# EB Gravure – Novel Printing Concept for Sustainable Packaging

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## Abstract

Packaging and converting industries are under enormous pressure to reduce their "carbon footprint" while meeting constantly rising functional and aesthetic performance requirements for packaging materials. These ambitious goals must be achieved without significant increase in cost of packaging. Traditional solvent based printing technology is giving way to the new, low energy methods of printing and functionalizing packaging materials. Direct Gravure is known as one of the highest quality printing technologies available to packaging converters. Combining the benefits of the print fidelity associated with gravure printing and the physical properties achieved with electron beam (EB) chemistry and raw materials, offers a new approach to manufacturing of high performance packaging materials. The key benefits of "EB Gravure Printing" are high print quality, zero VOC, improved ink and print consistency, significantly cleaner press room environment, etc. The printing process is also complimented by the in-line application of coatings and/or adhesives, which provides packaging materials with outstanding aesthetics as well as chemical, physical and functional properties.

## Introduction

UV/EB curable inks and coatings have been used in packaging, and specifically in the food packaging markets, for many years, going back to the early 80's, when first TetraPak and then a few smaller converters adapted EB curing technology for manufacturing of low odor and low migration packaging. These original applications – gable top dairy and fruit juice liquid packaging, frozen food containing folding cartons and dry food (cookies) packaging, have not given up their strong market position. In fact, packaging market segments utilizing curable systems have grown significantly - UV curing joined EB as a technology of choice for several applications, including folding cartons, lids for small containers (yogurt and other dairy products), plastic cups, liquid packaging, outdoor and multiwall bags, and some others. Yet the share of UV/EB curable systems in the total volume of packaging inks, coatings and adhesives still doesn't exceed 4-5%.

Rapidly changing social and economic landscape with emphasis on reduction of carbon footprint in all areas of industrial activity promotes UV/ EB curing to the front line, as a technology of choice for most packaging and converting applications.

The major challenge is to implement the curing technology within the framework of existing and proven printing methods, such as Lithographic, Flexographic and Gravure printing.

UV and EB curable inks have been used in lithography, and over the last 20 years they have found their way in some segments of flexography. Gravure printing is the only remaining main stream printing method that has not been penetrated by this technology.

In this paper we introduce a technical approach to merging Gravure printing and EB curable inks and discuss the benefits and challenges of this merger for the packaging industry.

## EB Gravure - Technical Platform

Gravure printing is a technology utilizing very low viscosity ink systems for direct transfer of an image from the cells of engraved cylinder on to the printed media. Gravure offers a broad range of gray scale reproduction due to dual mechanism of the ink metering via varying cell size and depth. In Gravure printing highlights of the image are reproduced with very small and shallow cells, while very high density solids are achieved by transferring substantial ink volume from the large and deep cells. The latter is especially beneficial for special effect colors, such as metallics, producing strong visual effects unattainable by other printing methods.

The traditional Gravure press configuration requires inter-station drying of each color, often followed by the drying tunnel at the end of the press for removal of residual solvents or water, used to control viscosity of the inks. Gravure printing is dominated by solvent based systems that are generally more forgiving in respect to low foaming, re-wettability on the gravure cylinder, and drying speed. Gravure inks are low-solids liquid blends, so the total amount of solvent that has to be evacuated and incinerated during high speed printing is by far, the largest in printing industry. This makes solvent Gravure printing the least attractive printing method from the carbon footprint perspective.

Replacement of solvents with water brings new life to the Gravure printing. However, most of the fast drying water-based resin systems still contain volatile compounds, such as alcohol and ammonia, to control viscosity. Complete drying of the inks is essential to avoid blocking during storage and to maintain required physical properties of the ink layer.

Introduction of acrylate functionality into the water-dispersible polymer backbone presents an opportunity to eliminate ammonia from the ink composition and expand performance window for water-based Gravure inks.  This is achieved by combining air/heat drying with Electron Beam curing to obtain desirable physical properties of the printed packaging.  Ammonia-free water based inks are expected to have better viscosity stability during high speed printing. Target physical properties are attained immediately after EB curing.

Applying EB coatings is often required as the final step, for control of friction and desirable gloss of the finished packaging material. Inter-coat adhesion between EB coatings and water based inks is often limited due to presence of residual solvents, ammonia or water in the ink layer. Co-polymerization of acrylate functional ink and coating layers under EB irradiation significantly enhances inter-coat adhesion.

## Resin Chemistry and Ink Properties

Over the last decade a significant progress was made in introducing water-based acrylate functional polymers and oligomers [1-2]. The primarily targeted application for this chemistry has been the wood coating market. In this application, several layers of UV curable water-based dispersion are applied over the wood surface via spraying or roller application techniques; each layer is dried, UV cured; often sanded and then a next layer is applied on the top. Several consecutive layers may be applied on the top of each other according to this sequence, depending on the end use requirement (gloss level, hardness etc.)

EB flexographic printing was the first attempt to use water-based EB curable resins in printing [3-4]. In this application, complete drying of individual ink layers is not required or anticipated because wet trapping is controlled by viscosity gradients generated between consecutive layers due to partial evaporation of water. The wet layers of ink do not come in contact with hard surface of turn bars and complete solidification is achieved as a result of UV or EB curing.

EB Gravure printing method is similar to the wood coating model which requires complete drying of individual layers prior to applying the following layers.

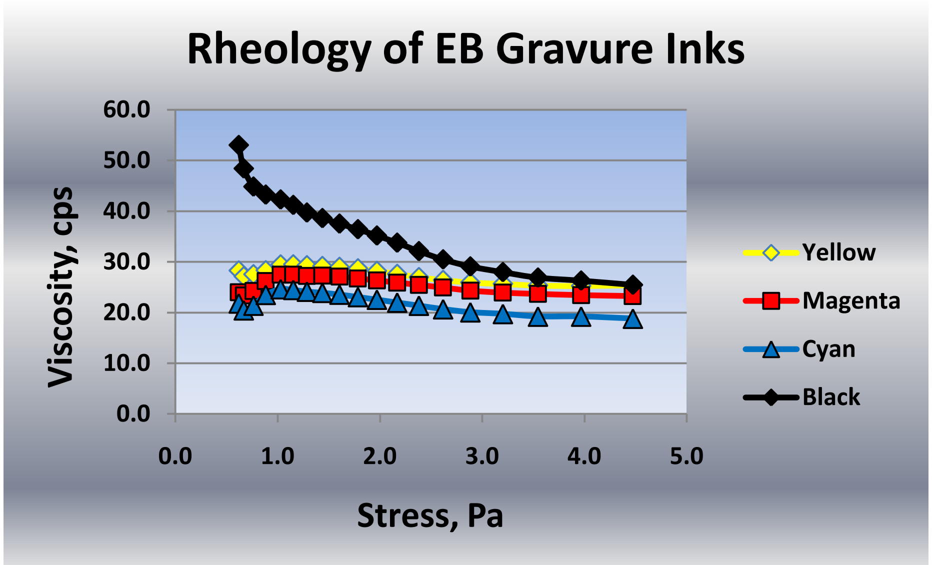
Unlike wood coating, EB Gravure is very fast process with web speeds exceeding 800 feet/min. The key criteria for selection of water-based acrylate functional dispersion for Gravure application are the drying speed and EB cure response. A number of resins were screened based on these two criteria in a model yellow Gravure ink composition. All model blends were prepared by mixing tested polymer dispersion with pigment dispersion, then drawing it down over PET film with #3 Mayer bar and allowing it to dry prior to testing for 5 min at 60$^{o}$C. Screening results are presented in the following table.

| Resin # | Chemistry - described by suppliers | IPA rubs before cure | EB Cure, 30 kGy, IPA rubs | Lay, Scuff, General Appearance |
|---|---|---|---|---|
| 1 | Acrylic | 2-3 | 7-8 | Fast drying, good lay, some scuffing |
| 2 | Aliphatic polyurethane | 2 | 40-45 | Fast drying, good lay, minimal scuffing |
| 3 | Aliphatic polyurethane | 4 | 40-45 | Fast drying, good lay, some scuffing |

| | | | | |
|---|---|---|---|---|
| 4 | Aliphatic polyurethane and acrylic copolymer | 8 | 7-9 | Product is not curable |
| 5 | Aliphatic polyurethane | 10-11 | 30-35 | Fast drying, good lay, minimal scuffing |
| 6 | Aliphatic polyurethane | 1 | 55-58 | Tacky before cure, very high gloss, some scuffing |
| 7 | Aliphatic polyurethane and acrylic copolymer | 2-3 | 45-50 | Fast drying, good lay, some scuffing |
| 8 | Polyurethane | 3-4 | 15-16 | Fast drying, good lay, some scuffing |
| 9 | Polyurethane - acrylic copolymer | 12-13 | 40-45 | Fast drying, good lay, some scuffing |
| 10 | Aliphatic polyester polyurethane | 4-5 | 10-13 | Fast drying, good lay, some scuffing |
| 11 | Polyurethane - acrylic copolymer | 3-4 | 55-60 | Fast drying, good lay, some scuffing |
| 12 | polyurethane | 13-15 | 95-100 | Fast drying, good lay, minimal scuffing |
| 13 | Acrylic dispersion | 1-2 | 40-45 | Slightly tacky |
| 14 | Acrylic emulsion | 1-2 | 55-58 | Tacky |
| 15 | Aliphatic polyurethane | 1-2 | 3 | Tacky, probably not curing |
| 16 | Aromatic polyurethane | 26 | 73 | Fast drying, good lay, some scuffing |
| 17 | Aromatic PU | 13-15 | over 100 | Fast drying, good lay, some scuffing |
| 18 | Polyester acrylate emulsion | 1 | 50-55 | Poor lay, tacky before cure |
| 19 | Polyester acrylate emulsion | 1 | 30-35 | Poor lay, tacky before cure |

It is evident that a broad range of water-based resin dispersions with different polymer back bones is currently available on the market, offering various drying and curing properties.

Gravure inks are generally very low viscosity liquids with relatively low pigmentation level. Typical rheological properties of EB Gravure inks, determined on a controlled stress rheometer at 25$^{o}$C are presented on **Graph 1**.

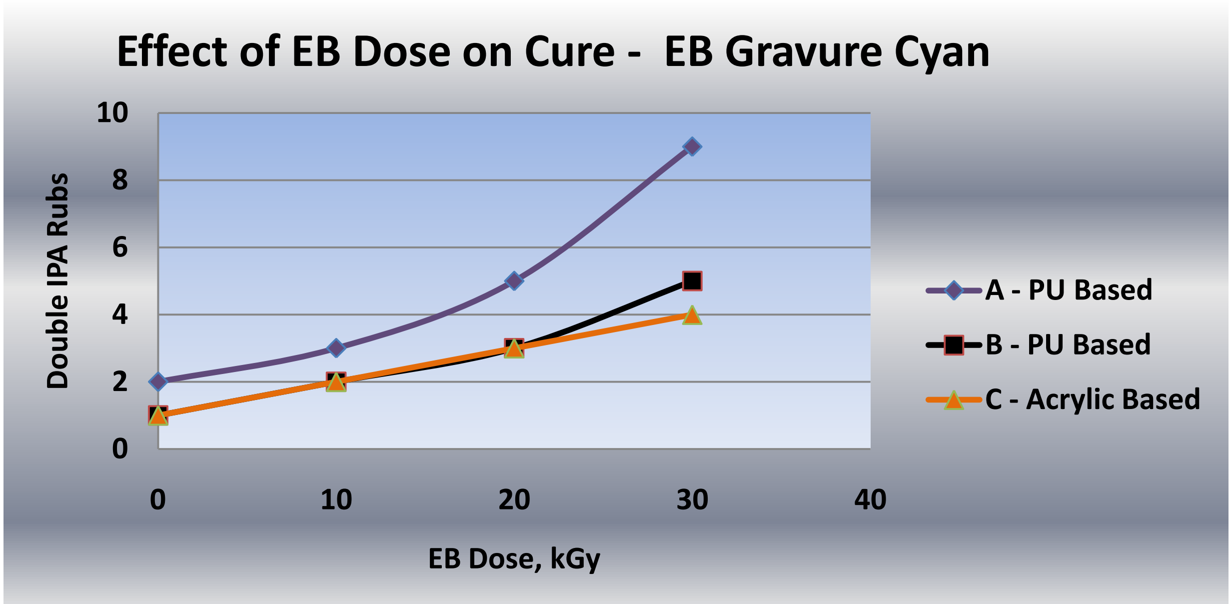



**Graph 1**

All process colors have viscosity in the range between 20 and 30 cps. Yellow, Magenta and Cyan have minimum flocculation even at extremely low stress levels under 1 Pa. Black shows some flocculation tendency that quickly disappears at moderately higher stress levels. Low viscosity and minimal viscosity gradient are important for good ink release from the cells and effective transfer at high press speeds.

EB curing of inks requires EB dose similar to those typically selected in all other EB printing applications. Final cross-linking density of the ink layer is a function of multiple factors, including selection of resin chemistry, pigment to binder ratio and target print density. In many cases the ink layer is cured through a top EB coating.

Graph 2 illustrates an effect of different EB doses and selection of resin chemistry on cross-linking density of EB Gravure Cyan ink.



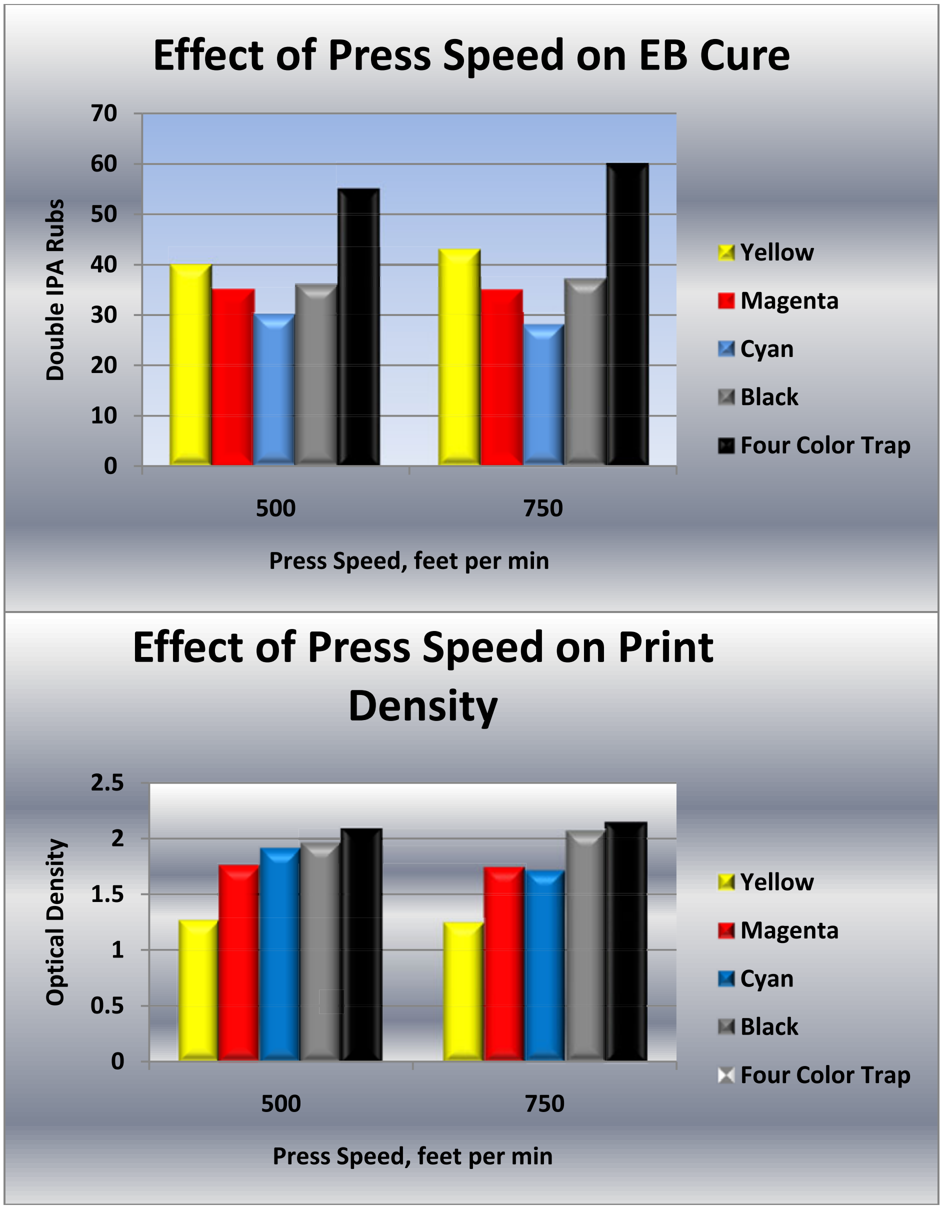

**Graph 2**

In this experiment, three model Cyan inks were prepared using two different polyurethane based dispersions (A and B) and one dispersion based on acrylic backbone polymer (?) (C). All inks were applied over the PET film with #3 Mayer bar, dried and cured at various EB doses at 100 kV acceleration voltage on the AEB laboratory EB processor. Optical density of the draw downs was between 1.55 and 1.65. While EB curing response is just one factor, determining selection of a resin for the ink vehicle, this plot suggests that "ink A" formulation has significantly better cure in the range between 10 and 30 kGy, than two other resins.

## Printing Press Testing

The GATF form with multiple color bars and gray scale targets was printed on Rotomec MW-80 Gravure press at Amgraph Packaging. Drying temperature was set at 225$^{o}$F and EB curing dose was 20 kGy. The color sequence was CMYK or Cyan, Magenta, Yellow and Black. 35# coated paper was used for printing. Print samples were taken at 500 and 750 fpm of press speed.

Print densities (OD) for each color have been very consistent at all speeds. Effect of press speed on the cross-linking density of each of the four(?) process colors and four color trap are summarized in Graph 3.




**Graph 3**

Optical print densities for each color are not affected by the press speed between 500 and 750 fpm. The same is true for solvent resistance of each color. The range for IPA rubs is between 30 and 40, which is exceptionally high for EB curable inks. Four color trap has even higher number of double rubs, around 60, due to higher film thicknes. While solvent resistance is not necessery a true measure of crosslinking density, it is a good indicator of physical properties assotiated with EB curable inks.

Considering the fact that typical water-based inks do not offer any significant solvent resistance (IPA rubs are in the range of 1-2), EB Gravure inks offer dramatic improvement in the product resistance even when printed at high press speeds and cured at moderatly low EB dose of 20 kGy.

An illustration of two printing jobs performed with standard water based Gravure inks and EB Gravure inks is presented below.

EB Gravure Inks


Standard water-based Inks


While further optimization of the printing performance is in progress, this image suggests that EB Gravure prinitng technology has its merits and is capable of producing good quality printing.

## Conclusions

EB Gravure prinitng represents a novel approach to improvement of phiscal properties of the packaging material, while achieving substantial reduction in the carbone foot print in comparison to traditional solvent based Gravure printing process.
Recent developments in the area of water-based EB curable polymers offer good oportunies in developing a broad range of EB Gravure inks, capable of meeting various end use performance targets.

***Aknowledgments***

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