A Study of Setting up a Plastic Waste Recycling Plant in Cameroon

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Abstract: ***This paper presents an approach to set up a plastic waste recycling plant using non-biodegradable plastic which are harmful to the environment. The objective is to find the appropriate set of equipment that can be used to ensure a profitable investment for any industrial waste recycling company to be set in Cameroon and in Sub-Saharan Africa in general. Once the equipment to be used for the recycling is chosen, it is necessary to design an overall layout of the unit considering the constraints related to the health and safety of employees as well as to the various risks of accidents or fire in the factory. Having performed the previous steps sequentially, a model implementation of the plastic waste recycling plant with a capacity of 1212kg/h of pellet is presented in this work. It includes three plastic waste recycling lines for the PET, the plastic films PP/PE and the rigid plastics HDPE/PP. The determination of the characteristics of the equipment from suppliers allowed us to calculate the apparent power of 1647.66 kVA and then to choose the appropriate transformer of 2000 kVA, followed by the calculation of the total water treatment of the processing plant which will have the capacity of 40 m³. Considering the net present value and payback period, this is a profitable business that potential investors would want to invest on.***

Keywords: Plant, Recycling, Sizing, Environment, Plastic waste

1. Introduction

The recycling of plastic waste according to [1] is an activity whose implementation makes it possible to solve the thorny problem of urban and suburban solid waste accumulation in Sub-Saharan Africa, been factory or domestic wastes. On the social level, it should be noted that plastic is omnipresent in objects of daily use, on the environment, plastic waste pollutes soil, air and water. Economically, recycling is interesting because local companies consume a large quantity of plastic resins. In addition, the activity can make it possible to create many jobs within the recycling plant, especially at the collection stage. Entrepreneurs in Cameroon and Sub-Saharan Africa in general wishing to set up a plastic waste recycling plant are facing several obstacles [2],[3]. The type of recyclable plastics is not controlled, the processes and technologies required and adapted to each type of plastic are still not well known, the establishment of factories is delicate and moreover, the environmental constraints inherent to setting up a plant must be considered. The objective of this work is to propose an approach allowing any potential investor to be able to easily set up a plastic waste recycling plant in Cameroon while respecting the rules of the art. In accordance with [4] technical guide on recycling, the plant will be use to recycle the most common plastic waste, particularly PET (Polyethylene terephthalate), HDPE (High Density Polyethylene), LDPE (Low Density Polyethylene) and PP (Polypropylene). The plant should not be polluting.

Achieving this objective in Cameroon is possible based on the favourable institutional context. Indeed, the Cameroonian State has set up a national strategy of waste management whose aim is to improve the living environment of populace through efficient waste management. In addition, there are several legislative provisions on toxic and dangerous waste [3], setting the conditions for sorting, collecting, transporting, recovering, recycling, treating and ultimately disposing of waste. Provisions regulating the manufacture, import and marketing of non-biodegradable packaging are also available to the general public [3]. The development of this work takes place in three main stages. It begins with the presentation of the equipment that is to say all the equipment necessary for the proper functioning of the plastic waste recycling plant. In the method, the steps used for the setting up of the plant will be presented, and then the results obtained will be presented and discussed.

2. Material

2.1 Process for the production of pellets based on plastic waste

Based on the work structure carried out by [5], a plastic waste recycling plant consists of three production lines, namely a line for recycling PET, a line for recycling plastic films PP/ PE and a line to recycle rigid plastics in HDPE/LDPE or PP. The three lines are similar because the process of transformation of plastic waste is identical and they are composed of machines having the same functions as described in Fig. 1 below. After receiving the raw materials in the processing line, they are stored in the warehouse and then they enter the washing line where they undergo grinding and washing to get out in the form of clean and dry flakes. At the end of the washing line, the flakes enter the granulation line and exit out as pellets.

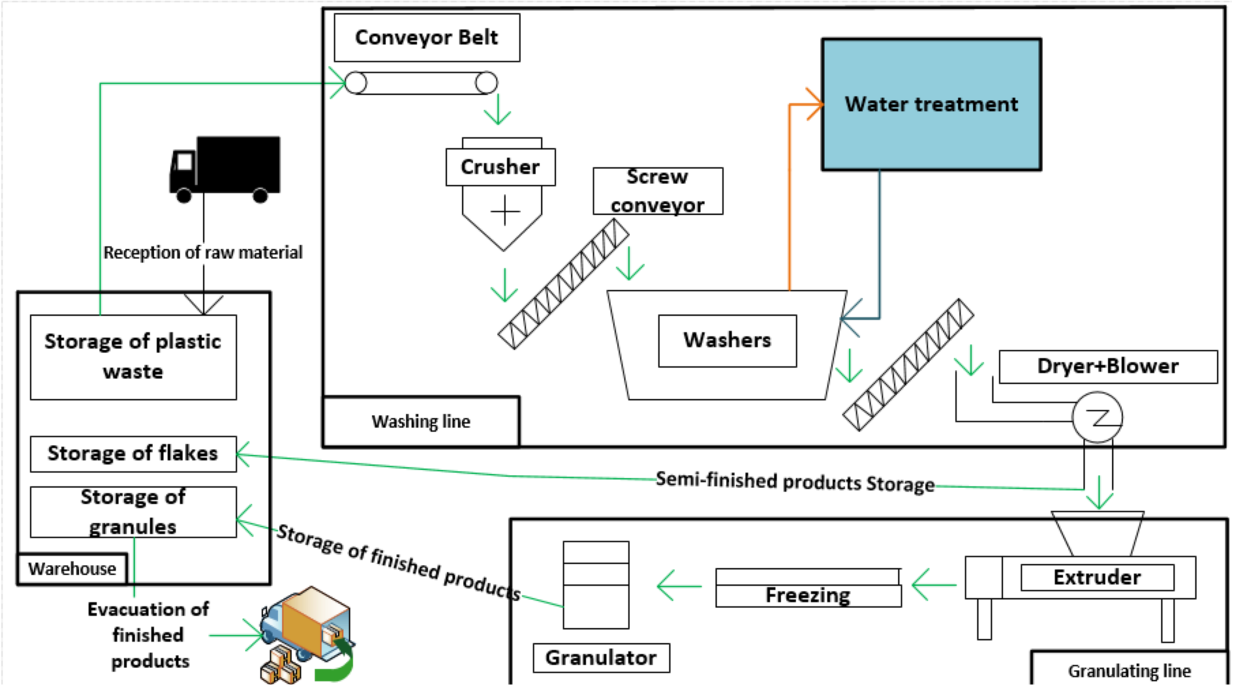

Figure 1: Block Flow of plastic waste recycling process

2.2Washing line equipment

The raw materials entering the washing line are conveyed by a conveyor belt to the desiccator responsible for removing the labels from the bottles [3], [5]. Afterwards, the bottles go through the manual sorting table, from there, another conveyor transports the bottles to the mill. The bottles leave the crusher in the form of shredded flakes or flakes and go to the washing tank using a screw conveyor. In the wash tub, the flakes will be separated from other plastics depending on the density. The flake that has a higher density than the water goes to the bottom where there is a screw conveyor that will route it to the washer. The heat washer uses hot water to remove residues of oil, detergent, hydrocarbons and kill germs or organisms (molds, fungi, yeasts) that may remain. Washing continues in the friction washer and the blades rotates at high speed to remove the adhesive materials. A screw conveyor then transports the flakes to a drip tray that removes the moisture contained. Continuous drying in the tube dryer blows warm air to move the flakes to the storage silo.

2.3Granulation lineequipment

The granulation line is composed of ten equipment which succeed one another [5]. In the subsequent production process, the flakes from the washing line pass through the extruder by pressure and fusion and transforms them into paste. Then this paste passes through a die consisting of a perforated plate. The dough comes out of the die as filaments, afterwards, these filaments enter a second extruder less powerful than the first and are retransformed into paste that comes out once again in the form of filaments after passing through a second die. Then the passage of the new filaments in a cooling tank filled with water and then well dried by a dryer. Subsequently, they pass through a granulator that cuts them with a blade so that they become plastic granules. A vibrating table then makes it possible to remove the pellets not having the appropriate size. Finally, the fan blows the pellets to a silo, it must be emphasized that this equipment require water to function. In order not to waste this water and not to pollute the environment, an industrial water treatment system is used in this case. In addition, the plant has a transformer based on the need and is supplied with a medium voltage.

2.4 Factory layout diagram

The Fig. 2 below shows the layout of the recycling plant, it appears that the warehouse (E) adjoins the granulation zone (ZG) and the washing zone (ZL), in accordance with proximity requirements for the work of [6].

This proximity is important because of the large flow of materials between these sections. It is also noted that the transformer (T) and the generator room (SG) are far from the rest of the sections to avoid the risk of fires because of the electric current. In the diagram above, there are also two gate houses (Gu) for the entrance and exit of the factory, an administrative building (BA), a quality laboratory (LQ), a canteen (C), a maintenance workshop (AM), a store (M), a water well (FE), a water treatment room (TE), an infirmary (I) and dressing rooms (V). There are two zones for possible extensions in the future and are also foreseen in the functional diagram of the factory.

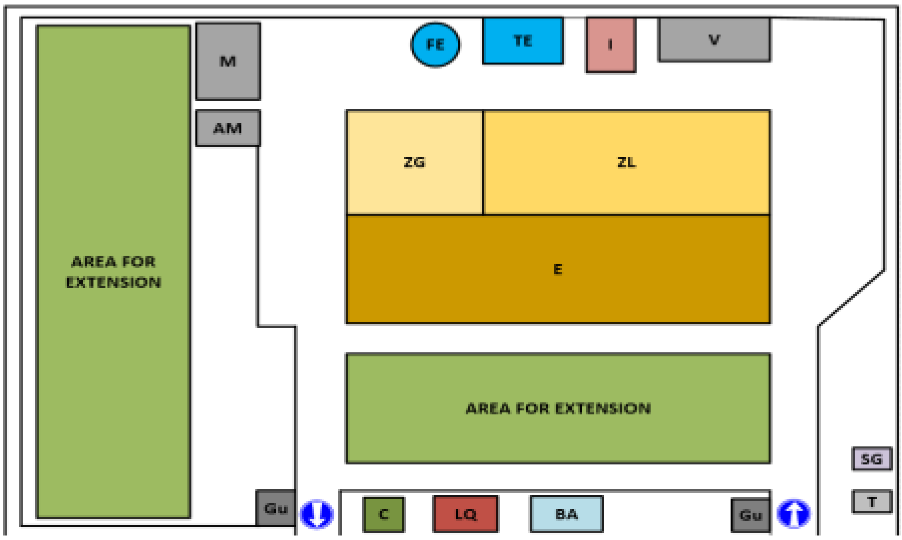

Figure 2: Layout diagram of the plant

3. Method

The study of setting up a plastic waste recycling plant takes place in three main stages. These are, the choice of process and recycling equipment to meet the expressed needs, determining of the energy needs for electricity and water for the implantation of the factory and finally assessing the feasibility of the production unit.

3.1 Choice of recycling process and equipment of the production unit

Choice of recycling process

The method of determining the appropriate recycling process for the production lineis by using a comparison benchmarking of four criteria unit[7]. These criteria are the cost of implementing the process, the complexity of the process, the effect on the environment and the energy consumption to be evaluated, a rating relationship is developed so that if a method has 10/10 on each criterion ($n_{ij} = 10 \; \forall \; i$), then its final score will be ten. For this reason, it is necessary that the sum of importance coefficients x_i be absolutely equal to one ($\sum_{i=1}^{4} x_i = 1$). Therefore, the Eq. 1 below gives the notation method.

$$N_j = \sum_{i=1}^{4} n_{ij} \; x_i \quad (1)$$

Whereas, N_j is the score of the process j, andx_i is the coefficient of importance of the criterion I and n_{ij} is the score of the process j for the $i$criterion

Table 1. below gives the scoring grid of the different processes in each criterion to be able to easily make the comparison.

Table 1: Scoring grid of recycling processes

Score	[0 ; 2[	[2 ; 4[	[4 ; 6[	[6 ; 8[	[8 ; 10]
Feedback	Very Weak	Weak	Acceptable	Good	Very Good

Indeed, the lower the cost of implantation, the higher the score, the lower the complexity of the process, the higher the score and the less the process negatively impacts the environment, the higher the score, and the lower the power consumption, the higher the score.

Choice of recycling equipment

The process of determining the best recycling equipment of a production unit is divided into three main stages which are; the statement of the problem to be solved, the elaboration of the functional specifications and the actual design of the equipment in the framework of the creation of a new working tool or the identification of characteristics and the definition of the performances to be achieved when it comes to the mechanisms or structures to be controlled by manufacturers [4]. At the end of the process, the proposed elements which would permit us to choose the right equipment from the manufacturers are decided using the strengths and weaknesses charts. To establish these diagrams, scores are given to manufacturers with respect to the criteria. Seven criteria are used which are the acquisition cost, the duration of the guarantee, water consumption, electricity consumption, size, product quality and the number of operators [5].

When the score is positive, then we are dealing the strength of equipment for the noted criterion. At the contrary, if the score is negative then it is rather a weakness of the equipment for the criterion noted. The marking scale of equipment in relation to manufacturers is given in Table 2 below. After comparing the scores awarded, one must choose the best equipment and finish with the implantation of the project.

Table 2: Scoring grid of equipment in relation to manufacturers

Score	[-6 ; -4[	[-4 ; -2[	[-2 ; 0[	[0 ; 2[	[2 ; 4[	[4 ; 6]
Feedback	Nul	Very Weak	Weak	Good	Very Good	Excellent

3.2 Determination of electricity and water requirement

Determination of the electricity requirement for the plant

According to the electrical installation guide [8], to find the installed electric power of the plant, we calculate the arithmetic sum of the power of installed receptors. Then we will obtain the power used from the Eq. 2 below:

$$P_u(kW) = \sum P_i * k_u * k_s \qquad (2)$$

Whereas, P_u is the power used in kW, P_i is the power installed in kW, k_u is the maximum use factor and k_s is the simultaneous use factor.

The apparent power is determined by using the Eq. 3 below.

$$S(kVA) = \sum \frac{P_u}{\eta * cos\phi} \qquad (3)$$

Whereas, S is the apparent power in kVA, η is the efficiency of the equipment and $cos\phi$ is the power factor of the equipment.

Determination of the water requirement for the plant

To calculate the water requirement for the plant, it is necessary to make an arithmetic sum of the water consumption of the equipment given by the manufacturers [5]. Therefore, the water consumption of the plant will be determined by Eq. 4 below.

$$C_t = \sum_{i=1}^{3} C_i \qquad (4)$$

Whereas, C_t is the total consumption of the production unit (in m^3/h), and C_i is the consumption of the i recycling line (in m^3/h).

3.3 Plant implementation process

As described in Fig. 3, the process of setting up a plant begins with the collection of data characterizing the company [9]. Particularly on the design project, the site environment, the manufacturing process, the methods and means of storage, the personnel and the organization as well as the fluids, energies and waste disposal routes. This phase is followed by the definition of the "activity sectors" where all the functional areas of the plant must be defined as well as the manufacturing, workshops and storage areas associated with maintenance, quality control, methods and scheduling, with tertiary activities. After the definition of the activity sectors will follow the determination of the needs of proximity and remoteness of these sectors considering the flows of materials, people or even information. Then, the layout diagram and finally the overall functional diagram as shown in Fig. 3 below.

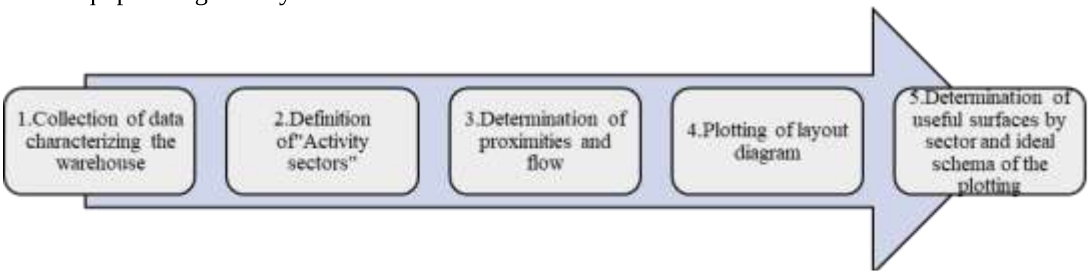

Figure 3: Steps of the plant implantation

3.4 Profitability of the investment

Cost of the investment

The total investment is obtained by adding the sum of several costs [10], the cost of equipment and infrastructures (*CE*), the cost of general services and storage (*C1*), the cost of studies and engineering (*C2*), the contractor's costs (*C3*) and allowance the contingencies (*C4*). The Eqs. 5 to 8 below are established by [10] to obtain these costs.

$$C1 = 0{,}4\, CE \qquad (5)$$

The general services here refer to the cost of labor for the completion of infrastructure construction and installation of equipment. For the storage, they therefore correspond to 40% of the cost of equipment and infrastructures.

$$C2 = 0{,}12(C1 + CE) \qquad (6)$$

The engineering studies are as much for the design and the realization. They therefore correspond to 12% of the total cost of equipment, infrastructure, general services and storage.

$$C3 = 0{,}05(C1 + CE) \qquad (7)$$

The contractor's expenses correspond to the interests that will be obtained after the completion of the project. It corresponds to 5% of the costs of equipment, infrastructure as well as overhead and storage.

$$C4 = 0{,}2(CE + C1 + C2 + C3) \qquad (8)$$

For large projects, it is advisable to provide a budget margin for contingencies. A margin of 20% is therefore taken for all costs.

Net Present Value

The net present value (NPV) is obtained from the Eq. 9 below:

$$NPV = -I + \sum_{i=1}^{n} CF_i (1+t)^{-i} \quad (9)$$

Whereas, I is the invested capital, i is the number of the year, CF_i is the cash-flow of the year i, and$t$ is the investment rate.

Payback Period

The payback period for the invested capital is the time at which the cumulative amount of discounted cash flows is equal to the capital invested. It is determined by the Eq. 10 below.

$$DR = \frac{I}{FM} \quad (10)$$

Whereas, I is the total or invested capital, and FM is the sum of cash flows during the project.

4. Results and Discussion

4.1 Recycling process

Using the Eq. 1 and with the help of the Benchmarking developed by a team of three people consisting of a General Manager, a Director of studies and assisted by a trainee, the various recognized recycling processes were noted in each criterion [3], [4] and according to the grid in Table 1. The Fig. 4 below shows the results of scoring and comparison of processes.

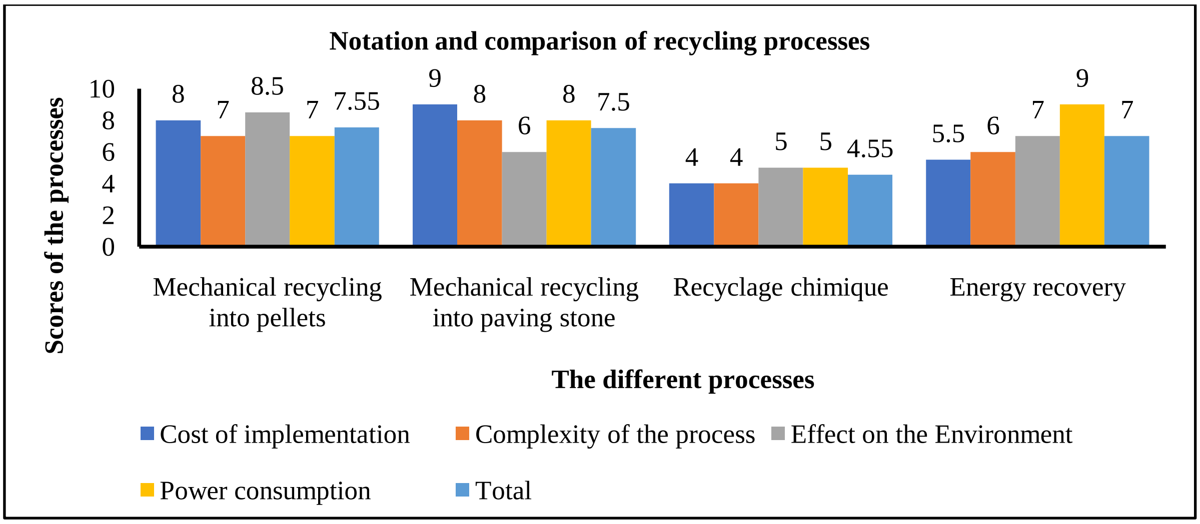

Figure 4: Notation and comparison of recycling processes

The analysis in Fig. 4 shows that the mechanical recycling in generally was well noted. However, the mechanical recycling into pellets on which the last choice is made distances out from the rest and with a lower environment impact.

4.2Characteristics of the equipment for the recycling unit

The characteristics of the equipment of the recycling unit in Tables 3 to 8 below are those of the different manufacturers. With the help of a Benchmarking developed using the grid given in Table 2 shown above, the choice of equipment in related to manufacturers is done.This equipment was separated using the strengths and weaknesses diagrams presented in Figs. 5 to 10. In these diagrams, seven criteria are used, which are the acquisition cost 1, duration of the warranty 2, water consumption 3, electricity consumption 4, measurement 5, quality of product 6, and the number of operators 7. In all that follows, the same approach is used for the choice of equipment for all three production lines.

4.2.1 Recycling line for PET

Equipment for PET washing line

Looking at the diagram of strengths and weaknesses in Fig. 5 below, it is clear that the scores of the criteria are all positive for the equipment manufacturer Jiangsu Lianshun Machinery CO that offers the best cleaning equipment PET.

Table 3: Characteristics of PET Washing Equipment

N°	Washing PET	DIANMEI Machinery	JIANGSU LIANSHUN Machinery CO.
1	Cost (in Fcfa)	34 278 000	35 460 000
2	Warranty period	12 months	12 months
3	Water consumption	12 tons/hour	1 ton/hour
4	Electricity consumption	150 kW max (105 average)	136.5 kW max (70% average)
5	Measurement (in meters)	50 x 15 x 5	50 x 3 x 3.5

6	Quality of products	Moisture: max 3% Bulk density: 0.3g/cm^3 Particle length: 12 - 16 mm	Small flakes
7	Number of operators	3	4

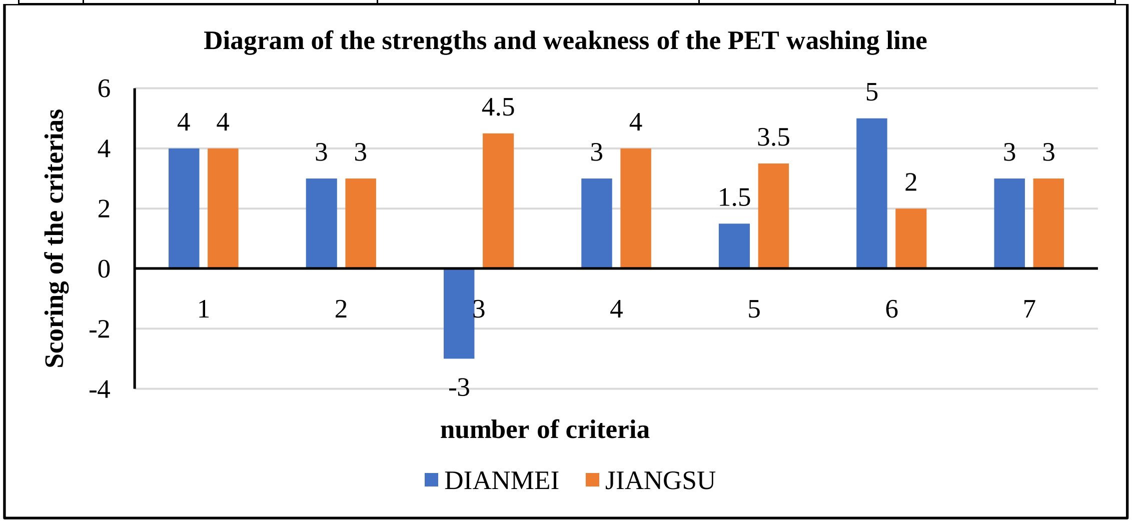

Figure 5: Diagram of the strengths and weaknesses of the PET washing line

Equipment of PET granulation line

Looking at the diagram of the strengths and weaknesses of Fig. 6, it appears that the criteria scores are all positive for the equipment of the manufacturer Haibin Machinery which offers the best PET granulation equipment.

Table 4: Characteristics of PET granulation equipment

N°	Granulation of PET	HAIBIN Machinery	BEION Machinery
1	Cost (in Fcfa)	23 462 700	53 190 000
2	Warranty	13 months	13 months
3	Water consumption	1 ton/hour	10 tons/hour
4	Power consumption	251.33 kW max (160 average)	268.55 maxi
5	Measurement (in meters)	20 x 5.5 x 3.5	5.8 x 1.2 x 2.1
6	Quality of products	Fine granules	Fine and dry granules
7	Number of operators	2 - 3	2 - 3

Paper ID: ART20192098 DOI: 10.21275/ART20192098

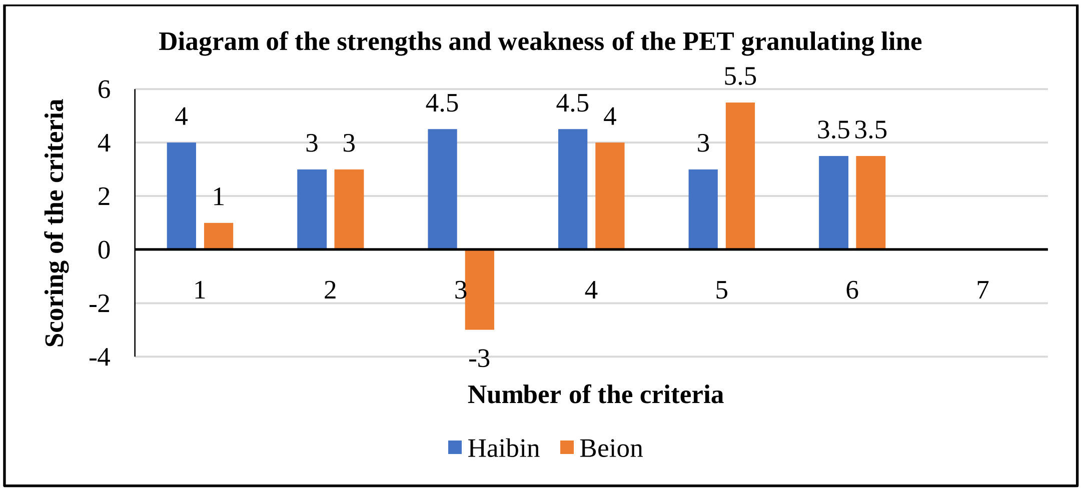

Figure 6: Diagram of strengths and weaknesses of the PET granulating line

4.2.2Plastic film recycling line for PP/PE

Equipment for PP/PE films washing line

Table 5: Characteristics of PP/PE films washing line

N°	Washing PP/PE film	DIANMEI Machinery	RECYCLING SCIENCE Technology
1	Cost (in Fcfa)	26 713 200	29 470 215
2	Warranty	12 months	12 months
3	Water consumption	8 tons/hour	5 tons/hour
4	Power consumption	228.15 kW max (150 average)	155.35 kW
5	Measurement (in meters)	50 X 8 X 5	30 x 5 x 5
6	Quality of products	Moisture: max 5% Bulk density: 0.3g/cm^3 Flake length: 50 - 80 mm	Moisture: approximately 8% Bulk density: 0.1 g/cm^3 Flake length: 40 - 60 mm
7	Number of operators	3	3

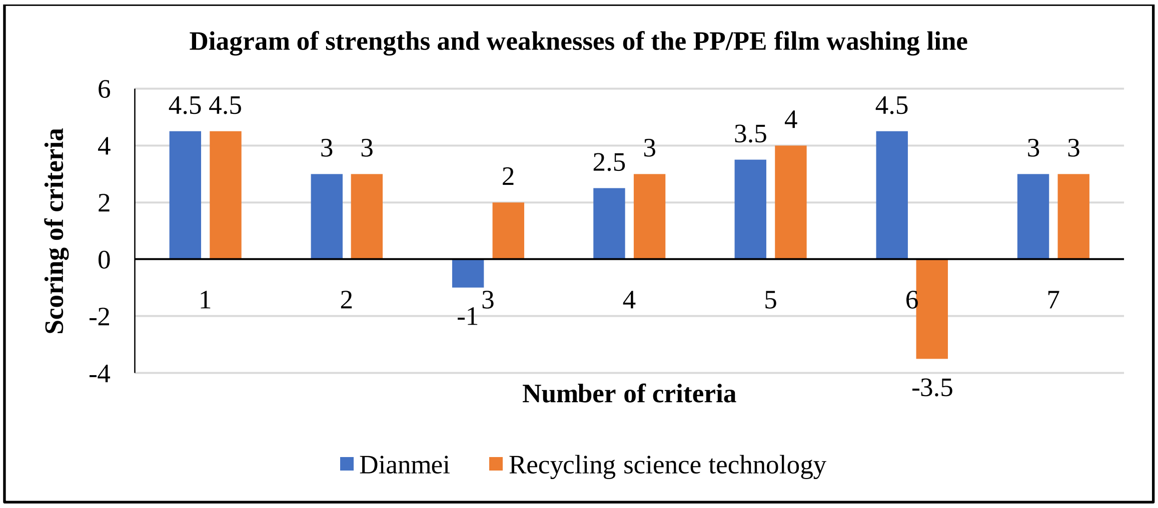

Figure 7: Diagram of strengths and weaknesses of the PP/PE film washing line

Upon reading the diagram of strengths and weaknesses on Fig. 7, it is clear that the criteria scores are positive and less negative for Dianmei Machinery equipment manufacturer which offers the best washing equipment PP/PE.

Equipment of PP/PE films granulating line

Table 6: Characteristics of PP/PE films granulating line

N°	Granulation PP/PE film	DIANMEI Machinery	LIANDIN Machinery
1	Cost (in Fcfa)	38 887 800	45 552 000
2	Warranty	12 months	12 months
3	Water consumption	5 tons/hour	8 tons/hour
4	Power consumption	342.2 kW max (280 kW average)	257.72 kW
5	Measurement (in meters)	20 X 5 X 4	25 x 5 x 4
6	Quality of products	Granules of PP/PE	Granules of PP/PE
7	Number of operators	2	3

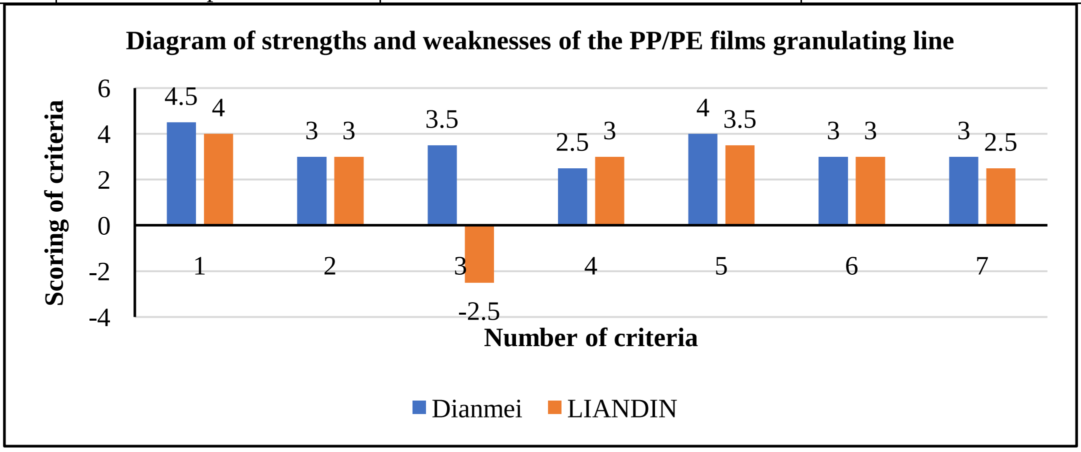

Figure 8: Diagram of strengths and weaknesses of the PP/PE films granulating line

The reading on the diagram of strengths and weaknesses on Fig. 8, shows that the scores of criteria are all positive for Dianmei Machinery equipment manufacturer which offers the best granulation equipment PP/PE.

The reading of the diagram of strengths and weaknesses on Fig. 9, shows that the scores of the criteria are all positive for Mooge Machinery CO equipment manufacturer which offers the best HDPE/PP wash equipment.

4.2.3Recycling line for rigid HDPE/PP

Equipment for HDPE/PPwashing line

Table 7: Characteristics of HDPE/PP washing line

N°	Washing HDPE/PP	MOOGE Machinery CO.	JIANGSU LIANSHUN Machinery CO.
1	Cost (in Fcfa)	33 687 000	34 278 000
2	Warranty	12 -18 months	12 months
3	Water consumption	1 tons/hour with recycling (4 - 5 tons for the first hour)	6 - 8 tons/hour
4	Power consumption	169.67 kW max	200 kW
5	Measurement (in meters)	25 x 3 x 4.5	25 x 2.5 x 3
6	Quality of products	Moisture: ≈ 5% Bulk density: variable Particle length: <16 mm	Small flakes
7	Number of operators	2 - 3	6

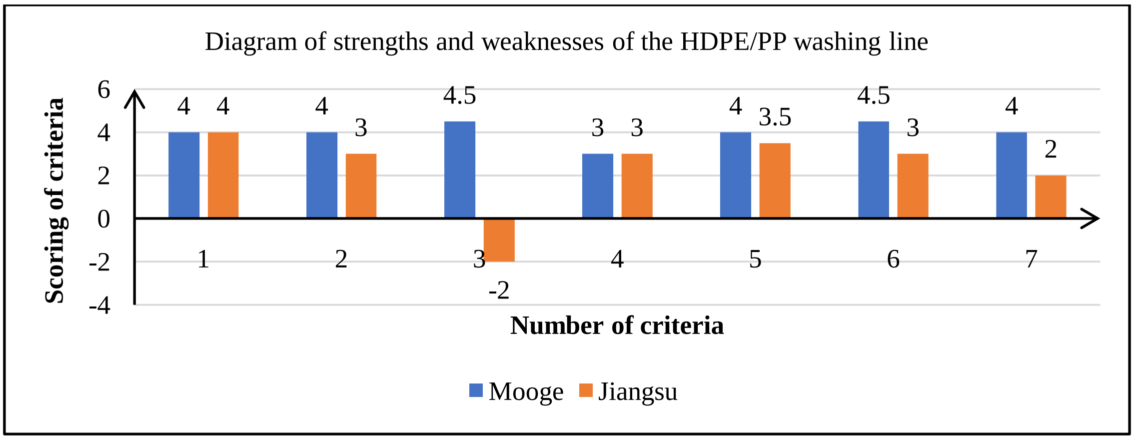

Figure 9: Diagram of strengths and weaknesses of the HDPE/PP Washing line

Equipment of the HDPE/PP granulating line

Table 8: Characteristics of HDPE/PP granulating equipment

N°	Granulation HDPE/PP	HORSE RIDER machinery	BEION Machinery
1	Cost (in Fcfa)	42 552 000	38 119 500
2	Warranty	12 months	15 months
3	Water consumption	5 tons/hour	10 tons/hour
4	Power consumption	329.74 kW	164.72
5	Measurement (in meters)	20 X 5.5 X 4	25 x 5 x 3
6	Quality of products	Pellets of HDPE/PP	Pellets of HDPE/PP
7	Number of operators	2	3

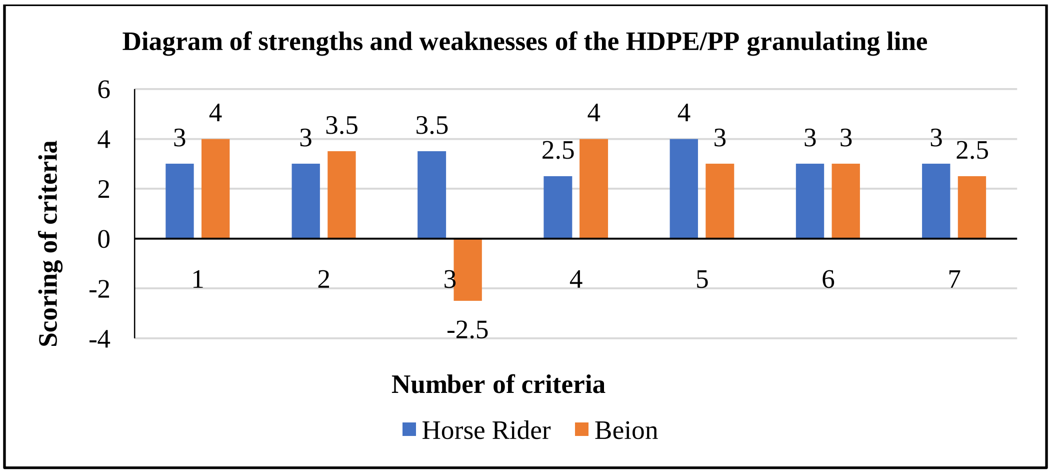

Figure 10: Diagram of strengths and weaknesses of the HDPE/PP granulating line

The reading on the diagram of strengths and weaknesses on Fig. 10, shows that the score of the criteria are all positive for Horse Rider Machinery CO equipment manufacturer which offers the best washing equipment for HDPE/PP.

4.3 Electricity and water requirements

Electricity requirements and supply equipment

With the Eq. 3 previously established, the result of the calculation of the apparent power of the plant is 1647.66 kVA. The choice of transformer is focused on the Nexan brand whose characteristics are summarized in Table 9.

Table 9: Characteristics of the Transformer

Power (kVA)	Standby losses (W)	Losses due to load(W)	Secondary current (A)	Voltage drop at full load (V)	Efficiency (%)
2000	2750	25500	2886.8	4.61%	98.27%

Water requirements and supply equipment

The arithmetic sum of the water consumption of the different lines was performed using Eq. 4 and obtained the results in Table 10 below, a total consumption of 25 m^3/h. But since the plant is allowed to grow and to experience over consumption, there must be two water treatment systems with a capacity of 20 m^3/h. The total water treatment unit will have a capacity of 40 m^3/h at a cost of 87,586,200 FCFA.

Table 10: Summary of water consumption of the recycling lines

Line	Maximal consumption (m^3/h)
Washing PET	1
Granulating PET	1
Washing PP/PE film	8
Granulating PP/PE film	5
Washing HDPE/PP FILM	5
Granulating HDPE/PP	5
Sum	25

4.4 Profitability

Investment

The investment costs are calculated using the Eqs. 5 to 8 and the values obtained are summarized in Table 11 below:

Table 11: List of the cost relative to investment (in FCFA)

CE	*C1*	*C2*	*C3*	*C4*	Sum
696 078 900	278 431 560	116 941 255	48 725 523	228 035 448	1 368 212 686

The total investment for the implantation of the plant with a capacity of 1212kg/h pellets is therefore estimated about 1,368,212,686 (one billion three hundred and sixty-eight million two hundred and twelve thousand six hundred and eighty-six) FCFA.

Net Present Value

The life span of the project is estimated at 5 years because it is during this period that the recycling of material has the best performance and therefore greater profitability. Indeed, the net present value obtained using Eq.9, in the 5 year of the project will be amount to 800,185,802 (eight million one hundred and eighty-five thousand eight hundred and two) FCFA.

Payback Period

The recovery period of the invested capital is determined by using the Eq. 10, which is in 2 years 1 month and 16 days. Considering the net present value (*NPV*) and payback period, the project can be considered profitable and cost-effective.

5. Conclusion

This work was intended to carry out "the study of setting up a plastic waste recycling plant in Cameroon". It was to analyze the elements that can treat the main types of plastic waste products in order to give them added values, while offering a recycling model adapted to the context that could be financially rewarding. After reviewing the main methods of recycling of existing plastic wastes, the choice of a method having the characteristics compatible with the needs was made and then the equipment was chosen to achieve the desired results and a general layout of the plant. The work ends with an analysis of the profitability of the project. In short, the recycling process considered appropriate for the project is that of grinding, washing and pelletizing of plastic wastes. Three lines were required for three types of waste (PET, PP/PE films, HDPE/PP rigid). The overall layout of the factory was carried out to reduce the risks for health and safety of people. Finally, the economic relevance was shown with a net value of 800,185,802 FCFA after 5 years and a payback period of 2 years 1 month and 16 days.

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