Mixing Oil and Water: Digital Printing On Hydrocarbon-based Flexible Films with Water-based Inkjet Systems

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Abstract

Packaging printing is a ~$500B market expected to grow at 3% CAGR through 2025, with digital printing growing at 10% CAGR. Printing of flexible food packaging has been trending toward water-based printing systems for reasons of health, safety, sustainability, and cost. Unlike most paper-based substrates, flexible films tend to be hydrophobic and water-impermeable, which makes it a challenge to achieve adequate wetting and adhesion of water-based inks, not to mention the subsequent drying to remove the water and any co-solvents that are in the inks. In this paper, we will briefly review the market trends in package printing, including common multilayer package structures, and provide an overview of the various digital printing technologies that are available today for printing on thin, flexible films. We will describe in detail an all-aqueous system of primer, printing inks, and post-coatings that overcomes the limitations of current systems and can be used for either surface or reverse printing of plastic labels, flexible packages, and vinyl wall coverings at production speeds of up to 300 meters per minute.

Background

Package printing is one of the few areas of the printing industry that is experiencing sustained growth, and the growth of digital package printing is outpacing traditional analog processes, such as flexography and offset lithography. When it comes to digital package printing, electrophotography and inkjet technologies are competing for market share. Most current production inkjet printing systems on the market use water-based inks, but for package and label printing there are also several manufacturers who offer UV-curable inks. Market forecasts indicate that water-

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based inks will eventually displace UV-curable and solvent-based inks, largely due to the ecological and economic advantages of water-based inks.

For digital printing on flexible packages and labels, which typically use hydrophobic, impermeable hydrocarbon-based films as the print substrates, up until now the technology choices have been either liquid electrophotography (LEP) using oil-based toners (inks) or piezoelectric drop-on-demand (p-DOD) and UV-curable inks. When water-based inks formulated for printing onto commercial offset papers or folding cartons are printed onto typical packaging films, it is difficult for the inks to adequately wet the surface of the film. And compared to paper-based substrates, printed films are also challenging to dry due to the low glass transition temperatures of the printed film, both of which lead to unacceptable print quality and durability.

In this paper, we describe a continuous inkjet (CIJ) platform, which uses low-humectant water-based pigment inks, for printing on all types of flexible films and other impermeable substrates at up to 200 m/min (650 ft/m). These award-winning digital package presses are designed and built by Uteco, and incorporate KODAK Stream Inkjet Technology and ULTRASTREAM Inkjet Technology, writing systems, inks, and primers. The result is a system designed to print at full production speeds on a wide variety of flexible packaging films using a process that we call the “4 Ps”: Prepare, Prime, Print, and Post-coat. Kodak received a 2020 InterTech Technology Award for Innovativeness from Printing Industries of America for the KODAK PROSPER QD Packaging Inks and Film Optimizer Agents. Kodak was also co-recipient of the award along with Uteco for the UTECO Sapphire EVO M Press.

Digital Production Printing on Flexible Films

Before we discuss production printing on flexible films with water-based inkjet inks, let’s first provide an overview of the alternative digital printing technologies available today for printing on film-based substrates.

Piezoelectric Drop-on-Demand Inkjet (p-DOD) with UV-curable Inks. One of the earliest examples of digital printing on flexible films is the :DOTRIX Modular™ press by Agfa Graphics, which was introduced to the market in 2009. This groundbreaking press used UV-curable inks and page-wide (25-inch print width) 300 dpi p-DOD printheads. Several other manufacturers, such as Domino, Canon and others, have recently introduced bespoke presses based on UV-curable p-DOD inkjet, primarily for narrow web label printing.

With UV-curable inkjet inks and p-DOD printheads, pigments are dispersed in a mixture of UV-curable monomers, oligomers, photo-initiator, and UV-sensitizer. Drops of ink are jetted on demand with electromechanical actuators behind each nozzle. Inks are “dried” by UV-curing, producing very durable print. The high viscosity of the UV-curable inks requires that the printhead is operated at elevated temperatures to lower the viscosity and enable reliable jetting. The relatively thick cured ink layers can adversely impact roll rewind quality and downstream lamination. Residual odor and food migration are concerns that are being addressed with the latest generations of UV-curable inks. Line-speeds for UV-curable p-DOD presses are typically < 100 m/min. When compared to water-based inkjet inks, UV-inks are significantly more expensive to manufacture.

Liquid Electrophotography (LEP). LEP, as embodied in the HP Indigo line of digital presses, has been around for many years, and HP has recently expanded its application space to printing on flexible films for packaging and labels. In LEP printing, the liquid toner, or "ink," comprises pigments and resins that are dispersed in a viscous, hydrocarbon oil. Charged pigment particles are electrostatically attracted to a laser-imaged photoconductor drum. Each color plane is then electrostatically transferred from the photoconductor drum, and the multi-color image is built up on a heated intermediate drum. The image film is transferred from the intermediate drum and fused to the substrate.1 Maximum line-speed for the HP Indigo 25K flexible packaging press is 31 m/min. Compared to water-based inkjet, LEP has lower productivity and higher running costs.

Sapphire, "QD" Water-Based Inks, and Film Optimizer Agent Primers

Water-based inks for flexible package printing provide a lower cost, more versatile and more eco-friendly alternative compared to UV-curable inks or oil-based liquid toners. However, the challenges with water-based inks include wetting the substrate, preventing lateral ink spread, removal of the water, and management of the residual ink humectants. This is especially challenging when printing onto flexible packaging films, which are hydrocarbon-based, hydrophobic and water impermeable. The keys to successfully printing with water-based inks on flexible films at full production speeds are instant colorant immobilization and ink fluid management, including both water and added humectants or other co-solvents. This can be accomplished by the "4 Ps" as discussed in more detail below.

Sapphire XGV. The original implementation of the "4 Ps" was a technology demonstration at drupa 2016 with a prototype system built by Uteco called the Sapphire XGV (XGV = eXpanded Gamut plus Varnish). This press employed KODAK S-Series Imprinting Systems operating at 600 x 600 dpi using KODAK Stream Inkjet Technology (more on how Stream works below). The press was configured to print two 4-inch lanes of cyan, magenta, yellow, black, orange, green and blue water-based inks onto a pre-primed 38-μm thick white BOPP film, which were then dried and post-printed in-line with a clear protective "digital varnish".

The cyan, magenta, yellow, and black water-based pigment inks used for the drupa 2016 demonstration were the original KODAK PROSPER Packaging Inks targeted at folding and corrugated carton applications and approved for indirect food contact applications. This ink set uses Kodak's proprietary nanoparticle milling and dispersion technology, which results in inks with very high chroma, color gamut, and Pantone™ coverage, all at lower pigment concentrations than achievable with larger, conventionally milled pigments. The FOA was a pre-production formulation, and it was applied to the white BOPP film off-line prior to printing. The technology behind the development of the expanded gamut ink set and the co-optimized "Film Optimizer Agent" (FOA) primer used for this demonstration was previously reported at the 2017 TAGA Annual Technical Conference.2

One of the learnings from the Sapphire XGV demonstration was that even though the inks had low humectant concentrations averaging only about 6 wt% per color, the printed and dried inks exhibited poor cohesive strength until fully cured. Compared to paper-based substrates which can tolerate surface temperatures approaching 90oC during drying, and which are also capable of absorbing residual humectants, thin flexible packaging films are impermeable to water and must be kept below about 60oC during drying to prevent thermal distortion. This makes it much more difficult to completely remove the water and the slower drying humectants from the ink film. The result of these milder drying conditions can be a relatively fragile ink layer even with low humectant ink formulations.

Sapphire EVO M and Sapphire EVO W. Following on the success and learnings from the Sapphire XGV demonstration at drupa 2016, the Sapphire EVO M press utilizes four 24.5-inch KODAK PROSER lineheads operating at a print resolution of 600 x 900 dpi and line speeds up to 200 m/min (655 ft/min). The base configuration incorporates the "4 Ps" (see Figure 1): a CDT unit to Prepare the film, a reverse gravure pre-coating station to apply the Primer, a CMYK Print zone followed by a proprietary drum drying system, and a gravure or flexo Post-coating unit to apply a varnish, a white flood- or pattern-coating, or other post-print layer. Additional pre- or post-coating stations are available options.

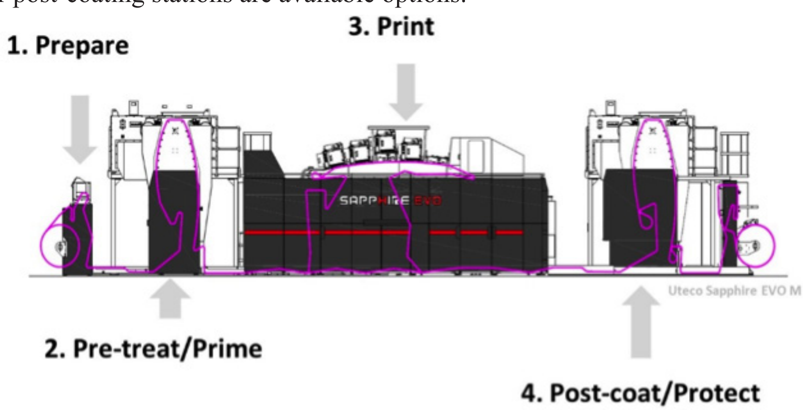

Figure 1. *Schematic of the UTECO Sapphire EVO M press illustrating the "4 Ps".*

Based on Sapphire XGV learnings, the CMYK ink set was reformulated, and the original triol humectants were replaced with one or more specific diols (glycols) with average humectant levels averaging ~6 wt% across the ink set.3 These new inks are known as KODAK QD Packaging Inks. In parallel, the FOA primer was co-optimized to improve its adhesion to the base film, the inks, and the post-coatings.3 Binder ratios and the dry coat weight aim of the FOA were also adjusted to increase its capacity to absorb any residual humectants. This combination of reformulated inks and primer can achieve lamination bond strengths > 3 N/cm using solvent-based, water-based, or solventless laminating adhesives available from multiple vendors.

From an output perspective, the main differences between the Sapphire EVO M and the Sapphire EVO W are the print width and the drop size/print resolution. These differences ae summarized in Figure 2. As a result of the higher in-line print resolution of 1800 dpi, the maximum line speed for the EVO W is 150 m/min (491 ft/min). The lineheads in each press use the same CMOS/MEMS-based silicon orifice plate technology that includes embedded low-power heaters around each nozzle. The heaters are used to stimulate the pressurized continuous jet of ink flowing through each nozzle, causing the column of ink to break up predictably and reproducibly into spherical drops of ink, with a primary drop volume between 3.5 and 4.0 pL depending on the waveform.

	CIJ Technology	Print Width (inches)	Print Drop Volume (pL)	Print Resolution (dpi)
EVO M	Stream	24.5	10.4	600 x 900
EVO W	ULTRASTRAM	49	3.7	600 x 1800

Figure 2. *Comparison of the key differences between the Sapphire EVO M and the Sapphire EVO W.*

For the EVO M, which uses the KODAK PROSPER linehead and KODAK Stream Inkjet Technology,4 print drops are 3X the size of the primary drops, and the drop deflection process uses an orthogonal stream of air to differentiate the heavier 3X print drops from the lighter 1X non-print drops: the lighter 1X drops are swept by the air stream onto the surface of a Coandă catcher and recirculated, while the heavier 3X print drops pass by the catcher and fall to the substrate (Figure 3). The 3X print drops, with a drop volume of 10.4 pL, are appropriately sized for 600 x 900 dpi print resolution.

The Sapphire EVO W is powered with Kodak's 4th generation of CIJ technology, called KODAK ULTRASTREAM. Although ULTRASTREAM uses the same thermally stimulated CMOS-MEMS silicon orifice plate technology as Stream, that is where the similarity ends. With ULTRASTREAM, the smaller, 3.75 pL, primary drops are selected for printing by using electrostatic deflection: charged drops are deflected to the catcher and recirculated, and uncharged drops fall to the substrate5 (Figure 4). The smaller print drops enable a print resolution of 600 x 1800 dpi, producing much sharper images and smoother tone scales.

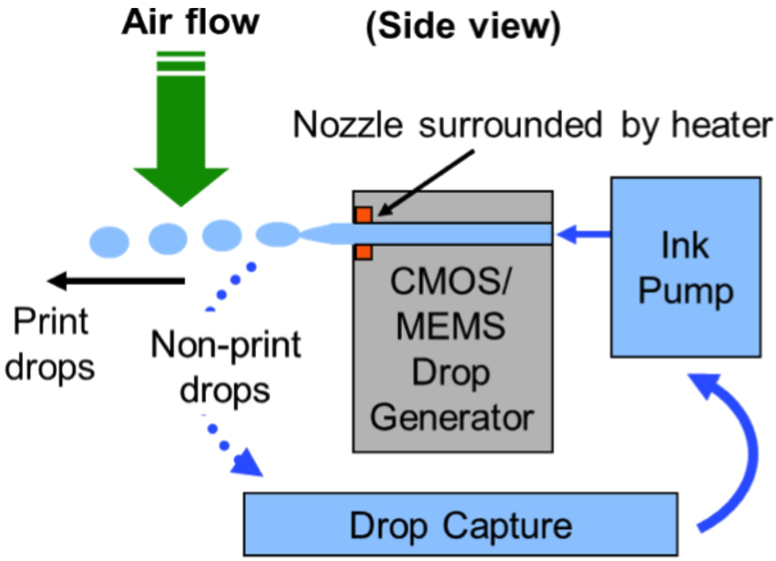

Figure 3. *Schematic of KODAK Stream Inkjet Technology drop generation and selection processes.*

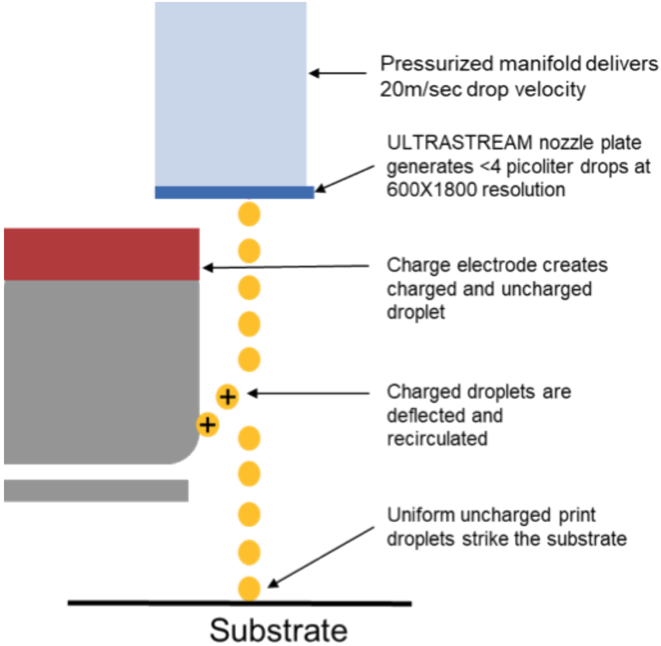

Figure 4. *Schematic of KODAK ULTRASTREAM Inkjet Technology drop generation and selection processes.*

The "4 Ps"

As mentioned previously, the key to successfully printing with water-based inkjet on a wide variety of flexible films is to practice the "4 Ps": Prepare, Prime, Print, and Post-coat. In this section, we will discuss each "P" in more detail.

Prepare. Most as-manufactured flexible films have very low surface energies and are impermeable to water-based fluids. Water-based inks will bead up when deposited on the surface of low surface energy flexible films, rather than spread and wet the surface. Hydrocarbon packaging films, such as polypropylene and polyethylene tend to be the most hydrophobic and have the lowest surface energies, ranging from 20 – 40 dyn/cm. Polyesters, such as PET, and polyamides, such as nylons, tend to be somewhat higher. It should be noted that many flexible films have co-extruded surface layers for heat sealing or gas barrier properties which can result in lower or higher surface energies compared to the base film composition.

Corona discharge treatment (CDT) is commonly used in the industry to prepare the surface of flexible film in order improve the wettability and adhesion of water-based fluid to the surface of the film. Corona treatment is accomplished by exposing the film surface to a high voltage corona discharge unit while passing the film between two spaced electrodes. This process oxidizes the surface and increases the free surface energy of the film. We have found that for water-based coating fluids and inks, a static surface energy of 45 dyn/cm or greater is desirable to achieve adequate wetting on the film. The optimum surface energy of the substrate will depend on the actual surface tension of the coating fluid or ink composition, which can vary as a function of the types and amounts of the ingredients of the composition.

Prime. Simply adjusting the surface energy by CDT of the film to achieve adequate wetting with a water-based ink is insufficient to produce acceptable print quality and durability. When a drop of a water-based ink with a static surface tension of > 30 dyn/cm is deposited directly onto a CDT-treated film substrate, effective wetting of the water-based ink is observed, but when a water-based pigment ink is used, the colorant will also spread laterally, often concentrating at the edges of the ink spot as it dries, causing a so-called "coffee ring" artifact. Likewise, when two drops are placed directly adjacent to each other before either drop has had a chance to dry, as is often encountered with high-speed, page-wide, singe-pass inkjet presses, the drops will spread and coalesce into each other, leading to objectionable levels of grain and/or mottle. Furthermore, when more than one color of ink is deposited, objectionable intercolor bleeding between ink drops is observed.

These issues, and more, are addressed by priming the film with KODAK PROSPER Packaging Film Optimizer Agent (FOA). Kodak's family of Optimizer Agents are designed to "tune" or "optimize" different classes of substrates to the Kodak nanoparticulate ink chemistry – Standard Optimizer Agent (SOA) for uncoated papers and carton boards, Enhanced Optimizer Agent (EOA) for coated papers and carton boards, and FOA for films and other impermeable surfaces – ensuring superior print quality and durability independent of substrate (see Figure 4). FOA is a water-based primer that comprises a proprietary mixture of divalent metal salts and crosslinkable hydrophilic polymeric binders. It is applied as a thin (~ 0.5 – 0.8 g/m2 dry coverage) transparent layer by a variety of coating applicators, most commonly as a flood coat via flexo or gravure. FOA provides excellent adhesion to base film and instantly binds and locks the pigments in place as soon as the drop impacts the surface. This enables wet-on-wet printing at speeds up to 200 m/min (655 ft/min). It is designed to absorb any residual ink humectants that are not completely removed during drying. It is compatible with a variety of post-coatings, including clear varnishes, white or gravure flexo opacifying layers, and most popular laminating adhesive chemistries. FOA is suitable for indirect food contact applications.

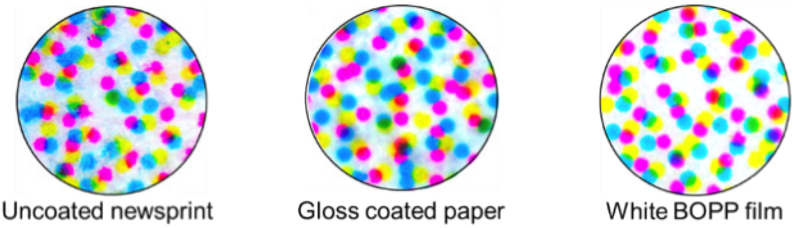

Figure 4. *10% CMY tints printed with KODAK PROSPER Packaging Inks at 50X magnification on a range of substrates that have been pre-treated with the corresponding Optimizer Agents, SOA, EOA, and FOA.*

Print. As noted above, KODAK QD Packaging Inks have been formulated in combination with the FOA to minimize humectant levels in the ink layer after printing and drying. These low humectant, quick drying CMYK ink formulations are printed wet-on-wet on the primed film, and then the inks are dried with a combination of hot forced air and near-IR irradiation. Dried ink layers are ~200 nm thick with very low residual humectants. Like FOA, QD packaging inks are suitable for indirect food contact applications. Expanded gamut (OGB) formulations are also available.1

Post-coat. The choice of the post-coat layer depends on the specific application. For surface print applications, such as labels and monofilm packaging, a water-based or solvent-based varnish is typically applied as a protective layer to the printed and dried film. QD inks and FOA are compatible with a range of overprint varnishes, including water-based, solvent-based and UV-curable, available from a variety of vendors.

For laminated packaging applications, the inks are typically reverse printed onto a clear base film. In this case, a white ink is either pattern- or flood-coated over the printed and dried film to provide an opacifying layer behind the image when viewed through the unprinted side of the clear film. The rewound roll is then ready to be laminated using either water-based, solvent-based, or solventless adhesives available from a variety of vendors. With KODAK QD Packaging Inks ~ 70% of the humectants are removed by drying, allowing the use of conventionally designed adhesive chemistries and process conditions for lamination.

Summary

In this paper, we have described the materials and processes that enable digital printing onto flexible packaging films. Up until recently, this was accomplished by either LEP, using oil-based inks, or p-DOD, using UV-curable inks. Kodak and Uteco have now a introduced a water-based platform for inkjet printing onto a wide range of hydrophobic, hydrocarbon-based flexible films at widths up to 49 inches and (1.25 m) line speeds up to 655 ft/min (200 m/min) that incorporates the "4 Ps" concept:

1. Prepare the film with CDT to raise the surface energy
2. Precoat the CDT-treated film with water-based KODAK Film Optimizer Agent primer
3. Print the primed film with low-humectant, water-based KODAK QD Packaging Inks
4. Post-coat the printed and dried film with a protective varnish (water-based, solvent-based, or UV-curable) or a white opacifying layer (water-based on solvent-based) followed by lamination (water-based, solvent-based, or solventless)

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