Contents lists available AInCEJ
Angolan Industry and Chemical Engineering Journal
Journal visit: aincej.com

Proposes For the Use of The Cleaner Production Tool (P+L) in the Hope Plastic Solid Waste Recycling Process

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ARTICLE INFO

Keywords:
Environment,
Plastic Waste,
Cleaner
Production.

Companies, as transformers of raw materials into finished products, have great responsibility in the protection, handling and use of available natural resources. Therefore, all efforts to promote sustainable development must be prioritized. In this context, the objective of this research is to present a proposal for the use of the environmental management tool Cleaner Production (P+L), in the HDPE plastic solid waste recycling process, in the recycling unit at the Glopol factory. Through semi-structured interviews and questionnaires, submitted to the Operators and the Production Supervisor of the aforementioned unit, it was possible to characterize the Glopol factory's recycling unit, and thus, find the main gaps inherent to the process, particularly in the separation operations. , washing and extrusion, which culminate in high water consumption and excessive waste generation (sludge and liquid effluent derived from the washing operation, and plastic sludge from the extrusion operation). After diagnosing the situation present at the Glopol factory, the proposal for adopting the P+L environmental management tool was presented, starting from planning and organization, to the implementation method, where it was possible to estimate that with the implementation of this tool, in recycling unit at the Glopol factory, it would be possible to reduce the water consumption of that unit by up to 25%, ensuring greater preservation of the natural resource. It was also possible to estimate that this adoption would bring a reduction of up to 40% in the waste generated, since through the adoption of the P+L tool, plastic waste would undergo sorting, and with this, the sludge generated in the washing, would be less and less. Such sludge would have a more environmentally correct destination, that is, it would be seen as a by-product of the process, and not as waste. As a result of the new reprocessing route for plastic sludge generated in the extrusion operation, operational gains were observed for Glopol, as the adoption of the P+L tool would bring a reduction in the plastic sludge reprocessing steps, and consequently in the time for this effect.

1. Introduction

Plastic is one of the materials that has accompanied humanity's technological development for more than 100 years, constituting a raw material in industrial processes that cover packaging, clothing, construction materials, insulation, among others, with a global demand of 359 million tonnes in 2018 (PlasticsEurope, 2019). This demand for plastics is currently projected to continue to increase, quadrupling by 2050 (Davidson, Furlong & McManus, 2021). One of the main characteristics of plastic is its inability to biodegrade in the short and medium term. According to the UN (2019), it is estimated that, depending on its components, it can take between 100 and 1000 years to disintegrate, thus causing a continuous increase in the generation of plastic waste. According to Geyer, Jambeck & Law (2017), by 2050, around 12 billion tons of plastic waste will have been dumped in trash or the environment, posing a serious threat to all forms of life on the planet.

There are different options for plastic waste management: mechanical recycling, recycling of chemicals and raw materials, pyrolysis, gasification, hydrocracking, depolymerization and incineration. Of these, mechanical recycling of plastic is one of the most used processes to recover plastic waste and use it in the manufacture of new raw material (Davidson et al. 2021). In the study presented by Sevigné-Itoiz et al. (2015) evaluated the quality and market of plastic waste and its application in the recycling industry in Spain. They carried out a material flow analysis and implemented the life cycle costing methodology in order to identify variants that reduce the environmental impact associated with greenhouse gases. Their research allowed them to determine a new model that increases the efficiency of the recycling process by up to 85% material efficiency compared to current marketing models. Another study presented by Khoo (2019) reported a process efficiency of 87.8%, in the case of polyethylene, that is, 0.878 kg of recycled plastic are obtained for each kg of previously separated waste. Arce (2022) presented a mechanical recycling strategy to recover waste in the pole manufacturing process in Mendoza, Argentina. It compared the environmental performance of two scenarios, landfill and recycling, the latter achieving a benefit rate of 22%. The authors also propose to carry out sensitivity analyzes in this type of study, in order to detect the parameters that most influence this type of process.

But despite significant economic and environmental incentives for recycling plastics through mechanical recycling, options for treating solid waste plastics at the end of their useful life are, in practice, quite limited. Pre-sorting plastics before recycling is expensive and time-consuming, recycling requires large amounts of energy and often results in low-quality polymers, and current technologies cannot be applied to many polymeric materials. Furthermore, the plastic recycling process itself generates waste. Inadequate management of this secondary waste (sorting) helps to increase the environmental and economic impact on organizations involved in this area. Recent research points the way to process improvements using new methodologies, such as life cycle costing methodology, cleaner production methodology or recently, circular economy methodology. Or chemical recycling methods with lower energy requirements, compatibility of mixed plastic waste to avoid the need for sorting and the extension of recycling technologies to traditionally non-recyclable polymers.

Cleaner Production (P+L) is the application of an integrated technical, economic and environmental strategy to processes and products, in order to increase efficiency in the use of raw materials, water and energy through non-generation, minimization or recycling of waste and emissions with environmental and economic benefits (Senai, 2010). In recent years, it has evolved and stands out as the main production strategy to prevent environmental impacts and resource efficiency, especially due to its potential to increase operational control and generate financial gains for companies.

González, Dominguez & Suppen (2007) carried out a technical, economic and environmental assessment of the reuse of bleach in the different phases of the soft drink production process using P+L tools. The authors used the life cycle analysis method to evaluate environmental impacts before and after the application of cleaner production measures in the company. The results showed significant reductions in environmental impact, and economically proposed two variants that were viable for the company's top management. Cardenas et al (2019) applied the P+L methodology to a pig farm in the Amazon. They evaluated five improvement options related to various phases of the process. The instruments used were initial environmental analysis, ecomaps, flow analysis and economic analysis. The comparative analysis detected one of the options (option 2) with a higher net present value equivalent to 5696.94 over a 5-year payback period and a lower economic impact by effectively reusing waste derived from production. Other research that highlights the importance of applying the P+L methodology is presented in Recanati, Marveggio & Dotelli (2018); Guallo et al (2020); Calderon et al (2021); Ramos et al (2021); between others.

The Glopol factory, located in the municipality of Viana, district of Capalanga, province of Luanda, Angola, is a thermoplastics factory dedicated to the transformation of polymers (HDPE, PP, LDPE and PET) and the recycling of solid plastic waste through the mechanical recycling. As a result of the direct observation carried out in the recycling unit of the Glopol factory, and the questionnaires and interviews carried out with the Operators and the Production Supervisor, it was possible to identify some challenges faced by the factory, regarding the HDPE plastic waste recycling process, a since this process generates a significant amount of waste (sludge and liquid effluents derived from the washing process, and plastic sludge from the extrusion process), which constitute a harmful hazard for the environment. This research proposes to present the results obtained with the application of the P+L methodology to the HDPE plastic waste recycling process, as well as the improvement measures that will allow a reduction in environmental impact that will improve your organization and respect the regulations in force in Angola .

2. Methodology

The research is classified as explanatory, as it sought to identify the most advantageous way of recycling HDPE plastic solid waste (through the P+L tool. The research is also classified as exploratory, as it aims to provide greater familiarity with the problem, making it explicit. The research is classified as qualitative because it does not use statistical data as the main source of the process(Gil, 2009). The natural environment was used as the main source for data collection, with the researcher as a key instrument, who maintains direct contact with the environment and the object of study. The data collected is, therefore, descriptive, as it portrays as much as possible the studied reality of the recycling process.

As for the approach method, this research used the deductive method, as it started from a general analysis of the situation of solid plastic waste at an international and national level, to a proposal for using the P+L tool within the recycling unit from Glopol. The hypothetical method was also used, since a hypothesis was raised to express the difficulties of the problem. The present research is of an applied nature in that it sought to raise knowledge about the HDPE plastic solid waste recycling process and the P+L tool, in ways to be applied in a real situation.

Bibliographical research was used: since, according to(Prodanov & Freitas, 2013) due to the fact that this research is based on materials already published, with the aim of putting the researcher in direct contact with all the material already written on the subject of research, and case studies in the field, with the aim of collecting and analyzing information about the unit of recycling at the Glopol factory.

For data analysis, the content analysis technique was used. In a case study developed by Yin (2001), it is not necessary to limit yourself to a single source of evidence, it can be based on broad sources.

According to Sampieri (2006), the sample is a subgroup of the population of interest, from which data will be collected and which is precisely defined or delimited in advance. To obtain a representative sample, the sample size must not be less than 10% of the population, according to(Carmo & Ferreira, 1998), as cited by(Alfredo & Molina, 2021).

Therefore, due to time constraints, and the fact that the factory places great value on man-hour productivity, it was out of the question to interview and survey the population as a whole. To select the sample, a simple random sampling technique was used, in which 13 Operators belonging to shift A were selected, representing a sample of 33.33% of the population of Operators from the recycling unit at the Glopol factory, who responded to a questionnaire of approximately 10 questions.

The Ishikawa diagram was used, which according to Miguel (2001), consists of a tool used to analyze the causes of a given effect. It will be used to determine the various causes underlying the main discrepancies throughout the process, specifically in the separation, washing and extrusion operations.

In order to block barriers opposing the implementation of Cleaner Production, action plans were drawn up for each of the barriers identified, using the 5W1H tool. The most current plans (5W2H or 5W3H) were not used, due to the fact that the aforementioned factory is in the process of organizing its accounting.

For the purposes of presenting representative data, some variables were calculated, which helped to analyze deficiencies and losses during the operations targeted in this study, through the relationships presented in Equation 1, based on the mass balance in the washing operation.

$$P_r = S_p - E_i \qquad (1)$$

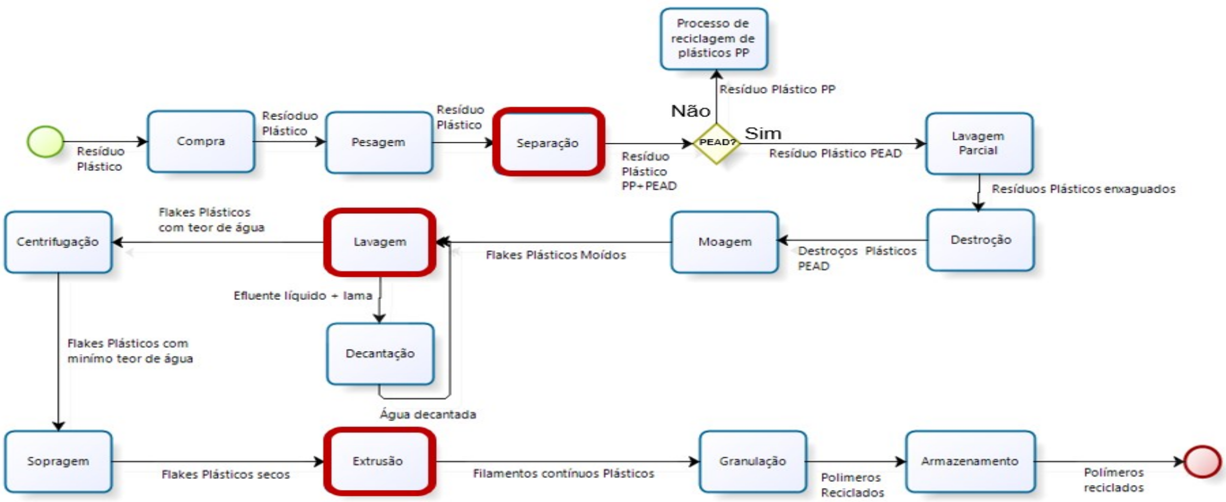
To determine the outputs or total produced, the Equation 2 is used.

$$S_p = E_i + A \qquad (2)$$

3. Results and Discussions

During the participatory observations made in the recycling unit of the Glopol factory, it was possible to verify that the separation, washing and extrusion processes are those that generate large amounts of waste and emissions, and at the same time, those that cause large financial losses, which is why which constituted the focus for the application of the environmental management tool Cleaner Production (P+L). In Figure 1 it is possible to observe the current mechanical recycling process at the Golpol factory:

Figure 1: Mechanical recycling process at the Glopol factory

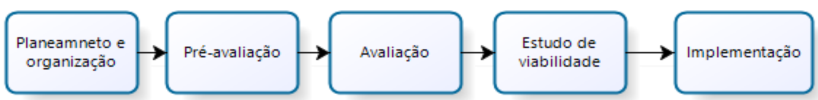


Source: Author (2022).

To use the P+L tool in the HDPE plastic solid waste recycling process, in the recycling unit at the Glopol factory, a series of steps were followed (Figure 2).

This research proposes a complete reformulation of the HDPE solid plastic waste recycling process, in such a way that plastic waste, upon arriving at the Glopol factory, previously undergoes screening, in order to validate or invalidate the supply. After sorting, suitable waste is purchased and sent to the normal course of the process, and unsuitable waste returns to the supplier. Upon finding the separation operation, it is proposed to divide the production lines for post-industrial and post-consumer waste.

Figure 2: P+L tool steps to be applied at the Glopol factory



Source: CNTL (2000).

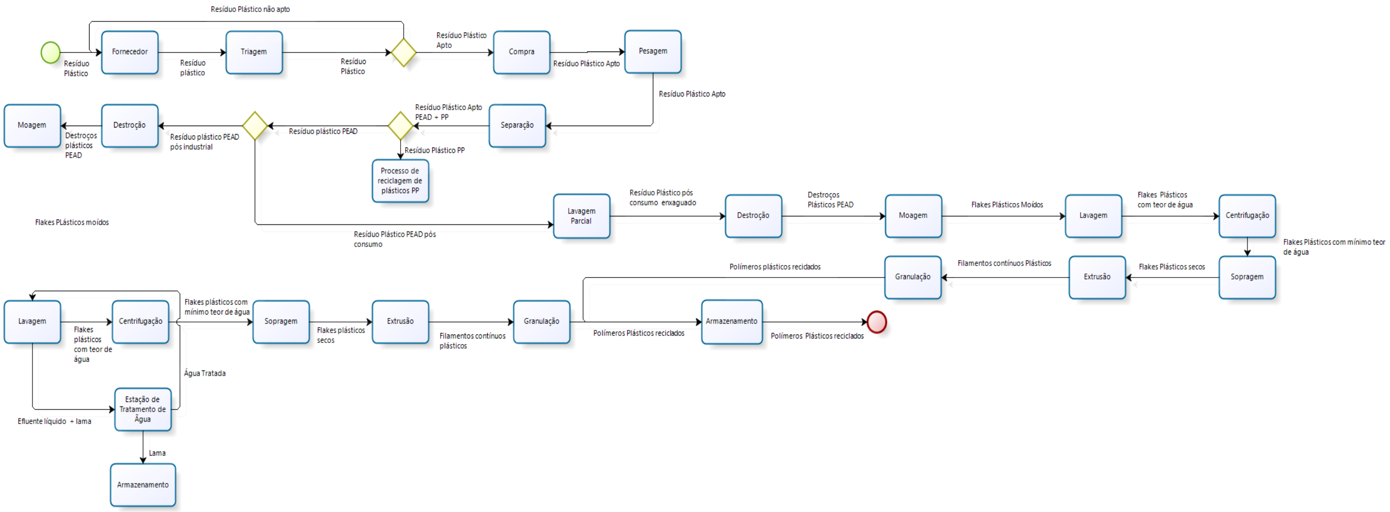
Since Glopol's physical arrangement is by process, this separation would be easily implemented. Post-industrial waste goes to processing where the partial washing operation will not exist, and post-consumer waste will go to the process that has currently been carried out by Glopol, that is, with partial washing.

It is also proposed to build an ETA to treat water from washing, so that it can be properly recirculated in the process. Finally, it is proposed that the sludge generated in the extrusion process is reprocessed only in the grinding operation, and then returned to the extruder. In figure 3, it is possible to visualize the aforementioned proposal, in a systemic way through a flowchart.

3.1. Separation Operation

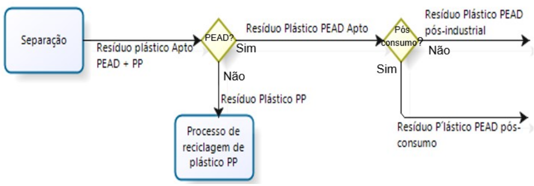
For this operation, it is proposed that quality specifications be created for the waste received, so that suppliers, mainly of post-consumer waste, look at the raw material they send to Glopol as a product to be delivered according to customer specifications. The waste will go through a sorting process, in order to analyze its level of contamination, and only waste deemed suitable will be able to continue towards the process. A separation between post-industrial and post-consumer waste processing lines is also proposed, as post-industrial waste does not require a significant amount of water for washing. This separation is expected to reduce water consumption in that unit, as the same amount of water would no longer be used to wash waste of relatively different origins and levels of contamination. In Figure 4 an illustrative presentation of what is proposed to be changed in the separation process is presented.

Figure 3: Proposal for using the P+L tool in the HDPE plastic solid waste recycling process



Source: Author (2022).

Figure 4: P+L applied to the separation operation.



Source: Author (2022)

3.2. Washing Operation

For this operation, it is proposed to reduce the amount of water that is used to wash post-industrial waste, as it does not require the same treatment as post-consumer waste. The idea is to rationalize the use of this natural resource as much as possible. In this way, the partial washing step for post-industrial waste no longer exists. It is also proposed to better monitor the amount of water used in the washer, that is, that the washer is rigorously filled with the amount of water established by the manufacturer (100 liters), in order to avoid unnecessary overflow of water, making the unorganized washing environment.

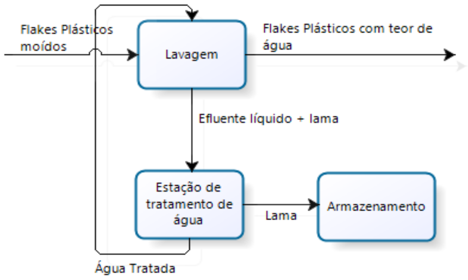
To give greater value to washing water, it is proposed to take advantage of the existing decantation system to create a water treatment plant, which would ultimately eliminate the generation of liquid effluent in the washing operation, allowing for a better system. of water recirculation. This station would also reduce the number of water shipments carried out, which would culminate in greater preservation of the most precious natural resource (water). On the other hand, the liquid effluent would no longer be discarded into the soil, providing greater preservation of the environment. In figure 5 it is possible to observe the washing environment at the Glopol facts

Figure 5: Glopol factory washing environment.

Source: Author (2022).

For the sludge generated in this stage, it is proposed that it be stored appropriately, that is, that it be treated as a by-product of the process, which can be used in another process, where it can generate value. Figure 6 illustrates the principles of P+L, applied to the washing process.

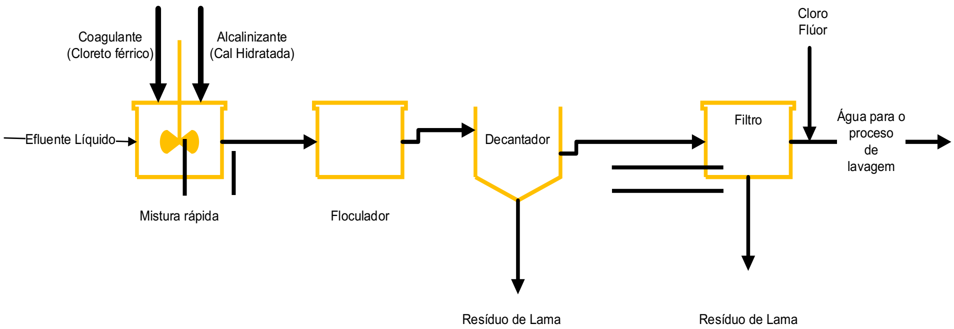
Figure 6: P+L applied to the washing operation.



Source: Author (2022).

Figure 7 presents a simplified flowchart of the water treatment process, which could be implemented at Glopol, that is, taking advantage of the existing decantation system (Figure 8).

Figure 7: Simplified flowchart of the water treatment process.



Source: Adapted (Zanei, 2020).

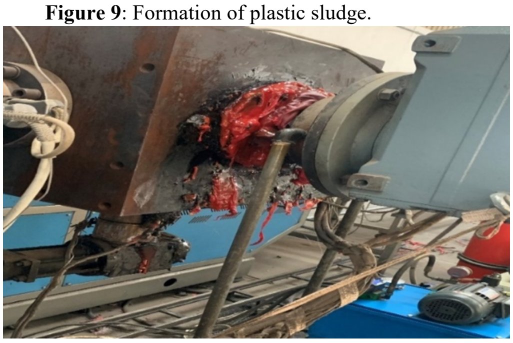
Figure 8: Washing area connected to the decantation system.

Source: Author (2022).

3.3. Extrusion Operation

For this operation, it is proposed to divide the break times of the operators working on the extruder (Table 1), in order to avoid stops during this period, as a result of direct observation made during the study visit, it was possible to verify that the operators were less willing to work, minutes before and minutes after lunch time, in Figure 9 it is possible to observe the residues formed by the constant stops.

Figure 9: Formation of plastic sludge.



Source: Author (2022).

Table 1: Distribution of work centers per hour.

Period from 11:30 to 12:30	Period from 12:30 to 13:30
Operator 1 (Kbm Extruder)	Operator 3 (Kbm Extruder)
Operator 2 (Beier Extruder)	Operator 4 (Beier Extruder)
	Operator 5 (Beier Extruder)

Source: Author (2022).

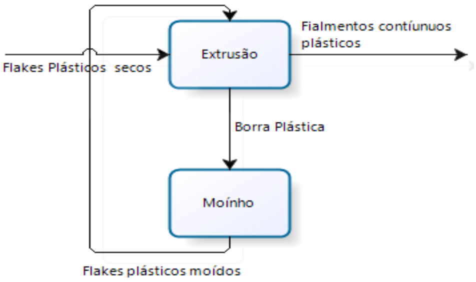
The proposal also includes preventive maintenance, in order to avoid unnecessary stops during the process. There is a strong need to train operators in the relative knowledge of the consequences of the temperature of the system in which they work, as this will allow them to be more careful not to exceed the optimum temperature. In figure 10 it is possible to observe the plastic sludge formed in the extrusion process.

Figure 10: Plastic sludge from the extrusion process.

Source: Author (2022).

In this way, the formation of plastic sludge would be avoided in this operation, which means rework, as the sludge generated returns to the beginning of the process, so as not to lose material. However, it is important to take into account that the sludge generated will be reduced and not eliminated, as there will always be waste in a process. Therefore, we must look for ways to rationalize its reprocessing. It is proposed to reprocess this residue only in the grinding process, and then send it to the extruder, as it does not require destruction due to its texture, nor washing, as it was generated in the same process. Figure 11 shows the P+L applied to the extrusion process.

Figure 11: P+L applied to the extrusion process.



Source: Author (2022).

A material balance was made to allow the quantification of previously unknown losses or emissions. The material balance brings understanding about the source and cause of waste and emissions. This understanding is necessary to generate cleaner production opportunities. The material balance is not only used to identify inputs and outputs, but also the costs associated with those inputs and outputs. In table 2 it is possible to observe the annual mass balance for water and in table 3 the HDPE, relating to the year 2021.

Table 2: Annual material balance (water) for the year 2021.

Year	Annual consumption	Annual costs	Number of shipments
2021	1920000 liters	2220000 kz	24

Source: Freitas (2021).

Table 3: Annual material balance (HDPE Plastics) for the year 2021.

Year	Feedstock	Annual costs	Annual production
2021	1313639kg	580283750kz	1087311 kg

Source: Freitas (2021).

It is proposed to carry out a daily balance of material from the recycling process, to build historical data, in such a way that it is possible to have a view of when it was output, in relation to what was input, and how much residue was formed. With the proposal in question, it would be possible to observe a significant decrease in the number of loads carried out, and consequently in water consumption, since the partial washing stage will be eliminated for post-industrial waste, therefore, it is expected that is presented below (see table 4).

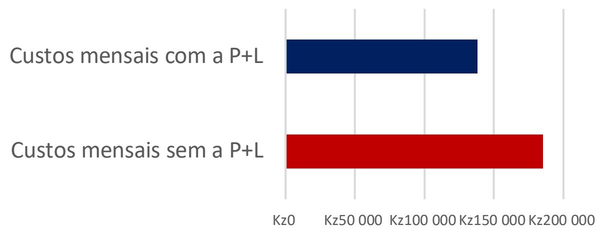
Table 4: Analysis of water consumption, without and with P+L (estimate).

Without P+L	With P+L
Monthly filled tank volume: 160000 liters	Monthly filled tank volume: 120000 liters
Number of tank fills (in the month): 2	Number of tank fills (in the month): 1.5
Washer supply: 10000 liters	Washer supply: 10000 liters
Number of washer fills (in the month): 16	Number of washer fills (in the month): 12

Source: (Author, 2022).

In Figure 12, the estimated monthly costs with the implementation of P+L measures are presented.

Figure 12: Estimated monthly water consumption costs.



Source: (Author, 2022).

Using the estimates presented above, it is possible to observe that with the adoption of P+L, there is a reduction in water consumption of up to 25%, which ends up reducing the number of annual charges, the aforementioned payment for water, and the quantity to be supplied, as illustrated in Table 5.

Table 5: Forecast of the annual material balance (water) for the year 2024.

Year	Annual consumption	Annual costs	Number of shipments
2024	1440000 liters	1665000 kz	18

Source: Author (2022).

The adoption of P+L is also expected to reach the value stipulated by Glopol as the minimum acceptable losses in the process (10%), representing a 40% decrease in losses currently generated, as seen in Table 6.

Table 6: Forecast of the annual material balance (HDPE Plastics) for the year 2024.

Year	Feedstock	Annual costs	Annual production
2024	1313639kg	580283750kz	1182275 kg

Source: (Author, 2022).

4. Conclusion

The development of this research enabled an analysis of how the Cleaner Production tool can be applied in the HDPE plastic solid waste recycling process. This is a topic worthy of attention, as recycling has been a measure increasingly adopted across the country. However, like any process, recycling also generates waste, which is why measures must be taken to allow recycling in an environmentally sustainable way.

This research focused on operations within the recycling process, which generate greater amounts of waste and greater financial losses, having found that, at the level of the separation operation, the lack of sorting, the workers' poor knowledge and the conditions of work, are the basis for this operation to cause numerous discrepancies, and thus affect subsequent operations, as a poorly done separation ends up sending raw materials with a high level of contamination to the process, thus making it unfeasible.

In the washing operation, it was possible to verify that the greater the level of contamination of the raw material, the greater the amount of sludge generated, hence the great importance of good separation.

It was also possible to verify that the high water consumption is due to the failure to rationalize this resource when filling the washer, as well as the fact that the same amount of water is used for waste with different origins and contamination levels. Therefore, supervision at the time of filling and the separation of production lines for post-industrial and post-consumer waste proved to be the most correct alternatives to overcome these problems.

In the extrusion operation, it was possible to verify that the biggest cause of excessive generation of plastic sludge is due to the lack of monitoring of the optimal working temperature, as well as due to constant stops in the extruder. Therefore, the division of Operators during peak sludge formation times, the focus on preventive maintenance and training of workers, proved to be the most viable alternatives.

The proposal to use the Cleaner Production (P+L) tool in the HDPE plastic solid waste recycling process, in the recycling unit at the Glopol factory, which was presented in this research, allows for a reduction of approximately 25% in consumption of water during the washing operation.

The proposal presented also allows for a significant reduction in the plastic sludge generated during the extrusion operation, as well as a reduction in the time and resources spent on its reprocessing, since this proposal eliminates 4 steps in the process of valuing the sludge generated.

It was also observed that it was possible to reduce the sludge generated in the washing process by up to 40%, as a result of the reduction in the levels of contamination with which plastic waste would reach Glopol. This proposal allows us to look at the mud from washing as a by-product of the process, and not as waste, which could be a way to generate new business opportunities.

Acknowledgement

We thank the ……………………

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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