Design, Analysis and Fabrication of Blow Molding Machine Along With 500ml Bottle Mold

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By

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ABSTRACT

Blow molding is a manufacturing process by which hollow plastic parts are formed. In General, there are three main types of blow molding: extrusion blow molding, injection Blow molding and injection stretch blow molding. The blow molding process begins with melting down the plastic and forming it into a parison or in the case of injection and injection stretch blow molding a preform. The parison is a tube like piece of plastic with a hole in one end through which compressed air can pass. The parison is then clamped into a mold and air is blown into it. The air pressure then pushes the plastic out to match the mold. Once the plastic has cooled and hardened the mold opens up and the part is ejected.

Main objective of our project is to make small machine to make plastic bottles/balls up to 500 bottles per day approx. Another objective of the project is to help cottage industry.

PREFACE

This thesis is presented to the NUST School of Mechanical and Manufacturing Engineering (SMME), Islamabad in partial fulfillment of the requirement of the degree BE Mechanical Engineering for the student authors and describes in detail all the efforts that led to completion of their Final Year Project titled “Design, Analysis and Fabrication of Blow Molding Machine”. This thesis elaborates extensively all the stages that this project went through from conception phase all the way to the finalization phase and also sheds some light on the methodology and calculations that were adopted in order to design the machine and the mold. While organizing this thesis, care has been taken to strictly keep it in accordance with the recommended format provided by the SMME. The authors have made a conscious method to use simple and lucid diction and explain the major concepts of plastic injection molding to the readers in a simple yet comprehensive manner. Visual aids like pictures, drawings, tables and graphs etc. have been used wherever necessary to add to the overall clarity of the report. Furthermore, design calculations and formulae have also been written. A dedicated chapter at the end identifies certain areas in which there is some room for improvement to make this machine even better and more useful. This chapter also points out the aspects on which our juniors can work to get better results from this machine.

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First and foremost, we are very thankful to our Creator and Sustainer Allah Almighty, The Most Beneficent and The Most Merciful, Who has helped and guided us through each and every step of this project and thesis. Indeed nothing is possible without His divine decree.

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Finally, we would like to thank all the individuals who helped in the completion this project in one way or the other.

ORIGINALITY REPORT

We certify that this research work titled "*Design, Analysis and Fabrication of Blow Molding Machine to Manufacture Bottles"* is our own work. The work has not been presented elsewhere for assessment. The material used from other sources has been properly acknowledged.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

EBM	Extrusion Blow Molding
SBM	Stretch Blow Molding
PS	Polystyrene
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PET	Polyethylene terephthalate
PVC	Poly vinyl Chloride

NOMENCLATURE

Parison: Melted plastic tube with is inflated to create hollow profile required

CHAPTER 1 **INTRODUCTION**

Plastics nowadays have become an essential part of day to day life. Plastics serve a variety of purposes. Their flexible nature is what makes them so popular in industry. Plastics' properties can be changed as per the requirement of the task that they will be used for. For example to make products that are required to be durable and long lasting like furniture and appliances a high quality plastics are used that are tough and can bear great load. Plastics that are not tough are used to make nondurable goods like shopping bags, soft-drink bottles, and shampoo bottles etc. In short, plastics provide a wider range in terms of properties and cost than any other material. Due to an increased demand of plastics, a number of processes are used to transform plastics into different items. Following are some processes used in plastic manufacturing;

1. Blow Molding
2. Calendaring
3. Cast or Blow film
4. Coating
5. Extrusion,
6. Injection Molding
7. Thermoforming
8. Transfer molding
9. Rotational molding

Blow molding is one of the most common and most ancient molding technique. It is a technique best used for making hollow items like bottles, bowls, containers etc. In blow molding a heated plastic tube is inflated until it fills the mold and forms the desired shape. The steps and the components of the process are described in detail in the next section. Our project 'Design and fabrication of blow molding machine' aims to make a small machine that can make small items of common use like bottles, glass , cups, shampoo bottles and utensils. Some of the required properties of our desired machine are listed below:

- Compact size
- Portable
- Low power consumption
- Low skill level requirement
- Low operating cost
- Easy maintenance and operation
- Sufficient production rate

CHAPTER 2 **Literature Review**

BLOW MOULDING

Blow molding is a manufacturing process by which hollow plastic parts are formed.

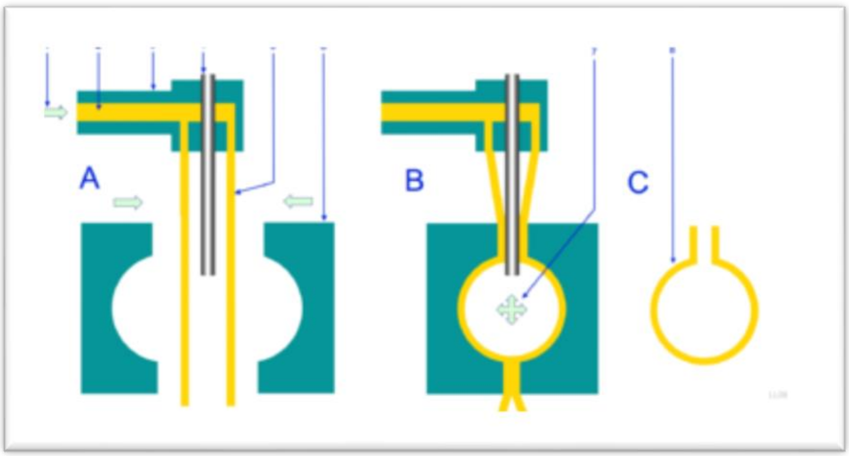


Figure 1(Blow Molding Basics)

TYPES

Blow molding is of following types:

- extrusion blow molding
- injection blow molding
- injection stretch blow molding

GENERAL PROCEDURE

The process principle is same as glassblowing .The blow molding process begins with melting down the plastic and forming it into a parison(pipe like shape) or in the case of injection and injection stretch blow molding (ISB) a preform.

The parison is a tube-like piece of plastic with a hole in one end through which compressed air can pass.

The parison is then clamped into a mold and air is blown into it. The air pressure then pushes the plastic out to match the mold. Once the plastic has cooled and hardened the mold opens up and the part is ejected.

EXTRUSION BLOW MOULDING (EBM)

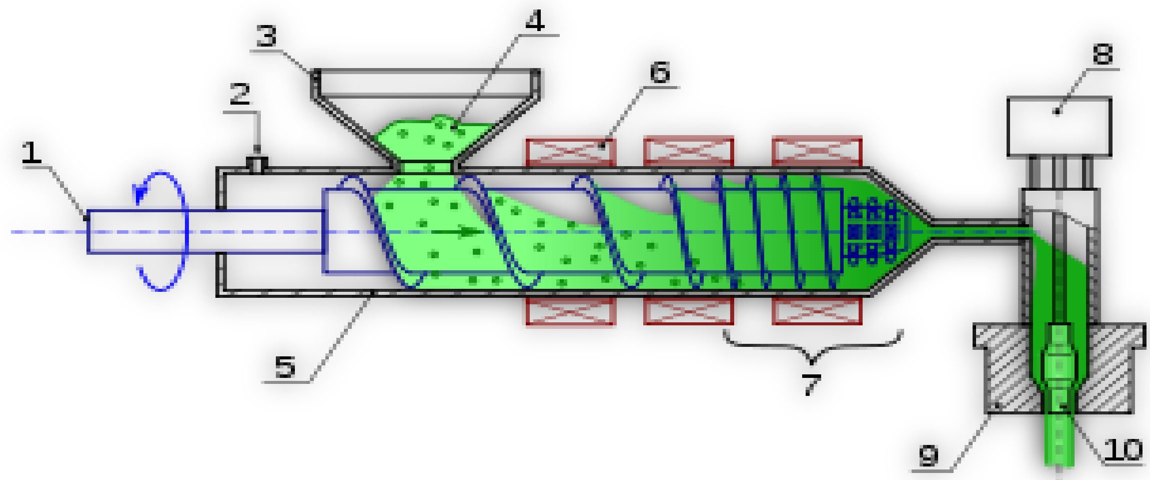


Figure 2 (Basic Mechanism and Components)

1. Motor
2. Hot gases exit nozzle
3. Hopper
4. Plastic pallets
5. Barrel
6. Heaters
7. Metering Zone
8. Accumulator Head
9. Extrusion Die
10. Wall thickness adjustment mechanism

In extrusion blow molding (EBM), plastic is melted and extruded into a hollow tube (a parison). This parison is then captured by a cooled metal mold. Air is then blown into the parison, inflating it into the shape of the hollow bottle, container, or part. After the plastic has cooled sufficiently, the mold is opened and the part is ejected.

Variations

- Continuous Extrusion Blow Molding
- Intermittent Extrusion Blow Molding

Continuous Extrusion Blow Molding

In Continuous Extrusion Blow Molding the parison is extruded continuously and the individual parts are cut off by a suitable knife.

Intermittent Extrusion Blow Molding

In Intermittent blow molding there are two processes

- reciprocating screw machinery

straight intermittent is similar to injection molding whereby the screw turns, then stops to stop pushing out the material.

Accumulator head machinery

With the accumulator method, an accumulator receives melted plastic and when the previous mold has cooled and enough plastic has gathered, a rod pushes the melted plastic and forms the parison. In this case the screw may turn continuously or intermittently.

EXAMPLES

Examples of parts made by the EBM process include most polyethylene hollow products, Milk bottles, shampoo bottles, Automotive ducting, watering cans and hollow industrial parts such as drums.

ADVANTAGES

Advantages of blow molding include:

- low tool and die cost
- fast production rates;
- ability to mold complex part
- Handles can be incorporated in the design
- Low melting temperatures and blowing pressures are required

DISADVANTAGES

Disadvantages of blow molding include:

- limited to hollow parts
- low strength
- to increase barrier properties multilayer parisons of different materials are used thus not recyclable
- To make wide neck jars spin trimming is necessary

SPIN TRIMMING

Containers such as jars often have an excess of material due to the molding process. This is trimmed off by spinning a knife around the container which cuts the material away. This excess plastic is then recycled to create new moldings. Spin Trimmers are used on a number of materials, such as PVC, HDPE and PE+LDPE.

PARAMETERS

Blow moulding machine provides the following functions:	*FOLLOWING POINTS ARE FOR FURTHER STUDIES:*
• Melting ∓ pumping of plastics melt in to the Die by the EXTRUDER	• Understanding of screw plasticising ∓ temperature profile is important. • Optimised screw design to handle specified polymer is required.
• Forming of parison - hollow tube of plastic melt - by the DIE	• It should supply melt with uniform pressure, viscosity and temperature at all around the exit of die. These should not vary with time. • Weld lines should be strongly merged by suufficient back pressure. • Balanced melt flow, compresion ratio, land length ∓ lback pressure are important factors in Die design.
• Clamping two halves of moulds (cavities) around the parison and holding it clamped and cut off the parison - CLAMP UNIT	Clamp unit moves between PARISON STATION and; BLOW STATION. It close, clamp ∓ opens mould aroung parison at parison station. After parison is cut it moves the mould to Blow station. After the AIR BLOW into the mould , it opens and ejects the bottle. These movements are controlled by HYDRAULIC SYSTEM.
• Expanding parison into the mould cavity with compressed air, thereby allowing parison to take up shape of the mould cavity,- BLOWING UNIT	• At Blow station BLOW PIN enters the mould and blows air into the mould. Cooling of mould takes place. • Here HEAT EXCHANGE system in the mould requires good understanding. Cooling System should be well designed.
• Exhausting the air from the moulded part and cool the plastics.	Ejection is carried out at Blow Station after the exhausting air from the mould.

Blow molding produces hollow three-dimensional articles from many of the thermoplastics materials which are available as granules or powders. The simplest tool consists of two female parts which contain a cavity when closed. Granules or powder are softened in a plasticizing cylinder and extruded into a vertical tube or "parison". The soft, warm parison is surrounded by the open mold which is then closed, thereby sealing the lower end of the parison. This is then inflated pneumatically (from the other end) to conform the surface of the mold.

Clearly the outside dimensions of the article can be accurately determined, but the wall thickness, and its distribution, depends on the size of the parison and the geometry of the mold.

Die design and selection of parison size and its wall thickness is very important. Melt flow pattern, compression of melt, land length, back pressure are important factors in die design. Controls for varying parison wall thickness in number of steps are available. This feature allows to produce bottles with fairly uniform wall thickness.

It is not easy to mold-in lugs and bosses and holes.

The bottle produced by Extrusion molding are expected to have following characteristics:

- Barrier against gas and vapor
- Environmental resistance
- Impact resistance
- Clarity or colorful

• Printability

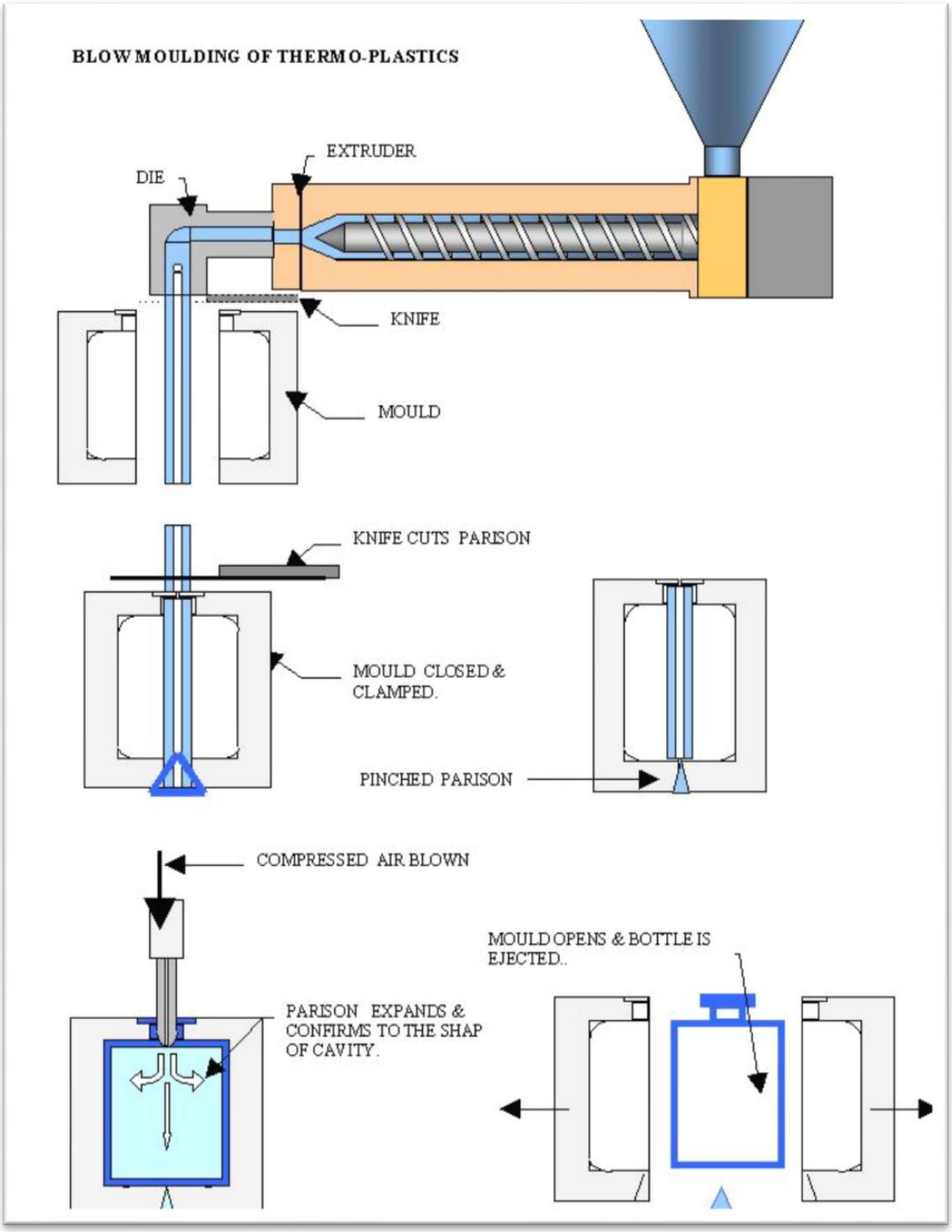


Figure 3(Basic mechanism)

BLOW MOLDING MACHINE

The machine provides the following functions:

- Melting of plastic,
- Forming the parison - hollow tube of molten plastic,
- Clamping two halves of mold around the parison and holding it closed,
- Expanding parison into the mold cavity with compressed air there by allowing parison to take up the shape of the mold cavity,
- Exhausting the air from the molded part and cool the plastic.

To carry out the above mentions sequence of operations the Blow molding machine incorporates the following parts:

- **Extruder**: to plasticise the plastic, special screw for HDPE, RPVC, PP are designed.
- **Parison head**: (cross head and die assembly) to create the desired size of parison,
- **Mold clamp unit**: to open, close and clamp the mold and to shift the mold to and fro between the centre lines of extrusion and blow (pin) station. Another hydraulic cylinder is used for shifting mold clamp unit from parison head to blow/ejection station.
- **Blow and ejection stations**: (also known as calibration station). This stations should be connected to source of compressed air to inflate the parison.
- **Hydraulic systems**: to operate in proper sequence the mold clamp unit - mold open, close and clamp.
- **Pneumatic system**: to operate in proper sequence

    (a) Pre-blow-support air, movement of blow unit.

    (e) Inflating unit.

- **Electrical control panel**:

    (a) To control step less speed variation of AC motor of extruder.

    (b) Temperature control of barrel heaters and die heater zones,

(c) To control the sequence of operation involving hydraulic and pneumatic.

- **Extruder**: In present day machines the extruder is placed horizontally. It consists of screw, barrel with heaters, gear box, Dc drive for steeples variation of screw RPM. Screw of L/D ratio of 10 to 30 is used. Screw profile is designed to suit the polymer being used.

  HDPE screw: It is decompression type screw with one compression zones. Compression ratio are high i.e. of the order of 3.2 to 3.5. A small feed zone and longer compression and metering zone with gradual tapering according to compression ratio.

  PVC screw: It is specially designed keeping in mind the heat sensitive nature and high abrasion of PVC. It is therefore a three zone screw with a short feed zone and a longer compression zone with gradual taper and a lower compression ratio of 1.9 to 2.

  PP screw: This screw has three zone with longer compression and metering zones.

In this process the parison is continuously extruded. Screw RPM of extruder is adjusted to give right length of parison during one cycle time.

PARISON HEAD ASSEMBLY

It consist of mainly

- Cross head
- Torpedo spider mandrel
- Die body,
- Die ring,
- Mandrel insert,
- Die centering screw,
- Heaters, Thermostat.

SIDE FED HEAD*:*

For HDPE

This design is suitable for processing polyethylene. The melt coming from extruder and progresses towards the die ring, in the uniform tubular shape. The melt emerges from the die ring with balanced flow mandrel.

In order to control the temperature of melt in parison head, it is necessary to prove heaters and thermocouples on the parison head. The entire surface of the head can be divided in to 2 or 3 heater zones with independent temperature controller.

Mandrel is connected to an adjusting rod which can be moved up or down wards to vary the gap (wall thickness) between die-ring and mandrel. The plastic melt flow passage between die-ring and mandrel at die exit is divergent or convergent. Four adjusting screws are provided on the die body for centering the mandrel. Right combination of inserts are to be selected for a given bottle.

TWO PARISON HEAD

For HDPE

Two parison head is used for blow molding small bottles of HDPE, LDPE AND PP. It melt flow is bifurcated in the adapter. For precise balancing the flow leading to both parison head, separate throttle valves are provided on both the side of the adapter.

TOP FED HEAD

For PVC

It is also known as spider / torpedo head. This design is suitable for materials like PVC, PC etc. as they make high demands on the precision of the temperature control and flow behavior. This requires flow path of low resistance eliminating dead zones to avoid stagnation of material.

With this head design, the melt flows axially on to the cone shaped torpedo tip and two web spider. Then it passes through the die ring and core in tubular form. The length of the flow between spider web and die ring exit should be enough for re-join the melt at the operating back pressure on the melt. Pre-blow air \ support air connection is provided by a connecting hole in the web of spider and torpedo as shown in the figure.

Centering screws are provided on die body to make the die gap uniform at die exit.

ACCUMULATOR HEAD

Accumulator head is storing part of the machine. Its storing capacity is usually 30-40x the part weight. It is built to create uniform temperature profile in melted plastic. When uniform temperature is ensured then plastic is pushed forward to the die exit.

Blow Molding Materials

It is not possible to mold all polymers by Blow molding. Some polymers, such as PP (Polypropylene), cannot be made to form a parison because of small intermolecular forces and low viscosity at elevated temperatures. Other polymers, such as a mixture of resin and glass fiber in woven or mat form, are unsuitable by their physical nature for use in the process. In general polymers with high viscosity at elevated temperatures are suitable. These include both plain polymers and those reinforced with mineral particles or short random fibers of glass or carbon. Polymers commonly used for Blow molding and their melting points are given below:

Table 1 (Melting Temperature of Polymers)

Material	**Melting Temperature (^{o}C)**
Polystyrene (PS)	240
Polyamide (PA)	220
Low Density Polyethylene (LDPE)	110
High Density Polyethylene (HDPE)	126
Polyethylene terephthalate	260
Polyvinyl Chloride (PVC)	115

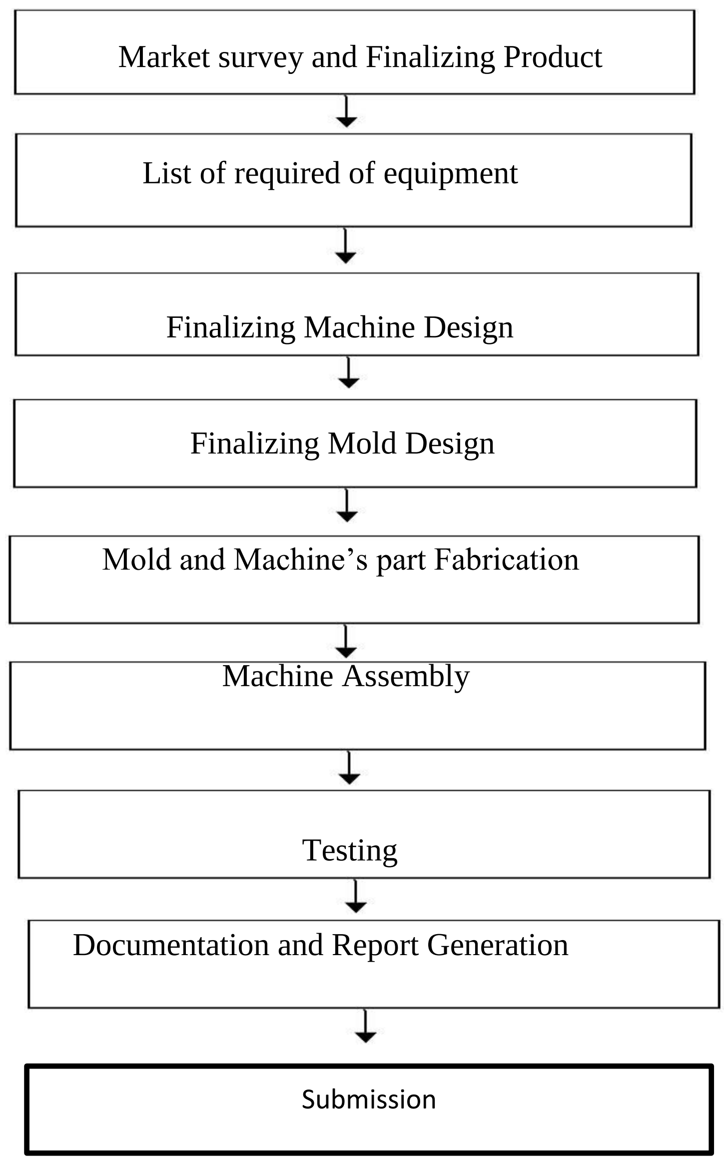
A comparison of some physical properties of different thermoplastic polymers is shown in the table below

Table 0 (Physical Properties of Polymers)

Thermoplastic	**Yield Strength (MN/m^2)**	**Heat Deflection Temperature**	**Elastic Modulus**
High Density Polyethylene	23	42	925
Low Density Polyethylene	20	30	400
PVC	41	99	2100
PS	66	115	2800
Polyethylene terephthalate	113	227	7500

CHAPTER 3 **METHODOLOGY**

Literature Review



PRODUCT SELECTION:

Blow molding can be used to manufacture a variety of products which include bottles, toys, fluid containers and balls etc.

Selection Criteria:

Since our project focuses on cottage industry so we had to pick something cost effective and well demanded, therefore the criteria for selection of the product included,

- Product Cost
- Complexity
- Market Demand

Final Selection:

Based on selected criteria, we surveyed local markets for demand of the available of products as well as the costs involved. On that basis we selected bottles as our product for the machine.

MATERIAL SELECTION:

There are many plastics and resin materials being used for extrusion blow molding some notable ones are as follows,

High Density Polyethylene (HDPE):

HDPE is the most widely used resin for extrusion blown plastic bottles. This material is economical, impact resistant, and provides a good moisture barrier. HDPE is compatible with a wide range of products including acids and caustics but is not compatible with solvents. It is usually supplied in FDA approved food grade. HDPE is naturally translucent and flexible. The addition of color will make HDPE opaque although not glossy. Adding extra weight to the bottle will yield a. HDPE rigid container can be supplied electro-treated or flame-treated by request so that it can be ready for silk screen decoration. While HDPE provides good protection at below freezing temperatures, it cannot be used with products filled at over 180°F or products requiring a hermetic seal. A glossy surface can be achieved with the use of the special copolymer resin, High Gloss HDPE.

Low Density Polyethylene (LDPE):

LDPE is similar to HDPE in composition but it is less rigid and chemically resistant than HDPE, and more translucent. It is used primarily for squeeze applications. LDPE is significantly expensive than HDPE but yields a glossy bottle upon colored production.

Medium Density Polyethylene (MDPE):

MDPE lies mid way from LDPE to HDPE. The bottles are less translucent than LDPE but more flexible than HDPE. It also yields glossy bottle when produced in colors.

Polypropylene (PP):
PP is naturally translucent material. It can be easily processed in Blow Molding. It has excellent chemical resistance. In color production it too gives a glossy finish.

Polyethylene terephthalate (PETG):
PETG has reasonable durability alongwith excellent gloss, clarity and sparkle desired for clear bottles. Normally it is used to manufacture shampoo bottles and cosmetic products.

PRODUCT DESIGN:

Nowadays bottles come in endless designs and shapes. So we had to select a suitable bottle design as well, keeping in mind the cost, demand, complexity and shape.

First we made some designs on Pro E but after consulting with supervisors and surveying the market we had to let go of those designs since they were not cost effective and had complex shapes in terms of manufacturing ease.

So in the end we redesigned a relatively simple bottle with a generic shape and reasonable volume capacity.

Die/Mold Design:
After finalizing the product, we had to design the mold or die for product. The designs were again carried out on Pro-E and were manufactured from a local manufacturing resource.

MACHINE DESIGN:

After selection of product and design of mold, the next thing was the machine design. For that purpose we surveyed local manufacturing resources, industrial resorts and internet for information on common designs being used. After comparing them and making it more and more simple in design which would in turn lower the cost, we came up with a modified generic design.

The Construction:
The machine consists of following parts,

- Head
- Barrel
- Screw
- Heaters
- Gear Box
- Motor
- Thermocouple panel
- Compressor

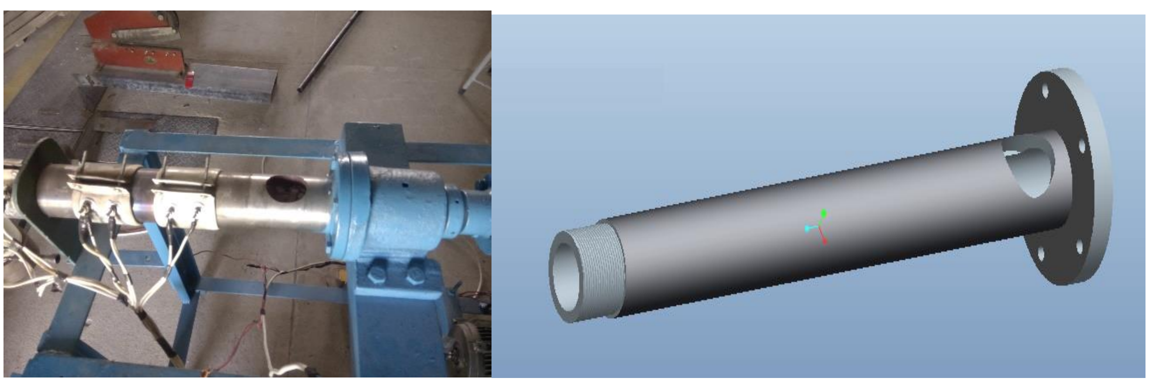
Head:
Machine head is one of the key parts of the machine. Its size gives the range of moldable products. For determination of heads size, the barrel size also matters.

Machine head consists of the most high power heater relative to the rest of them. Pictures are showing CAD design and manufactured parts.

Figure 4 (CAD Model and Manufactured Head)

Barrel:
Barrel is through which the material moves forward and is homogenized. Barrel holds the screw as well as provides enclosure. Pictures are showing CAD design and manufactured parts.

Figure 5 (CAD Model and Manufactured Barrel)



Screw:
Screw is responsible for the forward motion and mixing of the molten material. It is enclosed in the barrel and is powered by the motor via gearbox. Pictures are showing CAD design and manufactured parts.

Figure 6 (CAD Model and Manufactured Screw)

Gear Box:
A gear box is used in order to control the speed of the screw and the whole material passage. It transfers the rpm of motor to the screw. There is no CAD model for gear box because it was purchased as it is.

Figure 7 (Gear Box)

Motor:
A motor is required to power the screw and to rotate it. The motor used in our design was a 5 HP motor. When motor runs, gears transfer the power and the screw rotates and so the material moves forward.

Figure 8 (Motor)

Heaters:
Heaters are used to melt the material. We used resistant band heaters for our purpose. In our design 5 heaters were used. The heater power calculations were done properly as per the need of the design and then the heaters were fabricated. Two heater is wrapped to the Head, rest are wrapped on the barrel.

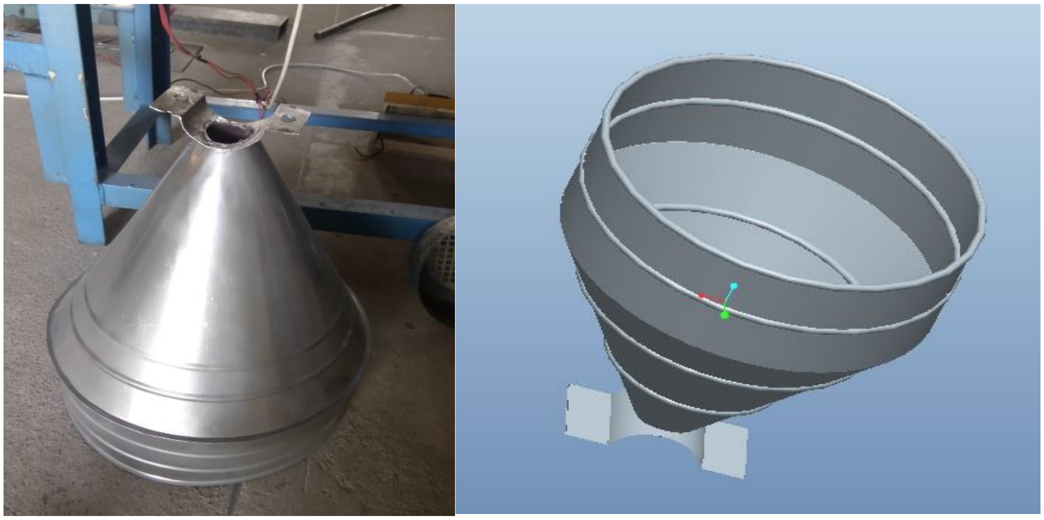
Thermostat Panel:
The heaters can be well controlled and customized. For that purpose a thermostat panel is also installed. It can regulate the power of heaters which in turn saves electricity units sued in turn saving cost. We calibrated the heater and found the temperatures on different levels of thermostat and then set temperatures as per our design calculations.

Figure 9 (Thermostat Panel)

Compressor:
A compressor is required to blow air into the parison inside the mold in order for the parison to take molds shape. Connection of air is given from compressor through top of the head. Air throw is controlled with a valve. We did not buy compressor rather we used MRC's compressor because it was sufficient for our operation.

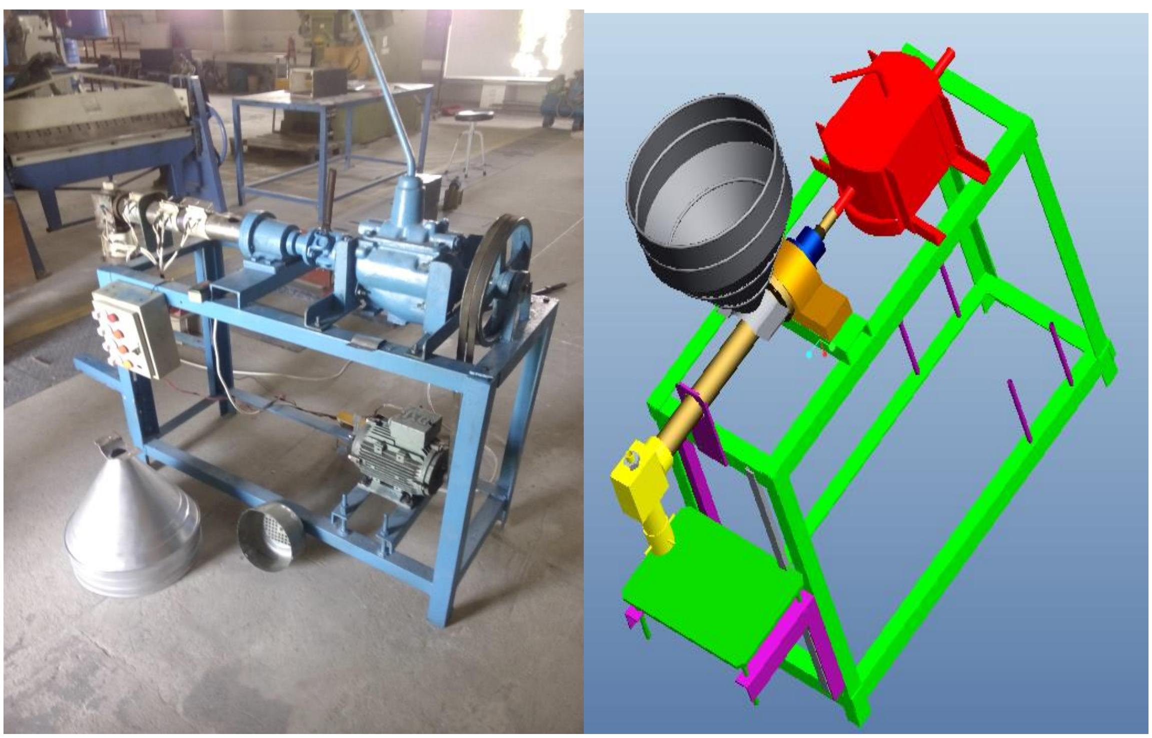
Hopper

Figure 10 (Hopper)



Machine Assembly:

Figure 11 (Final Assembly)



Calculations and analysis.

Screw:

In screw design most important thing is thread depth and thread pitch. Diameter/Length ratios are recommended by material manufactures for different materials. We designed machine for HDPE, for HDPE recommended L/D are 10:1-20:1 we chose 10-1 and for 10:1 diameter range in 4-4.5cm we took 4.4cm as our diameter. Our length was 44cm thread plus 25cm without threads.

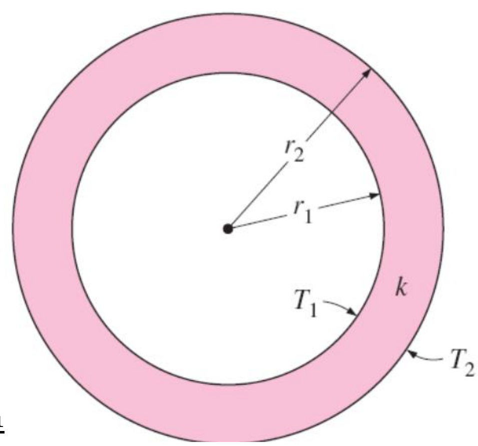
For thread depth and pitch calculations analytical formulas are devised as for exact calculations nonlinear analysis of non-Nutonion fluid is required. We avoided that because our supervisor advised us to use simple formulas and avoid non-linear analysis. Screw normally has three zones

- Feed zone
- Transition zone
- Metering zone

Feed zone

In feed zone thread depth is related to feed flow rate which in our case is calculated by exit rate required. Our part weight is 15g and from heat transfer

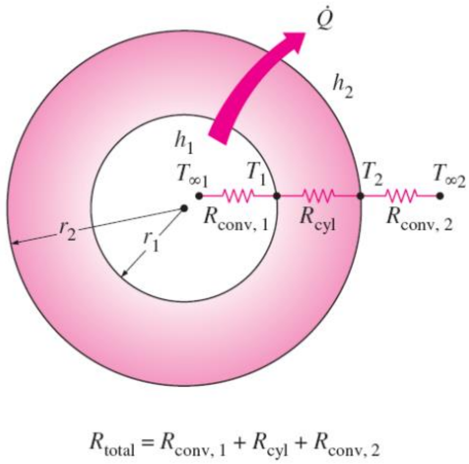
Figure 12 (Heat Transfer Model 1)



$$\dot{Q}_{cyl} = \frac{T_2 - T_1}{R_{sph}}$$

$$R_{cyl} = \frac{\ln(\frac{r_2}{r_1})}{2\pi L k}$$

Figure 13



Here convection constant for air at 2bars pre-blow pressure is taken from convection table.

$$\dot{Q}_t = \frac{T_{\infty 2} - T_{\infty 1}}{R_t}$$

$$R_t = R_{conv,1} + R_{conv,2} + R_{conv,3}$$

$$R_{conv} = \frac{1}{2\pi L r h}$$

By keeping inner and outer temperatures of the pareison 150 ^oC and 160^oC we find out the heat transfer rate and by compressor rating we knew air flow rate and solving these two we get 3.4 seconds for full 20 gram parison extrusion here 5 gram is waste material. So the flow rate can be calculated it comes out to be

$\dot{Q} = 21.17$ kg/hr

Now we can use this flow rate in further calculations. The pitch of screw can be calculated from the following formula.

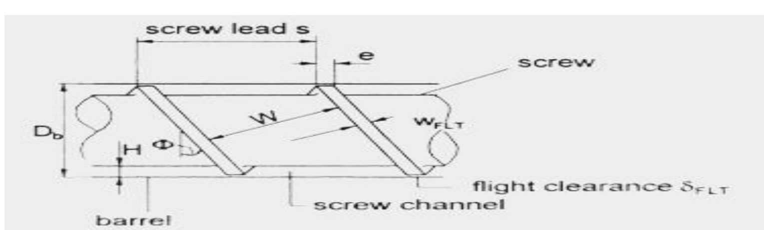


Figure 14 (Screw Design Parameters)

$$G = 60.\rho_0.N.\eta_F.\pi^2.H.D_b.(D_b - H).\frac{W}{W + W_{FLT}}.\sin\phi.\cos\phi \; and \; [\phi = \tan^{-1}[s/(\pi D_b)]]$$

Barrel diameter D_b= 45 mm

Screw lead s=? mm

Number of flights ν = 1

Flight width w_{FLT}= 5.5 mm

Channel width W =? mm

Depth of the feed zone H = 15mm

Conveying efficiency η_F = 0.436

Screw speed N = 100 rpm

Bulk density of the polymer ρ_0= 800 kg/m

Here feed zone depth is recommended according to the L/D ratio and the flight width is found using bearing stress analysis for maximum load max. Load of 30kN is applied by the polymer load is found by power screw analysis. From this formula we found the pitch of the screw. Which comes out to be ~25mm.

Table 3 Conveying efficiency.

Polymer	Smooth barrel	Grooved barrel
LDPE	0.44	0.8
HDPE	0.35	0.75
PP	0.25	0.6
PVC-P	0.45	0.8
PA	0.2	0.5
PET	0.17	0.52
PC	0.18	0.51
PS	0.22	0.65

Flow Rate in Metering zone.

$$Q = \alpha N - \beta \frac{\Delta P}{\mu}$$

Here Q is in Kg/hr N is RPM ΔP is axial pressure drop μ is viscosity. α and β are given by

$$\alpha = \frac{\pi^2 D^2 H}{2} \sin\theta\cos\theta$$

$$\beta = \frac{\pi D H^3}{12L} \sin^2\theta$$

Compression Ratio

$$C_r = \frac{H_F}{H_M}$$

Here H_f and H_m are screw thread depth in feed and metering zones respectively.

Screw FEM analysis.

Screw was analyzed in FEM software and was confirmed factor of safety >3

Von-mises Criteria.

Figure 15 (FEM analysis Screw, Von-mises Criteria)

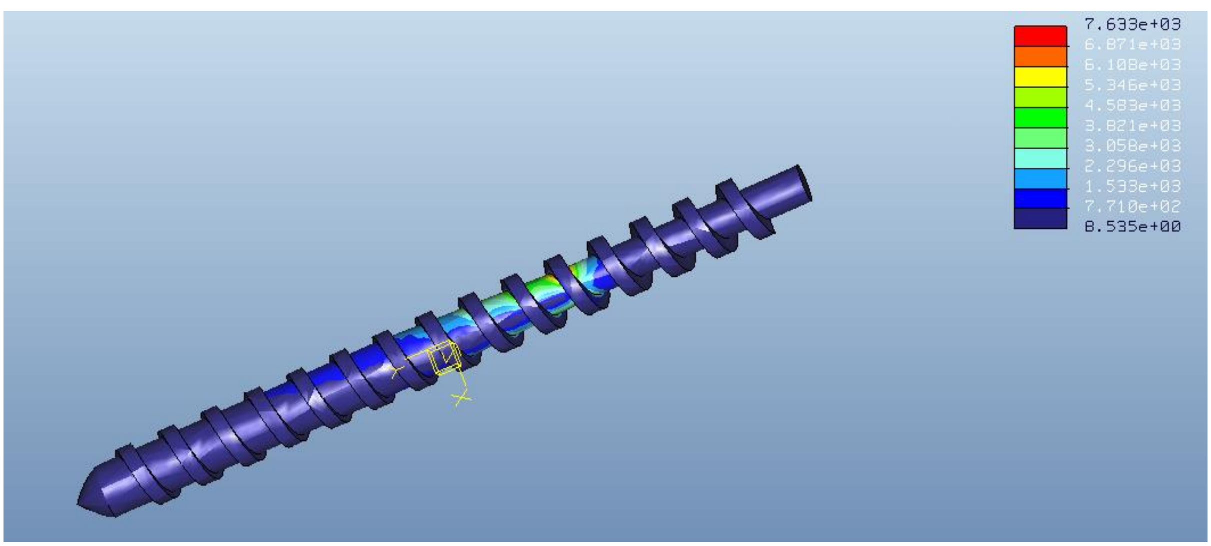
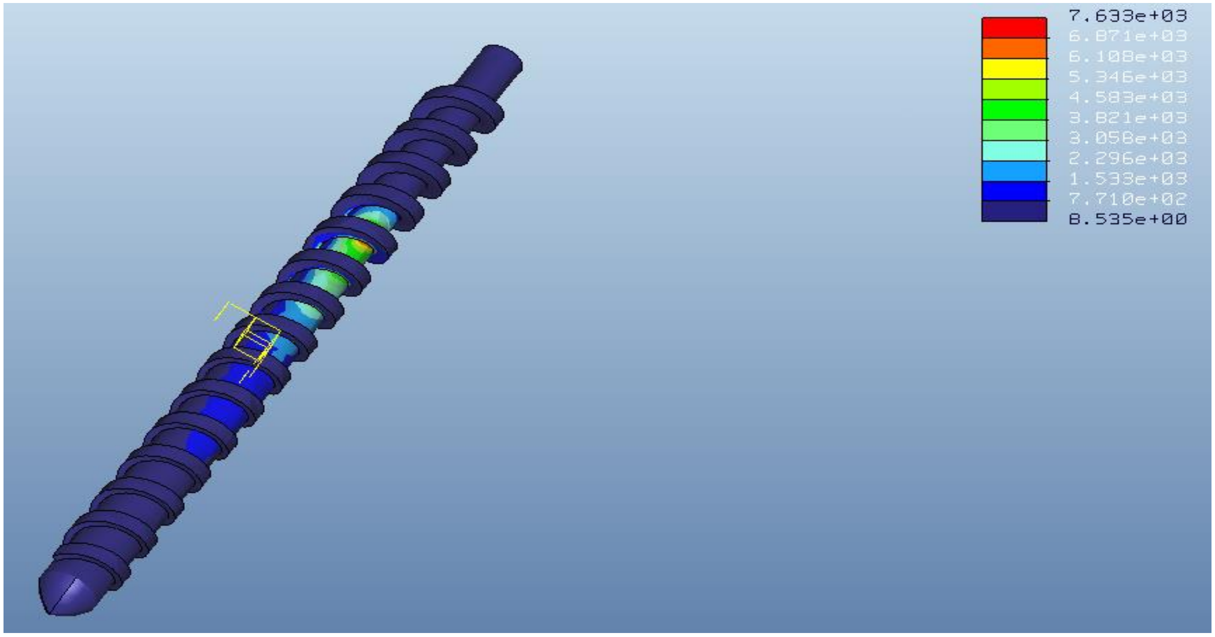


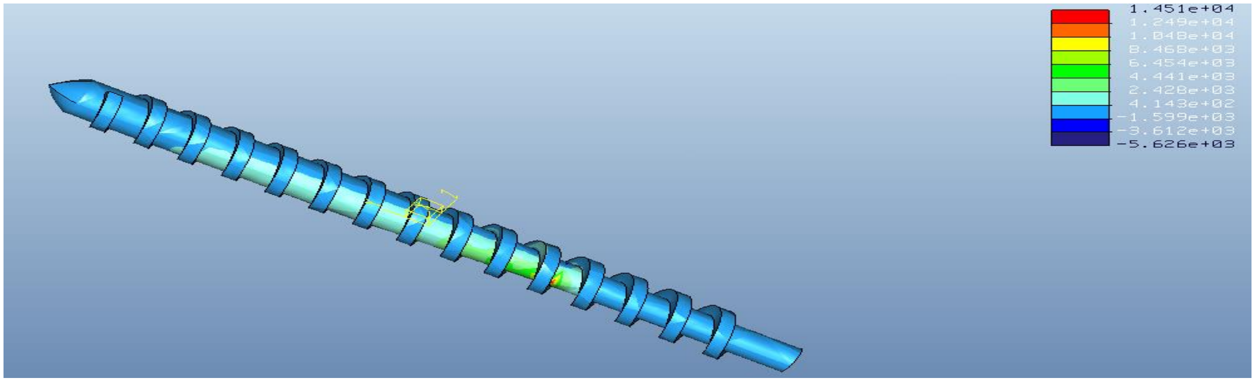
Figure 16 (FEM analysis Screw, Von-mises Criteria)



Max Principal Stress.

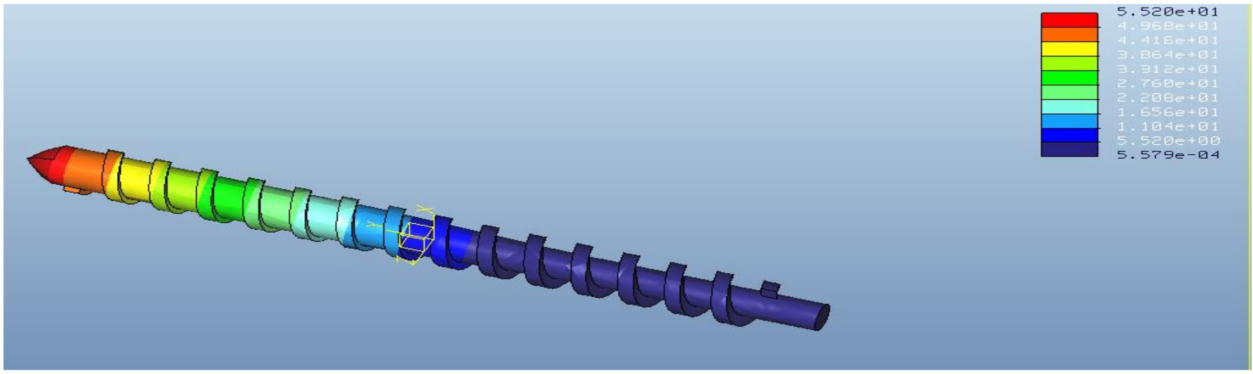
Figure 17 (FEM analysis Screw, Max Principal Stress)

Figure 18 (FEM analysis Screw, Max Principal Stress)



Displacement analysis.

Figure 19 (FEM analysis Screw, Displacement analysis)



Barrel and Head Analysis and Calculations.

Barrel thickness for HDPE and Mild steel is recommended 1cm. Pressure developed inside the barrel is in range of 150-200 Mpa. Shear barrel walls is estimated by

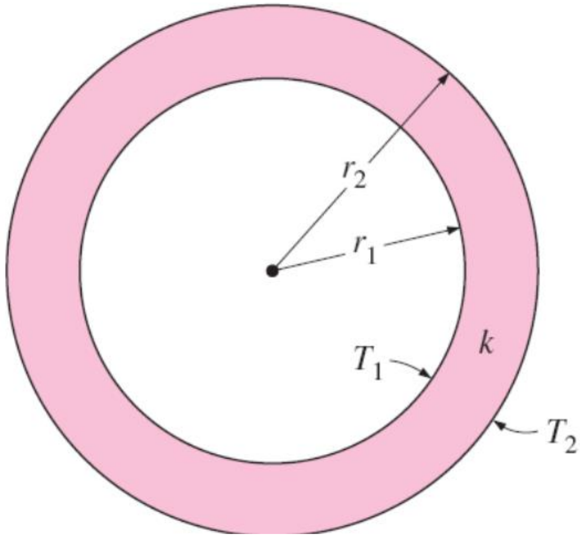
$$\tau_W = \frac{\Delta P}{2L_{die}} R_{die}$$

$$\tau_w = m\left[\left(\frac{3n+1}{4n}\right)\frac{4Q}{\pi R_{die}{}^3}\right]^n$$

These are two different relations but the give same results.

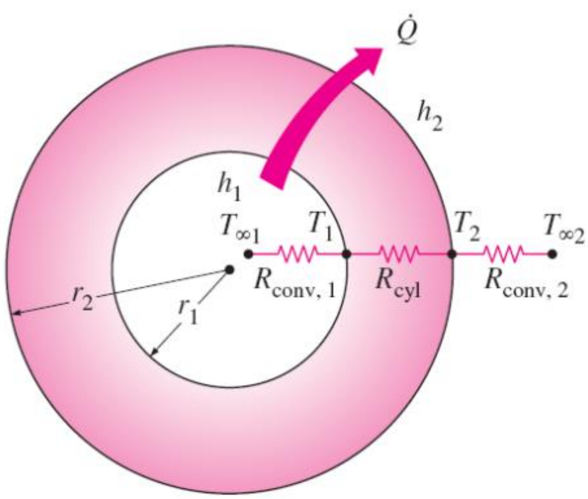
Heat transfer analysis of barrel yielded the heater wattages.

Figure 20 (Heat Transfer Model Barrel 1)



$\dot{Q}_{cyl} = \frac{T_2 - T_1}{R_{sph}}$ $R_{cyl} = \frac{\ln(\frac{r_2}{r_1})}{2\pi L k}$

Figure 21 (Heat Transfer Model Barrel 2)



$$R_{\text{total}} = R_{\text{conv},1} + R_{\text{cyl}} + R_{\text{conv},2}$$

Here convection constant for air at 2bars pre-blow pressure is taken from convection table.

$$\dot{Q}_t = \frac{T_{\infty 2} - T_{\infty 1}}{R_t}$$

$$R_t = R_{conv,1} + R_{conv,2} + R_{conv,3}$$

$$R_{conv} = \frac{1}{2\pi L r h}$$

The recommended temperatures of different materials in different screw zones are listed in **Table 4 (Recommended Temperatures for different Zones)**

Material	Zone 1 temp °F	Zone 2 temp °F	Zone 3 temp °F	Zone 4 temp °F	Head (A) temp °F	Melt temp °F
ABS	380–440	390–440	400–440	400–440	400–440	400–440
Acrylic	370–460	380–460	390–460	400–460	400–460	400–460
LDPE	320–340	320–350	330–360	340–370	330–380	340–380
HDPE	350–390	360–400	370–410	370–420	370–420	370–420
Nylon 6	440–480	450–480	460–480	470–490	440–510	450–510
Nylon 6/6	470–550	480–540	480–540	490–530	520–540	510–540
PC	440–480	450–480	460–480	470–490	460–510	460–510
PC/ABS	420–445	430–455	440–465	450–475	440–490	450–490
PP General purpose	340–430	350–440	360–450	370–450	390–460	390–450
PS General purpose	340–360	360–390	390–420	400–440	360–450	360–440
PS High impact	370–390	390–420	420–450	430–470	420–460	420–460
PVC Flexible	250–290	260–300	270–310	280–320	310–375	310–375
PVC Rigid	280–300	300–320	320–350	340–370	330–390	340–390
TPE (Hytrel)	300–400	310–410	330–430	350–450	370–460	370–450
TPU	360–450	360–460	360–460	360–470	370–475	340–465
TPU/PVC (Vythene)	300–320	310–330	320–340	330–360	340–365	350–365

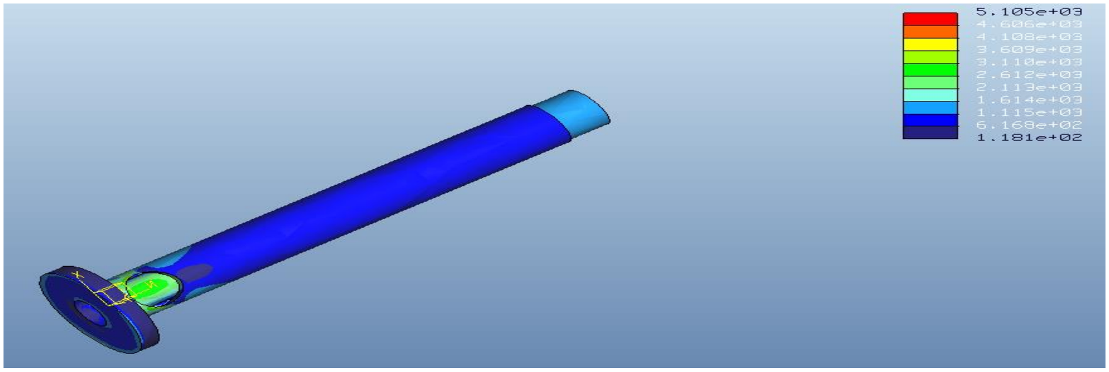
From this table we know $T_{\infty 2}, T_{\infty 1}$ so the heat transfer rate was found which yielded heater wattages for feed, transition, and metering zones. And the heater at the head and die.

Head was designed to store 0.75 ltrs of melted HDPE and extrusion die opening was kept 2 mm thick. Inner diameter 7mm and outer 13mm mean diameter 10mm. After the bottle is inflated parison is stretched 3.5 times the mean diameter

Barrel FEM Analysis.

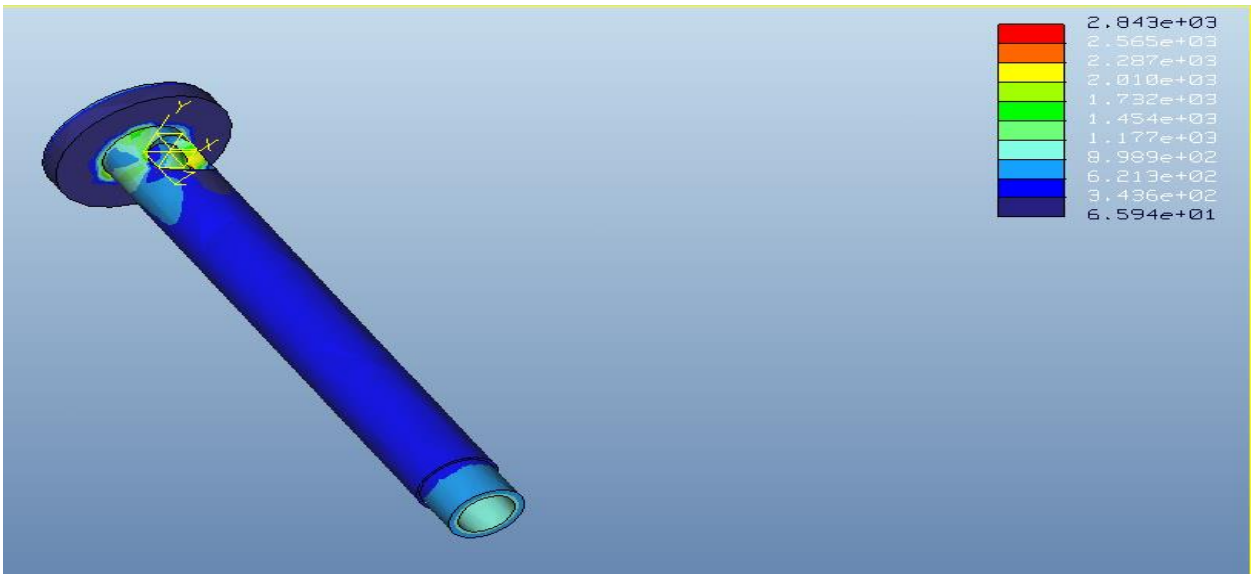
Von-Mises Criteria

Figure 22 (Barrel FEM Analysis, Von-Mises Criteria)



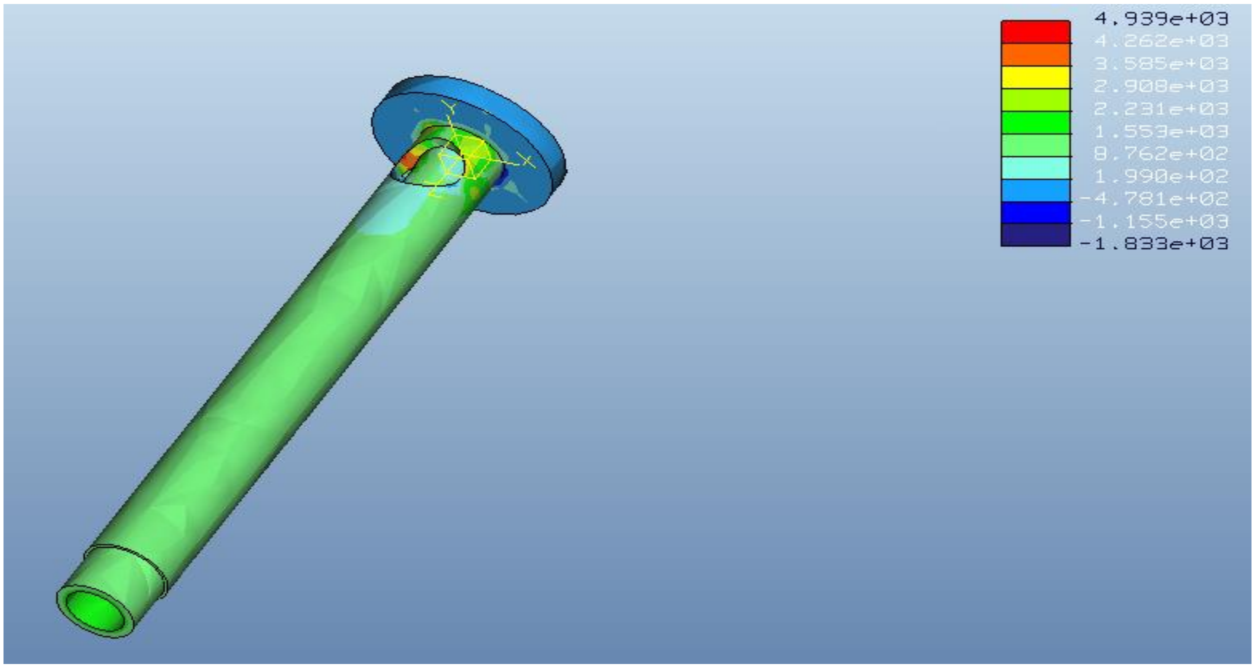
Max-Shear

Figure 23 (Barrel FEM Analysis, Max-Shear)



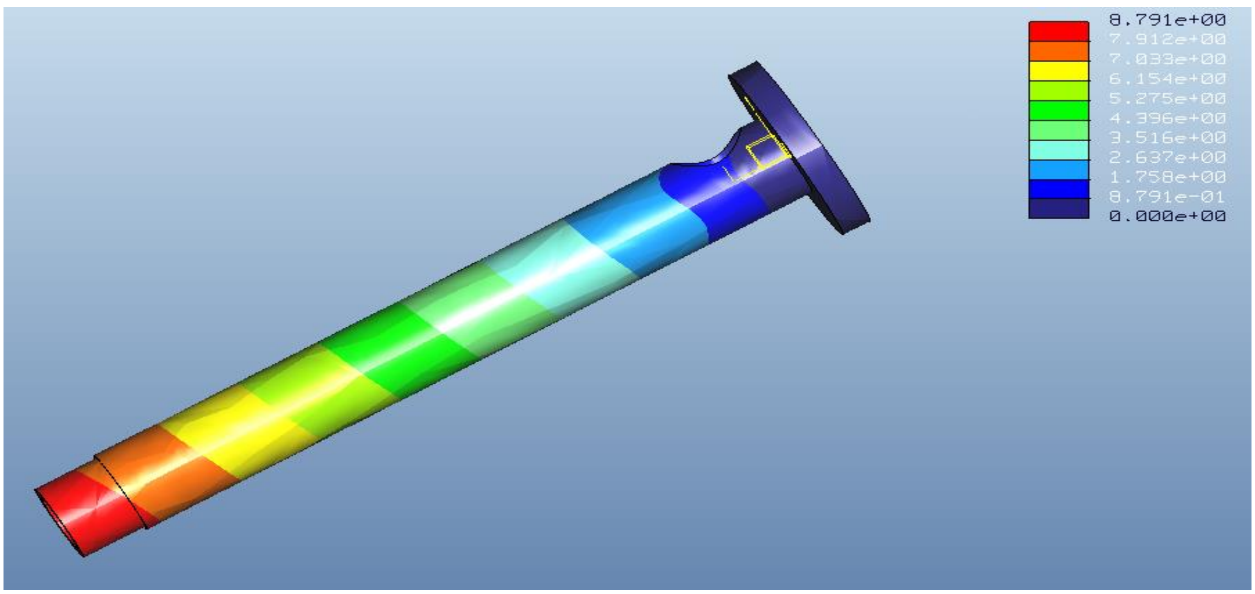
Max-Principal

Figure 24 (Barrel FEM Analysis, Max-Principal)



Max-Displacement

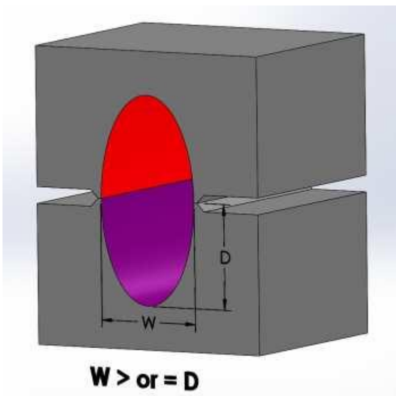
Figure 25 (Barrel FEM Analysis, Max- Displacement)



Mold Design Parameters

Exterior Surface (Mold Cavity) Design

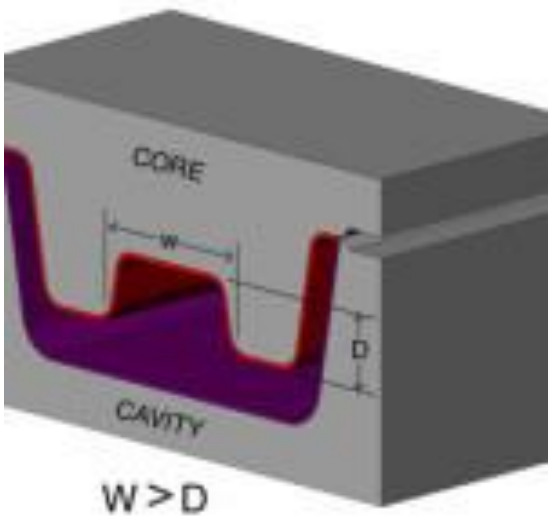
The inner and outer walls of the part are formed simultaneously and integrally, but interior and exterior designs are essentially independent so we review them separately. As the design develops, the designer should begin thinking about the interaction of the plastic and the mold that will produce the part. The visual exterior of many products is formed in one half of the mold called a cavity. Following are some of the features of mold to be considered. **Figure 26 (Mold Cavity)**



Cavity – Cavity Blow Ratio = W>D

A bottle is a typical example of a blow molded part formed using 2 cavity mold halves. A round bottle has a blow ratio that is comprised of a width=diameter and a depth=radius (2:1). The result is excellent material distribution in a round bottle. But, not all parts will be round how much stretch depend on Elongation elasticity of the material and how thin a wall you are willing to accept. But as a rule of thumb, the material won't stretch much further down into a cavity (Depth=D) than the width of material available to fit into the cavity (Width=W). So, try not to design your cavity-cavity part to be deeper than the width.

Figure 27 (Mold Cavity)



CHAPTER 3 **TESTING**

After the machine mold was developed, our next step was to use them to make our desired bottles. Step by step progress in this regard is mentioned below:

First Attempt

At first we chose light blue colored Polypropylene (PP) material pellets to test our machine and mold. The material was heated for several minutes in the machine's barrel. The thermostats of the heaters were kept at maximum capacity. When the material was extruded, it was not melted enough. When the material was extruded it was not fully melted and temperature distribution was not uniform. When the parison was extruded it had small punctures due to this reason it could be inflated properly. Another reason for defects was when we were testing for the first time we had small 5 bar compressor but even then it could only develop 3 bars max. So the bottles were not inflated properly they had small dents in them because required pressure to inflate was not being provided. Surface finish was very poor.

To overcome the defect a compressor of high pressure was used for the purpose and also because it was a test attempt and PP is cheap material as compared to Marlex HDPE so we tried it just for testing purpose it was even then a success because we designed the machine for HDPE it should not work with other materials.

Figure 28 (1st Attempt Bottle)

Second Attempt

In second attempt we changed the material we used pure white HDPE but we were not able to arrange high pressure compressor. We tied as our second attempt result was comparatively better bottle was not able inflate completely, i.e it had dents but it had much improved surface finish because machine is specially designed for HDPE and all the temperatures in different zones of machine are adjusted according to HDPE design guide. In second attempt there were no punctures in parison but bottles were not able to fully inflate due to low pressure.

Figure 29 (2nd Attempt Bottle)

Third Attempt

In our third attempt we borrowed compressor from MRC and performed the testing. Everyone was stunned by the result bottles were so smooth and symmetrical we could not even believe it was a great success with the help of Almighty Allah (S.W.T).

Figure 30 (3rd Attempt Bottle)

CHAPTER 5 **CONCLUSION AND RECOMMENDATION**

This machine is designed and fabricated for the small-scale production of small plastic articles at cottage industry level. Accordingly, it is endorsed for people with average income that are willing to manufacture small plastic articles such as bottles balls etc. to increase their livelihood.

Although the designed machine gives acceptable results and fulfills the requirements to be used in cottage industry but it can be improved further. Some of the aspects of this machine on which future work can be carried out are:

1. Knowing when to start extruding the plastic is very important. Each plastic material has its own recommended extrusion temperature. However, sensing the temperature at which the plastic is to be injected is largely based on personal expertise and experience. An efficient temperature monitoring device like a thermocouple can be used to overcome this deficiency.
2. Secondly a mold clamping mechanism can increase the production rate at least 1.5x , it can also improve the surface finish.
3. Third recommendation is automation using hydraulic clamping mechanism and pneumatic systems to eject the part and trim waste material can increase production rate more than 3 times the present.
4. Last recommendation is mold cooling system can also increase the production rates and can improve mold life span.

APPENDIX

Cost Analysis and Payback Period

Payback period for mold and machine was calculated keeping in mind if a man operates machine 3 hours a day and throughout the whole month.

Plastic per Ballpoint = 17 grams (including 13 % waste)

Ballpoints per kg = 60 Bottles

Bottles per day= 500 pieces

Bottles produced in 1 month = 15000

Plastic required for month = 255 kg

Price of plastic = 160*255 = 40800

As heaters of 1kW is being used, so electricity units consumed per month = 1200 units

Monthly Electricity charges = 1200(8) = 9600.

If Bottle is sold out at rate of 8 Rs. then price of 15000 Bottles = 120000 Rs.

Profit = 120000- 40800-9600 = 69600 Rs.

As cost of machine and mold is nearly 55000 Rs. then payback period = less than a months

Operating Instructions

a. Open the mold using mold handles at 180^{O} angle
b. Wear heat resistant glove to avoid burns
c. Watch the sticker on gear box and run machine in reverse gear
d. Turn the motor on for few minutes then turn it off.
e. Now put plastic pallets in hopper.
f. Let the heater run till the required temperature is reached.
g. When the required temperature is achieved, turn the motor on again.
h. Capture the parison between the mold cavities.
i. Clamp the mold tightly.

j. Release air from the compressor to inflate the bottle.
k. Remove the solidified plastic from the mold carefully.
l. Using sharp tool remove waste material.
m. Do not touch part with bare hand until it is fully cold.

Safety Precautions

- Stand on a wooden plank while operating the machine
- Preferably gloves should be worn while operating the machine
- Do not touch the machine's barrel while the heater is running
- Earth wire and circuit breaker should be used to protect from electric shock
- Ensure that proper ventilation and exhaust systems are in place to help prevent inhalation of harmful gases and vapors
- Follow good housekeeping procedures and keep floors clean to prevent slips, trips, and falls due to spilled pellets on the work floor

Components and their Material
Table 5 (Machine Components)

Sr. No.	Parts	Materials used	Fabricated/Bought
1	Mold	Mild Steel	Fabricated
2	Barrel	Mild Steel	Fabricated
3	Hopper	Sheet Metal	Fabricated
4	Screw	Carbon Steel	Fabricated
5	Head Assembly	Carbon Steel	Fabricated

6	Gear Box	Axle Steel	Bought
7	Stand Structure	Cast iron	Fabricated
8	Bolt	Cast Iron	Bought
9	Base structure	Cast Iron	Fabricated
10	Motor		Bought
11	Thermostat, Circuit Breaker and Wires		Bought
12	Pulleys	Gray Cast Iron	Casted
13	Universal Joint	Mild Steel	Bought
14	Belt		Bought
15	Heater		Bought

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