Studies on Mitigation of Printing Cost, Volatile Organic Compounds Emission and Sustainability in Printing Industries by Using Water-based Inks

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Abstract

Organic solvents have been frequently and excessively used in the printing process for a long time. The use of organic solvents in solvent-based ink is responsible for fire hazards, volatile organic compounds emission, and high manufacturing cost during printing. The present study aimed at replacing solvent based ink with water-based ink for reducing the volatile organic compounds emissions and carbon footprints in gravure printing without affecting overall printing quality. The PET film was printed with a water-based ink laser engraved cylinder having reduced cell depth and it resulted in the transfer of a low volume of inks on printing substrate. The cost of printing one kg of polyester film with water-based ink was reduced by US\$ 1.95 compared to solvent-based ink. The volatile organic compounds emissions for water-based ink were measured at 2478 ppm against 3373 ppm for solvent-based ink. The water-based ink reduced the carbon footprint by 3.04 kg, which was equivalent to CO₂ during printing of one kg polyester film used for making flexible pouches compared to solvent-based ink. The outcome of this study may be the benchmark to authorities for green manufacturing systems in gravure printing applications for the betterment of the environment and humanity.

Introduction

The world's packaging industry is growing at the rate of about 3-5% per annum and in Asia, it is growing at the rate of 29%. It is assumed that 80% of packaging is consumed by 20% of the population. Per capita consumption of plastic packaging is very low compared to other developed nations of the world. Many multinational companies are growing business and earning huge profits to cater to the demand of consumers (Patil et al. 2012). Printing is one of the key processes to make packaging attractive and provides the necessary information to consumers. Printing is defined by the directive as 'any reproduction activity of text and/or images in which, with the use of an image carrier, ink is transferred onto whatever type of surface. Rotogravure printing is the printing process using a cylinder as an image carrier, in which the printing area is below the non-printing area. Image carrier transferred the ink on printing substrate by using liquid inks. Inks on printing substrate dried through evaporation in hot air hood chamber (Hamer 1998; Rong et al. 2004; Saeidpourazar et al. 2012). Presently in India, most of the companies are using SB inks for rotogravure printing due to good printability, machinability, excellent drying, and having no issues like foaming, pH, adhesion etc (Epa 2001). Most of the printing units are trying to reduce the VOCs emissions and CFPs from their printing process, including utilizing the supply chain cycle efficiently (Kliopova-Galickaja and Kliaugaitė 2018; Hansuebsai et al. 2020). Printing ink consists of pigment, resin, functional additives, and vehicles. Solvent plays a vital role in printing to transfer the ink compositions on printing substrate (Howe et al. 2013). SB inks and solvents used for printing are highly volatile at room temperature. Solvent maintains the fluidity and ink transfer from engraving cell to substrate and must leave the printing substrate. SB inks for rotogravure have a solvent content of about 40-70%. Ready-to-use SB inks contain ~ 70% of solvent by volume. This consumption of solvent can be reduced by using WB ink, and it results in a reduction of ambient VOCs emission and carbon footprint. The development of

water-based inks is in the initial phase and could not attract attention due to drying and adhesion issues faced by printers.

Although global environmental problems are typically considered as a part of national and international decision-making, still there is no futuristic approach adopted by the industries and governments for reducing or eliminating the use of solvent in flexible packaging printing processes (Aydemir and Özsoy 2021). VOCs emissions evaporating to surroundings contain approximately 98 to 99% toxic compounds released by the printing industries (Kliopova-Galickaja and Kliaugaitė 2018). The most significant sources of VOCs emission in the printing process identified from ink holding tub, transferred volume of ink on printing substrate and solvent used in shop floor area for cleaning activities. In India, pollution control government bodies like NGT and CPCB are imposing restriction for using solvents and SB inks for printing and packaging purposes. In total, European liquid ink consumption for rotogravure printing is about 410,000 tons/year. The practice of mixing solvents in the printing process is not the futuristic vision for entire printing and packaging industries due to stern environmental impacts, health, safety and legislative issues (Pi et al. 2016).

Several studies have been performed on the reduction or elimination of VOC emissions during printing of flexible packaging but none of the collective studies is reported, which demonstrates the proper solution to replace SB inks (Ma et al. 2021; Mo et al. 2021). To bridge this extended gap over, efforts have been made to elucidate the advanced technology with the development of water-based ink to reduce the VOCs emissions during printing of flexible packaging laminates (Ramirez and Tumolva 2018). Initial use of WB ink was not reached the benchmark required to have a better option to replace the SB ink due to lack of drying and adhesion issues on printing substrate. To overcome of this problem, phase-wise changes are planned decisively, starting from modifying the engraving parameters by laser and formulating the development of water-based ink (Pugh and Guthrie 2002). The major bottlenecks for the use of water-based ink was to reduce the high volume of ink transferred to the substrate, improve drying rate and adhesion during the printing process [15–16]. By using the SB ink following issues are always demanding the solution;

- Solvents smell in ambient air as well in printed and laminated materials also
- Solvents are hazardous, highly volatile, and flammable
- Increasing operation cost
- Legal compliances and societal problems due to emission of VOCs

Keeping this in view, the present study aims at reducing the depth of engraving cells and improving cell geometry of laser engraving, which will be helpful to reduce the volume of transferred ink (Charipar et al. 2018). EME and LE cylinders were also compared for suitability for WB ink. Water-based ink is formulated and developed for the rotogravure printing process. The findings reveal that the developed ink is suitable for solvent-free printing and can replace SB ink, and has the potential to reduce VOC, CFP, and cost. The economic considerations such as incurred cost of technological development, raw material consumption, and cost-saving are also taken into consideration. Many studies conducted for gravure printing, but so

far, none of the studies have been reported for specific studies on reduction of cost, VOC, and CFP in gravure flexible packaging.

Materials And Method

SB ink was purchased from Sakata Inks, Noida, solvents (Ethyl acetate, Acetone, and Methyl ethyl ketone) were purchased from Jubilant Organosys, Noida by AGPL. Water-based ink was synthesized as per the method given by (Sharma et al. 2021). Copper surface finished cylinders were provided by the AGPL. PET film of thickness 10 μm was purchased from Film Division, Uflex Ltd, Noida.

Location of sampling site

Samples were prepared in the proofing area of AGPL, Noida, as shown in Fig 2. In AGPL, three proofing machines were installed and working; one proofing machine was used for the SB ink printing and another for the water-based ink printing. Samples were prepared at room temperature and 50% RH.

Reduction in ink volume

Printing is the most important process in packaging, and the cylinder has a major role in flexible packaging printing (Epa 2001). Fig.3 shows the difference of electronic and laser engraving depth difference by a cross-section of both. It is clear that electronic cells have a higher depth in comparison to laser cells (Fig.3). Depth of cylinder was the major apprehension for SB ink due to transfer of a high volume of ink volume by printing cylinder. With the reduction of depth and geometry of engraving cells, printing quality parameters were compared, and the volume of ink was optimized.

Difference in GSM

GSM was measured for SB and WB inks by coating on PET film by electronic and laser cylinders using JM Heaford proofing machine, UK by cyan and yellow printing inks. The sample was cut into 100mmx100mm size and evaluated for GSM using an electronic balance (Shimadzu Corporation, Japan). The following equations (1-4) were used for the calculation of dry and liquid inks' consumption for printing on PET film of thickness 10 μm .

$$\text{GSM} = \text{Thickness } (\mu\text{m}) \times \text{density} \quad (1)$$

$$\text{Mass} = \text{Volume} \times \text{Density} \quad (2)$$

$$\text{Film length (m)} = \text{Film weight} \times 10000000 / (\text{film size} \times \text{GSM}) \quad (3)$$

$$\text{Dry consumption of ink} = \text{Film length} \times \text{film width} \times \text{ink GSM} / 1000000 \quad (4)$$

The quantity of liquid ink will be calculated by multiplying the dry ink value with factor four.(ref)

Difference in ink thickness

SB and WB inks were transferred on a substrate by proofing machines and morphological studies were measured by FE-SEM (Mira 3Tescan), and cross-sections were prepared to determine the thickness layer of transferred ink on a substrate. The printed PET films were cut into small pieces and placed on the sample holder, and sputter-coated with Au-Pd before FE-SEM image observation (Pugh and Guthrie 2002).

Comparison of printing properties of SB and WB inks

The SB and WB inks were compared for composition (resin, pigment, additives and vehicle), printing and output quality parameters to study the performance of ink and its effect on cell depth (Ramirez and Tumolva 2018; Sharma et al. 2021). WB ink was synthesized with acrylic monomer, Acrylic acid(AA), methylmethacrylate(MMA) and butylacrylate(BA), 2-hydroxyethylmethacrylate(HEMA), (HPA) and azobisisobutyronitrile(AIBN) was used as an initiator at 78°C for 4 h. Both the inks were compared for viscosity, pH, particle size, while printing properties studied for colour strength, adhesion and drying.

Water solubility and viscosity

Water solubility and viscosity of both the inks were measured to control the flow property of ink which helped to maintain the shade and colour density according to standard shade cards. The viscosity of SB and WB inks was determined to observe its effect on printing quality and to maintain the homogeneity of ink used for printing (Havlíková et al. 1999; Liu et al. 2019). To examine the solubility of acrylic resin in water, 10g resin was added into 5-25 ml of deionized water with a gap of 5 ml and the resulting mixture was stirred for 30 min at room temperature. The solubility of the resin in water was examined based on the transparency of the resulting solution mixture. The resultant solution's viscosity was determined with the help of NDJ-85 digital viscometer (Komal Scientific Co., India). Briefly, the viscometer's probe was dipped into the 25 ml aqueous solution of resin, rotating at 250 rpm for one min at room temperature.

Solid content

Ink deposition on printing substrate was measured by solid contents transferred by printing cylinder. To determine the percentage of solid contents in SB and WB inks, one gram of acrylic resin was poured into a Petri dish and dried to a constant weight at 105°C. The solid content (%) was determined using the following equation (Wang et al. 2011):

$$\text{Solid contents (\%)} = \frac{w_1}{w_2} \times 100 \quad (5)$$

Where w_1 is the weight of resin after drying, and w_2 is the weight of resin before drying.

pH

pH played a role in WB ink for solubility of the acrylic-based resin in water, smooth transfer of ink constituents [22]. pH also helped in dispersing the pigment in ink composition and uniform distribution of

pigment throughout the printing process. pH was tested by pH meter (ESICO, Model- 1615, India) by dipping the probe in WB resin.

Particle size of inks

Ink particle size was important for dispersion on printing substrate. The smaller will be the particle size and the better will be the dispersion of ink particle size in tiny cells engraved on a cylinder. The average particle size of the inks was determined by Dynamic Light Scattering (DLS, Brookhaven Instrument) at a fixed scattering angle of 90°. The small number of inks (20µl) was dissolved in 10ml of deionized water, and the measured at 25°C in triplet (Pal and Fleming 2006; Wołosiak-Hnat et al. 2019).

Color strength

Colour strength was measured to study the effect on printing after reducing the cell depth and using SB and WB inks. WB ink had a higher pigment concentration compared to SB ink. LAB values were measured at five different places of a substrate (Lichtenberger; Wołosiak-Hnat et al. 2019; Hansuebsai et al. 2020).

Adhesion

Adhesion of ink on printing substrate was studied to observe the bonding of ink on PET film. Pigment particles were dispersed in a mixture of resin, additives and vehicles. The ink was applied on film by an automatic film applicator by coating rod of 4µm thickness at the speed of 250 rpm. Adhesion of printing ink on PET films was measured as per the method given by Aydemir et al., (Martínez-Landeros et al. 2019; Aydemir et al. 2021).

Drying rate

The drying rate of ink was not important for SB ink due to the highly volatile nature of solvents while it was most important for WB ink. Drying of print was on PET film was measured as per the method given by Liu et al., and Aspler et al., (Liu et al. 2019; Sharma et al. 2021).

Assessment of consumption of inks and solvents

In rotogravure printing, most of the printing press are having 8-10 printing stations to print a single artwork. The cost reduction studies were conducted by mitigating the amount of inks and solvent as a result of technological development in the printing process. Two cylinders of size 520x1100 mm were prepared and a normal coating of 175 LPI was done by electronic and laser-assisted engravings. The coating was done by printing cylinder with white ink on PET film as per the method given by Sharma et al. The difference in dry weight was measured for both types of printed samples and accordingly liquid weight was calculated.

Measurement of VOC emissions

A comparative analysis of reduction in VOCs due to decreased quantity of inks and solvent in printing by using both the engraved cylinders (Jiao et al. 2020). The equal quantity of solvent and ink were mixed to maintain the running viscosity of ink on the printing machine. The difference in consumption of inks and solvent was calculated based on the quantity of ink consumed and solid contents transferred on the printed substrate. VOCs emissions were measured by using a Gas Master VOCs meter (Swan Scientific LLP, New Delhi). The VOCs emissions (ton/year) were calculated by using Eq. (6):

$$X_{\text{VOC}} = M \times K \times 10^2 \quad (6)$$

where M was the volume of chemicals (solvents, paints, printing inks; ton/year) and K was the percentage composition of volatile substances (according to the material safety data sheet (MSDS) of the company).

Measurement of carbon footprint (CFP)

CFPs were estimated according to guidelines for the estimation and measurement of volatile organic compound emissions No. ECE/EB.AIR/ WG.5/2016/4 (UN ESC 2016). The method for evaluating CO₂ was taken from "Energy" of the Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories (Volume 2 of the IPCC 1996). CFPs were calculated reduction in ink and solvent consumption and recovery of solvent during proofing trial of gravure printing.

Case study for flexible packaging product

Flexible packaging products are available mainly in pouch form and these pouches are generally manufactured according to weight packaged in it. To understand the per pouch VOC and CFP emission, an additional study was conducted on actual packaging. Different packages of wheat flour atta packets of 10 kg, 5 kg, 1 kg and 500 gm were purchased from the local market to study the VOC and CFP emission. Total area of pouches was measured and data were compared with the conclusion of above study.

Results And Discussion

Properties of SB and WB inks

The resin was the main constituent of ink and held all the constituents of ink in it. The resin had the of binding and film-forming properties on the substrate and it highly dependent on the thermal and mechanical properties of the resin. In water-based inks, acrylic monomers were used to prepare the waterborne resin. Pigmentation is a very expensive and critical part of printing inks and played a key role in achieving colour and shade properties. Concentration of pigment vary in SB and WB ink (Table1 and Fig. 5). The role of solvent in the printing process was to transfer all the composition of ink to the printed substrate by engraved cells and finally must evaporate from the surface of the film immediately. The organic solvent in SB ink was the main factor (about 60-70%) for odour problem in printed materials. In

water-based ink, odor problem could be eliminated and reduction in VOCs emissions and odour problem could be controlled more effectively.

GSM of SB and WB inks was 2.14 and 1.52 g/m², respectively. The pH of WB inks was 8.7±0.2 which was required to maintain the solubility of resin and dispersion of pigment in inks. The viscosity of SB and WB inks was 0.7 and 0.8 poise, respectively. These values were following ISO standards.

Dry solid contents were the quantity printing substrate left after drying. The dry solid contents in WB ink (22%) were less compared to WB ink (40%) due to higher pigment concentration (10-15%). Pigment particles size was important for transferring the ink from tiny cells of the printing cylinder to the substrate. Laser engraved cylinder transferred the ink easily compared to EME cylinder. It was also observed that particle size of WB inks was 556 and 452 µm for cyan and yellow inks, respectively compared to particle size for SB ink (876 µm) for cyan ink).

Table 1. Comparison of SB and WB inks

Parameters	Unit	SB ink	WB ink
GSM	g/m ²	2.14 ± 0.16	1.52 ± 0.12
pH		N/A	8.8 ±
Dry solid Content	%	22 ± 0.08	40 ± 0.13
Pigmentation	%	15 ± 2	20 ± 2
Particle Size	µm	>0.5	<0.5
Dilution of ink	Solvent ratio %	60-70	IPA/DM ratio (20/80)
Ink thickness	µm	3.78 ± 0.17	2.72 ± 0.11

Effect of engraving cell depth on printing

Electronic engraving depth was helical and higher. Use of WB instead of organic solvent-based ink for flexible packaging was of utmost required to reduce the transferred volume of ink from printing cylinder to substrate. To achieve this goal various studies were conducted with electronic engraved cylinder by optimizing the cell depth, LPI, cell size and by using different types of the stylus. Unfortunately, none of the studies was able to provide hassle-free printing with WB ink. Comparison of the following parameters was performed at LPI-175, screen-100% and the trial was conducted with white ink for cell depth of 18, 15 and 12 µm, respectively.

An increase in cell depth of engraving cell increased the dot percentage and colour density due to higher volume of dry ink on printing substrate (Fig. 5).

Reduction in transferred ink volume

GSM

GSM of printing was directly related to the cost and quantity of laminate. GSM of printed samples by electronic engraving was 2.08 g/m^2 and for laser, it was 1.52 g/m^2 . The difference in GSM of electronic and laser engraving showed a difference of 0.56 g/m^2 of ink deposition which was related to the printing ink cost, colour and shade matching.

Ink thickness

Figure 6 shows the cross-section FE-SEM images of ink thickness for both the samples and it was evident that the ink thickness of electronic engraving was higher than the laser-printed samples (Nielsen et al. 2015; Sharma et al. 2021). For electronically engraved printing, it was measured $3.26 \pm 0.64 \mu\text{m}$ while for laser it was measured $2.68 \pm 0.51 \mu\text{m}$. Total $0.58 \mu\text{m}$ thickness of WB ink reduced in comparison to SB printed ink. The difference in ink thickness was due to variation in GSM of printed samples (Aghajani Derazkola and Simchi 2020; Guo et al. 2021).

Comparison of printing properties

Colour strength

Colour strength was measured for the high density (Optical density= 1.5 as per ISO standard) colour of magenta ink. Sample coated by laser cell was found more smooth and consistent printing compared to sample prepared by electronic cell. For sample-1 optical density was obtained 1.39 and for laser engraving, it was 1.35. Therefore, laser engraving could replace solvent-based ink in rotogravure printing due to less cell depth and less volume of transferred ink.

Adhesion

Adhesion is the important property of printing ink for the formation of a layer on printing substrate and physical bonding. Adhesion of printing ink on PET films showed good bonding of ink composition with PET film (S-1). Tape test by 3M adhesive tape (1.5 cm width) of printing samples showed more than 85% of bonding for samples printed with SW and WB inks. The higher value of adhesion improved the rub and abrasion properties of ink (Aydemir et al. 2021).

Drying rate

Drying is the main concern using the WB ink for the flexible packaging printing process because it reduced the volume of transferred ink. Therefore, it was possible to replace the SB with WB ink during the printing process (Rong et al. 2004). It was also observed that ink GSM could be reduced by maintaining the same printing quality parameters. In Fig. 7, cyan and yellow colour represented the samples printed by SB and WB inks, respectively. There was no thumb impression in samples printed with cyan colour (SB

ink) after 5 sec whereas in the case of samples printed with yellow colour (WB ink) thumb impression was observed after 7 sec. The drying time for substrate printed with WB ink would reduce on the printing machine due to hood temp when printed film passed through to the next printing station.

Reduction in consumption and cost-saving

Inks

The PET film was printed with WB ink by electronic and laser engraved printing processes. Dry and liquid inks consumption during the laser engraved printing process were reduced by 27.4% and 28% respectively compared to the electronic engraved printing process (Table2). The reduction in ink consumption was due to less cell depth of laser engraved cylinder compared to the electronic engraved cylinder and it resulted in the transfer of less volume of ink on printing substrate.

Table 2. Consumption of WB ink per kg of PET film in electronic and laser engraved printing process.

Substrate	Thickness, μm	GSM	Film weight, kg	Dry ink consumption, kg	Liquid ink consumption, kg
Printing by electronic engraved cylinder					
PET film	10 ± 0.55	1.68 ± 0.03	1	0.124 ± 0.011	0.50 ± 0.09
Printing by laser engraved cylinder					
PET film	10 ± 0.55	1.68 ± 0.02	1	0.090 ± 0.008	0.36 ± 0.06
Difference				0.034 ± 0.004	0.14 ± 0.02
Note- PET film thickness 10 μm and film weight one kg.					

Consumption of solvents

The role of solvent in printing ink was like a vehicle that helped to transfer all the ink composition on printing substrate and finally, the solvent was evaporated from the film surface to the ambient environment. Solvents were also used to dilute the printing ink, clean machinery parts, equipment and machine area. Most of the printing presses are also having a solvent recovery plant to recover evaporated solvent during printing.

Reduction in the quantity of solvent was calculated from reduction in ink (50-60%) consumption. In general, a 1:1 ratio is maintained for the dilution of ink to achieve the standard viscosity. It means that 1 kg of SW ink required one litre of solvent for use in the printing press. For WB ink only 20% of IPA was mixed with 80% of de-mineralised water for diluting the ink and to achieve the targeted viscosity. Solid content for SB and WB ink were measured 22% and 40%, respectively.

Cost reduction studies

Consumption of inks (SB and WB) and solvents for the printing of 1 kg of PET films was calculated to study the cost difference for both printing method (31). The reduction in the quantity of ink for laser engraved printing was found 11.48% compared to electronic engraving (Table 3). The difference in consumption of ink was mainly based on the dry ink weight measured for both the engraving systems. About 80% reduction in cost was mainly due to less organic solvent consumption in WB inks. It was observed that 500 gm of ink and 290 ml of organic solvent could be saved for the printing of one kg PET film. The total saving was about US \$ 1.95 when PET film was printed on a laser engraved cylinder for printing 1 kg of PET films using WB inks (S-2).

Table 3. Reduction in ink and solvent quantity.

Cost saving of Inks and Solvents						
Reduction in quantity of ink and solvent, kg		Ink Rate/kg	Solvent Rate/kg	Ink saving (\$)	Solvent saving (\$)	Total saving (\$)
Ink	0.500±0.042	12.36	1.10	6.18 ± 0.08	0.55 ± 0.03	6.73 ± 0.17
Solvent	0.290±0.027	15.11	1.37	4.38 ± 0.05	0.40 ± 0.03	4.78 ± 0.09
					Saved amount	1.95 ± 0.12
* Dollar rate conversion was calculated as on 7th June 2021.						

Reduction in VOCs emission

WB ink contained solvents like ethyl acetate, Acetone, IPA etc which were used to maintain the viscosity and colour. The VOCs emissions in SB ink was between 3172-3498 ± 27 ppm with an average of 3373 ppm [Fig. 8]. WB ink contained 10-20% of isopropyl alcohol for reducing the surface tension of water. The VOCs emissions in WB ink were between 1978-3122 ± 18 ppm with an average of 2478 ppm. The WB ink reduced VOCs emissions and maintained a less hazardous working place with good manpower health.

Reduction in carbon footprints

In the printing process, CFPs could be reduced by using WB ink and reducing organic solvents. The reduction in CFPs was calculated from the total reduction in ink and solvent and the recovery of evaporated solvent. The total reduction in CFPs using WB ink was 3.04 kg CO₂equivalent per unit compared to SW ink for printing of flexible packaging (Table 4).

Table 4. Reduction in CFP emissions from SB and WB inks.

Parameters	Quantity consumed	Unit	Factor	Emission factor (kg CO ₂ equivalent per unit)	Reference no.
SB ink					
Ink	0.500 ± 0.023	kg	2.5	1.25 ± 0.08	33
Solvent-acetone	0.5 ± 0.03	kg	2.19	1.095 ± 0.05	32
Solvent top up	0.5 ± 0.03	kg	2.19	1.095 ± 0.05	32
Solvent recovery	1.25 ± 0.06	kg/kWh	0.81	1.04 ± 0.03	5
Total				4.48 ± 0.12	
WB ink					
Ink	0.36 ± 0.027	kg	2.5	0.900 ± 0.035	31
Solvent-IPA	0.29 ± 0.018	kg	1.85	0.537 ± 0.022	32
Total				1.437 ± 0.035	
Reduction in carbon footprints				3.04 ± 0.03	

Greenhouse gases and VOCs emissions caused global warming and it was a major challenge to provide a breathable atmosphere to the next generation. Many steps were taken by several countries to control VOCs emission but fewer efforts were contributed in this context (Loyarte-López et al. 2020).

Case study for VOC and CFP for one pouch

Table 5. Shows the VOC and CFP for different weight pouches.

Packaged flour Weight (kg)	Size (mm)	Area of one pouch (m)	Area of 1 kg PET Film (m)	Total VOC (ppm)	Total CFP (gm)
10	560*820	0.614	59.5	9.23	30.99
5	450*670	0.493	59.5	7.42	24.90
1	270*420	0.592	59.5	8.90	14.74
0.5	240*350	0.531	59.5	7.91	26.56

This study shows that 10 kg of flexible packaging pouch emitted 9.23 ppm and 31 gm of CFP in the environment. Value of emission is reduced with reducing the packed product weight. This study is very

important to understand that just throwing packaging waste after use, how much VOC and CFP were loaded in the environment.

Uncertainty measurement

In this study, there were still uncertain factors due to the limitation of related parameters and measurements. Proofing was performed at room temperature and 50% RH and new stylus was used for the engraving to avoid any physical difference of depth in engraved cells by electronic engraving. It is also noteworthy that certainty of ink chemistry and chemical behaviour can not handle and compare like SB ink. Emission factor uncertainties VOCs emission were measured on proofing machine and there were three proofing machines in a single room providing common entry covered with PVC strips. Accuracy of work may be affected due to ambient VOC concentration.

All calibration certificates of monitoring and measuring devices and masterpiece of calibration tool were evidenced from authorized certification agencies. These preventive measures were taken to control any effect on monitoring results to a certain degree to reduce the uncertainty factor for the research work.

Conclusion

The water-based ink was replaced with solvent-based ink using laser engraved printing cylinders without affecting colour strength, adhesion, and drying rate. Water-based ink also showed a reduction in cost, Volatile organic compounds emissions and carbon footprint over solvent-based inks. Water-based ink showed a total reduction in cost by implementation of water-based ink for gravure printing the US \$ 1.95 for the printing of one kg of polyester film over solvent-based ink. Volatile organic compounds emissions and carbon footprint were reduced by 895 ppm and 3.04 kg, respectively at the proofing machine for the printing of one kg of polyester film. The findings also showed that use of laser engraved cylinder can replace solvent-based ink for gravure printing of flexible packaging. This study also enhances the awareness of consumers and consumers may also demand for more sustainability products. Outcome of this study can also be used to set the benchmark for industries to reduce volatile organic compounds and carbon footprint emission according to regulation by government bodies.

Abbreviations

MNC Multinational Companies

NGT National Green Tribunal

CPCB Central Pollution Control Board

EME Electro-mechanical Engraving

LE Laser Engraving

AGPL Afflatus Gravures Private Limited

RH Relative Humidity

GSM Grams Square Meter

RPM Rotation Per Minute

LPI Lines Per Inch

IPA Iso Propyl Alcohol

Declarations

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Statements and Declarations

- The authors have no relevant financial or non-financial interests to disclose.
- The authors have no competing interests to declare that are relevant to the content of this article.
- All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.
- The authors have no financial or proprietary interests in any material discussed in this article.

References

1. Aghajani Derazkola H, Simchi A (2020) A new procedure for the fabrication of dissimilar joints through injection of colloidal nanoparticles during friction stir processing: Proof concept for AA6062/PMMA joints. J Manuf Process 49:335–343. <https://doi.org/10.1016/j.jmapro.2019.12.008>
2. Aydemir C, Altay BN, Akyol M (2021) Surface analysis of polymer films for wettability and ink adhesion. Color Res Appl 46:489–499. <https://doi.org/10.1002/col.22579>
3. Aydemir C, Özsoy SA (2021) Environmental impact of printing inks and printing process. J Graph Eng Des 11:11–17. <https://doi.org/10.24867/JGED-2020-2-011>
4. Charipar KM, Charipar NA, Prestigiacomo JC, et al (2018) Laser printing of flip-chip interconnects for high frequency applications. J Manuf Process 32:110–115. <https://doi.org/10.1016/j.jmapro.2018.01.019>
5. Epa US (2001) The effect of ink temperature on solvent losses and print quality. Gravure 66–71

6. Guo X, Shen Y, Liu W, et al (2021) Estimation and prediction of industrial VOC emissions in Hebei province, China. *Atmosphere (Basel)* 12:1–20. <https://doi.org/10.3390/atmos12050530>
7. Hamer IAH (1998) Technological development of water-based packaging inks for gravure printing. *Pigment Resin Technol* 27:99–101. <https://doi.org/10.1108/03699429810693489>
8. Hansuebsai A, Kaosod A, Kanchanasing T (2020) A new environmental performance index based on the carbon footprint, VOC emissions, and waste in a printing house. *Eng Reports* 2:1–12. <https://doi.org/10.1002/eng2.12165>
9. Havlínová B, Cicák V, Brezová V, Horňáková L (1999) Water-reducible flexographic printing inks-rheological behaviour and interaction with paper substrates. *J Mater Sci* 34:2081–2088. <https://doi.org/10.1023/A:1004511826583>
10. Howe KS, Clark ER, Bowen J, Kendall K (2013) A novel water-based cathode ink formulation. *Int J Hydrogen Energy* 38:1731–1736. <https://doi.org/10.1016/j.ijhydene.2012.08.105>
11. Jiao C, Shao Q, Wu M, et al (2020) 2-(3,4-Epoxy) ethyltriethoxysilane-modified waterborne acrylic resin: Preparation and property analysis. *Polymer (Guildf)* 190:122196. <https://doi.org/10.1016/j.polymer.2020.122196>
12. Kliopova-Galickaja I, Kliaugaitė D (2018) VOC emission reduction and energy efficiency in the flexible packaging printing processes: analysis and implementation. *Clean Technol Environ Policy* 20:1805–1818. <https://doi.org/10.1007/s10098-018-1571-x>
13. Lichtenberger M Inks – Water-Based. 1–12
14. Lindner M, Rodler N, Jesdinszki M, et al (2018) Surface energy of corona treated PP, PE and PET films, its alteration as function of storage time and the effect of various corona dosages on their bond strength after lamination. *J Appl Polym Sci* 135:1–9. <https://doi.org/10.1002/app.45842>
15. Liu R, Sun Y, Gu H, Zhou X (2019) Progress in Organic Coatings Synthesis and application of acrylate copolymer as high ink-absorption and fast drying coating agent for polyester fabric. *Prog Org Coatings* 136:105298. <https://doi.org/10.1016/j.porgcoat.2019.105298>
16. Loyarte-López E, Barral M, Morla JC (2020) Methodology for carbon footprint calculation towards sustainable innovation in intangible assets. *Sustain* 12:1–14. <https://doi.org/10.3390/su12041629>
17. Ma X, Yang L, Wu H (2021) Removal of volatile organic compounds from the coal-fired flue gas by adsorption on activated carbon. *J Clean Prod* 302:126925. <https://doi.org/10.1016/j.jclepro.2021.126925>
18. Martínez-Landeros VH, Vargas-Islas SY, Cruz-González CE, et al (2019) Studies on the influence of surface treatment type, in the effectiveness of structural adhesive bonding, for carbon fiber reinforced composites. *J Manuf Process* 39:160–166. <https://doi.org/10.1016/j.jmapro.2019.02.014>
19. Mo Z, Lu S, Shao M (2021) Volatile organic compound (VOC) emissions and health risk assessment in paint and coatings industry in the Yangtze River Delta, China. *Environ Pollut* 269:115740. <https://doi.org/10.1016/j.envpol.2020.115740>
20. Nielsen KH, Karlsson S, Limbach R, Wondraczek L (2015) Quantitative image analysis for evaluating the abrasion resistance of nanoporous silica films on glass. *Sci Rep* 5:1–10.

<https://doi.org/10.1038/srep17708>

21. Pal L, Fleming P (2006) The Study of Ink Pigment Dispersion Parameters. *Rev Lit Arts Am* 2:61–70
22. Patil PP, Narkhede BE, Akarte MM (2012) An exploratory study of manufacturing strategy of packaging product-manufacturing companies in India. *Int J Qual Res* 6:233–249
23. Pi P, Chen X, Wen X, et al (2016) Preparation and characterization of ambient-temperature self-crosslinkable water-soluble acrylic resin for PE film ink. *J Coatings Technol Res* 13:73–80. <https://doi.org/10.1007/s11998-015-9742-8>
24. Pugh SL, Guthrie JT (2002) Some characteristics of pigments that affect the kinetics of fading of prints made from water-based liquid ink formulations. *Dye Pigment* 55:109–121. [https://doi.org/10.1016/S0143-7208\(02\)00066-9](https://doi.org/10.1016/S0143-7208(02)00066-9)
25. Ramirez JCC, Tumolva TP (2018) Analysis and optimization of water-based printing ink formulations for polyethylene films. *Appl Adhes Sci* 6:1–21. <https://doi.org/10.1186/s40563-017-0102-z>
26. Rong X, Pekarovic J, Pekarovicova A (2004) Gravure printability from laser and electromechanically engraved cylinder. *Proc Int Print Graph Arts Conf* 2004:151–154
27. Saeidpourazar R, Sangid MD, Rogers JA, Ferreira PM (2012) A prototype printer for laser driven micro-transfer printing. *J Manuf Process* 14:416–424. <https://doi.org/10.1016/j.jmapro.2012.09.014>
28. Sharma B, Sauraj S, Kumar B, et al (2021) Synthesis of waterborne acrylic copolymer resin as a binding agent for the development of water-based inks in the printing application. *Polym Eng Sci* 61:1569–1580. <https://doi.org/10.1002/pen.25681>
29. Wang R, Wang J, Lv W, et al (2011) Preparation of amphiphilic acrylic acid copolymer and its application in humidity-sensitive coatings. *J Appl Polym Sci* 120:3109–3117. <https://doi.org/10.1002/app.33473>
30. Wołosiak-Hnat A, Zych K, Mężyńska M, et al (2019) The influence of type and concentration of inorganic pigments on the polyurethane adhesive properties and adhesion of laminates. *Int J Adhes Adhes* 90:1–8. <https://doi.org/10.1016/j.ijadhadh.2019.01.004>
31. Future Of Inks Water Based by Adesh Katariya Packaging

Figures

Figure 1

Advantages and disadvantages of SB and WB ink

a

b

c

d

Figure 2

Shows the (a) sampling site AGPL (b), Electronic engraving section (c), Fully automatic laser engraving section (d), Proofing section, where printing was performed.

a) Electronic engraving cell

c) Laser engraving cell

b) Cross section of electronic engraving cell

d) Cross section of laser engraving cell

Figure 3

Difference between the electronic (a,b) and laser cell geometry (c,d). (Link: labthink, <https://www.think-lab.com> and AGPL)

Figure 4

Difference between solvent and water-based ink composition.

Figure 5

Comparison of engraving depth and effect on printing properties. SD for depth, dot%, color density for electronic and laser were measured sequentially ± 0.19, ± 1, and ± 0.07.

Figure 6

FE-SEM images showing the thickness of a), SB and b), WB printed ink on PET film.

Figure 7

Drying properties of substrate printed with a) SB by cyan ink and b) by WB yellow ink.

Figure 8

VOCs emissions in SB and WB inks during printing process.

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