# DESIGN AND FABRICATION OF RECYCLE CONVERTED PLASTIC WASTE INTO 3D PRINTING FILAMENT

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**Abstract:** *Nowadays one of the biggest drawbacks in 3D printing is the relatively high cost of filament, i.e. the 3D printer (thermo-) plastic, the "consumable" for your 3D printer. Prices for 3D printers have been continuously dropping, but filament prices did not follow the same path. Agreed, filament availability is far better than 2 or 3 years ago, as are color choices. Even the materials for 3D printing are becoming more and more varied and readily available. This is where home or desktop filament extruders come into play. Some cunning makers/inventors have been developing a way for private individuals to produce their 3D printer plastic at home, at only a fraction of its retail price. They developed a so-called "filament extruder" for home use, i.e. a machine capable of spewing out plastic filament which you can afterward use in your 3D printer. The photo below shows you how such an extruder looks like. Let's have a quick look at these machine's working principles before analyzing the filament production process as well as raw material prices.*

***Keyword:*** *Design, Fabrication, Recycle, Productivity, 3D Printing*

## 1. INTRODUCTION

The main aim of this work is to reduce the plastic waste that is rising in the present world and to achieve this; a system is designed incorporating a plastic extruder which plays a prominent part in recycling waste plastic into useful products. This work uses waste plastics and converts them into building materials with the help of an extruder, thereby reducing plastic waste which is a key factor for environmental pollution. Presently waste plastics are effectively converted into useful building materials like bricks, interlocks, roof tiles, railway sleepers, paving slabs, retaining blocks, etc., using either single-origin plastic waste material or a mixture of different plastic wastes along with waste rubber powder as filler. Thermoplastics can be heated up to form products and then if these end products are re-heated, the plastic will soften and melt again. These include PET, HDPE, LDPE, PP, PVC, PS, etc. Thermoset plastics can be melted and formed, but once they take shape after they have solidified, they stay solid and, unlike thermoplastics cannot be re-melted. These include Multilayer and Laminated Plastics, Bakelite, Polycarbonate, Melamine, Nylon Etc.

## 2. MOTIVATION AND OBJECTIVES

### 2.1. Motivation

'3D-printing' is a versatile and emerging technology that is utilized across the world. 3D-printing require a filament to process. The cost of filament governs the cost of 3D-printed objects costs. Filament extrusion machines are usually available for industrial use, capable of creating hundreds of feet of long filament in a day. So these filaments are expensive for many end-users. This work will make easily available filament extruder to small scale industries and colleges. As the manufacturers have to buy these filaments from various vendors, the cost of 3D printing increases. To overcome the problem faced by the manufacturers, small workshop owners, the need for 3D-filament making machine arises. This project focuses on designing and fabricating a portable fused deposition 3D printer filament making machine with cheap and easily available components to draw 1.75 mm diameter ABS filament.

### 2.2. Objectives

Considering the requirements here an essential to justify a substitute to the responsibility in consuming to purchase from a supplier-base, a filament. It could be attainment to achieve, in an in-house production for own purpose, the compulsory measure of materials. The main theme of our project is to produce the extruder machine at a low cost. We can use the recyclable plastics in this process. The objectives identified to fulfill these requirements are listed below:

1. To develop a 3D printing filament making extruder that can be used by small scale manufacturing units, companies, colleges who have portable 3D printer in-house
2. To Perform design calculations to base the development of filament making extruder
3. To satisfy the in house requirements for the production of filament

## 3. LITERATURE REVIEW

As 3D printing is growing fast and giving a boost to product development, the factories doing 3D printing need to continuously meet the printing requirements and maintain an adequate amount of inventory of the filament. Today there are bounty choices while picking a printer and a variety of organizations that fabricate, what's more, sell these printers. In any case, the majority of the 3D printer depends on the Fused Deposition Method, which employments, for the most part, PLA and ABS as the printer material. This expulsion based 3D printer utilizes a wired fiber of measurement 1.75mm or 3mm for printing. So a large portion of the assembling units, organizations, universities who have the 3D printer in-house are reliant on outsider providers and need to purchase the 3D printer fiber from these providers. Many different materials can be used for 3D printing, such as ABS plastic, PLA, polyamide (nylon), glass filled polyamide, stereolithographic materials (epoxy resins), silver, titanium, steel, wax, photopolymers and polycarbonate [1]. The results of the research affirm a positive relationship of access to AM devices to perceived interest, motivation, and ease of learning of mechanical engineering. Entry-level additive technologies offer a hands-on experience within academia, fostering the acquisition of technical knowledge [2]. Available material for 3D printing costs high and the plastic filament used is manufactured and it is mostly imported. To reduce the manufacturing cost and plastic filament's cost, this extruder machine is developed [3]. The extrusion process was analyzed using Taguchi and ANOVA methods. The results of this study indicate that the spooler speed of 4 rpm, extrusion speed of 40 rpm, and extrusion temperature of 200°C in the parameter setting produces an average filament diameter of 1.6 mm [4]. Manufacturers and producers are using 3D printers for fabricating parts at various points in the production line, including manufacturing tools, jigs. A part that is printed on a metal-3D printer, surfaces machined to enhance its finish and separated from its build-plate using a wire-EDM could be an inspiring instance of modern-manufacturing technology, however, it wouldn’t count as an instance of hybrid-manufacturing [5]. Taguchi method is unable to deal with multi-response problems that are of main interest today, owing to the increasing complexity of manufacturing processes and products. Several recent studies have been conducted to solve this problem. But, they did not effectively treat situations where responses are correlated and situations in which control factors have continuous values [6]. The recent work is to design and develop a tabletop filament extruder were the materials which had got wasted during the 3D printing process can be collected and reformed into a filament for reuse. This proposed system also overcomes all the disadvantages [7]. In 3D printing, a good finish must be offered as a product result. It needs to be solid and durable; therefore, the produced filament should yield good final results, durable and resistant. In this project, the tailored processed filament is characterized by checking its tensile stress and comparing its results with commercial filaments [8-9]. Fabrication of Basic Screw Extruder to Manufacture 3d Printers Filament was discussed [10]. Much researches have been attempted towards the stability, improvement of surface characteristics, process parameter study but very limited work carried out on the sustainability issues. Environmental sustainability and energy efficiency factors are key factors for the better utilization of the resources [11-12]. With the gradual development of 3D printing technology FDM (fused deposition modeling), ie the fritting of the thermoplastic in the shape of the fibers and putting it into the layers, more demands are placed on the materials used [13]. New metal/polymer composite filaments for fused deposition modeling (FDM) processes were developed to observe the thermo-mechanical properties of the new filaments. The acrylonitrile butadiene styrene (ABS) thermoplastic was mixed with copper and iron Particles [14-15]. Multi-objective evolutionary optimization algorithms (MOEA) are used for the optimization of plasticizing single screw extrusion. Extrusion machines are usually sized for industrial use, capable of creating hundreds of feet of filament a day. This filament is expensive to purchase, and many end-users would prefer to extrude their filament, from a virgin plastic input or plastic waste input. There are no home-scale filament extruders on the market for Polyethylene Terephthalate (PET) plastic waste. For this purpose, a specific MOEA is linked to available process modeling routines [16]. The methodology is used to set the operating conditions and identify the screw geometry for a specific case study, thus demonstrating the practical utility of this approach [17].

## 4. METHODS AND METHODOLOGY

### 4.1. Components Filament Extruder

A single screw extruder available in the market for injection molding has the following components:

### 4.2. Screw Conveyor

The screw conveyor is a screw rod with variable core diameter, generally increasing core diameter and with varying pitch or constant pitch. The function of the screw conveyor is to transport the material from the hopper to the extrusion head and also creates s build-up in pressure. It has three sections, feed section, conveying section, and metering section.

### 4.3. Drive train

The drive train consists of a high torque motor and a gearbox. The drive train is used to rotate the screw conveyor at a constant speed.

### 4.4. Feeding Unit

The feeding unit is in the form of a hopper that can hold enough quantity of raw material for one batch and is designed to provide the exact amount of raw material at a constant rate.

### 4.5. Heating System

The heating system uses the principle of inductive heating to melt the raw material in the barrel as it is being conveyed along the length of the screw. It can be either clamped onto the barrel or wound on to it.

### 4.6. Casing

The casing is in the form of a steel barrel that encases the screw and supports the bearings which support the screw.

### 4.7. Extrusion Head

The extrusion head is fixed at the end of the screw conveyor. Its function is to compress the molten material and extrude the material in the required form.

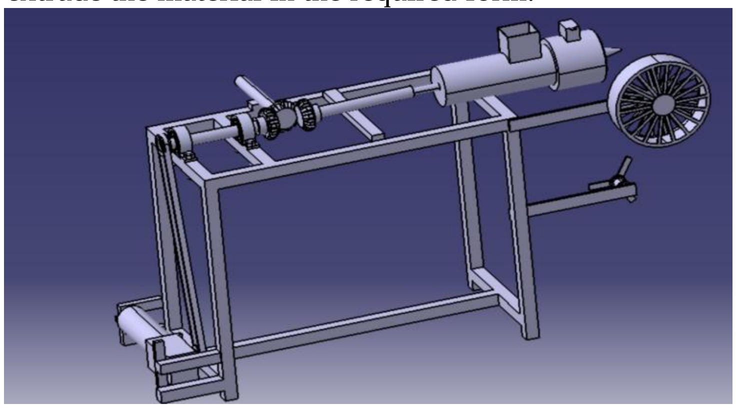

**Fig. 1.** 3D Printing Filament Extrude Machine Diagram

The design of the 3D printing filament extrude machine is shown in Figure 1. The methodology and stages in designing of the proposed model are shown in the Flow chart represented in Figure 2.

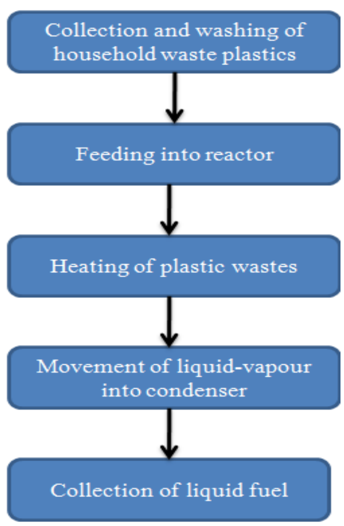


**Fig. 2.** Process flow of the proposed model

### 4.8. Proposed Methodology

This methodology consists of fabricating filament feedstock to be used for the fabrication of 3D printed mechanical test samples. The recycling process consists of the re-extrusion of the material up to of five cycles in total. For every extrusion process, a set of characterization tests are performed, as follows

(1) size-exclusion chromatography (SEC)
(2) Rheology
(3) Melt Flow Index (MFI).

These tests are made after the extrusion process. It is intended to correlate the mechanical performance of the 3D printing samples with the morphological structure of the recycled polymer. Figure 1 shows the methodology proposed.

 

**4.9. Step by Step Process**

The step by step process of working has listed

**4.9.1. Grinding-** After collecting the bottles, which are the PET plastic waste used to work with, the first stage is grinding the bottles, to shred the material into pieces of small size, so that they are a suitable feedstock for extruders.

**4.9.2. Washing-** Research on this operation has been useful to know how companies or other authors do the plastic washing process. Characteristics such as temperature (room, 40°C, 65°C), the agitation type according to employ glass bar or net bag, washing phases, and the idea of reusing rinse water.

**4.9.3. Drying-** The third operation of the circular economy process, is the drying process. This is essential due to the characteristics of the PET material as it tends to absorb water from the environment because of hygroscopicity, which is a tendency of a solid substance to absorb moisture from the surrounding atmosphere.

**4.9.4. Extrusion-** After doing the aforementioned processes the material should be cleaned and dried and ready to the procedure to the extrusion. This dissertation pursues to develop a suitable methodology to produce a recycled filament as a feedstock of 3D printing.

**4.9.5. Printing**- After accomplishing all the previous operations the filament is ready to be used in the printer. This filament will be the feedstock of the 3D printers which have the function to effectuate the printing operation.

**5. COMPONENTS**

**5.1. Hopper-**Changing the machine to a vertical orientation necessitated a redesign of the hopper from AkaBot 1.0. We chose a gravity-fed hopper design because of its simplicity as shown Figure 3. The material is loaded at the top of the machine and then as the auger picks up material, the pressure due to gravity keeps the material flowing to the input part.  is a computer rendering of the hopper.

**Fig. 3.** Hopper

**5.2. Band Heater-** There are three 250 Watt band heaters on the outside of the chamber. These band heaters are 2.000 in (5.08 cm) in length and operate on 120 VAC. They are made by Tempco and are in the same product line as those used on AkaBot 1.0. They have a maximum temperature of 482°C (900°F), making them an ideal choice as represented in Figure 4..

 

**Fig. 4.** Band Heater

**5.3. Temperature Regulator-** There are two independent control systems, the heating system, and the motor, that control the various aspects of the machine and ensure that it is functioning properly to create a uniform filament. The temperature regulator is shown in Figure 5.

**Fig. 5.** Temperature Regulator

**5.4. 12 V DC Motor-** The motor for the system is a 10 RPM motor with a stall torque of 368 oz-in (26.5 kg-cm). The motor is controlled by a Single Pole Single Throw switch. This switch is wired in series with the power source from a 12 V supply and the motor. This was the simplest control system. It is a single-speed system with the revolutions per minute selected by the speed of the motor and the gearing between the motor and the auger. The motor used in the present work is shown in Figure 6. The gear ratio was selected to be 2.5:1, resulting in an auger speed of 4 RPM. This speed transfer occurred using a chain drive.

**Fig. 6.** 12 V DC Motor

**5.5. Extruder Screw:** The material is forced through the length of the chamber by a screw auger. Initially, we believed this to be the most important part of the system and much of our initial design work was spent on this single component. The component shown in Figure 7. As testing progressed, we determined the importance of this part was less than anticipated and we could use a cheaper solution.

 

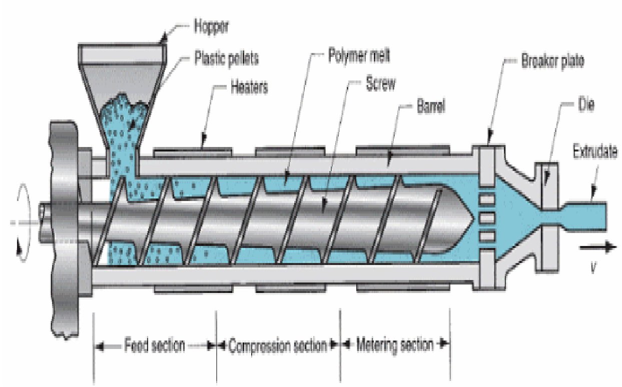


**Fig. 7.** Extruder screw

**5.6. Chain Drive:** Chain drives normally transmit power from one rotating shaft to another. Chain drives maintain a positive speed ratio between driver and driven sprockets. The chain drive used is shown in Figure 8. The driver and driven sprockets will rotate in the same direction on typical chain drives.

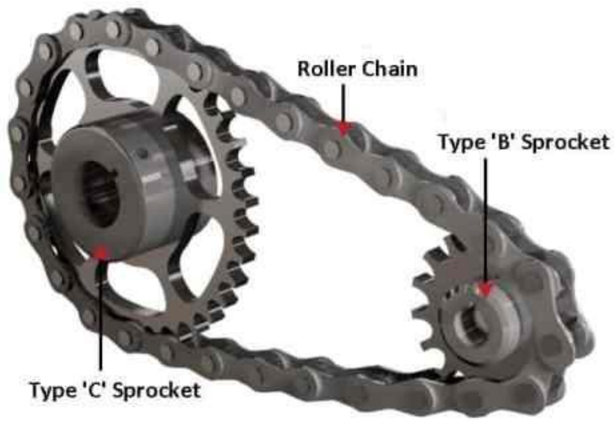


**Fig 8.** Chain drive

**5.7. Extraction Die-** The die is made from 360 Brass. We chose this material for a variety of reasons. The temperature on the die needs to be controlled very precisely to make sure the material does not begin to solidify in the die, but it also cannot be so hot that it takes a long time to cool when it comes out the end. The extraction dies are shown in Figure 9. Brass has a melting temperature of 930°C, meaning we did not have to worry about material deformation. It also has a high thermal conductivity so that it can transfer its heat.


 

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**Fig. 9.** Extraction Die

### 5.8. Design

**Commands used-** Fly Through, Fit View, Layer control, Pan, Rotate, Zoom, Normal View, Standard Views, View Types: Shaded/ Hidden, line/ Wireframe/ User Defined.

**Designing Process-**We built on the work completed by the senior design team from last year. They were able to create a working prototype of a plastic extruder that showed promising results. We refined the design, made improvements, and created a new device that can be implemented in rural India. Our primary goal for this project was to design a machine that produces a consistent filament output with the same properties as commercial 3D printing filament. The previous team was able to produce a filament, but it was not ductile enough to be used by a commercial 3D printer. We tested a variety of commercially available filaments to set specifications and tolerances for our final product. After we designed this auger and ran simulations on it, we concluded that the cost to machine the hardware would outweigh the benefits. After testing AkaBot 1.0 with an off-the-shelf auger and making a few modifications, we concluded that we could use an off-the-shelf auger and still improve the material properties by simply changing the orientation of the machine and decreasing the clearance between the chamber and the auger. The final step in creating a uniform filament was to design the die that the plastic is pushed through and then is cooled from a liquid to a solid. This die determined the final shape of the filament. We researched how the filament is affected by various spooling rates to determine the right one for our needs. The detailed view and the top view of the machine are shown in Figure 10 and Figure 11 respectively.

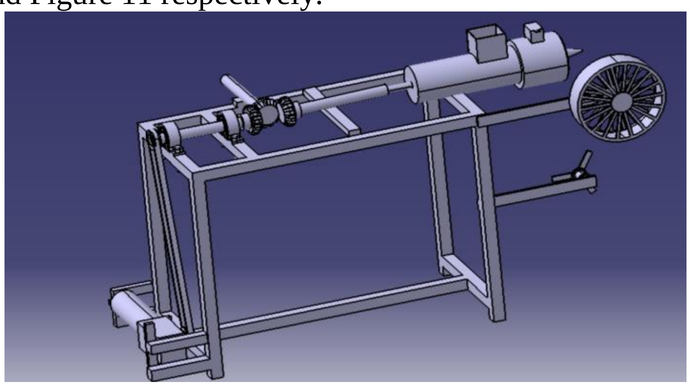

**Fig. 10.** Detailed view of the machine

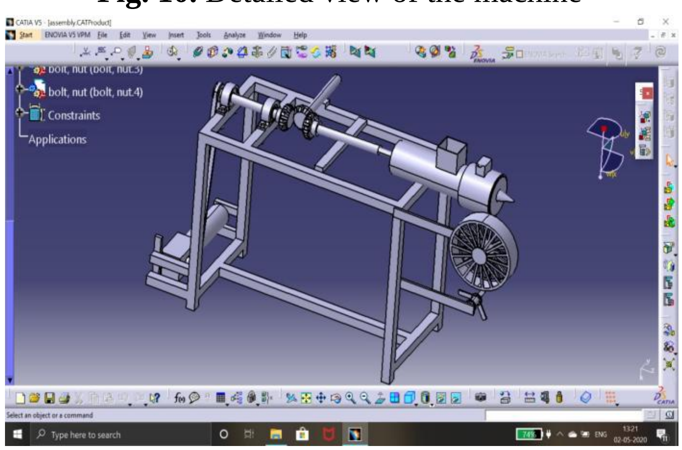


**Fig. 11.** Top view of the machine

### 5.9. Working principle

The Illustration below gives you a simple overview of the common working principles of a standard desktop-type filament extruder. The main part of the extruder is a barrel containing a screw (also sometimes referred to as an "auger" or a "drill"), which is connected to a heater (or heat chamber or heat element) towards its far end. On the other end, the screw is connected to an electric motor which will, via mechanical action, transport the so-called resin pellets) through the barrel towards the heater. Pellets are gravity-fed continuously from a hopper (a kind of feeding funnel). As the motor is continuously driving the auger, the resin pellets are pushed into the heater. The thermoplastic pellets will soften and melt because of the heat and are then pushed mechanically through a die.

**5.10. Filament Extrusion Process:** Filament is extruded from so-called "raw resin pellets". Photo number 9 gives you a good example of what these pellets look like. Note that the pellets in this photo are destined for injection molding and made from materials that may not be suited for 3D printing – if you want to purchase pellets for extruding filament at home, you need to look for pellets suited for extruding and not those for injection molding. If you are not sure about which type of pellets you are about to purchase, just drop a mail to the manufacturer or wholesaler who can help you with this matter.

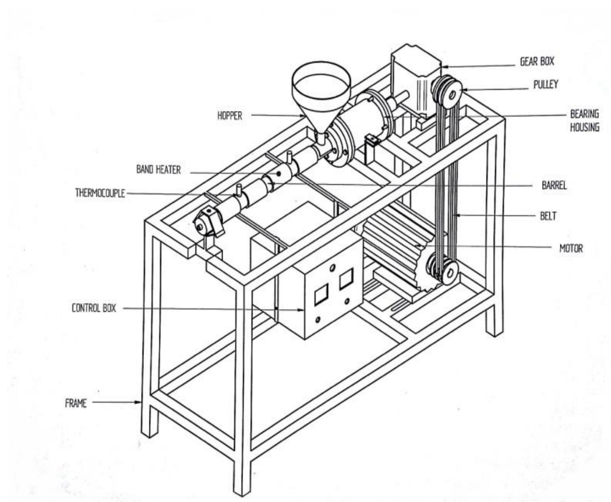


**Fig. 12.** Overall Machine Block Diagram

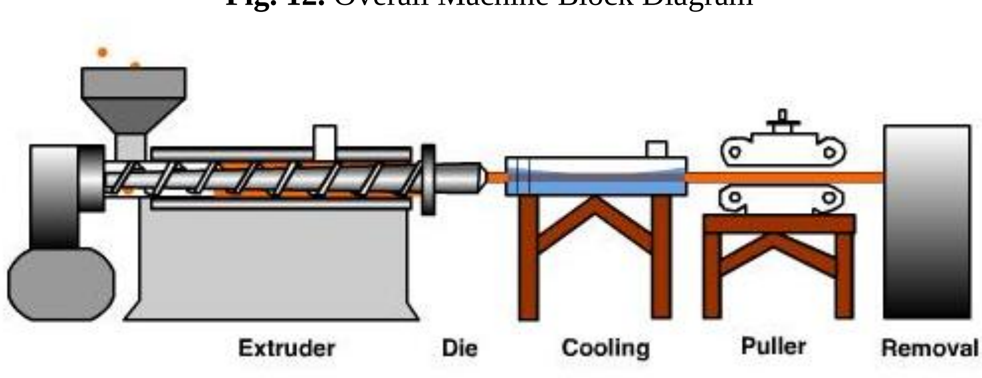


**Fig. 13.** Filament Extrusion Process Block Diagram

  

**Types of Plastics Used:** Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Polypropylene(PP)

**1. . Manufacturing**

The extrusion and the printing stages which are the most important because any previous operation is focused on achieving the suitable feedstock for both extruders and 3D printers with the purpose to make a good product and demonstrating that the circular economy related to the material is being dealt, PET bottles, makes sense to extract value when it is waste. The Filament extrusion is shown in Figure 13. Regarding the proposed extrusion scenarios, these are classified into four main groups, according to its percentage of recycled material used in the feedstock to extrude, which is also mixed with virgin material. Results proved a lower quality of recycled material compared to a virgin whose resins have different characteristics. This effect can be supported by Hu et al. (2009) who highlighted different thermo-mechanical properties between recycled and virgin PET. This behavior in the 3Devo Composer 450 could be explained by the decrease in the molecular weight of recycled PET or other parameters related to the processing whose quality is impossible to be matched to industrially processed flakes.

**5.12. Contraction of the Frame:** Give machine one of the important part is frame this frame contract to rectangular block to using of the welding operation and then other parts will be joint to frame

**5.12.1. Motor Specification**: Model – 12V DC Motor. Features 12V – 200RPM – 3.6KG•CM torque DC gear head motor 30:1 Gear Ratio

**5.12.2. Construction of Hopper and Extrusion Screw:** Frame is to be fitted to the barrel and bevel gear mechanism to the connection of extrusion of the die hopper and barrel is welded to the permanent joint and the barrel one end is closed to the disc type of the metal and another side of the barrel is connecting to the extrusion die.

**5.12.3. Filament Characterization:** The formed filament will be mechanically characterized. Mechanical properties such as strain stress, yield strength, hardness, impact strength, or bending are essential tests a baseline to all newly manufactured materials.

**5.12.4. Overall Assembly:** Extruder screw is kept inside the barrel. The barrel is mounted on the frame. The barrel is connected to the gearbox and the gearbox gets the power from the electric motor through the pulley and belt. Extruder die is kept at the front of the barrel. Heaters are placed around the barrel and the die heater is placed around the die. Three-phase AC supply is given for the heaters and a single-phase AC supply is given for the electric motor.

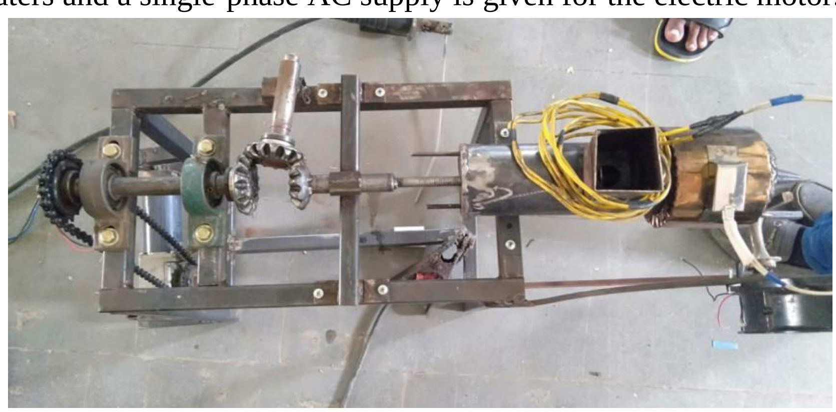

**Fig. 12.** Overall Assemblies

## 6. CONCLUSIONS

In summary, the goal of this project is to create a PET filament from recycled plastic water bottles that meets the same standards as commercially available spools for 3D printing. The overall assembly is shown in Figure 12. Beginning with plastic water bottle shreds made design will melt and extrude the filament through a cooling system, which will then be spooled and ready for use. This process is important because it will give individuals in rural communities access to a cheap filament, thus making 3D printing an accessible means of advanced manufacturing. The importance of this project stretches beyond recycling, to the need for grassroots entrepreneurship in many low-income areas. With access to low-cost manufacturing techniques, local enterprise and vocational training can help improve the lives of many, leading to an increase in the number of small businesses and jobs in rural communities.

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