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A Systematic Investigation into Printing Defects in Central Impression (CI) Flexographic Printing on Low-Density Polyethylene (LDPE) Substrates

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Abstract

Printing quality in Central Impression (CI) flexographic printing on Low-Density Polyethylene (LDPE) substrates is strongly influenced by the interaction between substrate surface properties, ink behaviour, and press operating conditions. Despite its wide application in flexible packaging, maintaining consistent print quality remains challenging due to the frequent occurrence of various printing defects. The present investigation systematically examines common defects observed during CI flexographic printing on LDPE films, including ink smearing, dot gain, banding, pinholing, poor ink adhesion, and registration errors. The effects of key process parameters such as printing speed, impression pressure, anilox roller volume, ink viscosity, and substrate surface energy are critically analysed to understand their contribution to defect formation. Controlled printing trials were conducted using LDPE substrates with defined specifications to evaluate variations in print quality under different operating conditions.

Results indicate that defect formation is predominantly governed by the combined influence of low surface energy of LDPE, suboptimal ink rheology, and mechanical variations within the printing system. Inadequate wetting and adhesion behaviour leads to ink transfer issues, while improper balance between anilox selection and ink viscosity contributes to tonal inconsistency and print unevenness. Additionally, mechanical instabilities in CI flexographic systems are found to significantly affect registration accuracy and cause banding defects.

Findings highlight the necessity of optimizing substrate treatment, ink formulation, and press parameters to minimize defect occurrence and enhance overall print performance on LDPE materials used in flexible packaging applications.

Keywords; CI flexographic printing, Low-Density Polyethylene (LDPE), Printing defects, Flexible packaging, Ink adhesion, Dot gain, Anilox roller, Substrate surface energy, Print quality analysis, Process optimization

INTRODUCTION

Central Impression (CI) flexographic printing has emerged as one of the most widely used technologies in the flexible packaging industry due to its ability to deliver high-speed production with consistent print quality on a variety of non-absorbent substrates. LDPE (Low-Density Polyethylene) is a commonly used packaging film because of its flexibility, chemical resistance, and cost-effectiveness. However, printing on LDPE using CI flexography presents significant technical challenges due to its low surface energy and poor ink wettability, which often lead to inconsistent ink transfer and various print quality issues.

In CI flexographic systems, the printing process is highly sensitive to multiple interrelated parameters such as ink rheology, anilox roller specification, impression pressure, printing speed, and substrate surface characteristics. Any imbalance in these parameters can result in visible printing defects, including dot gain, banding, pinholing, misregistration, and ink smearing. The continuous nature of CI presses, while advantageous for productivity, further amplifies the impact of even minor process variations, making defect control a critical aspect of production management.

Despite advancements in press technology and ink formulations, achieving defect-free printing on LDPE remains a persistent challenge in industrial practice. A systematic understanding of how substrate properties and process parameters interact to generate printing defects is essential for improving print stability and quality. Therefore, it becomes important to investigate the root causes of these defects in a structured manner, with the aim of identifying effective strategies for optimizing CI flexographic printing performance on LDPE substrates.

Research Objective

The study of printing defects in Central Impression (CI) flexographic printing on Low-Density Polyethylene (LDPE) substrates requires a systematic understanding of how material properties, ink characteristics, and process parameters collectively influence print quality. In order to achieve a clear and structured investigation, the research is directed toward identifying the key causes of defects and evaluating the factors responsible for their occurrence during the printing process.

- To identify and analyze the major printing defects occurring in CI flexographic printing on LDPE substrates, such as dot gain, banding, pinholing, ink smearing, and registration errors.
- To examine the influence of substrate properties, ink behavior, and key process parameters (printing speed, impression pressure, anilox volume, and ink viscosity) on the formation of printing defects.

RESEARCH METHODOLOGY

Research methodology refers to the systematic approach used to conduct a study in a structured and scientific manner. In this research paper, the methodology is designed to investigate printing defects in Central Impression (CI) flexographic printing on Low-Density Polyethylene (LDPE) substrates. The focus is on identifying major defects, understanding their causes, and analyzing the influence of key process parameters, ink properties, and substrate characteristics on print quality. The study adopts a descriptive and analytical research approach. The descriptive aspect is used to identify and classify common printing defects observed in CI flexographic printing, while the analytical aspect examines the relationship between process variables and the occurrence of these defects. The research is based on practical printing observations supported by industrial printing conditions reported in relevant literature, ensuring that the findings reflect real production environments.

The materials and setup considered in this study include LDPE film substrates used in flexible packaging, a CI flexographic printing system, photopolymer printing plates, anilox rollers of defined specifications, and solvent- or water-based inks commonly used in flexographic applications. Key process variables such as ink viscosity, printing speed, impression pressure, anilox volume, and substrate surface treatment are considered as influencing factors. The resulting print samples are evaluated for defects such as dot gain, banding, pinholing, ink smearing, misregistration, and density variations using visual inspection and basic measuring tools such as densitometers and magnifiers. The collected observations are analysed through comparative evaluation of different printing conditions. Variations in process parameters are related to changes in defect occurrence to identify probable root causes. The analysis focuses on establishing relationships between substrate behaviour, ink transfer characteristics, and machine settings. Standard printing conditions are maintained as far as possible to ensure consistency, and repeated observations are used to improve reliability. This methodological framework provides a practical and structured basis for understanding defect formation in CI flexographic printing on LDPE substrates.

DATA COLLECTION & ANALYSIS

Data for this study were collected from production records and on-machine observations over a period of three months in CI flexographic printing on LDPE substrates, focusing on wastage patterns caused by major printing defects. The recorded defects included dot gain, colour variation, mottle, blurring, ink smearing, drying problems (including lamination issues), misting (ghosting), edge flare, pinholing, plate marking, and hickeys. Each production run was monitored to document the frequency, severity, and impact of these defects on overall print quality and material wastage. The collected data were then analysed using a comparative and trend-based approach to identify the most recurring defects and their contribution to production losses, enabling a clear understanding of defect behaviour and supporting process improvement in CI flexographic printing on LDPE substrates.

Table 1, Wastage Pattern in M-I on PSSAs

Wastage Pattern in M-I			
S.No.	**Defect Name**	**Wastage**	**Wastage %**
1	Dot Gain	47397.78	0.81%
2	Colour Variation	42716.51	0.73%

3	Mottle	38035.25	0.65%
4	Blurring	29843.04	0.51%
5	Ink Smearing	24576.62	0.42%
6	Drying Problems (Lamination Issues)	21065.68	0.36%
7	Misting (Ghosting)	15799.26	0.27%
8	Edge Flare	13458.62	0.23%
9	Pinholing	11800	0.20%
10	Plate Marking	7400	0.13%
11	Hickeys	3300	0.06%
	Total	255392.8	4.37%

The table-1, illustrates the wastage pattern in the M-I process on PSSAs, showing that dot gain is the highest contributor with 47,397.78 units (0.81%), followed closely by colour variation and mottle. At the other end of the scale, hickeys represent the lowest wastage at just 3,300 units (0.06%), while plate marking and pinholing also remain relatively minor. Altogether, the cumulative wastage across all defects amounts to 255,392.8 units, which equals 4.37% of total production. This distribution emphasizes that while several defects exist, tackling the top three i.e., dot gain, colour variation, and mottle would yield the most significant reduction in overall losses.

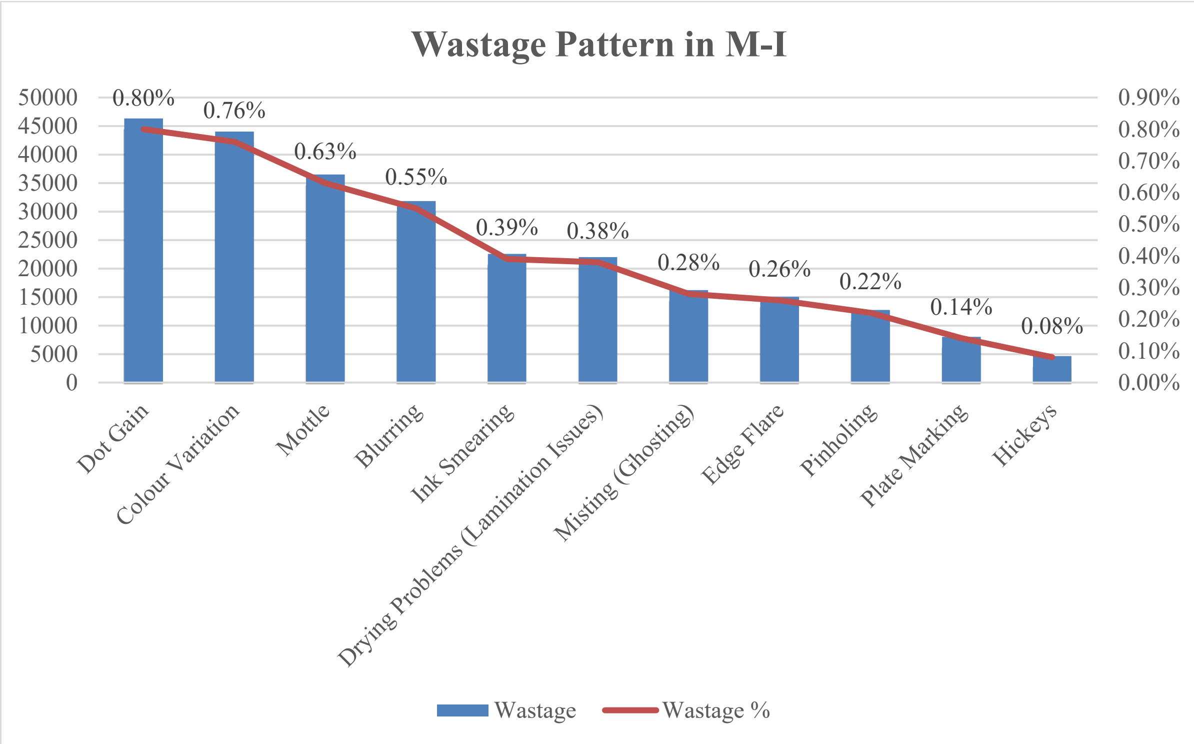

Figure 1, Comparative Wastage Pattern in M-I

Table 2, Wastage Pattern in M-II on PSSAs

Wastage Pattern in M-II			
S.No.	**Defect Name**	**Wastage**	**Wastage %**
1	Dot Gain	44064.9	0.78%
2	Colour Variation	44629.84	0.79%
3	Mottle	35025.95	0.62%
4	Blurring	29941.53	0.53%
5	Ink Smearing	25422.06	0.45%
6	Drying Problems (Lamination Issues)	19772.71	0.35%
7	Misting (Ghosting)	14123.36	0.25%
8	Edge Flare	15253.23	0.27%
9	Pinholing	10168.86	0.18%
10	Plate Marking	6765.91	0.12%
11	Hickeys	2827.46	0.05%
	Total	247995.8	4.39%

The table-2 highlights the distribution of printing defects in the M-II process on PSSAs, with Colour Variation emerging as the highest contributor at 44,629.84 units (0.79%), closely followed by Dot Gain at 44,064.9 units (0.78%). In contrast, Hickeys represent the lowest wastage, only 2,827.46 units (0.05%), while Plate Marking and Pinholing also remain relatively minor contributors. Mid-range defects such as Mottle (35,025.95 units, 0.62%) and Blurring (29,941.53 units, 0.53%) add noticeable impact but are not as critical as the top two. Overall, the cumulative wastage across all defects amounts to 247,995.8 units, accounting for 4.39% of total production, underscoring that addressing Colour Variation and Dot Gain would yield the most significant improvements in reducing losses.

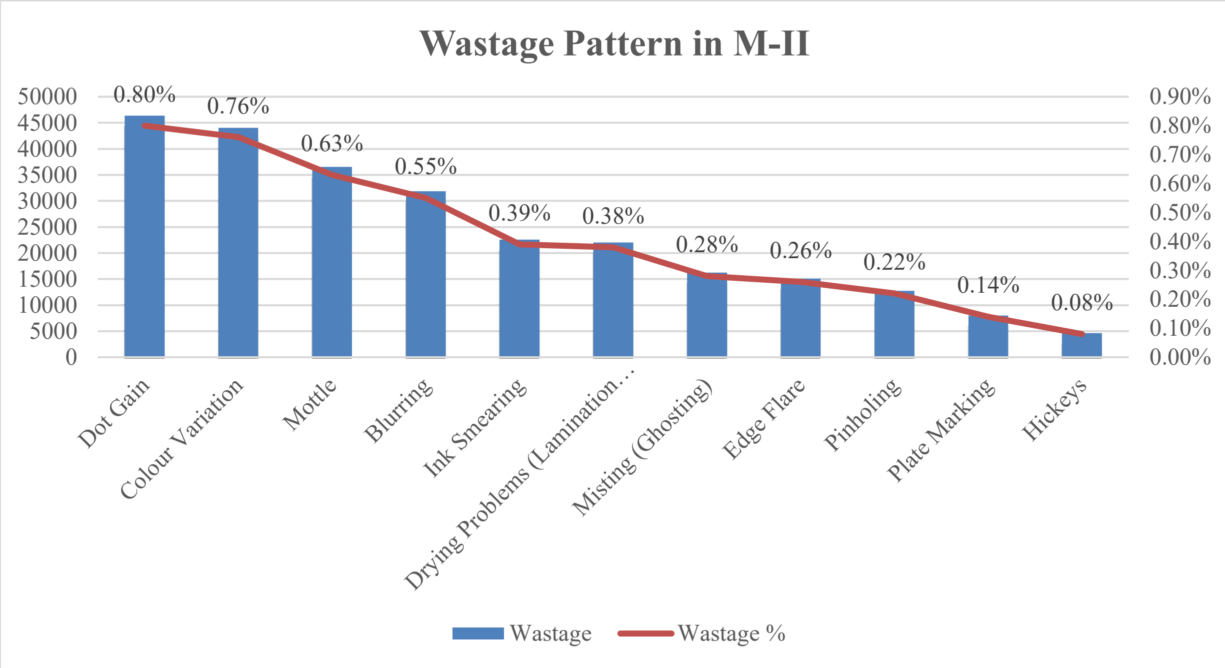

Figure 2, Comparative Wastage Pattern in M-II

Table 3, Wastage Pattern in M-III on PSSAs

Wastage Pattern in M-III			
S.No.	**Defect Name**	**Wastage**	**Wastage %**
1	Dot Gain	46350.83	0.80%
2	Colour Variation	44033.29	0.76%
3	Mottle	36501.28	0.63%
4	Blurring	31866.19	0.55%
5	Ink Smearing	22596.03	0.39%
6	Drying Problems (Lamination Issues)	22016.64	0.38%
7	Misting (Ghosting)	16222.79	0.28%
8	Edge Flare	15064.02	0.26%
9	Pinholing	12746.48	0.22%
10	Plate Marking	8031.4	0.14%
11	Hickeys	4635.08	0.08%
	Total	260064	4.49%

The table-3 outlines the wastage distribution in the M-III process on PSSAs, where Dot Gain is the highest contributor with 46,350.83 units (0.80%), followed closely by Colour Variation at 44,033.29 units (0.76%). Among the mid-range defects, Mottle (36,501.28 units, 0.63%) and Blurring (31,866.19 units, 0.55%) add significant impact, while Ink Smearing and Drying Problems each account for around 0.38–0.39%. At the lower end, Hickeys represent the smallest wastage at 4,635.08 units (0.08%), with Plate Marking (8,031.4 units, 0.14%) and Pinholing (12,746.48 units, 0.22%) also contributing minimally. Overall, the cumulative wastage across all defects amounts to 260,064 units, equating to 4.49% of total production, highlighting that Dot Gain and Colour Variation remain the most critical issues to address for reducing losses.

Table 4, Wastage Pattern in M-I, M-II and M-III on PSSAs

Defects	**M-I**		**M-II**		**M-III**	
	TP = 5851578 Meters		**TP = 5649347 Meters**		**TP = 5793854 Meters**	
	Wastage	**Wastage %**	**Wastage**	**Wastage %**	**Wastage**	**Wastage %**
Dot Gain	47397.78	0.81%	44064.9	0.78%	46350.83	0.80%
Colour Variation	42716.51	0.73%	44629.84	0.79%	44033.29	0.76%

Mottle	38035.25	0.65%	35025.95	0.62%	36501.28	0.63%
Blurring	29843.04	0.51%	29941.53	0.53%	31866.19	0.55%
Ink Smearing	24576.62	0.42%	25422.06	0.45%	22596.03	0.39%
Drying Problems (Lamination Issues)	21065.68	0.36%	19772.71	0.35%	22016.64	0.38%
Misting (Ghosting)	15799.26	0.27%	14123.36	0.25%	16222.79	0.28%
Edge Flare	13458.62	0.23%	15253.23	0.27%	15064.02	0.26%
Pinholing	11800	0.20%	10168.86	0.18%	12746.48	0.22%
Plate Marking	7400	0.13%	6765.91	0.12%	8031.4	0.14%
Hickeys	3300	0.06%	2827.46	0.05%	4635.08	0.08%
Total	255392.8	4.37%	247995.8	4.39%	260064	4.49%

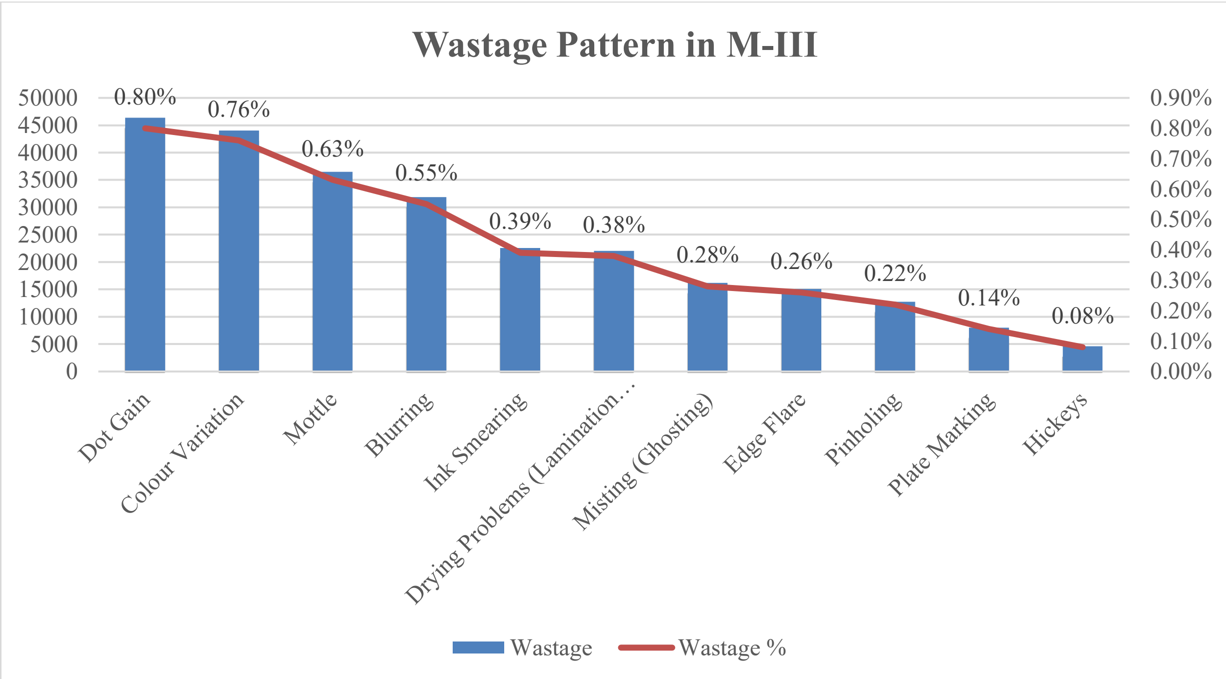

Figure 3, Comparative

Wastage Pattern in M-III

The comparative table summarizes wastage patterns across three machines (M-I, M-II, and M-III) on PSSAs. All three machines show similar overall wastage levels, ranging between 4.37% and 4.49% of total production, with M-III recording the highest at 260,064 units (4.49%) and M-I the lowest at 255,392.8 units (4.37%). Among individual defects, Dot Gain and Colour Variation consistently emerge as the largest contributors across all machines, each accounting for around 0.76–0.81% of wastage. Mid-range defects such as Mottle (0.62–0.65%) and Blurring (0.51–0.55%) also add noticeable impact, while Ink Smearing and Drying Problems remain moderate contributors. At the lower end, Hickeys consistently represent the smallest wastage, ranging from 0.05% to 0.08%, followed by Plate Marking and Pinholing. Overall, the data highlights that while minor defects vary slightly between machines, the dominant issues i.e., Dot Gain and Colour Variation remain stable across all three, making them the most critical targets for process improvement.

RESULTS & DISCUSSION

The analysis of wastage patterns across M-I, M-II, and M-III on PSSAs shows that all three machines exhibit similar overall wastage levels, ranging between 4.37% and 4.49% of total production. M-I recorded 255,392.8 units (4.37%), M-II slightly lower at 247,995.8 units (4.39%), while M-III was the highest at 260,064 units (4.49%). Across all machines, Dot Gain and Colour Variation consistently emerged as the most significant defects, each contributing around 0.76–0.81% of wastage. Mid-range defects such as Mottle and Blurring added noticeable impact, ranging between 0.51–0.65%, while Ink Smearing and Drying Problems contributed moderately. At the lower end, Hickeys remained the least significant defect, accounting for only 0.05–0.08%, with Plate Marking and Pinholing also contributing minimally.

The results clearly indicate that Dot Gain and Colour Variation are systemic issues, appearing as dominant contributors across all three machines. This suggests that the root causes lie in ink transfer, press calibration, or color management processes rather than machine-specific faults. Addressing these two defects would yield the most substantial reduction in overall wastage.

Although M-II recorded the lowest absolute wastage, its percentage was nearly identical to M-I, highlighting that efficiency gains are marginal between machines. M-III, however, showed slightly higher wastage, pointing to weaker process control or variability in substrate handling. Mid-range defects such as Mottle and Blurring consistently contributed around 0.6%, underscoring the need for improved substrate quality and press stability.

Minor defects like Hickeys, Plate Marking, and Pinholing had negligible impact on overall wastage. While they should not be ignored, they are not priority areas for corrective action. Instead, strategic focus should be placed on common root causes across machines ink formulation, substrate consistency, and calibration practices.

CONCLUSION

The comparative study of wastage patterns across M-I, M-II, and M-III on PSSAs demonstrates that overall wastage levels remain relatively stable, ranging between 4.37% and 4.49% of total production. Despite minor variations in absolute values, the defect distribution is consistent across all machines. Dot Gain and Colour Variation are the most critical defects, contributing the highest share of wastage in every case, while Mottle and Blurring emerge as secondary but recurring issues. Minor defects such as Hickeys, Plate Marking, and Pinholing have negligible impact and do not significantly affect overall efficiency.

This consistency indicates that the root causes of wastage are systemic rather than machine-specific, pointing to challenges in ink transfer, color management, and substrate stability. Therefore, corrective and preventive actions should prioritize these dominant defects, supported by improvements in press calibration and substrate handling. By focusing on these areas, organizations can achieve meaningful reductions in production losses and enhance overall process efficiency.

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