Design and Fabrication Recycling of Plastic System

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Abstract— Plastics are inexpensive, lightweight and durable materials, which can readily be molded into a variety of products that find use in a wide range of applications. Recycling is one of the most important actions currently available to reduce these impacts and represents one of the most dynamic areas in the plastics industry today.

The present work en compass (design and fabrication shredder/crusher and extruder of plastic machines) the shredder/crusher of plastic machine is consisting of the four main parts; they are system drive, box, hopper and three blade rotating cutter. Crushing is the process waste into smaller size approximately 0.5 –1cm. The size can be varied depending upon the blade placement with in the crusher. The plastic wastes after segregation fed into the crusher through a Hooper undergo crushing between the stator and rotor. The rotor is driven by an l/2 hp electric motor. The crushed particles there after moves into the extruder of breaking down the plastic.

The extruder of plastic machine is consisting of the five main parts; they are hopper, drive of screw, barrel, and nozzle (die), heaters and control system. Extruder is the prime part of the machine where in the crushed particles gets drawn into wires through a die. Screw is the heart of the extruder, which employs heating element through its length .The heat for melting the Crushed plastics is controlled using a heating control unit. The Screw, which is motor driven conveys the molten Plastic to the opening of the die.

Keywords— Plastics recycling, Density of polymers, Shredder, Extruder of plastic machine and, Mass flow rate.

1 Introduction

Recycling is a complex method of environment protection, which aim is the limitation of the raw materials consumption and decrease of waste quantity. It should be a multiple system of the same materials using in the next material and usable goods [1].

In practice, recycling is often the necessity and it always becomes the only reasonable strategy of the working if consider waste formation in the End of Life phase – EoL [2]. Every product has to be designed, produced, sold, consumed or exploited and every product, after time, doesn't satisfy the needs because of the physical or moral consumption [2, 3].

It becomes waste. The EoL analysis leads to resources sustainment model. Product recovery as an elongation of product life cycle can concern the whole products, theirs components and materials and raw materials, generally recovered value. The basic possibilities of recovery: reuse, remanufacturing, reclaim, recycling Fig. 1.

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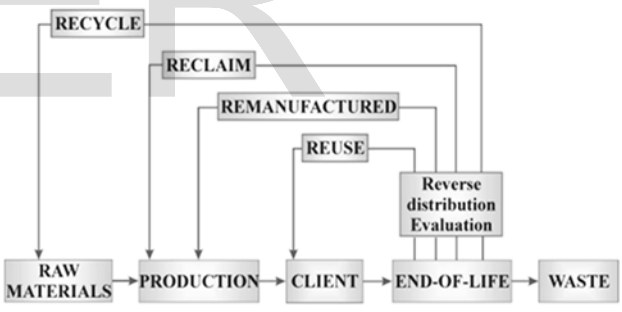

Fig.1 Schema of EoL recovery system [2]

1.1 Roles of recycling

Recycling has both environmental and economic benefits.

a. Recycling helps to conserve natural resources

b. Recycling helps to save money.

c. Recycling conserves energy.

d. Recycling saves landfill space

e. Recycling provides jobs for people

f. Recycling provides alternate materials.[4]

1.2 Recycling methods

The most beneficial and durable way of waste problem solution is avoidance of waste formation. The healthy for the environment life style, goods consumption and waste treatment promotes 3R principle.

The first principle (Reduce) reminds about possibility of waste quantity reduction by limitation of unnecessary products consumption.

The **second one (Reuse)** takes into consideration a possibility of products reuse which are generally recognize as disposable.

The third principle (Recycle) speaks that not all waste can be avoidance like not all kinds of products can be repeatedly usage.

Waste processing technologies containing the secondary processes make possible waste utilization on the basis of methods:

- **Chemical recycling** is the process of recycling waste products by partially altering their chemical structure with chemical processes for example fuel oil production from plastics, heat-insulating materials production, package production etc.
- **Resources recycling** consist in macromolecule degradation on fractions about molecular lesser mass, for example: hydrolysis, alcoholics, hydration and pyrolysis methods which can be reused as monomers or resources to the same (or others) chemical products production.
- **Thermal recycling** is used for waste materials assumed to be in the final disposal phase. It involves waste materials combustion using the resultant heat generated as energy. It contains production from these waste liquid, solid and gaseous fuels in the aim of energy recovery.[5]
- **Material recycling** is the most available and the most often usage method of recycling. It depends on following direct waste processing in the aim of material obtaining which is full value raw material to the further processing.
- **Biological recycling** contains oxygen treatment even composting of solid waste or oxygen-free treatment of waste which are subject to biodegradation in condition control with microorganism's usage. As a result of this transformation an organic matter or methane are generated. [6]

1.3 Plastic definition & recycling of plastics

Plastics are made up of long chain molecules called polymers. Various types of polymers can be made from hydrocarbons derived from coal, natural gas, oil and organic oils which are transformed into materials with desirable properties [7].

Waste is now a global problem, and one that must be addressed in order to solve the world's resource and energy challenges. Plastics are made from limited resources such as petroleum, and huge advances are being made in the development of technologies to recycle plastic waste among other resources. Mechanical recycling methods to make plastic products and feedstock recycling methods that use plastic as a raw material in the chemical industry have been widely adopted, and awareness has also grown recently of the importance of Thermal recycling as a means of using plastics as an energy source to conserve petroleum resources [8].
Plastics that can be readily recycled are

Thermoplastics which means they will soften when heated. *Thermosetting* Plastics harden when heated, are often used in electrical applications and are not suitable for recycling. *Thermoplastics* are light, durable, moldable, hygienic and economic, making them suitable for a wide variety of applications including food and product packaging, car manufacturing, agriculture and housing products. *Thermoplastics* can be repeatedly reformed into new products and are the focus of this technical brief [7].

1.4 Process for recycling of the recycling

The recycling of plastics is carried out in a five step process:

Step 1- Plastics collection
This is done through roadside collections, special recycling bins and directly from industries that use a lot of plastic.

Step 2 - Manual sorting
At this stage nails and stones are removed, and the plastic is sorted into three types: PET, HDPE and 'other'.

Step 3 - Chipping
The sorted plastic is cut into small pieces ready to be melted down.

Step 4 - Washing
This stage removes contaminants such as paper labels, dirt and remnants of the product originally contained in the plastic.

Step 5 – Pelleting
The plastic is then melted down and extruded into small pellets ready for reuse [9].

2. Literature Review of the Machines

2.1 Extruder Machine

Extrusion is a high volume manufacturing process. The plastic material is melted with the application of heat and extruded through die into a desired shape. A cylindrical rotating screw is placed inside the barrel which forces out molten plastic material through a die. The extruded material takes shape according to the cross-section of die [10].

2.1.1 Design screw, barrel and die

1. Screw Design

The design of screw is important for plastic processing. It has mainly three different functions: namely, feeding mechanism; uniform melting and mixing of plastic and finally it generates the pressure to push the molten material through die.

A screw length (L) is referenced to its diameter (D) as L/D ratio. Generally, L/D ratio is used as 24:1, but for more mixing and output, it may increase up to 32:1. There are three possible zones in a screw length i.e. feed zone, melting zone, and metering zone.

a. Feed zone: In this zone, the resin is inserted from hopper into the barrel, and the channel depth is constant.

b. Melting zone: The plastic material is melted and the channel depth gets progressively smaller. It is also called the transition or compression zone.

c. Metering zone: The molten plastic is mixed at uniform temperature and pressure and forwarded through the die. The channel depth is constant throughout this zone.

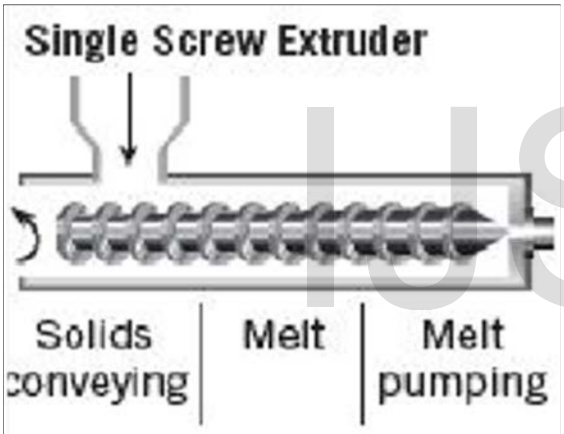

Fig. 2 cross-section of Single Screw extruder.

2. Extruder barrel

Internal diameter of barrel typically ranges from 25 to 150 mm (1.0 to 6.0 in) and L/D ratio ranges from 10 to 30. Higher L/D is used for thermoplastics and lower for elastomers Feedstock fed by gravity onto screw whose rotation moves material through barrel.

Electric heaters melt feedstock: subsequent mixing and mechanical working adds heat which maintains the melt. **[10].**

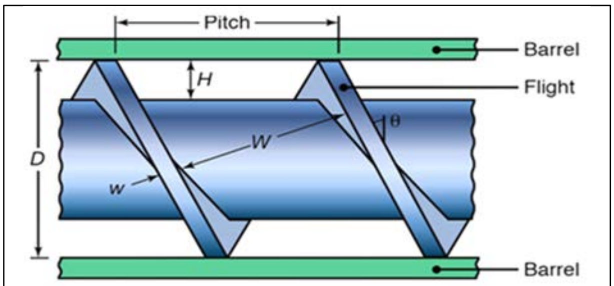

Fig.3 Details of an extruder screw inside the barrel [10].

3. Die end of extruder

Progress of plastic melt through barrel leads ultimately to the die zone. Before reaching die, the melt passes through a screen pack – series of wire meshes supported by a stiff plate containing small axial holes.

Die configurations and extruder products

The shape of the die orifice determines the cross-sectional shape of the extrudate.

Common die profiles and corresponding extruded shapes:

- Solid profiles
- Hollow profiles, such as tubes
- Wire and cable coating
- Sheet and film
- Filaments [11].

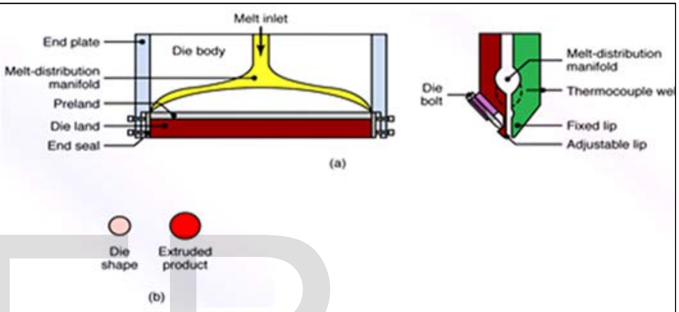

Fig.4 Common extrusion doe geometries: (a) coat-hanger die for extruding sheet; (b) round doe for producing rods [11].

2.1.2 Application and Material Used

The different types of plastic **materials** that can be used in extrusion process are Polyethylene, Polypropylene (PP), Acetal, Acrylic, Nylon (Polyamides), Polystyrene, Polyvinyl Chloride (PVC), Acrylonitrile Butadiene Styrene (ABS) and Polycarbonate.

• The extrusion process is used for manufacturing rods, plates and tubes, wire and cable coating, hose liners, hose mandrels, filaments, sheet, multilayer film, medical packaging and food packaging, sheathing, and jacketing

• Single conductor (wire) or multiple conductor (cable) covering

• Flat ribbon multi-conductor cables for appliance cords, TV antenna cables.

• Decorative trim elements with polished brass, Al, or chrome plated substrates in a protective, transparent cover. (Plastic bag ties)[10].

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2.2 Crushing/Shredding of Machine:

The large particles of plastic need to be broken down into small pieces to reduce storage and transportation space requirement. Such broken down HDPE, PP, and LDPE plastics can be sold as raw material for plastic production without any further processing. On the other hand, it can be re-extruded (the process is explained below) to produce pellets for plastic manufacturing. For PETE crushing can also be done to reduce the storage space requirement and easy transportation for further processing. A crusher should be used for this purpose and the resultant broken pieces of plastics should be the size of 2 – 0.5 cm. It is important to prevent mixing of plastic types to maintain the quality and value of the plastic. Mixed crushed plastics can be used only for low value and low quality products such as junction boxes used in electrical work or plastic lumbers. The crusher should comprise of a rotating set of blades, feeding hopper, and motor. The size of the feeder depends on the maximum size of plastic that needs to be crushed [12].

3. Experimental Work and Design

3.1 Extruder Machine

The major techniques employed in construction of the designed machine include machining operation on lathe machine, drilling operations on drilling machine, boring operation on lathe machine, keyway cutting on slotting machine, flame cutting using oxyacetylene gas welding machines, grinding for good finishing, electric welding using arc welding machine. The line diagram the machine is shown in the Fig.5.

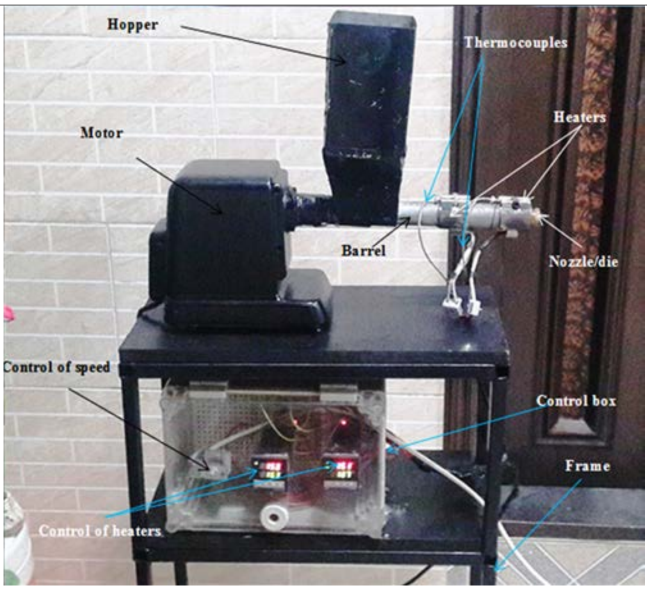

Fig. 5 Photograph of the Extruder machine

3.3.1 Construction of the Hopper

Take the sheet plate which is thickness 1mm and cut the sheet by the Universal sheet metal forming machine and Hand Tools (Scissors), after joining the sheets by Resistance Spot Welding (RSW) machine. Finally smoothing and coating.

- Material of the plate is steel.
- The hopper is used to feeding a plastic into barrel.

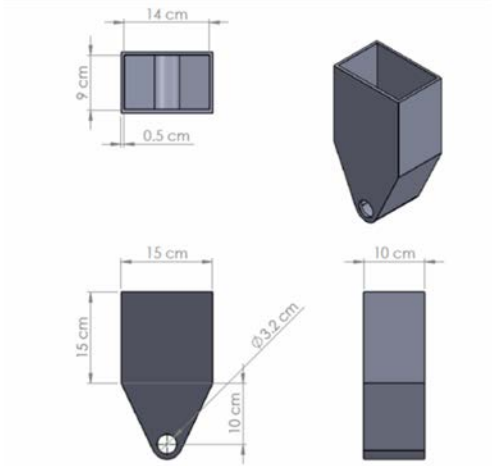

Fig. 6 Hopper of the extruder

3.1.2 Construction of the Barrel

Take the pipe of the outer diameter (32mm), cut the pipe (30cm) in length by the Saw Machine, and cut out the marked area at the right of the pipe where the pellets should fall in, then making outer thread at right side of the barrel and inner thread at left side of the barrel by The Turning Machine, finally smoothing and coating. Take the screw and smoothing the surface with weld the piece (coupling) at the first side by The Welding Machine.

- The outer and inner diameter barrel is (32 and 25) cm and the length 25cm. The length thread both sides is 25mm and standard thread is metric M32X4 and M25X4.
- Should prevent the barrel from driving and the screw easily rotating in barrel without contact the wall of the pipe.

The barrel is used to feeding the melt granulate from the hopper into the die by the screw.

Fig. 7 Barrel and screw of the extruder

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3.1.3 Nozzle of the Extruder

Depending on the material we process the diameter of the hole in the nozzle will vary and finding the right dimension is a process of trial and error. We take the outside the tooth copper mouth nozzle outlet pipe/gas connection tube.

- The material of nozzle is copper.
- The thread of a nozzle is M25X4.
- The nozzle used is feeding the melt plastic from the barrel for shaping the product.

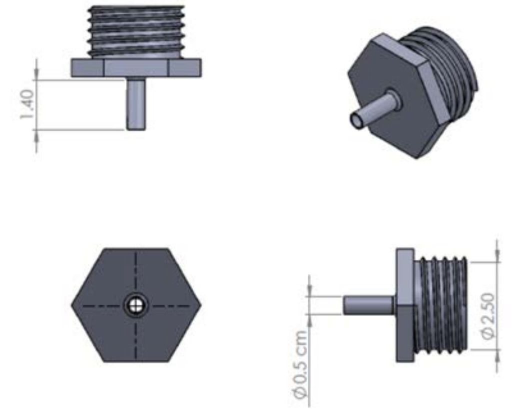


Fig. 8 Nozzle of the extruder

3.1.4 Band heater and temperature Probe (K-Type Thermocouple)

Take two the mica band heaters to melt plastic and Thermocouple to range temperature of heater.

- Push the band heater on the tap extender. It should sit around the end of the extender.
- Fix the thermocouple with some heat resistant tape.

The mica band heater:

- The diameter 30X40mm screw fixing circular flexible Mica Band Heater AC 220V tail outlet.
- The power of heater is 300W.
- The melting temperature of heater between (0 – 400) ^{o}C
- Used widely for plastic machine heating.
- Rust resistant steel sheath, stainless steel clamp type lock-up, notched sleeve allows installation, flush with nozzle and mica insulation.

The REX-C100 Temperature controller (thermocouple):

- Length= 1M, sensor diameter= 4.5mm, control temperature rang= 0-400 ^{0}C
- Internal insulation: Fiberglass and external shielding: Insulated shielding**.**

Fig. 9 Heaters and thermocouples

3.1.5 Control Box

Take the box fiber is used to synthesize the control speed of motor and the two control heaters.

- The box of: Length= 30cm, High=20cm and Width =16cm

Motor controller:

Connect the motor controller via of box switch to the power supply. Then connect the motor to the motor controller.

- Maximum power= 2000W, input voltage= AC 220V, and voltage regulation= 50-220V

Control heaters (Max.40A SSR):

Connect the heaters controller via of box switch to the power supply. Then connect the heaters and thermocouple to the heater controller.

- Output current 40A, output voltage= 24-380V AC and power= AC 100-240V 50/60HZ

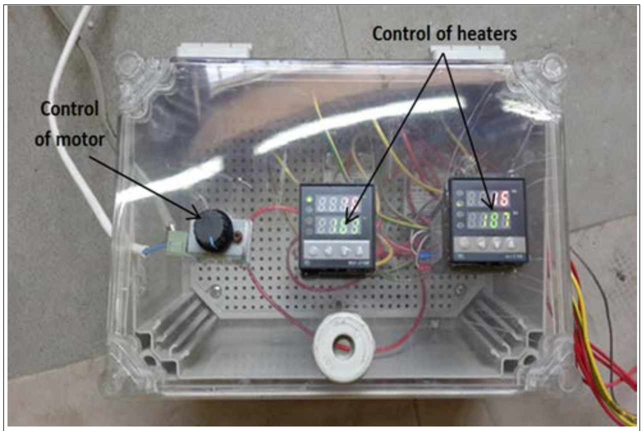


Fig. 10 Control box of the extruder

3.2 Shredder/Crasher Machine

The major techniques employed in construction of the designed machine include machining operation on lathe machine, drilling operations on drilling machine, boring operation on lathe machine, keyway cutting on slotting machine, flame cutting using oxyacetylene gas welding machines, grinding for good finishing, electric welding using arc welding machine. Basically, these constructional techniques were broken down into four sub-heading namely; cutting operation, machining operation, welding operation and assembly; and finishing operation. The line diagram the machine is shown in the Fig.11 and 12.

3.2.1 Construction of the Hopper

Take the sheet plate which is thickness 2mm and creating shape like duct of the air flow which is the cross section area is 30X35cm and creating three holes away the duct each four sides by

- The material is tin galvanize.
- The hopper is used to feeding the material.

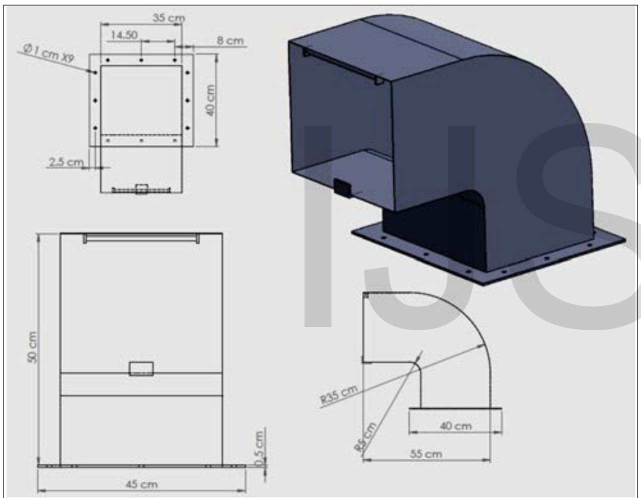


Fig. 13 Hopper of the extruder

3.2.2 Construction of the Shaft, Supports and Knives

Take the cylinder rod (ø 50mm) and cut away 70cm in length by Saw Machine, then reduce the diameter for 49mm by Lathe Machine. After reduce the diameter for 44mm in 15cm length at an each sides and create the hole (ø 15mm) on the one side by lathe machine after create thread. After creating the place to key by Milling Machine. Finally smoothing and coating.

- The material of the shaft is steel.
- The shaft is used to rotate the knives and fixed the supports.
- The hollow is used to fixed the pulley

Take the sheet plate that the thickness 30mm and cut away three piece is shown fig.15 by plasma CNC. After create the three holes for each supports are 15mm in diameter by Drilling Machine and make the thread for each supports by taper stock. Finally smoothing and coating.

- The material of the supports is carbon steel
- The supports are used to fix the knives.

Take the five leaf springs of car and unwinding the springs by heating and Press Machine, after cutting away the pieces each 34cm in length by Plasma CNC Machine and smoothing by Grinding Machine. Then creating the edgy in the sides by Milling Machine and creating three slot holes in the knives each 15mm in diameter.

- The material used for the leaf spring is plain carbon steel having 0.9 to 1.0 % carbon.
- The holes in the knives are used to fix the knives.

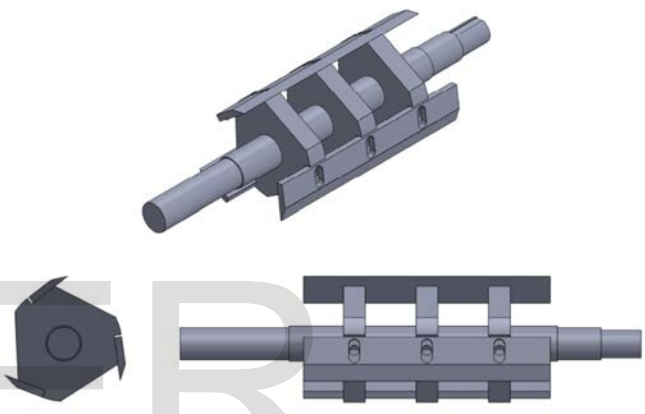


Fig. 14 Assemble of the shaft,supports and knives

3.2.3 Construction of the Box

Take the sheet plate as thickness 10mm and cut for four pieces with two holes (ø5cm) by Plasma CNC Machine is shown fig.16 after the three pieces joining permanent by using the weld and the other piece joining non-permanent by using the bolt.

- Take the sheet plate as (width=4cm and thickness=3mm) and cut for eight pieces as the four pieces are 40cm in length and the four other pieces are 37cm by Saw Machine, then create three holes in each the pieces that 10mm in diameters. The four pieces is free but the four other pieces are joining over the box by welding. They will serve a fixed of the duct.
- Take the sheet plate as (width =7cm and thickness =10mm) and cut for two pieces as each parts are 20cm in length then create the two holes(ø15mm) in the each pieces, after joining in the outside bellow the holes box by welding. They will using to set and fixed the brackets.
- Take the sheet plate as (width=4cm and thickness =10mm) and cut for two pieces as each parts are 37cm in

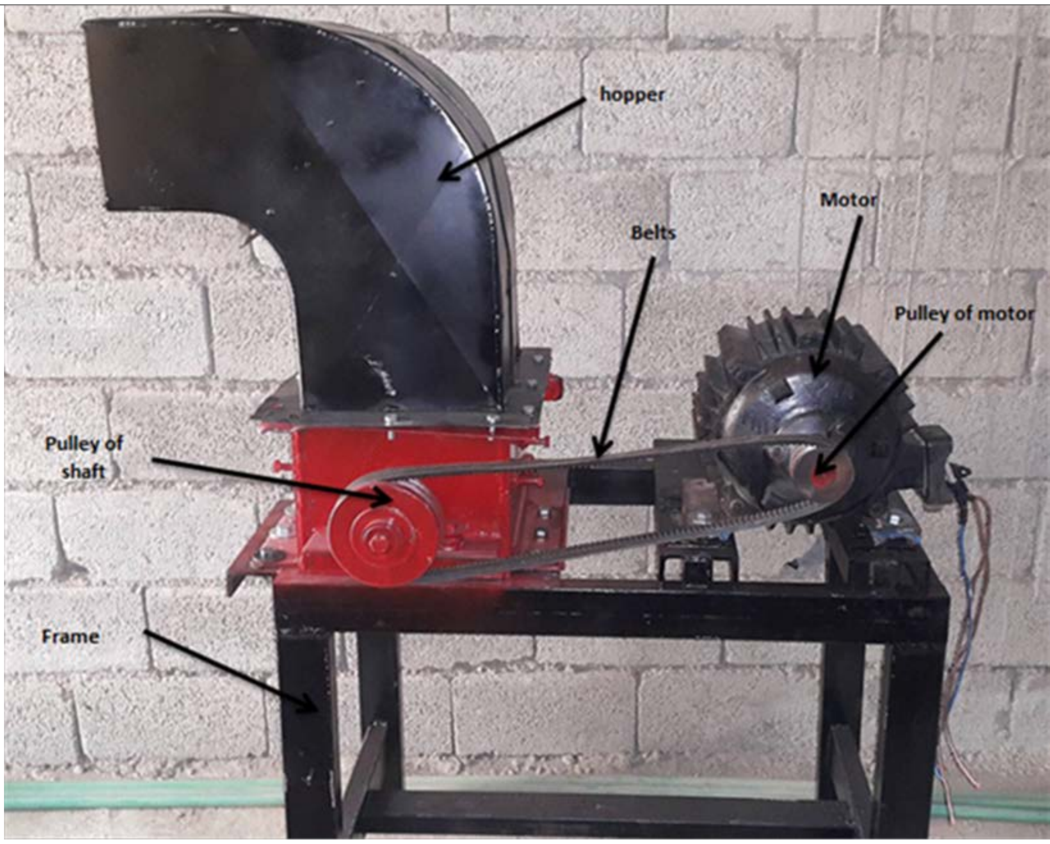


Fig. 11 Photograph of the shredder machine

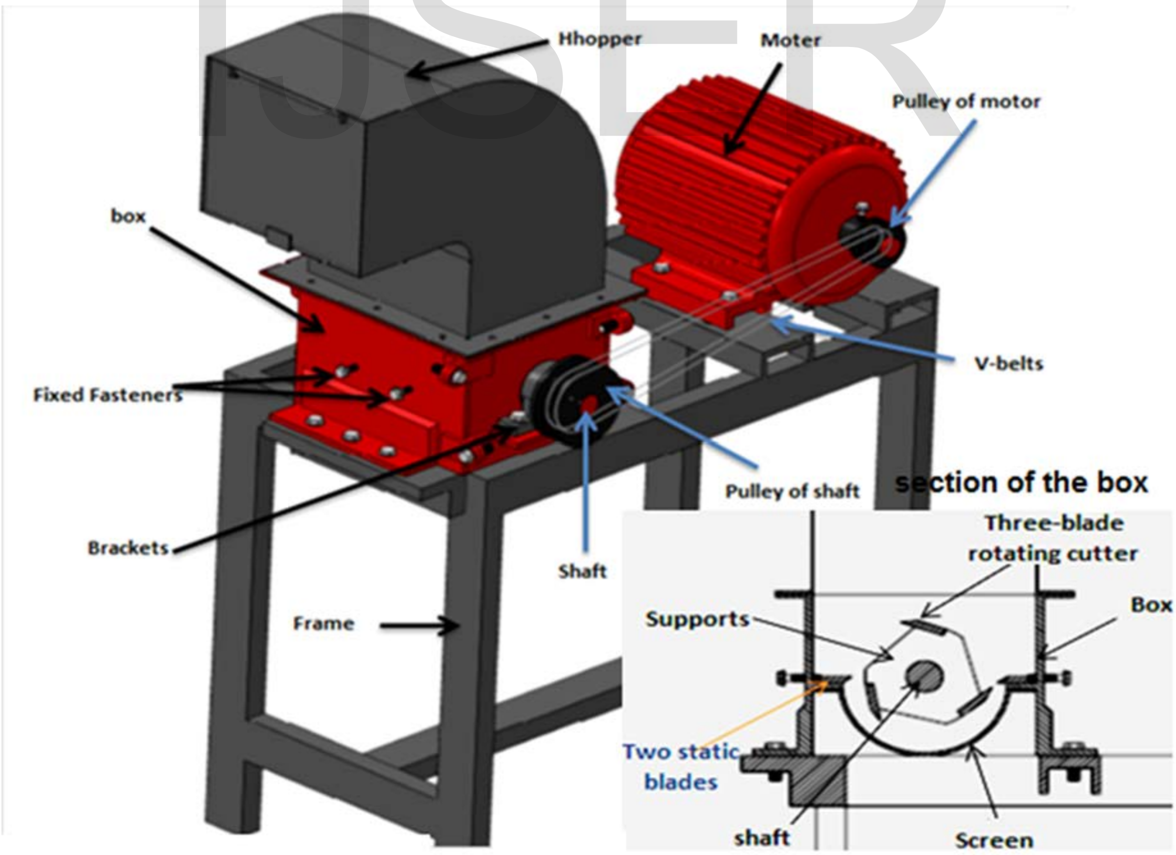


Fig. 12 Shredder machine and section of the box

length then create the three holes (ø15mm) in the each pieces, after joining in the inside box by welding. They will using to set and fixed the two knives and the screen.

- Take the plate angle as (width= 8X8cm and thickness =10mm) and cut for two pieces as each parts are 25cm in length then create the three holes (ø15mm) in the each pieces, after joining in the outside box by welding. They will use to the fixed the box over the frame.

- Creating the four holes, after using four the screw to gauge of the two static knives.

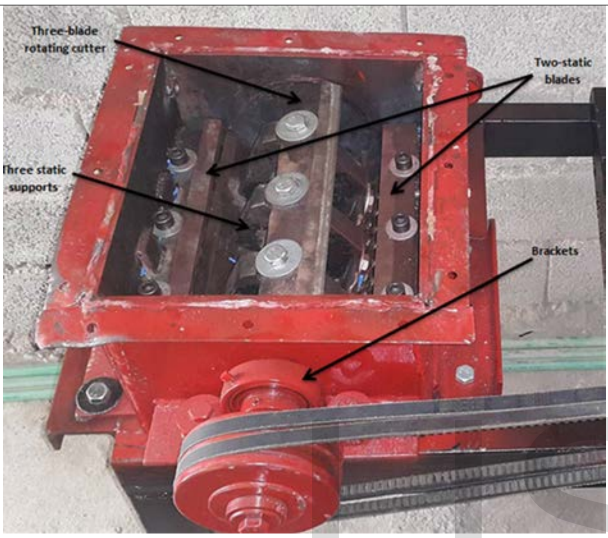


Fig. 15 Photograph of the box

3.2.4 Drive of the System

For driving the system, we needs have two pulleys, two belts, two brackets and the motor capacity of motor is equal to 2.8 KW (3.75hp)

- Take the two pulleys as:

. Diameter of the pulley one is 5cm as connect to the motor by set screw, the length of pulley is 5cm and have location for two belts.

. Diameter of the pulley two is 15cm as connect to the shaft by set screw, the length of this pulley is 8cm and have location for two belts.

- Take the two belts as each belt the length 1700mm

- Take the two brackets as each bracket 45mm in diameter.

- Take the motor as:

Three-phase squirrel, voltage rage=220/380V, the current =11.4/6.6 A, the power=2.8kw (3.75hp) and weight=76kg

3.2.5 Construction of the Screen

Take the sheet plate as (thickness=4mm) and cut with creating the holes (ø1cm) as the length, high and width are (35, 30 and12 cm) by Plasma CNC Machine after warp by Pressing Machine is shown fig. 16.

- The material of the screen is carbon steel.

- The numbers of holes are 270 holes.

- Create the three holes (ø15mm) in the two edge of the screen by Drilling Machine.

- The screen is used to feeding the cut materials as dimension 1cm.

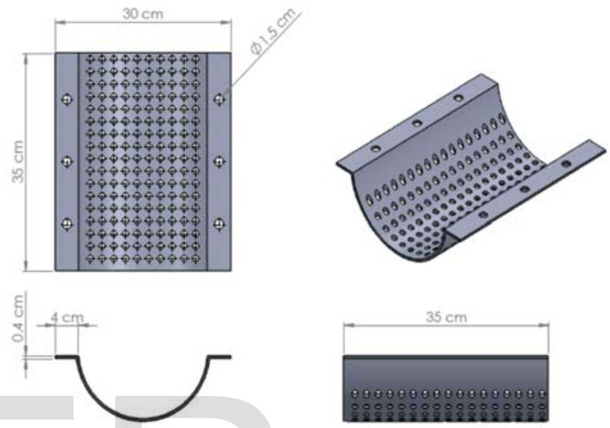
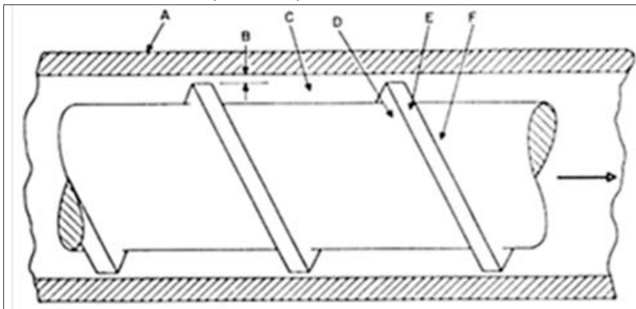


Fig. 16 screen of the shredder

4. Theoretical

4.1 Extrusion

The principle works of extruder is the rotation of screw by using a motor, and melt a materials by using heaters, and this extruder is needed a motor and heater when capacity of motor is equal to 200W the screw rotated by 20-180r.p.m and The melting temperature of heaters between (0 – 400) ^{o}C, and can be determine flow,



No.	Name of parts
A	Barrel
B	Screw clearance
C	Channel
D	Trailing flight
E	Flight land
F	Direction

Fig. 17 Screw details

die characteristics and torque of motor by data's from table (1)

$$P = \frac{2\pi N T_M}{60} \quad (1)$$

The torque of the motor (T_M) equal to the torque of the screw, Referring to the element of fluid between the screw flights as shown in Fig.17, this equation may be rearranged using the following substitutions.

$$W = (p - e) * \cos \emptyset \quad (2)$$

The tangential velocity at the barrel surface is determined from the rotation speed of the screw:

$$V = \pi D_S N \quad (3)$$

Down Channel Velocity Component

$V_D = V \cos \emptyset$ or

$$V_D = \pi D_S \cos \emptyset \quad (4)$$

TABLE (1)

Data are needed to calculation.

Specification	Symbol	Quantity	Unit
Power of motor	P	200	W
Speed	N	100	r.p.m
Torsional strength for steel 42.11	τ	330	Mpa
Tensile strength for steel 42.11	σ	450	Mpa
Flight Length	L	25	cm
Screw Diameter	D_s	24	mm
Screw pitch	p	30	mm
Screw flight angle	ø	17°	degree
Channel depth	H	2.5	mm
Screw clearance	h	0.5	mm
Diameter of barrel	D_B	25	mm
Flight width	w	6	mm
Coefficient of friction	μ	0.25	-----
Diameter of die	D_D	4	mm
Die length	L_D	12	mm

TABLE 2

Data are found in calculation

Specification	Symbol	Quantity	Unit
The torque of the motor	T_M	19.108	N.m
The torque of the screw	T_S	19.108	N.m
The tangential velocity at the barrel	V	125.6	mm/s
Channel Velocity Component	V_D	120.1	mm/s
The screw flights	W	22.95	mm

4.1.1 Power law model

"The power law model is one of the simplest models for presenting the viscous-shear behavior of plastic melt. The law accurately demonstrates the shear thinning region in the viscosity versus strain rate curve". The proponents of the law suggested the relationship between viscosity and shear rate as follows:

$$\eta = m\gamma^n \quad (5)$$

Where m = consistency index
n = power law index
γ = shear rate
η = viscosity

TABLE 3

Power law parameters for some common plastics. [12].

Polymers	$m(pa - s)^n$	n	T(°C)
High density PE	2.00 x 10^4	0.41	180
Low density PE	6.00 x 10^3	0.39	160
PP	7.5 0x 10^3	0.38	200
PA	66 6.00 x 10^2	0.66	300
PC	6.00 x 10^2	0.98	300

4.1.2 Shear Rate

The rate of shearing or shear rate is one of the most important parameters in polymer melt processing. If the process is to be described qualitatively, the shear rate in the fluid at any location needs to be known.

$$\gamma = \frac{6Q}{WH^2} \quad (6)$$

Where: Q = Maximum flow rate
W = Screw flights
H = Channel depth [13]

4.1.3 Analysis of the Flow in Extruder

As discussed in the previous section, it is convenient to consider the output from the extruder as consisting of three components - drag flow, pressure flow and leakage. The derivation of the equation for output assumes that in the metering zone the melt has a constant viscosity and its flow is isothermal in a wide shallow channel. These conditions are most likely to be approached in the metering zone, assuming that there is no leakage.

1. Drag Flow

The flow due to the internal friction between the malt pool and the barrel walls and the shear action of the screw constitutes the drag flow.

$$Q_D = \frac{1}{2} * WHV_D \quad (7)$$

Where: W= Screw flights
H = Channel depth
V_D = Channel Velocity Component [8]

2. Pressure Flow

The pressure flow of a fluid is cause by a pressure difference. "The pressure drop is linear in direction of flow in channels with parallel walls. In the metering section an extruder screw, pressure flow is the relatively backward flow of material down the screw channel caused by pressure in the head"

$$Q_P = -\frac{WH^3 \sin\emptyset}{12\eta}\frac{dP}{dL} \tag{8}$$

4.1.4 Total Output

The total output is the combination of drag flow and back pressure flow and leakage. The extruder and die characteristics graph can be extracted. So from (7) and (8).

$$Q_T = Q_D + Q_P = \frac{1}{2} * WHV_D - \frac{WH^3 \sin\emptyset}{12\eta}\frac{dP}{dL} \tag{9}$$

For many practical purposes sufficient accuracy is obtained by neglecting the leakage flow term. In addition the pressure gradient is often considered as linear so $\frac{dP}{dL} = \frac{P}{L}$

$$Q_T = \frac{1}{2}\pi^2 D_S{}^2 NH \sin\emptyset \cos\emptyset - \frac{\pi DH^3 (\sin\emptyset)^2}{12\eta}\frac{P}{L} \tag{10}$$

Where Q_D = Drag flow (m^3/s)
Q_P = Pressure flow
D_S = Diameter of the screw
N = Screw revolution (rpm)
H =Channel depth of the screw (m)
$\emptyset$ = Helix angle of screw
L = Length of the screw (m)
P = Operation pressure (Pa)
η =Viscosity (Pa.s)

When there is no pressure build up at the end of the extruder, any flow is due to drag and maximum flow rate Q_{max} can be obtained. The equation then can be reduced to only the drag term as follows.

$$Q = Q_{max} = \frac{1}{2}\pi^2 D_S{}^2 NH \sin\emptyset \cos\emptyset \tag{11}$$

$$mass\ flow\ rate = A.v.\rho \tag{12}$$

Similarly, when there is a high pressure drop at the end of the extruder the output of the extruder, Q becomes equal to zero (Q=0) and the maximum pressure is obtained from the equation.

$$\frac{1}{2}\pi^2 D_S{}^2 NH \sin\emptyset \cos\emptyset = \frac{\pi DH^3 (\sin\emptyset)^2}{12\eta}\frac{P}{L} \tag{13}$$

Hence $P = P_{max} = \frac{6\pi D_S L N \eta}{H^2 \tan\emptyset}$ (14)

4.5 Extruder/Die Characteristics

There is a simple relation between pressure drop and volumetric flow rate in the die.

$$Q = K\frac{P}{\eta}$$

Where

$K = \frac{\pi R^4}{8L_d}$ For circular cross-section of die can be extracted using the formula.

Therefor $Q = \frac{\pi R^4 P}{8L_d \eta}$ (15)

Where L_d is the length of the Die.
R is the radius of the Die
P is the Operation pressure
η is the Viscosity

The operating point for an extruder/die combination may also be determined from equations (10) and (15).

$$Q = \frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset - \frac{\pi DH^3 (\sin\emptyset)^2}{12\eta}\frac{P}{L} = \frac{KR^4 P}{8L_d \eta} \tag{16}$$

Using equation (9) it is possible to modify the expression for the operation pressure to the more general form.

$$P_{op} = \frac{2\pi\eta D_S{}^2 NH \sin\phi \cos\phi}{\left(\frac{R^2}{2L_d}\right) + \left(\frac{D_S H^3 (\sin\phi)^2}{3L}\right)} \tag{17}$$

So for a capillary die, the pressure at the operating point is given by [13]

$$P_{op} = \frac{2\pi\eta D_S{}^2 NH \sin\phi \cos\phi}{\left(\frac{fbd^3}{2\pi L_d}\right) + \left(\frac{D_S H^3 (\sin\phi)^2}{3L}\right)} \tag{18}$$

TABLE 4
Data are found in calculation

Specification	Symbol	Quantity	Unit
Maximum flow rate	Q_{max}	$3.31 * 10^{-6}$	m^3/s
Maximum pressure	P_{max}	12.89	MPa
Shear rate	γ	529.6	s^{-1}
Viscous-shear	η	130.78	$pa.s$
Flow rate in die	Q	$3.307 * 10^{-10}$	m^3/s
The operating pressure is obtained	P_{OP}	3.307	MPa
The operating flow rate is obtained	Q_{OP}	$1.32 * 10^{-11}$	m^3/s

4.1.7Strength Calculation of Simple Worm Extruder

Worms are much stressed functional parts of the worm extruders. They are stored in the bearings, which allow rotational movement of the worm and capture the axial and radial forces.

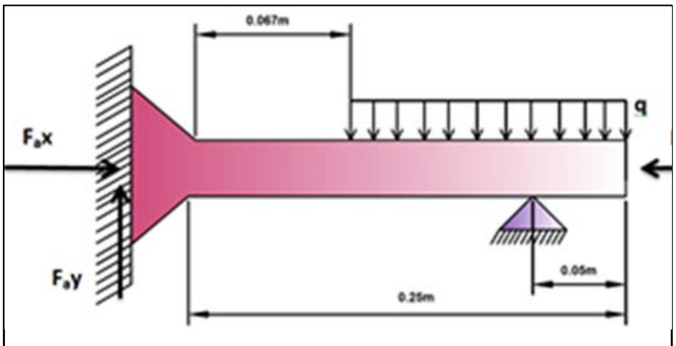


Fig. 18 load a single warm

The sizes of forces acting on the bearings are calculated from the following relations:

$$T_s = q * length * \frac{D_s}{2} \quad (19)$$

From table (1) T_s = 19.108N.m and D_s = 0.024m

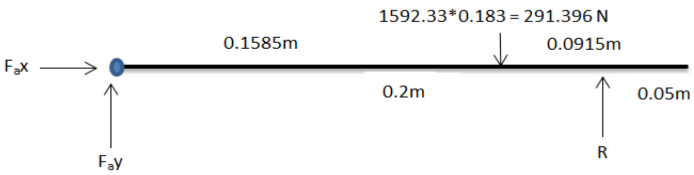
$$19.108 = q * m * \frac{0.024}{2} \quad \Longrightarrow \quad \boldsymbol{q = 1592.33\ N/m}$$

$$F_a x = A_s * P_{max} \quad \Longrightarrow \quad F_a x = \frac{\pi * D_s^{\,2}}{4} * 12.89 * 10^6$$

$$F_a x = \frac{3.14 * 0.024^2}{4} * 12.89 * 10^6 \quad \Longrightarrow \quad \boldsymbol{F_a x = 5828.34\ N}$$

$F_a x$ = F

Where: T_s = torque of the screw [m]
D_s= diameter of the screw [m]
p = pressure at the end of the worm [MPa],
q = continuous load [N.mm-1]
A_s= screw cross-section area [m²]
$F_a x$= axial force of the screw [N]



$$\Sigma M_a = 0$$

$$0.2R = 0.1585 * 291.396 \quad \Longrightarrow \quad \boldsymbol{R = 230.931N}$$

$$\Sigma F_Y = 0$$

$$F_a y = 291.396 - 230.931 \quad \Longrightarrow \quad \boldsymbol{F_a y = 60.46467\ N}$$

4.2 Shredder/Crasher

The principle work of crasher is the rotation of shaft by using a motor, and transmitting torque from motor to shaft through the belt by using pulley, and this crusher is needed a motor when capacity of motor is equal to 2.8KW shaft is minimum rotated by 500r.p.m and can be determine torque of motor by power-P- of motor and speed-N.

$$P = 2\pi NT/60 \quad (20)$$

$$2.8 * 1000 = 2\pi 500 Tm/60$$

T_m=53503.185 N.mm

To convert torque of motor-Tm- to torque pulley-T- of shaft find ratio(i) between two pulleys and torque-T- of every support is equal because of every pulley is rotated as the same speed-N-

$$i = D/D_m = T/T_m \quad (21)$$

Where: D_m= diameter of pulley motor (8cm)
D= diameter of pulley shaft (15cm)

i=15/8=1.875

T= 1.875 X 53503.185= 100318.472 N.mm

To find the force of the pulley-F1- and -F2- when is caused by tension of belt on the pulley through using the diameter of pulley D=15cm and torque of roller T=100318.472 N.mm and assuming F2/F1=0.3

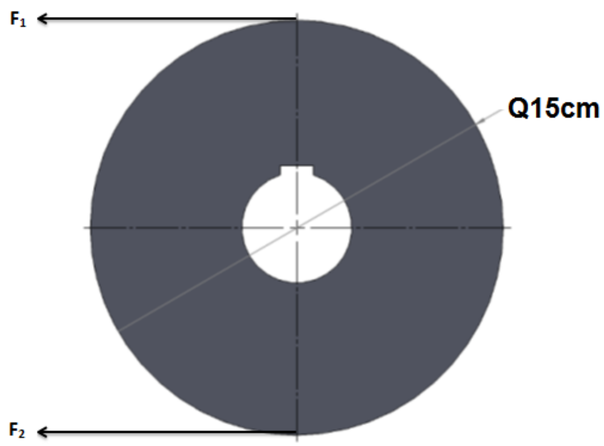
$$T = (F1 - F2) * D/2 \quad (22)$$

F_1=1028.907 N

F_2=308.672 N

FR = F1 + F2

F_R=1337.579 N



The tight side force of belt on the pulley of the shaft (F_1=1028.907 N), slack side force on the pulley of the shaft (F_2=308.672 N) and resultant force on pulley (F_R=1337.579 N) when tight side force of belt on the pulley is equal to 0.3 slack side force on the pulley.

4.2.1 Calculation Shear Stress on the Shaft

The shaft applied of combine stress due to applied of bending strength-σ- and torsional strength-τ- and find maximum bending moment -mb- by vertical plane and horizontal plane and using torque-T- and diameter shaft d=4.9cm from table (1)

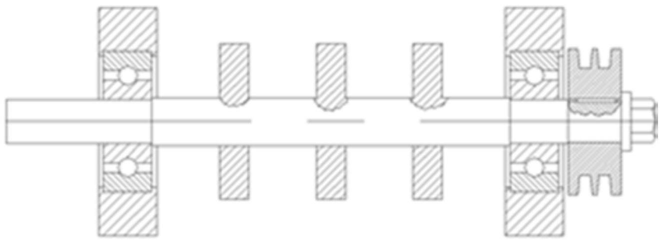


Fig. 19 section of shaft

To find the crushing force-Fc- is applied on the shaft can be determine by ultimate crushing strength (σ=250mpa) for limestone from table (1) and area of support (A=9cm) when contact to limestone is caused to crushing.

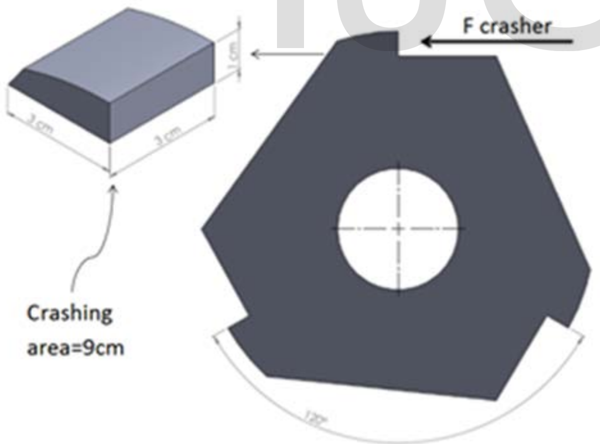


Fig. 20 Crashing area of the supports

$$Fc = \sigma A \quad (23)$$

$F_c = 250 \text{ X } 90 = 22500$ N

$$\text{Fcrusher} = \text{FcSin}\phi + \text{Fc}$$

$$\text{Fcrusher} = 22500 \text{ Sin}120 + 22500$$

$$\text{Fcrusher} = 41981.572 \text{ N}$$

Vertical Plane

F crusher = 0, F pulley = 0
F(C, D, E) = weight of supports X 9.81
= 5kg X 9.81N/Kg
= 49.05 N (for each supports)

$$\sum MA = 0$$

$$40F_B = 10(49.05) + 20(49.05) + 30(49.05), FB = 73.6 \text{ N}$$

$$\sum FY = 0$$

$$F_A = 49.05\ X\ 3 - 73.6\ ,\ FD = 73.6\text{N}$$

Maximum bending moment in vertical plane =981N.cm

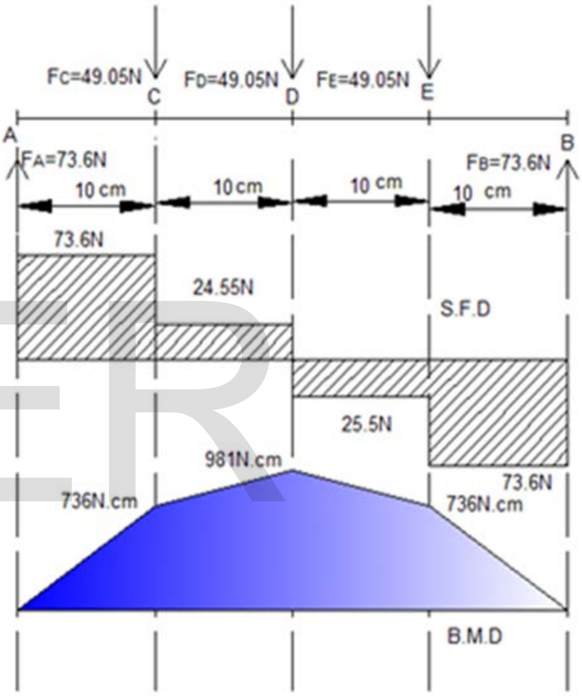


Diagram (4.1) shear force and bending moment diagram vertical plane for shaft

Horizontal plane

F crusher = 41981.572 N, F pulley = 1337.579 N
F(C, D, E) = F crusher, F_R = F pulley

$$\sum MA = 0$$

$$40F_B{'}10(49.05) + 20(49.05) + 30(49.05) - 45(1337.579)$$

$$FB' = 61467.582 \text{ N}$$

$$\sum FY = 0$$

$$F_A{'} = 49.05\ X\ 3 - 1337.579 - 61467.582$$

$$FA' = 63139.555\text{N}$$

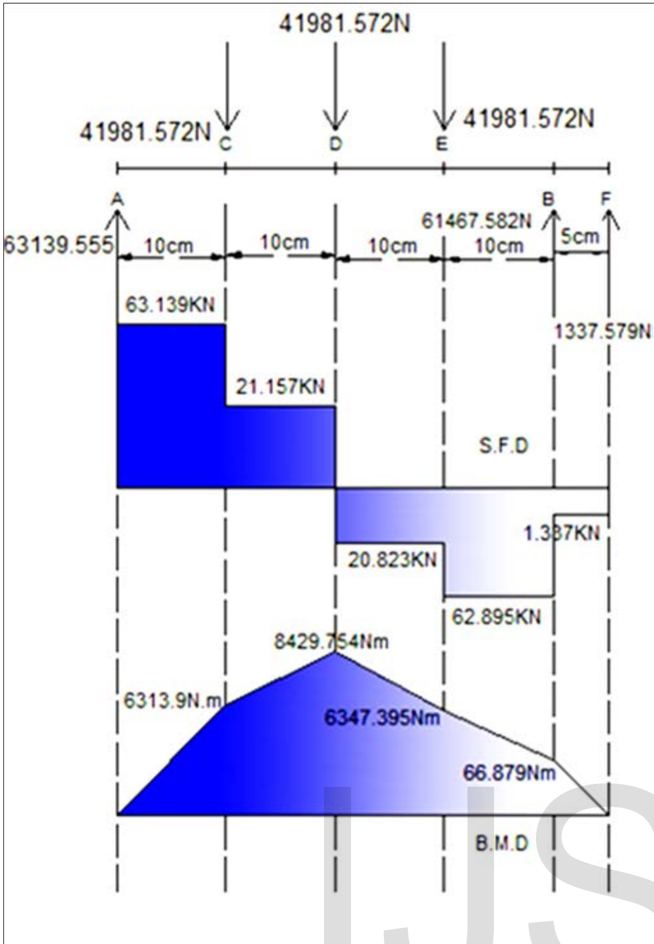


Diagram (4.2):- Shear force and bending moment diagram horizontal plane for hammering roller shaft

Maximum bending moment in horizontal plane =8429.754N.cm

$$\mathrm{Mb} = \sqrt{(\mathrm{mbv})^2 + (\mathrm{mbh})^2} \quad (24)$$

$$\mathrm{mb} = \sqrt{(981)^2 + (8429.754)^2}$$

$$\mathrm{mb} = 8486.643\mathrm{Nm}$$

$$\tau = \frac{16}{\pi d^3}\sqrt{mb^2 + T^2} \quad (25)$$

$$\tau = \frac{16}{\pi 0.49^3}\sqrt{(8486.643)^2 + (100.318)^2}$$

$$\tau = 88.259KPa$$

Maximum shear stress of shaft equal to 88.259KPa

4.2.2 Calculation of the Life of Bearing

In shaft use deep groove ball bearing, to find life of bearing most be determine ideal load -P- by radial factor-X- thrust factor-Y- radial load-Pr- and thrust load-Pa- when.
[X=1, Y=0] not axial load.

1- Find Life of Bearing (A)

$$\mathrm{Pr} = \sqrt{(\mathrm{FAv})^2 + (\mathrm{FAh})^2} \quad (26)$$

$$\mathrm{Pr} = \sqrt{(73.6)^2 + (63139.555)^2},\ \mathrm{Pr} = 63139.598\mathrm{N}$$

$$\mathrm{P} = \mathrm{X.Pr} + \mathrm{Y.Pa} \quad (27)$$

$$\mathrm{P} = 1 * 63139.598 + \mathrm{Y} * 0,\ \mathrm{P} = 63139.589\mathrm{N}$$

To find life of bearing (A) use ideal load (P=63139.589N) speed factor (Fn=0.41) and temperature factor (Ft=1) and load capacity of bearing (C=405000N)

$$\mathrm{Fl} = \mathrm{Fn.Ft.C/P} \quad (28)$$

$$\mathrm{Fl} = 0.41 * 1 * (405000)/63139.589,\ \mathrm{Fl} = 2.62$$

$$\mathrm{Lh} = 8000\mathrm{h} = \text{operational houre}$$

2- Find Life of Bearing (B)

$$\mathrm{Pr} = \sqrt{(\mathrm{FBv})^2 + (\mathrm{FBh})^2},\ \mathrm{Pr} = \sqrt{(73.6)^2 + (61467.582)^2}$$

$$\mathrm{Pr} = 61467.626\mathrm{N},\ \mathrm{P} = \mathrm{X.Pr} + \mathrm{Y.Pa}$$

$$\mathrm{P} = 1 * 61467.626 + \mathrm{Y} * 0,\ \mathrm{P} = 61467.626\mathrm{N}$$

To find life of bearing (B) use ideal load (P=61467.626N) speed factor (Fn=0.41) and temperature factor (Ft=1) and load capacity of bearing (C=405000N) from table (4.1)

$$\mathrm{Fl} = \mathrm{Fn.Ft.C/P}$$

$$\mathrm{Fl} = 0.41 * 1 * (405000)/61467.626,\ \mathrm{Fl} = 2.7$$

$$\mathrm{Lh} = 8500\mathrm{h} = \text{operational houre}$$

4.2.3 Calculation of Shear Stress on the Key

To find shear stress on the key need determine the force on the key when length of the key (L=5cm) and width (b=1.2cm) .

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$$F.key = T \times d.shaft/2 \quad (29)$$
$$= 100.318 \times 42/2'$$
$$= 2106.678 \text{ N}$$

$$\tau = \frac{Fkey}{Lb} \quad (30)$$

$$\tau = \frac{2106.678}{50*12} = 3.511\ MPa$$

5. RESULTS AND DISCUSSION

5.1 Shredder Machine

Construction and design all of the parts, the rotor shaft was checked for torsion and bending and was found safe. The key rotor was checked for shear stress and was safe. Determine life of bearings by hour. The Driving mechanism of rotor was designed in such a way that the V belt was safe and was able to transmit required speed to the rotor from the motor. An appropriate casing structure is also proposed for housing the crushers' assembly

To measure the mass flow rate of granulate in the shredder; there is test for high-density polyethylene (HDPE), as shown in fig. 21.

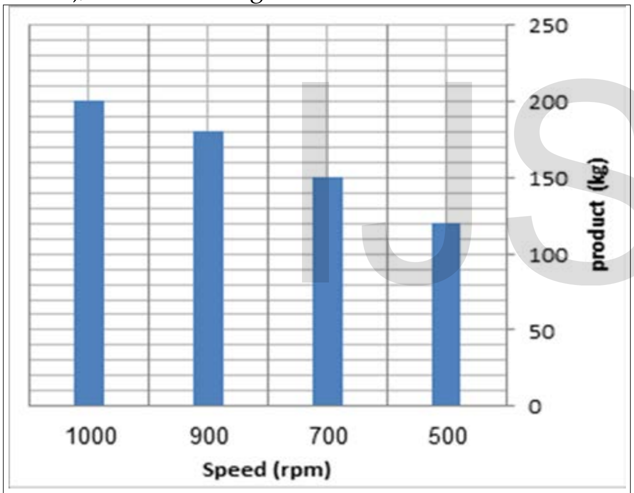

fig. 21 Relationship between speed and product for (HDPE)

In fig.21. is shown that product/mass flow rate(HDPE) increase when speed of motor is rise for range one hour work. When the speed of motor a lot, time of life of the knives is abatement, so should be working in reasonable of speed.

5.2 Extruder Machine

Construction and design all of the parts, the rotor screw was checked for torsion and bending. Determine the flow rate of extruder for screw and die.

To measure the mass flow rate of the polymers in the extruder machine, there are test for HDPE (high-density polyethylene), LDPE (low-density polyethylene), PP (polypropylene), and PS (polystyrene), as shown in fig.22,23 and 24.

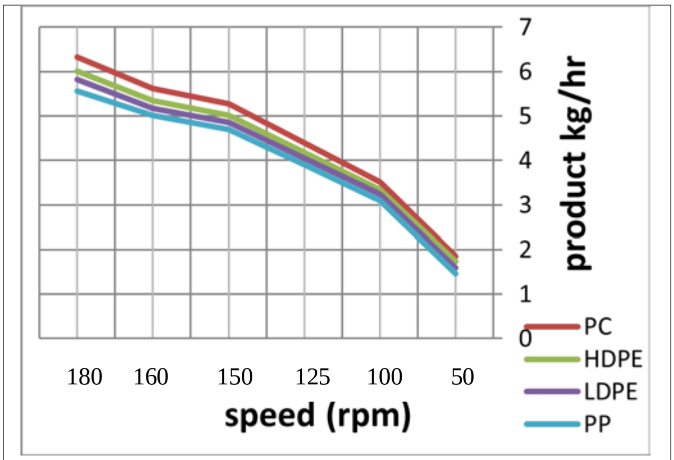

Fig. 22 Relationship between speed of motor (rpm) and output (kg)

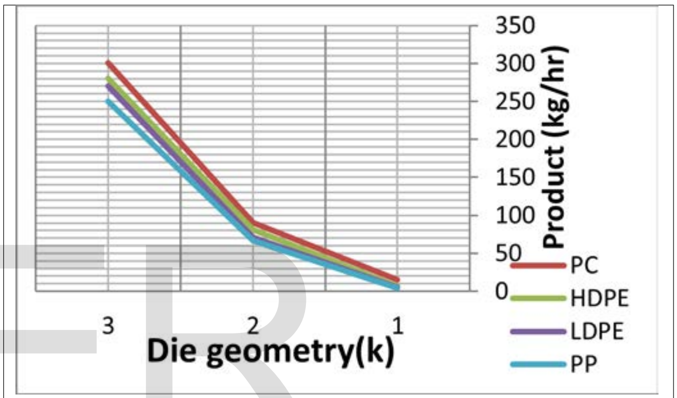

Fig. 23 relationship between Die geometry(k) and product (kg/hr)

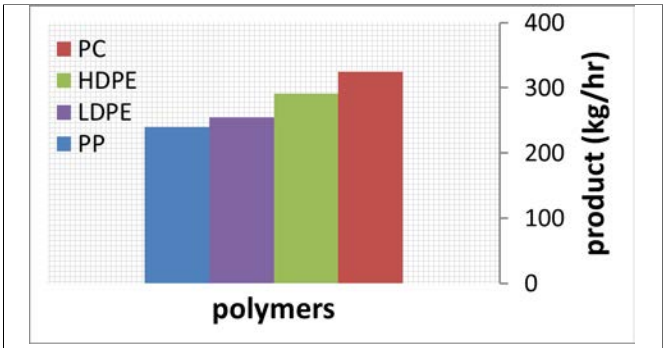

Fig. 24 relationship between polymers and product (kg/hr)

In fig.22 relationship between speed of motor and product/mass flow rate for the four polymers, we putting that product polymers increase when the speed of motor is rise, product of the PC greater than all of them, as shown fig. 24 because the density of PC lower than all of them as the PC low melting temperature and easily move in barrel. So that product increases when the density is low.

In fig.23 relationship between Die geometry and product/mass flow rate for the four polymers,

Die geometry

K1= 0.5233 mm^3
K2= 14.7249 mm^3
K3= 61.3281 mm^3

The product in the (K3) greater than (K1and K2) for all of them because area/volume of the die is great. So that product increases when the die geometry is great.

6. CONCLUSIONS

Based on a limited amount of experimentation, several conclusions can be made regarding the use of extruder and shredder for combustion research.

1. Recycling is a complex method of environment protection, which aim is the limitation of the raw materials consumption and decrease of waste quantity.
2. The PC is high flow rate because low density.
3. The large particles of plastic need to be broken down into small pieces to reduce storage and transportation space requirement.
4. Shredder machine; - product/mass flow rate (HDPE) increase when speed of motor is rise.
5. Extruder machine; - product increases when the die geometry is great and the density of polymers are low.

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NOMENCLATURE

P	**Power**	**Kw**
T_m	Torque of motor	N.m
N	Speed of motor	rpm
V	Tangential velocity	mm/s
V_D	Channel velocity component	Mm/s
D_S	Diameter screw	mm
T_S	Torque of screw	N.m
Q	Maximum flow rate	mm^3/s
DB	Diameter of barrel	mm
Qd	Drag flow	mm^3/s
Qp	Pressure flow	mm^3/s
QT	Total flow	mm^3/s
Pmax.	Pressure maximum	MPa
Qop	The operating flow rate is obtained	mm^3/s
Pop	The operating pressure is obtained	MPa
K	Circular cross-section/volume	mm^3
f	Flow coefficient	---
R	Radius of the die	mm
D	Diameter pulley of shaft	mm
Dm	Diameter pulley of motor	mm
d	Diameter of shaft	mm
i	Reduction ratio	---
FR	Resultant force	N
Mb	Bending moment	N.m
Mbv	Maximum bending moment in vertical plane	N.m
Mbh	Maximum bending moment in horizontal plane	N.m
Pr	Radial force	N
Pa	Axial force	N
P	Ideal force	N
Fn	Speed factor	----
Ft	Temperature factor	----
C	Capacity of bearing	N
Fl	Life of bearing	---
Lh	Operation hour	Hr

Greek Symbols

ρ	**Density**	**g/cm**
Ø	Screw fligth angle	degree
γ	Shear rate	s^{-1}
τ	Shear stress	MPa
η	Viscisity	Pa.s
σ	Normal stress	MPa

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