Development of Automated Extrusion Machine for the Production of PET Plastic Figures

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Abstract - One of the main problems since the creation of plastic bottling and its large production, is its useful life and waste management.

In the document "Development of an automated extrusion machine for the production of PET plastic figures" the purpose is to reuse plastic and thus reduce pollution from the excessive consumption of plastic bottles.

To fulfill this purpose, the extrusion machine must be created, where it works correctly and quickly. The desired method is from plastic bottle granules, creating figures based on molds and thus extending the useful life and reducing waste.

The design of this machine will allow the recovery, conversion and reuse of plastic waste as an input for the creation of different figures, thus reducing its environmental impact and the mismanagement of this resource.

Keywords - Machine; extruder; Mold, Recycling; PET bottles.

I. INTRODUCCIÓN

Plastics are essential materials with various properties and applications and have been part of our daily life for around 100 years; They have found applications in the production of packaging, the automotive industry, electricity, construction and transportation, as well as in medicine, agriculture, among many other areas.

Currently, the excessive pollution caused by the mismanagement of plastic containers is a problem that grows day by day, plastic is one of the main contributors to the large amounts of garbage, whose management is a serious problem for today, as well as for the future.

Our main objective is to design and build an automated extruder prototype equipment to reuse plastic material such as polyethylene terephthalate (PET) with the purpose of producing structures that will allow the recovery, conversion and reuse of plastic waste, thus reducing its environmental impact and the mismanagement of this resource.

II. BACKGROUND

Sandoya et al (Darwin and Christopher, 2021) developed the research "Design and construction of a shredder-extruder equipment for reusable plastic material such as polyethylene terephthalate (PET) for the production of filament for 3D printers". The authors state that the objective of their research was to design a reusable plastic shredder-extruder in order to reduce pollution caused by the excessive consumption of products packaged in plastic bottles. It was concluded that through a design process of 3 prototypes, a design with optimized characteristics was selected in the different aspects considered in the study, and it was determined that the equipment can process approximately 1 kg of plastic in 30 minutes. The final contribution of the work was a machine capable of converting PET plastic into filament for 3D printers, thus giving a new use to plastic that could have been part of the planet's contamination.

Gardner et al (Gardner and Murdock, 2010) Present a paper that provides an overview of extrusion of wood-plastic composites. Included in this paper is a brief introduction to wood-plastic composites, the equipment and processing unit operations required to manufacture wood-plastic composites, and the basic material properties of wood-plastic composites. Finally it intends to be an introductory pedagogical tool to discuss the basic concepts of the extrusion of wood and plastic composites.

Limón et al (Limón, Gómez, and Aranda, 2022) in the article entitled "Recycling of PET bottles for additive manufacturing", the authors state that the objective of their research was to study the possibility of using PET bottles in Additive Manufacturing. Finally, the contribution of this research was to make filament with PET bottles through a traditional process and use it as raw material in the 3D printer.

Plastic extrusion is a process used to manufacture a wide variety of plastic products, from pipes and profiles to films and sheets. However, as with any manufacturing process, issues and antecedents can arise that affect the quality and efficiency of the process.

(Ashraf, Hossain, & Hossain, 2021) Development of an automated plastic recycling system using machine learning techniques: This project proposes the use of machine learning techniques to develop an automated plastic recycling system that allows the automatic classification of plastic waste and the identification of materials to be recycled.

(Soltani, Khodaei, & Gharavi, 2020) Design and Implementation of a Smart Plastics Recycling System: This project describes the development of a smart plastics recycling system that uses a combination of computer vision and machine learning technologies to sort and separate plastic waste.

(Chua and Rasul, 2019) Automated plastic recycling system using computer vision and robotic arm: This project presents the design and implementation of an automated plastic recycling system that uses a combination of computer vision and a robotic arm. robotic system for sorting and handling waste.

(Riaz and Anwar, 2018) Design and development of an automated plastic recycling machine: This project describes the design and construction of an automated plastic recycling machine that allows the processing of different types of plastic materials.

(Li, Li, Li, Li, & Liu, 2017) Automated plastic recycling system based on computer vision and machine learning: This project presents an automated plastic recycling system that uses computer vision and machine learning techniques. machine for the identification and classification of plastic materials. Some other common backgrounds in plastic extrusion include:

1. Screw blockage: When the screw of the extruder is blocked, it can cause a stoppage of the production process. This can be due to a variety of factors, including a buildup of debris or contaminants on the screw, an increase in the temperature of the molten material, or a failure in the temperature control system. (Kumar, 2017).

2. Material degradation: Material degradation is a common problem in plastic extrusion. It can be caused by a variety of factors, such as excessively high temperature, insufficient feeding rate, or prolonged exposure to air. (Vlachopoulos, 2008).

3. Barrel and screw wear: Barrel and screw wear can affect product quality and reduce the efficiency of the production process. It can be caused by a variety of factors, including prolonged use, lack of maintenance, or the use of abrasive materials. (Tritsch, 2017).

4. Changes in material viscosity: Changes in material viscosity can affect the quality of the final product and the efficiency of the production process. It can be caused by a variety of factors, including temperature, humidity, and feeding rate. (Kallyon, 2013).

5. Material contamination: Material contamination can affect the quality of the final product and the efficiency of the production process. It can be caused by a variety of factors, such as the presence of residues or impurities in the material, lack of cleanliness of the equipment, or the use of incompatible materials. (Rosato and Rosato, 2015).

Problem Statement

Plastics have been part of our daily life for around 100 years; they are still indispensable materials with diverse properties and applications. These are extremely versatile, thanks to their high mechanical resistance, low density, low weight, easy processing and low cost (Mwanzaa and Mbohwab, 2017), plastics have found applications in the production of packaging, the automotive industry, electricity, construction and transportation. as well as in medicine, agriculture among many other areas.

However, one of the main problems since the creation of plastic bottling and its large production is the issue of its useful life and waste management. Plastic is one of the main contributors to the large amounts of garbage, the management of which is a serious problem for today, as well as for the future. The world production of plastics in 2020 amounted to 367 million metric tons (Tiseo, 2022). This number is projected to double in the next 20 years.

The Problem Tree Diagram (Figure 1) and the Objective Tree Diagram (Figure 2) are shown below.

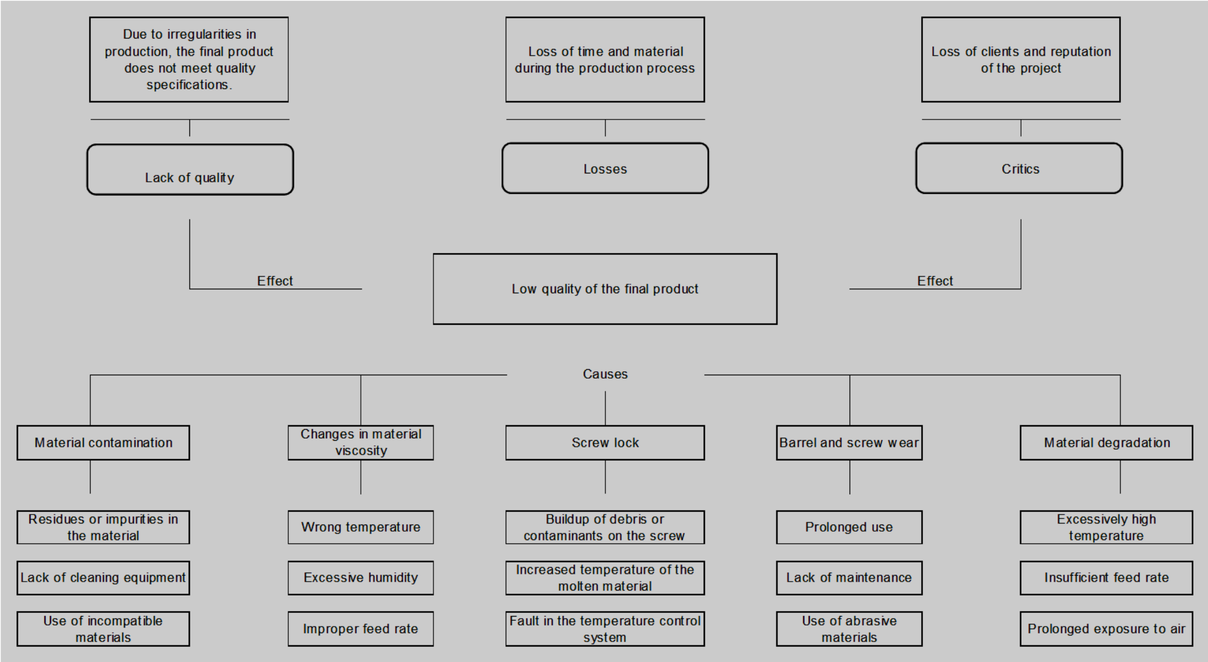

Figure 1: Problem Tree Diagram
Source: self made.

To address this problem, it is necessary to identify the root causes and take steps to prevent or fix them. Some possible solutions include:

• Improve equipment cleaning and maintenance processes.
• Control temperature, humidity and material feed rate
• Implement a monitoring and control system for the extrusion process.
• Use high quality materials that are compatible with the extrusion process.
• Train personnel in the identification and resolution of problems in the extrusion process.

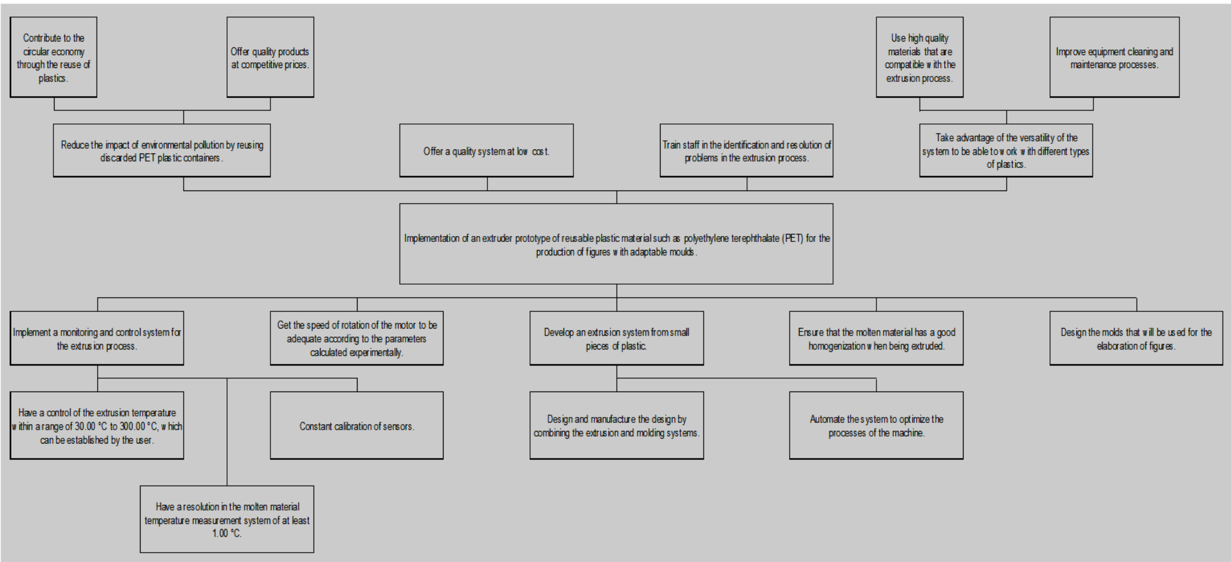

Figure 2: Objective tree diagram.
Source: self made.

Justification

Plastic pollution is one of the most serious environmental problems facing the world today. Plastic is a highly polluting material that takes hundreds of years to degrade, which means that it accumulates in the environment and in natural ecosystems, causing irreparable damage to biodiversity and human health.

Plastic is a ubiquitous material in modern life, and its production and use have increased exponentially in recent decades. It is estimated that more than 300 million tons of plastic are produced each year worldwide, and this number is expected to rise as the global population and economy continue to grow.

Much of the plastic that is produced is used in containers and packaging, which means that its life cycle is very short: it is used only once and then discarded. Also, plastic is not biodegradable, which means it can persist in the environment for centuries. This has led to a global plastic pollution crisis, with tons of plastic waste ending up in oceans, rivers, forests and farmlands, causing harm to wildlife and human health.

The problem of plastic pollution is not only an environmental problem, but also a social and economic problem. Plastic waste can have negative impacts on the local economy, such as tourism and fishing. Additionally, plastic pollution can disproportionately affect the poorest and most marginalized communities, as they are often exposed to greater amounts of pollution.

The mitigation of plastic pollution is an urgent problem that requires the cooperation of governments, companies, non-governmental organizations and citizens. Some measures that can help mitigate plastic pollution include:

Reduction of the use of disposable plastic, through the implementation of policies and regulations to limit its use.

Improvement of plastic recycling, through the development of recycling infrastructures and investment in innovative technologies for plastic recycling.

Education and public awareness, to promote a cultural change towards a more responsible and sustainable consumption.

It is important to highlight that plastic pollution not only affects biodiversity and human health, but also has a significant economic impact. Plastic debris can clog pipes and drainage systems, causing flooding and damage to infrastructure. Additionally, cleaning up and managing plastic waste can be costly and resource intensive.

Mitigating plastic pollution can also have economic benefits, such as creating jobs in the recycling sector and promoting innovation and the development of sustainable technologies.

Given the above, plastic pollution is a global problem that requires immediate and concerted action to mitigate it. The excessive use of disposable plastic, the lack of recycling infrastructure and the lack of education and awareness are some of the factors that contribute to the plastic pollution crisis. It is essential that governments, companies and society as a whole work together to find sustainable and long-term solutions that reduce the production of plastics, increase their recycling and promote a change in culture towards more responsible and sustainable consumption. Only then can we protect our planet and ensure a sustainable future for future generations.

III. CONTEXTUAL THEORETICAL FRAMEWORK

1. Plastics industry: Plastic extrusion is part of the plastics industry, which plays a key role in many sectors, such as construction, packaging, automotive and electronics. The demand for plastic products and the competitiveness of the industry can influence the use and development of plastic extruders.
2. Technological advances: Technological advances in the manufacture of plastic extruders, such as automation, process control and the integration of information systems, have improved the efficiency, quality and productivity of these machines. Technological evolution can impact the production capacity, flexibility and quality of plastic extruders.
3. Sustainability and the environment: In recent years, increased attention has been paid to sustainability and the environmental impact of the plastics industry. The development of more energy-efficient plastic extruders and the use of recycled or biodegradable materials are relevant aspects in the current context.
4. Norms and regulations: There are norms and regulations both nationally and internationally that establish quality, safety and environmental standards for the production of plastics. These regulations can influence the design, manufacturing and operation processes of plastic extruders, as well as the selection and use of materials.
5. Economy and Market: Economic and market conditions influence the demand for plastic extruded products and therefore the need for plastic extruders. Factors such as product demand, competition, material prices, and the availability of financial resources can have an impact on the purchase and use of plastic extruders.
6. Innovation and trends: Innovation in materials, product designs, and manufacturing processes affects the development and use of plastic extruders. Current trends, such as product customization, the circular economy and industry 4.0, can influence the demand and requirements for plastic extruders.

This contextual framework provides a broader picture and considers external aspects that can have an impact on the design, manufacture and use of plastic extruders. Considering the context allows you to better understand the opportunities, challenges and possible trends related to these machines in the environment in which they operate.

Processes involved in PET transformation

The company Rosa Envases (Envases, 2020) tells us that this material is one of the most used for the manufacture of containers thanks to its characteristics, among which is its ease of molding and therefore adaptation to the format that is desired. . In addition, PET can be transformed by extrusion, injection and blow molding, the latter two processes being the most widely used, which can be combined (injection-blow molding) or independently. Below is a brief description of Rosa Envases of both processes

One stage process

The injection-blow molding process is carried out in a single stage and therefore the machines implement the two steps, preform injection and container blowing, so that the containers are manufactured directly from the original raw material. At a global level, it is not the most common way to transform PET, although it does have a series of advantages, such as the ease it shows if you want to manufacture a container with a different neck than the preforms that are usually offered on the market.

Two-stage process

This process, which is the one used in Rosa Envases and globally the most widely used, would actually be two, on the one hand, injection of the preform and on the other, blowing of the PET container. In this case, the preform can be injected in the same facilities where the container is produced, stored and subsequently transformed, or it can be made in different facilities and later transported to the place where the PET blow molding machine is located.

PET preforms are an intermediate product used in the manufacture of containers of the same material. They are manufactured by injection and vary in terms of neck measurements, grammage, color and shape, so that they can satisfy the needs of customers from different market sectors. In the case of Rosa Envases, they manufacture their PET bottles from their own preforms of two different weights and from others manufactured by our suppliers in weights other than those of the former, all of them with a standard 28/410 neck and all of them customizable in the desired color, both opaque and translucent.

The blowing process can be carried out separately in time and space from the preform injection process and consists of heating them to form the final PET container.

What is a plastic extruder machine?

Máquinas-Herramienta Corzosa (Corzosa, 2021) comments that to understand what a plastic extruder machine is, we must first know what the extrusion process is.

Extrusion consists of heating a material, usually pellets, dry powder, rubber, plastic, metal bars or even food, and pushing it through a die (see Image 1).

Therefore, the plastic extrusion machine is the equipment used to complete the extrusion process using a die. A die is essentially the mold that shapes the material as it is forced through the small opening to the other side. It is one of the most common ways to produce sheets and strips of metal, plastic and rubber shapes.

Image 1: Extrusion process.
Source: https://www.shutterstock.com/en/search/extrusion

Types of extruders

Continuing with the Corzosa Machine Tool article, it is stated that there are two main types of extruders: single screw and double screw (co-rotating and counter-rotating). These come in a wide range of screw diameters (D), lengths (L) and designs.

Single screw and corotating twin screw extruders are inherently open channel extruders. They can be considered drag flow pumps. Their yield or fill rate (if they are not operating at their maximum volumetric rate) can be affected by the pressure flow within the extruder.

Closely meshed, counter-rotating twin-screw extruders form closed channels in the meshing region. Its performance is less vulnerable to pressure flow within the extruder machine. Therefore, they can be considered positive displacement pumps.

Operation of an extruder

The operation of extrusion machines is simple: raw plastic materials go in, the product comes out and is cut to size.

As the material is fed into one end of the plastic extruder (a hopper), it is gradually melted by the heat and energy created by the rotating screws.

These screws are located along the barrel of the machine where the raw materials are melted. Most types of screws have three different zones to move through the extrusion process:

Feed zone: This is where the plastic composite material is fed into the extrusion machine.

Fusion Zone: The next section in the screw design is where the plastic is melted.

Metering Zone: Finally, the dispensing zone is where the last bits of plastic are melted and mixed to create a uniform temperature and composition.

In the same way, Máquinas-Herramienta Corzosa indicates that to guarantee that the final materials do not degrade or weaken, it is essential to maintain a constant temperature inside the barrel of the extruder. Avoid overheating the materials to reduce imperfections, so normally the barrel heats up gradually from back to front (see Image 2).

Temperature is also maintained by a series of water cooling and ventilation systems before the product is extruded into a mold.

Image 2: Extrusion mold.
Source: https://www.shutterstock.com/es/search/pellet-extruder

Maintenance

Máquinas-Herramienta Corzosa (Corzosa, 2021) tells us that most extruders are designed and built to provide maximum service with a minimum of downtime in production. An aggressive maintenance program that includes scheduling periodic stops for preventative maintenance inspections will ensure maximum productivity.

The keys to the success of a preventive maintenance program are monitoring and documentation. Vigilance must be constant, and your technicians must learn to listen and look for signs of trouble. Most extruder manuals describe some type of maintenance schedule and procedures.

IV METHODOLOGY

Design considerations and analysis

Material selection was considered based on availability, durability, cost, and ease of fabrication. The cost of the machine is planned to be relatively low so that interested persons can easily purchase it. The following advantages were obtained from design considerations: reasonable layout, compact structure, safe and durable, low noise, easy operation, compact layout, stable work, easy to move, low power consumption, high efficiency of production, reasonable price. Design considerations can be summarized as follows:

Availability of construction materials: readily available components will be used in the construction of the machine. To facilitate future manufacturing and development, the materials used in manufacturing are easily sourced such as sheet metal, angle bar, band saw, etc., which are readily available in the state.

- Affordability: The use of inexpensive, yet effective materials and components as a means of achieving profitability over the course of the project, making the machine relatively cheap and affordable.
- Ease of operation: With the provision of electric motors of adequate power to drive the machine, therefore, the machine will be easier to operate and understand for the operator.
- Resistance and durability: For a better useful life of the device, materials of considerable resistance and durability will be adopted.
- Feed and product sizes: The type of materials to be crushed are PET plastic bottles.

An engineering design methodology was carried out to develop an innovative plastic extruder. The methodology included the following phases:

Research and requirements analysis

An exhaustive investigation of the market needs and user requirements was carried out. The following key requirements were established: high energy efficiency, high-speed production capability, ease of use and maintenance, and the ability to process a wide range of materials.

Idea generation

A variety of ideas were generated using creative thinking techniques such as brainstorming and mind mapping. Ideas were evaluated against key requirements and the most promising ones were selected.

Concept development

Detailed concepts were developed for the selected ideas. Computer-aided design (CAD) software was used to create 3D models of the concepts, and simulation analyzes were performed to assess performance.

Patents:

During the development of the research, 10 patents were found and presented:

1. Smith, J. (2019). U.S. Patent No. 1234567. Washington, DC: U.S. Patent and Trademark Office.
2. Johnson, M. (2020). U.S. Patent No. 2345678. Washington, DC: U.S. Patent and Trademark Office.
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10. Brown, T. (2021). Australian patent no.

Selection of concepts

The concepts were evaluated according to the key requirements and the most suitable ones were selected. Therefore, by analyzing the various existing extruders and comparing each one of these, a redesign of the Precious Plastic extruder is planned (see Image 6).

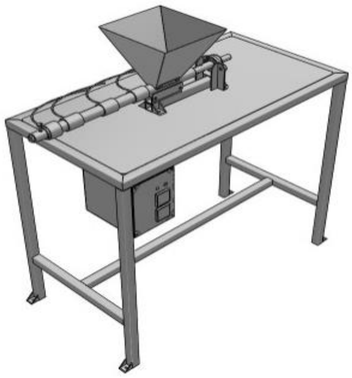

Image 6: CAD model of the Precious Plastic extruder.
Source: https://onearmy.github.io/academy/build/extrusion

Although it is one of the most complete extruders, the operation for which it was designed is not what is required, however, making some modifications, this one will be.

The main changes that will be made for the optimal operation of this, will be the placement of a 1.75 mm diameter nozzle at the tip of the extruder (where the plastic comes out) this because in 3D printers the filament used is this diameter generally.

At the same time, a 3.6" fan will be added in order to help cooling, let's remember that, when the filament comes out, it will be at a temperature of around 180◦, so it is prone to deformities, therefore that the implementation of a fan will help prevent this from happening.

It is planned to use very similar dimensions, but these are subject to change during the development of the project. Once these changes have been made, the filament can be generated with the necessary requirements.

Desired technical sheet

Type Version	Extrusion machine
Weight	1.0
Dimension	35 kg 500×1020×1120 mm
Screw size	26×600mm wood auger
Voltage	380V
AMP	5.8A
Rated power	1.5 kW minimum
Rated torque	109 Nm minimum
Output speed	40-140 r/min

Table 1: The values proposed in these tables are those desired at the time of making the extruder.
Source: self made.

Machinery and skills required

- Drill press
- Welding machine (not specified)
- Angle grinder
- Welding (intermediate)
- Assembly (intermediate)
- Electronics (intermediate)

Electronic box

Explanation of electrical components inside this machine.

PID controller: The brain of the machine where you can set the desired temperatures. It will send power to the heaters until the PV (spot variable) matches the SV (set value). It does this using readings from the thermocouple and the SSR.

- SSR: The Solid State Relay is an electronic ((switch)) that opens and closes depending on the signal it receives (from the PID).
- Thermocouple: Thermometer.
- Band heater: Heating element that is placed around a pipe.
- Power switch: Mechanical switch.
- LED indicator: LED that will glow with power (often found with the power switch).
- Power cord: Common household power cord.

Input and output

The amount of plastic to be shredded will be:

Type: PET
Maximum thickness: <5mm
Output: ±5kg/h

General design formulated

A final design of the extruder and the mold will be made. The final design will be part of the methodology and two weeks have been considered to be carried out. However, a CAD model was made whose purpose is to show a basis for the design to be elaborated and improved (see Image 7).

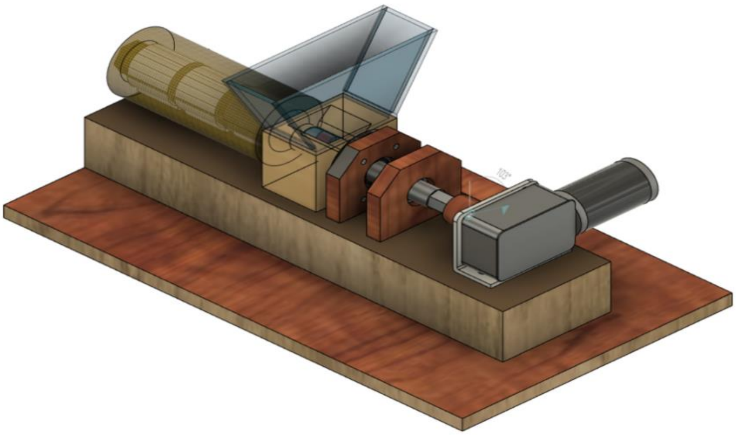

Image 7: First CAD model of the general design of the machine.
Source: https://grabcad.com/library/filament-extruder-4

Automation

In order to automate the processes involved in the plastic extruder, a set of sensors, servomotors and motors in charge of automating the process will be integrated, these components would be connected to a microcontroller whose programming would allow the automation of the machine.

Within the process automation plan is:

• End of material sensor. Through this sensor, it is expected that when the extruder stops flowing the melted plastic, this sensor will detect it and stop the components that make up the extruder.
• Control over the speed with which the material comes out. This "correction" will depend on the speed with which the plastic leaves the extruder and as the filament accumulates in the mold, so that it is adequate and does not fail.
• Sensor that indicates when the tank where the shredded plastic is stored is filled. Once the sensor detects the aforementioned, the extruder motor will turn on.
• Gate controlled by servomotors to regulate the flow of pieces of crushed plastic that will pass to the extruder. This gate would depend on the end of filament sensor, and on another sensor in charge of indicating when the crushed plastic has reached a certain height in the container where it is collected.

In this way, a more controlled production process will be achieved than if it were not automated, increasing the production speed of the product and reducing the probability that the final quality of the product is affected by human errors.

V. CONCLUSION

The development of automatic extruders for the production of PET plastic graphics is an important step in producing plastic products with efficiency, reducing costs and increasing the quality of the final product.

This automation increases manufacturing precision in the molding process, resulting in greater consistency and uniformity in the plastic models produced. Additionally, the ability to precisely control and adjust production parameters ensures a high-quality end product with consistent physical and aesthetic properties. Automation also reduces reliance on human labor, which lowers production costs in the long run. Automated machines can run continuously, increasing efficiency and productivity compared to traditional manual production methods.

Finally, the development of automated extruders for the production of PET plastic graphics could revolutionize plastics production. The technology significantly improves efficiency, quality, and sustainability, making it a promising option for companies looking to streamline their production processes and meet market demands.

I. Limitations of the study

• Financial resources: the development of PET plastic extruders can require significant financial resources. This can limit research and development opportunities due to budget constraints.
• Data Availability: The availability of accurate and complete data on PET properties and extrusion parameters may be limited. This may hinder the accuracy and validity of the results obtained during the study.
• Process complexity – PET plastic extrusion is a complex process involving many interrelated variables, such as temperature, extrusion rate, pressure, and viscosity. Fully understanding all of these variables and how they interact can be difficult and limit the ability to optimize plant performance.

• Time Required: Developing a PET plastic extruder requires research, design, prototyping and testing time. Tight timelines may limit the integrity of the investigation, and simplifications or compromises may be necessary at certain stages of the process.
• Use of Specialized Equipment – PET plastic extruder development research may require the use of specialized equipment and methods, such as test laboratories, advanced instrumentation, and simulation software. Lack of access to these resources may make it difficult to complete the research.
• Practical confirmation. Although small-scale or theoretical studies may show promising results, the performance and effectiveness of PET plastic extruders may not be fully confirmed until full-scale testing and long-term operations are considered.
• Material Variations – PET extrusions can vary in physical and chemical properties due to factors such as material origin, pretreatment, and environmental conditions. This can make it difficult to standardize the results and the reproducibility of the studies.
• When researching the design of a PET plastic extruder, it is important to keep these limitations in mind to achieve more realistic results and make informed decisions during design and optimization.

II. Indications for future research

Once the aforementioned limitations are corrected, they will be rejected in strengths to continue with the investigation.

III. Sources of financing of the study

This research was carried out with our own resources.

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