# Waste Reduction in Polypropylene Tape Production through use of Cleaner Production Technologies

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**Abstract:** The case study organization within the textile industry produces a diverse array of polypropylene tapes, including flat and fibrillated varieties in various colors. The company has been facing key environmental challenges on reducing material waste, exploring sustainable materials, enhancing energy efficiency, and ensuring compliance with environmental regulations. The manufacturing process of polypropylene tape within the textile sector generates a substantial amount of non-biodegradable waste materials, which presents environmental challenges and poses a risk to the health of workers involved in the process. This research seeks to examine the root causes of waste and provide possible cleaner production solutions for reduction in polypropylene tape waste. The first step was to plan for the Cleaner Production Assessment, followed by a walk-through inspection of the extrusion department was undertaken in order to systematically comprehend the entire process. Cleaner production assessment was thereafter undertaken with the objective of collecting data and evaluating waste production in the extrusion department. A fishbone diagram was employed to evaluate the fundamental causes of waste, and a material balance was performed to meticulously monitor the utilization of raw materials during a process, while also accounting for losses, waste products, and emissions. This was followed by identification and implementation of cleaner production opportunities which included use of high-quality polypropylene resin, improvement of storage and handling of raw materials, and optimization of extrusion temperature and speed settings. Tracking the results of polypropylene tape waste over a period of 8 months after implementation and comparing with waste production before implementation of the CP options, the results showed a marked improvement. The results were validated through t-tests of two specimens with disparate variances, concluding that the implementation of cleaner production opportunities significantly reduced polypropylene tape waste.

**Keywords:** Cleaner Production Technology, Material, Polypropylene Tape, Textile Industry, Waste Reduction

## Introduction

The textile sector is important to humanity and extremely important to the worldwide financial system. In particular, the textile sector emits 15 to 35 tonnes of $CO_2$ equivalent for every ton of fabric manufactured and is also accountable for the yearly usage of around 93 billion metric tons of water (Soares et al., 2024). The textile business is regarded as one of the highest polluting companies, with domestic textiles and clothes being among the most polluting products in the EU alone. Producing any textile item consumes a large number of resources, including power, water, vitamins, and substances, which finally leads to significant ecological costs. Textile industry provides 10% of global greenhouse gas emissions. And, the textile business is growing, with a significant growth over the last 10 years (Yasin & Sun, 2019). The textile company's use of large amounts of water, along with the removal of hazardous metals in the soil, air, and water, makes achieving sustainable development in the fabric supply chain one of the primary concerns. As a result, the implementation of CP primarily for the fabric industry is a mitigator of the negative environmental effects while acquiring better environmental outcomes (de Oliveira Neto et al., 2019). Water is indispensable in the fabric sector, necessitating millions of litres to enable production operations. Most water is utilized during the dyeing procedure since it serves as the solution for generating various coloured materials based on what the consumer wants.

The textile business uses more water than all sectors and the dyeing segment absorbs higher than 50% of all water utilized, absorbing 200L of water per kg of cloth each day (Pervez et al., 2021). Cleaner production focuses on preventive methods to decrease and prevent the formation of emissions and resources, increase financial and ecological benefits, effective use of material resources, water, and electricity, recycling, garbage reuse, and workplace health advantages (Oliveira Neto et al., 2020). The organization in this case study employs over 600 individuals and operates within the textile and packaging sector, specializing in the production of various polypropylene tapes, including flat and fibrillated types, available in multiple colors and packaging formats. They also specialize in production of durable, high-quality bulk bags for industrial and commercial use. The company has been facing key environmental challenges on reducing material waste, exploring sustainable materials, enhancing energy efficiency, and ensuring compliance with environmental regulations. The manufacture of polypropylene yarn tape in the textile sector produces significant waste, which is categorized as non-biodegradable, negatively affecting the environment and jeopardizing the health of workers. Hence, this study seeks to examine the execution of cleaner production technologies in the textile industry to tackle their waste issue and to evaluate the waste generated.

## Literature Review

### Background on cleaner production

Manufacturing businesses are rapidly adopting cleaner production, which is a technique aimed at minimizing pollution and waste while improving manufacturing output. Innovative methods such as cloud manufacturing and Internet of Things, are being utilized to achieve cleaner production(Ma et al., 2019). Cleaner manufacturing is a greener technique to reduce emissions and waste while increasing product productivity. Cleaner production has proven to be an effective technique to minimize the utilization of energy and enhance material use throughout the entire manufacturing process (Ma et al., 2019). Cleaner manufacturing approaches have also received extensive attention because of their promise to reduce environmental impact while improving process efficiency and quality. Cleaner manufacturing methods include reducing resource utilization, intelligent waste management, and the adoption of more efficient technologies (Nuryanto et al., 2024). Cleaner production solutions include proper material and energy management, staff training, improved logistics, increased accessibility to information, raw material substitution, process and design modifications, and waste recycling. The advantages of cleaner production implementation include reducing the utilization of raw materials, water, and energy, emissions, formation of sewage, solid waste, and dangerous materials, and improving safety and health elements (Rahim et al., 2020). According to Prigozhin et al., (2023). Cleaner production is an ecological leadership technique used to optimize, adapt, or change processes, products, and services; nevertheless, its adoption should not be viewed as a cost, but rather as an undertaking that guarantees proficiency, productivity, and profits. When the procedure is properly developed, the implementation of cleaner production technologies aligns with the optimization of processes, resulting in cost savings, increased productivity, enhanced product quality and consistency, reduced waste, and consequently lower expenses related to waste management, as well as a better business reputation among consumers, vendors, stakeholders, society, and financial institutions (Prigozhin et al., 2023). This manufacturing mode employs a comprehensive ecological prevention strategy to mitigate or eliminate potential adverse effects on humans and their surroundings, while fully addressing human needs and optimizing societal and economic benefits (Bian et al., 2022).

### Waste Generated in the Textile Sector

The quantity of waste generated in the fabric sector during the production of yarn tape varies based on the particular procedures and materials used. Regarding polyester production, the waste generated during the process typically amounts to approximately 7% of the overall production. Out of this waste, the industry manages to reuse around 4% (Gan et al., 2024). This trash comprises several forms of polyester waste, including hard waste generated during spinning operations and soft waste generated during spinning and post-spinning processes (Gan et al., 2024). Furthermore, the worldwide textile and garment sector generates a staggering 92 million tonnes of waste each year, underscoring the substantial ecological consequences of textile manufacturing (Soares et al., 2024). Hence, the fabric sector produces a substantial quantity of waste while manufacturing yarn tape, with the exact proportions depending on the particular materials and procedures employed (Soares et al., 2024). The waste produced by the textile industry has an extensive environmental effect and includes hazardous materials, end-of-life textiles, and fabric scraps. Human health is impacted by the pollution of water, air, and land that results from improper disposal of these wastes (Patnaik & Tshifularo, 2021). The excessive water uses of the sector and the discharge of wastewater containing dyes make these problems worse (Rathoure et al., 2019). The industry can mitigate human and environmental impacts by identifying methods to minimize, refurbish, and regenerate created trash, rendering it non-harmful (Rathoure et al., 2019).

The textile industry produces significant quantities of solid debris, which can be categorized as pre-consumer and post-consumer disposal products Pre-consumer textile waste encompasses materials resulting from fabrication flaws and erratic designs created for temporary sale and usage. This type of waste is utilized in textile manufacturing procedures, although it is classified as production waste, it is intrinsically linked to pre-consumer waste materials. A significant quantity of unused fabric bundles and fabric thresholds has resulted in substantial waste on the factory floor, while fabric flaws also contribute to waste during production. The pre-consumer waste group constitutes the majority of brittle debris (Pervez et al., 2021).

**Implementation of Cleaner Production Technologies in Industry**

Despite the hurdles encountered in the application of cleaner production technologies, numerous studies have evidenced their promise within the textile sector.

Cleaner production methods play a vital role in sustainable development by seeking to reduce environmental harm and increase social and economic advantages (Prigozhin et al., 2023). These technologies involve several approaches, such as the utilization of renewable energy and unprocessed resources, cutting-edge machinery, and measures to mitigate pollution(Bian et al., 2022). Giannetti et al., (2021) underscored the importance of cleaner production in contributing to sustainable development, particularly through its evolution in scope and targets. Rahim et al., (2020) established a system to discover cleaner production possibilities, which involves adjusting operating settings, adopting better housekeeping practices, and utilizing new technologies. Amjad et al., (2021) propose integrating agile production, sustainable manufacturing, and innovations from Industry 4.0 to achieve efficient and environmentally friendly production. This integration aims to reduce lead time, non-value-added time, and greenhouse gas emissions. de Mello Santos et al., (2022) has put up a framework to facilitate the advancement of cleaner production, encompassing government initiatives, scientific research, and industrial involvement. Prabhu & Asolekar, (2022) applied Cleaner Production Technology to the production of dyes used by various industries, including the textile industry. The study concentrated on improving cleaner production methods and optimizing the utilization of colours through reuse and recycling. As a result, there was a 26% decrease in the amount of wastewater produced and a 74% decrease in the amount of material transferred to specialized facilities for hazardous waste handling.

Maama et al., (2021) developed Structural Adjustment Model (SEM) to assess the effect of CP on ecological, economic and operational efficiency in the South African sugar company. It offered facts to illustrate that sugar production enterprises in South Africa profit from CP in terms of improving ecological, working, and financial/economic efficiency.

The textile sector encounters numerous obstacles when it comes to adopting cleaner production technology according to (Yasin & Sun, 2019). They emphasized the scarcity of sustainable materials and production techniques, specifically in finishing procedures, to save water and energy usage. They stated that companies could encounter opposition from stakeholders because they have to modify current processes and technology in order to implement cleaner manufacturing methods. Ju et al., (2022) highlighted that cleaner manufacturing standards have a significant effect on the growing technical intricacy of textile exporters, especially in the eastern region and larger firms. Pervez et al., (2021) opined that companies in the textile industry face intense competition and must navigate the delicate balance between reducing costs and adhering to cleaner production practices mandated by society and government regulations. Therefore, it is evident that the industry faces certain difficulties in implementing cleaner production. The study emphasized the necessity of adopting a comprehensive approach to tackle the challenges associated with implementing cleaner production technologies in the textile industry.

Dehghani & Goyal, (2022) advanced additive manufacturing technology through 3D printing for the sustainable production of textile yarns, aiming to minimize substance waste and energy usage. de Oliveira Neto et al., (2019) asserted that the implementation of Cleaner Production methods in Brazilian textile sectors via technical innovation facilitated the recognition of the financial and ecological advantages associated with Sustainable Development. In the related study of Oliveira Neto et al., (2020) they opined that even though cleaner production sustainable makes sustainable development possible, it should be noted that cleaner production methods are implemented at different extents due to differences in company sizes, i.e. large corporations implement cleaner production methods at much higher levels than small and medium-sized organizations, owing to their necessity for constant investment in brand enhancement to augment market position. Maama et al., (2021) indicated that cleaner production has shown a favorable and substantial correlation with the financial and ecological sustainability of a sugar production company in South Africa. In the study of Okai-Mensah et al., (2022); Vinod et al., (2021) they examined sustainability measures associated with the adoption of cleaner production technologies. Their research revealed that the utilization of greener materials has the potential to serve as environmentally friendly and sustainable raw materials for reinforcing polymer composites in a textile setting.

Cleaner production reduces garbage using improved procedures because it decreases the utilization of resources and contamination generation, enhances the business's image, increases satisfaction among workers due to beneficial effects on health and safety, and minimizes the cost of operation of productive systems, boosting financial performance and exploiting the business's revenues (de Mello Santos et al., 2022). These studies highlight the potential of cleaner production technologies in the textile industry, emphasizing their positive effects on the environment and the economy. Hence, it is clear that the implementation of cleaner manufacturing methods may effectively tackle the waste problem.

## Methodology

### Planning the Cleaner Production Assessment

The first step was to plan for the CP Assessment, comprehending that the company was working towards ISO 14001 certification as a risk management policy for environment. It was imperative that the objectives and targets should be measurable, acceptable to the employees, flexible and adaptable to changing requirements. A project team was established to create a comprehensive work plan and a timeline for actions related to the CP assessment. Roles were assigned for each work to ensure the project's staff understood their duties properly.

### Cleaner Production Pre-Assessment

A walk-through inspection of the extrusion department was undertaken in order to systematically comprehend the entire process, with particular attention to places where products, wastes, and emissions are produced at the department. The pre-assessment aims to summarize the production and ecological factors of the extrusion department. The pre-assessment also emphasised the primary procedure of the extrusion department and the crucial inputs and outputs associated with that procedure.

### Cleaner Production Assessment

The purpose of the evaluation stage was to collect data and evaluate waste production in the extrusion department. A fishbone diagram was used to identify the primary basis of waste in the production of polypropylene tape. The next step was to conduct a material balance to accurately track the utilization of resources throughout a process, as well as to account for any losses, waste products, and emissions that occur as a result of the process. This was followed by identification and implementation of cleaner production opportunities.

The most straightforward approach to assess the various choices involved assembling a group comprising the project team and management people to individually deliberate on the potential solutions. The aim of the assessment and feasibility study phase was to assess the potential CP possibilities and to identify those appropriate for implementation. Environmental evaluation focused on determining the positive and negative environmental impacts of the proposed CP option while technical evaluation was used to determine whether the opportunity requires staff changes or additional training or maintenance. The objective of economic evaluation was to evaluate the cost effectiveness of the CP opportunities.

A comparative ranking analysis was undertaken to prioritise opportunities that were more feasible for implementation. Scores were allocated to each CP alternative on a scale of one to ten, determined by its performance relative to a defined set of feasibility evaluation requirements. Total feasibility score was then multiplied by overall impact of CP opportunity, which was also scored on a scale of one to ten to give a total score for each CP opportunity. Lastly, the highly ranked CP options were ranked, implemented and the quantifiable benefits that were derived from the implementation were recorded.

## Results and Discussion

### Overview of Production Process

The case study organization manufactures various polypropylene tapes, including flat and fibrillated types, available in multiple colors and packaging formats. They also specialize in production of durable, high-quality bulk bags for industrial and commercial use. Despite the challenges faced by the firm, management strives on reducing material waste, exploring sustainable materials, enhancing energy efficiency, and ensuring compliance with environmental regulations.

Figure 1 depicts the process flow of the tapeline machine, Lorex E105B30D 800HS, which was utilized to produce polypropylene tapes in preparation for the weaving process. The machine receives its material input in the form of polymer granules (pellets) from sacks. The machine processes the granules to manufacture polypropylene tapes.

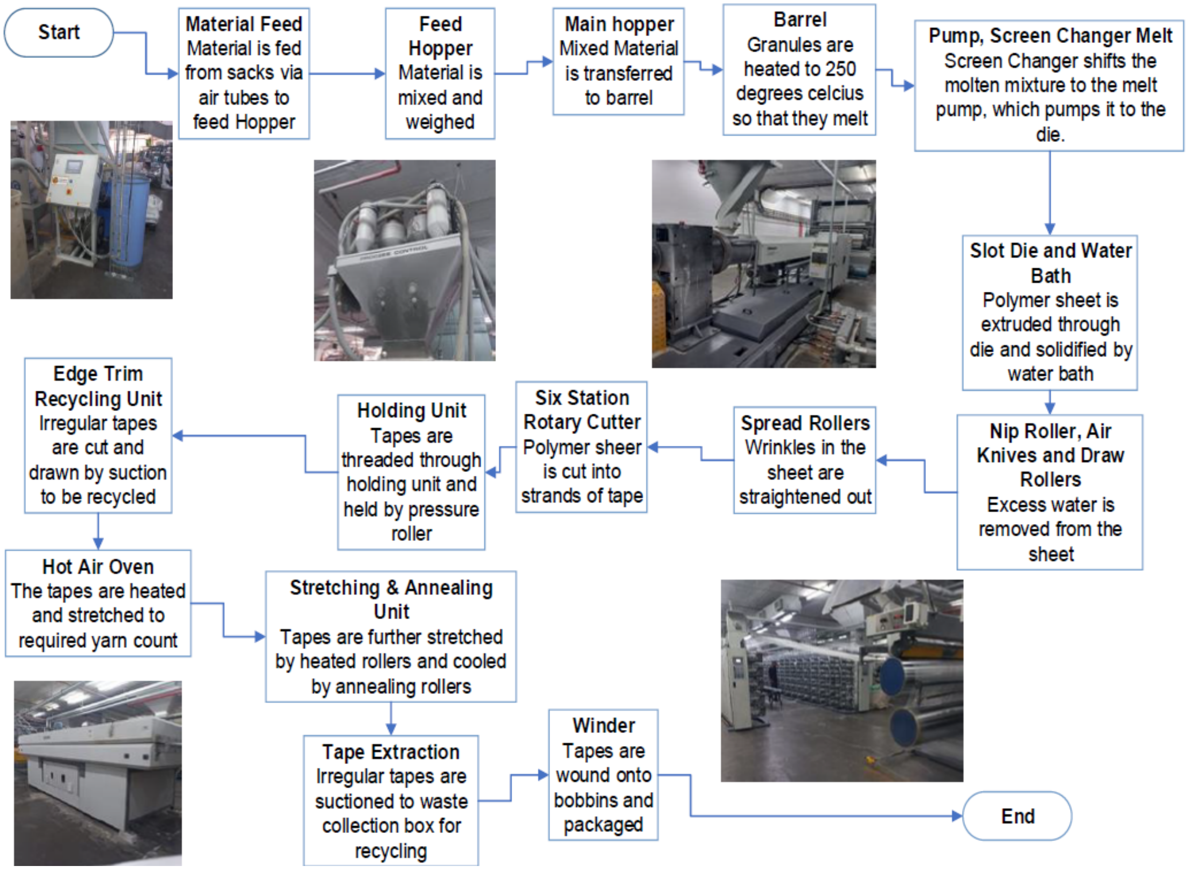


Figure 1: Extrusion Department Process Overview

**Inputs and Outputs of Process**

Figure 2 illustrates the raw materials that undergo certain processes to produce the desired output which is the polypropylene tape. It also highlights the waste from those processes.

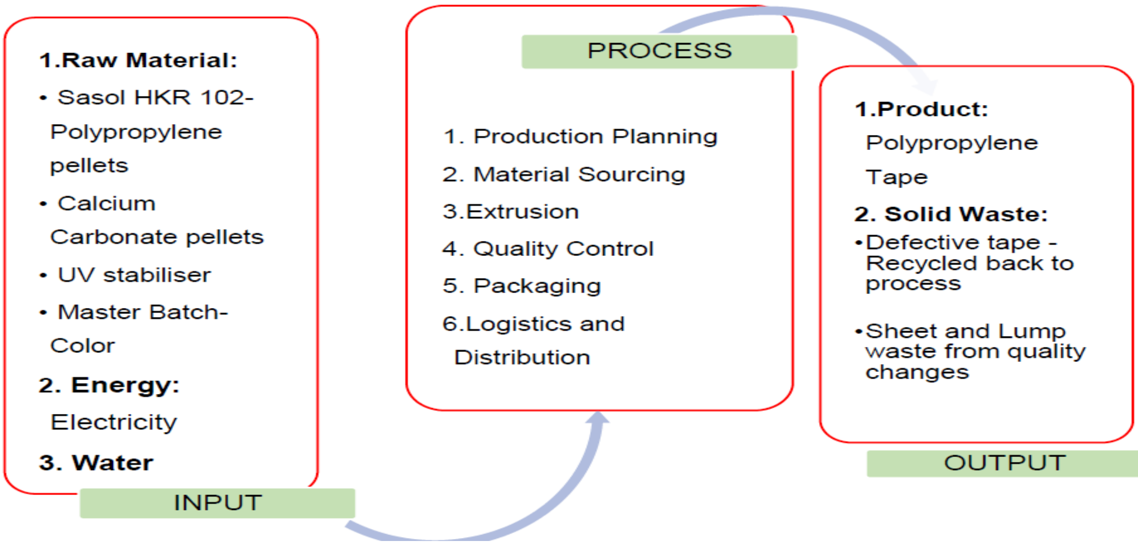


Figure 2: Input, Process and Output of Extrusion Department

This examination emphasized the process overview of the extrusion section. The creation of polypropylene tape is achieved by an extrusion method that utilizes polypropylene pellets, UV stabilizer, calcium, and masterbatch colour as the input components. The waste produced from this procedure is likewise a by-product of this technique. Additionally, it was discovered that the organization is actively pursuing ISO 14001 certification, which signifies their commitment to implementing an environmental management policy. This suggests that the organization is not in compliance with international environmental requirements, which may explain the absence of waste management in the extrusion department.

**Pre-Assessment Results**

The walk-through inspection of the extrusion department highlighted that there were indications of inadequate cleaning, such as disorganized or obstructed workspaces on the shopfloor. Prioritizing the housekeeping issue is advisable as its resolution does not necessitate additional inquiry or an evaluation and feasibility study with the adoption of the 5s methodology. This suggests that a solution with minimal or no expenses can be put into effect. To minimize the consumption of virgin materials and the expenses associated with waste disposal, it is noteworthy that the company employs granulators for the recycling of defective materials and off-cuts. However, the extrusion unit's housekeeping required urgent and thorough attention. There was a presence of general waste in the unit, which has the potential to become mixed with production waste and result in inefficiencies in the recycling process.

The raw material for the production of polypropylene tape is shown in Table 1:

Table 1: Standard raw material quantity for polypropylene tap

| Raw Material | Kilograms (kg) |
|---|---|
| Polypropylene | 1000 |
| Calcium Carbonate | 2.25 |
| UV Stabilizer | 1.25 |
| Colour Masterbatch | 3 |
| Filler Aid | 3.5 |
| Total | 1010 |

The production of polypropylene tape generates sheet and lump waste, which is creating an unsightly environment at the unit and producing land and air pollution in the storage area. The non-biodegradable waste emits tape particles into the surrounding air, consequently polluting the external environment.

Figure 3 shows the two major types of waste produced by the organization, indicating that sheet waste is more that lump waste.

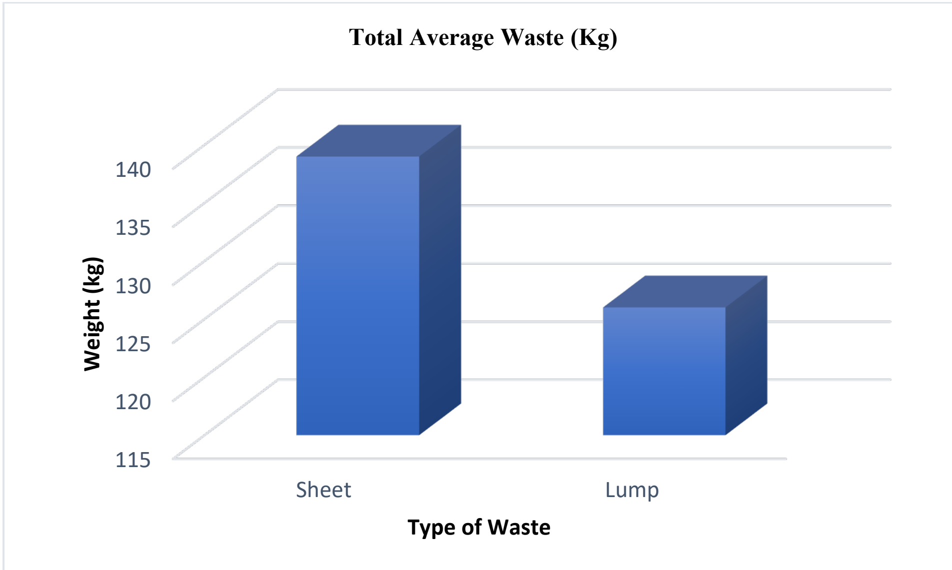


Figure 3: Comparison of Sheet and Lump waste

Table 2 shows sample data collected for sheet and lump waste measurement for 3 weeks period.

Table 2: Waste Production at Extrusion for 3 - week period

| Date | Sheet Waste (Kg) | Lump Waste (Kg) | Total Waste (Kg) |
|---|---|---|---|
| 22/04/2024 | 155 | 103 | 258 |
| 23/04/2024 | 150 | 194 | 344 |
| 24/04/2024 | 140 | 127 | 267 |
| 25/04/2024 | 175 | 145 | 320 |
| 26/05/2024 | 125 | 113 | 238 |
| 29/04/2024 | 140 | 115 | 255 |
| 30/04/2024 | 109 | 102 | 211 |
| 01/05/2024 | 148 | 106 | 254 |
| 02/05/2024 | 121 | 116 | 237 |
| 03/05/2024 | 132 | 115 | 247 |
| 06/05/2024 | 178 | 102 | 280 |
| 07/05/2024 | 165 | 127 | 292 |
| 08/05/2024 | 115 | 135 | 250 |
| 09/05/2024 | 123 | 166 | 289 |
| 10/05/2024 | 108 | 122 | 230 |
| **Average Per Day** | **139** | **126** | **265** |

Considering 22 working days per month, the average amount of waste produced per month is about 5.8 tons.

**Cleaner Production Assessment Results**

**Material balance**

As indicated in Table 1, a single batch uses 1010kg of raw material, and the company produced about 16 batches a day, which cascades to 16.4 tons a day. A material balance of the extrusion process was conducted and it was found that the total material input was not equal to the total material output. Table 1 shown the total raw materials used daily.

Total Raw Material In = Total Material Out + Defective Tape + Sheet and Lump Waste … (1)

i.e. 16.4 tons per day = 15.2 tons polypropylene tape per day + 527 kg Defective Tape + 265 kg Sheet and Lump Waste.

According to the data presented in Table 2, the average daily waste production is around 139 Kg for sheet waste and 126 Kg for Lump waste, resulting in a total waste of 265 Kg. Thus, based on equation 1.

**Root cause analysis for causes of waste**

A Fishbone Diagram (Ishikawa Diagram) helps identify potential causes of waste in the production of polypropylene tapes by categorizing them into key areas. Below is a breakdown of the common causes using the 6 Ms framework:

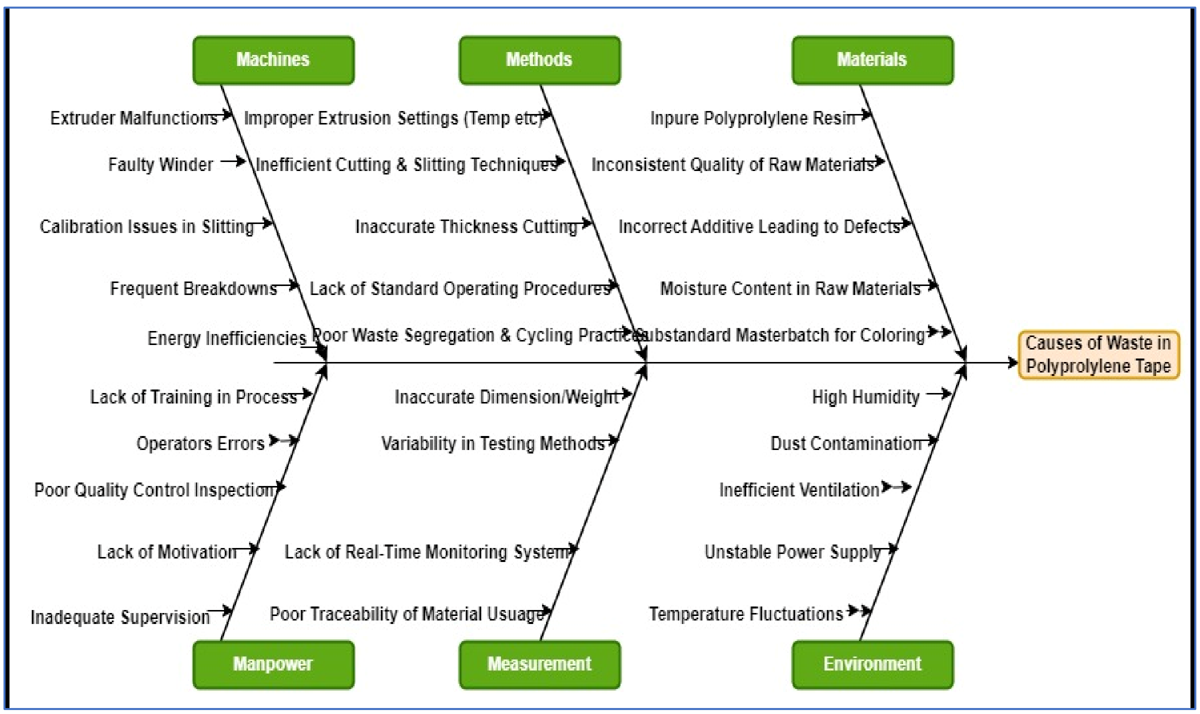


Figure 4: Fishbone Diagram for Causes of Waste in Polypropylene Tape

**Identification of Cleaner production Opportunities**

Cleaner production emphasises on waste reduction, efficiency enhancement, and environmental effect mitigation. Raw material optimization represents a critical opportunity in polypropylene tape production, involving the utilization of high-quality polypropylene resin to mitigate defects and material wastage, enhancement of material blending methods to guarantee optimal additive mixing and reduce discrepancies, reduction of moisture in raw materials through improved drying systems to avert processing defects, and the implementation of closed-loop recycling by reusing off-cuts and defective tapes in production. The CP opportunities for waste reduction strategies include the implementation of a comprehensive quality control system to identify defects promptly and avert superfluous waste, the minimization of packaging waste through the optimization of packaging material utilization, and the enhancement of storage and handling practices for raw materials to avoid pollution and decay. The feasibility and impact of CP opportunity scores were derived from the CP project team. The most viable alternatives were selected in close consultation with the organization's leadership.

Table 3: Identification of Cleaner production Opportunities

| Number | CP Opportunity | Environmental feasibility score | Technical feasibility score | Economic feasibility score | Impact of CP opportunity | Total score |
|---|---|---|---|---|---|---|
| 1 | Use of high-quality polypropylene resin | 5 | 7 | 5 | 7 | **119** |
| 2 | Improvement of material blending techniques | 3 | 6 | 5 | 6 | **84** |
| 3 | Improvement of cutting and slitting precision | 3 | 7 | 6 | 6 | **96** |
| 4 | Optimisation of extrusion temperature and speed settings | 6 | 5 | 5 | 7 | **112** |
| 5 | Implementation of robust quality control system | 4 | 5 | 3 | 7 | **84** |
| 6 | Improvement of storage and handling of raw materials | 5 | 5 | 7 | 7 | **119** |

From section 3.3, the total feasibility score was then multiplied by overall impact of CP opportunity, which was also scored on a scale of 1 to 10 to give a total score for each CP opportunity. Lastly, the highly ranked CP options were ranked, implemented and the quantifiable benefits that were derived from the implementation were recorded.

Ranking from highest to lowest score, the results in Table 3 demonstrated that CP options 1 and 6 should be implemented first, followed by CP option 4.

**Implementation of Cleaner production Opportunities**

The implementation phase focused on CP options 1, 6 and 4, while the other remaining CP options 3. 2 and 5 were documented for future projects. Concerning CP option 1, strict incoming material inspections were implemented to test the moisture content and melt flow indices of the raw material that was fed into the extruder. A moisture tester was critical in assuring a consistent, high quality finished product. Moisture analysers were connected to computers to observe and analyse the drying process and its effects on the sample. The melt flow index tester was used for rapid testing of the melt mass flow rate of plastics and designed for incoming goods inspection as well as for continuous production monitoring. The system featured entirely automated detection of the suitable test sequence, control of the preheating phase through specified set values for melt mass flow rate and melt volume flow rate, along with automatic detection and establishment of test sequences based on verify factors. In addition, melt flow index testing aided in conducting quick comparisons on new material suppliers, and hence select a better supplier for the raw materials. The impact of the CP implementation was reduced material rejection due to inconsistency or contamination.

Concerning CP option 6, which is improvement of storage and handling of raw materials, it was imperative to store polypropylene resin in dry, temperature-controlled environments. The installation of a Munters ML180L dehumidifier for plastic material in the warehouse ensured preservation of the quality of polypropylene resin, securing its long-lasting performance. The stand-alone desiccant dehumidifier would remove water vapour from the warehouse, and equipped with integrated humidistats, the versatile unit would keep relative humidity in check, safeguarding production uptime and product safety. In addition, First-In-First-Out (FIFO) inventory management was installed, that is deploying a pallet racking system to allow easy access to older stock, resin batches were labelled with clear manufacturing or receiving dates and using a barcode tracking to automate FIFO process. The impact of the CP implementation was reduced processing defects due to quality raw material, devoid of moisture absorption and resin degradation.

Concerning CP option 6, which is optimisation of extrusion temperature and speed settings, it was imperative to fine-tune extrusion temperature, screw speed, and die pressure to minimise defects on tapes. A gradual temperature profile was used, spanning from 180–200°C for preheating in the hopper zone, 210–230°C for homogenisation in the compression zone, 230–250°C in the metering Zone, with a die temperature ranging from 190–220°C to prevent thermal degradation. The screw speed was optimised based on die size and throughput requirements, steady screw speed was maintained to avoid sudden pressure fluctuations, while high-torque, low-speed settings were in some cases used for better polymer homogenisation. Die pressure was regulated by balancing die pressure through adjustment of screw speed and temperature. to prevent tape thickness variations, resin flow was monitored to ensure uniformity and die lips were regularly cleaned to prevent resin build-up. The impact of the CP implementation was reduced scrap which was previously caused by over-processing, uneven thickness, or burned material.

It is worth noting that since the three CP options that were implemented were inter-related, it was difficult to track the improvement in terms of waste reduction for each CP. However, tracking over a period of 8 months after implementation and comparing with waste production before implementation of the CP options, the results shown in Figure 5 showed a marked improvement.

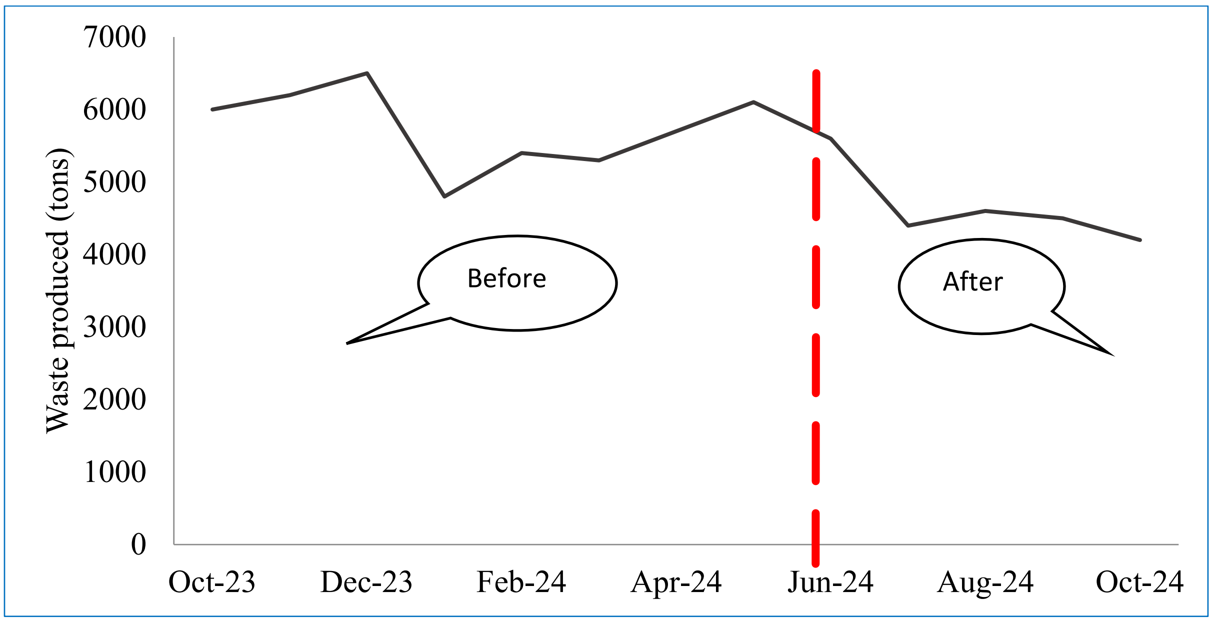


Figure 5: Before and After scenarios for monthly waste production

The findings were verified to determine if the process changes contributed to the reduction in monthly waste production or if the changes were attributable to chance. Table 3 presents the t-test results for the two specimens' disparate variances. The level of significance was set at $p = 0.05$ to reject the null hypothesis, If $P(T <= t)$ for the two-tailed test is below 0.05, the null hypothesis is declined and it was concluded that the implementation of cleaner production opportunities yielded a noteworthy reduction in polypropylene tape waste as revealed in the before-scenario and the after-scenarios.

Next page

Table 4: Results of the t-Test for Two Samples with Assumed disparate Variances

| | **Before scenario of monthly waste production** | **After scenario of monthly waste production** |
|---|---|---|
| Mean | 5733.333 | 4233.75 |
| Variance | 275000 | 79969.64 |
| Observations | 9 | 8 |
| Hypothesized Mean Difference | 0 | |
| df | 13 | |
| t Stat | 7.446732 | |
| P(T<=t) 1-tail | 2.43E-06 | |
| t Critical 1-tail | 1.770933 | |
| P(T<=t) 2-tail | 4.86E-06 | |
| t Critical 2-tail | 2.160369 | |

**Recommendations for Cleaner Production Technologies**

The following points are recommendations of cleaner production technologies:

- Cradle-to-Cradle Design: This design approach prioritizes the creation of items that may be recycled or repurposed indefinitely without losing their value. By incorporating end-of-life concerns into the design of polypropylene tape, such as facilitating easy disassembly and recycling, it is possible to minimize the initial waste generated.
- Chemical recycling involves employing procedures like depolymerization or catalytic cracking to dismantle plastics into their molecular constituents. These constituents can subsequently be utilized to manufacture new products.
- Biodegradable alternatives exist for specific purposes, while polypropylene itself is not biodegradable. Exploring the feasibility of using these alternatives as potential replacements for polypropylene tape manufacturing could provide a more environmentally friendly production solution with lower ecological consequences, such as utilizing biopolymers.
- Resource efficiency and optimization involve the use of techniques like lean manufacturing and process optimization to identify and eliminate inefficiencies in production processes. This results in a reduction in the development of waste in the form of sheets and lumps, as well as a decrease in the consumption of polypropylene.
- Inline quality control and defect detection through the installation of infrared scanners and cameras at strategic process positions with the view to reduce defect production.

**Conclusion**

The necessity for enhancing the company's environmental regulations and practices, is to strives to obtain ISO 14001 certification with the potential to result in the examination and execution of more environmentally friendly production methods. The implementation of cleaner production technologies has shown great potential in solving the waste issue in textile industries. This was achieved through waste reduction, material substitution, and repurposing of created waste. Employing 5S in an extrusion unit promotes production, minimizes downtime, and improves workplace safety. It establishes a systematic environment in which raw materials circulate seamlessly, waste is reduced, and machinery functions optimally. Another viable option was utilizing biodegradable materials like biopolymers or repurposing waste will derive benefits for the company, such as identifying potential external buyers for the waste materials. The raw material optimization and waste reduction strategies are the critical opportunity in polypropylene tape production. In conclusion, the implementation of cleaner production technology in polypropylene tape manufacturing mitigate waste, improves efficiency, and fosters sustainability. However, this study was limited by the inability to conduct trial experiments on the usage of biopolymers and the inability to apply any cleaner production technology due to managerial constraints. This presents prospects for additional investigation into the examination of biopolymers as an alternative to polypropylene in the textile sector. The focus would be on assessing the impact of this substitution on the characteristics of the tape bobbins produced, and determining if these attributes can be preserved or enhanced through the utilization of biopolymers.

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