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Sustainable Flexible Packaging Optimization: Enhancing Efficiency Through Reducing Wastage & Material Consumption During Manufacturing Process

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Abstract: As the packaging industry becomes increasingly competitive, optimizing operations is essential to reducing costs and improving efficiency. This proposal focuses on enhancing the material input-output ratio, reducing waste, and minimizing environmental impact, thereby supporting both economic sustainability and ecological responsibility. Reducing cylinder etching is proposed to lower ink consumption without compromising print quality. To maintain the overall GSM, the thickness of the Low-Density Polyethylene (LDPE) film will be increased. The implemented strategy led to a reduction of 1,748 kg in material consumption, resulting in cost savings of BDT. 696,160 for every 25,000 kg job. This strategy balances cost efficiency with sustainability, positioning the company as a leader in responsible innovation. By optimizing ink use and LDPE film thickness, operational efficiency is improved while ensuring long-term profitability and a reduced environmental footprint.

Keywords: *Sustainable Flexible Packaging, Environmental Impact, GSM (Grams Per Square Meter), Efficiency, Optimization, Return on Investment (ROI), VOC (Volatile Organic Compounds), Cylinder Etching Depth, LDPE (Low-Density-Polyethylene).*

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I. INTRODUCTION

The packaging industry is highly competitive, with companies placing significant emphasis on cost reduction, production efficiency, and achieving sustainability goals. In this rapidly evolving landscape, businesses must adopt eco-friendly materials and innovative processes to remain competitive. This involves not only reducing costs and minimizing waste but also meeting consumer and regulatory demands while maintaining product quality. However, the industry faces several challenges, including rising material costs, supply chain disruptions, and increasing pressure to adopt sustainable practices. To stay ahead in this competitive environment, it is crucial to focus on improving material efficiency and adopting sustainable production methods.

➢ *Background of the Study*

Material efficiency is a key solution to the challenges faced by the packaging industry. Optimizing the material input-output ratio can help companies reduce waste, lower costs, and improve sustainability. Sustainable practices not only minimize environmental impact but also cater to growing consumer demand for eco-friendly solutions, strengthen brand reputation, and contribute to long-term business success. Current practices mainly focus on optimizing ink usage and adjusting material thickness. This study proposes additional improvements, such as reducing cylinder etching to decrease ink consumption and increasing the thickness of LDPE (Low-Density Polyethylene) film to maintain GSM (grams per square meter), thereby improving both operational efficiency and sustainability.

➢ *Significance of the Study*

This study is vital for addressing the industry's growing demand for cost-effective and sustainable manufacturing. By reducing production costs, minimizing waste, and lowering environmental impact, the proposed improvements not only align with global sustainability goals but also support compliance with tightening environmental regulations. Enhancing material efficiency and refining production processes ensures long-term profitability while giving the company a competitive edge in a market increasingly driven by eco-conscious consumers and regulatory standards. The findings will reinforce the company's reputation for responsible innovation and contribute to the industry's broader shift toward sustainable, compliant, and efficient operations.

➢ *Aims and Objectives of the Study*

- To evaluate the current practices in the packaging industry regarding material efficiency and sustainability.
- To propose innovative solutions that improve production processes, reduce waste, and optimize material efficiency.
- To assess the impact of reducing cylinder etching and increasing LDPE film thickness on operational efficiency and sustainability.
- To position the company as an industry leader in sustainable practices by introducing more efficient and eco-friendly methods.
- To provide a framework for the broader packaging industry to adopt and adapt these solutions, ensuring both short-term and long-term success.

✓ *Overall, this Study is Designed Following the Below Steps:*

- Step 1 introduces the challenges and importance of sustainability and material efficiency in the packaging industry.
- Step 2 reviews relevant literature on current practices related to material usage and sustainable production.
- Step 3 outlines the research methods used to assess and improve existing operations.
- Step 4 presents and discusses the research findings and their implications.
- Step 5 concludes with key insights and practical recommendations for enhancing efficiency and sustainability.

II. LITERATURE REVIEW

Sustainable packaging has emerged as a critical focus in both academic research and industrial innovation, driven by growing environmental concerns, resource limitations, and evolving consumer expectations. Industries now face mounting pressure to reduce their ecological footprint while maintaining economic competitiveness. Efforts increasingly focus on optimizing material usage, minimizing waste, and enhancing production efficiency. Recent research (McKinsey & Company, 2023; Smithers, 2022) underscores the importance of reducing ink and solvent consumption, adjusting film thickness, and incorporating recyclable or biodegradable components. Despite these advancements, practical implementations—such as optimizing cylinder etching and refining LDPE film specifications remain underexplored. This chapter reviews current literature on sustainable packaging practices, identifying key trends, technological developments, and gaps that this study addresses through targeted material and process optimization strategies.

➢ *Sustainable Packaging: Concepts and Importance*

Sustainable packaging is defined by the Sustainable Packaging Coalition as packaging that is "beneficial, safe and

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healthy for individuals and communities throughout its life cycle, meets market criteria for performance and cost, and is sourced, manufactured, transported, and recycled using renewable energy." (SPC, 2021). Research by Lewis (2012) and Accorsi et al. (2014) emphasizes its contributions to environmental conservation, brand reputation, and long-term profitability.

This shift is further catalyzed by policy regulations such as the EU Packaging Waste Directive (2018) and the U.S. Sustainable Materials Management Program, both of which mandate reductions in material usage, increased recyclability, and lower greenhouse gas (GHG) emissions. Compliance with these frameworks is now a competitive imperative.

➢ *Material Optimization in Flexible Packaging*

Flexible packaging has gained popularity due to its lightweight nature and adaptability. However, as Singh et al. (2016) and updated studies like *Zhou et al. (2023)* note, the multilayer structure poses challenges in recycling and increases waste complexity.

Research (Gu et al., 2018; Mahalik & Nambiar, 2010; Mehta & D'Souza, 2022) demonstrates that reducing film thickness, modifying resin types, and applying lean manufacturing principles can improve the material input-output ratio without compromising performance. This thesis builds on that foundation, applying a process-integrated optimization model tailored for the flexipack industry.

➢ *Printing Process Optimization*

Rotogravure printing is favored for its quality and speed but is often criticized for high ink and solvent usage. Studies by Zhao et al. (2019) and Choudhary & Kumar (2020) describe this as a critical area for cost and emission reductions. More recently, Fernandez & Lim (2022) report that digital controls and AI-driven ink monitoring systems can reduce wastage by over 20%.

Reducing cylinder etching depth is a practical alternative. Patel & Rao (2017) demonstrated ink consumption reductions of up to 30% without visual compromise. However, *Tanaka et al. (2023)* caution that excessive etching reduction may affect ink adhesion and long-run consistency—highlighting the need for calibrated optimization, as proposed in this thesis.

➢ *Film and Lamination Efficiency*

LDPE remains a preferred component in multilayer films due to its barrier properties and flexibility. Increasing LDPE thickness to maintain GSM after ink reduction, as proposed by Kumar et al. (2021), is seen as a cost-neutral adjustment.

Lamination processes, particularly solventless ones, are often praised for environmental benefits. Ghosh et al. (2020) support this, citing reduced VOC (volatile organic compounds) emissions. However, Chatterjee & Rana (2022) point out that solventless lamination may face challenges like slower curing times, limited adhesive compatibility, and higher initial equipment cost—making it less viable for high-speed operations without further R&D. This thesis acknowledges solventless options but focuses on more immediately applicable strategies.

➢ *Environmental Impact and Circular Economy*

Minimizing waste is crucial for achieving the goals of a circular economy. The Ellen MacArthur Foundation (2020) emphasizes the need to focus on reducing the use of new materials, improving recyclability, and designing products for reuse at the end of their lifecycle.

The material reduction of 1,748 kg, as detailed in this thesis, supports these goals. In addition, recent innovations such as solvent recovery systems and bio-based polymers are emerging as viable solutions for greener production (Tavares et al., 2019; Bocken et al., 2016; Rodriguez et al., 2023). While these technologies are still maturing, they represent promising paths for scalability.

➢ *Gaps in Existing Literature*

Despite growing research on sustainable packaging, most studies remain siloed—focusing either on ink reduction, solvent use, or packaging material. Few offer a comprehensive framework that integrates ink control, GSM balancing, cost analysis, and environmental benefits. Moreover, while policy compliance is well-documented, its linkage to production optimization remains understudied. This thesis bridges these gaps by proposing a unified, data-driven strategy tailored to the flexipack sector, reinforcing both operational efficiency and regulatory alignment.

➢ *Comparative Summary of Key Studies:*

Flexible Packaging sustainability and efficiency, highlighting various approaches to cost reduction, material optimization, and environmental impact.

Table 1 Flexible Packaging Sustainability and Efficiency

Author(s)	Focus Area	Key Findings	Limitations/Notes
Patel & Rao (2017)	Cylinder etching	Ink savings up to 30%	Lacks environmental impact data
Kumar et al. (2021)	LDPE thickness adjustment	Maintains GSM with cost neutrality	Assumes consistent film quality
Ghosh et al. (2020)	Solventless lamination	Reduces VOC (volatile organic compounds) emissions	Slower curing; adhesive limitations
Mehta & D'Souza (2022)	Material lean optimization	Enhances input-output efficiency	Needs broader industry validation
Rodriguez et al. (2023)	Bio-based materials	Promising for scalability and GHG reduction	Higher cost; limited infrastructure
Fernandez & Lim (2022)	Digital ink control systems	Up to 20% ink waste reduction via AI	High capital expenditure; integration challenges
This Thesis	Integrated material-ink-GSM model	Combines cost, quality, and sustainability in a flexipack context	Fills current literature and practice gap

➢ *Summary*

The reviewed literature emphasizes the importance of material efficiency, waste reduction, and sustainable innovation in packaging. However, this study stands out by integrating these areas into a unified, practical optimization framework—specifically through controlled cylinder etching and LDPE thickness adjustments. In doing so, it not only advances academic discourse but also offers actionable insights aligned with regulatory compliance and industry competitiveness.

III. METHODOLOGY

This chapter presents the research methodology adopted to evaluate material optimization strategies in flexible packaging. It outlines the systematic approach employed for data collection, sample selection, and data analysis to ensure reliability and validity. This methodology supports the research objectives by combining technical assessments, quantitative analysis, and industry-specific process mapping. The goal is to evaluate the effectiveness of reducing ink usage through cylinder etching optimization and adjusting LDPE film specifications to balance GSM and enhance sustainability.

➢ *Flexipack Packaging Industry Overview*

The flexible packaging industry leverages materials such as plastic films, foils, and papers to produce lightweight, durable packaging like pouches and wraps. These solutions cater to the food, pharmaceutical, and consumer goods sectors. Recent trends emphasize sustainability, recyclability, and reduced resource use without compromising functionality.

➢ *Key Processes in Flexi Pack Production*

- Bill of Materials (BOM): Specifies materials (films, inks, resins, adhesives) and quantities per job.
- Printing Process: Utilizes etched cylinders to transfer ink to substrates. Inspections follow to verify color accuracy and defect-free printing.
- Lamination: Layers like MPET and MCPP are bonded using solvent-based or solventless adhesives.
- Cutting & Converting: Final stage converting laminated rolls into ready-to-use forms.

➢ *Printing Technology*

- Rotogravure Printing: High-speed process using engraved cylinders for individual colors. Ink transfer and drying systems are optimized for mass production. Ink viscosity, etching depth, and drying speed are key control parameters.

➢ *Lamination Techniques*

- Solvent-Based: Uses volatile organic compounds (VOCs) for strong bonding.
- Solventless: Eco-friendly alternative with 100% solid adhesives. Suitable for most film types and reduces emissions. However, it may face challenges in bonding dissimilar materials and longer curing times (Ghosh et al., 2020).

➢ *Multilayer Extrusion Machines*

- LDPE Film Production: Uses multilayer extrusion with features like automatic thickness control and PLC systems to ensure precision. LDPE provides barrier properties, flexibility, and impact resistance, essential for food-grade packaging.

➢ *Factors Contributing to Weight Changes in Flexi Pack Production:*

- Material Type & Thickness: Thicker or denser films (like PET) increase weight.
- Lamination: More layers and adhesives contribute to added GSM.
- Ink Coverage: Higher ink volume or metallic inks raise final weight. Optimizing ink usage without compromising print quality is essential for reducing material weight and improving overall efficiency.

➢ *Job Summary:*

Table 2 Job Summary with Detail Description

Description	
Customer	ACI FOODS LIMITED
Job	Fun Plain Cake (Butter) Wrapper New Size
Structure	PET+MPET+LDPE
Cylinder Size (mm)	900
Cylinder Type	PU Based
Film Size (mm)	780
Order Qty (Kg)	25000
No. Cylinder	8
Ups	4

➢ *Sample:*

Fig 1 Work Sample Picture

➢ *Data Collection & Analysis*

- *Data Collection:*

✓ Production Records: Material input-output logs, BOM sheets, and cost breakdowns.

✓ Observational Data: Direct monitoring of printing and lamination processes.

✓ Interviews: Informal interviews with process engineers and operators to validate process behaviors.

✓ Lab Analysis: Random samples tested for print quality, ink adhesion, and layer integrity.

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- *Analysis Techniques:*

✓ Comparative GSM Analysis: Pre vs. post-modification weight and cost metrics.
✓ Input-Output Ratio Analysis: Measured overall efficiency changes.
✓ Cost-Benefit Evaluation: Savings from reduced ink/chemicals versus increased resin usage.
✓ Environmental Impact Projection: Environmental Impact Projection: Based on material savings and VOC reduction.

IV. RESULTS AND DISCUSSION

➢ *Key Findings Preview*

This chapter presents the key outcomes of the optimization strategy implemented in flexible packaging production. The comparative analysis between the pre-optimization (GSM-2.6) and optimized (GSM-1.6) phases reveals improvements in material efficiency, cost savings, and environmental sustainability. Notably, a reduction in printing ink and solvent usage significantly contributed to operational savings while maintaining GSM consistency and structural quality. The chapter also explores the strategic implications of these findings in terms of environmental impact, process scalability, and return on investment (ROI).

➢ *Material Breakdown (GSM-1.6 vs. GSM-2.6): Total Material (Kg)*

- *Total Material Usage:*

✓ GSM-1.6 (Optimized): 32,470 kg
✓ GSM-2.6 (Original): 34,218 kg
✓ Material Savings: 1,748 kg

Table 3 Material Analysis Breakdown

SL	Item Name	For GSM-1.6		For GSM-2.6		Changes of Materials in KG	Item Price Per Kg (Taka)	Cost(Taka)
		Material in KG	Material in Meter	Material in KG	Material in Meter			
1	PET FILM	7009	542588	7009	542588	0	220	0
2	MPET FILM	7059	542588	7059	542588	0	260	0
3	GRANULES-RESIN/LD	9596	542588	9178	542588	-418	200	-83600
4	PRINTING INK (PU Based)	2309		3753		1444	450	649800
5	ETHYL	577		938		361	170	61370
6	TOLUENE	577		938		361	190	68590
7	SOLVENT BASE ADHESIVE	1189		1189		0	350	0
8	SOLVENT BASE HARDENER	64		64		0	350	0
9	SOLVENT LESS ADHESIVE	574		574		0	450	0
10	SOLVENT LESS HARDENER	345		345		0	450	0
11	ETHYL	3171		3171		0	170	0
Total Material		32470		34218		Total Savings		৳696,160.00
Savings Per Kg Order								৳27.85

- *Cost Analysis:*

✓ Granules/LDPE: Increased usage, +BDT.83,600
✓ Printing Ink: Reduced usage, -BDT.649,800
✓ Ethyl & Toluene: Reduced usage, -BDT. 129,960
✓ Net Savings: BDT. 696,160
✓ Savings per kg order: BDT. 27.85

➢ *GSM Changes & Material Efficiency*

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Table 4 Material GSM vs. Efficiency

SL	Item Name	When Ink GSM-1.6			When Ink GSM-2.6			Changes
		Thickness	Density	GSM	Thickness	Density	GSM	
1	PET FILM	12	1.4	16.8	12	1.4	16.8	0
2	MPET FILM	12	1.41	16.92	12	1.41	16.92	0
3	GRANULES-RESIN	25	0.92	23	23.91	0.92	21.997	1.003
4	PRINTING INK	1.6	1	1.6	2.6	1	2.6	-1.000
5	GUM1	2	1	2	2	1	2	0
6	GUM2	2	1	2	2	1	2	0
TOTAL GSM				62.320			62.317	0.003
Remarks		Total GSM is 99.99% constant						

- PET Film & MPET Film: No change in thickness, density, or GSM.
- Granules-Resin: A slight increase in GSM from 23 to 21.997, with a minimal change of +1.003.
- Printing Ink: Printing Ink: GSM reduced from 2.6 to 1.6, resulting in a –1.000 change

The overall GSM remains unchanged, with a difference of just 0.003%, highlighting a consistent material balance between the previous and optimized phases.

➢ *Summary of Key Findings*

The optimization initiative focused on two major changes:

- Reduced cylinder etching depth to minimize excess ink transfer.
- Increased LDPE (granules-resin) thickness to stabilize GSM and maintain package integrity.

✓ *These Changes Led to:*

- A net material reduction of 1,748 kg.
- BDT. 696,160 in total cost savings, equivalent to BDT. 27.85 per kg.
- Maintained GSM levels with a minimal variation of +0.003, confirming process precision.
- Lower usage of VOC (volatile organic compounds)-emitting solvents, improving sustainability.

➢ *Comparative Analysis: Optimized vs. Previous Approach*

- *Material & Cost Breakdown:*

Table 5 Cost Impact Analysis: GSM-1.6 (Optimized) vs. GSM-2.6 (Previous)

Item	GSM-1.6 (Optimized) (Kg)	GSM-2.6 (Previous) (Kg)	Difference (Kg)	Unit Price (BDT/Kg)	Cost Impact (BDT)
PET Film	7,009	7,009	0	220	0
MPET Film	7,059	7,059	0	260	0
LDPE (Granules)	9,596	9,178	418	200	83,600
PU Printing Ink	2,309	3,753	-1,444	450	-649,800
Ethyl Solvent	577	938	-361	170	-61,370
Toluene Solvent	577	938	-361	190	-68,590
Others	No Change	No Change	0	—	0
Total	32,470 Kg	34,218 Kg	–1,748 Kg	—	-696,160

✓ *Conclusion:*

The increase in LDPE cost was more than offset by ink and solvent savings, validating the cost-efficiency of the GSM-1.6 approach.

➢ *Material Efficiency and GSM Control:*

Table 6 Flexible Packaging Structure Component Analysis (g/Square m)

Material	Optimized Structure (GSM-1.6)	Previous Structure (GSM-2.6)	Difference (g/m2)
PET Film	16.8	16.8	0
MPET Film	16.92	16.92	0
LDPE (Granules)	23	21.997	1.003
Printing Ink	1.6	2.6	-1
Adhesives (Gum 1 & 2)	4	4	0
Total GSM	62.32	62.317	0.003

* *Insights:*

The near-identical total GSM shows successful control over material balance, confirming production consistency and precision.

➢ *Operational Impact*

* Material Input Reduction: A 5.1% cut in total material usage reflects leaner, more efficient operations.
* Ink and Solvent Control: Reduced ink transfer via cylinder depth adjustment led to lower VOC emissions and cost.
* Print Quality: Maintained with no visible compromise, supporting long-term process scalability.

➢ *Environmental & Sustainability Gains*

* Waste Minimization: A 1,748 kg drop in material usage reduces both production waste and post-consumer disposal.
* VOC (volatile organic compounds) Emission Control: Lower usage of ethyl and toluene directly contributes to cleaner production.
* Sustainable Roadmap:
* Evaluate bio-based inks and resins.
* Introduce solvent recovery systems to create a closed-loop process.

➢ *Risk Assessment and Limitations:*

One critical consideration when implementing reduced cylinder etching depth is the potential impact on the mileage warranty provided by printing cylinder suppliers. These warranties are typically based on standard etching specifications that ensure durability and consistent performance over a defined production volume. By decreasing the etching depth to optimize ink consumption, the cylinder's usable lifespan may be shortened, potentially leading to a reduced warranty period and more frequent reworking. This, in turn, could result in additional maintenance-related expenses. However, it is important to emphasize that the cost of cylinder rework is comparatively minor relative to the substantial cost savings achieved through reduced ink and solvent usage. Therefore, while this limitation should be acknowledged in strategic planning, it does not diminish the overall effectiveness or economic value of the optimization initiative.

➢ *Strategic Business Value & ROI:*

Table 7 Financial and Operational Impact of Optimization

Metric	Value	Interpretation
Total Savings	BDT 696,160	The net cost reduction achieved on a specific production batch (implied from the difference calculation in the previous table).
Savings Per Kg	BDT 27.85	The amount saved for every kilogram of the final product produced using the optimized structure.
Material Saved	1,748 Kg	The total reduction in raw material and solvent consumption for the production batch.
Estimated Investment in Process Changes	BDT 250,000 (approx.)	The initial cost required to implement the necessary adjustments (e.g., cylinder etching, digital control system calibration, training).
Payback Period	≈1 job(25,000 Kg batch)	The time required to recover the investment cost. In this case, the total savings from a single production run (BDT 696,160) are more than double the investment (BDT 250,000), resulting in an immediate payback within the first job.

- *Insights:*

✓ The payback for the investment occurred within a single production cycle—making ROI immediate and highly favorable.
✓ This positions the optimization strategy as a scalable, low-risk, high-impact solution.
✓ Enhances brand image in sustainability and strengthens market competitiveness.

➢ *Discussion*

While this study focused on material efficiency in flexible packaging, future research can delve deeper into technology-driven optimization, specifically:

- *AI-Powered Ink and Solvent Optimization:*

Use machine learning models to analyze print patterns and automatically adjust ink/solvent ratios, minimizing waste without human intervention.

- *IoT-Based Monitoring for Real-Time Sustainability Metrics:*

Deploy smart sensors to track GSM, VOC levels, and material flow, enabling predictive maintenance and immediate corrective actions.

By exploring these tech-enabled solutions, future studies can unlock new dimensions of sustainability, precision, and cost savings - laying the groundwork for Industry 4.0 in packaging.

V. CONCLUSION

The transition from GSM-2.6 to GSM-1.6 achieved its objectives of cost reduction, process efficiency, and sustainability. The strategy yielded tangible financial benefits (৳696,160 saved), minimized waste, and maintained product quality—all within a consistent GSM profile. With a rapid payback and scalability potential, this initiative lays the groundwork for broader adoption of eco-efficient practices in flexible packaging.

This study evaluated process optimization strategies to enhance material efficiency, reduce waste, and improve sustainability in the flexible packaging industry. The key changes—reducing cylinder etching depth to minimize ink usage and increasing LDPE film thickness to stabilize GSM—delivered measurable improvements in both economic and environmental performance.

A total cost savings of BDT. 696,160 was achieved for a 25,000 kg job, primarily through a significant reduction in printing ink and solvent consumption. Despite a slight increase in resin usage, the total material input dropped by 5.1%, reducing waste by 1,748 kg. GSM remained stable (+0.003 variance), ensuring product quality and production reliability were not compromised. These results validate the approach as a viable pathway to cost-efficiency and sustainable manufacturing.

RECOMMENDATIONS

To support ongoing process improvement, the following actionable steps are categorized into short-term and long-term initiatives:

- *Top 3 Short-Term Actions (High ROI & Immediate Implementation):*

- *Implement Solventless Lamination:*

Switch to solventless lamination to eliminate VOC emissions and reduce environmental impact.

- *Introduce Closed-Loop Solvent Recovery Systems:*

Recover and reuse solvents to reduce waste, lower costs, and minimize pollution.

- *Monitor Material KPIs Continuously:*

Establish real-time tracking for material usage, cost metrics, and waste levels to identify inefficiencies and drive improvements.

- *Long-Term Strategic Initiatives (For Future Scaling & Innovation):*

- *Explore Bio-based and Recycled Resins:*

Test and integrate eco-friendly alternatives to LDPE without compromising structural integrity.

- *Transition to Bio-Based Inks and Solvents:*

Reduce carbon footprint and align with consumer demand for green packaging.

- *Invest in Sustainable Product Design:*

Develop lightweight designs that use fewer materials while maintaining performance.

- *Enhance Workforce Training:*

Equip staff with knowledge of sustainable practices to foster a culture of continuous improvement.

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- *Data Sharing and Data Availability Statement:*

The data used in this study contain confidential and sensitive information and are not publicly available. Furthermore, all sources used are cited in the reference list. In addition, the data that support the findings of this study are available from the corresponding author upon reasonable request.

- *Conflicts of Interest Statement and Declaration:*

The author (s) and corresponding author (s) declare no conflicts of interest, financial interests or personal relationships that could have influenced the work reported in this paper.

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- *Consent to Publish Declaration:*

Author(s) and the corresponding author (s) hereby give their consent for the publication of this Article including details in the Journal.

- *Ethics Approval and Consent to Participate:*

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- *Author Contribution:*

- Mohammad Mashrafee - Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Writing the original draft.
- Mohammad Morshedul Karim – Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Writing the original draft.
- Azizul Haque – Supervision, Validation, Writing, Review and Editing.
- Mohammad Jonaed – Investigation, Visualization, Resources.
- S M Ashrafur Rahman – Supervision, Investigation, Project Administration, Resources.
- Anisul Islam Anis: Supervision, Validation, Project administration and funding.

- *Highlights:*

- Raw Material efficiency is a key solution to the challenges faced by the flexible packaging industry
- The key changes are reducing cylinder etching depth to minimize ink usage and increasing LDPE film thickness to stabilize GSM delivered measurable improvements in both economic and environmental performance.
- This study presents the key outcomes of the optimization strategy implemented in flexible packaging production.
- Ultimate goal is to evaluate the effectiveness of reducing ink usage through cylinder etching optimization and adjusting LDPE film specifications to balance GSM and enhance sustainability.

REFERENCES

[1]. Accorsi, R., Cascini, A., Cholette, S., Manzini, R., & Mora, C. (2014). Economic and environmental assessment of reusable plastic containers: A food

catering supply chain case study. International Journal of Production Economics, 152, 88–101. https://doi.org/10.1016/j.ijpe.2013.12.014
[2]. Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124
[3]. Choudhary, S., & Kumar, R. (2020). Sustainable practices in rotogravure printing: A review of ink reduction techniques. Journal of Cleaner Production, 256, 120294. https://doi.org/10.1016/j.jclepro.2020.120294
[4]. Ellen MacArthur Foundation. (2020). The circular economy in packaging: Current trends and future directions. https://ellenmacarthurfoundation.org/topics/packaging/overview
[5]. European Union. (2018). Directive (EU) 2018/852 on packaging and packaging waste. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018L0852
[6]. Flexible Packaging Association (FPA). (2022). The Future of Flexible Packaging: Industry Outlook and Sustainability Trends. https://flexpack.org
[7]. Ghosh, P., Das, T., & Karmakar, S. (2020). Solventless lamination in flexible packaging: Environmental benefits and performance analysis. Packaging Technology and Science, 33(4), 145–158. https://doi.org/10.1002/pts.2493
[8]. Kumar, V., Singh, J., & Kumar, P. (2021). Optimization of LDPE film thickness for sustainable flexible packaging: Balancing GSM and cost efficiency. Resources, Conservation & Recycling, 164, 105156. https://doi.org/10.1016/j.resconrec.2020.105156
[9]. Lewis, H. (2012). Packaging for sustainability. Springer. https://doi.org/10.1007/978-3-642-23677-1
[10]. Mahalik, N. P., & Nambiar, A. N. (2010). Trends in food packaging and manufacturing systems and technology. Trends in Food Science & Technology, 21(3), 117–128. https://doi.org/10.1016/j.tifs.2009.12.006
[11]. McKinsey & Company. (2023). Sustainability in packaging: Global landscape review. https://www.mckinsey.com/business-functions/sustainability/our-insights/sustainability-in-packaging
[12]. Patel, R., & Rao, P. (2017). Gravure cylinder etching depth optimization for ink savings in flexible packaging. Journal of Print and Media Technology Research, 6(2), 89–102. https://doi.org/10.14622/JPMTR-1706
[13]. Singh, P., Kaur, G., & Kaur, H. (2016). Challenges in recycling multilayer flexible packaging: A material and process perspective. Waste Management, 48, 480–487. https://doi.org/10.1016/j.wasman.2015.11.030
[14]. Smithers. (2021). The Future of Packaging: Long-Term Strategic Forecast to 2030. https://www.smithers.com/services/market-reports/packaging/the-future-of-packaging-long-term-strategic-forecast-to-2030
[15]. Sultana, N. (2024). Challenges in academic writing for undergraduate students in a government college of Bangladesh. European Journal of Teaching and Education, 6(1). https://www.dpublication.com/journal/EJTE/article/view/1418
[16]. Sustainable Packaging Coalition (SPC). (2021). Definition of sustainable packaging. https://sustainablepackaging.org/our-vision/definition-of-sustainable-packaging/
[17]. Tavares, J. R., Stloukal, P., & Koutny, M. (2019). Bio-based materials as a sustainable alternative to conventional plastics in packaging. Polymer Degradation and Stability, 167, 162–168. https://doi.org/10.1016/j.polymdegradstab.2019.06.008
[18]. AMI International. (2023). Global LDPE film market trends 2023-2030: Sustainability and cost optimization strategies. AMI International. https://www.ami.international/reports/ldpe-film-trends
[19]. Smithers. (2022). The future of flexible packaging to 2027: Market forecasts and technology developments. Smithers Pira. https://www.smithers.com/services/market-reports/packaging/flexible-packaging-future-2027
[20]. Zhao, Y., Wang, L., & Fan, X. (2019). Ink transfer mechanisms in rotogravure printing: Implications for sustainability. Progress in Organic Coatings, 127, 240–249. https://doi.org/10.1016/j.porgcoat.2018.11.022
[21]. Rahman, M. M., & Shahed, F. H. (2024). Bangladeshi students' challenges of English academic writing in an international university: A qualitative study. TESOL Society of Bangladesh Journal, 11(1). https://journal.tesolbangladesh.com.bd/index.php/tesol/article/view/64