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Study and Construction of a Plastic Recycling Injection Manual Press

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ABSTRACT: In order to contribute to the fight against environmental pollution due to plastic packaging, a prototype extruder was designed and produced from an existing press. To carry out this project, we first carried out a study of the characteristics of the different organic polymers from which we selected High Density PolyEthylene (HDPE) as a material to recycle. Internal and external functional analyzes allowed us to characterize and prioritize service functions. After having determined the technological solutions by deploying the FAST (Functional Analysis System Technic) method, we proceeded to dimension the mechanical and electrical elements. The volume of the feed hopper is 841486.54 mm3 and can support a load of 0.7936 Kg, the pressure of the injection cylinder was evaluated at 174 bars, the force of the piston was evaluated at 37.14 N, the force of withdrawal of the cylinder is 29.3N. The barrel is a cylindrical tube measuring 34×26 and 530 mm in length. The material used to make most of the parts is stainless steel for its good resistance and its conductivity coefficient, which optimizes its thermal diffusivity. Digital modeling was done using SolidWorks software. Creating the prototype of the plastic extruder cost around 150,000 XAF.

KEYWORDS: Study and construction, Plastic recycling, Injection press, HDPE.

1. INTRODUCTION

Plastic injection is one of the processes best suited to the mass production of microtechnical parts **[1], [2].** The plastic injection process occupies a particular place compared to other processes for shaping plastic materials, it transforms a quarter of plastic products and exploits all of the resources via designed molds **[3]**. To obtain a part by injection several resources are used, in addition to qualified personnel for adjustment, control and monitoring operations, there are plastic extruders**[4]**, which can be horizontal, vertical, twin screw or special presses, finally the mold which constitutes the basic component since it gives the material the shape of the desired part. We will therefore make a presentation of these extruders and the production prototype.

2. MATERIAL AND METHODS

2.1. Raw material quantities and characteristics

By the end of 2018, all primary plastic waste ever generated by humankind had reached 6900 Mt. This amount is made up of 5600 Mt of polymer resin, 900 Mt of polymer fibers, and 400 Mt of additives. The composition of the polymer resin is 2300 Mt PE, 1300 Mt PP, 400 Mt PS, 300 Mt PVC, 800 Mt PET, 300 Mt PUR, and 200 Mt others **[5]**. Figure 1 shows that plastics waste are growing exponentially during time, and that HDPE waste are the third more important in Mt.

On Figure 2 1950 to 2017 are historical data, and 2018 to 2050 are trend projections. Assuming these linear trends, the global recycling rate would reach 43% in 2050, the global incineration rate would be 50% in 2050, and the global discard rate would be down to 7%. This is just one possible future scenario. There are any number of reasons why the global recycling and incineration rates might not develop in such a way.

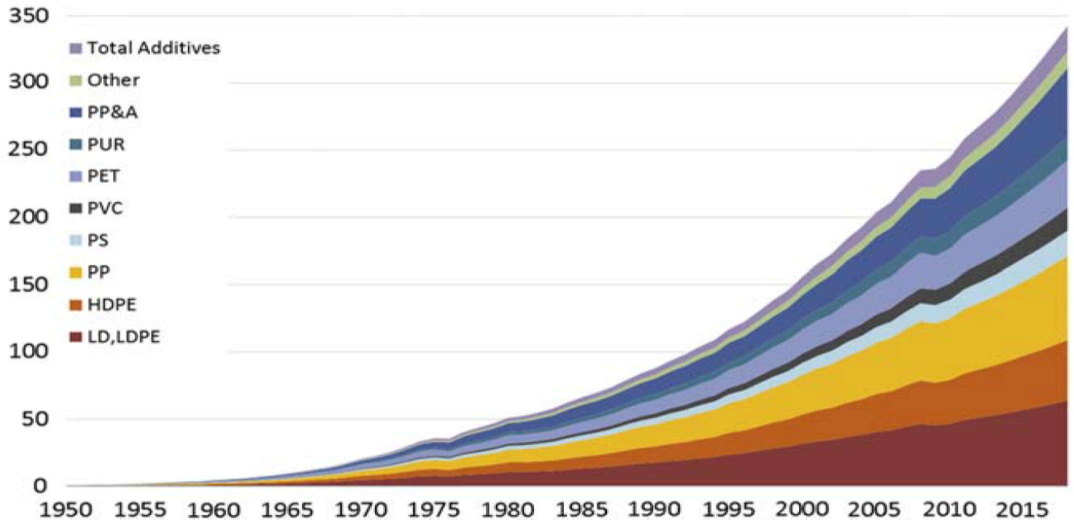

Figure 1: Global annual primary plastic waste generation (in Mt) by type from 1950 to 2018 [5]

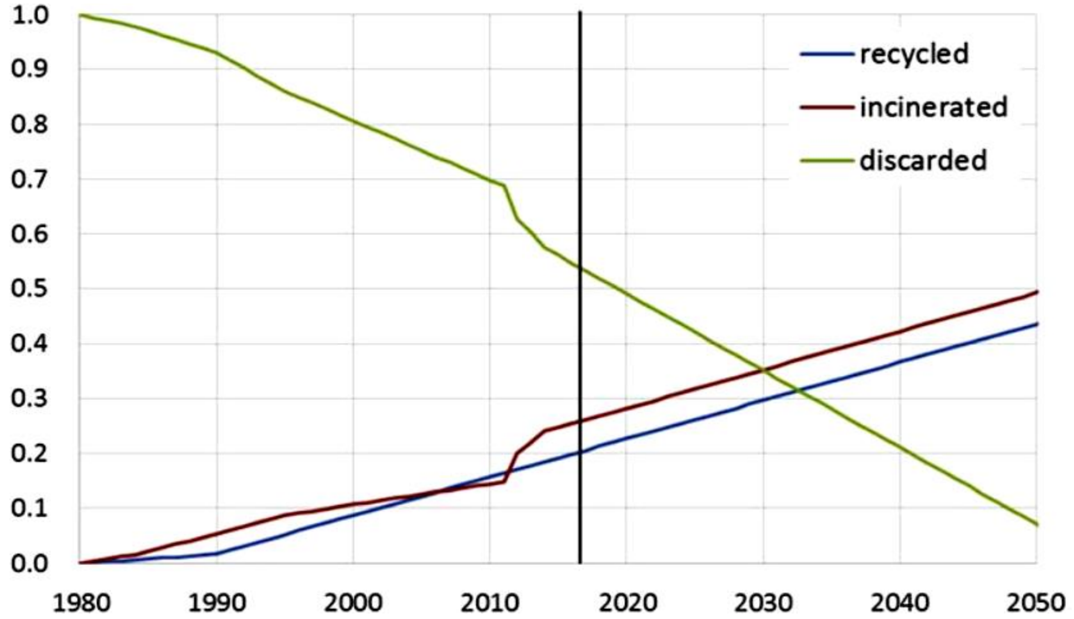

Figure 2: Projection of global trends in recycling, incineration, and discarding of plastic waste [5]

The raw material considered for the extruder to be produced is High Density PolyEthylene HDPE (HDPE-High Density PolyEthylen), due to its abundance among plastic waste and the fact that it is recyclable twice (see following table). The Table below, inspired by [2], gives the main physico-thermal characteristics of HDPE**[6], [7], [8]**.

Table 1: Physico-thermal properties of HDPE

Description	Value	Description	Value
Recycling symbol	2 HDPE	Density	0.94 – 0.965
		Maximum operating temperature	105 ^{0}C
Chemical formula	$(C_2H_4)_n$	Embrittlement temperature	- 50 ^{0}C
Volumic mass	0.941 – 0.965g/cm^3	Melting temperature	85 – 140 ^{0}C
		Glass temperature transition	- 110 ^{0}C
Thermal conductivity	0.46 – 0.51 W/m.K		

We see in the table above that HDPE has interesting properties for extrusion.

2.2 Methods

2.2.1 Design methods

One of the tools used by NPD is APTE method (Application aux Techniques d’Enterprise or in English: APplication to business TEcHniques). APTE has been created by Gilbert Barbey in 1964 and is focused on the functional analysis at the early stages of design [9], [10]. Currently, this method is deposed by APTE Company and designates a functional analysis method in addition to value analysis to drive innovations and projects optimization [11]. The APTE (Application to Business Techniques) method is used to establish the functional specifications, through the horned beast and Otopus diagrams. The FAST (Function Analysis System Technic) diagram then allows you to move from service functions to technical functions and then to the appropriate technological solutions.

2.2.2 Sizing methods

Hopper sizing

Sizing a feed hopper consists of:

- Geometric configuration and annotation:

It consists of determining the volume of the hopper in cubic meters by providing data on the dimensions from the shape and limit angles.

- Evaluate the hopper load:

This involves calculating the total mass of thermoplastic granules contained in the hopper using the formula:

$$\text{MassG} = \text{mass of a granule} \times \text{Number of granules} \quad (1)$$

$$\text{Number of granules} = \frac{\textit{Hopper volume}}{\textit{Volume of one granule}} \quad (2)$$

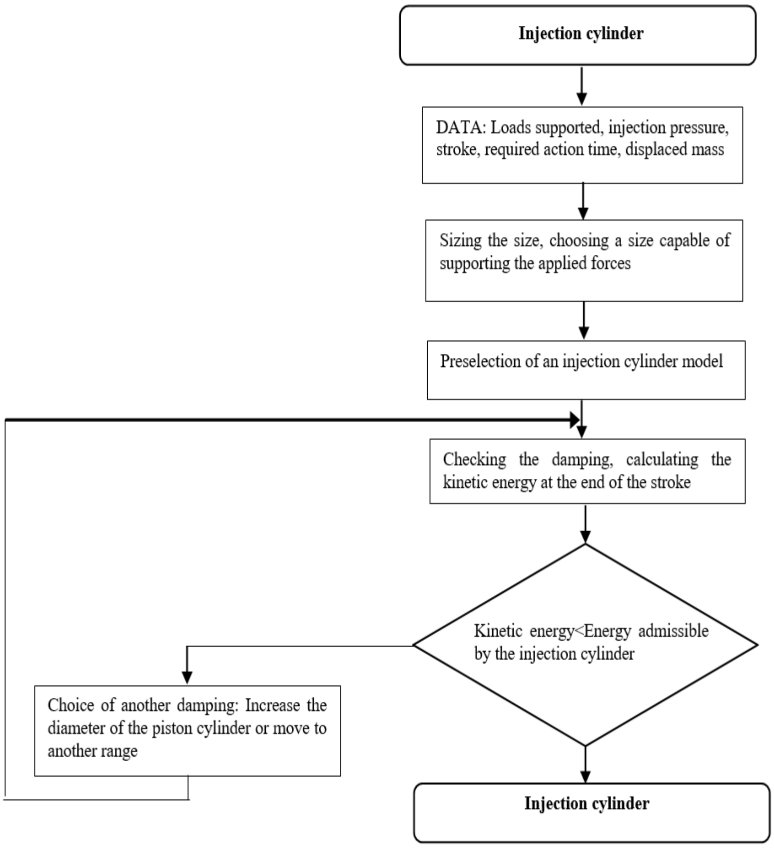

Figure 3: Summary of the choice of the injection cylinder

Sizing the injection cylinder

The injection cylinder is made up of two cylindrical rods with a diameter difference, so the upper part is called the rod and the lower part called the piston.

Sizing the injection cylinder will provide the following data:

- The mass of the injection cylinder: which is determined from knowledge of the material, namely its density.
- The force developed by the piston given by the following formula:

$$F_P = M_T \times g \quad (3)$$

M_T = total injection mass

g = Gravity intensity = 9,8 m/s^2

- Injection pressure
- $P = \frac{F}{S}$ (4)

P = Injection pressure
F= Force developed by the injection cylinder
S = Injection cylinder diameter section

Lever arm sizing
Forces are not enough to explain movements. For rotation, we must also take into account the distance between the axis of rotation and the line of action, this is what we call lever arm. The arm on which the force is applied must be longer than the resistance arm by the same number of times as the resisting force is greater than the force applied. Transposed to the level of a mathematical equation, this formula is expressed like this:

$$\frac{L}{l} = \frac{R}{E} \quad (5)$$

L = Length of the arm on which the effort is applied
l= length of resistance arm
R= Resistance by weight or power
E= Force applied in the form of effort

Moment of a force

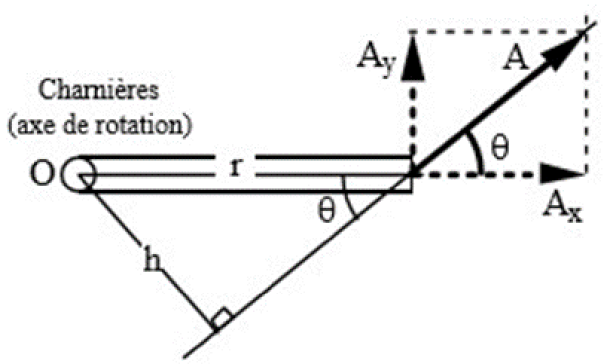

Figure 4: Rotation axis representation

From these observations we can operationally define the moment of a force with respect to an axis of rotation as being: “The product of the magnitude of the force multiplied by the distance between its line of action and the axis of rotation considered” The distance or lever arm is measured perpendicular to the line of action of the force. We calculate the moment of the force with respect to the axis of rotation "O" in the figure above as:

$$\boldsymbol{M_0} = \textbf{Force} \times \textbf{Lever arm (perpendicular)} \quad (6)$$
$$\boldsymbol{M_0} = \textbf{A} \times \textbf{h} \quad (7)$$

For calculating the moment from a drawing (graphical method), this method is relatively easy to use. However, for the analytical calculation of the moment, it is sometimes difficult to calculate the "lever arm" h. We always note the moment M indexed by the axis of rotation "O" relative to which we measure the moment Mo. From the laws of trigonometry, we can deduce that:

$$h = r sin\theta \quad (8)$$

So:

$$M_0 = A \times r sin\theta \quad (9)$$

Likewise, if we observe the components of A, we will have:

$$A_x = A cos\theta \quad (10)$$
$$A_y = A sin\theta \quad (11)$$

As we see and as we defined, the moment of force is the product of the force multiplied by the lever arm measured perpendicularly. The horizontal component of A (Ax) does not have a lever arm (its line of action passes through O »; h = 0) so its moment is necessarily equal to 0 too. The vertical component of A (Ay) is already perpendicular to the lever arm "r" so its moment is equal to:

$$M_0 = A_y \times r \quad (12)$$

As we have $Ay = A\ sin\theta$ then

$$M_0 = A sin\theta \times r \quad (13)$$

The moment of a force can be calculated by the sum of the moments of the components of this force. When the force tends to rotate a body counterclockwise around any axis its moment will be positive whereas if it tends to rotate clockwise this moment will be negative. This convention will be useful when calculating the total or resultant moment on a body. In summary:

Moment of a force (Mo) = force × lever arm (N.m) or ∑ *moment of components* of this force

Resultant moment (∑ Mo) = ∑ *moment of each force* or ∑ *moment* of force components

Mo (+) → The body tends to rotate counterclockwise around O

Mo (−) → The body tends to rotate clockwise around O

Sizing the plastic injection mold

It is the number of parts to be molded which determines the size of a mold. The manufacture of a plastic injection mold depends on the part to be produced. The sizing of a mold depends on:

- The shape of the room
- The dimensions of the part according to the specifications
- The raw material
- The tolerances of the part
- Machine capabilities
- Production rates

Calculation of thermal diffusivity

Thermal diffusivity is a physical quantity that characterizes the ability of a material to transfer heat (thermal energy) through this material. It depends on the material's ability to conduct heat (thermal conductivity) and its ability to accumulate heat (volumic heat capacity).

Thermal conductivity changes with temperature. For solids, it responds to the following law:

$$\lambda = \lambda_0 (1 + \alpha\theta) \quad (14)$$

λ_0 = Thermal conductivity on a material at 0°C

α = Characteristic coefficient of each material

θ = Temperature (°C)

α is positive for thermal insulators and negative for thermal conductors.
When the temperature increases, an insulator loses its insulation capacity and conversely the conductor loses its conduction capacity.
We determine the thermal diffusivity by the formula:

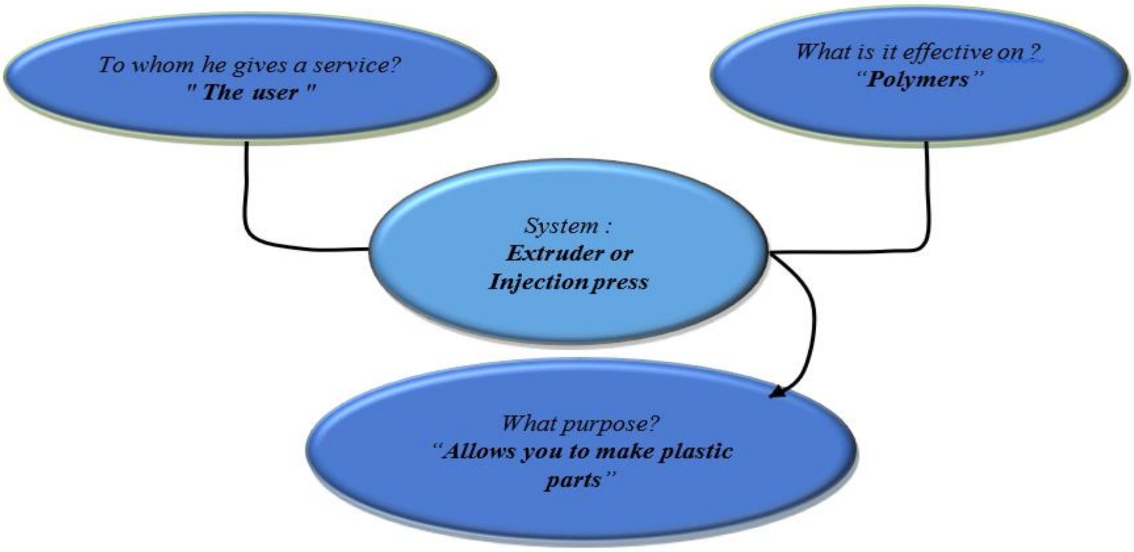

Figure 5: Horn diagram of plastic extrude

$$\mathbf{D} = \frac{\lambda}{\rho c} \quad (15)$$

λ = Thermal conductivity of the material (W/m/K)

ρ = Density of the material (Kg/m^3)

c = Specific heat capacity of the material (J/Kg/K)

Thermal diffusivity is an intensive quantity. It determines the thermal inertia of a solid.

Calculation of cooling time

The part will be ejected when it reaches a temperature called the demolding temperature, this temperature can be reached in the center of the part or it can be an average temperature of the entire part.
1st case: the part is injected only if the temperature in the center of the part reaches the demolding temperature, in this case the cooling time is obtained by the following formula:

$$t_c = \frac{S^2}{a\pi^2} ln\left(\frac{4}{\pi}\frac{\theta_i - \theta_M}{\theta_{dem} - \theta_M}\right) \quad (16)$$

2nd case: the part is injected only if the average temperature of the part reaches the demolding temperature, in this case the cooling time is obtained by the following formula:

$$t_c = \frac{S^2}{a\pi^2} ln\left(\frac{4}{\pi^2}\frac{\theta_i - \theta_M}{\theta_{dem} - \theta_M}\right) \quad (17)$$

S = Thickness of the part (mm)

D = Thermal diffusivity of the injected material (mm/s)

θi = Injection temperature (°C)

θM = Mold temperature (°C)

θdem = Demolding temperature (°C)

tc = Cooling time (s)

3. RESULTS AND DISCUSSION

3.1. Fundamental expression of the need for the plastic extruder

Figure 5 defines the need that the system responds to overall.

3.2. Functional specifications

The definition of the service functions of our system is given in Figure 6 and Table 2.

Service functions	Features	Constraints
MF: Allow melting and transfer of raw material into the mold	Feed with granules Fusion of raw material and Injection of melted material under pressure	Check the dosage of the raw material, adjust to the melting temperature of the polymer
CR1: Consume little energy (electrical energy)	Low electrical energy consumption	Use of local electricity network: 220V-50Hz
CR2: Regulate the heating temperature	Set the regulator to a temperature a little higher than the melting temperature of the polymer	Use polymer melting temperature
CR3: Have easy maintenance	Maintenance levels 1 and 2 must be executable by the user	Facilitate the assembly and disassembly range
CR4: Have a smaller footprint in the environment of use	The equipment must be of considerable dimensions to facilitate access to areas of use	Dimension made according to the quantity of parts to be provided
CR5: Have a lesser impact on the environment	Do not cause pollution	Use of a non-toxic plastic material
CR6: Comply with standards (dimensions, mechanical safety)	Compliance of measures	Verification from a reference model
CR7: Communicate operating information to the operator	Inform the user about the operating principle and maintenance methods of the equipment	Train the user

Table 2: Functional specifications of the plastic injection

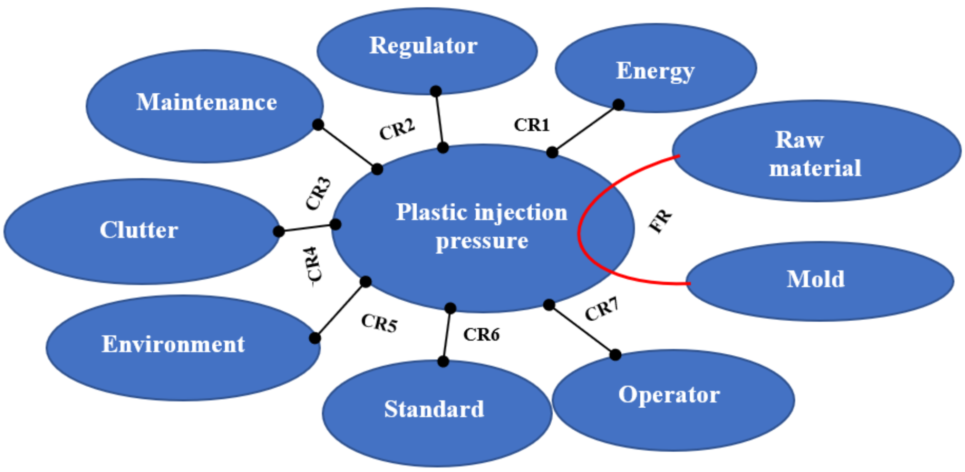

Figure 6: Octopus diagram of plastic extruder

They formalize the need; by detailing the formalities expected from our system, it allows us to specify the characteristics of the different functions defined above. The presentation recommended by the French standard NFX 50 – 151 for Value Analysis is that of the FCC table (Functions, Characteristics, Constraints) in which, on several columns, the service functions are identified with the elements which characterize them.

3.3. Expression of technological solutions

The FAST diagram of the main function "Melting and transferring HDPE" makes it possible to determine the possible constructive solutions for each technical function. For each of them, the solution implemented is the best from a feasibility and cost point of view.

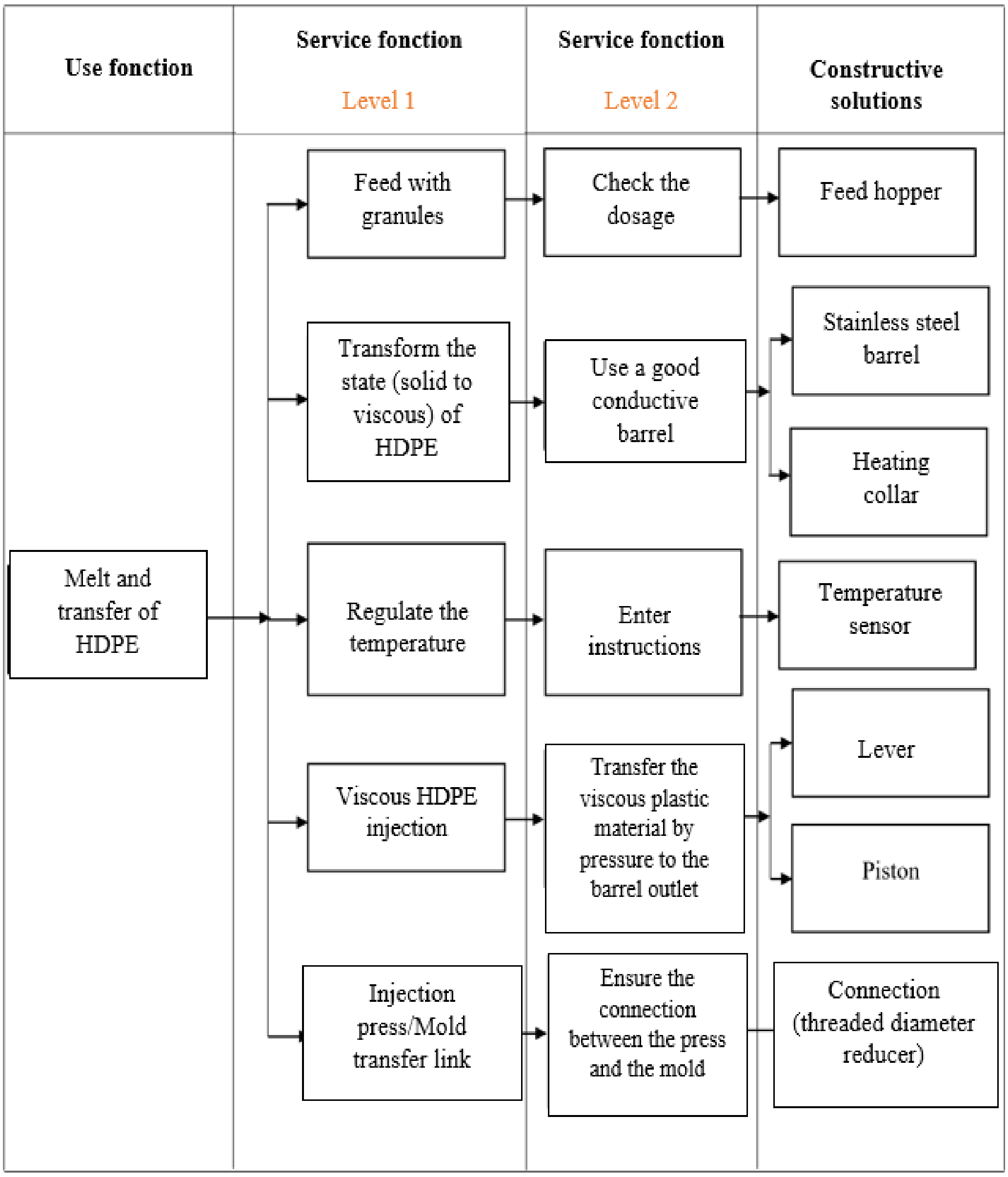

Figure 7: FAST diagram of plastic extruder

3.4 Results on the injection press

Choice of barrel

We have chosen a barrel with the follow wing characteristic

Table 3: Barrel features

Designation	Features	Material
Cylindrical tube 34×26	L = 530 mm	Stainless steel

The choice of stainless-steel material is due to its good resistance and its conductivity coefficient, which optimizes its thermal diffusivity.

The inside diameter of the barrel must be between [30; 40]mm taking into account the volume of the granules and also limiting the pressure of the injection cylinder. Or with an opening of 100 mm for the passage of granules through the feed hopper.

Hopper sizing results feed

The shape of the hopper chosen is that of any polygon having 04 faces, namely:

- 02 faces on the left and right sides having a shape similar to a right triangle sectioned at its apex to direct the pellets towards the barrel
- A face placed in front similar to a regular tetrahedron sectioned below to serve as a limit for the travel of the thermoplastic granules
- A face below connecting the hopper to the barrel to limit losses of raw materials

To achieve this design, the characteristics of the sheet metal used are as follows listed in following table.

Table 3: Characteristics of the sheet metal used for the hopper

Designation	Features	Material
Sheet metal	2 mm thick	Steel

Injection cylinder sizing results

Table 4: Characteristics of the injection cylinder piston

Designation	Features	Material
Cylindrical tube	D = 30 mm L = 26 mm	Steel

Table 5: Characteristics of injection cylinder rod

Designation	Features	Material
Solid cylindrical bar	d= 26 mm l = 685 mm	Steel

The injection cylinder must be greater than 150 mm long to facilitate the work of the lever arm.

Table 6: Lever arm characteristics

Designation	Features	Material
Square tube 30×30×4	L = 1100 mm	Steel

Table 7: Others features

Designation	Features
Number of granules	49.6
Mass of injection cylinder	2.99 kg
M_0	4.35 KN.m
D	$3,75.\ 10^{-6} m^2/s$
t_C	194 734 s
V_{Hopper}	841486.54 mm^3

3.5. 3D modeling and creation of the plastic extruder

Figure 8 illustrates the 3D modeling of the plastic extruder produced in SolidWorks, with an indication of the various elements that constitute it, as well as its rendering after completion.

101: Base; 02: Barrel; 03: Heater; 04: Press support; 05:Hopper; 06: Control box; 07: Lever arm; 08: Injection cylinder.

Figure 1: 3D modeling and overview of the extruder produced

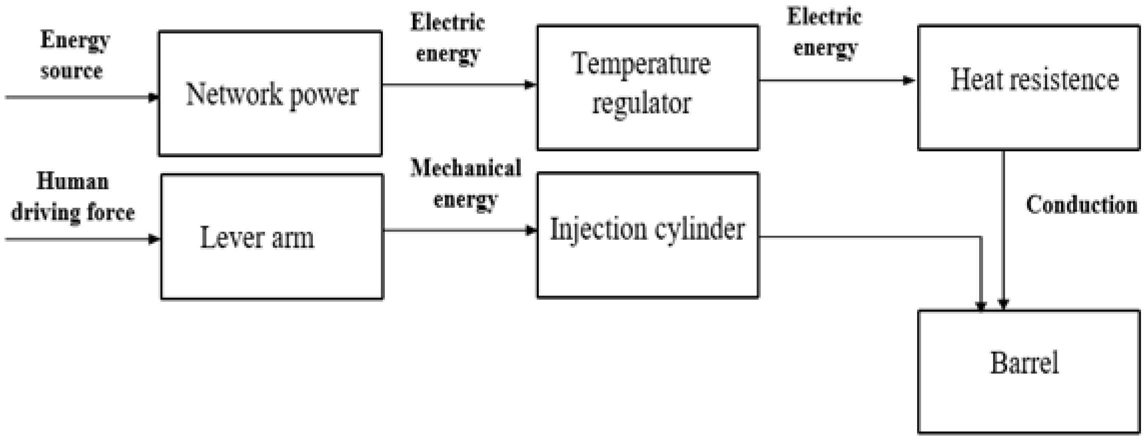

Figure 9: Block diagram of the extrusion system

The technical characteristics were determined by calculation during sizing based on the characteristics of the HDPE.

Table 8: Technical characteristics of the injection press produced

Equipment	Features
Hopper Capacity (Kg)	0.7936 Kg
Injection Cylinder Pressure (Bars)	174 Bars
Injection force (KN)	37.14 *N*
Withdrawal force (KN)	29.3 N

These characteristics will have to be updated after various tests carried out on the plastic extruder produced.

4. CONCLUSION

The main objective of this work was to design and produce a vertical plastic extruder based on an existing model **[12]**. With a view to contributing to the problem of pollution caused by plastic packaging, we carried out an analysis of the existing situation, designed and produced a prototype of a vertical extruder used for the needs of small businesses. From our research and the choice of the extruder prototype to create; we have developed sizing methods by highlighting calculation parameters aimed at obtaining information on the characteristics and dimensions of the parts to be produced. The differences with the initial model **[12]** are at the level of the injection nozzle, as well as the heating resistance system. The mechanical components have also been adjusted to the work material available on the market. Tests will have to be carried out on the injection press produced to characterize it precisely, as well as the molds produced to be able to operate it profitably.

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