Universidad Autónoma de Querétaro

Facultad de Ingeniería

Ingeniería en
Automatización

PROTOTYPE OF A SEMI-AUTOMATED MACHINE FOR CUTTING GLASS BOTTLE OF EASY ACCESS

TESIS

That as part of the requirements to obtain the degree of

Automation Engineer

Present:

García Guerrero Jovheiry Christopher

Main advisor

Juvenal Rodríguez Reséndiz

Centro Universitario
Querétaro, QRO
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President

Hugo Rodríguez Reséndiz
Secretary

José Luis Avendaño Juárez
Vocals

Carlos Miguel Torres Hernández
Substitute

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This thesis is dedicated to those looking to create a world where technology and nature coexist and believe in engineering as a tool to create a better future and not destroy it. It is also dedicated to my family, friends, and people who help me grow every day better than the last day.

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Abstract

The development of recycling technologies and processes is something that humanity has implemented and improved over time. Also, new trends for recycling have been developed. Recycling aims to reduce the footprint in the environment, reuse material to solve the scarcity of raw materials or obtain monetary benefits. Upcycling is an artistic recycling trend that aims to get new valuable objects. It reduces wastes, recycles used things, and brings new valuable objects. The upcycled products are usable for personal use or as decorative and artistic objects. This work presents the design, construction, and use of a semi-automated machine prototype. It is based on upcycling glass bottles and focused on the development of sustainable glass recycling culture. The prototype consists of four systems: the support structure allows to keep stable the prototype, the glass bottle holder grids and rotates the glass bottle, the heating resistor holder accomplish the necessary characteristics to contains the heating element, and the electronic system controls the process, obtains data and send information for its interpretation.

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Introduction

According to the *Diccionario de la Real Academia Española*, in its online version, the word *reciclar* (recycle) refers to submitting used material to a reuse process [1]. Now at days, recycling is an activity with multiples benefits and is implemented at different levels. Industries, organizations, or individuals perform it. The reasons and objectives for recycling vary according to the necessity to solve.

1.1   A brief history of recycling

The activity of recycling has been practiced since the first permanent establishments of man arose. Tools were elaborated from elements such as wood and stone. The policy followed was to reuse those that had deteriorated or had remained from other settlements because the production was so tricky. This type of conduct is presented during the pre-hispanic era, where the bones of animals, stones, and wood were used to produce tools for hunting and using in daily activities.

Even after the emergence of metallurgy, waste and unusable metal objects were already recycled to form new objects or products. A case of this was in China, whereby in 2500 B.C., where they recycled metal. A similar situation was in ancient Rome, where the Romans used recycled glass to make their famous mosaics [2]. Also, various civilizations collected human excrement, mixed it with other organic components to create fertilizer, and used urine to color skin paints [3].

Even though reusing and recycling have been present since the beginning of civilization and different cultures have carried out various recycling types throughout history, these activities have not always been used. The fact that processing of raw materials and their transformation became quick and straightforward tasks. It overshadowed reusing and recycling. Only in times of war, people took an interest in reusing materials and recovered objects from recycling. One of these cases was during the War of Independence in North America, at the end of the 18Th century, where recycling became a frequent practice. Another similar incident happened during the First World War. However, it was only in the Second World War when several countries launched official campaigns to recycle and use all kinds of resources, from metal and paper, see Figure 1.1. After the war, the bonanza returned with the forgetfulness of these practices. [4].

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Figure 1.1: Recycling campaign poster in the second world war.

In 1960, the interest in recycling re-emerged due to the promotion of the first environmental movements. As a consequence, the first Earth Day was held in 1970. Also, the recycling logo, which everyone identifies, was unveiled [5]. It is the one formed with three arrows, based on triangular mandalas and the Möbius band, which symbolizes the three steps of the recycling circuit: the collection of waste, their processing, and their return to the production process, see Figure 1.2 [6].

Figure 1.2: Möbius tape.

Today recycling has became an industry in its own right. It demonstrates being a profitable activity while promotes the reduction of waste. Also, recycling obtains benefits from the usual procedures of researching and developing. It aims to find new techniques and processes for improving this activity.

1.2 The glass recycling case

There are several ways to recycle glass products in a complete or partial form. Complete recycling requires the destruction of the entire bottle to produce a new object, while partial recycling takes only a part of the bottle to transform into a new item. At the industry level, glass is recycling into cullet (glass crashed into small pieces). The process requires crushing all of the glass bottles. Cullet production reduces the extraction of raw material. It brings energy savings because the cullet melts at a lower temperature as raw materials, avoids provision and calcination processes, and reduces environmental contaminants like $C0_2$ [7]. Glass recycling is known as integral. It does not create waste, and new products do not lose their qualities and properties [8]. Figure 1.3 adapts the integral recycling of glass bottles according to *ANFEVI* (*Asociación Nacional de Fabricantes de Embases de Vidrio*).
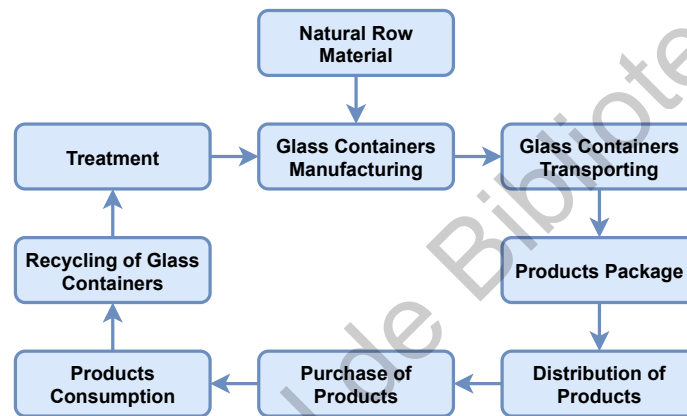
Figure 1.3: Integral glass recycling process.

There are different ways of glass recycling. New studies and methods aim to reuse glass waste, like the experimental study focused on the reuse of cathode ray tube glass [9] and the use of cement pastes modified with recycled glass to supplementary cementitious materials [10].
Organizations and individuals usually collect glass bottles for their sale or disposal in gathering centers. In some cases, they use glass bottles for to produce new usable objects. It is known as upcycling.

1.3 Upcycling as a new opportunity

Due to recycling have penetrated deeply into the conscience of society, different trends have merged in the last decade. Upcycling is a term whose origin comes from the combination of the words of the English language "upgrading" (to add value) and "recycling" (to reuse). It is an artistic trend of the 21st century. Upcycling combines the recycling and reusing of waste. It aims to convert waste into an artistic creation or usable object [11]. See Figure 1.4 for an example of upcycling inside UAQ (*Universidad Autónoma de Querétaro*) installations.

Figure 1.4: An example of upcycling inside UAQ installations.

Upcycling is considered partial recycling. A part of the glass bottle is used for new objects, while the leftovers (glass waste) are not used. Due to upcycling, organizations and individuals have a new way to recycle glass bottles. It consists of cutting over a glass bottle to produce a utility and decorative object. Most of the cuts are done by using a cutter or a phenomenon known as thermal shock. Figure 1.5 demonstrates some products obtained by upcycling of glass bottles.

Figure 1.5: Upcycled products from glass bottles containers by the organization *Cerrando el Ciclo*.

Various tools have been developed to realize this activity. Table 1.1 compiles some patents of tools or devices focused on making cuts for upcycling.

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Patent	Title	Short description
US20130333542A1[12], CA2818364A1 [13].	Bottle Cutter.	Bottle cutter with two curved components, of which a cutting wheel is placed in one, which through the rotation of the container performs the cut.
US3845555A [14].	Bottle Cutter.	Device to make surface cuts around bottles of different sizes and shapes.
US3744692A [15].	Bottle Cutter.	Apparatus for cutting glass articles such as containers and tubes.
US3699829A [16].	Method and apparatus for cutting glass bottle and the like.	A method and apparatus for cutting egg cylinders, such as glass bottles.
10414684 [17].	A bottle cutter apparatus, systems and methods of using the same are provided.	A Bottle cutter apparatus, systems and methods of using the same.
9809484 [18], MX-2013006835-A [19]	Bottle cutter.	A bottle cutter has a body having two generally accurate components connected to each other by straight parallel members.

Table 1.1: Patents of some bottle cutters.

Usually, these allow cutting over glass bottles using a blade and a heating process. Figure 1.6 displays common steps used for cutting glass bottles, according to different glass cutters.
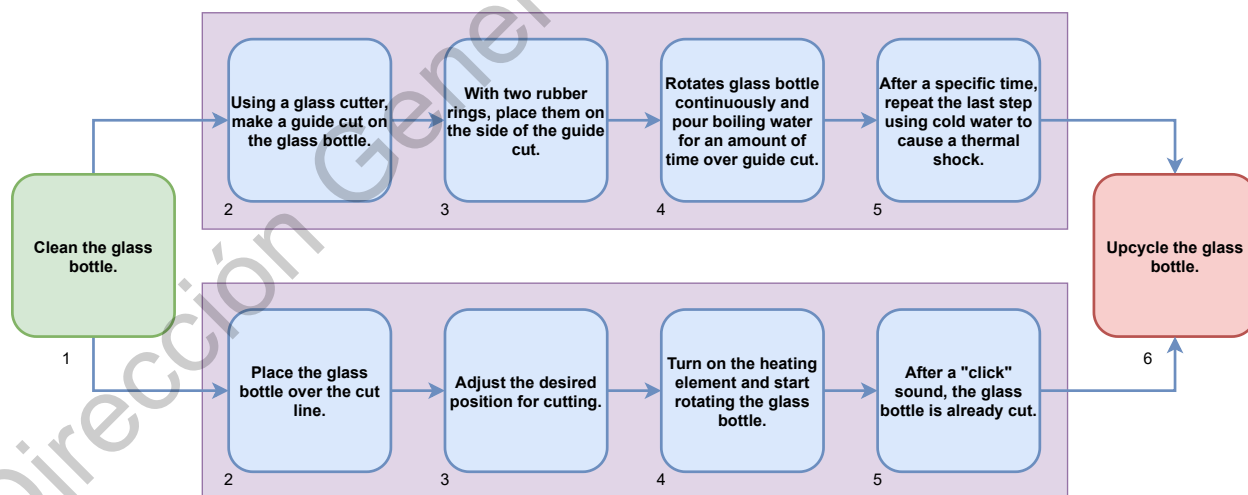
Figure 1.6: Common steps for glass bottles cutting.

There are numerous commercial tools focused on this area. With a variety of prices and materials that offers multiple benefits. Table 1.2 contains information about some of these tools:

Name	Price	Short Description
Bottle Cutter Glass Cutter Kit, for Cutting Wine Bottle or Jars to Craft	US$29.89	5 wheels allow rotating manually a glass bottle. A knife cuts over the bottle.
DIY Glass Wine Beer Jar Bottle Cutter Recycle Cutting Tool Kit Art Craft.	C$45.26	8 wheels allow to rotating manually a glass bottle. A knife in the top part cuts over the bottle.
New Beer Glass Wine Bottle Cutter Cutting Machine Jar DIY Kit Craft Recycle Tool	US$16.58	3 wheals allow to rotating the glass bottle. A knife cuts over the glass bottle.
Glass Bottle Cutter DIY Wine Beer Glassware Cutting Tool Set Brand New	US $6.64	An structure allows rotating the glass bottle. A knife cuts over the glass bottle.

Table 1.2: Commercial bottle cutters.

Most of these models use a special cutting blade, see Figure 1.7. If it is damaged, it needs to be replaced. The problem is that the blade is not available in Mexico. Most models of glass bottles cutters are not produced or sold in local or national stores.

Figure 1.7: Blade used in most of commercial models for glass bottles cutters.

1.4 The case of USW recycling in Mexico

Although the population regularly has recycled glass, the materials most in demand by the recycling industry are plastic, paper, and cardboard. Organizations and individuals skip glass recycling due to the low price in local markets. According to [7], in Mexico, the value for plastic waste is 18 to 92 times the price for glass waste, paper is 10 times, and cardboard is 14 times. Glass recycling is not worthy compared to similar activities.

According to the Ministry of Environment and Natural Resources of Mexico (SEMARNAT by its acronym in Spanish), 53.1 million tons of USW (Urban Solid Waste) were generated, and glass occupies the fourth position of the USW produced in Mexico in 2012 with 5.9% of the total, see Figure 1.8, and the fourth position of the USW collected in 2012 with 13.8%, see Figure 1.9 [20].

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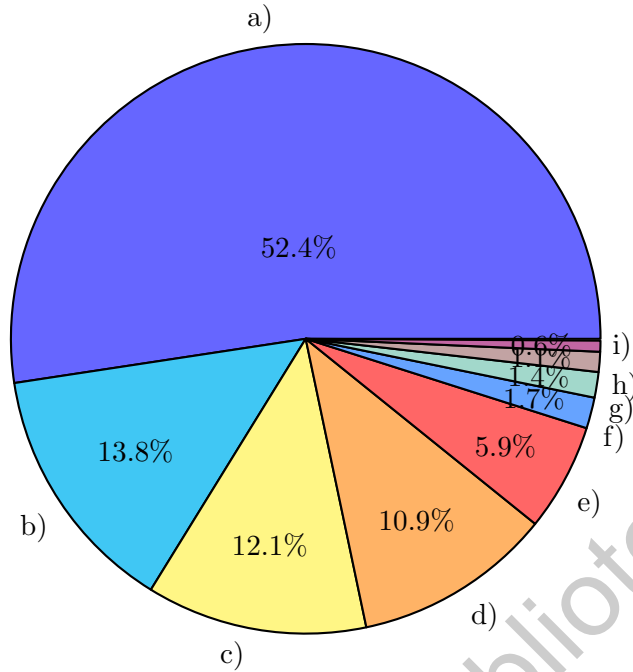
Figure 1.8: Composition of USW in Mexico 2012: a) Waste food, Gardens and similar organic materials; b) Paper, cardboard and paper products; c) Other type of garbage; d) Plastics; e) Glass; f) Aluminium; g) Textile; h) Ferrous Metals; i) Other Non-Ferrous Metals.
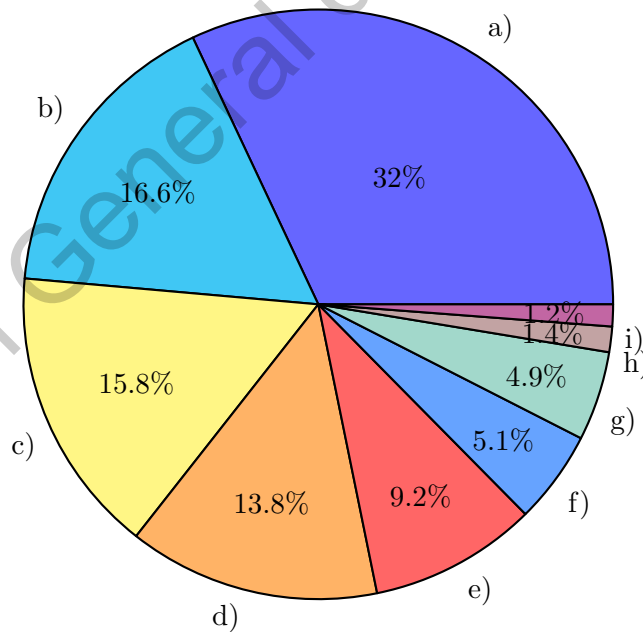
Figure 1.9: Composition of valuable USW collected in Mexico 2012: a) Paper and Cardboard; b) Other; c) PET; d) Glass; e) Plastic; f) Electronics and domestic appliances; g) Iron, sheet and steel; h) Aluminium i) Copper, bronze and lead.

According to [20] and [21], both reports introduced the same data for the USW recycling rate in Mexico. In 2012, Mexico only recycled 9.6% of USW. Despite these reports contains data from its respective year, the data for the recycling rate of USW considers the same year. No new information is introduced or compared for USW recycling rates. *Cerrando el Ciclo*, an association focused on the recycling of glass, comments that 2.5 million tons of glass bottles are generated annually in Mexico, but only 12% of these are recycled [22]. Mexico keeps low values for USW recycling rates while USW generation continues increasing. Figures 1.10, 1.11, and 1.12 presents the amount of USW disposed in landfills, landfills controlled, and uncontrolled sites [23].
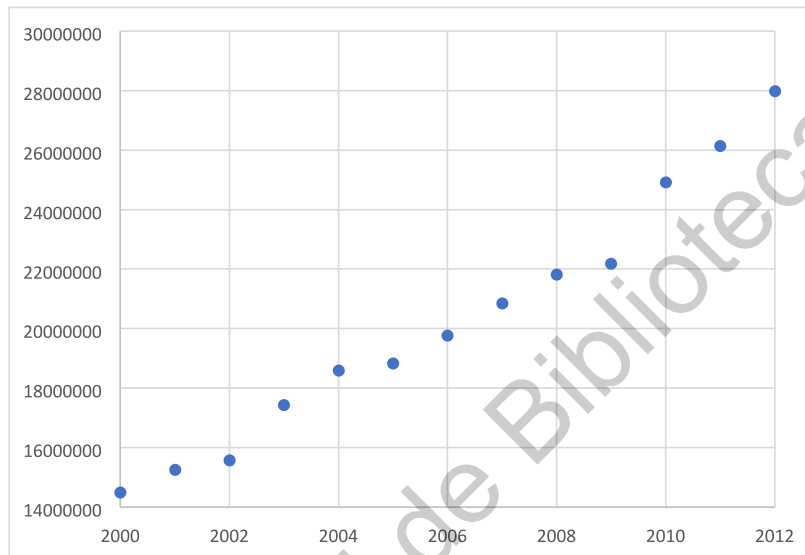
Figure 1.10: Final provision of USW - landfills.

Figure 1.11: Final provision of USW - landfills controlled.
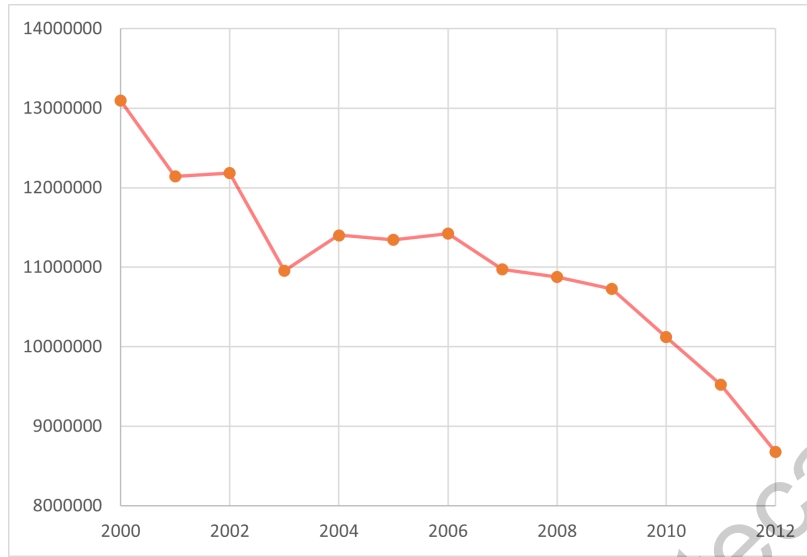
Figure 1.12: Final provision of USW - uncontrolled sites (open air dumps).

The quantity of USW deposited in landfills has been growing regularly, while uncontrolled sites has constantly decreased. Recycling and upcycling glass bottles help to reduce the amount of USW disposed on landfills or similar sites. Mexico only has a few laws/norms for the control of USW. Table 1.3 introduces the principal laws and norms related to USW.

Laws/Norms	Purpose
General Law for The Prevention of Comprehensive Waste Management (LGP-GIR)	Law that refers to the protection of the environment in matters of prevention and integral waste management in the national territory [24].
Regulations of The General Law for The Prevention of Comprehensive Waste Management	Law whose objective is to regulate the LGPGIR [25].
NORM NMX-AA-091-1987 – Soil Quality - Terminology	It establishes a frame of reference for the terms primarily used in preventing and controlling soil contamination by solid waste. [26].

Table 1.3: Laws/Norms related to USW.

In recent years, the former secretary of SEMARNAT, Victor M. Toledo, has visualized a set of actions to achieve some of the Sustainable Development Goals (SDG) [27]. The goals considered for the 31 States and the Federal District are 1, 2, 3, 4, 5, 8, 9, 11, 16, and 17. Also, goals 6, 7, 10, 13, 14, and 15 are considered at national level [28]. The SDG number 12 is not used, although it aims to ensure sustainable production and consumption patterns.

The culture of glass recycling has been increasing worldwide because it has been committed to

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developing technologies to comply with environmental policies. According to [7], data by INEGI (by its acronym in Spanish, *Instituto Nacional de Estadística y Geografía*) in 2012 shows a percentage of 0.77% of material recovered compared with the USW recollected in gathering centers. In years of 2014, 2016, and 2018 the value reach 0.50%, 2.02%, and 1.82% respectively. These values are so low and do not consider the informal recycling sector. In the case of the OECD (Organisation for Economic Co-operation and Development), Mexico recycled 1%-5% between the years 1991 and 2012. After the year 2012, there is no data for recycling percentage in Mexico by OECD [29]. The culture of recycling in Mexico is not as implemented as required. The recycling rates vary between institutions, but these keep low values. Also, recycling rates have not grown as USW generation rates.

1.5 Motivation

Awareness about caring for the environment has been growing over the last decades. Many achievements have been established, causing the slow growth of the footprint due to human activity in the natural environment. These are not enough because the population and the generation of USW grow at a rapid rate. According to INEGI (the National Institute of Statistics and Geography, by its acronym in Spanish), between the years 2010 and 2015, the population of Mexico increased by 7 million inhabitants. It represents an average annual growth of 1.4 percent [30]. USW recycling keeps low rates and does not grow at the same rate as the USW generation. It creates a necessity for improving the culture of environmental protection and waste reduction. Both need to succeed at a similar rate as the human activity does. As soon as people exceed the capacity of the environment to recover, no efforts will be enough to repair the problem. It will affect not only humanity but all forms of life existing in our world. The project aims to improve the glass recycling culture in Mexico. It is not as implemented as similar activities. By offering more benefits for individuals and organizations from Mexico, the amount of glass waste in the environment should be reduced while protected. Also, the use and promotion of this project create an opportunity for implementing the Quintuple Helix Model.

1.6 Problem formulation

According to SEMARNAT, the generation of USW in 2012 reach 44 million tons. Data from 2017 presents a production of 53.1 million tons of USW annually. An increment of 20.68% of these, but only 9.6% of the total volume of USW generated was recycled. Data from 2017 showed only 83.93% of USW was collected, and 78.54% was disposed. Only 9.63% of the waste was recycled [31]. The glass stands out in the fourth position of the collected USW recoverable with 13.8% of the total generated [20], but only 12% was recycled [22]. It is necessary to create new recycling glass strategies because glass is not biodegradable and remains stable for a long time.

1.7 Objectives

1.7.1 General objective

Implementing a semi-automated prototype for glass bottle upcycling focused on little organizations and individuals. The process of upcycling requires making a transversal cut to glass bottles using

the phenomenon known as thermal shock. The prototype is designed for glass bottles with a determined range of height and diameter. Also, it aims to offer a culture of sustainability.

1.7.2 Specific objectives

- Research locally the size of bottles that can be found daily to design the prototype.

- To develop a mechanical system capable of holding bottles of different diameter sizes and rotating employing an electric motor.

- To manufacture a mechanical system of support formed with a pair of extremities, capable of resisting the temperatures produced by a couple of electrical resistances located in this one, that does not allow the passage of the electrical current present in the resistances.

- To carry out a study on the relation of cutting time in bottles. It depends on the temperature, the thickness of the glass, and the diameter present in the bottle and to obtain the necessary data to elaborate behavior graphs.

1.8 Thesis structure

The thesis is organized as follows:

- Chapter 1 introduces vital information for understanding the problem to solve and the proposed solution.

- Chapter 2 contains technical and relevant information to understand the project.

- Chapter 3 presents the methodology used to develop the prototype and obtain results through experimentation.

- Chapter 4 shows the results obtained by experimentation and the analysis of these.

- Chapter 5 talks about the conclusions and future works that may arise from this research.

1.9 Competitiveness

It is possible to interpret according to the definition of competitiveness, in the online web page of Cambridge Dictionary, that is the ability to being able to compete and take advantages over its competitors and thus be more successful [32]. Usually is based on competitive advantage, i.e., a specific skill, resources, technology, or attributes that make it superior to the person who has it. Competitiveness is a relative concept in which the performance of someone or some object is compared to its similar.

There are some commercial recycling devices focused on upcycling glass bottles. They are only bought by using online stores. One of the most significant drawbacks of these devices is that some models are cheap but do not offer high durability in some cases. Also, their parts and pieces are not available in local stores and need to be imported. It is the case of one of the essential parts, the blade, to perform the cut over the glass. It needs to be imported because the model used for the cutter is not available in Mexico. For this reason, the project looks for the creation and

improvement of a prototype that could ever be competitive in the actual marketplace. It offers quality, lasts for a high amount of time, and reduces the effort by the users. In the case when a replacement is required, the piece is obtained quickly and easily.

Also, the development of this project fits perfectly into the Quintuple Helix Model. It is known as the collaboration of the five helixes (Political System, Educational System, Economic System, Public Based on the Media and Culture, and the Environment). The government aims to develop proposals and projects to encourage the practice of recycling. These have the objective of reducing the USW and its impact generated on the environment. These goals may be partially met when using the prototype for glass bottle upcycling and recycling. The products upcycled increase the period of life in the cycle of the bottle and obtain a new value. These may be used for its commercialization. The development and dissemination of this project will promote the creation and continuous improvement of social awareness about recycling, the benefits obtained from the result of this activity, and the improvement of the quality of life.

State of Art

In this chapter, the information related to the main concepts about the project, functionality, and characteristics of electronic components, and theoretical information are recollected. Also, it contains the main features for designing and implementing the prototype.

2.1 Glass bottle

Glass is the focus material for recovering. It is an inorganic product that has cooled to a rigid state without experiencing crystallization. The primary raw materials used for the manufacture of glass containers are, in addition to the glass mentioned above, the hull, silica sand, sodium carbonate, and limestone [33].

The first glass containers focused on the conservation and storage of specific products were developed by the Romans, who improved the blowing technique used by the Egyptians around 200 BC. In the mid-seventeenth century, the glass bottle Modern was designed by Sir Kenelm Digby. The design consisted of a cylindrical body with fallen shoulders topped by a long neck. In the 18th century, the food industry was born because the researcher Nicolás Appert found that certain packaged foods sealed in glass jars and subsequently heated retained their characteristics.

In 1876, the American Weber devised a machine for semi-automatic packaging production. In 1900 was created the first automatic machine focused on the mass production of glass containers [34]. The three most commonly used types of glass containers are:

A) Glass bottles with a narrow neck, whose diameter is smaller than 35mm. It is focused on liquids.

B) Wide neck glass jars with diameter greater than 35mm. It is focused mainly on solid foods, jams, and compotes.

C) Glass containers for pharmaceutical, cosmetic, chemical, and perfume products.

Figure 2.1 displays an example of glass bottles for each case [35].

Figure 2.1: Most used glass containers.

2.1.1 Design and characteristics

Glass bottles are used as containers for different products. Usually, the industrial glass bottle for beverage shares the same base for its design. Figure 2.2 shows the scheme for the industrial glass bottle and jar:
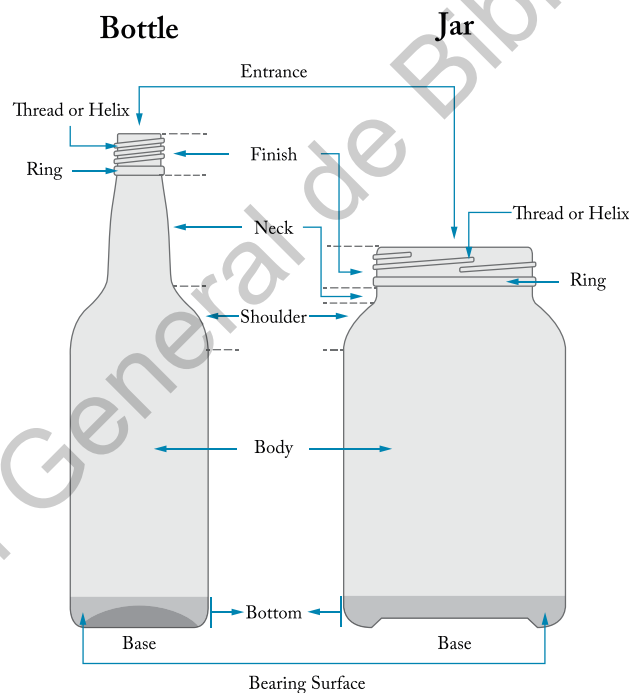
Figure 2.2: Industrial glass bottle and jar scheme.

2.1.2 Criteria for glass bottle recycling

When glass bottles and containers are recycled, both are classified according to their color (amber/brown, green, and crystalline). Depending on the color, extra profits are obtained [36].An example of this is the protection of products sensitive to light. When recycling glass waste, it is

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recommended to recycle by color to keep its protective properties. Another criterion for its classification in recycling plants is the presence of inorganic and non-magnetic foreign materials. These are magnetic metals, aluminum, lead, organic matter, labels, paint on glass, and contamination (garbage, moisture, sand, earth, ant, or lime) within the proposed limits [37]. Different treatment processes are used according to the foreign material present inside or over the glass bottle.

2.2 Thermal shock

Thermal shock is the phenomenon used for glass bottle upcycling. It can occur in refractory materials, such as glass and porcelain. Thermal shock generates great efforts in refractory material by temperature cycles. The main factors that affect this phenomenon are:

- Working conditions: Conditions in which the material is elaborated.

- Dimensions: Thickness of the refractory material.

- Geometry: The shape of the object.

- Temperature cycle: A cycle where temperature varies.

Depending on these factors, the thermal shock causes internal cracks [38], see Figure 2.3.

Figure 2.3: An example of thermal shock in ceramics.

Some containers require a thermal resistance since the packaged products, such as jams and chocolate creams, are hot. It facilitates their circulation through industrial facilities and to avoid damage to their structure. A guide cut is recommended to be made over the glass bottles before cutting. It helps to control the cracks generated by thermal shock. The guide cut decreases the time for cutting and increases the precision of the cut produced.

2.3 Temperature control

The principal factor for controlling thermal shock is the temperature cycle. Varying the temperature on a glass bottle helps to produce internal cracks. Also, temperature control aims to avoid excessive use of the heating element and keeps the temperature. It requires a heating element, a measurement device, a programming code for controlling, and an electronic circuit for operating.

2.3.1 Heating element

An electric heater cartridge-type is used for the heating element. This electrical resistance type is manufactured with a helical-shaped Nickel-Chrome core housed in a ceramic body of high dielectric insulation and optimum thermal conductivity by coating the resistance with magnesium oxide, lined with a 304 stainless steel tube [39]. Figure 2.4 displays the composition of the electric heater cartridge-type.

Figure 2.4: Cartridge type resistor.

When comparing with the commercial model, this type of heating resistor brings the following benefits:

- It offers more significant security for the user. The current can not flow outside the resistor.

- The period of life is bigger.

- It is used for long periods with no risk of damage.

2.3.2 Measuring device

A thermocouple is used as a measuring device. These are a type of sensor focused on measuring temperature, composed of two different metals joined by one end. The thermocouple type K contains a positive nickel-chrome type conductor and a negative nickel-aluminum conductor. When presenting some variation in the junction temperature, the sensor will give a voltage proportional to the temperature [40].

Different types of thermocouples have other metals in the union or the calibrations of this. The most used and known are the thermocouples types J, K, E, and T. Table 2.1 contains the range of temperature for every type of thermocouple:

Type	Temperature Range
J	0°C to +750°C
K	-200°C to +1250°C
E	-200°C to +900°C
T	-200°C to +350°C

Table 2.1: Temperature range of thermocouples J, K, E, and T.

A thermocouple type T is a good option for the prototype. Its temperature range is enough for a temperature controller, but this thermocouple is not as common as others. The thermocouple type K is cheaper than type J, E, and T. Also, it is more common to find in stores, in case it requires a replacement. That is the reason why it is used in the prototype.

2.3.3 Programming code

For controlling the temperature, an automatic control system is implemented. These systems result from the interconnection of elements formed within a system. This arrangement allows controlling the system. Some of its components are susceptible to being controlled by the application of a signal $r(t)$, through a function $g(t)$, to obtain a response $y(t)$ [41], see Figure 2.5:

g(t)

r(t) → **System or Process** → **y(t)**

r(t) = Input
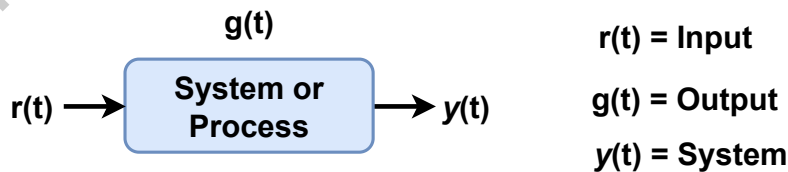
g(t) = Output

y(t) = System

Figure 2.5: Basic representation of a control system.

The input-output link is a cause-and-effect relationship with the system, so the process to be controlled relates the output to the input.

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There are two types of control systems, open-loop systems and closed-loop systems. The action of open-loop control systems, know as no automatic, is proportional to the input and is independent of any previous output. In contrast, closed-loop control systems, known as automatic, relate the control to input and output.

Other definitions explain that in open-loop systems, the output is not compared to the reference input. It is economical but does not have precision. In closed-loop systems, the input is compared with a previous state of the output, and the new output is proportional to the difference between input and output [42].

This project implements a PID controller as the automatic control system. It is a combination of three types of controllers, Proportional, Integral, and Derivative.

The controller known as a PID Controller has its output proportional to the error, added to an equivalent quantity of integral of error and a proportionate amount of the derived error [43]. It is expressed as:

$$G(t) = K_p e(t) + \frac{K_p}{T_i} \int e(t)dt + K_p T_d \frac{de(t)}{dt} \tag{2.1}$$

In which:

$$\frac{K_p}{T_i} = K_i \tag{2.2}$$

$$K_p T_d = K_d \tag{2.3}$$

Using Equation 2.2 and 2.3, 2.1 can be expressed as:

$$G(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{2.4}$$

Where T_i is the integration time and T_d is the derivative time, while $e(t)$ is the difference of the input with the output. The Equations (2.2) to (2.4) are used to obtain a function for implementing the PID controller into a microcontroller. Also, thanks to an example of Microchip for implementing a PID controller for a PIC18 microcontroller [44]. Equation (2.4) can be reinterpreted as:

$$PID_{value} = PID_p + PID_i + PID_d \tag{2.5}$$

Proportional part can be interpreted as:

$$PID_p = (K_p)(PID_{error}) \tag{2.6}$$

When interpreting the integral part, next equation is obtained:

$$PID_i = PID_{i.previous} + (K_i)(PID_{error}) \tag{2.7}$$

Also, the result of the derived is:

$$PID_d = Kd \frac{PID_{error} - PID_{error.previous}}{T_{sampling}} \tag{2.8}$$

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The difference of time between measures is interpreted as the sampling time ($T_{sampling}$). Due to the PID controller is used to control the temperature of the heating element, the controller error is:

$$PID_{error} = Temp_{SetPoint} - Temp_{actual} \tag{2.9}$$

Table 2.2 summaries what each variable represents.

Variable	Representation
PID_{value}	Value resulting from the PID controller
PID_p	Proportional value of the controller
PID_i	Integral value of the controller
$PID_{i.previous}$	Last value of the integral part
PID_d	Derivative value of the controller
PID_{error}	Actual value of the error. It is the difference between the desired value and the current value of the temperature
$PID_{error.previous}$	Last value of the error
Kp	Proportional constant
Ki	Integral constant
Kd	Derivative constant

Table 2.2: Variables and constants for the PID temperature controller.

The device for controlling the temperature is a microcontroller PIC18F4550. It offers the characteristic of interruption by timer. This interruption is used for calculating PID values in equal periods. The programming code is available in Annex II.

2.3.4   Electronic circuit

As mentioned before, the controller device used is a microcontroller PIC18F4550. The package used for the project consists of the 40 PIN PDIP (Plastic Dual Inline Package), see Figure 2.6.
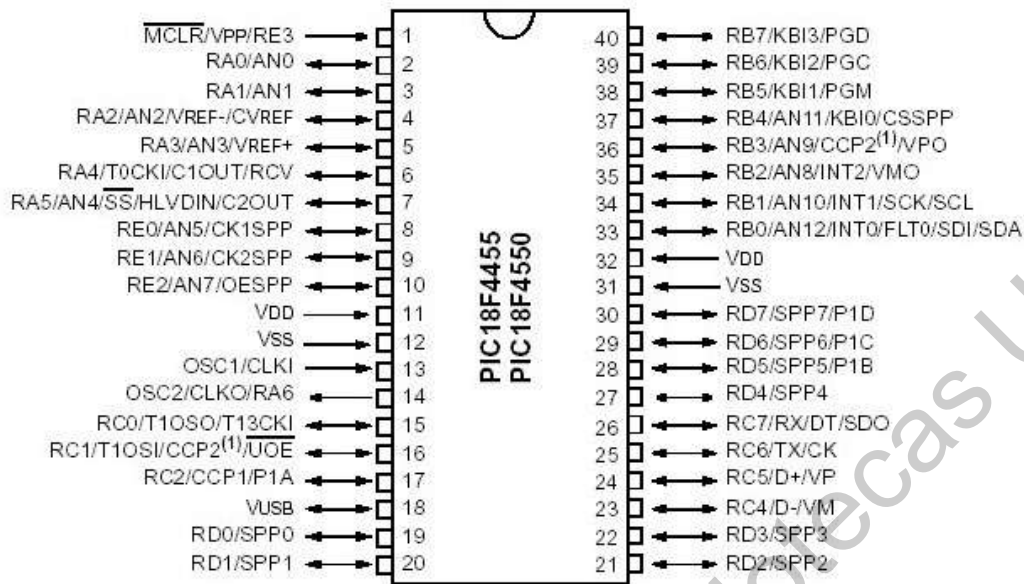
Figure 2.6: Diagram of PIC18F4550.

Table 2.3 contains some features of PIC18F4550:

Operation Frequency	48 Mhz
Interrupt Sources	20
I/O Ports	A, B, C, D, E
Capture/Compare/PWM Modules	1
Enhanced capture/Compare/PWM Modules	1
Serial Communications	MSSP, Enhanced USART
Universal Serial Bus Module	1
10-Bit Analog-to-Digital Module	13
Comparators	2

Table 2.3: Features of PIC18F4550.

The data of temperature is obtained by the MAX6675 module. It is a sophisticated thermocouple-to-digital converter with a built-in 12-bit analog-to-digital converter, see Figure 2.7.

20
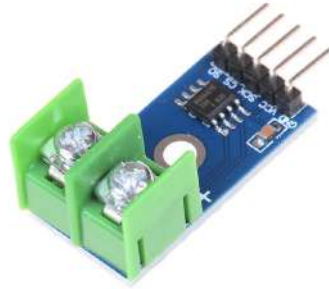
Figure 2.7: MAX6675 integrated circuit.

MAX6675 contains a cold-junction compensation sensing and correction, a digital controller, an SPI-compatible interface, and associated control logic [45]. Table 2.4 contains the characteristics of MAX6675:

Data output of 12-bit
Resolution of 0.25°C
Thermocouple accuracy of 8 LSB
Allows readings as high as +1024°C
Direct digital conversion of Type -K thermocouple output
Cold-Junction Compensation
Simple SPI-Compatible Serial Interface
Open Thermocouple Detection

Table 2.4: Characteristics from MAX6675 integrated circuit.

The MAX6675 chip has eight pins to control it. But in the MAX6675 integrated circuit, only five are available for its use. Table 2.5 details these and its function:

Name	Function
GND	Ground
VCC	Positive Supply
SCK	Serial Clock Input
CS	Chip Select. Set CS low to enable the serial interface
SO	Serial Data Output

Table 2.5: Pin description of MAX6675 integrate circuit.

Figure 2.8 shows the serial interface protocol to use the integrated circuit:

21
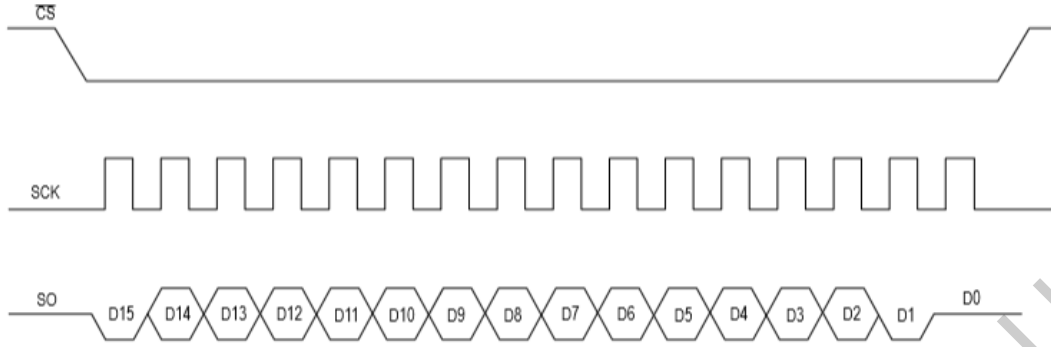
Figure 2.8: Serial interface protocol for MAX66775.

Also, Table 2.6 describes the bits of the output:

Bit(s)	Description
0	State
1	Device ID
2	Thermocouple Input
3-14	Temperature Reading (bit 3 is the LSB and 13 is the MSB)
15	Dummy Sign Bit

Table 2.6: Bits description for the serial interface protocol for MAX6675.

The library "max6675.c" contains the necessary functions to obtain the data implementing an SPI Bus. It facilitates the use of the integrated circuit. Table 2.7 explains these functions:

Function	Objective
init_TC	Initialize the chip to keep converting data
read_TC	Obtain data and verify if the thermocouple is not connected
sortout	Returns only the bits conversing temperature
toFloat_TC	Adjusts data to floating-point format, and accounts for the decimal point
do_everthing	When called, it realizes functions "read_TC", "sortout", and "toFloat_TC" in this order

Table 2.7: Functions available in "max6675.c" library.

For a better understanding of the "max6675.c" library, the code is available in Annex I. The microcontroller sends the data to an Analog Discovery device. It is an oscilloscope portable designed by ANALOG DEVICES and XILINX, see Figure 2.9. Analog discovery allows to measure, visualize, analyze, record, and control mixed-signal circuits.

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Figure 2.9: Analog discovery device.

It is powered by a hi-speed USB (Universal Serial Bus) port and the free WaveForms software. Analog discovery is used as an oscilloscope, wave generator, protocol analyzer, and other 11 tasks. It contains 30 pines. Fifteen of these are distributed as Digital I/O Signals, four for Scope Channels, four as Ground, two as Voltage Power Supply, two for Waveform Generator, and two as Trigger Ins. Figure 2.10 displays the distribution of the 30 pines:
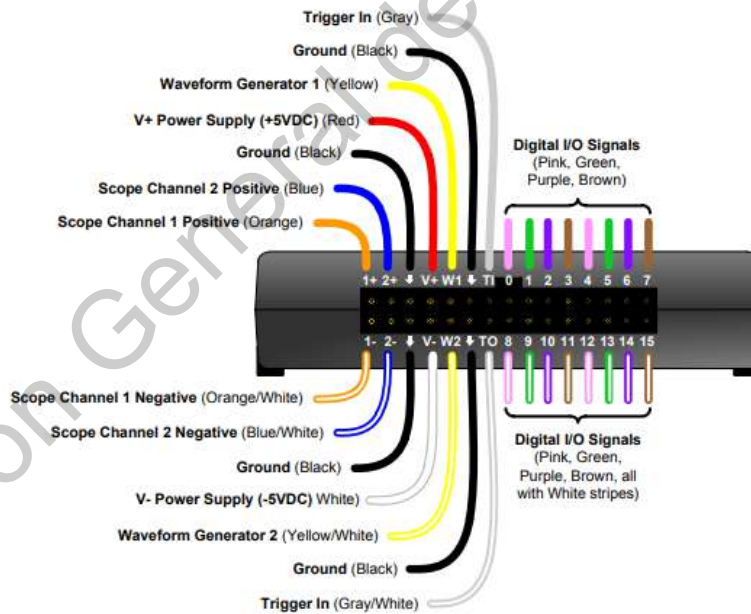
Figure 2.10: Pins distribution for analog discovery.

Table 2.8 contains the main features that offers Analog Discovery:

Characteristic	Details
Dual Channel Oscilloscope	• Fully differential inputs, up to 100 MSPS, 14-bit ADC, up to 16KSa/channel memory • 1 Mohm/24 pF inputs, +-20V Max • Real-time FFTs, X-Y plots, complex math and measurements on all channels • 5 MHZ analog signal bandwidth
Dual Channel Function Generator	• Single-ended outputs, up to 100 MSPS, 14-bit D/A, up to 16KSa/channel memory • Arbitrary and pre-defined waves up to +-5V • Sweeps, envelopes, AM and FM modulation • Bode plot feature using standard, Nyquist & Nichols coordinates • Can drive 50Ohms
Digital I/O	• 16 Signals, 100MSPS, 4KSa/channel memory • Any signal can be input (logic Analyzer) or output (pattern generator or virtual I/O) • Cross-triggers with scope channels
Power Supplies	• Two fixed +-5V, 50mA

Table 2.8: Main characteristics of analog discovery device.

The software used by analog discovery is WaveForms. It is the virtual instrument for Electronic Explorer, Analog Discovery, Analog Discovery 2, and Analog Discovery 2 - NI Edition devices [46]. It uses Analog Discovery for 11 applications. Table 2.9 presents some of the principal applications and their characteristics.

Application	Characteristic
Oscilloscope	• XY, data, histogram, measurements view, cursor, hottrack • Stream acquisition • Data logging
Waveform Generator	• Function, custom and sweep generator, AM/FM options, play mode
Logic Analyzer	• Simple (edge/level) trigger • Signal, bus, SPI, I2C, UART protocol Interpreters • CAN, I2S, Custom protocol interpreters
Pattern Generator	• Clock, pulse, binary, Gray, Johnson counters, custom
Network Analyzer	• Reference Channels • Attenuation setting • Auto Range/Offset
Spectrum Analyzer	• Measurements, time view • Components list
Protocol Analyzer	• UART, I2C, SPI, CAN, AVR

Table 2.9: Main applications of WaveForms software.

Materials and Methods

The prototype is divided into two principal parts: electronic and structure. The electronic part must perform control tasks, such as temperature control. In contrast, the structure part needs to provide and satisfy different characteristics to improve how users execute the cutting job. This section introduces the information about the required features and functionality of the prototype, the methodology used to develop it, and the proposed methods for the experimentation stage.

3.1 Considerations and requirements

A consideration usually prevents events, facilitates the use, or improves the functionality and some others aspects of the prototype. The following considerations and requirements help to develop the first concept of the project.

3.1.1 Simple design and easy use

The prototype needs to be comfortable and straightforward for its use. The following points are considered to achieve a simple and easy use:

- The system for adapting the heating element position (vertical position) must be simple. If it is hard to adapt, the efforts done by the user and the time for complete the process increase.

- The system for adjusting the heating element position (horizontal position) with the glass bottle body or neck width should be fast. If it is hard to change, the efforts done by the user and the time for complete the process increase.

- The system for grabbing the glass bottle needs to be easy. If it is complicated, the efforts done by the user and the time for complete the process increase.

3.1.2 High precision and performance

The cutting process can be tedious and challenging. It provokes fatigue over users for long working periods, hinders continuous processes, affects the precision of cuts, and reduces the quantity of upcycled products obtained. The following points are considered to reduce efforts on the user, increase the accuracy of cuts, and have a good performance:

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- The system for adapting the heating element position (vertical position) must be stable during the cutting process. If it is not stable, the cut done may vary, and the time may increase.

- The system for adjusting the heating element position (horizontal position) must be stable during the cutting process. If it is not stable, the glass bottle may not touch the heating element increasing the time. Also, it aims to avoid variations in cuts.

- The system for grabbing the glass bottle must be stable during the cutting process. If it is not stable, the glass bottle may fall.

3.1.3 Long period of use

One consideration for the prototype is using it for extended periods to increase the number of upcycled glass bottles. It may reduce the period of life of the structure and its components. Also, it may damage these, causing the requirement of repairs. The following points are considered to avoid this situation:

- The material proposed should be durable and offer high quality.

- For a long period of use, the structure can absorb some of the process heat. It represents a problem if the prototype needs to be transferred after its use. The design should consider a practical way to reduce the heat transferred.

3.1.4 Easy application of preventive and corrective maintenance

When using something continuously, it may require repairs, replacements, or cleaning. Depending on the type, it requires a significant amount of time. If the prototype requires a replacement not available in local stores, the user stops upcycling processes. The following points are considered to prevent this:

- The materials from the prototype structure should be available in local stores. In the case it requires a replacement, the user can obtain these and avoid lost time.

- The electronic pieces should be available in local stores. If the electronic circuit requires replacements, the user can purchase these and avoid lost time.

- Dissemble the prototype structure should not be so challenging. It aims to avoid long periods of maintenance. Also, assembling the structure should be easy.

3.1.5 Others considerations

There is a proposal to investigate various commercial glass bottles. It has the objective to know their values and characteristics. The research aims to design some systems and parts of the structure. According to some commercial models and the experience obtained with a similar project developed by two alumni of the Faculty of Engineering [47], most of the models have some common problems:

- The necessity to replace the heating element was higher than expected.

- Overuse of the heating element caused damage to it.

- When the prototype is used for extended periods or air circulation is deficient, the temperature over the surface and the structure could not decrease faster. It represented a problem when it was necessary to move the cutter to another place. Also, it reduces its period of life. In some cases where the user did not follow the security recommendations, the user may get injuries.

Also, other points, not as dangerous as previous ones, are considered for improving the design and the cutting process. These points are the next:

- Commercial cutters need someone to rotate the glass bottle. In a long period of work, the user presents fatigue. If less effort is required, the rate of production of bottles upcycled is increased.
- In models using heating elements, the user needs to turn on/off the heating element. If the cutter operates the switching on/off the resistor, the heating resistor will turn on when required. The user reduces the efforts, obtains energy savings, and protects the heating element from overuse.
- Most of the cutters devices that do not incorporate a heating element use steps where hot water increases the temperature, and cold water decreases the same. It aims to cause the phenomena known as thermal shock. Water is a natural resource that must be protected.

According with the last points, the next are considered to design the prototype:

- The structure needs to consider a safe way to move from one place to another when it is required.
- The design considers using a better heating element to reduce the number of replacements.
- The structure designed considers a way to resolve the high temperature present in the structure to avoid making injuries.

These points are essential, bring more security and production for the user, and improve performance.

3.2 Understanding the process

An essential element of the circuit is the PIC18F4550 microcontroller. It must perform the control and communication tasks to produce the cut. Figure 3.1 presents the general process diagram for tasks performed around PIC18F4550.
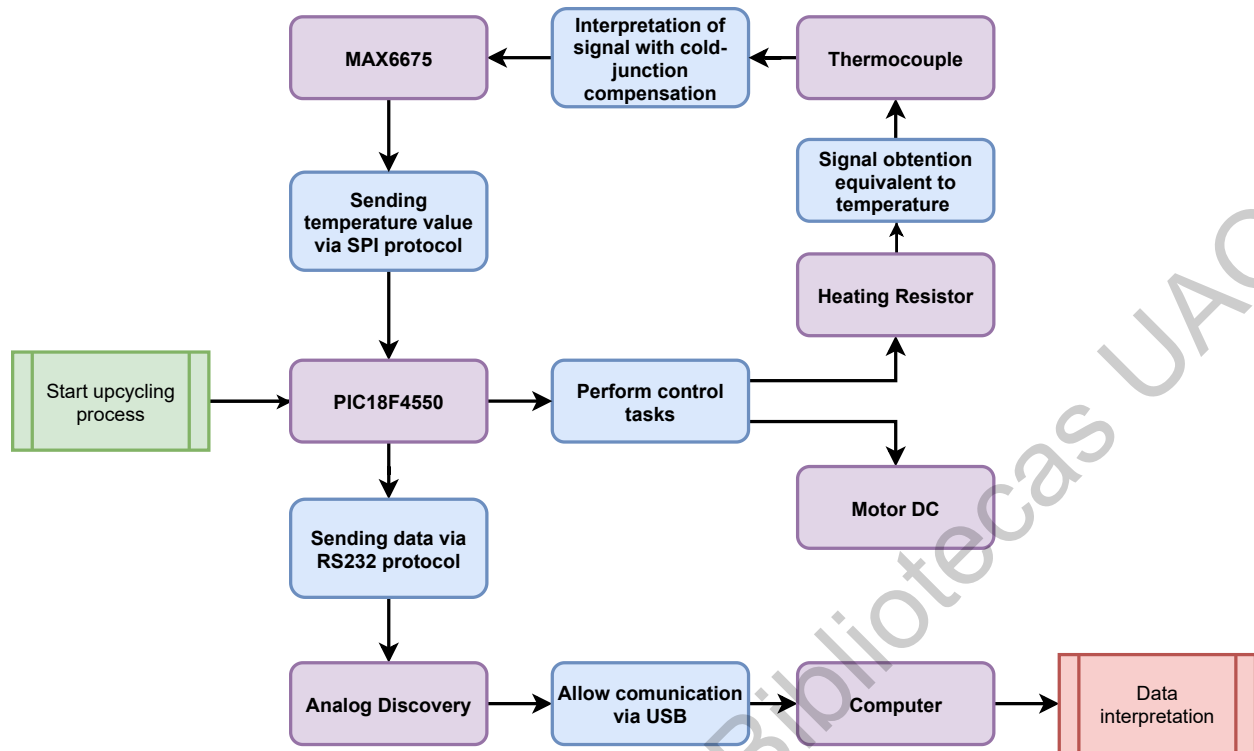
Figure 3.1: Proposed general process diagram.

The proposed general process for glass bottle upcycling is not automatic because it requires human intervention. The process only used an automatic control focused on temperature. No automatic control is used for controlling the start or end of the glass cutting process, neither for changing glass bottles for a new process or modifying the position for cutting.

The variable of temperature is the most important of the project because it is unique to control. In the thermal shock phenomenon, the more massive the temperature gradient is, the faster the shear effect will occur. But excessive use of the heating element may decrease its period of life and produce excessive energy consumption.

The task for controlling the motor DC only produces a PWM signal for varying the temperature, and no feedback is obtained. It aims to verify by experimentation if velocity can improve the upcycling process and its effects. The glass bottle touches once the heating resistor. Rotating the bottle is essential to keep the same temperature in the guide cut line. An open-loop controller is used to vary the velocity.

Data from the PID controller is obtained for its interpretation. Every time the values are required, these are sent to a computer.

3.2.1 Data collection

The temperature controller requires a temperature reading. This variable is obtained by the MAX6675 module and interpreted by PIC18F4550 for controlling tasks. Also, PIC18F4550 sends data for its interpretation using the Analog Discovery device. Figure 3.2 presents the communication diagram between PIC18F4550, MAX6675, and Analog Discovery:
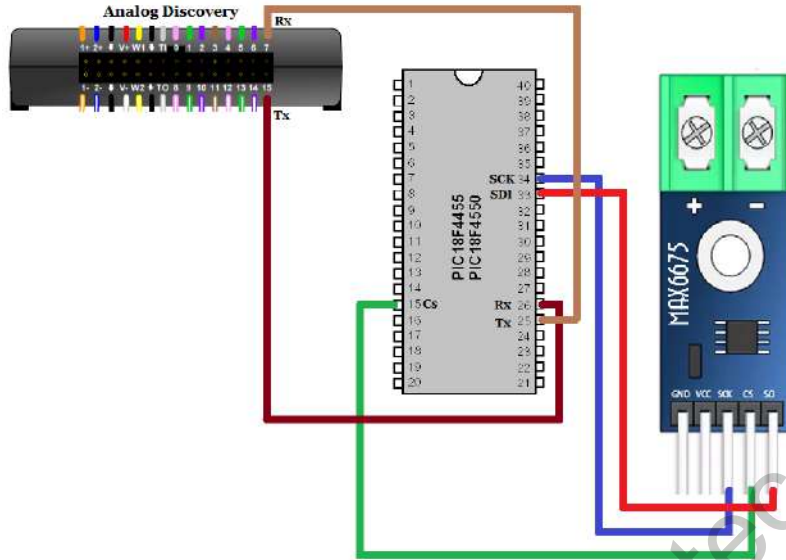
Figure 3.2: PIC18F4550 communication diagram.

3.3 Methodology

The methodology used considers elaborating the first sketch, implementing improvements, obtaining data, and interpreting the results. Thus, the following sections show the process used for the development of the project:

3.3.1 Design of the prototype structure

A good design allows having a preview of the prototype. Also, it may display improvement areas. For designing the first sketch was necessary to follow the following steps:

1. Perform the investigation about the sizes of bottles presented in the area.

2. Develop a technical paper design of the mechanical systems for holding the bottle and supporting the resistances based on the following needs:

   - The restraint system must have an electric motor capable of exerting the force and speed necessary to rotate the bottle.

   - The support system must consider the adaptability and the correct contact of the heating element with the glass bottle. elements with the glass bottle.

   - The prototype structure should be easy to assemble and disassemble.

3. Analyze and detect improvements in the prototype design, and incorporate protection elements focused on the user.

4. Develop a technical design of the prototype with improvements in CAD software.

3.3.2 Prototype elaboration: structure and electronic circuit

Developing the prototype structure and the electronic circuit is an important step. An error caused by these may produce others in the experimentation stage. It is the reason to be careful during the elaboration process. The following points represent the process followed:

1. Investigate and obtain the appropriate materials that help the construction of the previously designed systems taking into account the following considerations:

   - The support system design should consider materials that do not allow the passage of electric current to the structure in an accident.
   - The cable used to connect the power supply of the electric resistors must withstand the high temperatures coming from the resistor.

2. Buy the materials and carry out the actions required to adapt these to the required design measures.

3. Design the electronic control system capable of varying the speed of the motor, the temperature of the resistors, and collecting the data for its analysis. The design must comply with the following:

   - The electronic system should not contain elements that do not benefit the accomplishment of the control task. Also, items that imply unjustified extra costs are not allowed.
   - The electronic system must have at least one protection system.
   - The human-machine interface system must contain two regulating knobs, one for the motor speed and another for the temperature, an on/off button, a start button, and a stop button.

4. Carry out the structure and electrical circuit assembly. Apply some functional tests for each system and implement corrections or improvements required.

3.3.3 Experimenting stage

Experimenting with the prototype allows obtaining valuable data to understand the behavior of the process. This data shows the functionality and performance of the design. Analyzing it aims to discover or implement improvements. It was necessary to follow the following steps to achieve this:

1. Implement the temperature controller, the velocity controller, and the communication in the microcontroller.

2. Prepare tests focused on obtaining and analyzing the data collected regarding the variables of temperature, voltage, and current present in the resistors in the system, the percentage of speed by the electric motor, and the time for complete the cutting process.

3. Obtain the value of temperature, thickness, and diameter.

4. Perform the interpretation of the data obtained by using graphs.

Results: Design, Implementation, and Interpretation

In this section, the data and results obtained are introduced. Results are presented according to the prototype structure, the electronic circuit, the programming code, and the experimentation stage.

4.1 Prototype structure

As a first introduction to the obtained results, it is necessary to know the background behind the proposed design.

4.1.1 Research of local glass bottles

This research aims to obtain data about the design of glass bottles available in local stores.

- Neck diameter: The measure needs to be obtained immediately down the ring. This part helps as a support for the grip of the bottle.

- Helix height: This value must include the height of the ring. It represents the part introduced in the grip system.

- Body diameter: If the body shape is not cylindrical, the measure needs to be obtained in the more extended zone.

- Bottle height: The measure is obtained from the top to the base of the bottle.

By analyzing the results from the research about the characteristics of local glass bottles, three groups of glass bottles are proposed according to their diameters. The first group considers glass bottles with a neck diameter between 20-29 mm, the second group considers a neck diameter between 30-39 mm, and the last group considers a neck diameter bigger than 40mm. Most of the bottles in the first groups are for soda and wine. In the second and third groups, the most common bottles are for juice and coffee. These results may help to design some parts of the prototype, like the system to grab the bottle and the length required in some pieces. Table 4.1 contains the data obtained.

Bottle´s Mark	Neck Diameter	Helix Height	Body Diameter	Height	Color Type
Café Olé 281 ml	41 mm	19 mm	65 mm	152 mm	Crystalline
Snapple 473 ml	35 mm	13 mm	72 mm	175 mm	Crystalline
Sprite 235 ml	25 mm	18 mm	56 mm	189 mm	Green
BÚHO 355 ml	24 mm	10 mm	61 mm	230 mm	Crystalline
San Pellegrino 250 ml	21 mm	10 mm	52 mm	172 mm	Green
StrongBow 330 ml	25 mm	12 mm	57 mm	220 mm	Crystalline
Source Perrier 330 ml	24 mm	19 mm	68 mm	190 mm	Green
del Valle 413 ml	35 mm	12 mm	64 mm	182 mm	Crystalline
Jumex 450 ml	34 mm	17 mm	68 mm	193 mm	Crystalline
Chela Libre 660 ml	25 mm	17 mm	75 mm	287 mm	Amber/Brown
Riunite Lambrusco 750 ml	27 mm	16 mm	86 mm	296 mm	Amber/Brown
Caribe Cooler 300 ml	25 mm	19 mm	60 mm	195 mm	Crystalline

Table 4.1: Characteristics of glass bottles.

Also, Table 4.1 includes the color type. It is only used to recognize the glass bottle.

4.1.2 Structure Design

According to the requirements, the following points are proposed for designing the structure:

- The structure uses 20x20mm Bosch aluminum profile pieces. These offer high durability and hardness. Its design allows implementing vertical and horizontal movement.

- The heating element holder uses two arms focused as support of the heating element. It allows adapting to different glass bottle diameters. Both arms use the same aluminum profile as structure.

- As a protection element, both heating holders arms use a piece of PTFE (polytetrafluoroethylene). These contain inside the cartridge-type resistance. The PTFE pieces can withstand high temperatures without altering their physical properties and preventing the passage of any electrical current that might occur outside the resistors.

- The grip system uses a pair of springs with pieces designed to apply force to keep the glass bottle in the same position.

- An electric motor rotates the grip system.

A first design of the structure was developed using the previous points and CAD software. Figure 4.1 displays the first design of the prototype:
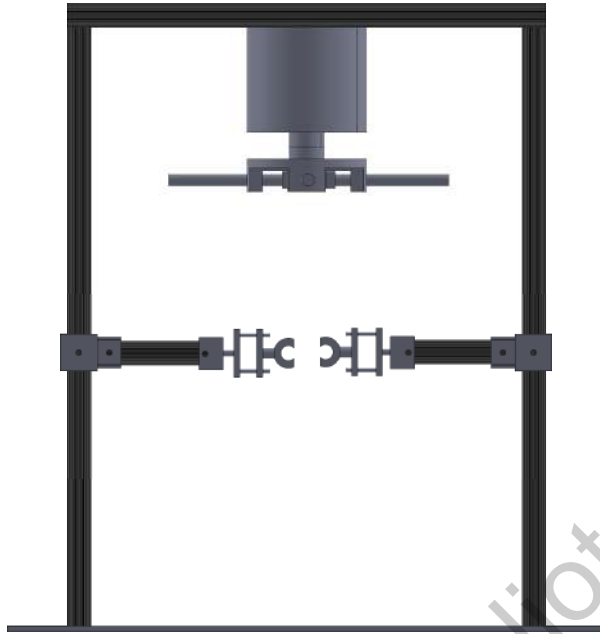
Figure 4.1: First design of the prototype structure.

According to the methodology, it is necessary to make improvements over the initial model of the prototype. As a recommendation, some experiments are required to hold and rotate different glass bottles. As a result of these first experiments, the following problems were founded:

- Trying to adjust the position of the heating element is more complicated and takes more time than expected. In both cases, when changing vertical and horizontal positions.
- The systems to grab and the glass bottle were hard to use.
- The position of the resistor was not stable. It affected the thermal shock phenomenon by increasing the time and the quality of the cut.

The analysis of these points highlights some improvement areas. The following points introduce these:

- Modify the system to change the position of the heating element. Two horizontal pieces are considered in the first design. The new design considers a vertical structure for these arms and a shorter design of the horizontal pieces. It allows improving how the horizontal position is adjusted to the bottle.
- The system to grab the bottle considers adjusting only for the neck of the bottle. It reduces the size and complexity of the system.
- Implement as a working condition, a stage previous upcycling to make a cut guide over the bottle. It aims to reduce the time and increase the precision of the cut.

Thanks to these new improvements, the structure model of the cutter changed. Figure 4.2 displays the new model:
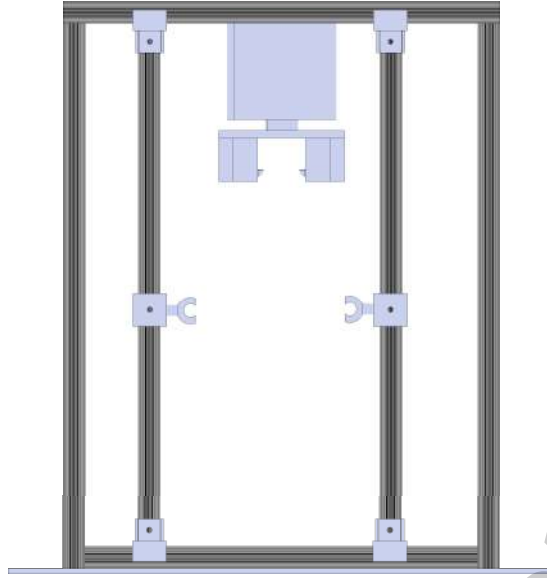
35

Figure 4.2: Last design of the prototype structure.

The following points introduced the dimensions of the structure:

- The maximum height allowed for glass bottles is 30 cm.

- The width allowed for glass bottles is 15 cm. If there is a necessity to cut a bigger glass bottle, the maximum width available is 21 cm (a change of parts is necessary).

- The maximum neck width allowed for glass bottles support is 4.5 cm. There is a vertical space of 4.5 cm for glass bottle introduction using the helix height.

- The height of the prototype structure is 50 cm, and the width is 44 cm.

4.2 Electronic circuit

The objective of the electronic circuit is to have control over the heating element and the motor DC, obtain the temperature value presents on the heating element, and send data related to the PID controller for its interpretation.

4.2.1 Circuit design

As a first stage for designing the electronic circuit, a simulation was required using PROTEUS software. Due to PROTEUS does not contain some elements or devices used, these were replaced according to the following points:

- Analog discovery device is replaced by an oscilloscope.
- Heater cartridge-type is substituted by an oven.

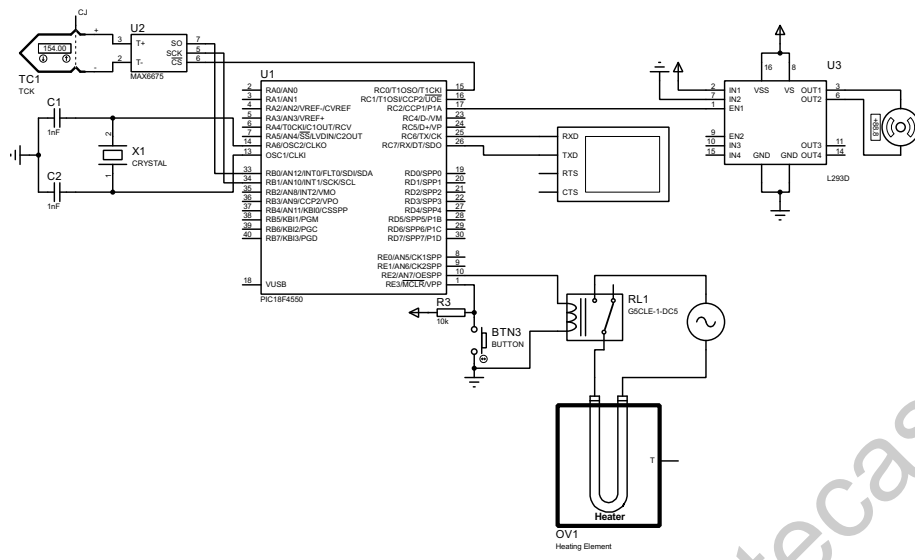Figure 4.3 displays the circuit proposed.

Figure 4.3: Proposed electric circuit for controlling.

The values for PID controller, temperature set-point, and velocity set-point are configured inside the programming code. Figure 4.4 displays the prototype obtained.

Figure 4.4: Glass bottle cutter prototype.

4.3 Programming code

The code used for programming the PIC18F4550 is available at Annex II. For a best understand of the code used, Figure 4.5 introduces the routine implemented inside the PIC18F4550:
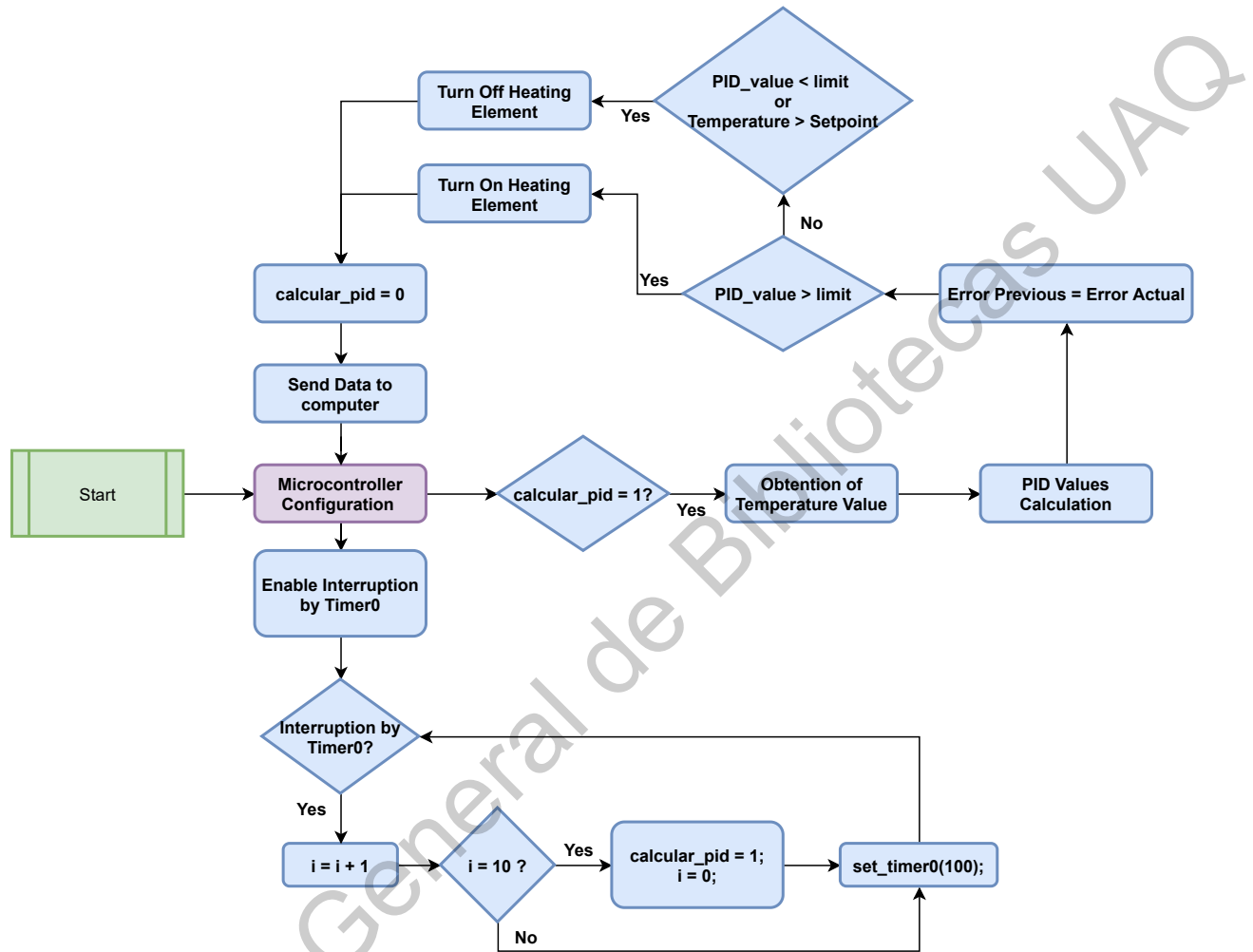
Figure 4.5: Routine implemented in PIC18F4550

There are two routines proposed. The first routine focuses on interruption by *timer0*, and the second routine focuses on task execution. The interruption routine aims to execute every 0.2 seconds approximately the task routine. Using the configuration of 8 bits for *timer0*, Equation 4.1 helps to calculate the value necessary for $TMR0L$.

$$T = 4 * \frac{1}{f_{osc}} * (256 - TMR0L) * Prescaler \tag{4.1}$$

According with Equation 4.1, when $TMR0L = 0$ and $Prescaler = 256$, the maximum value obtained is $T = 0.032768$ seconds. It is too low to reach a value for T equal to 0.2 seconds. When using $TMR0L = 100$, T is equal to 0.019968 seconds. Using this case, it is necessary to repeat 10 times the interruption by *timer0* to reach a value of $T = 0.19968$.

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The second routine only is executed when the first routine is executed 10 times. This routine aims to obtain the values for PID controller and send the data for its interpretation.

4.4   Experimentation stage

The objectives for this stage are:

- Verify the time difference when a guide cut is done before upcycling. The experimentation requires a sample of few glass bottles.

- Obtain behavior graphs related to the cutting process time and realize the factors that affect the cutting process.

- Verify if varying the velocity of the motor, the time for the cutting process decreases or the quality of the cut increases.

As mentioned in Section 2.2, a cut guide is recommended for decreasing the time for upcycling and increasing the precision of the cut. It is considered as a working condition. There are others working conditions to consider. All these are introduced in the following points:

- Avoiding cracks before the cutting process: the thermal shock generates new cracks in different directions. It affects the products obtained.

    – It is recommended to avoid the cutting process when glass bottles already exhibit cracks.

- Cleaning inside and outside of glass bottle: a suitable cleaning process allows to avoid unwanted situations.

    – Dust and solid materials cleaning: the presence of these may affect the performance of the cutting process.
    – Remove stickers and tags: if these are presented during the cutting process, they can burn and increase the difficulty of cleaning.
    – Remove liquid remains: Depending on the temperature present on the heating element, the liquids can evaporate. It is dangerous, especially when the bottle cap is still presented and the liquid contains alcohol.

- Make a cut guide over glass bottle: it decreases the time for the cutting process and increases the quality of the cut obtained by thermal shock.

    – It is recommended when making the cut guide to keep it at the same level.
    – A glass bottle can have various guide cuts. The number of these depends on the products to be obtained.

4.4.1   Behavior graphs

Results are presented in 3 different graphics. Figure 4.6 and Figure 4.7 display the time required for glass bottle cutting when the heating element starts at room temperature.
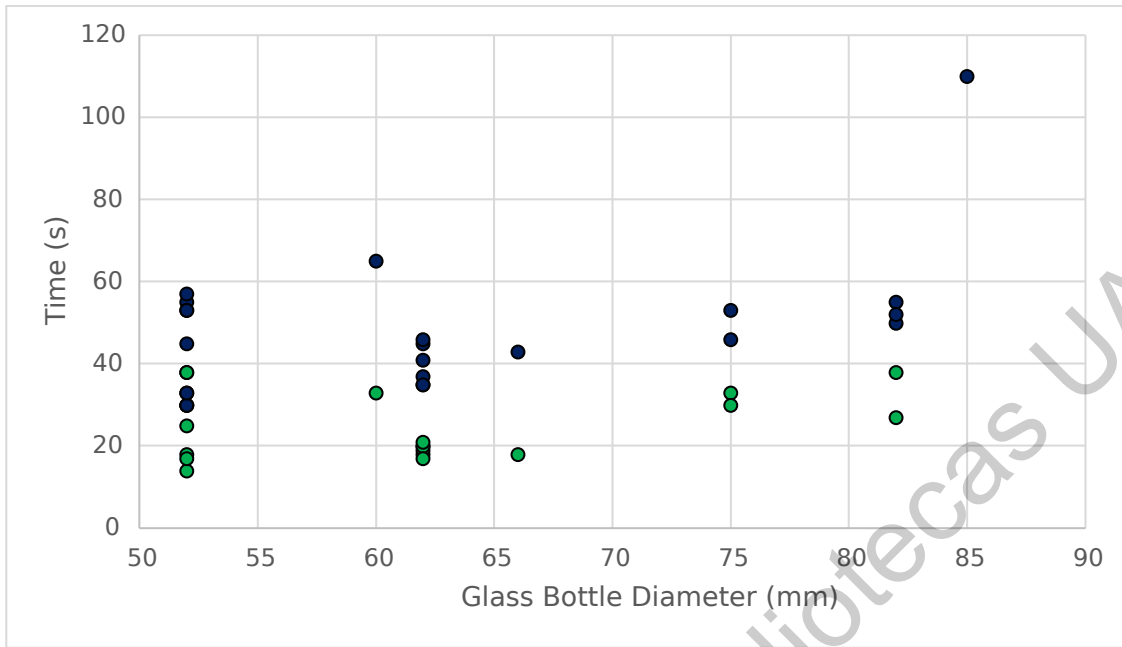
Figure 4.6: Behavior graph: glass bottle diameter vs time.
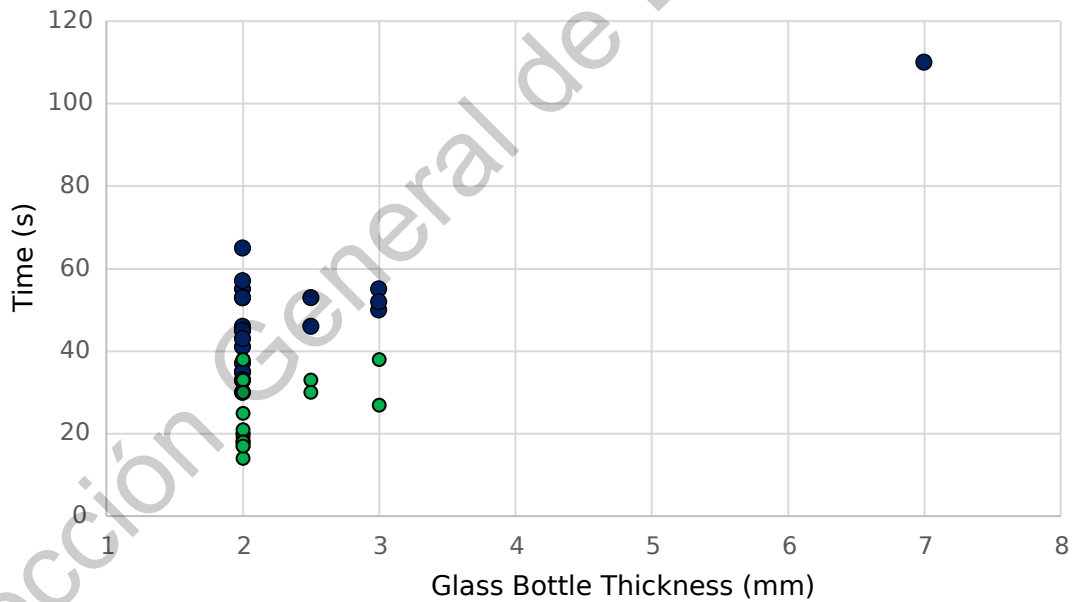
Figure 4.7: Behavior graph: glass bottle thickness vs time.

The green dots represent the cases when the first cracks appeared, and the blue dots represent when the cut was complete. Due to the shape of some glass bottles was not cylindrical, the values of thickness and diameter were measured where the cut was done. Figure 4.8 shows the time required for glass bottle cutting when the heating element had reached the temperature desired.
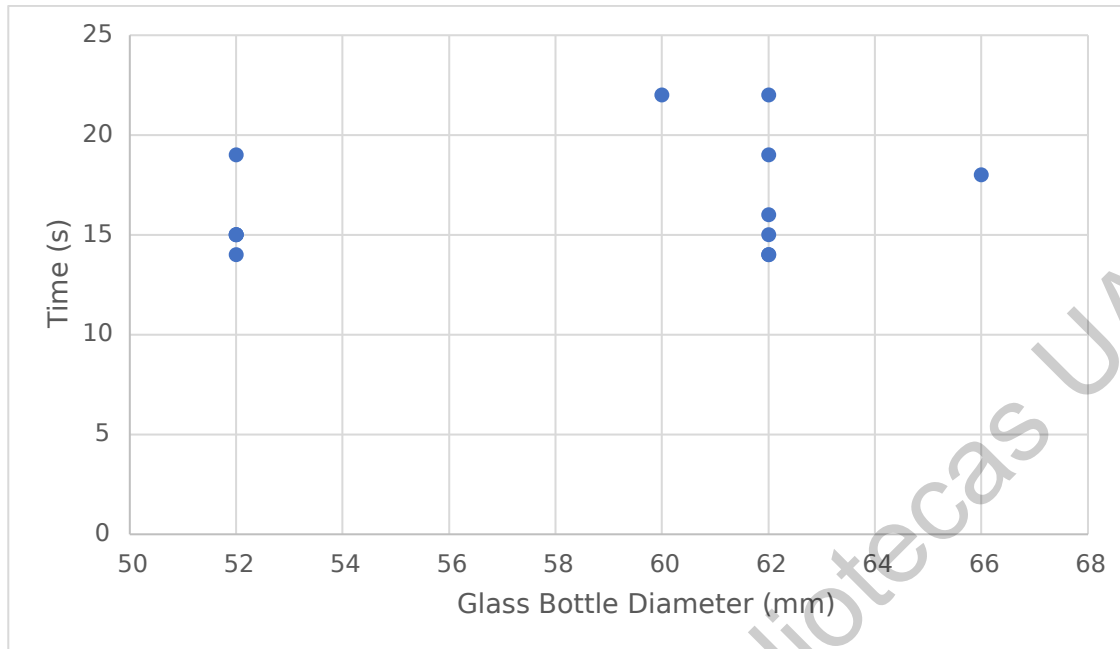
Figure 4.8: Behavior graph: glass bottle thickness vs time - stable temperature

The thickness for all glass bottles in Figure 4.8 is 2 mm. By analyzing Figure 4.6 and Figure 4.7, the next points are concluded:

- There is a minor increment in the time for glass bottle cutting while glass bottle diameter increases.

- There is a minor increment in the time for glass bottle cutting while glass bottle thickness increases.

- There are cases where there is a big difference in the time for glass bottle cutting. It may be attributed to the quality of the guide cut.

By analyzing Figure 4.8, the next point is concluded:

- There are cases where there is a big difference in the time for glass bottle cutting for the same thickness. It may be attributed to the quality of the guide cut.

By comparing Figure 4.6, Figure 4.7, and Figure 4.8 is concluded that:

- The ideal case for the cutting process is when the prototype is used for continuous cutting processes.

- The implementation of the guide cut is of vital importance. A high-quality guide cut decreases the time for cutting processes.

Some experiments were focused on varying the rotation velocity for reducing the time for glass bottle cutting. All these did not show a notable difference in the time, neither in the quality. The main factor that affects the time and quality is the guide cut.

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4.5 The opportunity for implementing a sustainable glass recycling culture

As mentioned in Section 1.3, upcycling uses waste for creating new products. Upcycling may be incorporated into the integral glass recycling process. Figure 4.9 introduces the integral glass recycling process with the implementation of upcycling:
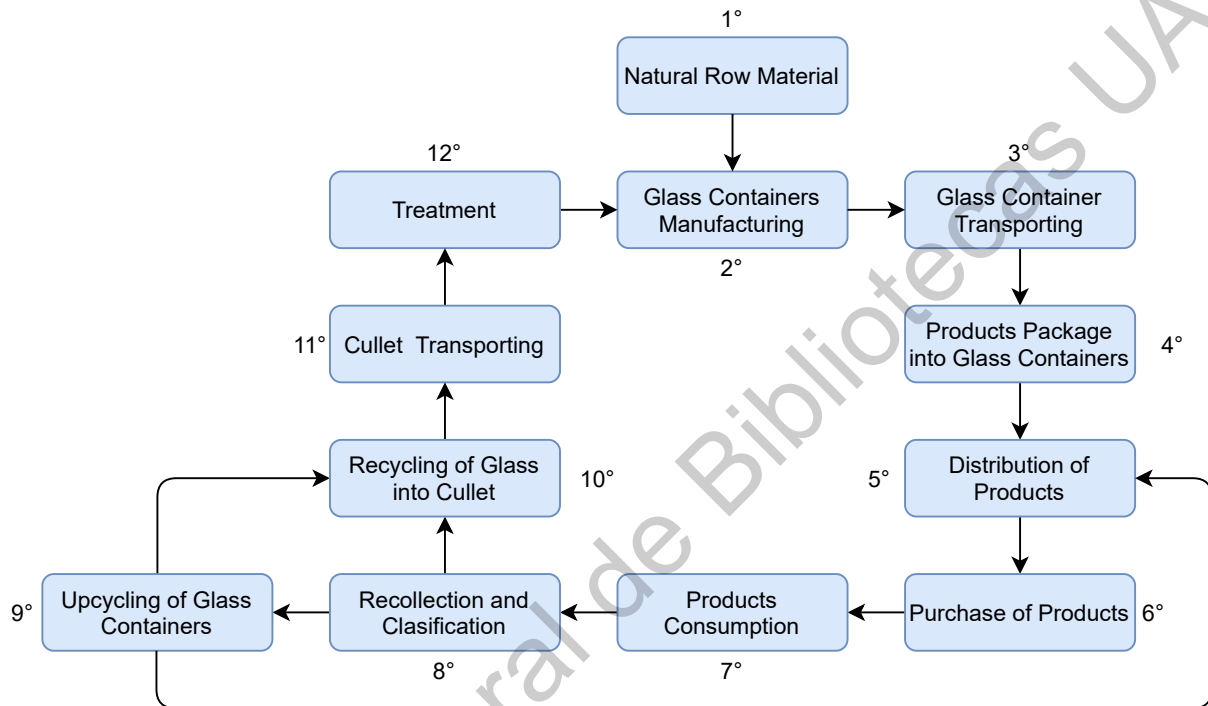
Figure 4.9: New integral glass recycling process.

The benefits obtained from this new process are introduced in the following points:

- The USW generation for glass products is cut immediately. New products are reincorporated into the integral glass recycling process.

- The products obtain a new value. It may be an artistic value, a monetary value, or a usability value.

- The waste not used for upcycling is reincorporated for its recycling. The best option for recycling is for cullet generation.

As mentioned in Section 1.5, this project creates an opportunity for implementing a Quintuple Helix Model. In this model, the five helices are education, economic, political, society, and natural environment. The development of this project is a result of the first helix, the education system. Figure 4.10 presents a proposal for a quintuple helix model.
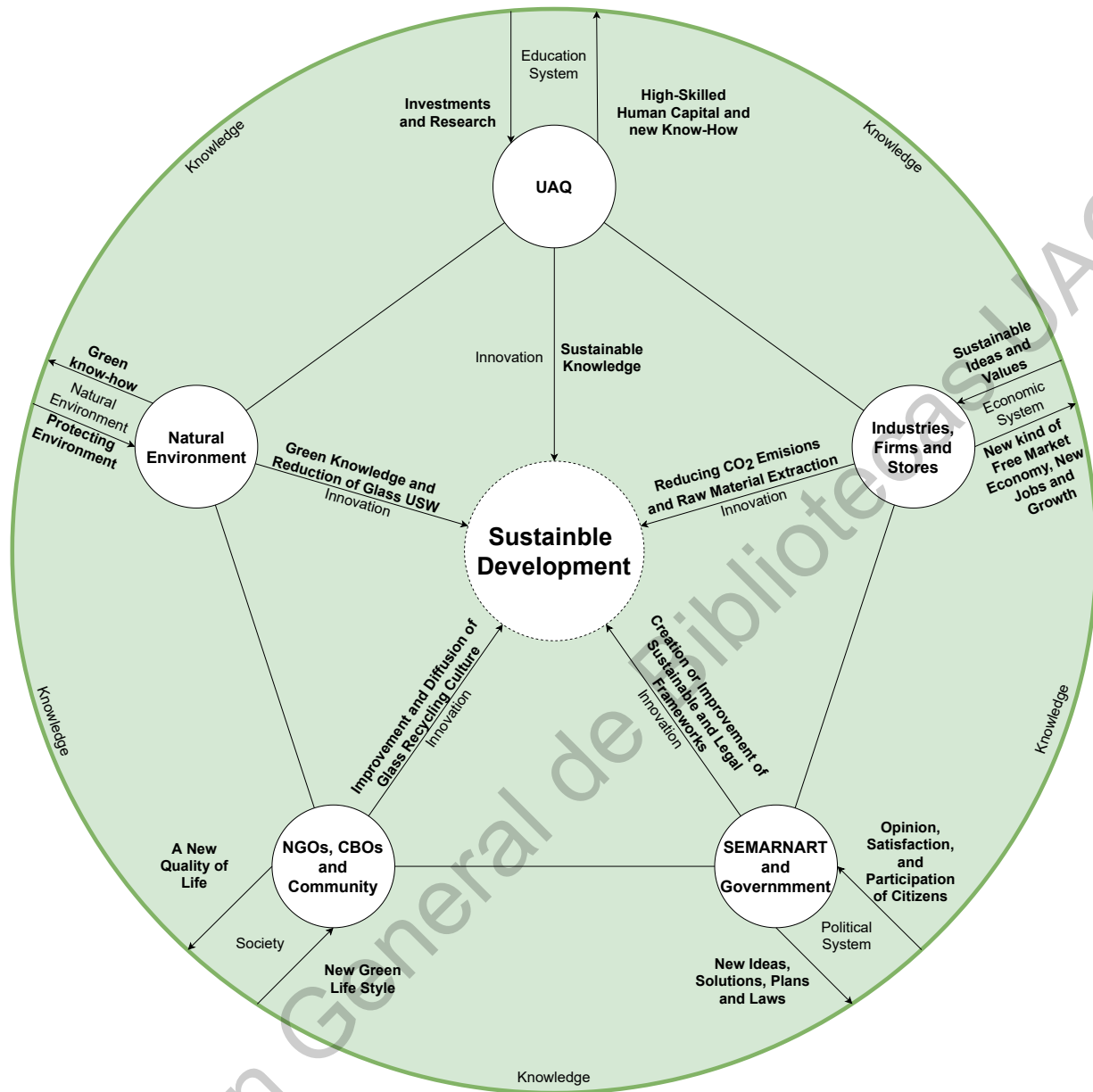
Figure 4.10: The quintuple helix model proposed.

In the quintuple helix model, there is a continuous circulation of knowledge. Each helix can take advantage of the knowledge as input. The proposal in Figure 4.10 has as principal promoter helix the education system. It provides new knowledge for the other four helices. These have the opportunity to produce new outputs thanks to the knowledge circulation. These new outputs circulate as new knowledge for the others helices. As a result, the circulation knowledge in this proposal aims to:

- for the political system: create more opportunities to reduce USW, encourage recycling practices, and improve sustainable and legal frameworks.

- for the economic system: create new jobs, produce new green products, and reduce the extraction of raw material and CO_2 emissions.

- for the society: spread the benefits of glass recycling, improve the glass recycling culture, and generate a new style of green life.

- for the natural environment: reduce the amount of glass USW available in the ecosystem, decrease the impact of glass USW and CO_2 emissions, and reduce the effects of raw material extraction.

Also, the same knowledge circulation brings new opportunities for the education system. As a result of it and the implementation of this project, it brings an opportunity for implementing glass waste management inside the UAQ installations. Figure 4.11 displays a proposal that incorporates some activities with the objective of glass waste reduction.
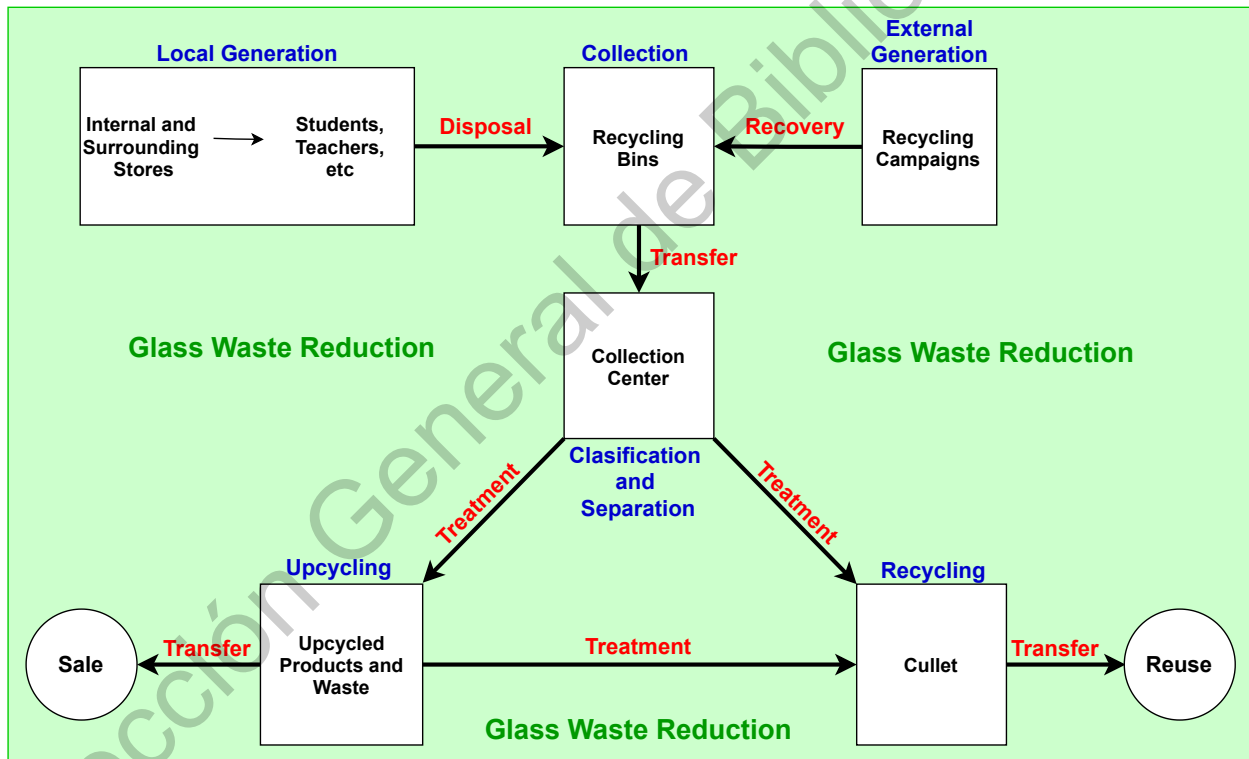
Figure 4.11: Proposal for a glass waste management.

Also, this proposal can be incorporated as a part of integral solid waste management focused on glass waste (ISWM). The implementation of this proposed creates a new opportunity for cooperation with the others four helices. Figure 4.12 shows some stakeholders that may have an interest with the proposal of Figure 4.11.

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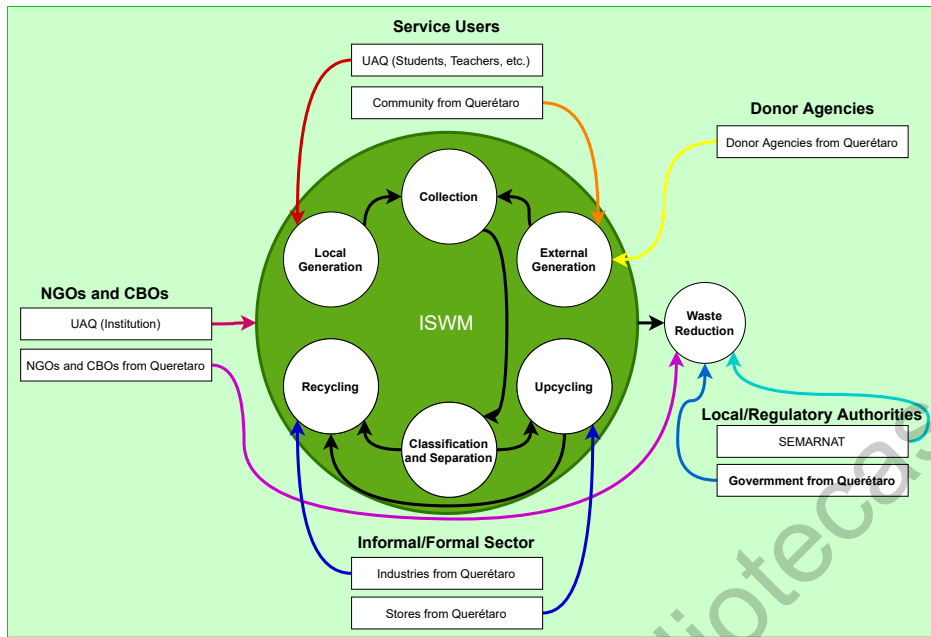
Figure 4.12: Stakeholders involved in the glass waste management proposal.

Each stakeholder constitutes a part of the five helices. The implementation of the glass waste management proposal brings a necessity to consider some aspects for a good performance. Figure 4.13 introduces some aspects required for each helix.
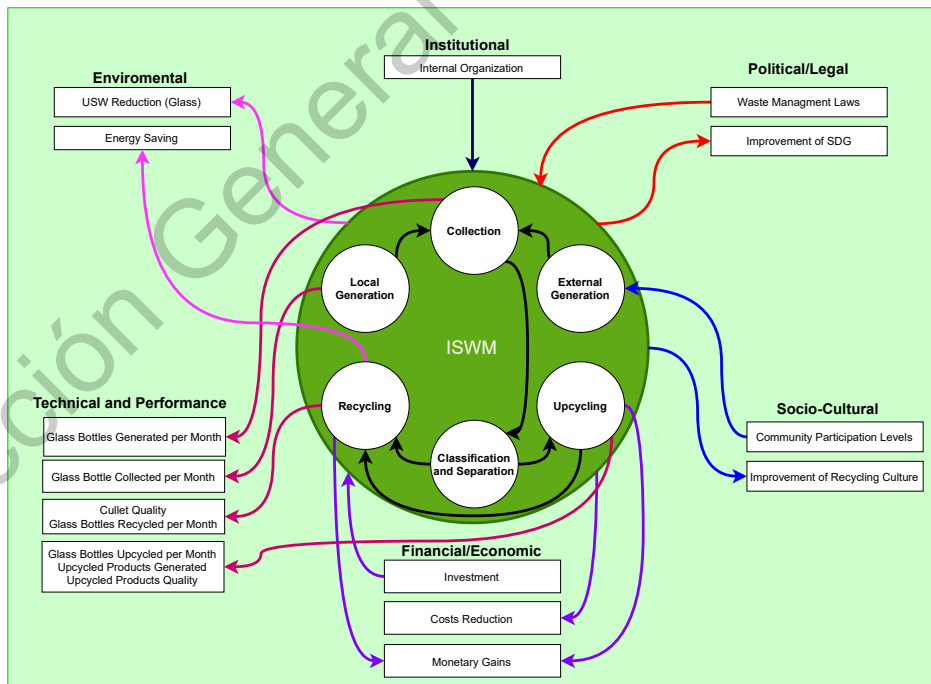
Figure 4.13: Aspects involved in the glass waste management proposal.

4.6 Prototype and cuts: analysis

During the practice of experimentation stage, the following points were realized:

- The quality of the cut performed is directly related to the quality of the guide cut. If it is performed in the wrong way, the quality of the resulting cut decreases.

- A deep guide cut decreases the cutting time.

- Shallow guide cuts required more time for performing the cuts. Also, these produced different effects on cuts, but these depend on the condition of glass bottles. Some cuts were not completed in the same position as the guide cut, others were not in line, and the quality decreased.

- Removing stickers, caps, dust, and solid or liquid substances from glass bottles is essential. The presence of these affects the time and quality of the product obtained.

- The surface of glass bottles is hot when the cut is performed. It may cause injuries if the user does not consider security measures.

- The cut performed produces a sharp edge. It is necessary to use sandpapers to reduce the sharp edge.

Figure 4.14 and Figure 4.15 display some glass bottles cut and a basic example of upcycled products.

Figure 4.14: Some examples of cuts performed.

Figure 4.15: A basic example of upcycled products from glass bottles.

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Conclusions

Despite recycling has been used for many centuries and glass recycling brings many benefits, glass recycling rates in Mexico show a lack of participation. A considerable part of society aims to obtain more economic benefits than ecologic benefits. The principal factor that affects participation levels in glass recycling activities is the low price that glass waste has in local markets. The trend of upcycling focused on glass bottles brings a new opportunity for obtaining more economic benefits. This activity aims to generate more benefits for organizations and individuals.

The development and use of the glass cutter prototype aim to use upcycling as a vital activity. It has the objectives of increasing the participation levels in recycling campaigns and creating new opportunities for USW reduction. These can be achieved by divulging the many benefits that society (individuals, community-based organizations, and non-governmental organizations), industry, government, and natural environment may obtain. The prototype avoids using water resources for glass bottle upcycling and the constant use of replacement required in most commercial models of glass bottle cutters. It reduces the efforts needed by the user when upcycling glass bottles.

The glass bottle cutter prototype produces the cuts quickly, but there is a time variation of these relative to the guide cut. Also, the way that the guide cut is performed affects the quality of the cut done. The prototype provides an alternative solution of the use of water to produce the thermal shock. Its dimensions allow a wide range of commercial glass bottles and enable its use with no complexity. Also, its design grants facilities for performing the glass cutting process and does not require much effort by the users. The glass bottles upcycled may create new objects with monetary, artistic, or usability value.

Also, as a result of developing the prototype, a new proposal for waste management focused on glass bottles is proposed for its use in UAQ installations. This proposal demonstrates a relation with the quintuple helix model proposed. Thanks to this, and as an achievement, an article was published in the indexed Journal of Sustainability from MDPI (Multidisciplinary Digital Publishing Institute). It is found as "Sustainable Glass Recycling Culture-Based on Semi-Automatic Glass Bottle Cutter Prototype".

The project may be used for:

- Participate in exhibitions and events to promote the culture of recycling.

- Promote its use as an alternative tool in the glass bottle recycling activity.

- Carry out campaigns for the collection and recycling of glass bottles.

- Implement courses on the recycling of glass bottles, the various ways of recycling, and how to carry them out.

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List of Abbreviations

Abbreviation	Meaning
ANFEVI	from Spanish Language *Asociación Nacional de Fabricantes de Envases de Vidrio*.
UAQ	from Spanish Language *Universidad Autónoma de Querétaro*.
SEMARNAT	from Spanish Language *Secretaría de Medio Ambiente y Recursos Naturales*.
USW	Urban Solid Waste.
LGPGIR	from Spanish Language *Ley General para la Prevención y Gestión de los Residuos*.
INEGI	from Spanish Language *Instituto Nacional de Estadística y Geografía*.
SDG	Sustainable Development Goals.
OECD	Organisation for Economic Co-operation and Development
PDIP	Plastic Dual Inline Package
LSB	Less Significant Bits
MSB	Most Significant Bits
USB	Universal Serial Bus
ISWM	Integrated Solid Waste Management.
MDPI	Multidisciplinary Digital Publishing Institute.

Table A.1: Table of abbreviations

Code of "max6675.c" library

```
#ifndef TC_CLK
    #define TC_CLK      PIN_C3
#endif

#ifndef TC_CS
    #define TC_CS       PIN_C0
#endif

#ifndef TC_DATA
    #define TC_DATA     PIN_C4
#endif


int1 thermocouple_error;

void init_TC(void)
{
    output_low(TC_CLK);
    output_low(TC_DATA);
    output_high(TC_CS);
}

int16 read_TC(void)
{
    int8 i;
    int16 data;

    output_low(TC_CS);
    delay_ms(1);
    for (i=0;i<16;i++){
        shift_left(&data,2,input(TC_DATA));
```

```
        output_high(TC_CLK);
        delay_us(1);
        output_low(TC_CLK);
        delay_us(1);
    }

    thermocouple_error=bit_test(data,2);
    delay_ms(1);
    output_high(TC_CS);
    return(data);
}

int16 sortout(int16 raw)
{
    return(0x0FFF & (raw>>3));
}

float toFloat_TC(int16 tmp)
{
return((float)tmp/2.021142857-44);
}

float do_everything(void)
{
    init_TC();
    delay_ms(200);
    return(toFloat_TC(sortout(read_TC())));
}
```

PIC18F4550 Programming Code

```
#include <18F4550.h>
#fuses INTRC_IO, NOWDT, PUT, BROWNOUT, NOLVP
#use delay (internal=8Mhz)
#use RS232(BAUD=9600, BITS=8, PARITY=N, xmit=pin_c6, rcv=pin_c7)
#include <string.h>
#include "max6675.c"

char msg[64];
float temp_thermocouple;
float SP_vel;
float SP_vel_read;
float SP_temp;
float temp_read;

float error, error_previous, acumulative_error;
float kp=10.0, ki=0.1, kd=2.0;
float PID_prop, PID_int, PID_der, PID_value;
float t_sampling=0.19968;

int timer_int=0, calcular_pid=0, start=0;

#int_timer0
void timer(){
    timer_int=timer_int+1;
    if(timer_int==10){
        calcular_pid=1;
        timer_int=0;
    }
    else if(timer_int>10){
        timer_int=0;
    }
```

```
    set_timer0 (100);
}


void reset_variables (){
    temp_thermocouple =0.00;
    SP_vel=0.00;
    SP_vel_read=0;
    SP_temp=0.00;
    temp_read=0;
    error=0;
    error_previous=0;
    acumulative_error=0;
    PID_prop=0;
    PID_int=0;
    PID_der=0;
    PID_value=0;
    start=0;
}

void sending_datta ()
{
    sprintf (msg,"Thermocouple:%3.2f − SetPoint:%3.2f − %4.4f\r\n",
    temp_read, SP_temp, error );
    printf("%s",msg);
    printf("%4.4f + %4.4f + %4.4f = %4.4f\r\n",
    PID_prop, PID_int, PID_der, PID_value);
}

void sp_reading ()
{
    SP_temp= 250;
    SP_vel=100;
}

void calculo_error (){
    error = SP_temp − temp_read;
}

void calculo_proportional (){
    PID_prop = kp*error;
}

void calculo_integral (){
    acumulative_error = acumulative_error + error;
```

```
        PID_int = ki * acumulative_error;
    }

    void calculo_derivative(){
        PID_der = kd * ((error-error_previous)/t_sampling) ;
    }

    void calculo_pid(){
        temp_read=0;
        temp_read=do_everything();
        sp_reading();
        calculo_error();
        calculo_proportional();
        calculo_integral();
        calculo_derivative();
        PID_value = PID_prop + PID_int + PID_der;
        error_previous = error;
        if(PID_value>400){
            PID_value=400;
        }
        else if(PID_value<0){
            PID_value=0;
        }
        sending_datta();
        if(PID_value>400){
            output_high(PIN_E2);
        }
        else if(PID_value<=400||temp_read>SP_temp){
            output_low(PIN_E2);
        }
        calcular_pid=0;
    }

    void main()
    {
        setup_timer_0(rtcc_div_256|rtcc_internal|rtcc_8_bit);
        set_timer0(100);
        set_tris_b(0b00001101);
        set_tris_c(0b10000000);
        setup_oscillator(OSC_8MHZ|OSC_INTRC);
        enable_interrupts(int_Timer0);
        enable_interrupts(global);
        reset_variables();
        printf("Test: Temperature Controller\r\n");
        while(TRUE)
```

```
{
    if(calcular_pid==1){
        calculo_pid();
    }
}
}
```