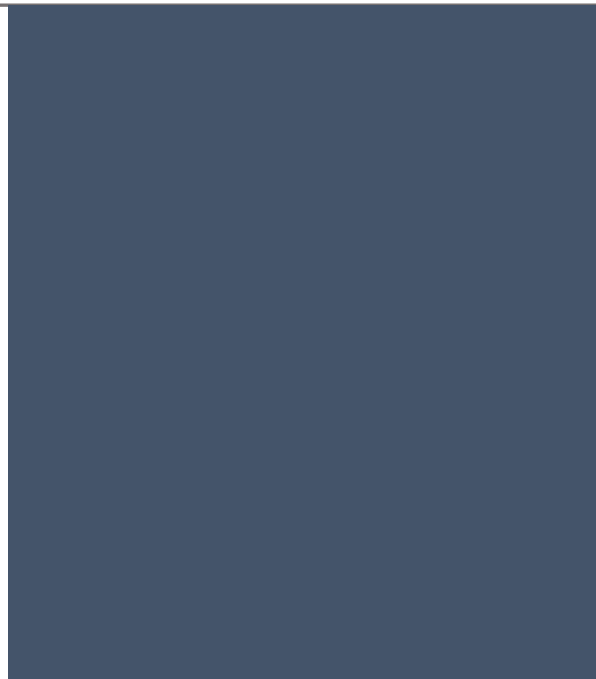




Precious Plastic

Paul Thomas (1708327)



1. Executive Summary

This report details the re-design of a Precious Plastic extruder machine for use with recycled plastic. Precious plastic model uses open source machine design to develop a global community of people working to eradicate plastic pollution.

This report documents the process of the extruder re-design. From the original design through to a final design specific to its new customer requirements. The report details use of design development tools such as QFD, FMEA, Product Design Spec (PDS) and Solid works 3d cad software. It researches the basic principles of an extrusion machine and applies them design process.

Finally concluding on the success of the project and suggesting further recommendations design improvement.

Table of Contents

1. Executive Summary	1
2.0 Introduction.....	4
3.0 Design Specification	5
3.1 The Problem Statement	5
3.1.1 Basic Customer Design Requirements	5
3.2 QFD Matrix.....	6
3.3 Extrusion Market Conditions	8
3.3.1 Market Design Requirements	8
3.4 Conformity Requirements	9
3.4.1 Conformity Design Requirements	11
3.5 Life in Service Requirements	12
3.5.1 Life in Service Design Requirements	12
3.6 Product Design Specification	13
4.0 Extrusion Background Information	14
4.1 Types of extruders:	14
4.1.1 Single Screw Extruders:.....	14
4.1.2 Double Screw Extruder:	14
4.1.3 Vented Extruders:	14
4.2 Extruder Machine Components.....	15
4.2.1 Screw:.....	15
4.2.2 Barrel:	16
4.2.3 Die:	17
4.2.4 The Drive Systems	17
4.2.5 Heating and Cooling Systems in Extruder	17
5.0 Design Critical Appraisal	18
5.1 Precious plastics Extrusion Machine.....	18
5.2 Commercial Machines.....	19
3.2.1 Single Screw Plastic Extruder	19
3.2.2 PVC Pipe Extrusion line PVC Pipe Extrusion Line.....	20
5.3 Precious Plastic Machine Limitations and Areas for Improvements	21
5.31 Safety	21
5.3.2 Efficiency	21
5.3.3 User engagement and interaction	22
5.3.4 Machine Cost.....	22

5.3.5 Barrel	24
5.3.6 Screw.....	25
5.3.7 Hopper	26
5.3.8 Drive Components	27
6.0 Design Development.....	29
6.1 Barrel, Screw and Drive Design Considerations	29
6.2 Safe Electrical System	32
6.3 Design Idea 1.....	33
6.4 Design Idea 2.....	34
6.5 Design Idea 3.....	35
6.6 Design Idea 4.....	36
7.0 Design Appraisal	37
7.1 Drive System.....	37
7.2 Hopper Design	37
7.3 Machine Guarding.....	38
7.4 Adjustable Machine Height	39
8.0 Final Design	40
8.0 Supporting Material	47
8.1 Materials List.....	47
8.2 Extruder FMEA	48
9.0 Conclusion.....	52
10.0 References.....	54

2.0 Introduction

The ever-increasing amount of plastic used in the modern world is creating a huge impact in terms of its disposal. The need to recycle is becoming more and more important. The recycling of plastics has many advantages over continually creating new plastic. Recycling one tonne of plastic can save approx. 3.8 barrels of oil. 2.12 tonne of plastic was recycled in 2008, this saved 7.6 million tonnes of oil. The advantage of recycling is obvious when faced with figures like these. (Recycling-guide.org.uk, 2018)

Plastic recycling has its own challenges, due to a low entropy mixed plastic must be sorted before recycling can take place. A macromolecule of plastic interacts with its environment along its entire length. The number of different plastics used are endless, many products are made from mixed plastics, creating problems when trying to recycle.

The three steps of plastic recycling

- First, depolymerization is the step of transferring a polymer in a mixture of monomers.
- Second, thermal depolymerization is a depolymerization step using hydrous pyrolysis for the reduction of complex organic materials (often waste products of various sorts, often biomass and plastic) in a light crude oil.
- Third, the heat compression process has taken all unsorted, cleaned plastic in all forms, from soft plastic bags to hard industrial waste.

The recycling of plastic should not just be the problem for governments and industry. Everyone can have an impact however small.

Precious Plastic is trying to raise awareness and create a small-scale recycling processing plant to help overcome this problem. "Precious Plastic is a global community of hundreds of people working towards a solution to plastic pollution" (Hakkens, 2018)

The Precious Plastic recycling model is to be adopted by Cwmaman council, under the name Precious Plastic Aman Valley. It will be used for community engagement and raising awareness of the issues regarding plastic and our environment. The unit will be used by ex-forces personnel, people with mental health, school children so the difference in user's capabilities will be vast.

The unit and machine designs are fully operational but Precious Plastic Aman Valley representative Rob approached our university group with the task of redesigning the machines to meet their more specific requirements.

3.0 Design Specification

3.1 The Problem Statement

The unit and machine designs are fully operational but Precious Plastic Aman Valley representative Rob approached our university group with the task of redesigning the machines to meet their more specific requirements. The outcome of this meeting resulted in a QFD and answers to different requirements discussed in the following sections.

3.1.1 Basic Customer Design Requirements

- They have a budget of £16000 for all the machines.
- The specific requirements were simple, they want the machines to be safe, simple and effective.
- The machines would ideally be interchangeable and educational.
- Proficient guarding for safety but still enable users to be fully engaged in the process.
- More hands on for adults but still interactive for the children.

3.2 QFD Matrix

The QFD matrix is a design tool for converting customer requirements into design features. The matrix illustrates the relationships between different characteristics. These relationships can then be used by designers to prioritise the real important feature to concentrate in the design.

Below is the QFD produced after our meeting with Rob from Precious Plastics Aman valley, its uses the specific requirements from the meeting and correlates the relationships with design characteristics set out in the assignment brief.

The company comparison section has been left due the special nature of this project. The design brief requires a one-off design for a specific purpose. This would be become an important tool if the product was to be designed for release on the open market.

The information gained can be specific to the designer who produces the QFD, completing this as part of a design team would be advantageous.

The QFD has pinpointed key areas to focus the new designs upon. There are strong relationship scores for design characteristics regarding cost, simplicity, user engagement and health and safety.

Cost or budget is a major requirement in this design, this will affect the ability to fulfil all other customer needs. There is a strong correlation between reliability, design for manufacture and maintenance. Also, regarding health and safety and the user engagement.

Title: Precious Plastic Asian valley

Author: Paul Thomas 1709327

Date: 01/06/2018

Notes:



		Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14	Column 15	Column 16
		Direction of Improvement Minimize (*) Maximize (▲) in target (○)															
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "How")													
				Demanded Quality (a.k.a. "Customer Requirement" or "What")													
				Reliability	Design for Manufacture	Cost of Manufacture	Life in Service	Running Costs	Design for Maintenance	Health and Safety	Early operated by any user						
1	9	10.1	7.0	○	○						○						
2	9	11.8	8.0	▲	○	○			▲	○							
3	9	13.0	9.0		○	▲					○						
4	3	13.0	9.0		○	○	○		○								
6	9	13.0	9.0	○	○	○	○	○	○								
6	3	10.1	7.0		▲	▲					○						
7	9	8.7	6.0		▲	▲				○	○						
8	9	10.1	7.0	○	○	○	○	○									
9	9	10.1	7.0	○	○	○			○		▲						
10																	
				Target or Limit Value													
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)													
				Max Relationship Value in Column 320.3 331.9 314.5 187.0 208.7 299.4 182.6 214.5													
				Weight / Importance 15.9 16.4 15.6 9.3 10.3 12.8 9.0 10.6													
				Relative Weight													

Powered by QFD Online <http://www.qfdonline.com>

3.3 Extrusion Market Conditions

The typical Plastic extrusion machine used in industries have dedicated market requirements. The machine is defined by product type, material, cost and product use.

Product Types include - Single Screw, Twin Screw and Vented Screw

Material Types include – PVC, PP, PE and Others

Market Use include – Automotive, Oil & Gas, Consumer Goods, Packaging and Others

Product Use - Blown film extrusion, Sheet/film extrusion, Tubing extrusion, Co-extrusion and Extrusion coating

In relation to the machine for Precious Plastic in Aman valley, this changes somewhat. The niche purpose of the machine brings with it, different criteria. As the machine will be a one off there will be no target market for sale but the target will be the customer i.e. Aman valley. Some of the requirements discussed are mentioned below.

3.3.1 Market Design Requirements

Target Price

- £16000 is the total cost for the whole project

Material

- Mixed use recycled plastic
- Possibly mixed with virgin material for certain products

Product Use

- To create products with real value,
- Either for sale or use with in the makers space (3d printer filament)

Market Use

- Within the Precious Plastic recycling scheme Aman valley

Appearance/Image/Style

- The machine must have an educational element. Engagement for the user are paramount importance.

3.4 Conformity Requirements

The niche market of the machine to be designed requires thought into how its conformity will be classed. For new machine used in industry the (HSE, 2018) states “When first placed on the market or first put into service, machinery must meet all relevant Essential Health and Safety Requirements (EHSRs) in the Directive. The machine should be designed to the ‘state of the art’, and be accompanied by user instructions, a Declaration of Conformity, and bear a CE marking.”

The standard safety requirements for setting up an extrusion machine as explained by (HSE, 2018) are as follow.

- “Carry out purging at slow speed and reduced pressure.
- Use heat-resistant gloves/gauntlets and, if necessary, arm protection while handling hot machine parts or extruded plastic.
- Wear full-face visors and head protection for all operations where there is a risk from molten plastic.
- Do not stand directly in front of the die while it is in operation either when removing it or if making process checks on new extrusion
- Minimise the number of people in the area.
- Ensure there is appropriate lifting equipment for the dies.”

These guidelines were produced as the number of accidents being caused by an extrusion machine at setup being significantly higher than when the machine was operational.”

See Table 1 below for potential hazards described by (HSE, 2018)

Table 1 Practical safeguards for extruders

Hazard	Safeguard
Trap at feed nip during normal operation (ie other than start-up/feeding)	Access to the rotating screws (main drive and feed) should be prevented, eg a hopper construction providing a safe distance that complies with BS EN ISO 13857. Alternatively, provide fixed guarding (eg a grille) at the openings. If the hopper and/or the feed throat is removable, then these should either be interlocked with the screw drive, or access to the screw should be prevented by a fixed grille.
Traps at other openings in the barrel	If there is access to the dangerous movement of the screw, then these should be protected by design, fixed or interlocked guards.
Burns from hot surfaces	Protect hot parts above 80 °C against accidental contact using guards or insulation. Where hot parts are necessarily exposed (eg at the die head), warning signs are required.
Burns from molten splash, in particular at start-up with material in the barrel	Where practical, use splash guards at the die. Operators will also need to wear personal protective equipment to prevent burns. Fencing, barriers or other measures may also be necessary to exclude other people from entering the area to reduce the risks when starting the machines.

Trapping by crammer feed system elements	Protect danger areas by design, fixed or interlocked guards. Any openings in the barrel exposed by movement of the crammer system should be guarded as for main feed opening.
Access to mechanical screen changer	Fixed and/or interlocked guards required.

Operator safety checklist - (HSE, 2018) recommends “Regular checks by the operator are a good way of identifying problems as well as making sure machinery is safe for use. It is recommended that operator checks are carried out at regular intervals, as a suggestion daily or after mould changes. contains the recommended minimum checks the operator should carry out on a regular basis.”

See Table 3 below for an example of a user checklist (HSE, 2018)

Table 3 Recommended minimum checks for the operator to carry out

The answer to all questions should be 'yes' or action needs to be taken	Yes	No
Are all fixed and interlocked guards in place, in good condition and secure?		
Are all interlocking devices correctly aligned and securely attached to guards?		
Does opening an interlocked guard immediately stop the parts it protects?		
When an interlocked guard is open do all dangerous parts remain stationary if a start control is pressed?		
Where time-delay interlocks are fitted do they prevent access until rotation of dangerous parts has stopped?		
Are fixed guards held in place with fastenings that require a tool to undo them?		
Where pressure-sensitive mats are fitted then does the pressure-sensitive mat indicator work when the mat is stepped on?		
Do any trip devices function correctly?		
Are all control unit enclosures closed, locked and the keys removed?		
Where two-hand controls are provided do both buttons have to be pressed together for the machine to operate?		
Where hold-to-run controls are provided, if you release the button does the machine stop?		
Where fitted, are adjustable guards adjusted correctly?		
Are safety devices, interlocks and guards free from evidence of being tampered with?		

The potential hazards and checklists designed by (HSE, 2018) are meant for industry but many of the highlighted issues will be similar.

The main use of this machine will be for social engagement and education. This will include School children, young adults and adults. As a result, the health safety requirements could vary from the industrial standards described by the HSE.

With HSE being more targeted at industry. Another source of information was required, I contacted DATA design and technology association for more advise. They advise schools, colleges and other education suppliers regarding their health and safety. They are a leading authority of safety in education. According to an email received from Mark Elwell who is the lead Health and safety consultant from (DATA). "If your machines involve moving parts, I would recommend that a full guarding system is incorporated and if it mains powered that it complies with the usual isolator, start stop and emergency stop, and emergency stop fitted. The use of a key switch might want to be considered as this will guarantee you can control user access to the machine. Other features will be micro switches fitted to all guards and doors that are no-volt return" (Elwell, 2018)

3.4.1 Conformity Design Requirements

Safety Requirements

- Guarding of moving parts
- Guarding of hot parts
- Interlocked guards
- Twin button operation
- Safety lock off (key operated)
- Emergency stops
- Mandatory basic PPE equipment
 - Gloves/gauntlets
 - Googles
 - safety footwear

Customer Safety Requirements

- Removable Guards
- Different levels of guards determined by user skill level

3.5 Life in Service Requirements

Good design doesn't just concentrate on operational/budget goals and neglect life in service costs. Decisions made at design are critical to life cycle costs. According to (Machinedesign.com, 2018) "studies show that conceptual design accounts for only 4% of product cost and results in 70% of the total life-cycle costs. In the entire product-development phase, conceptual design accounts for 15% of initial product cost (including manufacturing equipment and production tools) and results in 95% of the total life-cycle costs. Other studies suggest that an additional 5% invested in improving part design can lower lifetime maintenance costs by 25%." These should be real considerations regardless of budget requirements, a small extra investment at the design stage should see real performance benefits once operational.

When considering maintenance, access to correct machine information is vital. The need for part numbers, mechanical/electrical drawings and possibly repair techniques is critical. An inventory of parts for critical components would be desirable.

Common signs to look for when maintaining extrusion machine are

- Screw/ Barrel Wear
- Excess Motor load
- Increased Heater usage

These common problems arise as the result of several factors. Screw wear is a slow process unless there is a major machine failure. Running an extruder at excessive speeds generates higher shear forces on the screw, when combined with acid/resin rich plastics, can cause major failure. Often the sign that an extruder needs running at higher speeds is due to the screw showing signs of wear. The screw will perform less efficiently due to increased clearance in the barrel. This creates less heat and pressure in the barrel, resulting in the motor speed being increasing or increased heater usage to counterattack this loss of efficiency. An industry guideline for screw replacement is when the original clearance between screw and barrel has increased four times (Rauwendda, 2009).

3.5.1 Life in Service Design Requirements

Target life

- The precious plastic model is new to Aman valley, but 5+ yrs. is considered minimum usage requirement

Operating Environment Spec

- Metal container
- Resistant to climate conditions
- Extraction system interaction
- Robust to withstand unit travel

Maintenance requirements

- Provide machine literature
- Creation of parts list
- Consider availability of components
- Consider increasing quality of component for increased life cycle.
- Guidance on extruder machine common faults

3.6 Product Design Specification

Product Design Specifications give a clear idea for the designer to understand the required specification to design the product. This design specification is the result of a QFD matrix results, further consideration of Life in service, conformity, market requirements. They are derived from discussions with the design customer. The result is PDS, its outlines the major criteria considered for product design specification as shown in Table below. Due to the nature of the project, the specification must be flexible. The budget constraints mean that the sourcing of component must be determined by availability. For example, if they are donated a motor, which is quite likely due to the nature of the project. If this is different from the spec, the gearbox required would also need to be compatible to the donated motor

No	Feature	Specification
1	Name	Extrusion Machine
2	Drive System	Motor, Gear Reduction and key/spline Drive
3	Process	Screw Extrusion
4	Frame Material	Aluminium or steel extrusion
5	Screw Material	Steel – Hardened, Nitrided or Surface Plated
6	Barrel Material	Steel – Hardened, Lined or Surface Plated
7	Manufacture	Machining, Hardening, Welding and Fabrication
9	Safety	Guarding, E-stop, Dual Button Start and Limit Switches, HSE
10	Cost	£16000 total project cost – low cost desirable
11	Life of Product	5 yrs. + Regular Maintenance required
12	Motor Spec	20 HP/15KW Nominal Speed 1700RPM
13	Gear Reduction	17:5:1 Double Reduction
14	Screw Spec	Single three stage compression screw
15	Bearing	Thrust Bearing and Housing
16	Working Rpm	70-100rpm
17	Dimensions	2M by 1.5M max
18	Production Use	Discontinuous Sporadic Use
19	Environment	Container, Access to electric and extraction
20	Sustainability	Consider environmental impact
21	Ergonomics	95 th Percentile – Special considerations for children
22	Company Constraints	Special considerations – recycling, sustainability message driven by precious plastics.

4.0 Extrusion Background Information

4.1 Types of extruders:

Three main types of extruder are used in the production of polymers. Each can be classed as either continuous or discontinuous. Continuous extruder extrudes via part rotation, discontinuous extrude in recurring manner more suited to batch injection moulding.

Extrusion is just not restricted to the polymer industry, it is also used for food production in metal and aluminium industry.

In its simplest form the operation is very basic. The selected material is fed into a hopper by gravity, this feeds into a barrel. The rotation of a screw pushes material, creating friction which in turn creates heat to aid in melting the material.

4.1.1 Single Screw Extruders:

The screw is the main component used for mixing. The screw can be classed single or multiple extruders. Most commonly a single screw is used in polymer production due to its simple design, relative low cost and reliability (Maddock, 1995). The screw has three sections, feed, compression and metering. Passing through these sections turns the polymer from solid state to a soft workable state. The screw starts with deep flights, slowly decreasing linearly, this causes compression and friction which in turn creates heat (Rauwendda, 2009).

4.1.2 Double Screw Extruder:

The double screw works on the same basic principles as the single screw design. The presence of two screws is more effective in its increased ability to mix and generate heat as the polymer moves along the screw. The friction between barrel and screw are greater than the single screw design. Screws can more in the same or different direction depending on its specific use (Rauwendda, 2009).

4.1.3 Vented Extruders:

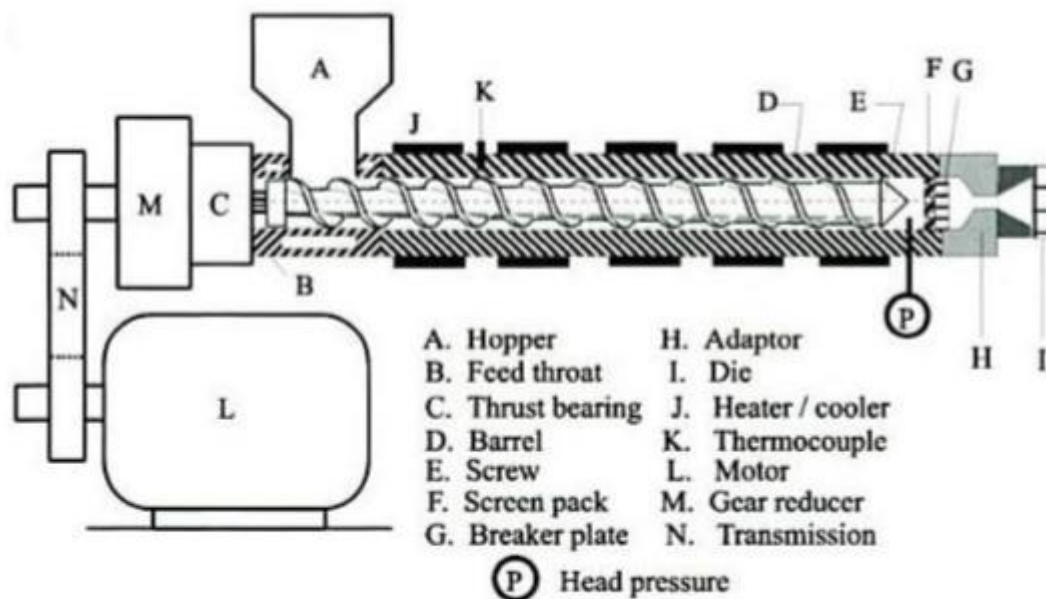
Vented extruders incorporate openings for hot gases to escape, these hot gases are often created during continuous polymer production. These opening are also used to add certain fibres/fillers used in certain polymer production. The vents are simply closed when not needed.

The nature of this system has led to a two-stage screw, this provides areas of no positive pressure at the vented barrels openings. This enables gases to escape and materials to be added without polymer being forced out (Rauwendda, 2009).

4.2 Extruder Machine Components

The extrusion machine is a vital part of modern polymer production. It uses in injection moulding and extrusion make its versatility in polymer production incredibly important.

The extruder main components are the hopper used to feed solid material in the barrel, tubular barrel housing the screw, electronically controlled heating elements.



Extruder Components (Barr & Chung, 1966)

4.2.1 Screw:

The extrusion screw is a paramount component within the machine. The mixing of polymer from solid state to workable polymer is done by the screw. Most screws have three distinct zones, each differing from each other (Rauwendda, 2009).

Feed zone - The feed zone is where the solid material enters the extruder. The width of the flight and the channel distance is generally continuous over the zone.

Melting zone - Melting begins, the screw rotates, increasing pressure, polymer resins melt as the channel depth decreases.

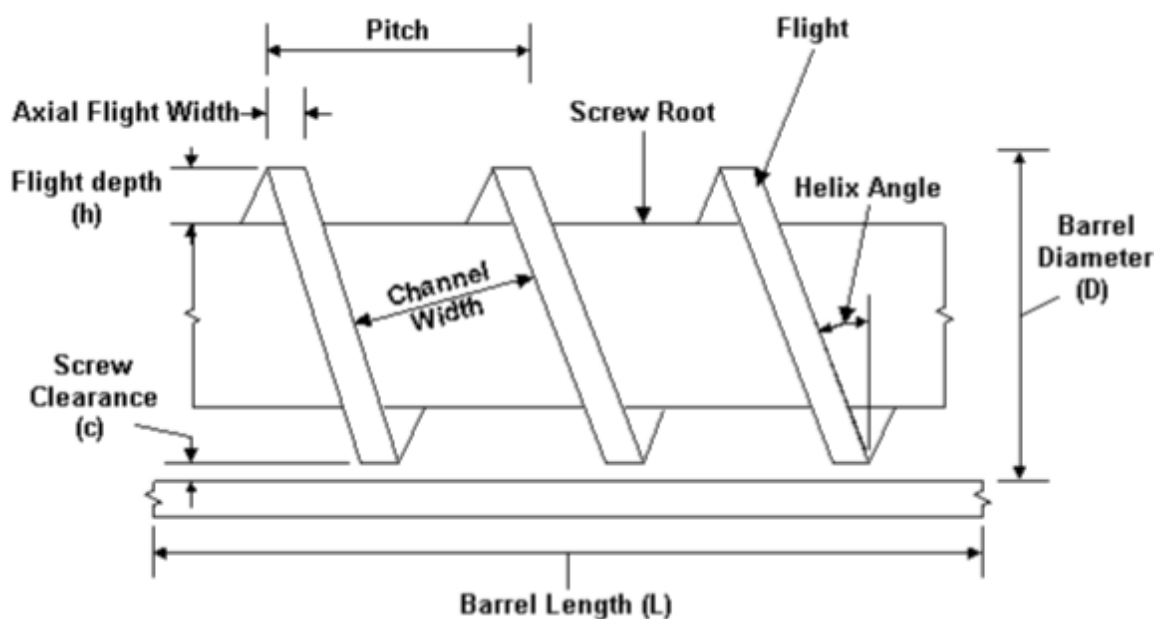
Metering zone - The channel depth is again constant throughout the zone, melting and mixing of the polymer to a uniform temperature and composition occurs. Barrel heaters can assist to complete polymer heating (Crawford, 1998).

Vented (two-stage) screw have two extra zones:

Decompression zone - Two-thirds down the screw, a channel allows any stuck gases (usually moisture or air) to be removed out by vacuum (Barr & Chung, 1966).

Second metering zone. Similar to first metering zone, it has a larger channel depth, this helps force melted polymer through the screens and die.

“The L: D ratio of an extruder screw is defined as the length of an extruder screw with respect to its diameter” (Crawford, 1998). L: D ratio of 24:1 are common but can be as much as 32:1 for industrial size machines. The increased ratio can aid faster mixing but require higher power input. The twin screw machines often use screw with a 36:1 ratio (Crawford, 1998). A screw also has a compression ratio, usually 2.5:1 to 4:1 (Crawford, 1998).



Screw Detail (Barr & Chung, 1966)

4.2.2 Barrel:

The barrel houses the rotating screw used to extrude the polymer. The barrel will be covered with insulating material used to prevent heat escaping. The heating elements are attached to the outside to control temperatures needed during production. The barrel may have several heaters along its length controlling temperature in the three different zones. Some barrels will be designed with passages cast into them, this enables a cooling medium to further control temperature. The cooling medium is most often water but can also be oil (Rauwendda, 2009).

The barrels must be designed to effectively house the screw without causing damage, handle the most efficient volume of polymer and withstand the pressure created during production (Rauwendda, 2009).

4.2.3 Die:

A die is used at the end of the extruder to shape and size any components. Its designed to create products to specified sizes and tolerances. The barrel and screw have created pressure of the molten polymer which is then forced into the die. The correct design of the die allows for efficient flow of material completely filling the die (Rauwendda, 2009).

4.2.4 The Drive Systems

Motor - The extruder is driven via a motor. DC Or AC motors have been used historically, with AC now the preferred option. The AC motors are digital and brushless, with ratings varying from 25kw to 85kw. The motor is used to rotate the screw, either directly or with use of a pulley or gearbox. These allow for the most efficient transmission of the motor output considering the high torque required. The motor and drive are vitally important in regards the performance of any extrusion machine (Rauwendda, 2009).

Cooling – Extruders use a cooling medium most often water. The water circulates around precast channels in the barrel. This is turn with heating elements gives greater control over the polymer temperatures (Barr & Chung, 1966).

The PLC Control – The extruder is controlled via a PLC system, this would handle all aspects of the extrusion control system such heating, cooling and screw control.

4.2.5 Heating and Cooling Systems in Extruder

The extrusion process can require heating elements for the maintenance of the desired temperatures required for optimal polymer production. The heating is needed particularly at start-up and to main desired temperatures. Three methods are traditionally used, electric, fluid and steam heating. The electric heating method is most common (Rauwendda, 2009). This is due to its ability to cover larger temperature ranges, relative low costs and ease of use and maintenance.

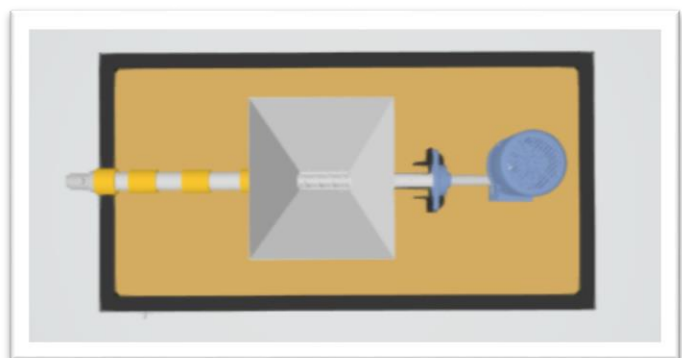
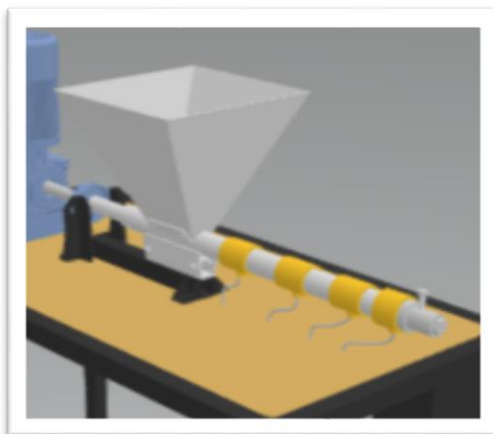
The heaters are placed along the barrel length, the larger the extruder the more heaters are needed. Each zone will be separately controlled via the PLC so that a required temperature profile can be maintained. The temperature profile required varies depending on the polymer being produced (Crawford, 1998). The heater elements can be electric resistance heating bands or ceramic heating bands often insulated with mica.

5.0 Design Critical Appraisal

5.1 Precious plastics Extrusion Machine



“Extrusion is a continuous process where plastic flakes are inserted into the hopper and extruded into a line of plastic. The extrusion machine runs continuously so, technically, if you have enough plastic and a well-streamlined process you could be recycling 24/7. With the extrusion machine you can create filament, granulate or get creative working with moulds. This machine is also great for educational purposes as the process is very straightforward and easy to understand. This technique nicely blends differently coloured plastics together and outputs a homogeneous and smooth colour.” (Hakkens, 2018)



5.2 Commercial Machines

3.2.1 Single Screw Plastic Extruder

(Small Industrial Machine)
estimated cost £5000-£55000

- Suitable for many types of plastic.
- Plc Interface control system, automatic control of whole process
- Excellent temperature control
- Water cooled
- High performance drive system: wear resistant, low maintenance
- High performance gearbox
- High efficiency and low noise
- Plc safety control, interlock, e-stops, fixed guard

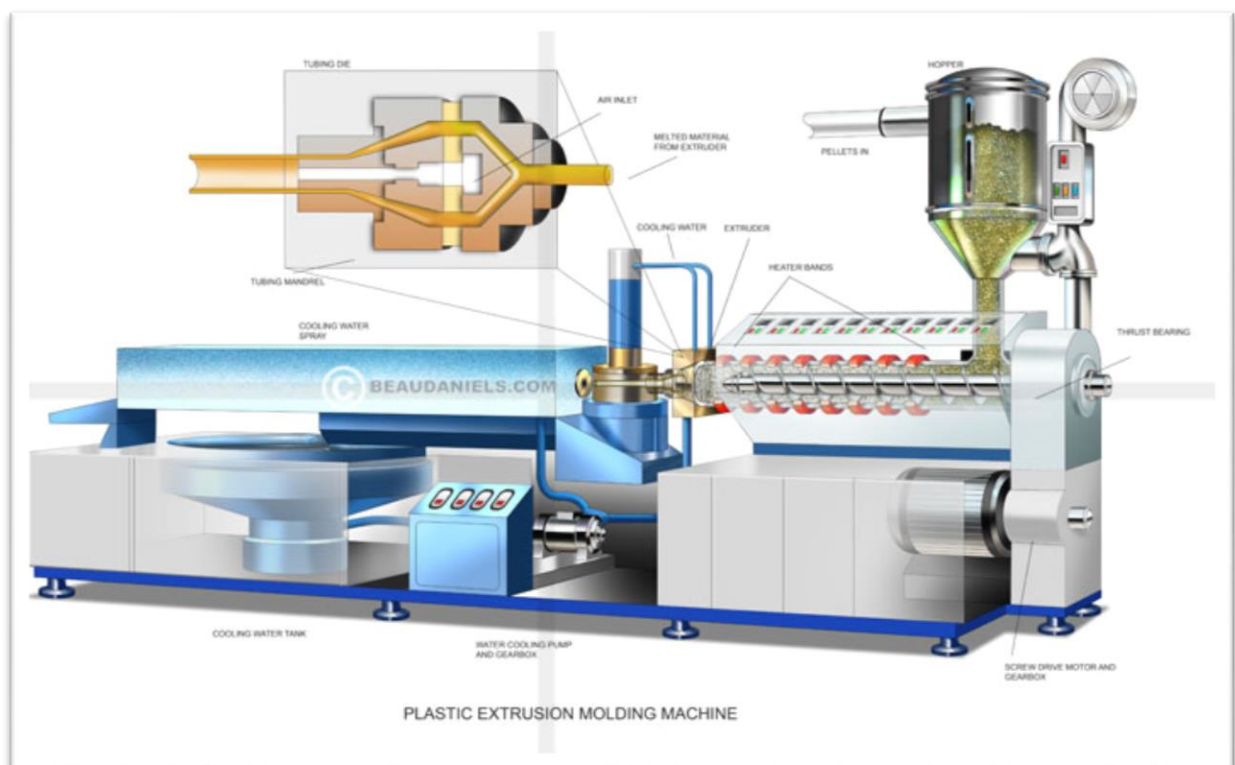


Diagram (Beaudaniels.com)

3.2.2 PVC Pipe Extrusion line PVC Pipe Extrusion Line



(Large industry) Estimated cost £200000-£1000000

Application:

- UPVC pipe extrusion lines
- Producing
 - Water supply pipe
 - Drainage pipe
 - Electrical conduits
 - UPVC pipes.

Features

- Produces pipe of up to 1000mm diameter
- Conical Twin-screw extruder
- Asynchronous Parallel-screw extruder.
- The haul-off pedrail machine
- Cutter type
 - Annular cutting type
 - Planetary cutting type.
- Safety
 - Plc control system, interlock, e-stop
 - Full enclosed machine parts

- Fixed guarding

5.3 Precious Plastic Machine Limitations and Areas for Improvements

The extrusion machine designed by precious plastic does exactly as it intended. It gives users an end product and basic an understanding of the process. It does this whilst needing very little money or skill to make.

The brief from Cwmaman council requires this product to be improved to meet their more specific use. The aim is to reduce an improved extrusion machine, but an industry standard machine would not be suitable either. The brief has an element of user engagement and interaction to consider. The machine could be vastly improved by increasing the quality of its parts. Improving its health safety, educational and interaction experience.

5.3.1 Safety

With the potential users ranging from children, young adults through to adults, various parts of the machine need guarding. Safety of the machine is not practical for its intended use with Cwmaman council. No guarding is currently in place. There are numerous areas which would need changes regarding its safety.

The barrel and heater elements - Reach temperatures of 200/300 degrees. Currently users have access to both barrel and the heaters. The risk of injury is high, there is a serious potential to burns.

The motor, screw and connecting shaft are un-guarded, this chance of injury needs to be addressed. The rotation of these parts could cause serious injury. The speeds involved would depend on the machines setup but currently no protection is in place.

The hopper design currently enables users to get near to the revolving screw at its base.

Extrusion machines designed for industry allow for very little interaction with moving or hot parts. The machines are shrouded in steel fixed guards that need tools to remove.

The PLC control system contains safety features controlling temperature, pressure and ensuring the operator is safe.

Industry uses safe operation systems, these involve E-stops, Time delayed guard openings, full plc control

5.3.2 Efficiency

The machine is the most basic form an extruder. It models the systems used in small and large industry without replicating the standard of their features. The design of all its components could be vastly improved. The barrel and screw need appropriate limits and fits. The screw is currently an auger drill bit, this would move the plastic but has its limitations. The screws used in industry are specifically designed to both move the material and increase the pressure. This creates its own heat and helps force the plastic from the end nozzle. The heat generated from the pressure in the screw, enables the use of heaters to be reduced, improving the machines power usage.

The drives, screws and PLC systems used in industry provide optimal control and plastic production. The machines use one or possibly twin screws. They have heating and cooling systems; the temperature control is critical. They use haul off and cutting machines. The motors, gearing and bearings are designed for optimal performance.

5.3.3 User engagement and interaction

The brief from Cwmaman council requires the machines to be used for social interaction and engagement. The current design does allow for the user to get an understanding of its parts and process but in doing this it becomes potentially dangerous to use.

In industry the interaction of users is purely for operation. The machines components are guarded or contained within the machine footprint. The only interaction is between a manually operated control panel or possibly touch screen control system.

The new guarding needed for its safety could ideally be removable, this would enable a greater learning experience for different levels of user. It could be see-through, enabling users to still see the full production method. A method of viewing the screw in the barrel would be desirable.

Drive components could be added that were not needed, extra gearing or pulleys for example. This could be used to educate the users of additional engineering principles. This would need to be balanced with machine performance as these extra components might have a detrimental effect.

5.3.4 Machine Cost

The extrusion machine designed by precious plastic is done on a very small budget. Whilst it has resulted in a working extruder, its performance is restricted by the sum of its parts. Industry machine costs widely varied. Ranging from £5000 to £1000000 for an extrusion production Line. The brief from Cwmaman council is small by industry standards but does give scope to improve many of the components in our extrusion machine design.

Close inspection of the bill of materials listed for the precious plastic extrusion machine, gives a clear insight to the choice of materials and components used. Many are described as sourced from scrapyards, hardware stores or eBay. The total price of its parts is \$192. With a total budget of £16000, that gives us an opportunity to improve the quality of its components and ultimately final performance.

The mechanical components are listed to make the performance related parts of the extruder include a bearing, motor, drill and tube. There is no performance related information provided. The research done previously in this assignment, provides information related to the screw, barrel, motor and gear reduction being paramount to well performing extruder. This research will be invaluable when developing our design specification for our design process.

Description	Material	Details	Quantity	Where to get it	Remarks	Price
Machine parts						
- Strip	Steel	30x3MM	10cm	Scrapyard		1
• Round bar	Steel	30MM	5.5 cm	Scrapyard	accurate and smooth from the inside	2
• Round bar	Steel	25MM	22 cm	Scrapyard		3
□ Square tube	Steel	30x30x3MM	800 cm	Scrapyard		35
o Tube	Steel	34x26x4MM	53 cm	Scrapyard/ Metal shop	make sure if fits the drill	1
L Angle profile	Steel	30x30x3mm	32	Scrapyard		2
Sheet metal	Steel	1mm		scrapyard		15
Motor	-		1	scrapyard	Around 70 RPM	30
Bearing	-		1	scrapyard/hardware store	UCFL 204	5
Drill	-	26 x 600 MM	1	scrapyard/hardware store	make sure if fits the tube	30

The electrical components listed are again sourced on eBay or scrapyards. The specification is again very limited. The industry standard machine has a much greater degree of control over there heater elements and temperature control. This will not be possible with these components and might be unattainable in our budget constraints.

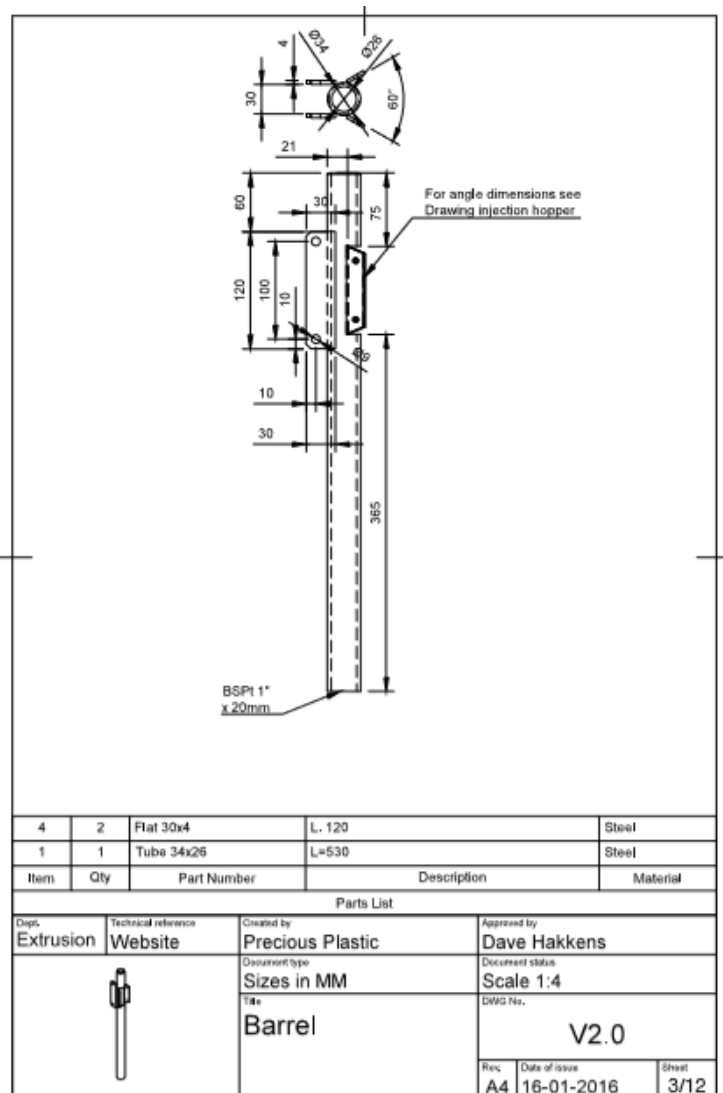
Electronics						
PID Controller	-	0-400 Degree	2x	Ebay		20
SSR	-	2-24 V	2x	Ebay		8
Thermocouple	-	Type K	2x	Ebay		15
Bandheater	metal	35x45MM	3x	Ebay		18
Bandheater	metal	40x45 MM				
Power switch	-	220V	1x	Scrapyard/Hardware store		3
Led indicator	-	220V	1x	Hardware store		3
Powercord	-		5 M	Scrapyard/Hardware store		2
				Total		€192
						Price varies depending on where you live

5.3.5 Barrel

The precious plastics extrusion barrel is made following the blueprint below. The drawing specifies steel for its material but gives no specific grade of steel. According to (Maddock, 1995) “Extruder barrels are made of tool steels, but often with wear-resistant or corrosion-resistant liners”. Using this information to select a more suitable material, would result in a much better product in terms of performance, reliability and maintenance.

The Tolerancing on the drawing is not specified so supplies no information regarding the kind of limits and fits required for efficient plastic production. The Bill of Materials on the precious plastic website carries several remarks regarding the barrel and screw. They describe the barrel as “accurate and smooth from the inside” and regarding the screw “make sure it fits in the tube” (Hakkens, 2018). These descriptions are vague, no real information on the type of fit is supplied. This style of manufacturing leaves would require the manufacturer to have an understanding of engineering to end up with a usable machine.

To improve the barrel, appropriate sizes and fits should be chosen. A more suitable material should also be selected. Welding of brackets should be avoided, the heat generated in the tube would possibly distort the tube. Possible venting could be allowed for, this would depend on the screw selected.



5.3.6 Screw

“In the plans of the current extrusion machine a basic drill is being used in the barrel to push and melt the plastic to the nozzle. This seems to work, however, in the industry a different type of screw is used which compresses the plastic while it’s melting. These are way less accessible than the drill, for obvious reasons.



I was quickly doing some research on this yesterday and it seems to be a world on its own with different designs of screws, different compression ratios and different zones” (Hakkens, 2018).

This statement shows the current performance of the screw in relation to industry screw design. The precious plastic auger drill is not a reliable replacement for a screw. As can be seen in the photographs, the technical design of the screws couldn’t be further apart.

The basic principles learnt though our researched of the extrusion process will provide the knowledge to choose suitable screw parameters.

The L:D ratio of 24:1 or 32:1 and a suitable compression ratio to suit the type of plastic being used will be required. This along with suitable material and surface hardening will provide a suitable product.

5.3.7 Hopper

The precious plastic hopper blueprint is shown below. The diagram shows the most basic of design. The taper of the hopper is used with gravity to feed the screw with the necessary plastic. The hopper must keep us with material demand. As a result, the size must be appropriate to each machine.

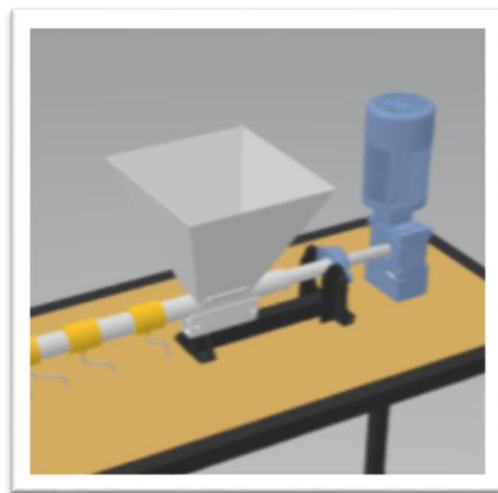
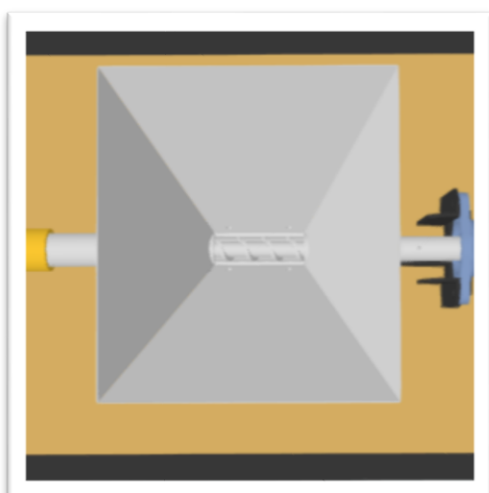
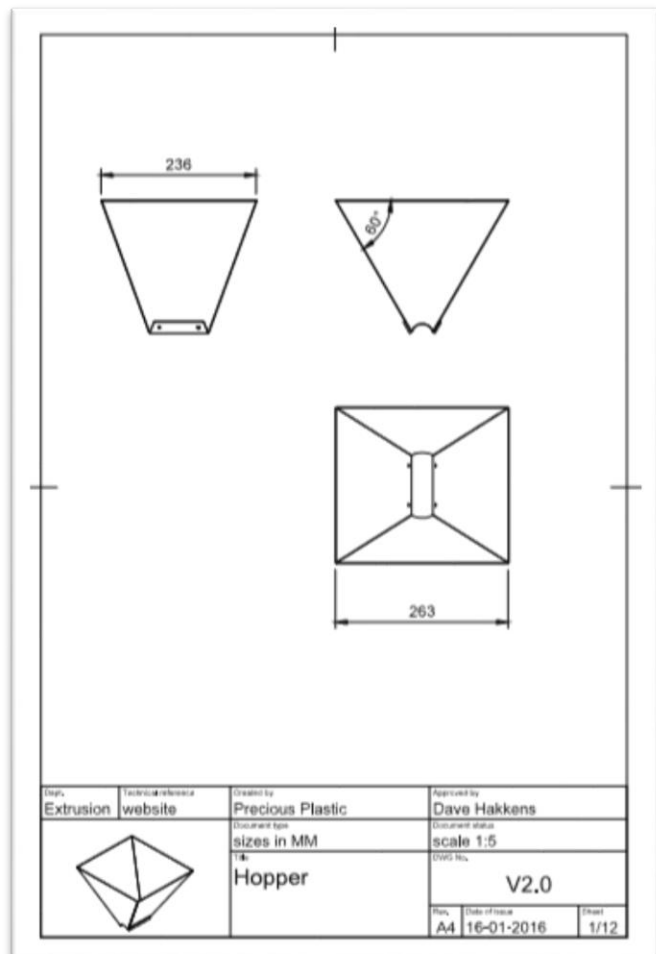
Industry hopper features include automatic feed into the hopper, Interlocked lids. Some include an additional screw at the bottom of the hopper to control the material speed into the main barrel

The hopper safety features need improvement, the distance from the top to the screw at the bottom is short.

The dimensions of this could be increased to create a safe zone at the bottom of the hopper.

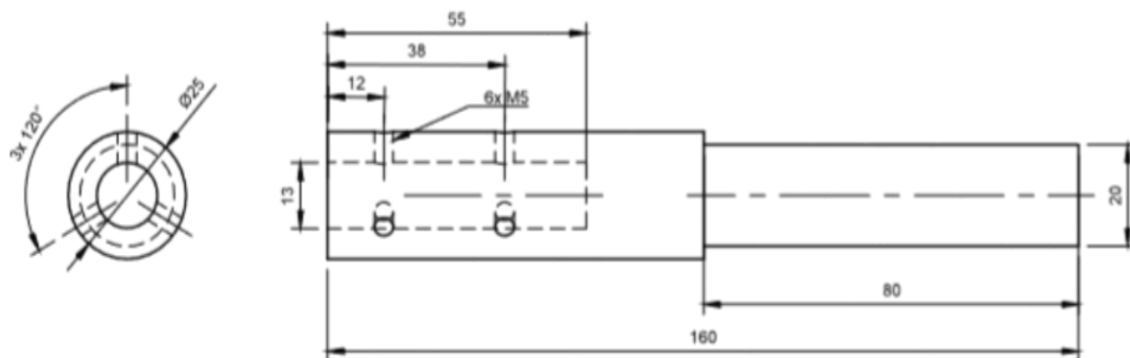
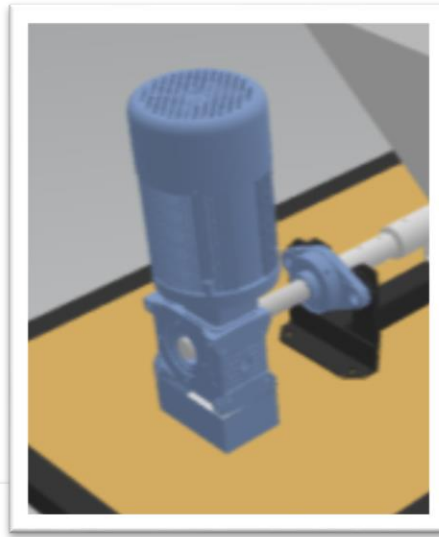
A lid could be added, this could be electronically controlled. Machine could not be operated until it was closed.

The shape of the hopper could be changed to limit the access at the top of the hopper.



5.3.8 Drive Components

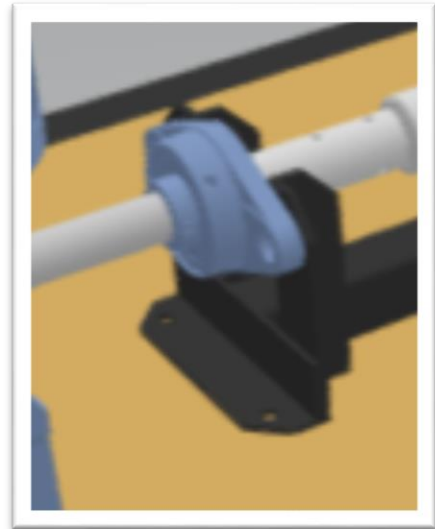
The drive components need to be well designed for an effective extruder performance. When extruding, a screw revolves slowly, speeds of 70-100rpm being optimal. A Motor can have speeds ranging from 500 - 1700 rpm. A method of reducing this will be needed. This reduction should be calculated accurately to improve machine performance. The precious plastic machine has no information regarding this. The user would be required to source a motor and gearbox to suit.



The shaft connecting the motor and screw uses three grub screws to drive the two parts. The amount of torque generated in the extrusion process can be very high, this drive method would not be suitable on a higher performance machine. With our brief to improve on the process then the recognised industry method would be a keyway or spline. The shaft doesn't allow for any alignment adjustment. The alignment of barrel, shaft, screw is critical to machine performance. The introduction of a coupler that would allow for adjustment would be critical to superior performance.

The bearing used is a ucfl 204, this is a standard roller bearing. The price would be the lower end of the market, this would be the same for its performance.

During the extrusion process, the screw would generate pressure backwards as it conveys the plastic along the barrel. As a result the force on this bearing and its housing would be considerable. The nature of the screw used currently means the pressure is reduced as the screw is not efficient. The use of an appropriate thrust bearing would be more vital with a higher performing screw. This would result in increased machine performance.



6.0 Design Development

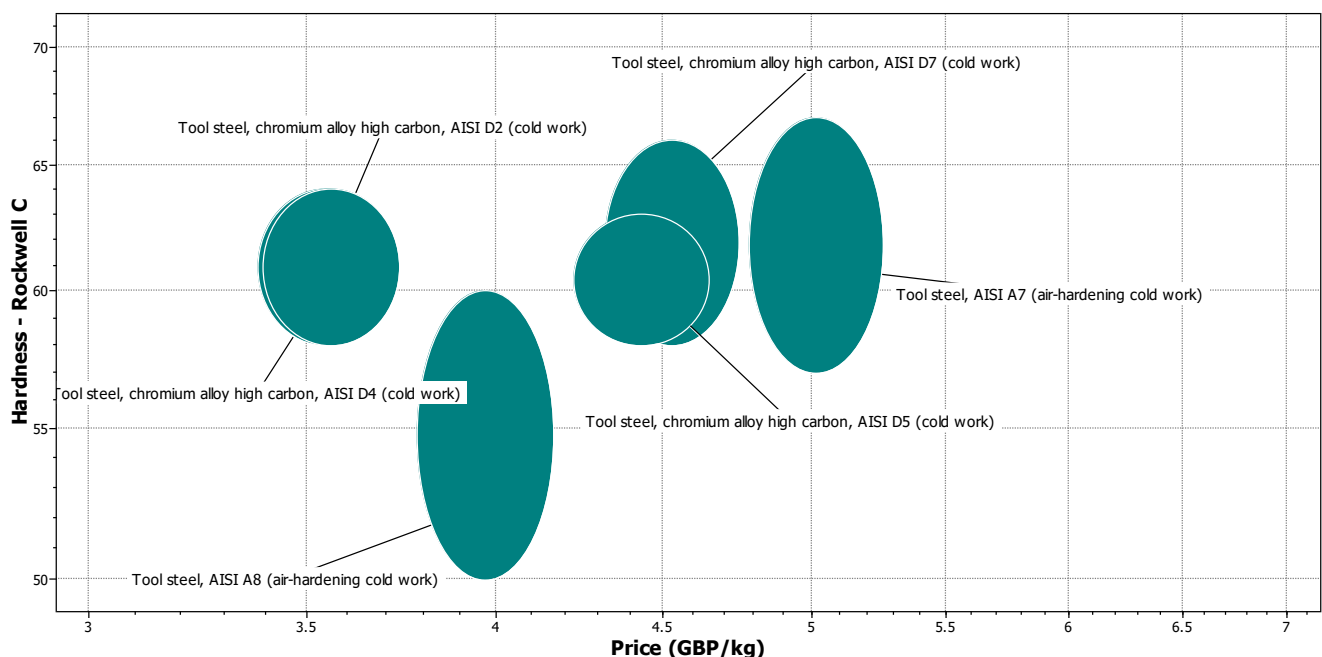
To complete the design process, I will consider different elements of the extruder. I will take into consideration barrel and screw design, drive components, system safety and finally user engagement.

6.1 Barrel, Screw and Drive Design Considerations

For this design process I will suggest an appropriate material for both barrel and screw. The nature of the brief being driven by cost means that the sourcing of parts must be fluid. These parts could be donated, sourced from salvage or eBay and similar establishments.

Two components of the extrusion machine which need careful consideration are the barrel and screw. They work in conjunction to turn plastic pellet into molten plastic at the nozzle. The relationship between these two is vital to a successful extrusion machine. According to (360-Engineering, 2018) "Selecting extrusion machines requires an analysis of extruder screws, barrels, and tips". For an effective design, the materials and limits and fits of the two-need careful consideration.

The extrusion process creates a lot of stress on the barrel and screw, torsional forces on the screw, pressure in the barrel mean material selection is vitally important. This must be combined with high wear resistance as the clearance between the parts is minimal. According to (Sampspa.com, 2018) pressures reach up to 10,000 psi or 700 bar. With normal operating pressures generally range between 1,000 and 5,000 psi. or 70 and 350 bar." The barrel must be designed with this mind. Common material selection for barrel are "tool steels, but often with wear-resistant or corrosion-resistant (360-Engineering, 2018)."



“Screw materials include high-carbon, high-chrome, and proprietary tool steels. Nitriding, chrome plating, and carbide coating are common surface treatments for extruder screws. (360-Engineering, 2018).” According to (Sampspa.com, 2018) “nitriding depth of around 0.5 mm, to obtain screw hardness of around 800 HV and barrel hardness of approximately 1000 HV are desirable.”

For successful design process the correct selection of characteristics of these machine parts is essential. Above is a graph generated on CES Edu pack, it has enabled me to select materials with the required properties. This graph shows the material Rockwell hardness score plotted against Price. With budget and material hardness two major parameters for our material selection for both barrel and screw.

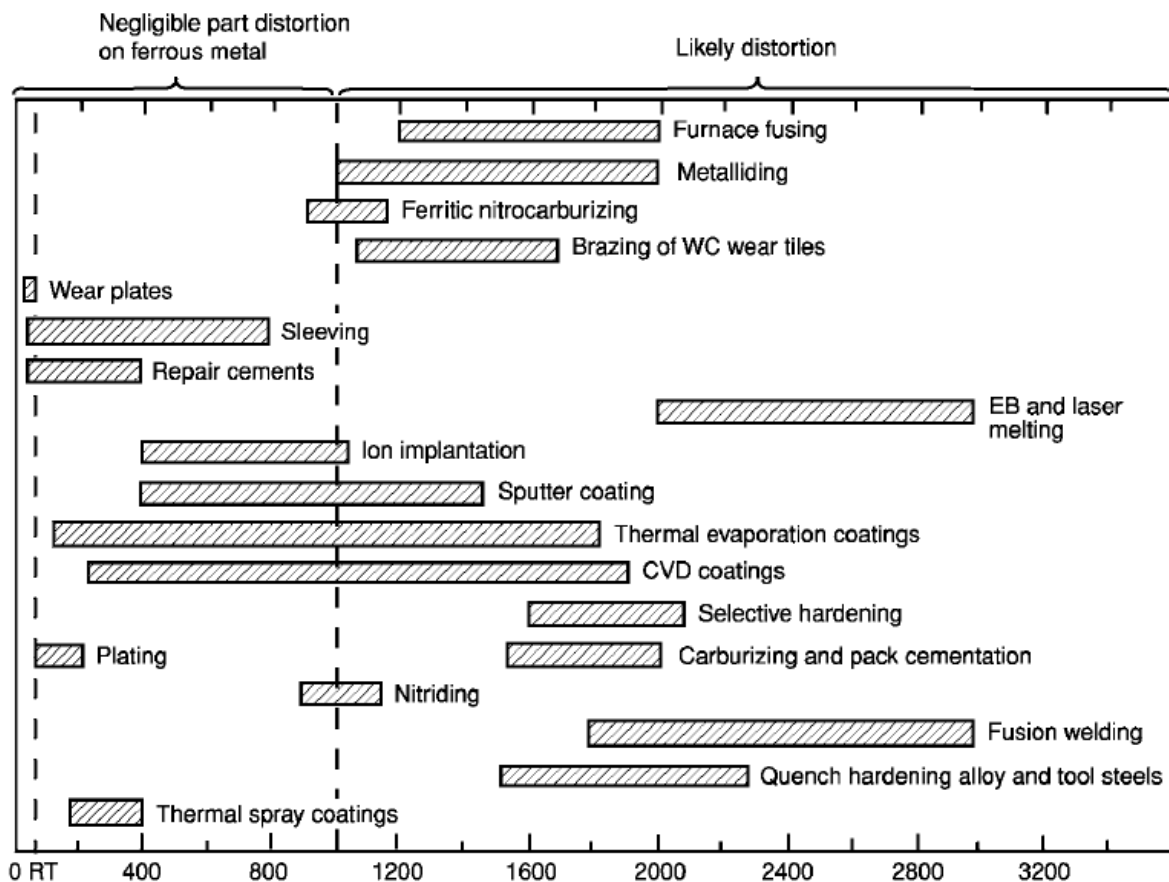


Figure - Temperature of distortion graph (Asminternational, 2002)

The chart above shows the temperature which different surface hardening heat treatment processes take place. It correlates this information against the amount of distortion that takes place during this process. This information is critical as the barrel and screw must be running perfectly concentric with very small tolerances of clearance. The need for surface hardness for both screw and barrel is vital for a long-life cycle.

In summary from the information above, the material selection for the barrel and screw is vitally important. There are numerous options available, a suitable choice would be a tool steel such as AISI d2, when combined with a surface heat treatment of nitriding. This would provide our material hardness with minimal distortion.

According to (Bucorp.com, 2013) nitriding AISI D2 creates a hard surface layer 1250HV1 with very high resistance to erosion and wear.

The screw design can vary depending on machine design. The exacting dimensions of the screw are vital to control plastic production and its relationship with the barrel. Described by (Engineering-360, 2018) "Screw section lengths, flight depth, flight pitch, length-to-diameter ratio, and radius are also important specifications to consider when selecting these components for plastic machinery".

In summary three-stage single screw would be most appropriate for our design. It would be capable of a wide range of plastic types and processes. It would require less knowledge regarding installation and maintenance than a twin or vented screw design. The design of these screws varies widely from different suppliers. Many are patented and are the result of sophisticated development processes. The desired outcome for our design is to meet the brief from Cwmaman council and provide a product which can mirror industry standard machine but on a reduced budget. To do this then procurement of a suitable screw is vital.

Also needing consideration are the motor and gear reduction used to produce the required 70/100 RPM for optimal plastic production. We will need to source a motor and gear reduction method capable of achieving this target. Motors are available in numerous ratings, common ratings being 3600, 1800, 1200 or 900 RPM so the gear reduction method needs correlation with motor for the correct output (World-gain.com, 2018). According to (Plasticsmachinerymagazine.com, 2018) the motor design should include a 15% safety factor for its torque rating. The extrusion system will need more power to work harder as the screw and barrel wear. Nominal speed ratios for the gear reduction are 5:1, 7:1, 9:1, 15:1 and 25:1. The connection to motor can vary depending on required mounting method (World-gain.com, 2018)

6.2 Safe Electrical System



Figure – E-Stop



Figure - Key Operated E-Stop

A safe system of work needs to be designed to enable all users to use the machine without endangering themselves. This system would apply to all designs.

- The machine should be fitted with a control panel, which will control the motor, forward/reverse and off. The heater elements, on/off plus auto temperature control from thermostats.
- A twin button operation system.
- Emergency stops with a key operated e-stop for full isolation.
- A safe work practice sheet could be kept with the machine, this could fully explain the operation of machine and any potential dangers.
- The machine could have a colour system which highlighted dangerous areas of the machine, potential pinch points and hot surfaces.

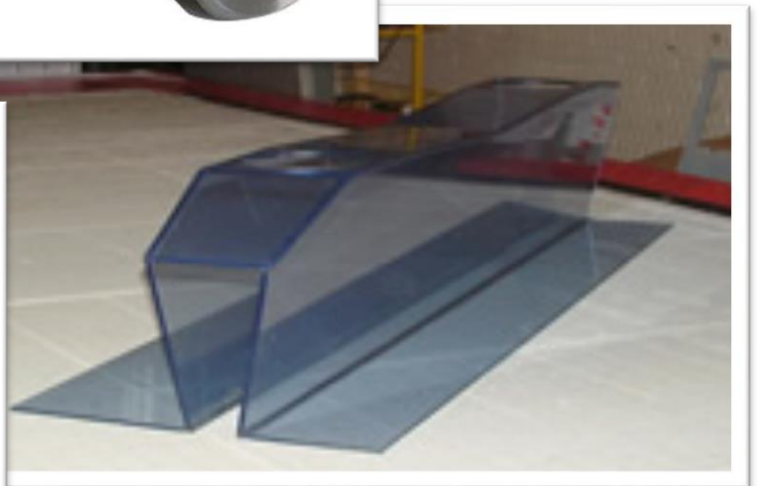
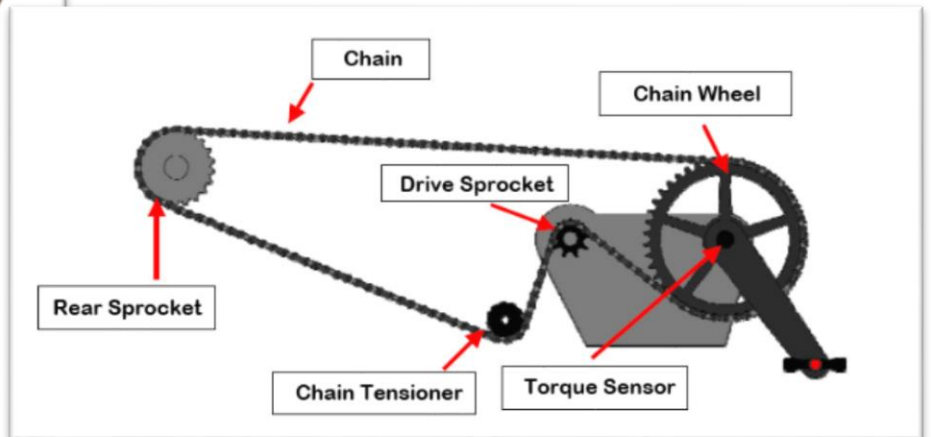


Figure - Control Panel



Figure - Twin Button Operation

6.3 Design Idea 1



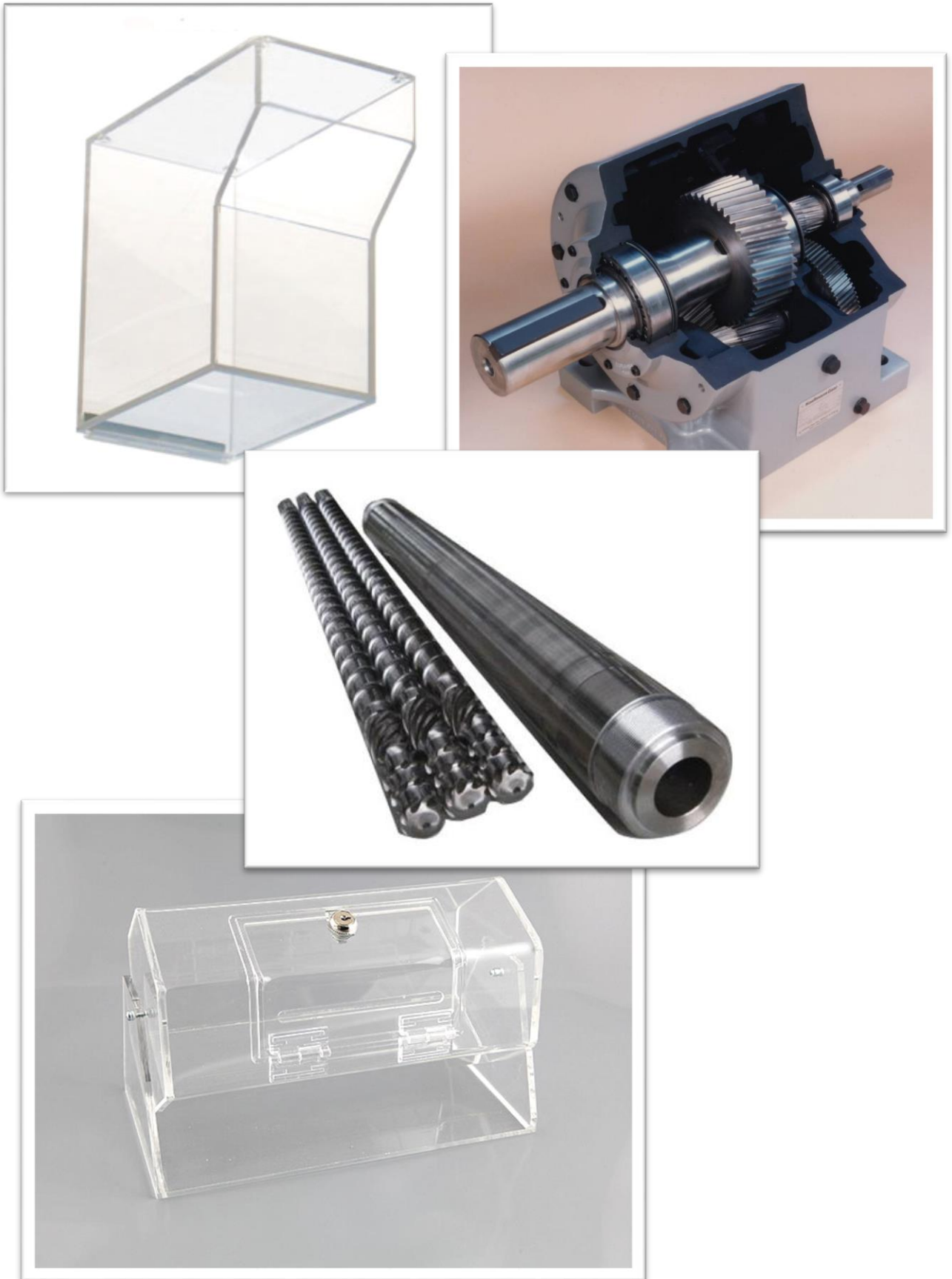
6.4 Design Idea 2



6.5 Design Idea 3



6.6 Design Idea 4



7.0 Design Appraisal

7.1 Drive System

Design 1

This design plays on the use of social engagement and utilises a bicycle sprocket design to supply the drive required for the extrusion system. Whilst the machine could be driven by pedal power the need for constant power needs a more reliable source. This sprocket system could be driven by a motor instead, this would give it the suitable constant power source. The appeal was the ability to see the gearing working, this added element of engineering would be engaging for the user. The ability of the socket system to with stand the torque required is doubtful, resulting in maintenance or a shortened life cycle.

Design 2

This design incorporates a standard motor and gearbox reduction method. It would be able to withstand the machines requirements in terms of torque, speeds and life cycle. With our brief of designing an extruder which can produce useable products then this must be considered.

Design 3

This design also plays on the social engagement and user experience. The ability to utilise a power tool and simple sprocket/belt system would be interesting to use. The same problems as design 1 are an issue, would the system of drive be able to meet the requirements of the extrusion process. This is doubtful and if it could, the life cycle of any such product under this load would be dramatically reduced.

Design 4

Here the drive is a traditional gear reduction box, this would be attached to a suitable motor to provide the input speeds. The idea of enabling the user to see what is happening whilst combining with a system of providing the necessary drive and torque required. This would involve machining a window or section of the gearbox casing which could be replaced by glass/Perspex.

7.2 Hopper Design

Design 1

The hopper design is a traditional cylinder, it produced out of a sheet steel and coloured yellow. The skill level to make a cylindrical hopper is higher than a simple tapered one. This would bring with increased costs compared to the most basic design, the benefit from the different shape is negligible. The use of colour could be possibly used to highlight different parts of the machine for education purposes. The

shallow depth of the hopper is a concern for reaching down to the moving parts, the need of a lid would be critical.

Design 2

This design of hopper is the traditional sheet metal square tapered shape, it uses gravity to feed material down its tapered sides. It designed only with its most basic function in mind. The ease of manufacture is a positive for this design. It needs basic fabrication and welding skills to produce a satisfactory result. This design also provides no safety feature, the hopper is shallow without lid, so would need improvement.

Design 3

The design here uses three Perspex cylinders, normally used for storage of different food items. The Perspex design allows users to see the material inside, this would be a desirable feature for the user interaction. The three different containers could be utilised either to produce a random mix of colour or possibly the hopper could be interchangeable. Storing a different plastic in each and simply swapping over when the hopper is empty. The hopper has a lid which is good, but the changeover process would need attention, as the moving parts would be next to the hopper location point.

Design 4

This design again uses Perspex which gives the user a clear view of the plastic moving through the hopper. The hopper is not tapered which would need addressing to help the plastic efficiently enter the barrel. This design would possibly allow material to get stuck in its corners areas. The kink at the top of the design could be utilised if improved, the design could include an area for the plastic to be introduced while the kinked entrance would make it much harder to get near any moving parts.

7.3 Machine Guarding

Design 1

The guard is designed for the barrel and heating elements. It is bolted as fixed guard but could be improved with hinge and introducing interlocks for safety. The material choice of Perspex would be good for engagement whilst keeping users safe. The desire to see as much of the process as possible whilst keeping the user safe needs good design to be achieved. This is a simple design which could be easily/cheaply produced.

Design 2

The guard here is designed to cover the whole process. Its level of user engagement will be greatly reduced. The guard is made of Perspex, users could see the machine but will be unable to get too near the machine. The guard would cover the hopper which will mean a stop of the machine to fill the hopper which more raw

material. The complexity of design would need specialist skills to produce. The increased cost could be utilised better on different parts of the machine.

Design 3

This design is based on a typical adjustable machine guard. The Perspex screen is used by the user to still operate machinery while afforded a small level of safety behind the guard. It is more suited to operations that need more user involvement to be operational. The guard does allow access along its sides which would allow users near the hot parts of the barrel. The guard would need manufacturing by a specialist due to the adjustable feature requiring specialist parts.

Design 4

This design utilises Perspex to increase the user interaction. The design would completely enclose the barrel, whilst it has a key operated hatch for access to the barrel. The design would make maintenance difficult to perform but could be used as a fixed guard and totally removed in certain circumstances. The guard does provide a good level of safety, as the barrel is completely enclosed.

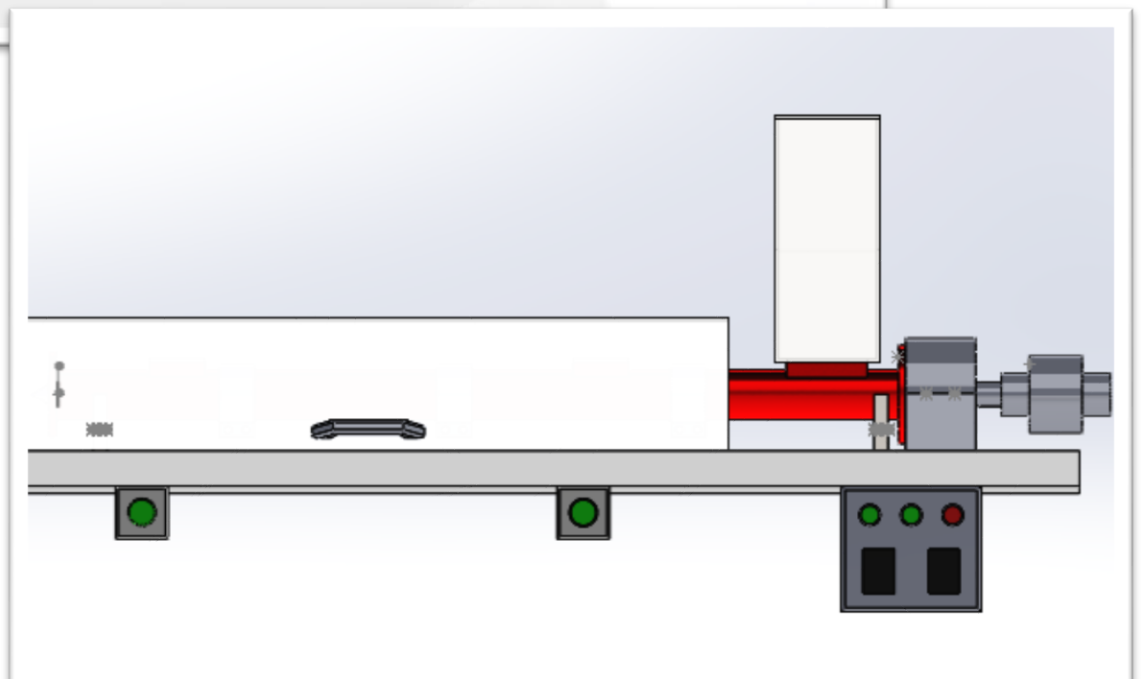
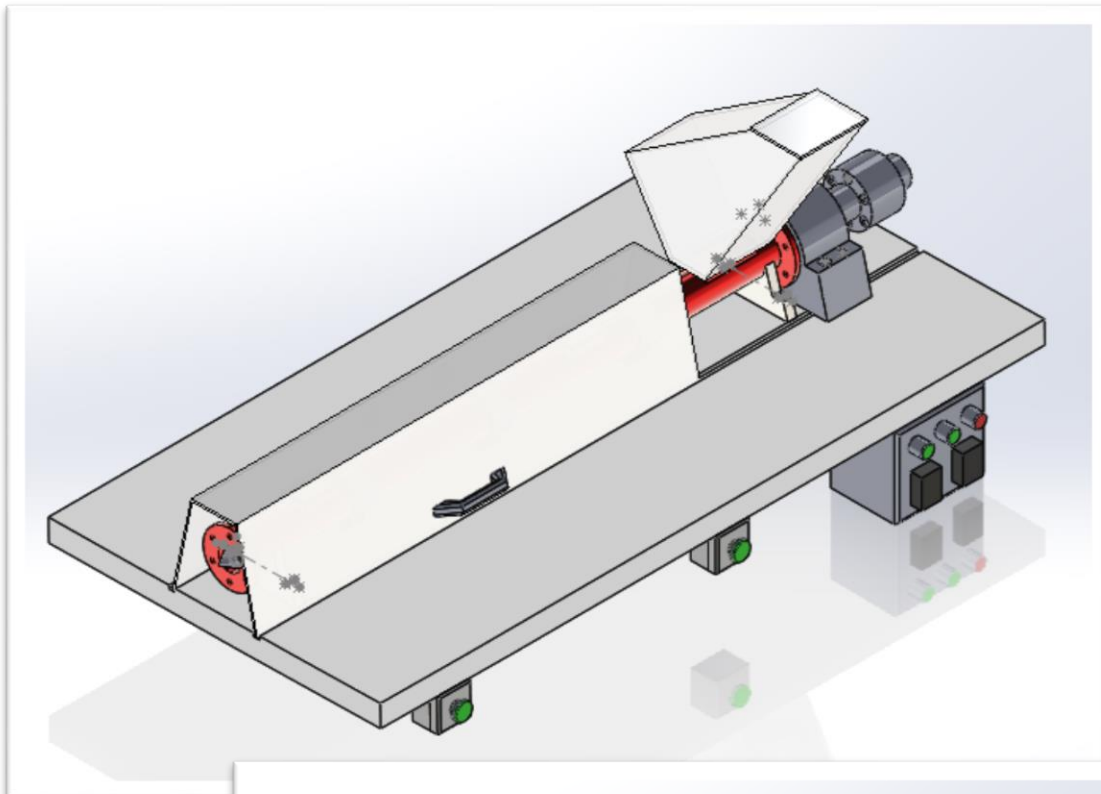
7.4 Adjustable Machine Height

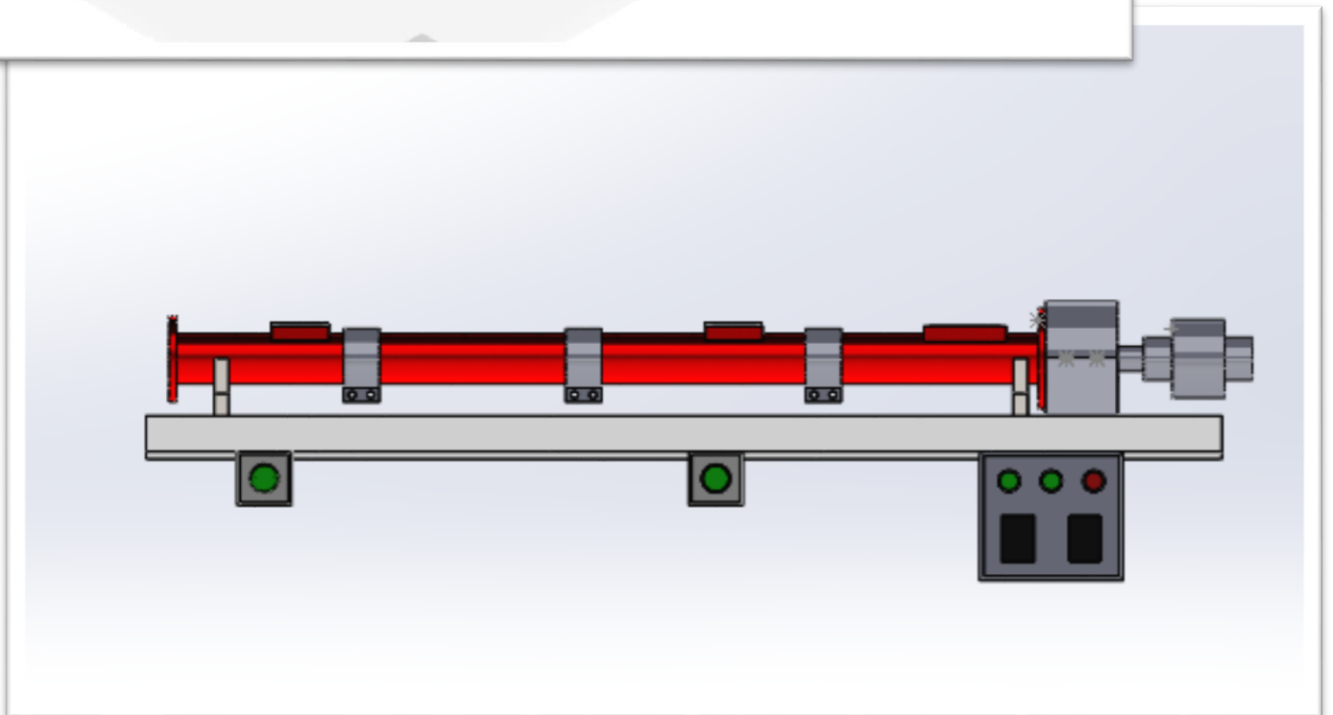
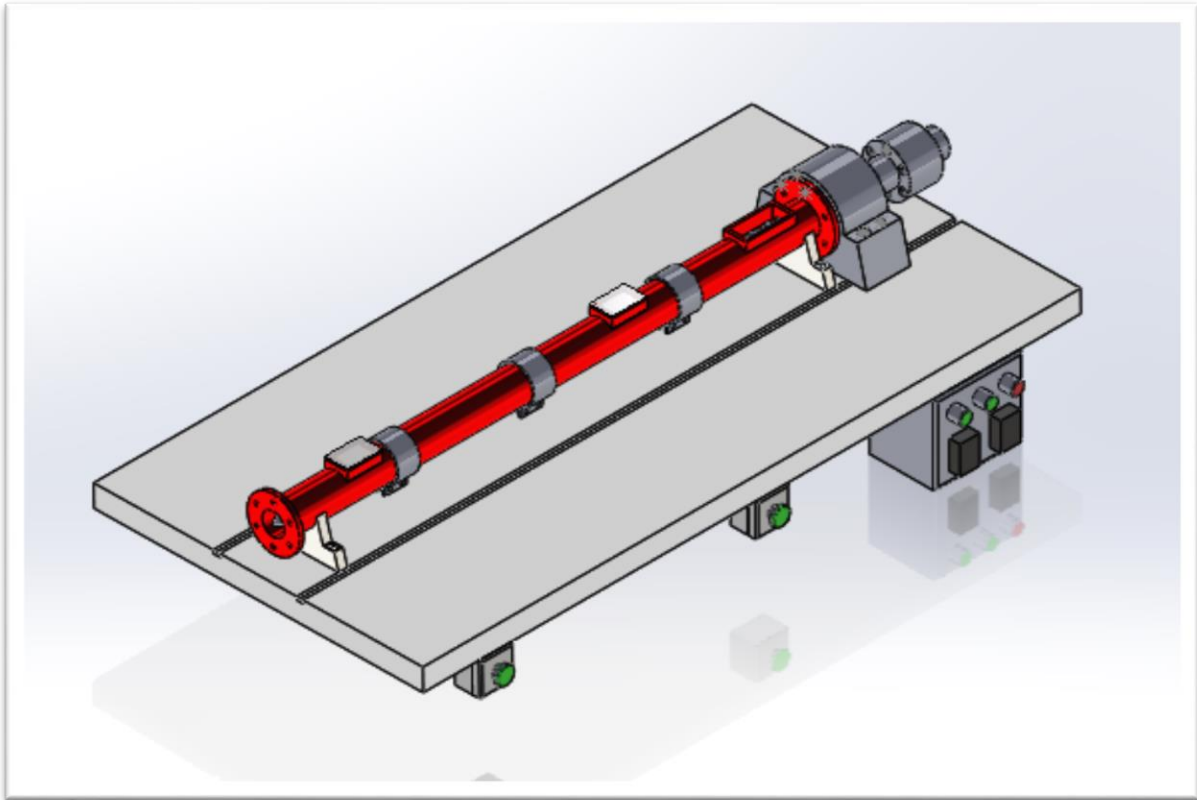
Design 1

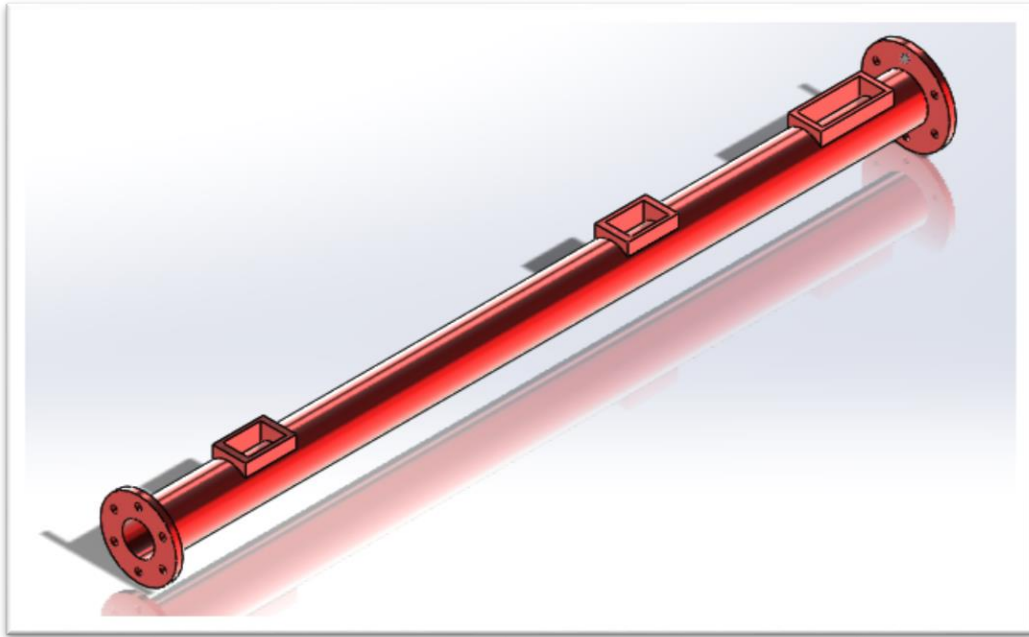
This design includes a bottle activated table frame work. The design would allow the machine to be lifted and lowered depending on the user requirements. The target user of the machine would include children, so this could be a particularly engaging feature. The weight and operating process would need careful consideration, could this type of frame be able to withstand its operational requirements.

8.0 Final Design

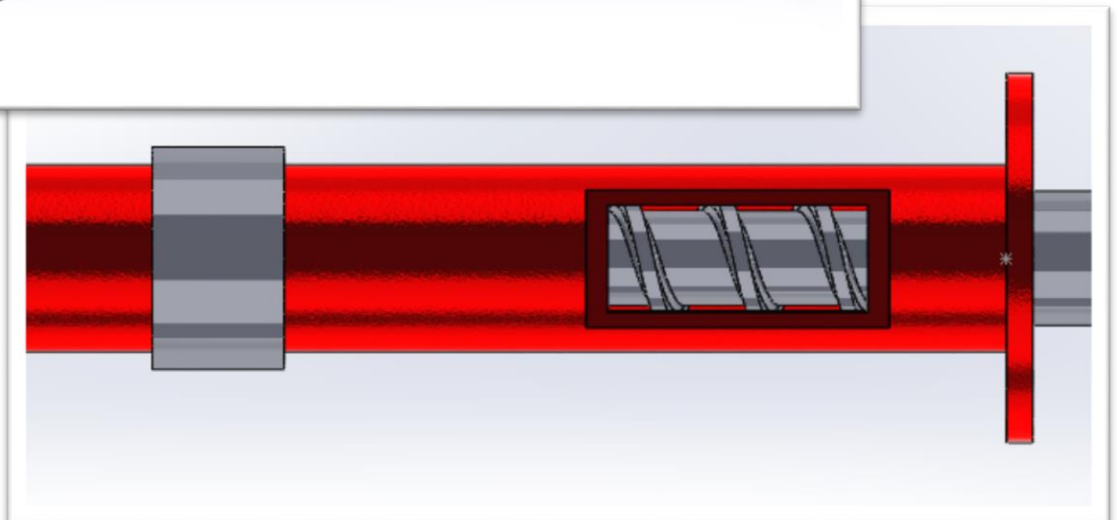
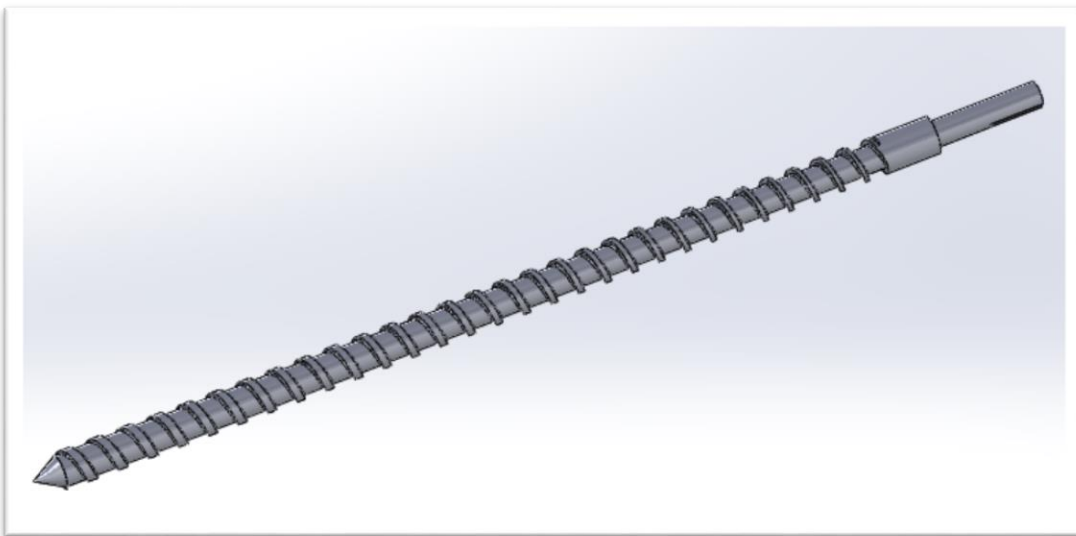
Here is the result of my design development and the design appraisal process. The result is an extruder machine which provides a marked improvement on the precious plastics open source design. The design now includes a system of safety appropriate for its intended users. The machines performance will be vastly improved due to its design and component quality. Increased user interaction, clear guarding, hopper and view ports into the barrel.





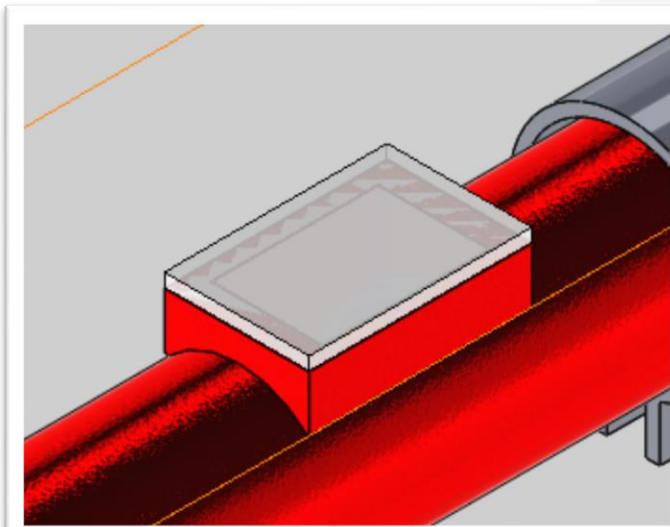
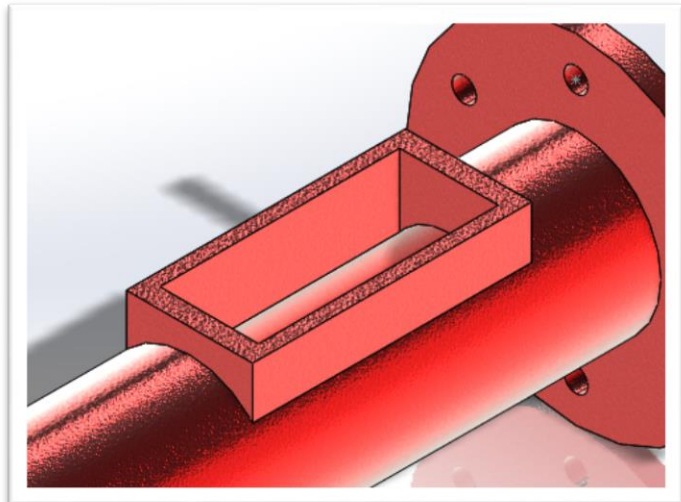


The extruder barrel is designed to work in conjunction with the screw. The two will have a clearance of under 0.05mm. The barrel/screw is made of a tool steel such as AISI D2, this will be hardened through the nitride process to achieve hardness values above 65 Rockwell. This selection of hardening process results in very little distortion, allowing for excellent performance.

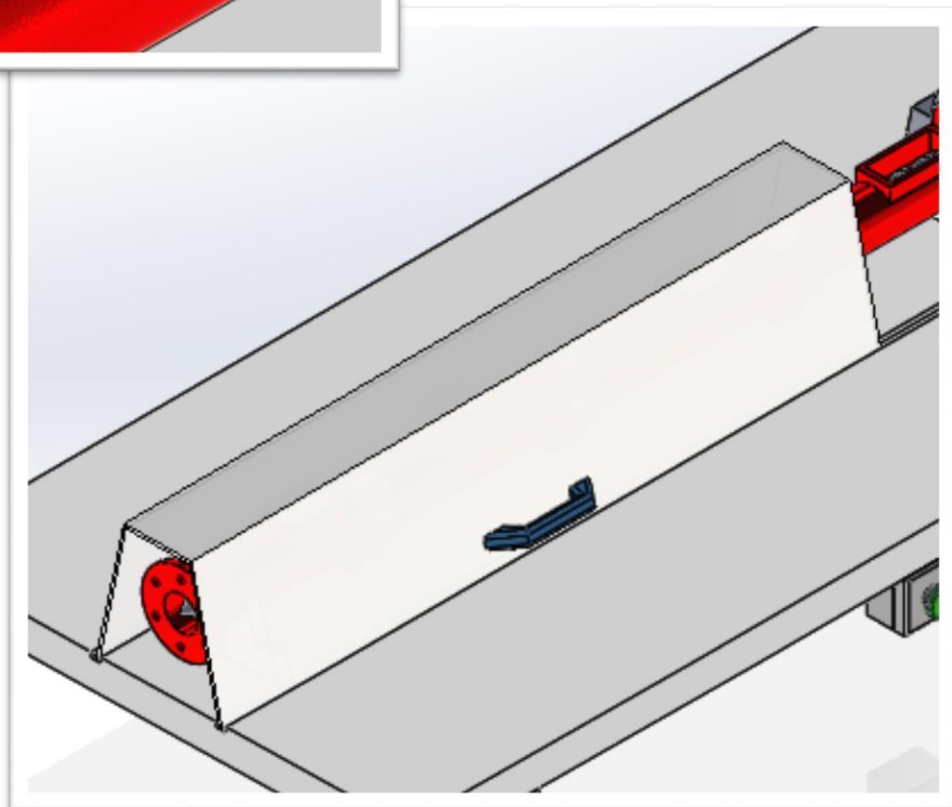


The barrel has a flange at the drive end. This is designed to provide a robust point of attachment for the thrust bearing housing and flexible coupling.

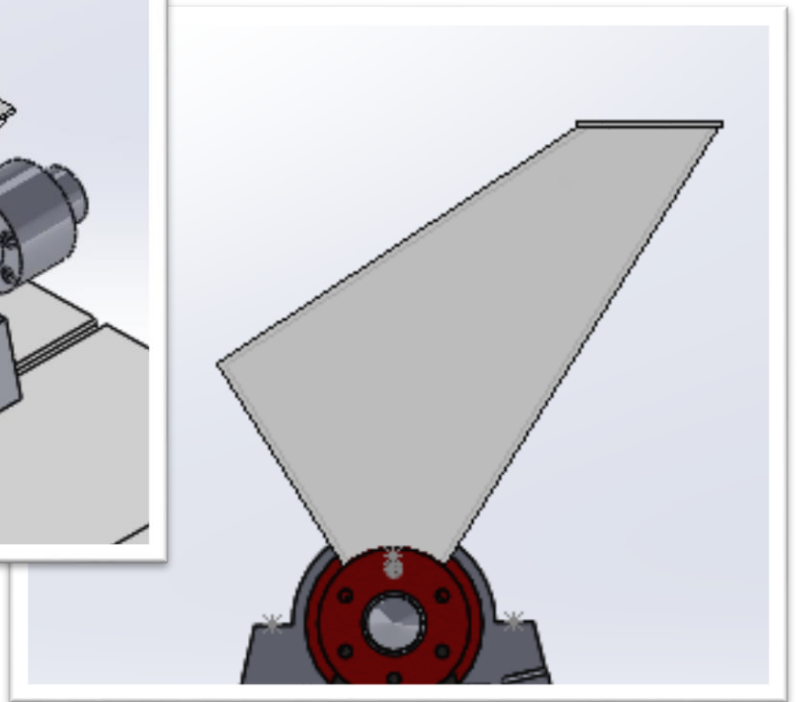
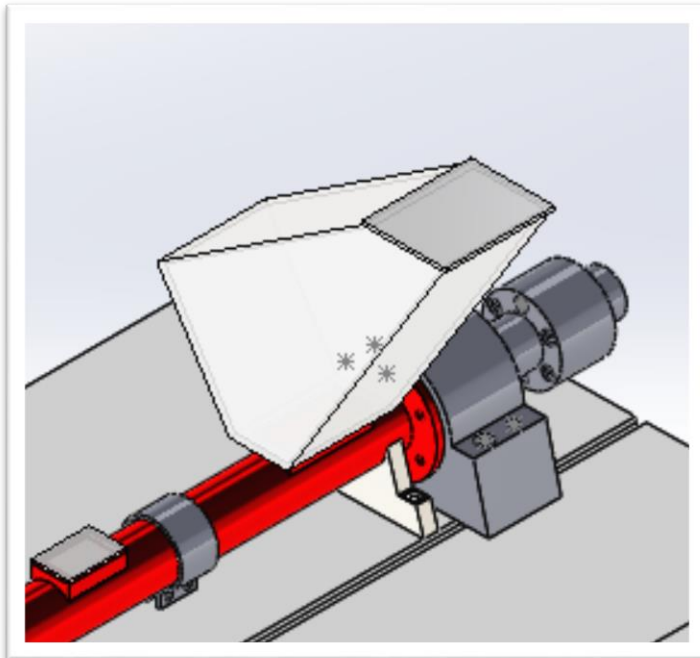
There is the opening for the hopper attachment, which allows access for raw material to reach the screw.



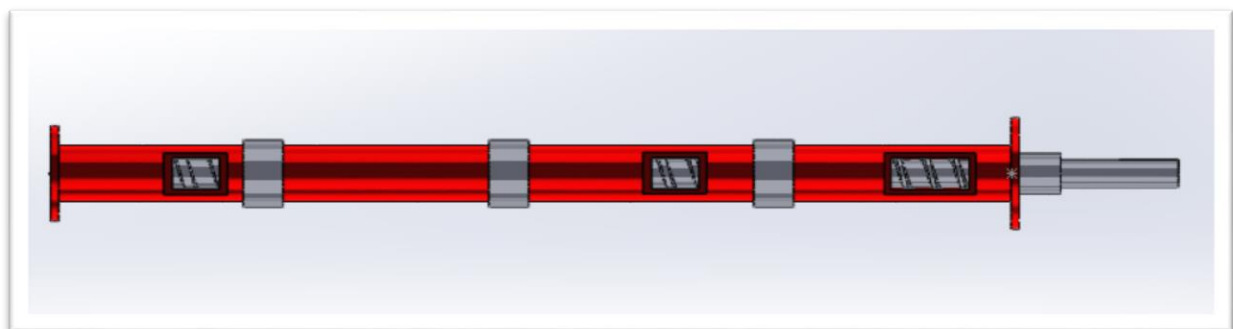
There are two viewing ports which allow users to view the plastic at different points along the screw. These would need to be fixed appropriately to cope with the pressure during the extrusion process. The colour red has been applied to the barrel to indicate its temperature, this would be part of the safety strategy.



The guard is made of Perspex and designed protect the user form the potentially hot surfaces of the barrel. The material selection allows for users to be able to still view the barrel and other components. Its simple design allows for ease of manufacture. The guard would be hinged allowing the guard to be raised and lowered when needed. The guard would be interlocked as part of the safe work system.

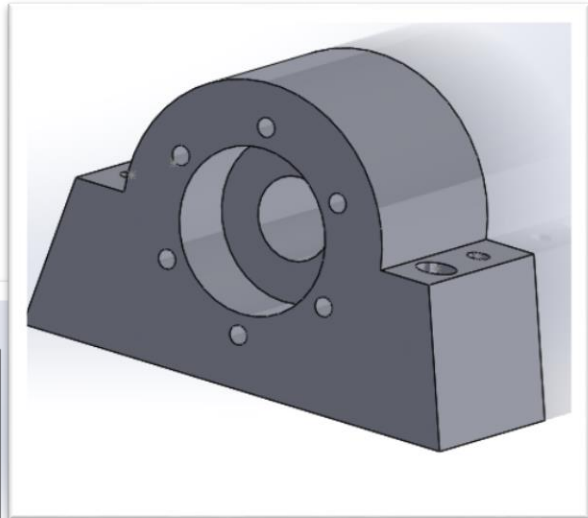
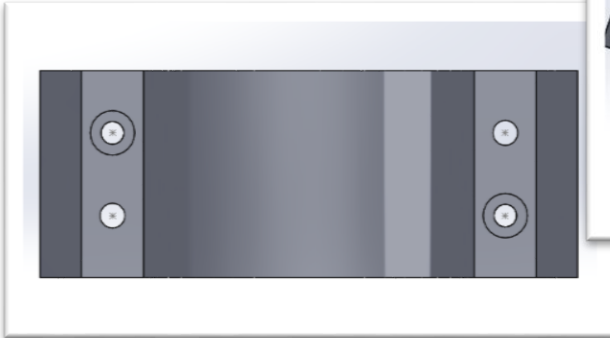


The Hopper is also designed with safety at the forefront. It must fulfil its basic need to provide material to it screw, but it unusual shape is designed to restrict the users access to the bottom of the hopper. The hopper material is Perspex, this is to enable users to see both the material and the screw in the barrel if the hopper is empty. The hopper is fitted with a lid which would be interlocked as part of the safe operation system.



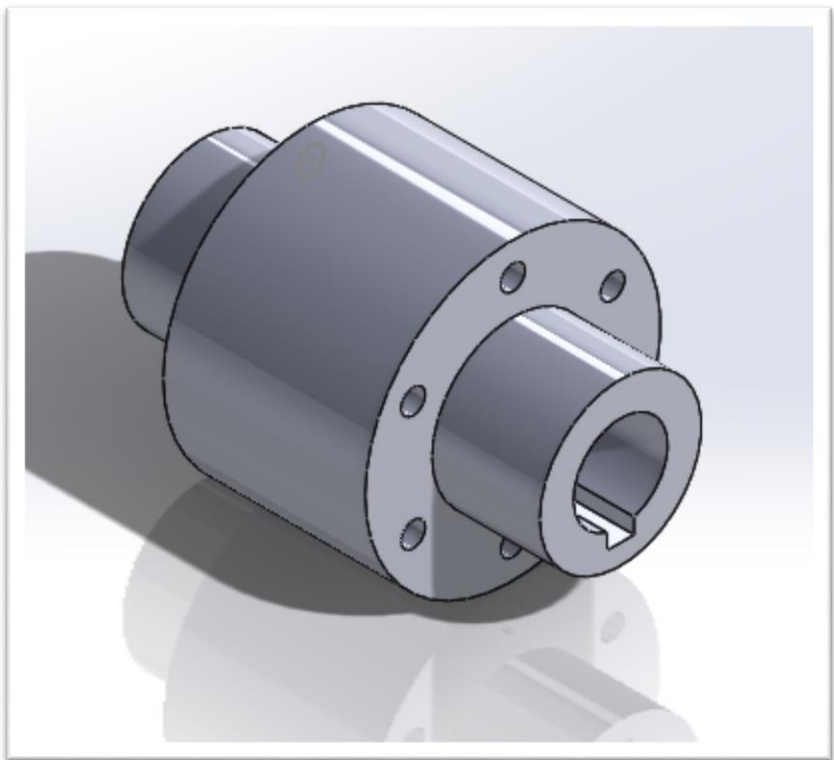
The barrel is fitted with three heaters bands to aid the extruder performance. These would be mica band heaters, they are thin, insulated but with excellent heat transfer properties.

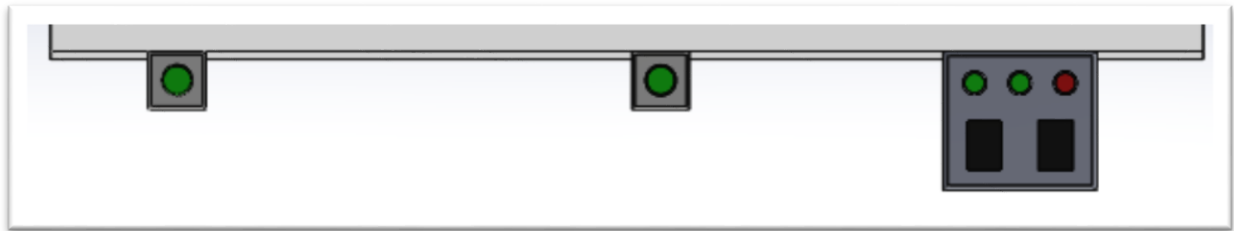
This is the bearing housing design for use with the redesigned barrel. It has direct mounting to the barrel and bolt and dowel holes for the work surface. The block has been designed to be robust enough to withstand the forces emitted during the extrusion process.



The bearing housing is fitted with a SKF gx35f thrust bearing, this design of thrust bearing is perfect due to its use of roller instead of balls. This enables it to work effectively even when submitted to misalignment. The thrust bearing is able to protect against radial and thrust loads.

A flexible coupling is placed between the gearbox and bearing housing. It transmits the torque also negating any misalignment. It will also provide protection against torque overload. The design of the coupling will disengage at dangerous torque levels.





The design will incorporate a two-hand safety operation system. By controlling the position of the operator's hands during any hazardous operation by means of needs to continually press two buttons. Once any one button is realised the power will be cut to the motor. A safe location of the button will be established, enabling users to still see the process but needing to keep hands away from hazards. This will work alongside the E-stop buttons which will cut power to any motor, the power will not return without the use of the power on button located on the main panel.



The main control panel will have the on/off, e-stop and thermostat temperature control features of the machine.

8.0 Supporting Material

8.1 Materials List

No	Part	Material	Approx. dimension	Quantity	Location
1	Barrel	AISI D2	Ø80 x 1200	1	Specialist
2	Screw	AISI D2	Ø 50 x 1200	1	Specialist
3	Hopper	Perspex	200 x 450	1	Fabricated
4	Main Frame	Mild Steel	1500 x 1000	1	Fabricated
5	Guard	Perspex	1200 x 250	1	Fabricated
6	Bearing Housing	Mild Steel	200 x 150	1	Machine shop
7	Coupling	Tool Steel	Ø 80 x 150	1	Specialist
8	Motor	1700rpm		1	Bought in
9	Band heaters	Mica		3	Bought in
11	E-stop			2	Electrical wholesaler
12	Interlock			2	Electrical wholesaler
13	Push Button			2	Electrical wholesaler
14	Gear box	Two step reducer		1	Bought in
15	Thrust Bearing	Skf Gx35f		1	Specialist
16	PID controller	0-400		1	Electrical wholesaler
17	SSR	2-24v		1	Electrical wholesaler
18	Thermocouple	Type K		1	Electrical wholesaler

FAILURE MODE AND EFFECTS ANALYSIS

Item: Precoius Plastic Aman Valley FMEA number: 1 Rev: 1
 Model: Extrusion Machine Page: 1
 Prepared by: Paul Thomas FMEA Date (Orig): 18/06/2018

Machine Component	Function	Potential Failure Mode	Potential Effect(s) of Failure	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Current Process Controls of supplied Extruder	Detection	RPN	Recommended Customer Action(s)	Action Results			
										S e v	O c c	D e t	R e p N
Motor	Provides rotational drive	Motor electrical failure	Screw Fails to rotate	Over heating from incorrect setup.	5	Motor control drive overload setting. Standard operating procedure (SOP), pre-work inspection.	8	320	Training.	8	2	2	32
		Motor Mechanical Failure	Screw Fails to rotate	Wear	5	Standard operating procedure (SOP), pre-work inspection.	8	128	Planned Maintenance/Inspection, Replacement on manufactures recommended operating hours.	8	1	2	16
Gearbox	Provides rotational drive, reduces motor speed and increases torque.	Gearbox seized	Screw Fails to rotate,	Seized Bearing Gear Failure	3	Motor control drive overload setting. Operating instructions, pre-work inspection & SOP	8	192	Planned Maintenance/Inspection, Lubrication.	8	1	2	16
			Noisy operation	Wear, Lubrication	3	Standard operating procedure (SOP), pre-work inspection.	8	45	Planned Maintenance/Inspection, Lubrication.	5	1	1	5

8.2 Extruder FMEA

Coupling	Transitions to rotation to extruder screw and corrects misalignment	Coupling wear	Screw Fails to rotate,	8	Wear, excessive misalignment	3	Standard operating procedure (SOP), pre-work inspection.	5	120	Planned Maintenance/Inspection,	8	3	1	24
			Noisy operation	8	Wear, excessive misalignment	3	Standard operating procedure (SOP), pre-work inspection.	5	120	Planned Maintenance/Inspection,	8	3	1	24
		Damage (twisted, sheared).	Screw no longer functional.	8	Incorrect setup, excessive torque	3	Motor control drive overload setting. Standard operating procedure (SOP), pre-work inspection.	4	96	Training.	8	1	2	16
			Worn	8	Wear through normal operation	3	Standard operating procedure (SOP), pre-work inspection.	4	96	Planned Maintenance/Inspection,	4	3	1	12
Screw	Plasticates and conveys polymer to die		Inefficient plasticating											

Band Heater	Provides heat to melt polymer	Electrical failure	Polymer does not melt.	8		Standard operating procedure (SOP), pre-work inspection.	4		96	Planned Maintenance/Inspection,	8	3	1	24
				Electrical fault										
Thermocouple	Measures temperature	Electrical failure	Polymer not melting or evidence of burning	8		Standard operating procedure (SOP), pre-work inspection.	4		192	Planned Maintenance/Inspection/ Calibration.	8	1	1	8
				Electrical fault										
PID Controller	Regulates temperature	Electrical failure	Polymer not melting or evidence of burning	8		Standard operating procedure (SOP), pre-work inspection.	8		192	Planned Maintenance/Inspection/ Calibration.	8	1	1	8
				Electrical fault										
Motor drive	Controls motor speed, torque and overload.	Electrical failure	Screw Fails to rotate	3		Standard operating procedure (SOP), pre-work inspection.	8		96	Planned Maintenance/Inspection,	8	2	1	16
				Electrical fault										

Severity		
Value	Description	Criteria
1	Irrelevant	No impact to product quality and process robustness
4	Slight	No impact to product quality
9	Important	Noticeable impact to product quality, but can be recovered by reprocessing
16	Critical	Definite impact to product quality that may require rework
25	Disastrous	Batch failure, not recoverable by rework

Probability		
Value	Description	Criteria
1	An unlikely probability of occurrence	Failure has never been seen in any relevant lab experiments, or scale-up batches yet but it is theoretically possible.
3	A remote probability of occurrence	Failure only seen once or twice in relevant lab experiments, never in scale-up batches.
5	An occasional probability of occurrence	Failure potential has been noted in several relevant lab experiments, or at scale-up. If procedures are followed the failure potential is minimal.
7	A moderate probability of occurrence	Failure potential has been noted in several relevant lab experiments, or at scale-up, in-process control maybe required to avoid failure.
9	A high probability of occurrence	Failure potential has been noted in several relevant lab experiment, or at scale-up, an active non-standard feed back control loop may be required.

Detection		
Value	Description	Criteria
1	High degree of detectability	A: Validated automatic detection system that is a direct measure of failure. B: Two or more manual operated validated detection systems, direct or indirect. (e.g. Control range and IPC)
3	Good detectability	A: Single manually operated validated detection system that is a direct measure of failure. (e.g. IPC of failure, validated PAT)
5	Likely to detect	A: Single manually operated validated detection system that is not a direct measure of failure. (e.g. PAT measurements or IPC's not directly linked to failure)
7	Fair detectability	A: Non validated (manual or automated) detection. (e.g. visual level check, visual inspection of vessels).
9	Low or no detectability	No ability to detect the failure

9.0 Conclusion

After careful consideration, the outcome of the design process must be a positive one. The development process enabled me to design a product which meets the target brief from our customer Precious Plastic Aman Valley. Upon reflection of this experience, I now recognise that I have gained a valuable insight into the design process for future projects.

It has also raised mine and my family's awareness of the problem regarding the use of plastic in the modern world. I now fully appreciate the issues raised by Precious Plastic, I understand that the bigger message is awareness of the problem. The current failings of the machines, paired with future development, will further establish this message.

The final product I designed fully meets the customer design brief, it has user engagement/interaction, a safe system of work, simple but effective design. This allows for low cost but with a marked performance improvement over the open source design from Precious Plastic.

The tools used throughout the design process empowered me, as the designer to isolate and develop the real areas of interest. These tools included a QFD matrix, product design specification (PDS), CES edupack material section and design isolation/development techniques. These were used to work out the customer needs, identify required design characteristics, develop designs and analyse/appraise these designs to find the best outcome for the customer.

Whilst I found this process quite difficult at times, I now fully understand the reason for it. I often had a preconceived idea already in mind. To overlook this and concentrate on the process identifies the real problems/targets for design.

The final design was the result of the customer design brief and the research of the extrusion machine. This research was invaluable in providing me the background knowledge to fully understand the process and the functional machine requirements. Without this research I would not have been able to design a machine capable of producing a useable product.

To support my final design, I produced an FMEA and material list. The material highlighted materials used, components and specifications. This could be used in conjunction with the FMEA to aid in problem identification and maintenance work.

I have several recommendations for further machine improvement. A method to more accurately control the barrel temperature. The industry machines often use heating and cooling techniques to accurately control the temperature of specific plastics. Further development would be to introduce a cooling medium as the plastic is projected through the die, most plastic require this process for material optimisation. This is material control characteristic is standard in industry. Finally, the Cwmaman council also operates a maker's space, this involves 3d printing opportunities. The 3d filament can be expensive, this machine would be perfect for making this product with a few improvements. To do this, the machine would need

Paul Thomas (1708327)

an additional fixture to tension and wind the product onto reels for the use in 3d printing.

10.0 References

Asminternational, 2002. *Surface Hardening of Steels: Understanding the Basics*, s.l.: s.n.

Barr, R. A. & Chung, C. I., 1966. *Estimating Polymer Cooling Capacity*. s.l., s.n.

Bucorp.com, 2013. *D2_data_sheet_*, s.l.: s.n.

Crawford, R., 1998. *Plastic Engineering*. 3rd ed. Oxford: Butterworth - Heinemann.

Elwell, M., 2018. *Lead Health and Safety Consultant (DATA)*. s.l.:s.n.

Engineering-360, 2018. *Engineering-360*. [Online]

Available at: <https://www.globalspec.com>

[Accessed 6 2018].

Hakkens, D., 2018. *Precious Plastic*. [Online]

Available at: <https://preciousplastic.com>

HSE, 2018. *HSE*. [Online]

Available at: <http://www.hse.gov.uk/pubns/ppis7.pdf>

Machinedesign.com, 2018. *Machinedesign.com*. [Online]

Available at: <http://www.machinedesign.com/basics-design/design-serviceability>

[Accessed 2018].

Maddock, B., 1995. A Visual Analysis of Flow and Mixing in Extruder Screw.

Plasticsmachinerymagazine.com, 2018. *Plasticsmachinerymagazine.com*. [Online]

Available at: <http://www.plasticsmachinerymagazine.com/technology/extrusion-film/-right-extruder-motor-is-key-to-maximizing-uptime.html>

[Accessed 2018].

Rauwendda, C., 2009. *Polymer Extrusion*. 4th ed. s.l.:Antec.

Recycling-guide.org.uk, 2018. *Recycling-guide.org.uk*. [Online]

Available at: www.recycling-guide.org.uk

[Accessed 2018].

Sampspa.com, 2018. *Sampspa.com*. [Online]

Available at: <https://www.sampspa.com/blog/>

[Accessed 2018].

World-grain.com, 2018. *World-grain.com*. [Online]

Available at: www.world-grain.com/Departments/Feed-Operations/2012/8/Motor-speed-reduction-method

[Accessed 2018].