Article

Advanced Extrusion Machine for Transforming PET

Máquina Extrusora Avanzada para Transformar PET

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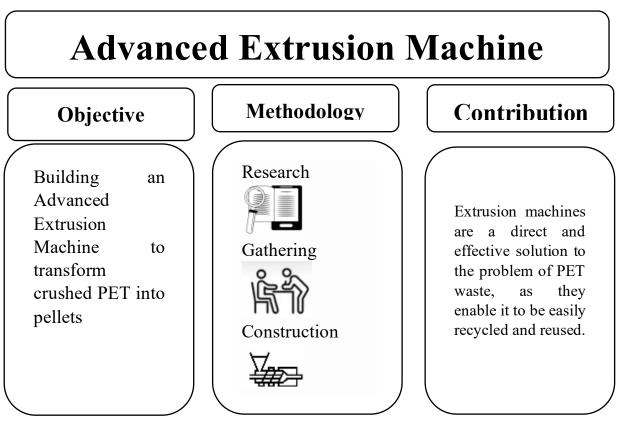
Abstract

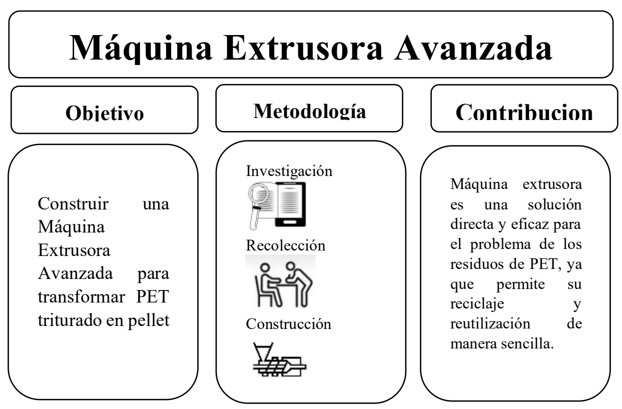
In the Microrregion One of Hidalgo, the accumulation of PET waste is causing a serious environmental crisis. To combat this, an **Advanced Extruder Machine** project is proposed. This project aims for a comprehensive solution. It aligns with **PRONACES** and focuses on preventing contamination and toxic agents resulting from poor waste management. The machine will be designed to minimize any negative impact on health and the environment. Collaboration with the municipalities of Ajacuba, Tetepango, Tezontepec de Aldama, Tlahuelilpan, and Tlaxcoapan is key. They will participate in the tests to ensure the technology is adapted to local needs. Expected results include a significant reduction in PET waste and greater environmental awareness. The Extruder Machine is a technological and sustainable solution that seeks to transform plastic waste management and protect the environment and community health.



Extrusion Machine, PET, Pellet

Resumen

En la Microrregión Uno de Hidalgo, la acumulación de residuos de PET genera una grave crisis ambiental. Para combatirla, se propone el proyecto de una **Máquina Extrusora Avanzada**. Este proyecto busca una solución integral. Se alinea con **PRONACES** y se centra en evitar la contaminación y los agentes tóxicos derivados de la mala gestión de residuos. La máquina será diseñada para minimizar cualquier impacto negativo en la salud y el entorno. La colaboración con los municipios de Ajacuba, Tetepango, Tezontepec de Aldama, Tlahuelilpan y Tlaxcoapan es clave. Ellos participarán en las pruebas para asegurar que la tecnología se adapte a las necesidades locales. Los resultados esperados incluyen una reducción significativa de residuos de PET y una mayor conciencia ambiental. La Máquina Extrusora es una solución tecnológica y sostenible que busca transformar la gestión de residuos plásticos y proteger el medio ambiente y la salud de la comunidad.



Máquina Extrusora, PET, Gránulo

Area: Development of strategic leading-edge technologies and open innovation for social transformation.

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Introduction

The construction of an advanced extrusion machine to transform PET represents a strategic and necessary response to an environmental problem affecting Micro-region One of the State of Hidalgo in the management of plastic waste, especially polyethylene terephthalate [PET].

This situation generates environmental and health risks due to the presence of toxic agents and polluting processes resulting from inadequate handling.

The problem is exacerbated by the fact that the social and economic dynamics of the municipalities involved, Ajacuba, Tetepango, Atitalaquia, Tlahuelilpan and Tlaxcoapan, do not consolidate effective recycling strategies due to a lack of institutional collaboration and technological solutions adapted to local conditions.

The Advanced Extruder Machine is conceptualised as an advanced technological solution that will not only address the accumulation of plastic waste, but will also incorporate specific measures to minimise the risks associated with toxic agents and polluting processes during the PET recycling process. The proposed extruder machine seeks to transform PET into reusable pellets, but also to change the way recycling is approached from a community, industrial, and environmentally responsible perspective. A key element in the successful development and execution of this project is collaboration with the municipalities of Micro-region One and guidance from the National Strategic Programmes [PRONACES].

The problem of polyethylene terephthalate [PET] recycling in Micro-region One of the State of Hidalgo represents a significant environmental and social challenge, with an average generation of 2,634.3 tonnes of municipal solid waste [MSW] per month [INEGI, 2021], highlighting the urgent need for sustainable technological solutions that enable this waste to be transformed into new valuable products.

The design of the Extruder Machine is based on an open-source filament extruder [see Figure 1], implemented for research and education, seeking to develop a low-cost extruder for real-time process analysis, which is necessary in the manufacture of 3D filaments.

This version facilitates the analysis of critical process variables such as temperature, rotation speed, and filament quality. Experimental validation confirmed its effectiveness under controlled conditions and flow variables.

Box 1

Figure 1

Filament extruder

Source: extrusora

The transport behaviour, evaluating virgin polypropylene, shredded polypropylene, and polyethylene powder with axial and helical grooves at speeds of up to 1350 rpm, according to Johann, Reißing, and Bonten [2022], demonstrated the influence of screw design on process efficiency for the development of extruders adapted to recycled materials such as PET.

The impact of contaminants released by plastics during their use and degradation, according to Khare and Khare [2023], highlights exposure to toxic compounds such as bisphenol A [BPA], present in plastic packaging, and its association with adverse effects on reproductive health and diseases such as breast cancer, an approach that is relevant when designing extrusion machines that allow these compounds to be safely removed during thermal recycling processes.

The extruder, which was built in-house, citing Meza, García, González, Sierra, Chávez, and Reyes [2022], consists of a carbon steel tube with an internal diameter of 1‘ containing another tube with a diameter of ¾’, which allows for adequate conduction and thermal insulation of the 500 W resistors, placed externally, for efficient heating of the tube.

It also uses a ½" diameter, 620 mm long wood drill bit as an extruder screw with a helical geometry.

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A coupler is also used to connect the drill bit to the gear motor, allowing the screw to rotate and transport the material. A feed system constructed of carbon steel, from which the plastic falls into the extrusion chamber. And a steel outlet nozzle with a 3 mm hole, designed to increase the flow rate and shape the molten plastic.

On the other hand, for the proper processing of recycled PET by extrusion, prior drying is essential to reduce its moisture content to less than 0.02%, which is typically achieved by heat treatment at 120–150°C for 4 hours. This step prevents thermal degradation of the polymer during processing, which is commonly carried out at a temperature range of 250–270 °C.

In experimental or laboratory applications, an extrusion system with 300 W electrical resistance has been implemented, controlled by a microcontroller using a PID loop, allowing a constant temperature of 200 °C to be maintained during the process [Kang, Kim, Kim, Kim & Koh, 2023].

The value of involving local communities in sustainable recycling projects from a participatory perspective, according to Warintarawej and Nillaor [2023], mixed grouping techniques in low-income areas demonstrated that the collaborative design of solutions favours their implementation and maintenance. This experience validates the proposed model for the Advanced Extruder Machine, which envisages collaboration with the aforementioned municipalities and local collectors, who currently collect PET without adding value through transformation.

It also responds to the goals of the National Programme for the Prevention and Comprehensive Management of Waste [SEMARNAT, 2022] by promoting clean and appropriate technologies for the Mexican context.

In theory, the construction of an Advanced Extruder Machine to transform crushed PET into pellets, using SolidWorks modelling, contributes to the sustainable management of plastic waste in Micro-region One of the State of Hidalgo.

Research methodology.

For a comprehensive analysis of the composition and quantity of PET waste in the micro-region, a mixed methodology was used for the design and construction of the Extruder Machine, following the guidelines proposed by Hernández, Fernández and Batista [2014], combining qualitative and quantitative approaches to take advantage of the complementarity of engineering projects that require both the precision of numerical analysis and the depth of conceptual and regulatory analysis.

The mixed methodology allows for the integration of quantitative data collection and analysis, essential for sizing and modelling the components of the extruder, with a qualitative approach that includes the review of regulations and conceptual design analysis.

Diagnosing Main Sources of PET.

The increase in plastic waste threatens environmental health and creates waste management problems. The proposed extruder machine is positioned as a direct solution to address this problem, offering a way to recycle and reuse PET.

It is important to know the amount of MSW generated in each municipality of micro-region one, in kilograms per day: Tetepango 8,560 kg, Tlaxcoapan 20,000 kg, Tlahuelilpan 9,000 kg, Ajacuba 5,000 kg, and Tezontepec de Aldama 45,250 kg, considering that 30% is recyclable waste.

There is no precise data on PET collection, however, for two decades in Mexico, only 8% of PET containers introduced to the market were recovered, according to data from the civil association ECOCE [see Figure 2].

By mid-2023, 547,000 tonnes of PET will have been collected, indicating that more than 30 plants specialising in PET recycling recover 60% of the containers introduced into the Mexican market.

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Box 2

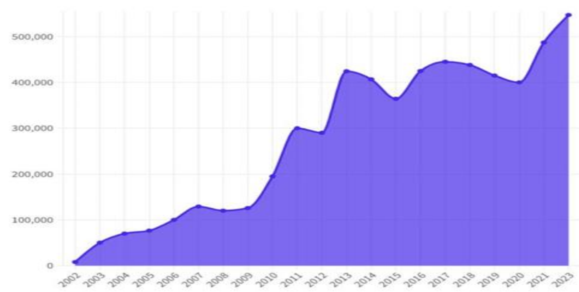

Figure 2

Collection of PET bottles in Mexico.

Source: ECOCE [2023]

Internationally, see Figure 3, Mexico ranks above countries such as Brazil, the United States, and Canada in terms of PET recovery. Although there are countries with higher recycling rates, such as China and Germany, Mexico leads the way in Latin America, putting it on a par with the European Union.

Box 3

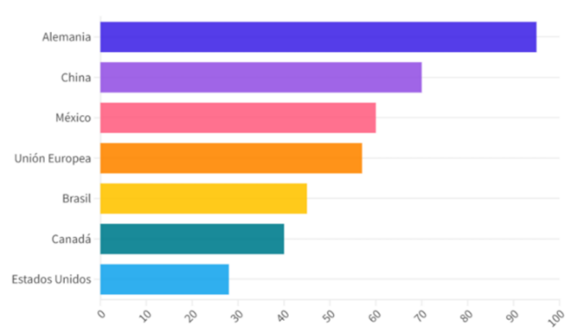

Figure 3

Statistics on PET Collection and Recycling Worldwide.

Source: ECOCE [2023]

Planning and Data Collection.

The data collected on total solid waste generation in Micro Region One of the state of Hidalgo, comprising the municipalities of Ajacuba, Atitalaquia, Tetepango, Tlahuelilpan, and Tlaxcoapan. The percentage of PET collected during the period between 2021 and August 2024 is detailed.

The research, based on a direct field approach, included visits to the municipal presidencies of each locality to gather accurate information on the quantities of PET generated in tonnes. This effort made it possible to fulfil the main objective of the research, ensuring the successful collection of the required data.

Based on the statements in Table 1, from the officials responsible for the areas of ecology and solid waste management.

Pérez [2024] shares that over the years, PET recycling and storage has decreased in the Municipality of Tlaxcoapan due to the implementation of strategies such as promoting the use of reusable bottles in schools and collection in special containers. These measures seek to reduce environmental pollution.

Box 4

Table 1

Amount of solid waste and percentage of PET.

Municipality	Years	Amount of waste solids	Percentage of waste solids	Percentage of PET	Total amount of PET
Ajacuba	2024	7500	68%	32%	2400
	2023	16500	74%	26%	4290
	2022	13200	66%	34%	4488
	2021	26000	60%	40%	10400
Tetepango	2024	11700	62%	38%	4446
	2023	17000	69%	31%	5270
	2022	15400	53%	47%	7238
	2021	23000	79%	21%	4830
Atitalaquia	2024	10000	62%	38%	3800
	2023	19200	73%	27%	5184
	2022	18900	69%	31%	5859
	2021	22300	67%	33%	7359
Tlahuelilpan	2024	8000	63%	37%	2960
	2023	12000	68%	32%	3840
	2022	12300	76%	24%	2952
	2021	15600	63%	37%	5772
Tlaxcoapan	2024	6000	59%	41%	2460
	2023	15000	71%	29%	4350
	2022	17800	68%	32%	5696
	2021	21000	75%	25%	5250

The Municipality of Ajacuba, to paraphrase Carranza [2024], has several resorts where PET waste from soft drinks and bottled water is generated; this waste is collected and sorted by municipal rubbish trucks to determine the total amount of solid waste and the percentage of PET generated annually.

Ultimately, the interviews conducted reflect local efforts to efficiently manage PET, despite the challenges associated with the generation and collection of this waste in the region.

Building the Extruder Machine Using Solidworks Modelling.

The feasibility of the project is supported by the availability of technologies such as SolidWorks and access to efficient materials. In addition, potential risks will be thoroughly evaluated, ensuring the safety of the project and reducing vulnerability to possible inconveniences.

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Developing Three-Dimensional Models Using SolidWorks Software.

The dimensioning of the spindle, including torsion, bending and fatigue verification, the definition of adjustments and tolerances for the barrel and its assemblies, and the design of bolted joints with their corresponding preload and tightening torque were carried out in accordance with Shigley's criteria [Budynas & Nisbett, 2015].

Given the thermal regime of the extrusion, the effects of temperature on properties and assembly clearances were incorporated, and the model was validated using finite element analysis [FEA] before issuing the graphic documentation.

When gathering essential information, including dimensions, specifications, and design constraints, see Figure 4, which shows the spindle.

Box 5

Figure 4

Spindle.

The assemblies are part of the components where geometric and dimensional constraints were applied to ensure their functionality and proper fit, in addition to materials and properties, by assigning materials to simulate physical behaviours such as strength and weight.

Barrel

Subsequently, the requirements were verified, dimensions were adjusted, and movement tests were performed to ensure the quality of the design, resulting in graphic documentation.

Construction of the Extruder Machine in 3D Printing.

In the development of the complete three-dimensional model in SolidWorks, citing Serrano, Castellanos, and Maturano, [2025], the dimensions, tolerances, and materials necessary for the manufacture of the prototype are specified; this model, see Figure 5, served as the basis for all subsequent phases of design and performance simulation.

Box 6

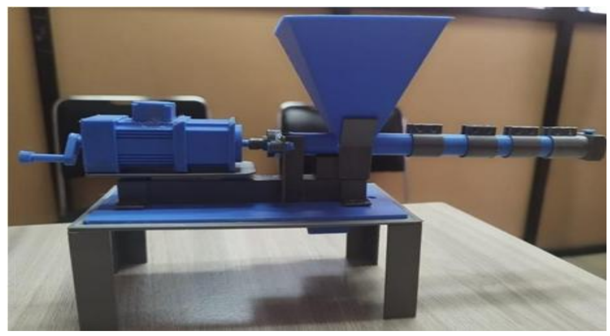

Figure 5

Prototype of a 3D extruder machine.

Component Specifications.

Functional extruder prototype designed for processing and melting recycled PET; the equipment has a simple extrusion system with gear motor, steel screw, heated barrel and digital temperature control, for laboratory testing or academic development.

Extruder type: Single screw.

Single screw extruder, a machine that uses a single heated cylinder to transform plastic material into a specific format. According to the fundamentals, see Table 2, of the design and operation of single screw extruders, the recommended rotation speed, expressed in revolutions per minute [RPM], depends on multiple technical variables.

Box 7

Table 2

Recommended Speed in RPM for Single-Screw Extruder.

Speed	RPM
Low speed	20-60
average speed	60-100
speed high	100-150+

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The recommended temperature in a single-screw extruder [see Table 3] is primarily determined by the type of polymer being processed, as each material has a specific melting range and characteristic thermal behaviour.

Box 8

Table 3

Recommended Speed in RPM for Single-Screw Extruder.

Material	Feeding area	Compression zone	Dosing zone	Nozzle
PE [polyethylene]	160-180	180-200	200-220	200-220
PP [polypropylene]	170-190	190-210	210-230	210-230
Rigid PVC	150-170	160-180	170-185	170-185
Flexible PVC	140-160	160-170	170-180	170-180
PET	230-250	250-270	270-280	270-280
ABS	180-200	200-220	220-230	220-230
PS [polystyrene]	170-190	190-210	210-230	210-230

Formula for calculating the extruder speed in RPM:

$$Velocidad\ del\ husillo(RPM) = \frac{[1000 \times Velocidad\ de\ corte\ [V]]}{[\pi \times Diámetro\ de\ herramienta\ [D]]} \quad [1]$$

Source : Cálculo de velocidad del husillo

Spindle speed [RPM]: Revolutions per minute at which the spindle must rotate.

Cutting speed [V]: Tangential speed of the tool or workpiece in metres per minute [m/min]. Depends on the material and type of operation.

Tool diameter [D]: Diameter of the tool or workpiece in millimetres [mm].

π [pi]: Mathematical constant, approximately 3.1416. [Maria, 2025]

Capacity of the conical container.

Top diameter 23 cm, height 22 cm, volume [approximate] 7.6 litres.

For the classification of the extruder, see Figure 6, which gives the diameter and length of the screw in a ratio *L*/*D* representing the length and diameter of the screw. The most common extruders are those with a screw diameter between 25.00 mm and 250.00 mm, and a length up to forty times the diameter. 25.00 mm and 250.00 mm, and a length up to forty times the diameter.

Box 9

Figure 6

Conical hopper.

Motorredutor.

Motorredutor monofásico, ver Figura 7 [motor com redutor de velocidade integrado], Tensão de funcionamento: 127 V [corrente alternada monofásica], Frequência: 60 Hz, marca WEQ, função transmite potência mecânica a baixas rotações, combinando um motor elétrico com um sistema de engrenagens redutoras para aumentar o binário e reduzir a velocidade de saída.

Box 10

Figure 7

Gear motor

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Screw.

The screw, see Figure 8, is one of the key elements of the extrusion system, specifically designed for the efficient processing of recycled PET flakes.

The technical specifications of the screw are as follows: nominal diameter of 9/16 inches [14.3 mm] and total length of 48 cm.

The helical design consists of 32 threads with a uniform pitch, arranged in a left-hand direction, which requires the direction of rotation [as seen from the hopper] to be clockwise to ensure the correct advancement of the material.

This design allows for controlled internal friction, promoting heat transfer and facilitating the transition of the polymer from a solid to a molten state. Along the way, the screw transports the PET from the hopper to the nozzle, progressively compressing it and ensuring a homogeneous feed in the extrusion zone.

Box 11

Figure 8
Husillo

PET Extruder Barrel

Structural and Functional Characteristics.

High-strength steel construction material, obtained through precision machining from solid bar with a nominal diameter of 9/16 inches.

Dimensions: total length 48 centimetres, internal diameter designed to fit 9/16" spindles, ensuring efficient axial displacement without loss of molten PET.

Technical Specifications of the Extrusion Nozzle.

The nozzle is the point through which the molten filament is expelled and controls the profile of the extruded material" [3Dwork Labs, n.d., para. 1].

The extrusion nozzle, see Figure 9, also known as a nozzle, is the terminal component of the extruder system, through which the molten polymer is directed and moulded into its final shape.

Construction material: AISI 304 or 316 stainless steel, recognised for its corrosion resistance and thermal stability [Material Mundial, s. f.].

Box

Figure 9
Extrusion nozzle

Functional Specifications of the Nozzle Support

Type 1 bearing [commonly classified as a mounted bearing] "is a mounted bearing used to support a rotating shaft" [BRR Mexico, 2019, para. X].

The die holder is a critical element of the extruder system: in addition to its structural function, it improves flow stability, operational efficiency and, consequently, the quality of the extruded product.

Structural Base Support for Recycled PET Extruder.

The structural support [see Figure 10] is a key element in the mechanical architecture of the extruder, whose essential function is to provide a firm and aligned base that absorbs and distributes the loads generated during continuous operation of the equipment.

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Box 13

Figure 10
Structural support

Electric Heating System

These products, made of aluminium, are resistant to oxidation and high temperatures. In addition, they maintain uniform heat distribution around the tube, reducing thermal irregularities [Vaqueiros Ferreteros, 2022].

In this project, cartridge or band electric resistors, powered at 127 V, with an operating range of 100 °C to 400 °C, were integrated, specifically designed to achieve stable working temperatures in continuous extrusion environments.

Thermal Instrumentation Using Type Y Sensors.

Made from a combination of iron and a copper-nickel alloy, with limited use in oxidising environments; it has a temperature range between 0°C and 750°C. Thermocouples operate on the basis of two metal wires of different materials joined at one end, known as a hot junction or measuring junction [SRC, 2018].

The installation of a sensor in each of the independent thermal zones of the barrel [feed zone and compression/metering zone] allows the thermal profile to be monitored with high resolution, preventing both overheating and unwanted cooling that could affect the viscosity of the molten polymer.

Thermal Control System

To achieve precise and efficient thermal control during the polyethylene terephthalate [PET] extrusion process, REX-C100 digital temperature controllers were implemented, widely recognised in industrial applications for their reliability, versatility and low operating cost.

Each REX-C100 controller is coupled to a Y-type sensor [thermocouple] made of stainless steel, which offers corrosion resistance, impermeability, and durability under demanding thermal conditions. This sensor captures the temperature in real time in each zone of the barrel, while the controller regulates the supply of electrical power to the heating elements by means of a solid-state or mechanical relay, thus ensuring constant and precise heat transfer.

Power Supply Specifications and System Operating Conditions.

The extrusion system is configured to operate with a 127 V alternating current [AC] supply, a specification compatible with domestic networks and conventional industrial installations in Mexico. This compatibility guarantees not only a stable connection to the electrical network, but also efficient and safe energy operation under continuous operating conditions.

Operational thermal capacity: the equipment has a thermal control range from 100 °C to 400 °C, allowing its use in applications with high thermal demands, such as the transformation of recycled polymers. This ensures that the material reaches its melting point without compromising its structural integrity or generating thermal degradation processes. It is recommended to operate the equipment in a ventilated environment to facilitate the dissipation of heat generated during the extrusion process and to avoid exposure to environments with relative humidity or direct contact with liquids.

Uses and Applications.

The tests represent a stage in the validation of the use of recycled PET as a secondary raw material, allowing quality protocols to be established for its reintroduction into production processes. Its implementation strengthens environmental sustainability initiatives by reducing dependence on virgin polymers and minimising the volume of plastic waste sent to final disposal. The equipment is positioned as a portable engineering testing laboratory, useful for higher education institutions and technological innovation centres operating in this region, enabling the development of skills in the field of recycling and the transformation of thermoplastic materials.
These tests promote:

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The training of local talent in micro-region one, specialising in the processing of recycled polymers.

The transfer of scientific and technological knowledge to local productive sectors in micro-region one, recyclers [small industries, workshops, cooperatives].

The development of community-based projects that bring together students, teachers and social actors in tangible solutions to environmental problems arising from the improper management of PET in micro-region one.

The PET extruder in this project plays an essential role as a technical-experimental validation platform for studying the thermal and mechanical parameters involved in the extrusion process of recycled materials. Its operation allows for the collection of empirical data relevant to the design, control, and optimisation of polymer processing systems. This system is adapted to CONAHCYT's strategic axes for use in applied research, specialised teaching and professional training in higher education institutions in the municipalities of Ajacuba, Tetepango, Tlaxcoapan, Atitalaquia and Tlahuelilpan, which make up Micro Region One of the State of Hidalgo.

Manufacturing Materials.

9/16‘ steel for spindle and barrel. Steel was selected for its mechanical and thermal resistance. The 9/16’ diameter, converted to 14.3 mm, may be too small if a higher flow rate is required. Bear in mind that PET is abrasive and corrosive when melted, and direct contact with unprotected carbon steel can wear down the material.

Electrical resistors [127V, up to 400°C] The appropriate resistance in terms of voltage and temperature for PET, which melts between 250 and 280°C.

Thermal efficiency depends on the type and location, and the heating bands need good heat transfer to avoid cold spots, which cause jams, so they are suitable for extruder manufacturing.

Type Y Temperature Sensor [2 units]. It is important to control small thermal fluctuations, because PET can crystallise if it cools unevenly.

An alternative would be a K-type thermocouple with a metal sheath and flat tip, as this has a range of -200 °C to 1260 °C and a fast thermal response.

WEQ gear motor, 127V, 60 Hz. WEQ is good for general use. The 127V makes it suitable for domestic mains power; the essential factors are output torque and RPM. In terms of interaction with PET, the motor moves the spindle against the resistance of the molten material, so it must be capable of operating at low RPM [30-80] with high torque.

Bearing washers, metal base plate and aluminium nozzle. The bearing washer supports the shaft and facilitates rotation, the metal base plate serves as a frame, and the aluminium nozzle is lightweight and easy to work with.

Limitations.

The prototype will be designed to process only PET [polyethylene terephthalate] in the form of clean, dry and sorted flakes. The system's capacity will be experimental, with a processing flow of less than 7.5 kg/h, which is sufficient to validate the thermomechanical principles of extrusion and demonstrate the basic functionality of the design. Auxiliary systems such as crushing, washing, pelletising or advanced automation are not contemplated.

The estimated budget for the development of the prototype is $7,200 MXN. This figure includes basic mechanical and electrical components, recyclable or reusable materials, and existing tools at ITSOEH. The financial feasibility is based on partial contributions from the institution, teachers and students. The purchase of specialised machinery or high-cost industrial simulation software is not contemplated.

The work team is composed of industrial engineering research teachers who are technical leaders of the project, students, and occasional support from institutional laboratory staff.

Impact.

The project's influence is felt at different levels, and its impact will be both direct and collateral, with expected and even unforeseen effects. It contributes to the environment by reducing plastic waste, promoting a culture of recycling and a circular economy.

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By transforming post-consumer PET into new products through extrusion, its improper disposal is avoided and waste recovery is promoted.

The development represents a low-cost economic solution for educational institutions and communities with limited resources, opening up the possibility of replicating the technology at the local level. The project could scale up to social recycling micro-enterprises, generating jobs and using plastic waste as a productive input.

Through the design and validation of the prototype, the culture of mechanical design, basic automation and rational energy use is strengthened. As a secondary impact, technical documentation and the use of computer-aided design [CAD/CAE] tools are promoted. From a social perspective, the project can influence environmental awareness in Micro Region One of the state of Hidalgo. By demonstrating that it is possible to transform PET locally, it promotes a sustainable and replicable educational model that can impact vulnerable communities if it is extended as a social programme.

Results

Obtained during the development of the project 'Construction of an advanced extruder machine prototype for PET recycling', with relevance, functionality and replicability in Micro Region One of the state of Hidalgo, made up of the municipalities of Ajacuba, Tetepango, Tlaxcoapan, Atitalaquia and Tlahuelilpan, a priority area served by CONAHCYT's strategic programme in its line of action on the environment and territorial sustainability.

Construction of extruder machine, see Figure 11. The prototype was designed using CAD software [SolidWorks], integrating a hopper feeding system, worm screw, band-type resistance heating zone and interchangeable extrusion nozzle.

The machine was manufactured with carbon steel and low-cost materials, a band-type resistance heating zone and an interchangeable extrusion nozzle.

Box 14

Figure 11

Construction of Extruder Machine, Barrel, Gear Motor and Components

The machine incorporates

- Feed hopper with non-return system
- 1045 steel screw, variable pitch [5-15 mm]
- Extrusion zone heated by band-type heating elements [2 x 250 W]
- PID controller for temperature regulation
- Interchangeable nozzles depending on the desired product

Technical Specifications of the PET Extruder Machine, see Annex 1, which shows its main design features, mechanical specifications, heating and control system, as well as operating conditions. The document contains information on uses and applications, the technical assurance plan implemented, the manufacturing process, the tests carried out, the integration of the work team, and a financial breakdown associated with the development of the prototype, including materials, software, tools, technical fees, travel, and dissemination of results.

Conclusions

The results achieved in this project allowed for the characterisation of the quantity, composition, and sources of PET generation in the municipalities that make up Microregion One, through the application of analytical methods and structured sampling techniques.

This information was essential for establishing the technical parameters required in its transformation process. An advanced extruder machine was also constructed, developed from SolidWorks modelling and integrated with applied engineering principles, prioritising thermal and mechanical efficiency.

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Article

The resulting prototype proved to be functional and replicable within the territorial context of Microregion One, offering a viable solution for PET utilisation and promoting sustainable plastic waste practices. A technically functional system was successfully implemented, but follow-up is required to consolidate its efficiency, scalability, and durability in the medium and long term.

Attachments

Appendix 1

Table 1

Technical Specifications

FICHA TÉCNICA DE MAQUINARIA

Nombre del equipo: Máquina Extrusora de Plástico PET – Prototipo

Modelo: EX-PET/IND-01

Categoria: Prototipo académico

Diseñado por: Ingeniería Industrial

DESCRIPCIÓN GENERAL:

Prototipo funcional de extrusora de plástico diseñado para el procesamiento y fundido de PET reciclado. El equipo cuenta con un sistema de extrusión simple con moto-reductor, husillo de acero, cañón calefaccionado y control digital de temperatura, especialmente pensado para pruebas de laboratorio o desarrollo académico.

CARACTERÍSTICAS PRINCIPALES:

- Tipo de extrusora: Monohusillo
- Material a procesar: Plástico PET reciclado (termofundido)
- Capacidad del contenedor cónico:
- Diámetro superior: 23 cm
- Altura: 22 cm
- Volumen (aproximado): 7.6 litros

ESPECIFICACIONES MECÁNICAS:

- Moto-reductor: Marca WEQ, 127V, 60 Hz
- Velocidad de husillo: 50–60 rpm
- Husillo:
- Material: Acero
- Diámetro: 9/16" (14.3 mm)
- Longitud: 48 cm
- Hélices: 32, dirección izquierda
- Cañón:
- Material: Acero, barra 9/16"
- Longitud: 48 cm
- Boquilla:
- Enganche: Cuerda milimétrica compatible con cañón de aluminio
- Soporte: 1 rondana tipo chumacera para sostén de base
- Soporte estructural:
- Tipo escuadra al inicio del cañón
- Fabricado en solera metálica

SISTEMA DE CALEFACCIÓN Y CONTROL:

- Resistencias:
- Cantidad: 5
- Ubicación: Distribuidas a lo largo del cañón
- Especificaciones: 127V, rango de temperatura de 100°C a 400°C
- Sensores de temperatura:
- Tipo: Sensor tipo Y
- Cantidad: 2 (uno por zona de control)
- Controladores:
- Modelo: REX-C100
- Función: Control independiente por zona del cañón

CONDICIONES DE OPERACIÓN:

- Alimentación eléctrica: 127V AC
- Rango de trabajo térmico: 100–400 °C
- Ambiente recomendado: Área ventilada, sin humedad excesiva

USOS Y APLICACIONES:

- Pruebas de extrusión con PET reciclado
- Formación académica y pruebas de ingeniería
- Validación de variables térmicas y mecánicas del proceso

OBSERVACIONES:

Este equipo es un prototipo académico. Su diseño está orientado a experimentación, investigación y formación de estudiantes en procesos de transformación de plásticos, no para producción industrial continua.

1. Plan de Aseguramiento Técnico del Material

Este plan contempla los **recursos necesarios para el diseño, fabricación y prueba** del prototipo de la máquina extrusora, garantizando su funcionamiento seguro y preciso dentro del entorno académico.

Recursos requeridos por etapa:

a) Diseño:

- Software CAD 3D: SolidWorks o AutoCAD para modelado estructural y mecánico.
- Manuales técnicos de materiales termoplásticos (PET).
- Referencias normativas para diseño de extrusoras (ANSI, ISO 12100).

b) Fabricación:

- Acero 9/16" para husillo y cañón.
- Resistencias eléctricas (5 unidades, 127V, hasta 400 °C).
- Sensor de temperatura tipo Y (2 unidades).
- Moto-reductor marca WEQ, 127V, 60 Hz.
- Rondanas tipo chumacera, solera metálica y boquilla de aluminio.
- Herramientas: torno, soldadora, cortadora y prensa.

c) Prueba del prototipo:

- Multímetro y pinza amperimétrica para verificar conexiones eléctricas.
- Termómetro digital infrarrojo para validación térmica.
- PET reciclado como material base para pruebas de extrusión.
- Guantes térmicos, lentes de seguridad y extractores de humo para laboratorio.

2. Relación de Recursos Humanos Involucrados

Rol	Función Principal	Experiencia Técnica Requerida
Líder de Proyecto	Coordinación general, cronograma, gestión de recursos	Conocimientos en gestión de proyectos y manufactura
Diseñador CAD	Modelado 3D del prototipo, diseño de husillo, soporte y cañón	Dominio de SolidWorks y fundamentos de diseño mecánico
Técnico en Procesos de Plástico	Selección de parámetros de extrusión y pruebas de PET	Conocimiento en polímeros, extrusión y seguridad de laboratorio
Técnico Eléctrico	Instalación de resistencias, sensores y controladores	Experiencia en sistemas de calefacción y control de temperatura
Operador de Taller Mecánico	Corte, soldadura y ensamble de piezas estructurales	Manejo de maquinaria de taller (torno, soldadora, cortadora, prensa)
Docente Asesor: Ing. Sergio Serrano	Supervisión técnica, validación académica del proceso	Experiencia en ingeniería mecánica o industrial, validación de prototipos

3. Desglose Financiero Preliminar

Este presupuesto cubre insumos, herramientas, software, validaciones y capacitación básica:

Categoria	Concepto	Costo (MXN)
Materiales e insumos	Acero, aluminio, resistencias, sensores, cableado	$2800
	Moto-reductor WEQ 127V	$0(Prestación del torno)
	Boquilla, rondanas, estructura metálica	$500
Herramientas y procesos	Corte, soldadura y maquila en taller	$3900
Software	Licencia SolidWorks educativa	$0 (uso académico)
	Simulación térmica (uso interno o gratuito)	$0(uso interno)
Capacitación y seguridad	Manual de operación, protocolo de seguridad	$0(uso académico)
	Equipo de protección personal (EPP)	$0(uso académico)
Validación técnica	Termómetro IR, pruebas eléctricas y térmicas	$0(uso interno)
TOTAL		**$7,200 MXN**

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. We have no financial interests or personal relationships that could have influenced the research described in this article.

Author contribution

The contribution of each researcher to each of the points developed in this research was defined based on:

Serrano-González, Sergio: Contributed the original idea for the project and the conceptual design of the Advanced Extruder Machine for Transforming PET. Defined the objectives, research methodology, and technical parameters of the prototype. He performed the analysis of experimental data, the interpretation of results, and the integration of the proposal into a continuous improvement model. He also prepared the discussion, conclusions, and final draft of the article.

Castellanos-López, Liliana Yadira: She supported the methodological design of the research and the structuring of the theoretical framework related to plastic extrusion and PET recycling technologies. She collaborated in the validation of the data collection instruments and in the critical review of the technical sections. She also contributed to the writing and academic correction of the manuscript.

Maturano-Maturano, Benito Armando: Participated in the execution of experimental tests of the extrusion prototype, compiling technical and operational information. He collaborated in the search and systematisation of scientific and technological background information on advanced PET extrusion. He contributed to the processing of information and the partial writing of the document.

Alvarado-Reséndiz, José Luis: He collaborated in the experimental phase by compiling and organising the operating data of the extrusion machine. He assisted in the preparation of tables, figures and technical results of the prototype. In addition, he contributed to the editing and writing of sections of the article.

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Availability of data and materials

The data supporting the results of this research were obtained from experimental tests carried out on the prototype of the Advanced Extrusion Machine for PET transformation, designed and developed at the facilities of the Instituto Tecnológico Superior del Occidente del Estado de Hidalgo [ITSOEH]. The data generated and analysed during this study were collected from Micro Region One of the State of Hidalgo, in municipal presidencies, ECOCE, SEMARNAT and INEGI.

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Abbreviations

PET	Polyethylene terephthalate is a thermoplastic polymer used in packaging and textiles due to its high strength and recyclability, [Castro, 2025].
BPA	Bisphenol A is a chemical substance used in combination with other substances to manufacture plastics and resins, [Autoridad Europea de Seguridad Alimentaria, 2025]
PID	The algorithm calculates the deviation or error between a measured value and a desired value. It consists of three different parameters: proportional, integral, and derivative. [Erazo-Velasco, 2022]
RSU	This is waste generated in homes, resulting from the disposal of materials used in domestic activities. [SEMARNAT, s. f.]
CAD	[Computer-Aided Design] o Computer-aided design refers to the set of digital software tools used in the design process, [Rodríguez & Rodríguez, 2024].
CAE	[Computer-Aided Engineering] is the application of computer tools to analyse the behaviour of the model created in CAD. [Reviriego & Reviriego, 2025]
RREX-C100	The REX-C100 PID temperature controller allows you to monitor and control the temperature in basic systems. [REX-C100 PID Temperature Controller SSR Output, n.d.]
RPM	Revolutions per minute is a unit of measurement used to express frequency or angular velocity and indicates the number of rotations per minute completed by a rotating body. [*¿Qué Es un RPM y Cómo Funciona?*, s. f.]

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