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RESEARCH ARTICLE

Study of print suitability of environment-friendly plastics using flexography printing

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Abstract

Environmental-friendly plastics (EFP) are new alternatives of fossil-based plastics. The EFP family mainly constitutes bio-plastics/bio-attributed plastics and post-consumer recycled plastics (PCR). EFP contributes around 10% of total plastics production in global plastic production. Presently EFP are mostly used in grocery bags, bin liners, compostable garbage bags and single-use plastics with single or spot color printing. Multi-color printing can add value or open new horizons for these materials, leading to high-value applications. It can also be used for high-speed printing or flexible packaging applications. Plastics available in this category come from both fossil-based and bio-based sources. Fossil-based bioplastics has almost similar degree of print suitability but materials coming from bio-based sources are yet to be explored for print suitability, especially with high-speed multi-color printing machines. Flexographic printing is known for high-quality and high-speed printing on different substrates, including paper, conventional plastics and fossil-based bio-plastics. The advantage of having a common impression cylinder (CIC) arrangement and the requirement of less pressure during printing makes it suitable for consideration for printing on EFP. Hence, this study, print suitability of EFP using flexography printing, is an attempt to explore the mutual compatibility of these substrates and printing process, which will prove to be a boon in the future for establishing EFP as a strong substitute for replacing conventional plastics.

Keywords: Print suitability, Environmentally-friendly plastics, Flexography printing, Ink density, Grayness, Ink trapping.

Introduction

Today's "Plastics" or "plastic materials" are the terms used to describe an extremely large family of very different materials with different characteristics, properties and uses. The plastic family offers a wide range of plastic materials, including new generation environmentally friendly substrates; it is reported that more than 40 different types of plastics are available with 100 springs. Many of them are being used significantly in flexible as well as rigid packaging applications. Printing on conventional plastics using compatible printing processes makes them beautiful and enables them to self-promote for high-value applications, which leads to more and more use of plastics (Kumar *et al*., 2023a). Printing on plastics has opened the door for ever-growing packaging demand, especially flexible packaging, which provides convenience in all walks of life. Printing on plastics was one of the most challenging jobs for printers in the last century. (Kumar *et al*., 2023b)

Need of Environmental Friendly Plastics for Printing and Packaging

Initially, plastics were made from environmentally friendly materials and were later manufactured from petroleum-based products (Coppola *et al*., 2021). A recent report from plastics Europe shows that the packaging sector uses 44% of plastics produced globally (Plastic Europe: Plastics – The Facts 2022, 2022) (Figure 1).

It is already established that plastics are not inherently bad in nature but they are bad for the environment as they are not environment-friendly because fossil-based plastics are not degradable (Ezgi Bezirhan Arikan & Havva Duygu Ozsoy, 2015). Different attempts were made to make fossil-based plastics compostable and degradable but resulted in micro-plastics, which is more dangerous for ecosystems and soils than conventional plastics. So, a great need arises for developing degradable substrates/materials for printing & packaging applications, especially from bio-based sources.

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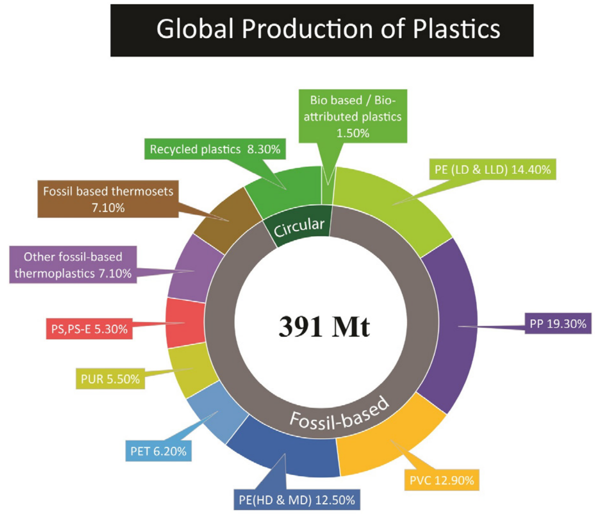

Source (PlasticEurope: Plastics – The Facts 2022, 2022)

Figure 1: Global plastics production and their types

Environmentally Friendly Plastics

Environmentally Friendly Plastics (EFPs) refer to a category of plastics designed to minimize environmental impact during their entire life cycle, from production to disposal (Figure 2). These plastics are typically degradable or compostable, which means they can be broken down naturally by microorganisms and decompose into natural elements without causing harm to the environment. Environmental-friendly plastics can be made from renewable resources and usually have a lower carbon footprint, which makes them a more sustainable option for various applications at conventional plastics (Kharb & Saharan, 2022).

These plastics are intended to address the problems associated with conventional fossil-based plastics, such as non-biodegradability, contribution towards microplastics, depletion of finite petroleum-based products and pollution (Othman *et al*., 2021). These are being considered as a potential solution to plastic pollution and the accumulation of non-biodegradable waste in the environment (Álvarez-Chávez *et al*., 2012).

Sustainability and biodegradability are the biggest strengths of EFPs coming from bio-based sources (EFP-BP) and hence, they have been readily accepted even in applications where they are marginally or sometimes more expensive than conventional plastics. Recently, researchers have reported some bio-based plastics that can be shaped suitably for application as substrates for printing for packaging applications.

The post-consumer recycled plastics (PCR) are popularly known as PCR plastics. Plastic materials are made from reprocessing discarded plastics that have completed their intended use by consumers or industries (Of *et al*., n.d.). It is derived from plastic products that have completed their intended life cycle and have been collected through household and business recycling programs. This type of recycled plastic is distinct from pre-consumer recycled plastic, generated from manufacturing waste or excess plastic materials before reaching the consumer.

PCR is part of circular plastics. Due to this, they are considered EFPs and categorized as environmentally friendly plastics-recycled plastics (EFP-RP) (Plastics Europe's Key Report to Eliminate Plastic Pollution, 2023). They have excellent potential to be used for printing & packaging applications due to similar surface characteristics with conventional plastics. World plastics production including Fossil based, including PCR and bio-based plastics in 2021 is reported as 390.7 million tonnes (Plastics Europe: Plastics – The Facts 2022, 2022) out of which only around 10% of plastics are circular, (including bio-based) plastics. Europe is trying to reach the objective of end plastic pollution by 2040 through a circular economy where all plastic applications are reused, recycled, and responsibly managed during and after use while enabling lower greenhouse gas (GHG) emissions (Plastics Europe's Key Report to Eliminate Plastic Pollution, 2023). However, there are plastics that are recyclable in nature and can be recycled, but they are not being recycled for very obvious reasons like cost-benefit analysis fossil-based conventional plastics that can be recycled but not being recycled are categorized as EFPs - conventional recyclable plastics (EFP-CP).

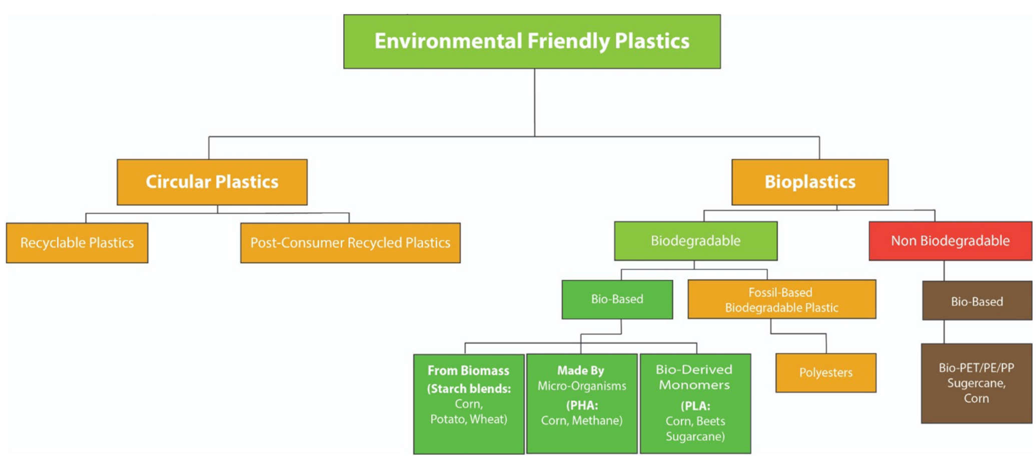

Figure 2: Categorization of EFPs

Printing on Plastics

Printing has touched almost every life after its invention, either in printed products or the form for packages. Printing processes are categorized into impact and non-impact, which are suitable for printing on different substrates. Every printing process has its own applications, advantages and limitations and is suitable for printing on different set of materials (Kipphan, 2001). Printing on plastics usually comes under flexible printing, in which the Gravure printing process and flexography printing process are the leading printing processes in this field.

Flexography Printing Process

Flexography is also a relief method of printing, exactly the same as the letterpress process of printing but with flexible plates. The process was first invented and patented in 1890 by Bibby, Baron and Sons. It is also known as the aniline process of printing. Flexography is widely used for printing packaging jobs, polythene and plastic carry bags, which do not emphasize a very high quality of printing. A wide variety of papers, paper boards, polyester and plastic films, metal foils and many other packaging substrates can be printed by flexography (Mendiratta, 2017). Suitable for high speed especially due to common impression cylinder (CIC) arrangement. Modern flexography printing machines with CIC arrangements and GTT technology for anilox have excellent print quality and compete with Gravure printing (*Vision CI Flexo*, 2023).

Print suitability on EFPs

Print suitability refers to the compatibility of the printing substrate, ink, and printing process for a specific printing job or application, either individually or as a combination. Printing, particularly flexible/package printing, is a versatile, high-quality printing job mostly done on non-absorbent surfaces like plastics and foils. Print suitability is a wider term and covers printability and runnability for specific printing substrates.

Printability

Printability is a complex interplay of substrate properties, ink characteristics, and printing machine settings. Printability refers to the ability of a substrate to accept ink evenly and produce high-quality printed results irrespective of the printing process. Printability can be measured, managed and maintained objectively to get desired results. The important and objective print parameters are solid ink density (SID), dot gain/tonal value increase (TVI), tracing, color difference, hue error, and grayness. All these print parameters are established and are measurable, manageable and maintainable during large and repeated print run.

- *SID*

SID or ink film thickness refers to the amount of printing ink applied to a printed surface to achieve a solid or opaque color, irrespective of process of printing. It is also known as print density (Jangra *et al.*, 2023) (Figure 3).

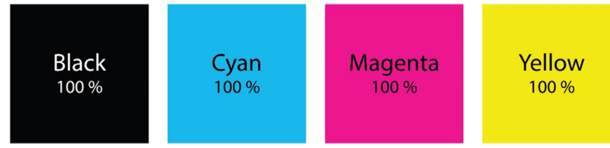

Figure 3: SID of process color

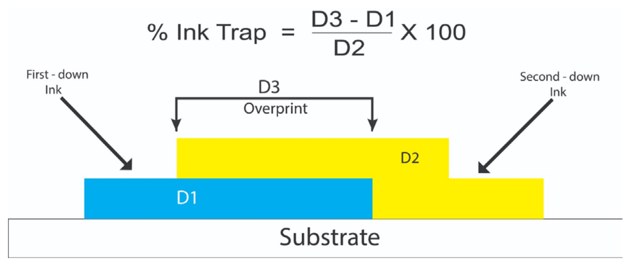

Figure 4: Ink trapping (Source: Chung & Hsu, 2008)

- *Grayness*

Grayness indicates the presence of gray in a color that makes it appear less saturated. Greyness are used to check for color consistency throughout the press run (x_Rite, n.d.). Grayness are presented in % and calculated using the following formula.

$$G = \frac{D_L}{D_H} X\ 100$$

where
D_L = Lowest density of C, M or Y
D_H = Highest density of C, M or Y

- *Ink trapping*

Ink trapping is a printing technique that involves overlapping of colors to prevent gaps or white spaces from appearing between them, which can happen due to misalignment or spreading of ink. This process is particularly crucial in high-speed multi-color printing, where multiple ink layers are applied one after another. By creating an overlap between colors, ink trapping ensures a seamless and vibrant final print. Frank Preucil in 1953 has, introduced an ink-trapping formula expressed as in Figure 4.

Runnability

Runnability refers to the ability of a printing press to consistently and efficiently produce high-quality prints over an extended print run, typically involving large quantities of printed material (Parola *et al.*, 2003).

Research Objective

Printability is a key aspect for printing on different substrates. The major objective of the research is to study printability aspects on EFPs using the flexographic printing process.

Materials and Methodology

For study and analysis of the printability of EFPs using the flexographic printing process, the following steps are followed:

Preparation of Test chart

A suitable test chart was prepared by incorporating various elements to check the printability and runnability of the substrate.

Printing Process

The flexography printing process was selected for this study under standard pressroom conditions.

Printing Machine

Printing on flexography printing press (Common Impression Cylinder arrangement) was done for selected substrates.

Selection of Substrate

Substrates were selected from a wide gamut of EFPs for this study, coded as recyclable circular plastic - Recyclable (EFP-CP), circular plastic - Post-consumer. Recycled plastics (EFP-RP) & bio-based/bio-attributed plastics (EFP-BP)

Selection of Printing Inks

Standard flexographic printing ink was used for this study.

Colorimetric Measuring Instrument

X-rite, exact spectrophotometer was used for capturing of data.

Image Carrier Preparation

Flexographic photopolymer plates were prepared for flexographic printing was made from Kodak-NX (Kodak NX, n.d.).

Selected substrates were printed on a flexographic printing machine with suitable process inks in standard press room conditions, maintaining all printing parameters. Prints were selected for study on equal intervals to check the consistency and accuracy of printing parameters for checking printability (Vision CI Flexo, 2023) (Table 1).

Data Analysis

While studying printability aspects of different EFP plastics on flexography printing, three types of EFP were considered: EFP-CP, EFP-RP and EFP-BP, which were printed using the flexographic printing process. Printability aspects taken into consideration are explained as below:

Table 1: Technical description of flexography printing machine

Technical Parameter	*Description*
Anilox Roller	GTT Technology
Number of colors	8
Web widths	920–1120–1320–1520 mm (36.2–44–51.9–59.8 in)
Print widths	900–1100–1300–1500 mm (35.4–43.3–51–59 in)
Printing cylinder repeat	820–1100 mm
Mechanical speed	max 400 m/min (1312 ft/min)
Automatic shafted winders, reel diameter	1020 mm

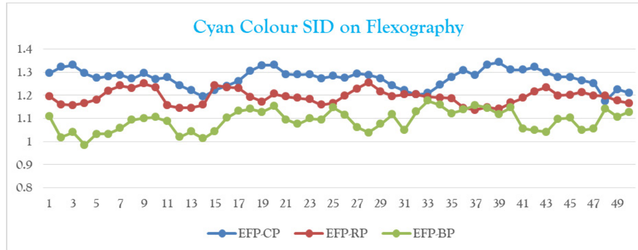

Figure 5: Cyan Color SID for Flexography Printing

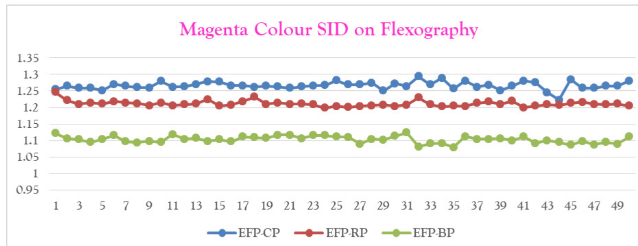

Figure 6 : Magenta color SID for flexography printing

SID

SID of cyan, magenta, yellow and black color on different EFP (CP, RP and BP) media printed using flexography printing (at 120 LPI) are presented below:

- *SID- cyan color*

Measured values for SID for flexographic printing at 120 LPI on selected EFPs, i.e., EFP-CP, EFP-RP and EFP-BP for cyan color are graphically presented in Figure 5. The minimum and maximum measured value for SID on EFP-CP, EFP-RP and EFP-BP were recorded between 1.1747 to 1.3435, 1.1360 to 1.2549, 0.9851 to 1.1771, respectively. The range of SID for cyan color was lowest for EFP-BP and found highest for EFP-CP. The minimum standard deviation for cyan color was found 0.0393 for EFP-CP. Figure 5 clearly depicts that substrate EFP-RP has consistent result and EFP-BP is very close to EFP-RP.

- *SID- magenta color*

The representation of data for SID for Flexographic printing on EFP, i.e., EFP-CP, EFP-RP and EFP-BP for magenta color is graphically presented in Figure 6. The minimum and maximum measured value for SID on EFP-CP, EFP-RP and EFP-BP were recorded between 1.2225 to 1.2937, 1.1987 to 1.2460, and 1.0794 to 1.1242, respectively. The range of SID for magenta color was lowest for EFP-BP and found highest for EFP-CP. The minimum standard deviation for magenta color was found 0.0086 for EFP-RP. Figure 6 clearly depicts that substrate EFP-RP has consistent results while EFP-BP is very close to EFP-RP.

- *SID- yellow color*

SID for flexographic printing at 120 LPI on EFP for yellow color is graphically presented in Figure 7. The minimum and maximum measured value for SID for yellow color on EFP-CP, EFP-RP and EFP-BP were recorded between 1.0393 to 1.1577, 0.9908 to 1.0995 and 0.6794 to 0.9910, respectively. The

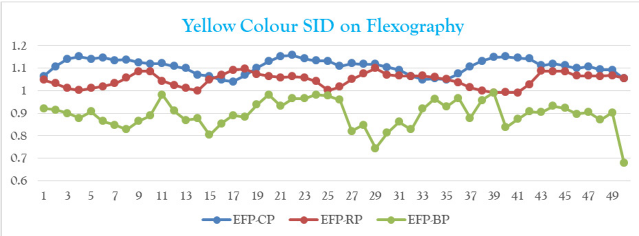

Figure 7: Yellow color SID for flexography printing

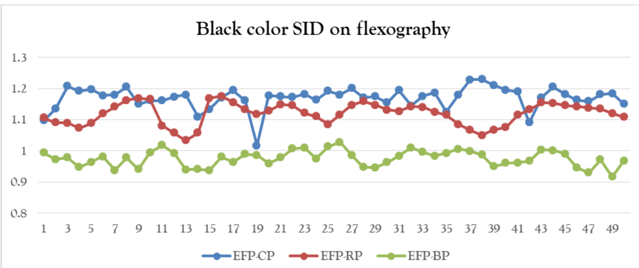

Figure 8: Black color SID for flexography printing

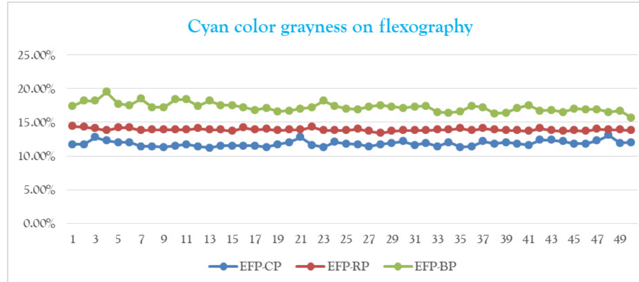

Figure 9: Grayness for cyan color for flexography printing

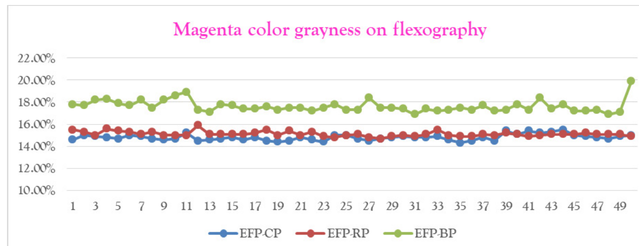

Figure 10: Grayness for magenta color for flexography printing

range of SID for yellow color was lowest for EFP-BP, while SID for EFP- CP was recorded as highest. The minimum standard deviation for the yellow color was found 0.0309 for EFP-RP. Figure 7 clearly depicts that substrate EFP-RP has consistent result while EFP-BP is close to EFP-RP.

- *SID- black color*

Figure 8 presents the data recorded for SID for black color on EFP, i.e., EFP-CP, EFP-RP and EFP-BP) by flexographic printing. The minimum and maximum measured values for SID for black color on EFP-CP, EFP-RP and EFP-BP were recorded between 1.0174 and 1.2295, 1.0337 and 1.1752, and 0.9171 and 1.0275, respectively. The range of SID for black color was lowest for EFP-BP and found highest for EFP-CP. The minimum standard deviation for black color was found to be 0.0256 for EFP-BP. Figure 8 clearly depicts that substrate EFP-BP has consistent results.

Grayness

Grayness of cyan, magenta, yellow and black colors on different EFP (CP, RP and BP) media printed using flexography printing (at 120 LPI) are presented below:

- *Grayness- cyan color*

Measured values for grayness for flexographic printing at 120 LPI on selected EFP, i.e., EFP-CP, EFP-RP and EFP-BP for cyan color are graphically presented in Figure 9. The minimum and maximum measured values for grayness on EFP-CP, EFP-RP and EFP-BP were recorded between 11.20 to 13.10%, 13.40 to 14.40% and 15.70 to 19.50%, respectively. The range of grayness for cyan color was recorded as lowest for EFP-CP and found to be highest for EFP-BP. The minimum standard deviation for cyan color was found to be 0.0019 for EFP-RP. Figure 9 shows that substrate EFP-RP has consistent results and the lowest standard deviation (0.0019).

- *Grayness - magenta color*

The representation of data for grayness on flexographic printing on EFP, i.e., EFP-CP, EFP-RP and EFP-BP for magenta color, is graphically presented in Figure 10. The minimum and maximum measured values for grayness on EFP-CP, EFP-RP and EFP-BP were recorded between 14.30 to 15.50%, 14.70 to 15.90% and 16.90 to 19.90%, respectively. The range of grayness for the magenta color was found lowest for EFP-CP and highest for EFP-BP. The minimum standard deviation for magenta color was found to be 0.0022 for EFP-RP. Figure 10 clearly depicts that substrate EFP-RP and EFP-CP have minor differences between their standard deviations.

- *Grayness - yellow color*

Grayness for flexographic printing at 120 LPI on EFP: EFP-CP, EFP-RP and EFP-BP) for yellow color is graphically presented in Figure 11. The minimum and maximum measured values for grayness for yellow color on EFP-CP, EFP-RP and EFP-BP were recorded between 0.10 to 1.40%, 1.70 to 3.00% and 3.40 to 5.80%, respectively. The range of grayness for yellow color was minimal for EFP-CP, while grayness for EFP- BP was recorded as the highest. The minimum standard deviation for yellow color was found to be 0.0030 for both EFP-CP and EFP-RP. Figure 11 clearly depicts that substrate EFP-RP and EFP-CP has consistent results and the deviation for both is equal to each other.

- *Grayness - black color*

Figure 12 presents the data recorded for grayness for black color on EFP, i.e., EFP-CP, EFP-RP and EFP-BP by flexographic printing at 120 LPI. The minimum and maximum measured value for grayness for black color on EFP-CP, EFP-RP and EFP-BP were recorded between 84.90 to 92.00%, 81.90 to 84.20% and 85.60 to 90.10%, respectively. The range of

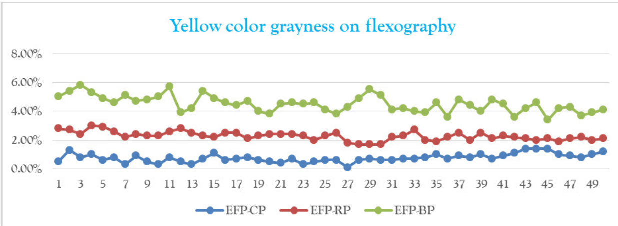

Figure 11: Grayness for yellow color for flexography printing

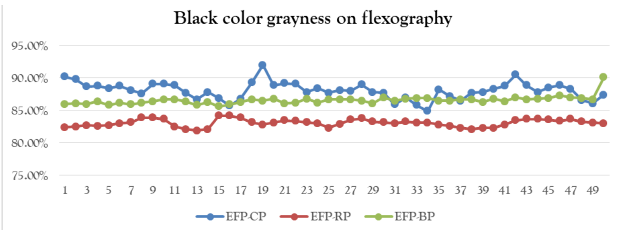

Figure 12: Grayness for black color for flexography printing

grayness for black color was exhibited lowest for EFP-RP and found highest in EFP-CP. The minimum standard deviation for black color was found 0.0058 for EFP-RP.

Ink trapping

Ink trapping of red, green and blue color on different EFP (CP, RP and BP) media printed using flexography printing (at 120 LPI) are presented below:

- *Ink trapping – red*

Measured values for ink trapping (Red) for flexographic printing at 120 LPI on selected EFP, i.e., EFP-CP, EFP-RP and EFP-BP for red color are graphically presented in Figure 13. The minimum and maximum measured value for ink trapping (Red) on EFP-CP, EFP-RP and EFP-BP were recorded between 65.10 to 75.80%, 68.50 to 78.40%, 97.70 to 99.80%, respectively. The range of ink trapping (Red) for red color was lowest in case of EFP-CP and found highest for EFP-BP. The minimum standard deviation for red color ink trapping was found 0.0051 for EFP-BP. Figure 13 clearly depicts that substrate EFP-BP has a consistent results for ink trapping for red color.

- *Ink trapping – green*

Ink trapping (Green) for flexographic printing at 120 LPI on EFP, i.e., EFP-CP, EFP-RP and EFP-BP for green color is graphically presented in Figure 14. The minimum and maximum measured value for ink trapping for green color on EFP-CP, EFP-RP and EFP-BP were recorded between 84.10 to 94.30%, 79.30 to 92.90% and 88.30 to 99.80%,

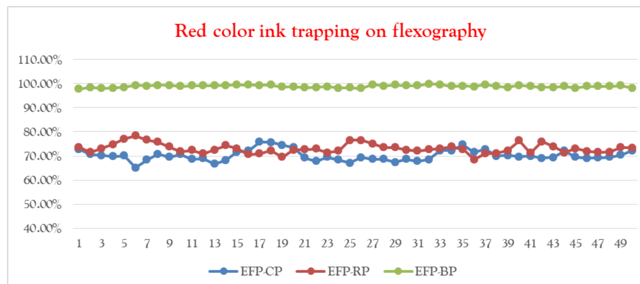

Figure 13: Red color ink trapping for flexography printing

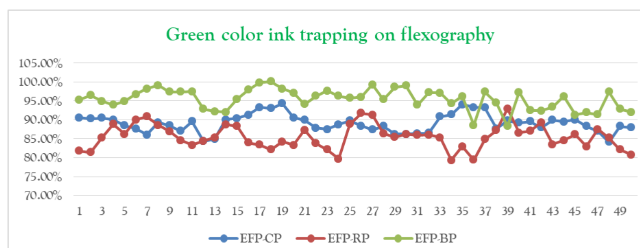

Figure 14: Green color ink trapping for flexography printing

Table 2: Printability (SID & Grayness) on EFP using flexographic process

Printing parameter		*Cyan*		*Magenta*		*Yellow*		*Black*	
		Mini.	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*
SID	EFP-CP	1.1747	1.3435	1.2225	1.2937	1.0393	1.1577	1.0174	1.2295
	EFP-RP	1.136	1.2549	1.1987	1.246	0.9908	1.0995	1.0337	1.1752
	EFP-BP	0.9851	1.1771	1.0794	1.1242	0.6794	0.991	0.9171	1.0275
Grayness	EFP-CP	11.20	13.10	14.30	15.50	0.10	1.40	84.90	92.00
	EFP-RP	13.40	14.40	14.70	15.90	1.70	3.00	81.90	84.20
	EFP-BP	15.70	19.50	16.90	19.90	3.40	5.80	85.60	90.10

Table 3: Printability (Ink Trapping) on EFP using flexographic process

Printing parameter		*Red*		*Green*		*Blue*	
		Mini.	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*
Ink Trapping	EFP-CP	65.10	75.80	84.10	94.30	72.70	81.50
	EFP-RP	68.50	78.40	79.30	92.90	78.90	87.80
	EFP-BP	97.70	99.80	88.30	99.80	97.50	98.80

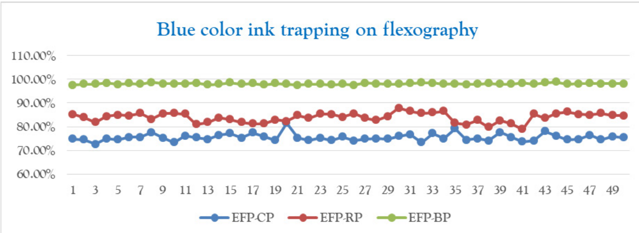

Figure 15: Blue color ink trapping for flexography printing

respectively. The range of ink trapping for green color was lowest in case of EFP-RP, while ink trapping (Green) for EFP-BP was highest. The minimum standard deviation for ink trapping for green color was found 0.0238 for EFP-CP.

- *Ink trapping - blue*

Figure 15 presents the data recorded for ink trapping (Blue) on EFP, i.e., EFP-CP, EFP-RP and EFP-BP by flexographic printing at 120 LPI. The minimum and maximum measured values for ink trapping for blue color on EFP-CP, EFP-RP and EFP-BP were recorded between 72.70 to 81.50%, 78.90 to 87.80% and 97.50 to 98.80%, respectively. The range of ink trapping for blue color was exhibited lowest for EFP-CP and found highest in EFP-BP. The minimum standard deviation for black color was found to be 0.0028 for EFP-BP. Figure 15 clearly depicts that substrate EFP-BP has consistent results.

Results and Discussion

Various printing parameters considered for printability aspects included SID, grayness and ink trapping during study. The collected information in context to printability on EFP is tabulated in Tables 2 and 3.

Conclusion

Printability study on EFP considering SID, grayness and ink trapping using flexography printing concluded that recorded data during study was very near to the printing standard values and replicated again and again. Consistency demonstrated was found on using standard statistic process of deviation, i.e., SD (standard deviation). EFP-RP demonstrated high consistency among considered substrates by exhibiting minimum standard deviation for all process color (Cyan, Magenta, Yellow and Black) in terms of SID. Grayness consistency for all process color (Cyan, Magenta, Yellow and Black) was exhibited by EFP-RP by demonstrating minimum deviation. Also, EFP-CP exhibited the same standard deviation for yellow color in terms of grayness. Ink trapping consistency was observed for red and blue color by EFP-BP while green by EFP- CP substrate.

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