Advancements in Web-Offset printing for Flexible Packaging and Labels

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Abstract

Printing flexible packaging and labels with a combination of web-offset utilizing sleeve cylinder technology and energy curable ink technology, like Electron Beam and UV, contributes to the elimination of solvents and VOCs and a reduction in total energy consumption in comparison to flexo and rotogravure, mainly because of the reduced use of fossil fuels for solvents, for heating of drying ovens and for balancing RTO operations. All together resulting in lower GHG emissions.

The four items presented in this paper contribute to the sustainability advantages of web-offset printing technology and at the same time improve circularity of packaging and label materials.

Extended Color Gamut offers a number of benefits of which reduction of press downtime and reduction of waste and costs are the main ones. The use of mono materials combined with surface printing eliminates the need for lamination and supports circular recycling. Inline application of deinking primers for energy curable inks also improves recycling and circularity of flexible packaging and labels. And LED-UV curing for film printing is expected to be the next step in energy savings.

The starting point

For decades web-offset printing was an outsider and not considered as a suitable technology for printing flexible packaging, although web-offset has some great benefits over technologies like flexo and rotogravure, such as high print quality, low-cost plates, fast prepress and instantaneous dry-cured products ready for further

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processing. All attributes welcome in a market where job run lengths are decreasing while demand for quality is on the rise and time to market is getting shorter.

Until 2003 web-offset printing lacked two indispensable requirements, which prevented the technology from entering the flexible packaging market. The first one was the commercial availability of inks that could be printed on non-absorbent substrates with sufficient adhesion and suitable for FCM applications.
The second requirement that was missing in web offset was a technology that allowed simple and cost efficient exchange of variable print repeat lengths in infinitely small steps.

With the development and maturation of radiation curing ink technologies during the eighties and nineties the first obstacle was largely taken. Especially the development of low voltage (80 – 300 kV) Electron Beam curing devices and low migration EB inks, eliminating the need for photo-initiators in the ink formulations and thus lowering migration risks, opened the way for web-offset to enter printing of FCM applications.

Also in the eighties and nineties, the first web-offset presses utilizing EB curing technology, printing on absorbent substrates like tobacco boxes and liquid board packaging, such as beverage cartons for milk and juice, entered into the market.
However, aspects like low migration, low odor and sufficient adhesion of the energy curable inks to various film substrates, in order to secure food safety and sufficient lamination bond strength, still required additional development efforts from raw materials suppliers and ink formulators. These developments got a boost from the moment on that variable sleeve offset press technology became commercially available for flexible packaging and label production..

The second requirement for web-offset printing to enter successfully the market of non-absorbent substrates for flexible packaging and labels, was to find a way to print efficiently and economically a large variety of repeat lengths, as is common practice in other technologies like flexo and rotogravure, and is one of the key requirements for printing flexible packaging.
This hurdle was tackled with the development and introduction of the variable sleeve offset press technology, abbreviated as VSOP, by Dutch offset press manufacturer Drent-Goebel in 2003. This inventive technology combined individual exchangeable sleeve cylinders with the accuracy and flexibility of servo drive systems.

In order to make the web-offset sleeve technology work robustly and economically relevant additional developments with industry partners and suppliers were required.

- Improved robustness of sleeve-cylinders.
  The first sleeve cylinders for offset were derived from PU based lightweight flexo sleeves. These first offset sleeves lacked the required robustness needed for the high pressures and torques that are typical for offset printing.

- Self-adhesive printing blankets
  Self-adhesive printing blankets are standard equipment on a VSOP press as the lightweight PU-composite or aluminum printing sleeve cylinders are not equipped with tensioning and clamping means for standard tensioning printing blankets. Suitable self-adhesive blankets, with a strong adhesive layer but on the other hand also easy and clean removable, required development efforts from various blanket manufacturers and blanket converters.

- Energy curable inks for FCM applications
  The commercially available Electron Beam and UV curable inks that were in 2003 on the market were developed and suitable for cardboard packaging such as for tobacco and liquid board packaging. However, for safe and robust printing of flexible packaging and labels for FCM applications, aspects like ink transfer, adhesion, low migration, low odor, resistance to thermal processing, and robust printing performance required development efforts from ink formulators.

- Digital controlled stepless plate benders
  Offset printing sleeve cylinders with infinite stepless print repeat lengths require accurate and repeatable stepless offset-plate benders. Till then offset presses had a fixed repeat size or maximum 3 to 4 different repeat sizes where plate benders for fixed plate sizes could do the job. The possibility of infinite stepless variable repeat sizes and a simple but effective plate mounting system required digitalization of the plate bending process and equipment, including optical detection means for exact and repeatable bending length.

With the fore mentioned four items rapidly solved and matured the VSOP technology took off and was readily accepted by the market. Within 5 years from the introduction numerous VSOP presses were produced and running in four different operation widths from 520 to 850, 1120 and 1250 mm. Applications varied from wrap around labels, shrink sleeves and in-mold labels to flexible packaging, liquid board packaging and folding carton applications.

The variable offset sleeve cylinder concept was rapidly embraced by several other web-offset press manufacturers all of which developed and launched their own models. Since then a few more followed and actually the second and third generation web-offset presses based on VSOP technology can be found in the market.

Subsequent developments were focused on operation and production efficiency, including faster job set-up and shortening change over times between jobs by fast sleeve change and sleeve preparation outside the press, reduction of set-up waste utilizing CIP-3/4 ink-key presetting, auto-washing and integration of turret un- and rewinders with auto splice function eliminating downtime and waste between reel changes.
The recent energy crisis and the globally growing awareness regarding the need for circular reuse of single-use packaging materials shifted the focus of development on increasing process sustainability and reduction of carbon footprint.
Reduction of energy consumption and material waste, moving to circular use of materials, are key drivers in today's packaging printing and converting industry. This includes transition of waste stream processes for single use packaging and labels in efficient and economical circular processes.
Addressing these challenges requires changes and adaptations of the ways in which packaging and labels are printed, supported by effective and efficient printing press configurations.

ECG Extended Color Gamut

Extended Color Gamut printing, or ECG, is the use of 6 or 7 process colors in fixed positions on the printing press, instead of the 4 standard process colors CMYK plus various spot colors. ECG offers several clear and convincing advantages regarding time and materials savings.

- Significant extension of the color gamut in comparison to CMYK.
- Reduction of PMS spot color inks.
  ECG can reproduce roughly 82% of PMS gamut within $\Delta E2000 \leq 2$.
- Time saving in job changeover.
  No washing nor re-coloring of the printing units.
- Savings on ink consumption.
  Less ink waste, and less consumption of washing fluids.
- Simple logistics, simple stock management and less storage space.
- No color mixing, no mixing errors, no quantity failures nor ink surplus.

The concept and benefits of ECG are not new at all. ECG has some well-known predecessors, like for example Hexachrome and Opaltone, however both never became quite as successful because of various reasons of which costs for license fees and the use of a non-standard color set might be two.

However, in order to benefit from ECG it requires accurate and stable color-to-color register on press and a robust level of standardization in pre-press and on-press procedures, including calibration and maintenance of printing and prepress equipment.

Besides web-offset other printing technologies also benefit from the use of ECG. Offset however, has some specific qualities, like good reproduction of finest screens and broadest choice of AM, FM and XM screen types and stable and accurate color-to-color register that makes offset ideally suited when it comes to ECG performance and execution.

Unfortunately not all spot colors can be reproduced easily and accurately with ECG. Based on the availability of accurate color profiles for a certain combination of consumables modern color conversion software can calculate and predict upfront which spot colors can be reproduced with ECG or, if not exact, how much the ΔE off-value will be. Depending on the ΔE value that is acceptable for the customer the use of one or more spot colors might still be required.

In practice it turns out that introducing one or more spot colors is cumbersome and inefficient on a press where the number of printing units equals the number of fixed colors. Apart from the question if the rest of the spot colors in the job can go without one or two of the 7 fixed ECG colors. As soon as one or more of the 7 fixed ECG colors have to be replaced by one or more spot colors the mentioned benefits of ECG regarding efficiency and waste reduction are largely lost.

One approach to prevent production inefficiency due to inevitable color swaps is not to allow jobs that require one or more spot colors to go on an ECG-dedicated press. And thus only produce the jobs that do match with the 7 fixed colors set. However, such an approach is only feasible when there other printing equipment available that can produce the jobs that require the use of spot colors.

Fig. 1 *Example of a 10-color web-offset press with EB curing for efficient combination of ECG jobs including spot colors. Courtesy DG press*

Another, more flexible and efficient approach is to opt for one, two or more additional printing units in a press. The modular set-up of in-line web-offset presses makes them ideally suited for optimization for the ECG-plus spot colors concept by utilizing a press configuration consisting of more printing units than just the required number of fixed ECG colors.

Besides the efficiency of the 7 fixed process colors, additional offset print-units, in up- and down-stream positions, provide the necessary functionality for spot colors, but also additional flexibility for specialty inks, for sorting purposes in recycling streams and for security purposes, and even for first- and last-down offset whites, without compromising the benefits of the 7 fixed ECG colors.

Mono-materials

A significant percentage of single-use flexible packaging is made from multi-material laminates. These laminates often consist of material combinations that cannot be recycled together in the same recycling process, and that are not economically separable from each other.

One upcoming trend to make flexible packaging more circular, is the switch from multi-material laminates to mono-material packaging. Mono-materials can be single layer films, co-extrusions but also laminates built from materials from the same chemical family that can go in the same recycling stream without the risk of downcycling.

Fig. 2 *Two examples of web-offset EB printed mono-material pouches*
Courtesy of Chemosvit (left)/Courtesy of Huhtamaki Flexibles Türkiye (right)

A growing number of film manufacturers and packaging converters put efforts and resources into the development of mono-material films for packaging and with success. One of the main challenges is obtaining barrier properties at the same level as with multi-material films can be achieved. Another challenge is the run-ability of the mono-materials on packaging lines.

Packaging made from mono-materials like PE, MDO-PE, PP or OPP in combination with barrier layers like EVOH, or barrier coatings, are suitable for many FCM packaging applications and at the same time offer improved recyclability.

A number of mono-material films are co-extrusions or pre-laminates, having generally a higher thickness and more stiffness than mono-films and therefore providing easier handling on press. Co-extrusions and pre-laminates are typically surface printed. When these films are not opaque white by themself, the application of a first-down white in-line in the press is required. The same is valid for packages that require windows.

Utilizing a first-down offset white has advantages for short runs because of the low cost and fast make-ready offset plates. Sharp printing of finest details and smooth gradients are additional advantages of offset white. When runs are longer or jobs demand higher opacity integrated flexo or rotogravure units in-line with the offset printing units might be favorable.

Many co-extrusion films, when surface printed and varnished, do not require lamination which provides benefits in terms of time, energy and material savings.

Fig. 3 *Multiple color EB web-offset press configuration for surface printing or reverse printing with inline up- and down-stream coating units*

A positive side effect of the Electron Beam unit is that it is able to cause additional crosslinking between the PE polymer chains, causing a higher density in the material resulting a slightly higher stiffness and slightly improving the barrier properties of the material. Such effects are helpful but not of decisive importance.

Deinking

To increase circular use of single-use flexible packaging and label films in recycling streams and obtain a clean recyclate that has properties and use equal or similar to those of a virgin material, the need for efficient and economic deinking of printed films is evident.

Printing ink systems based on water or solvent-soluble resins have an advantage by nature, as such inks are easier to release and dissolve when done in appropriate washing conditions. Energy curable inks on the other hand are not.

EB and UV energy curable inks as are typically used in web-offset printing are known for their good chemical resistance. This makes them the technology of choice for printing packaging and labels for detergents, alcohols or other solvents. But at the same time makes the high chemical resistance of energy curable inks de-inking of these inks more challenging.

Unfortunately, almost all printed flexible packaging and label films end up in the same waste recycle streams. And even when more advanced recycling installations facilitate material separation by main plastic families such as PET, PP, PE, based on NIR or watermark technologies, they will not yet be separated by printing ink technology. This demands a deinking process that is suitable to handle all kinds of ink systems.

The application of a deinking primer is a possible and viable solution. The actual deinking primers are not specifically developed for energy curable inks, but this is likely the application that might benefit the most from a deinking primer. However, other ink systems and deinking processes in general could also benefit from a standardized deinking primer approach.

A deinking primer enables easy release of the inks and varnish from film substrates in a hot water bath and caustic conditions as prescribed in the Association of Plastic Recyclers (APR) process standard for deinking and recycling criteria. Actual deinking primers are mainly water-based, but there are also UV-curable deinking primers on the market.

DG press got a request from the market about the inline application of a water-based deinking primer in a web-offset set-up for printing on CPET shrink sleeves. This triggered the question if the water-based deinking primer has sufficient chemical resistance when it comes in contact with the slightly acid dampening water as typically used in web-offset printing. Or would the deinking primer's release mechanism be triggered too easily and too early, causing print defects or other defects like for example blocking in the reel. And would the deinking functionality still be sufficient after being overprinted with UV offset inks.

The manufacturer of the selected water-based deinking primer, Siegwerk, stated that so far there was no experience with their water based deinking primers in combination with web-offset printing. A test was required to check compatibility of the water based deinking primer with the web-offset printing process and conditions in order to validate the feasibility of the application.

Primer application and observations from the deinking test

In November 2022 print tests were run with two generations of water-based deinking primer from Siegwerk, CIRKIT CLEARPRIME WB A01 and A04, on a VSOP web-offset press at company VUYE Flexible Packaging from Oudenaarde, Belgium. The utilized substrate was a CPET, type G11F03 from KP and the UV curable ink series was SunCure FLME from SunChemical. The primers were applied in a flexo coater with hot-air dryer at a weight of approximately 0,5 grams per square meter, and overprinted with CMYK inks plus partially an offset last down white.

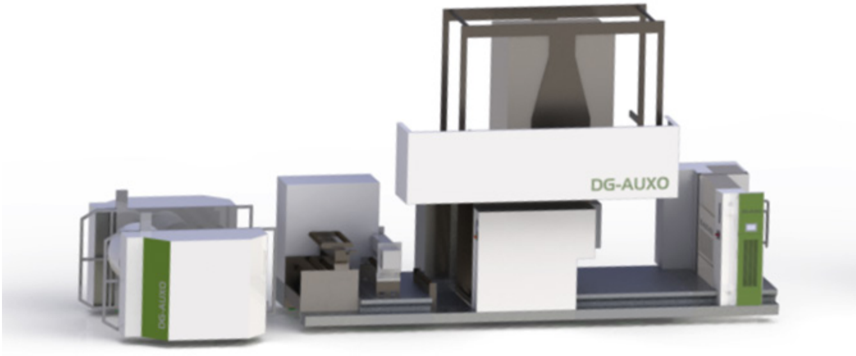

Fig.4 *Section of a DG-AUXO web-offset press with integrated upstream flexo unit with hot-air drying for in-line application of water-based deinking primer.*

When the packaging or label film requires windows or clean sealing areas it is inevitable to apply the deinking primer on a flexo coater in-line with the web-offset printing process (Fig.4) to maintain exact register with the printed image.

The reels from the test print were slit and sleeved, applying a solvent mixture of Dioxolane and Tetrahydrofuran. As both primers were applied over the full width of the substrate without recesses, the seaming solvent was applied on top of the de-inking primer, without a negative impact on the final strength of the seam. The sample reels were sent to the laboratory at Siegwerk (D) where deinking test were executed under APR-prescribed washing conditions.

Fig.5 *Left: Application of water-based deinking primer on an in-line flexo coater. Right: Slit and sleeved reels ready for deinking testing.*

The printed sleeves were cut into small pieces of 1cm^2 of which 1.2 gram was mixed with 38,8 gram of PET bottle flakes and immersed in 1% NaOH + 3% Triton X-100 at 85°C and stirred for 15 minutes. After 3 minutes the first signs of deinking were visible and after 15 minutes the cPET mixture of film and flakes was clean.

Fig. 6 *Left: Beaker with pieces of film sample.*
Right: First signs of deinking after 3 minutes.

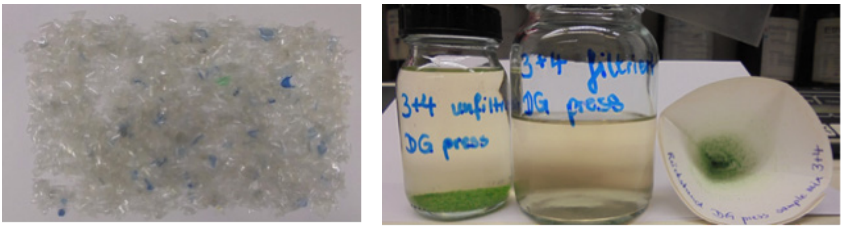

Fig. 7 *Left: Clean flakes after washing. Blue pieces are blue bottle flakes.*
Right: Unfiltered + Filtered wash water + Filtered particles

The final conclusions are, first, that the UV-offset inks did print very well on top of the WB-flexo applied primer without defects. And second, the printed samples easily deinked within 8 to 10 minutes leaving a clean mixture of CPET flakes. Slight bleeding of some pigments in the washing solution was visible but this was not considered problematic for continuous and repeated use of the wash water.

LED-UV

LED-UV curing of printing inks is expected to cause a breakthrough in printing industry as an energy-efficient alternative to other ink drying and curing technologies.

The sudden and dramatic increase of energy prices over the past year made many industries aware of their dependency and vulnerability regarding energy supply and costs impact. This forced them to look for energy efficient alternatives. The tense situation regarding energy supplies is no different for the printing industry, where especially in Europe high energy-consuming technologies, like flexo with hot-air drying and rotogravure printing, have come under serious economic pressure because of scarcity of natural gas.

Web-offset printing operations utilizing EB or UV energy curing typically consume less energy compared to technologies utilizing hot-air drying. Nevertheless offset printing operations were also impacted by the general price increase of energy. High costs for energy evaporate margins and force printers to apply significant price increases on their products with the risk of going out of business within weeks to months.

Against this background LED-UV hold strong cards when it comes to a reduction of energy consumption for ink drying and curing. And besides low energy consumption LED-UV pairs several additional advantages.

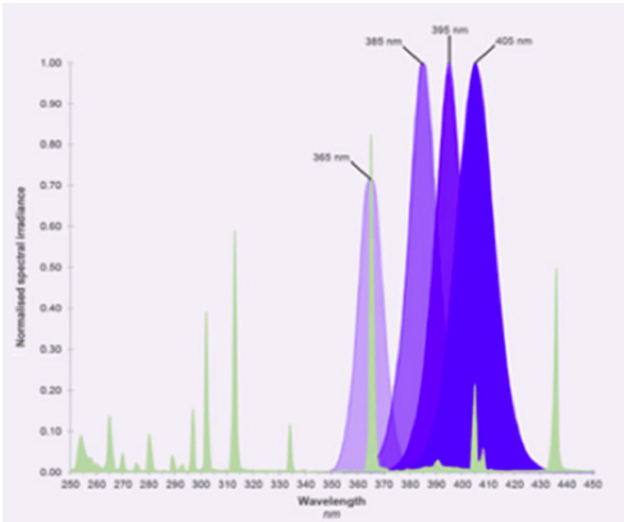

Fig.8 *LED-UV is highly efficient around 395 nm wavelength range.*
Courtesy of GEW

In contrast to conventional UV lamps LED-UV systems operating at wavelengths around 385 and 395 nanometers do not generate harmful ozone. The majority of the LED-UV systems actually in the market operate at wavelengths around 395 nm, with an extension in the 365 nm range.

LED-UV lamps are characterized by a long operating lifetime typically far over 20.000 hours. LED-UV installations operate on/off, reducing downtime between starts and stops. And LED-UV generates only little heat in comparison to conventional UV lamps, causing only little heat impact on the substrate.

Another, not quite unimportant aspect driving growing interest in LED-UV curing, is that in Europe the use of Mercury, which is an essential ingredient in conventional UV lamps, is restricted and will be banned completely within the coming years. However, for the moment the EU Commission granted the renewal of the exemption for UV curing lamps, till February 24, 2027.

Having mentioned all the foregoing, a complete 100% change of an actual curing/drying technology to a LED-UV-only installation is not feasible yet. LED-UV curing performing in the 395 nm range cannot provide solutions for all relevant applications. Curing of varnish and whites with LED-UV is still not fully developed and oxygen inhibition has a negative impact on surface curing of the ink, which may lead to an increased risk of set-off migration.

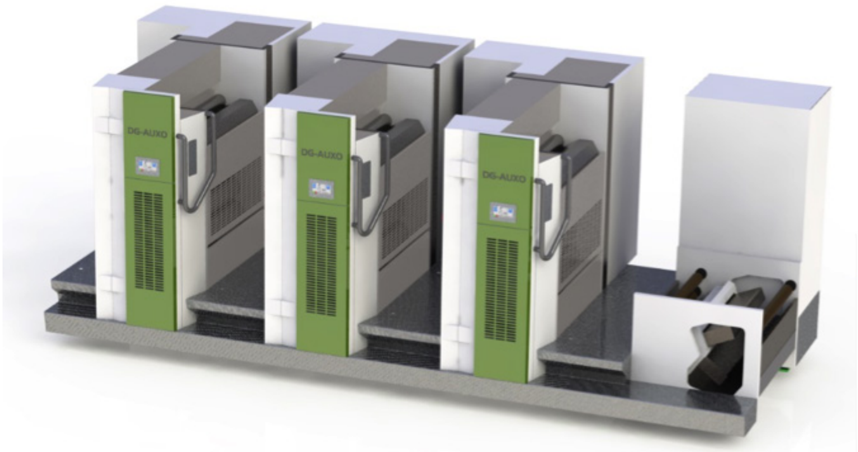

Fig.9 *DG-AUXO web-offset press with 2 lamp LED-UV end curing module for curing offset inks.*

Broadening the effective operational LED-UV range to lower wavelengths is required for improved surface cure. And efficient inertization of the curing area in the lamp housing by nitrogen can reduce inhibition of the polymerization by oxygen.

For sheet-fed printing with LED-UV of non-FCM applications on absorbent substrates, like paper and cardboard, inks with good performance are readily available, but when it comes to web-offset printing with LED-UV of FCM flexible packaging and labels on films the situation is more complicated. Lower reactivity of the FCM suitable photoinitiators seems to be the root cause.

So far only a small number of ink manufacturers have dedicated LED-UV products for web-offset printing on film, which are formulated for good transfer and adhesion to a number of film substrates. In addition, to be suitable for FCM applications, the LED-UV inks must be low-migration and low-odor formulated.

As a manufacturer of web-offset presses for flexible packaging and labels that are standard equipped with EB or conventional UV curing systems DG press followed closely the development and performance of LED-UV systems.

During 2020, driven by high prices for energy, customer interest in LED-UV systems showed significant growth. In the meantime, the number of LED-UV inks for web-offset printing of FCM applications on film had increased. Therefore, it was decided to explore and learn the actual status and performance of LED-UV technology in practice before offering and delivering the first presses with LED-UV to customers.

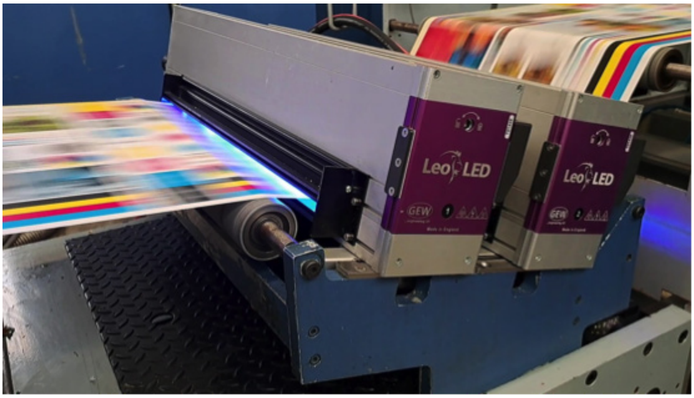

Fig.10 *Integration of two LED-UV lamps from GEW as end-curing test system on a web-offset press, model Vision*

In cooperation with LED-UV system manufacturer GEW from Crawley, UK one of their water-cooled LED-UV systems, type Leo-LED, with two moveable lamp units, was integrated on a 4-color web-offset press, model Vision. The two lamps were placed together after the offset printing units, requiring wet-trap printing of the 4 process color inks.

The installed LED-UV system has the following specifications. The peak wave length is 395 nanometer with a peak irradiance of 30 W/cm^2, and the energy density of the two lamps is 565 mJ/cm^2 at 50 m/min. The system is compact and easy to handle and the operation of the system is very user friendly especially when compared to conventional UV systems.

The first trials with CMYK inks were run between November 2022 and mid of February 2023 with LED-UV ink series from 5 manufacturers. As test substrates were selected two coated paper types and one BOPP cavitated label film and acrylic coated PET film. Plates were Kodak Trillian and Sonora, blankets were Kinyo AirTack J 0.95 and damping water was mixed with SunFount 480 at 3% and 5% IPA, with pH at an average of 4.8.

The main observations from the tests are that, apart from an initial issue because of an temperature in the press room, all inks performed well regarding transfer and dampening water compatibility.

Rub resistance in general is fair to good, but independent of which ink series were tested it is in most cases black that is the first color that shows weak resistance against rubbing at higher speeds, indicating insufficient cure. Optimal surface cure might be hindered by oxygen inhibition. Inertization of the curing area in the lamp housing with nitrogen might solve this, but will also add to the total production costs. Scratch resistance of the LED-UV inks seems slightly better than typically for conventional UV inks, which might be related to better deep cure of LED-UV inks.

Printing on non-absorbent substrates is in general more challenging as the ink and some dampening water stay at the surface of the substrate. The residual water must vaporize by convection. The fact that LED-UV lamps still create some heat is helpful in this regard. Tape test resistance, in the meaning of adhesion to film substrates, appears in general weaker when speeds increase.

Most FCM-formulated LED-UV inks in the test were notable for their extremely low odor. Exceptions could benefit from inertization of the curing area in the lamp housing.

Overall a good performance was observed on paper with the LED-UV ink series for paper. With both LED-UV lamps activated at 100% one ink series performed well up to 300 m/min, which is the max speed of the test press. When the same test was repeated with only one lamp activated the black of that same ink series did not sufficiently cure at its surface leading to early low rub resistance.

LED-UV wavelength impact		
Lower wavelengths	**vs**	**Higher wavelengths**
Surface cure		Deep cure
Lower energy efficiency		Higher energy efficiency
Relatively more heat		Relatively less heat
Less yellowing		More yellowing
Ozone		No ozone

Tab.1 *Relative performance indication of actual LED-UV applications.*

As the observations of the FCM-formulated ink series on films were quite positive and encouraging, DG press, in cooperation with its partners, will continue further trials and investigations, including LED-UV varnishes and of LED-UV whites, applied with offset and flexo, to closely follow and support the technology is already sufficiently fit for the various FCM applications in flexible packaging and labels, including positive pass of migration tests.

Concluding

Web-offset with energy curing offers sustainable printing of flexible packaging and labels due to the absence of solvents and VOCs in the inks, and the energy efficient curing of the inks when compared to hot-air drying technologies. The absence of thermal oxidizers and solvent recovery systems for handling solvent laden air is an important additional advantage of web-offset with energy curing and contributes positively to the overall sustainability of the packaging production process.

The combination of web-offset with the sustainability advantages of the four discussed technologies, Extended Color Gamut, Mono-materials, Deinking and LED-UV, makes the total picture regarding sustainable production of packaging and labels even better!