (Gupta and Khurmi, 2005)

The standard dimension of key for shaft of 30mm diameter are:

- Width of the key = 10mm
- Thickness of key = 8mm

3.4.4 Design of Hopper

A hopper is a large pyramidal or conical shaped container used in manufacturing processes to hold or feed in particulate. Hopper usually installed in two groups to allow for a greater quantity collection. The conical hopper is used for the collection of liquid and soft particulate while the pyramidal hopper is used to collect solid particulate. Most hoppers are of steel.

However, for the purpose of this design a pyramidal hopper is used for the collection of the crushed plastics from the crushing machine.

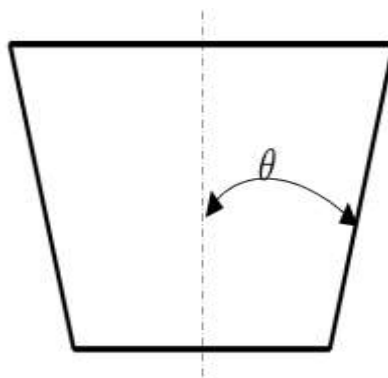


Fig 3.8; side view of a hopper

$$V = \frac{m}{\rho} \quad (3.41)$$

- m is the mass per feed = 20kg/hr.
- ρ is the density of the plastic = 1380kg/m³.

Therefore the volume $V = \frac{20}{1380}$

$$= 0.0145m^3$$

The volume of a pyramidal frustum $V = \frac{1}{3} \times A \times h$ (3.42)

$$V = 0.0145m^3$$

the base area of the frustum (A) = L x L. (3.43)

h is the height of the frustum = 0.319m

$$0.0145 = \frac{1}{3} \times A \times 0.319$$

$$A = 0.1364m$$

Therefore, $L = \sqrt{A} = 0.37m$

Base on the volume obtained as 0.0145m³, the following dimensions of hopper will be adopted in addition with allowance.

Therefore the size of the hopper is;

- Upper length= 370mm
- Lower length = 65mm
- Height = 319.98mm

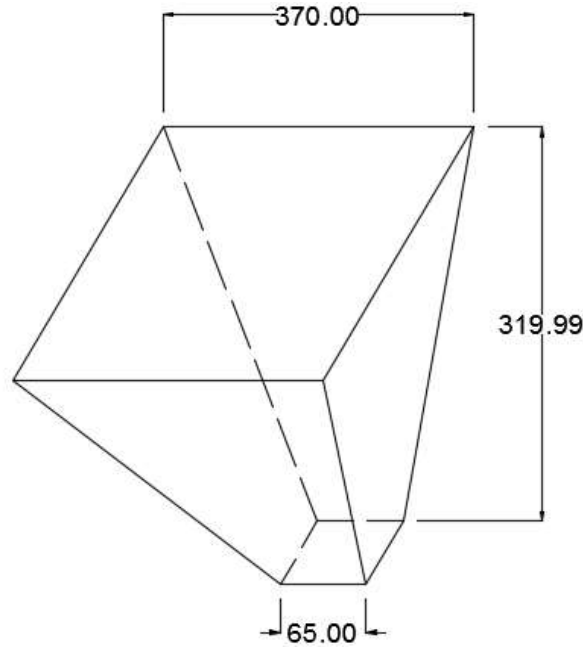


Fig 3.9; sketch of the hopper

3.4.5 Determining the Heat Required to Melt the Plastic

The processing temperature of most plastics is between 163°C and 250°C, even though that they melt between 108°C -121°C. The target temperature for melting polyethylene terephthalate (PET) are 75°C and 255°C (AZOcleantech, 2016). So we choose 255°C. The materials must be raised from room temperature (25°C) to 255°C. Assuming a polyethylene terephthalate (PET) of mass 0.095kg as calculated, So, the quantity of heat needed to raise the temperature of this mass from 25°C to 255°C (Q_{25-255}) and can be calculated using the equation: $Q_{25-255} = \text{Heat needed to raise the material to its melting point} + \text{Heat needed to melt the entire mass} + \text{Heat needed to raise the temperature of polyethylene terephthalate to 255°C}$.

$$Q_{25-255} = MC_p\Delta t_1 + ML + MC_p\Delta t_2 \quad (3.44)$$

Where M is the mass of the material = 2.08kg.

C_p is the specific heat capacity of the material = 1.250kJ/kgK. (engineeringtoolbox).

Latent heat of fusions (L) = 140kJ/kg (RMR Wellen, 2014).

Temperature from 25°C-121°C $\Delta t_1 = 121 - 25 = 96^\circ C$

Temperature from 121°C-255°C $\Delta t_2 = 255 - 121 = 134^\circ C$

$$\therefore Q_{25-255} = (2.08 \times 1.250 \times 96) + (2.08 \times 140) + (2.08 \times 1.250 \times 134)$$

$$Q_{25-255} = 889.2kJ$$

Therefore this amount of heat must be generated by the source and the amount of heat that will be lost through the wall of the heating chamber.

Heat supply by the source= heat lost through the walls of the chamber + heat used in raising the temperature

$$Q_c = \frac{2\pi L(T_1 + T_2)}{\frac{\ln \frac{r_2}{r_1} + \ln \frac{r_3}{r_2}}{\frac{K_a}{r_1} + \frac{K_b}{r_2}}} \quad (3.45)$$

Where, L is the length of the heating chamber (barrel) = 500mm; T_1 is temperature of the heating chamber (internal) = 255°C; T_2 is the external temperature of the heating chamber = 25°C; K_a is the thermal conductivity of the inside steel = 45W/mK; K_b is the thermal conductivity of the insulating material of the heating element = 0.23W/mK; K_c is the thermal conductivity of the outside steel = 45W/mK; r_1 is the radius of the heating chamber = 42.5mm; r_2 is the radius of the interface between the outside layer and the insulating layer = 45mm; r_3 is the radius of interface between the outside steel layer and insulating layer = 50mm.

$$\therefore, Q_c = \frac{2\pi \times (255 - 25)}{\frac{\ln \frac{45}{42.5}}{45} + \frac{\ln \frac{50}{45}}{0.23}}$$

$$Q_c = 7.25kW$$

The above value is the heat lost radially through the wall of the cylinder wall. Heat loss through the base Q_b and lid Q_l of the heating chamber was employed the relation;

$$Q_b = \frac{A(T_1 + T_2)}{\frac{d_a}{K_a} + \frac{d_b}{K_b} + \frac{d_c}{K_c}} \quad (3.46)$$

A is the area of the cylindrical barrel $= 2\pi rL$

$$r = 42.5mm$$

$$L = 500mm$$

$$\therefore, A = 2\pi \times 42.5 \times 500$$

$$A = 133517.68mm^2$$

$$A = 0.1335m^2$$

$d_a, d_b,$ and d_c are the diameters of the three layers of the composite walls 85mm, 90mm and 100mm respectively

$$Q_b = \frac{0.1335(255 - 25)}{\frac{0.085}{45} + \frac{0.09}{0.23} + \frac{0.1}{45}}$$

$$Q_b = \frac{30.71}{0.4138}$$

$$Q_b = 74.21W$$

Heat loss through the base and lid $= 74.21 \times 2 = 148.42W = 0.148kW$

It is expected that Q_{25-255} will be generated in 60 minutes, which requires a Power input

$$\text{of} = \frac{889.2}{60 \times 60} = 0.247 \text{ kW}.$$

$$\therefore, Q_{25-255} = 7.25 + 0.148 + 0.247$$

$$Q_{25-255} = 7.645 \text{ kW}$$

Therefore the heating source will supply a heat power of 7.645kW.

3.4.6 Bearing Analysis And Selection

Rolling bearing application involves proper selection, mounting and lubrication and possibly, shielding in order that the bearing functions under specified operating conditions. In other words bearing permits smooth, low friction movement between two surfaces. The movement can either be rotary (i.e., one surface moving over another). The figure 5 below shows a radial ball bearing.



Fig 3.10; Radial ball bearing

Bearings are evaluated on the basis of how much load they can carry, at what speed they can carry this load and how long they will serve under specified conditions. The use of rolling bearings rather than journal bearings in the system is stated below.

- (1) Rolling bearings have an advantage where starting torque is high because of the rolling action of the balls and rollers.
- (2) Where space limitations are present, rolling bearings are preferable if axial dimensions are limited.
- (3) Rolling bearings give warning (by becoming noisy) when failure is about to occur, whereas when failure occurs in journal bearings, it is sudden with more disastrous results.
- (4) Rolling bearings can take a combination of radial and thrust loads.
- (5) Rolling bearings can take high overloads for short periods.

Parameters for rating bearings are static and dynamic capacity. The former gives idea of deformation, while the latter gives the idea of fatigue.

Bearings for this system are expected to exhibit these characteristics

- (a) Low friction.
- (b) Accurate shaft alignment is always maintained.
- (c) Simple lubrications.
- (d) Easy replacement.
- (e) Carry radial loads.
- (f) Exert steady load.

3.4.6.1 Bearing Analysis

According to R.S Kurmi and J.K Gupta (2010), machines working 8 hours per day and not fully utilized e.g. stationary electric motors, general purpose gear units, life of bearing in hours ranges from 1200 – 20000 from table 27.3

If L_H = life of bearings in hours; L = life of bearing in revolutions; C_0 = static load capacity; C = dynamic load capacity; W = dynamic equivalent load; $R_B = W_R$ = radial load; W_A = axial or thrust load; V = rotational factor = 1 for most bearings; K_s = service factor from table 27.5, K_s for uniform and steady load, for ball bearing is 1.

From the ranges of bearing life, the average of a bearing is found to be 16000 hours. Therefore, $L_H = 16000$ hours

The relationship between the life in revolutions (L) and the life in working hours (L_H) is given by the below equation

$$L = 60 \times N \times L_H \quad (3.47)$$

Where; N is the speed in rpm; L_H = life of bearings in hours; and L = life of bearing in revolutions.

From the ranges of bearing life, the average of a bearing is found to be 19000 hours. Therefore, $L_H = 19000$ hours

Substituting; $N = 100$ rpm, $L_H = 19000$ hours to obtain L

$$L = 60 \times 100 \times 13333 = 80,000,000 \text{ rev.}$$

Dynamic equivalent load, is given by;

$$W = XVW_R + YW_A \quad (3.48)$$

Where; W = dynamic equivalent load; X= radial load factor; $R_B = W_R$ = radial load; Y= axial or thrust load factor; W_A = axial or thrust load; V = rotation factor.

By substituting; $W_A = 111.3\text{N}$; $W_R = 40.07\text{kN}$, since the value of C_0 is not known, then, $\frac{W_A}{W_R} =$

$$\frac{111.3}{40.07} = 0.0027$$

Since $\frac{W_A}{W_R} \leq e$

$$\text{Let } \frac{W_A}{C_0} = 0.25$$

From table 27.4 (KURMI and GUPTA, 2010)

We have the value of X and Y corresponding to $\frac{W_A}{C_0} = 0.25$, X= 1 and Y = 0.

Substituting the values of X= 1; Y=0; V=1; $W_R = 40.07\text{kN}$; $W_A = 0.1114\text{N}$; we have

$$W = (1 \times 1 \times 40.07) + (0 \times 0.1114) = 40.07\text{kN}$$

From table 27.5, we find out that the uniform and steady load, the service factor $K_s = 1$.

Therefore the bearing will be selected for $W = 40.07\text{kN}$

Basic dynamic load capacity

$$C = W \left(\left(\frac{L}{10^6} \right)^{\frac{1}{K}} \right) \quad (3.49)$$

Where; C = dynamic load capacity; W = dynamic equivalent load; L = life of bearing in revolutions; K=constant= 3(for all ball bearings).

By substituting values of; $W = 40.07N$; $L = 80,000,000rev$; $K=3$ in the above equation we have

$$C = 40.6 \left(\left(\frac{80000000}{10^6} \right)^{\frac{1}{3}} \right)$$

$$C = 8120N = 8.12kN \text{ Adopting } 10kN$$

From table 27.6(KURMI and GUPTA, 2010) the bearing No 206 is selected.

3.4.7 Gear Train Analysis And Selection

Gears are mainly design for transmission of power or motion, the accuracy of which depends upon the precision with which the gears are manufactured. Gears are used when positive drives are necessary and when centre distances are relatively short.

Spur gears are mainly used for general purpose in precision engineering due to some advantages, which includes;

1. Variations between gears have no effect on the velocity ratio between a pair of involutes gears
2. The involutes rack has straight teeth. Thus the complex involutes form on the gear can be generated from a simple cutter.
3. The involutes system has a standard pressure angle in either 20° or 14.5° .

3.4.7.1 Analysis

Velocity (speed) ratio (VR) in gears is given by;

$$VR = \frac{\omega_1}{\omega_2} = \frac{D_2}{D_1} \quad (3.50)$$

Where, ω_1 = speed of the pinion (small); ω_2 = speed of the gear (big) ; D_1 = diameter of the pinion; D_2 = diameter of gear.

$$\omega_1 = 280\text{rpm}; \omega_2 = 100\text{rpm}.$$

$$\text{Therefore, } VR = \frac{\omega_1}{\omega_2} = \frac{280}{100} = 2.80 \sim 3$$

$$3 = \frac{D_2}{D_1} \Rightarrow D_2 = 3D_1 \quad (3.51)$$

$$\text{But, } D = mT \quad (3.52)$$

m is the module and T is the number of teeth.

For pinion;

- Standard module of $m = 2$ was selected (Khurmi, 2005).
- Number of teeth was selected as $T = 18$ (Khurmi, 2005).

$$\text{Therefore, } D_1 = mT_1 = 2 \times 18 = 36\text{mm}.$$

$$D_2 = 3D_1 = 3 \times 36 = 108\text{mm}.$$

3.4.8 Selection of Die

A die was selected based on the size and shape of the pellets which are 3mm and circular in shape.

3.5 Materials Selection

The selection of materials for the construction was based on the design, function, availability and uses.

The materials are:

<i>S/N</i>	<i>Components</i>	<i>Type of materials</i>	<i>Identity</i>	<i>Yield stress (N/mm²)</i>	<i>Tensile stress (N/mm²)</i>
<i>1</i>	<i>Hopper</i>	<i>Metal sheet (mild steel)</i>	<i>IS Fe 490</i>	<i>290</i>	<i>490</i>
<i>2</i>	<i>Screw shaft</i>	<i>Mild steel</i>	<i>Fe 410</i>	<i>250</i>	<i>410</i>
<i>3</i>	<i>Barrel</i>	<i>Mild steel</i>	<i>Fe 410</i>	<i>250</i>	<i>410</i>
<i>4</i>	<i>Angle iron bar</i>	<i>Mild steel</i>	<i>Fe 290</i>	<i>170</i>	<i>290</i>
<i>5</i>	<i>Heater</i>	<i>High alloy Stainless steel</i>	<i>IS 04Cr17Ni12Mo 2</i>		
<i>6</i>	<i>Pulley</i>	<i>Cast iron</i>	<i>FG 150</i>		<i>150</i>
<i>7</i>	<i>Bearing</i>				
<i>8</i>	<i>Motor</i>				
<i>9</i>	<i>Die</i>				

CHAPTER FOUR

FABRICATION, ASSEMBLY, COST ANALYSIS AND TESTING OF EXTRUDING MACHINE

4.1 Fabrication

This section deals with the fabrication of the various parts of the extruding machine. The various component for the extruding machine were constructed using various tools, equipment and fabrication techniques.

4.1.1 Hopper

The hopper was constructed in form of a trapezoidal shape for smooth flow of the crushed plastics. The hopper was constructed of mild steel thickness 2mm. The steps involved in the construction of a hopper are:

- A mild steel sheet length of 2440mm by 1220mm width was bought from the market.
- A length of 1220mm by 300mm was cut using a grinding machine from the mild steel sheet
- Four trapezoidal shapes of length of 300mm by 300mm width by 65mm were marked out using scribe, meter rule and try square.
- The marked lines are cut using grinding wheel.
- The four pieces were welded using electric arc welding machine to form the hopper.

4.1.2 Extruder Barrel

The extruder barrel is made up of a cylinder of length 700mm the inner diameter of 84mm and a thickness of 6mm respectively. The steps involved in the construction of the heating chamber are:

- A hollow mild steel tube of 700mm length, 84mm inside diameter and 6mm thick was faced on both side to length 550mm and a diameter of 80mm on the lathe machine.
- At one of its end an opening was made of 65mm by 65mm using scriber to mark out and grinding machine to cut.
- The hopper was coupled to the heating chamber by welding using electric arc welding machine.
- The extruder barrel was wrapped with the barrel heaters and bolted to tighten it to the extruder barrel.

4.1.3 Screw Shafts

A mild steel screw shaft of length 1300mm with diameter 90mm diameter was faced and cut to 70mm diameter and length of 550mm using lathe and grinding machine respectively, further turning was carried out at length of 70mm from the left side of the shaft to a diameter of 30mm to accommodate the pulley and bearing, the other side was also turned through a length of 54mm to accommodate the bearings. The steps involved in design of shaft:

- A screw shaft having a pitch of 70mm, length 1300mm and 90mm faced and turned to a length of 550 mm and diameter of 70mm.
- Further turning to a 30mm diameter at a length of 70mm at the left hand side and 54mm at the other side was carried out.

4.1.4 The Die

A hole of diameter 3mm was drilled.

4.1.5 Frame

The frame was fabricated with two mild steel angle bar of 45mm by 45mm and 4mm thick of length 5500mm. The steps involved are:

- Four pieces of 1000mm four pieces of 800mm and six pieces 410mm were marked out using scriber, metre rule and try square.
- These marked lines were cut using grinding machine.
- The pieces were assembled and welded with arc welding machine to make the frame.

4.1.6 Bearing

Two 30 mm bore, single row rolling bearings were purchased from market.

4.1.7 The Pulleys

Two cast iron pulleys, one of diameter 180 mm and other diameter of 320 mm were purchased from market.

4.1.8 Electric Motor

A single phase 1hp capacity of 1450rpm speed electric motor was purchased from the market.

4.1.9 Belt

A two belt of 'A' type was purchased from the market.

4.1.10 Barrel Heaters

Three 2.5kW heaters made from stainless steel were bought from the market.

4.1.11 Reduction Gears

A reduction gear was bought from the market.

4.2 Assembly

After fabricating the various parts of the machine, they were inspected to ensure conformity with the designed specification after which assembling of the parts commenced.

The assembly was carried out on cleared floor space. The sequential steps are;

- 1) The angle iron was cut into sizes and welded to produce a frame.
- 2) The reduction gear was mounted on the frame.
- 3) The extruder barrel with the welded hopper were bolted to the frame of the machine.
- 4) The conveying screw (power screw) was inserted into the extruder barrel and it was supported by bearing at both ends.
- 5) The reduction gear and extruder barrel were coupled together.
- 6) The barrel heaters were wrapped on the extruder barrel and wired.
- 7) The entire body of the assembled machine painted to give it an esthetic outlook and most importantly to minimize the effective of corrosion.
- 8) The electric motor was mounted and bolted on its based.
- 9) The driven pulley was also fitted with the aid of a square key and the alignment w for each was checked and adjusted.
- 10) The belts (v-belt) were installed.

4.3 Principle of Operations

The machine is a power driven, the machine was switched on for 20minutes. The aim for this is to make the extruding barrel hot. Crushed plastics are loaded into hopper and feed into the barrel, this materials enters through the feed throat and come in contact with the screw to start extruding.

The rotating screw pushes the crushed plastics forward into the barrel which is heated and melted to molten plastic. A heating profile already set, which are 3 independent heater zones to gradually increase the temperature of the barrel. Then collect the extruded plastics in a container from the end of the extruder barrel.

4.4 Testing

The plastic extruding machine was tested with and without loading. The machine was switched on from the source and was allowed to run under no loading condition for 20minutes and it was observed that the machine was hot.

The machine was now tested by switching it on to run for 20minutes. The crushed plastics was then poured in through the feeding unit in small amount and later increased, the machine was not able to extrude the melted plastics through the die. On removing the die, the molten plastic started coming out in.so the die was placed back, it was also observed that the melted plastics could not again be extruded through the die. The die was then removed again but this time the plastics melted beyond its melting temperature which produced a choking smell.

During the testing, the problems observed are;

- Overheating of the crushed plastics due to absent of regulator to control the temperature.
- The molten plastic was not able to be extruded due to the size and shape of the die.

4.5 Cost Analysis

Since productivity is a measure of how efficient resources are utilized and managed in order to achieve the desired objectives or goals. Thus, a product is not complete unless the cost of design and construction of the product is evaluated.

The factors considered in costing this project are; material cost, labour cost and miscellaneous cost.

4.5.1 Material Cost

The cost of all materials used in the fabrication of the extruding machine which includes the materials, the cost and the quantity used are shown in the table below.

<i>S/N</i>	<i>Materials</i>	<i>Quantity</i>	<i>Unit price</i> <i>(N)</i>	<i>Total</i> <i>Amount(N)</i>
<i>1</i>	<i>2mm mild steel sheet</i>	<i>½</i>	<i>30,000</i>	<i>15,000</i>
<i>2</i>	<i>Mild steel tube 84mm internal diameter</i>	<i>1</i>	<i>15,000</i>	<i>15,000</i>
<i>3</i>	<i>45mmx45mm of thickness 4mm angle iron</i>	<i>3</i>	<i>4500</i>	<i>13,500</i>
<i>4</i>	<i>Ø12.5 inches pulley</i>	<i>1</i>	<i>2000</i>	<i>2000</i>
<i>5</i>	<i>Ø4 inches pulley</i>	<i>1</i>	<i>1500</i>	<i>1500</i>
<i>6</i>	<i>Electric motor</i>	<i>1</i>	<i>20,000</i>	<i>20,000</i>
<i>7</i>	<i>“A” type belt</i>	<i>1</i>	<i>350</i>	<i>350</i>
<i>8</i>	<i>Mild steel electrode (12 gauge)</i>	<i>1</i>	<i>1000</i>	<i>1000</i>
<i>9</i>	<i>Extruder heater</i>	<i>3</i>	<i>9000</i>	<i>27000</i>
<i>10</i>	<i>Bearing Ø 30mm</i>	<i>2 piece</i>	<i>1500</i>	<i>3000</i>
<i>11</i>	<i>Screw shaft of Ø 80 mm</i>	<i>1</i>	<i>9000</i>	<i>9000</i>
<i>12</i>	<i>A mild-steel rod of Ø 30mm</i>	<i>5</i>	<i>1000</i>	<i>5000</i>

Total= ₦97, 350.

4.5.2 Labour Cost

Most if not all, of the manufacturing operation were done by the group members. The various manufacturing operations and corresponding that would have been incurred are shown in the table below:

OPERATIONS	DESCRIPTION	COST(N)
Grinding	<i>The hopper, extrusion barrel, shaft, stand or Base.</i>	<i>2,000</i>
Lathe work	<i>Facing and turning</i>	<i>1,000</i>
Drilling	<i>Different size of holes bolting and orifice were drilled</i>	<i>1,000</i>
Welding	<i>Joining of different parts to unit</i>	<i>5,000</i>
Assembling	<i>Coupling of various unit together</i>	<i>2,000</i>
		Total= ₦11, 000

4.5.3 Miscellaneous Cost

This involves other non-manufacturing cost as follows:

Transportation: ₦5, 000

Total miscellaneous cost= ₦10, 000

Grand total= Material cost + labour cost + Miscellaneous cost

$$= 97,350 + 11,000 + 15,000$$

$$= ₦ 123,350.$$

4.6 Safety and Maintenance of the Machine

Safety is an act of avoiding the occurrence of accident while maintenance is the act of carrying out certain precautions for better performance. The following safety and maintenance should be observed when operating the machine;

- All component should be in the position before starting the machine.
- Avoid physical contact with extruding barrel or die.
- Wear safety apparatus.

- If any problem is notice, first switch off the machine before addressing the problem.
- Avoid looking directly into the hopper.
- The machine should be clean before and after operation.
- Always switch off the machine directly from the source after operation.
- Lubrication of rotating parts should be properly done.
- Routinely maintenance of machine is recommended for better performance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The design, construction and testing of a plastic extruding machine as part of a plastics recycling plant was completed and tested. The machine is capable of melting crushed plastics. The extruding machine is designed and constructed to enhance economic value, provide raw materials for plastic industries and environment.

The machine can be operated in any part of the country with electric power supply. The machine can be operated by even unskilled persons.

5.2 Recommendation

The following are recommended based on the problem encountered after testing the machine:

- The extruding machine should be improved by providing a temperature regulator to control the heat.
- The die should be designed and reconstructed for better extrusion of the melted plastic.

REFERENCES

- Abdullahi Y, Sa'ad A.B, Suleiman H.A, Tukur S.G, Nuhu M, Adnan A.M, Zakari B.Z, (2015). Design and Construction of a Modified Thermoplastic Crushing Machine. Department of Mechanical Engineering, Bayero University Kano.
- Adetola, O.A, Olajide, J.O and Olausi, A.P, (2014). Internal Journal of Scientific and Engineering Research, vol 5, page 1418. An introduction to plastics recycling. (2009).
- Andrew O.O, Festus A.O and Joe K.O, (2012). Industrial Engineering Letters, vol 2, pages 42 and 43 AZO materials, (www.azom.com/article.aspx?ArticleID=2047), (www.azocleantech.com/article.aspx?ArticleID=254), (November, 2016)
- Brandrup, J., recycling and recovery of plastics, 1996, Haner Verlag.
- Chee, W, 2010. A study of plastic recycling supply chain. Hull city.
- Gbasouzor .A.I, Ekwuzor. S.C and Keneddy. O.C, (2013). Proceeding of the congress on engineering, U.K London, Vol 1.
- Jamiu Y, Ahmad T.A, Sagiru M, Kabiru Y, Suleiman H.I and Abubakar A.A. Design, onstruction and testing of oil extraction machine, Department of mechanical engineering, Bayero University Kano. (2011)
- Jawad. A.b, (2010). Current state and potential for increasing plastic recycling in U.S. Columbia.
- Khurmi, R.S and Gupta, J.A (2005). A textbook of machine design. New Delhi.
- Kreso, J and Jenkinson, S (2012). Redesign of a single screw extruder. Worcester.
- Muhammed K.O, George F.E, Adeshina W.A, Aminu M.M and Taiwo M.M. (2013). Design, Construction and Testing of a Soap Plodder. Department of Mechanical Engineering, Bayero University Kano.
- Prof. Kusekar S.K, Morajkar C.E, Kashid S.N, Hipparkar K.S, Deshpande V.S, Assistant professor department of mechanical engineering, A.G.P I.T.Solapur, Maharashtra india. 2 students of the mechanical engineering department A.G.P. I.T., Solapur Maharashtra, india. (2015). International research journal of engineering and technology. Vol 2, pages 184-190.
- Rao, S.N and Schott, R.N (2008). Understanding Plastics Engineering calculations. Munich. Recycling plant practical action.
- Richard A.F, (1992). Design of recycling; a plastic bottle recycler.
- The Engineering ToolBox, (www.engineeringtoolbox.com/thermoplastics-properties), (November, 2016)

Thomasnet, (2016).Understanding Plastic Extrusion. Thomas publishing company.

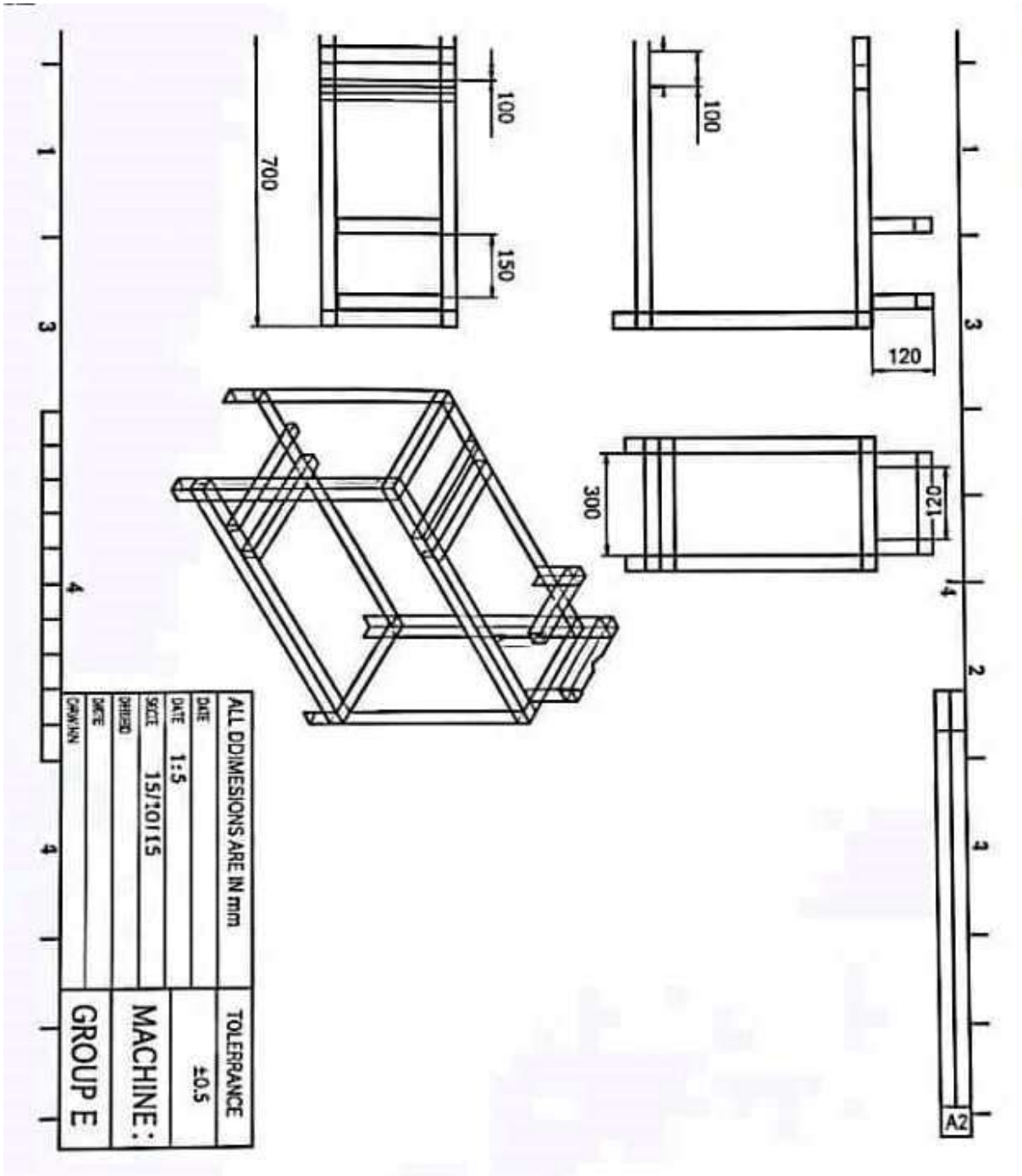
Ugoamadi, C.C and ihesiulor, O.K (2011).Nigerian Journal of Technology, vol 3, pages 72-77.

www.alibaba.com/showroom/price-of-plastic-extrusion-machine.html (November.2016)

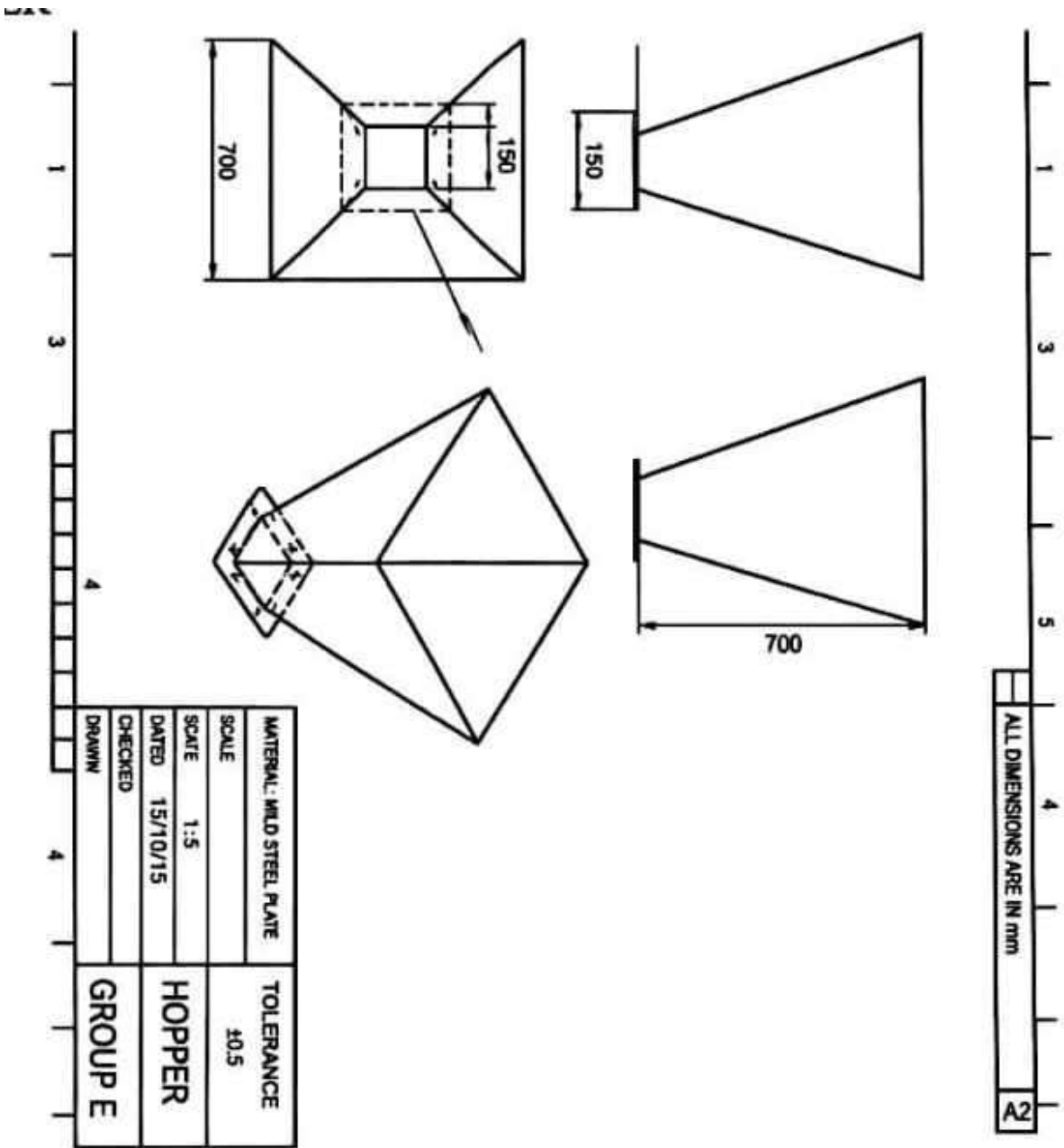
www.historyofplastic.com (July, 2016)

APPENDIX

FRAME

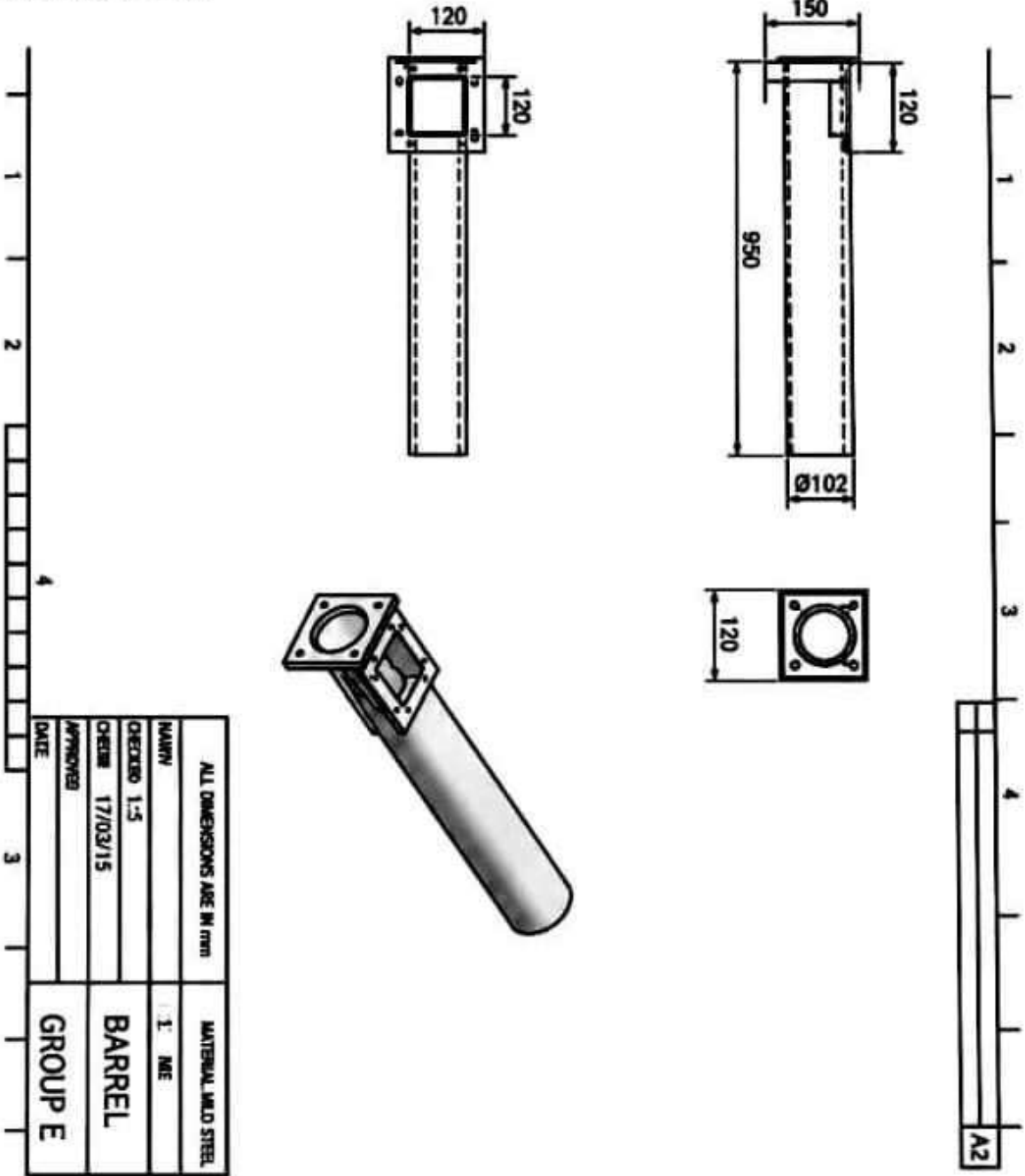


HOPPER

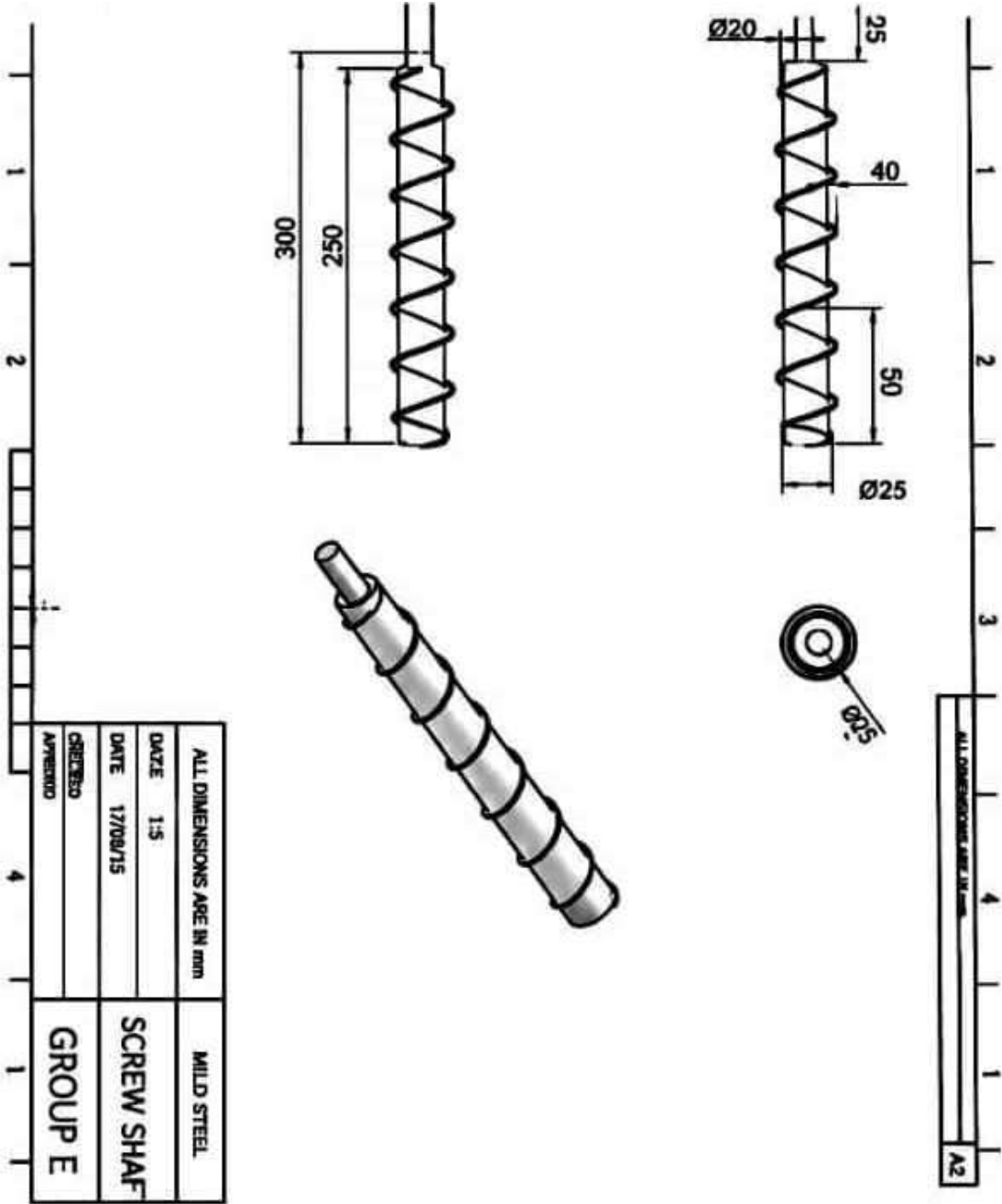


EXTRUDING BARREL

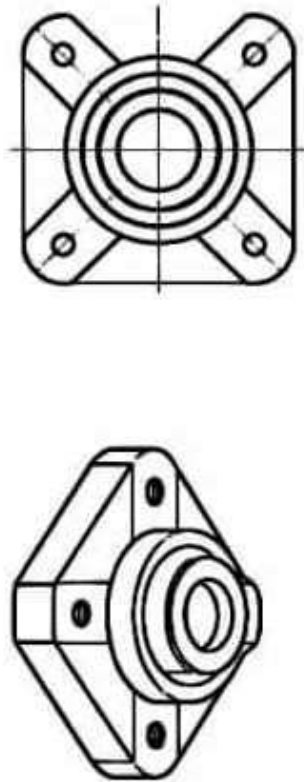
EXTRUDING BARREL



SCREW SHAFT

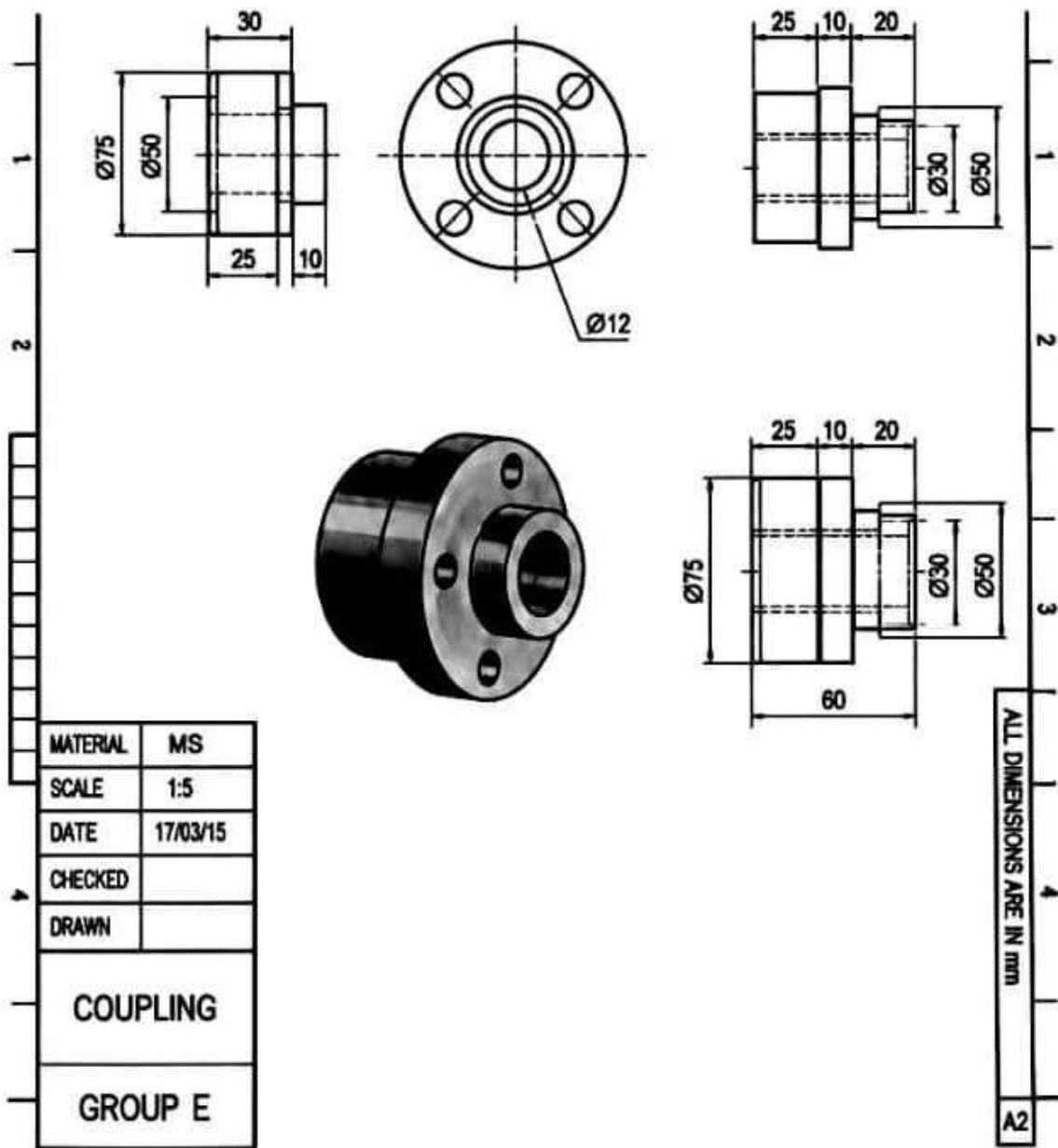


554

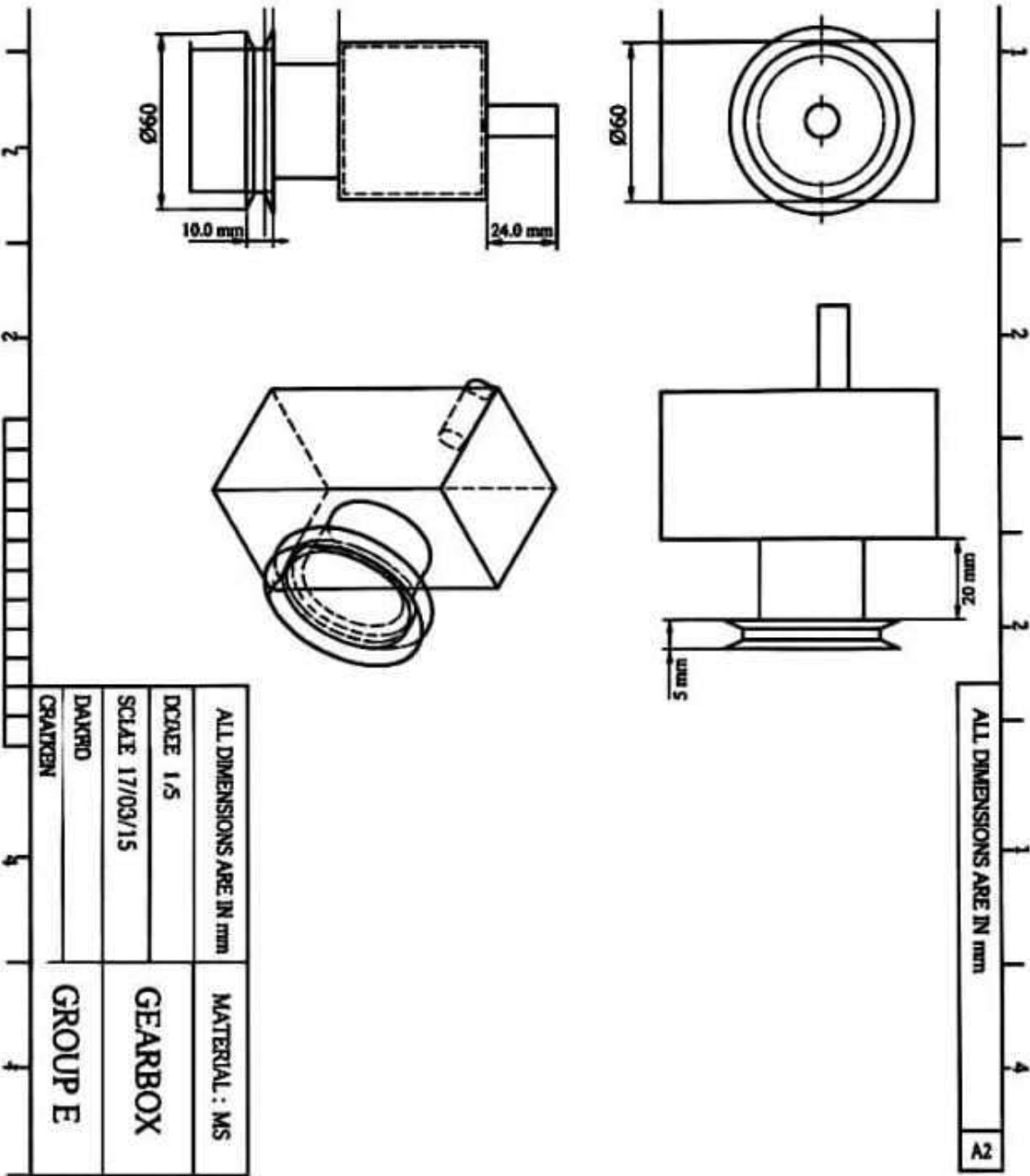


ALL DIMENSIONS ARE IN mm	MATERIAL
SCALE 1:5	BEARING
DATE 17/03/15	
CHECKED	
DRAWING	GROUP E

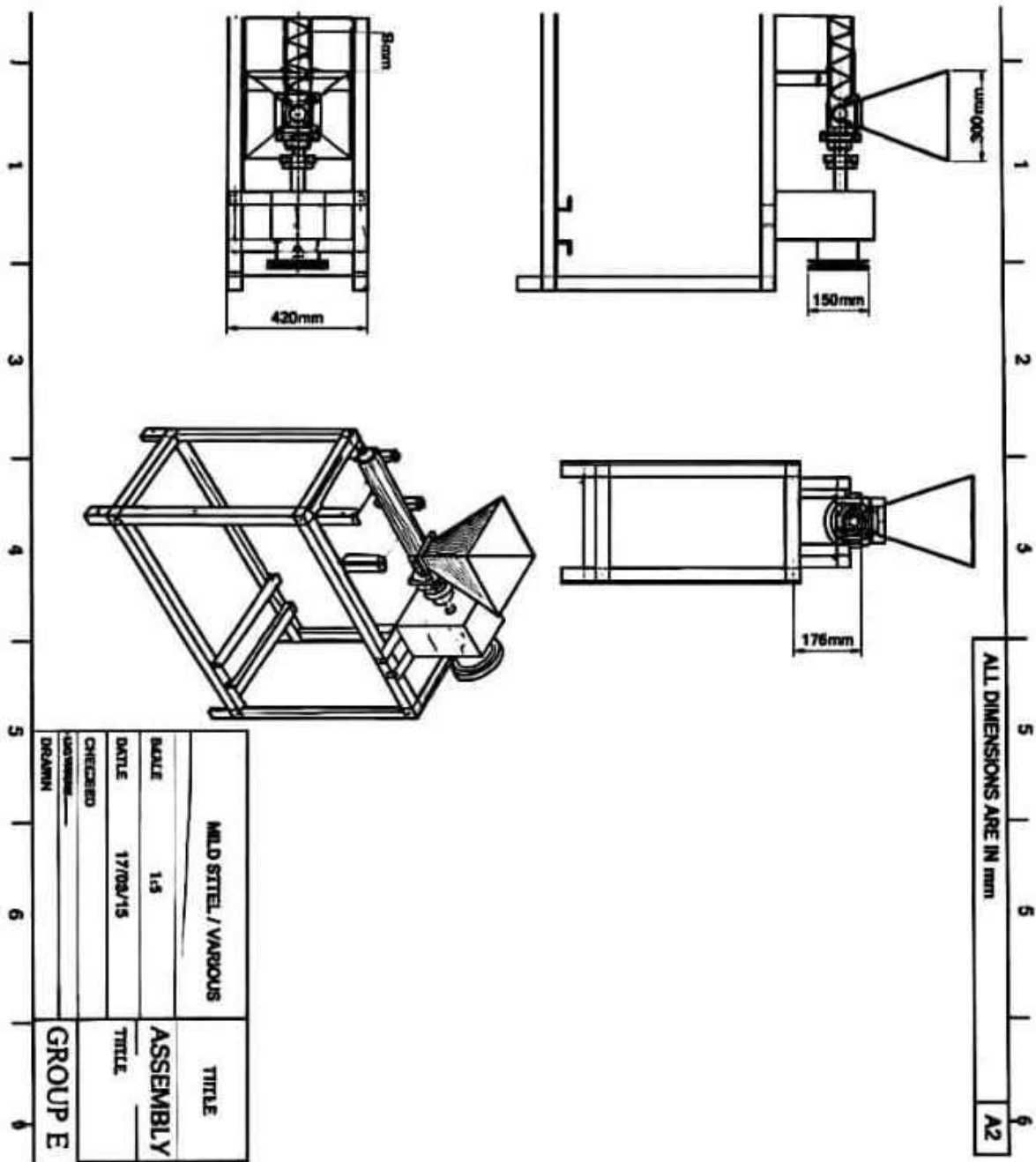
COUPLING



REDUCTION GEAR



ASSEMBLY



PLASTIC EXTRUDER

