UV LED is Shining New Light on an Old Subject

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The use of UV LED lamps for curing materials dates back to 1994, where dental applications were one of the first applications. In 2004, the first UV LED lamps were used to cure such things as adhesives, coatings, and inks but were limited in its use. At that time, the power output was unacceptable for use on high speed printing presses. In 2013-2014, the reality of high power UV LED lamps has not only provided us with new curing capabilities but is allowing traditional commercial printers the ability to compete in the UV curable markets. With new innovations in the lamp designs and formulation chemistries, the technology is finding new avenues of use including food packaging applications.

Background

In the 1990’s, UV curing technology started to take off for use in high speed printing markets. (prior to this, there were only some screen printing applications) One of the major contributing factors in the use of UV ink and coating was the fact that they contained little to no VOCs (Volatile Organic Compounds). By the elimination of the VOCs, UV inks and coatings does not require the need to recapture or incinerate the exhaust given off which is a requirement with traditional solvent / heatset inks and coatings. Because UV inks and coatings do not contain VOCs, hazardous air pollutants or SARA 313 compounds, environmental permits may not be required. Even today, the use of UV/EB inks and coatings remains as one of the lowest producers of pollution in the industry. The South Coast Air Quality Management District (SCAQMD) highlights UV/EB as a “Supercompliant” technology based on lack of environmental impact.

Another major benefit of UV inks and coating is that the amount of energy needed to cure a UV ink or coating is much less than that needed to dry solvent / heatset inks and coatings. The instant cure of the UV inks and coatings results in faster turnarounds and secondary finishing directly off press. Although the impact of UV curing on the environment is minimal, there is always room for improvement. As the price of oil continues to rise and the necessity for lower environmental impact increases, technology must adapt in order to conform. Within the past few years, developments have been made to make UV curing of inks and coatings even more energy efficient, thus reducing the impact on the environment even further.

Some of the drawbacks with traditional UV curing lamps are: The lamps contain a small amount of mercury. If they are broken, special care is needed to ensure that the mercury is contained and safely disposed of. Due to the toxic nature of the mercury, there is a push to eliminate its usage worldwide. Based on RoHS 2 (restrictions of hazardous substance) directives, the use of mercury needs to be eliminated in all instances where an acceptable alternative is available. Up until July 22, 2016, UV lamps for curing purposes have an exemption associated with them. If this exemption is not extended, the use and production of UV lamps containing mercury will not be allowed in Europe for curing purposes. UV curing lamps emit wavelengths in the UV region below 240 nm and if not filtered out, ozone is produced. Due to the health effects of ozone, either an exhaust to the outside or an activated carbon filter is needed to remove it from the production floor. A UV curing lamp must stay above a minimum light intensity in order to stay lit. If the energy falls below this level, the lamp would not produce light. Because UV lamps are not instant on or off, they take time to come up to full power and,
if shut off, they must cool prior to re-firing. A high amount of heat is generated which can distort non-porous substrates, resulting in registration issues. Additionally, it is possible to dry out paper / board substrates causing curl or cracking. To combat heat, the use of dichroic filters (used to remove IR energy), water cooling and air cooling have been utilized. The water cooling and air cooling needed for UV lamps, the exhaust needed to remove ozone, and the shutters that are used to allow the lamps the ability to stay on, makes them bulky. Efficiency of UV lamps is typically below 15% of the energy used.

The next step in improving one of the cleanest printing technologies was to eliminate some of the downsides of traditional UV lamp curing units. One of the first technologies used to reduce the drawbacks is the use of LED lights for curing. The use of LED lamps has been in use for many years with some of the first applications being dental, printed circuit boards and adhesives. The small compact size of a LED lamp was able to pinpoint the area needing attention with minimal heat generated. It has only been in recent years that the power of the UV LED lamps has been improved to the point that their use in high speed printing is a possibility.

UV LED lamps have addressed many of the drawbacks to traditional UV lamp technology. LED lamps produce UV light in a totally different way than traditional UV lamp technology. The light is produced by the movement of electrons within a semiconductor and not from an electrical arc in a vacuum as with a traditional UV lamp. By producing light in this manner, UV LED lamps do not contain mercury. A traditional UV lamp emits light energy below 240 nm which produces ozone. Ozone is considered as a respiratory tract irritant and can result in headaches, eyes, nose and throat irritation, and if exposure is too great, can lead to reduced lung capacity. Ozone is therefore controlled in the workplace by OSHA to have a permissible exposure limit of 0.1 ppm in air. In order to achieve these levels, traditional UV lamps have to be either vented or equipped with activated carbon filters which increase the size of the lamps considerably. Since UV LED lamps do not emit light energy below 240 nm, the need for extraction is eliminated. This will allow for the LED lamps to be smaller in size and reduces the energy necessary for the exhausting of the ozone. UV LED lamps are instant on/off. With traditional UV lamps, it takes some time for the lamp to reach full power. Once turned off, the traditional lamps have to cool down before being able to be re-fired. Because of these two factors, traditional UV lamps will use shutters and powering down techniques to minimize the number of times the lamps go from off to on and reducing the time to reach full power. Shutter mechanisms will increase the bulk of the lamp. Since UV LED lamps are instant on/off, shutters are not necessary and will result in a smaller size. UV LED lamps run at cooler temperatures than traditional UV lamps. A UV LED lamp runs at approximately 60° C whereas mercury lamps will produce heat in excess of 350° C. In order to remove heat, either large amounts of chilled air or water is required. UV LED lamps do require water or air cooling, but due to the lower temperatures, the size is minimal. The efficiency of a medium pressure mercury lamp is approx. 10-15%. Most of the energy produced is converted to IR energy, in the form of heat. With LED lamps, 25-30% efficiency of the energy is converted to useful UV light and the remaining energy consists of heat generation.4 Traditional UV lamps have a normal useful life between 1,000 and 2,000 hours. Some of the new UV LED high power lamps have a working lifetime of >20,000 hours. The energy required to run an LED lamp is 7.2k (180W/inch) Watts/lamp whereas the traditional UV lamp uses 12.2 kW (300 Watts/inch) Watts/ lamp. This difference in energy use can result in a significant savings.5

As with any technology, there are some drawbacks with UV LED lamps. At this time there are limited amounts of photoinitiators which absorb the light the LED lamps is emitting. Due to this limitation, the LED curing of varnishes and coatings becomes more challenging. The photoinitiators that are used to cure these products have a tendency to shift yellow when cured and results in good though cure but poor surface cure. This is fine for inks but not acceptable for use in coatings and
varnishes. The photoinitiators that absorb the correct wavelength of light are typically more expensive and higher amounts of photoinitiators are required to overcome oxygen inhibition to achieve proper curing. This increases the price of the ink and coating significantly. The LED lamps, at this time, cost almost 3.5x the amount as a traditional UV lamp. A 110 cm LED lamp would be approx. $102,000 whereas the corresponding arc lamp would be $28,500.\textsuperscript{7} As the technology increases in popularity and adoption, the prices of the units will go down. The power output of LED lamps is continually improving, although is still lacking when compared to traditional UV lamps. UV LED lamps have sufficient power to cure inks and coatings on most sheetfed presses but have limited use on high speed large format web presses.

UV LED lamps come in a variety of sizes, power and wavelengths. The output spectra of the LEDs are monochromatic. Their outputs only span, at the most, 40nm with the peak at 365, 385 or 395 nm. Other UV LEDs have been produced at 350, 405, 210, 250, 275 or 290 nm but most of these lamps are for specialty applications such as water purification. As a rule of thumb, as the output spectra is decreased so is the maximum intensity of the lamp.\textsuperscript{6} A 365 nm lamp at this time has a maximum output of 2 W / cm\textsuperscript{2} whereas the 395 nm lamp has a maximum output of 10-16 W / cm\textsuperscript{2}.

The first step in formulation of a UV ink or coating is to look at the wavelengths in which the lamp is emitting. In the case of most commercially available UV LED curing units for high speed printing, this would be between 385 and 410 nm. At this time, there are very few photoinitiators which absorb within these wavelengths. Even if the photoinitiator absorbs in this region, the primary absorption peaks of the compounds are usually less than 385 nm and therefore the efficiency of the photoinitiator to absorb all of the available light at 385 nm and above is diminished. By taking the output spectra of each of the photoinitiators, a graph can be made to pinpoint which photoinitiators are viable candidates. For example: Figure 1 shows the photoinitiators that absorb at 365 nm. It can be seen that at 365 nm, EMK (Ethyl Michler’s Ketone) gives the greatest absorbance. In order to have an ink or coating that will cure with a 365 nm UV LED lamp, it would be beneficial to use EMK in combination with other photoinitiators that have appreciable absorbance in the 365 nm output. Additionally, the same technique can be used for other wavelength lamps, such as 385 nm and 405 nm. (Figure 2 and Figure 3) Please note: the spectral data of the photoinitiators was obtained at a 100 ppm concentration with spectroscopy grade methanol using a Hewlett Packard Model 8453 UV/VIS Diode Array Spectrophotometer and a 1 cm quartz cell.

\textbf{Figure 1}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{365nmAbsorbance}
\caption{365 nm Absorbance of Photoinitiators (100 ppm Concentration of PI)}
\end{figure}
When using Norrish type II photoinitiators such as DETX (CAS# 82799-44-8), ITX (CAS#75081-21-9), EMK (CAS# 90-93-7), BMS (CAS# 83846-85-9), 4-MBP (CAS# 134-84-9), Esacure® 1001M (CAS# 272460-97-6) and MBF (CAS# 15206-55-0), an amine synergist must be used for hydrogen abstraction to produce a very active donor molecule which carries out the photo polymerization reaction. The reactivity of the type of amines increases in the following way:\(^8\)

\[(\text{C}_2\text{H}_5\text{)}_3\text{N} < \text{CH}_3\text{N} (\text{C}_2\text{H}_4\text{OH})_2 < (\text{CH}_3)_2\text{NCH}_2\text{CH(OH)}\text{CH}_3 < (\text{CH}_3)_2\text{NC}_6\text{H}_4\text{COOC}_2\text{H}_5\]
With UV LED lamps, the output is toward the high end of the UV electromagnetic spectrum (365 nm, 385 nm, 395 nm or 405 nm), since the wavelengths are longer, the light travels deeper in the ink or coating giving very good through cure but the lack of shorter wavelengths impacts the amount of surface cure. In order to achieve a non-tacky surface, it is very imperative that ways to maximize the amount of surface cure is examined. As with any UV free radical curing system, oxygen at the surface of the substrate inhibits the cure. In order to overcome this, the formulation must be optimized to reduce the oxygen inhibition at the surface of the ink or coating. The most effective ways to offset oxygen inhibition is the following:9

1. A combination of high levels of photoinitiators and high intensity light sources providing an excess of produced photoinitiator free radicals.
2. The use of a gas to remove the oxygen at the surface such as nitrogen or carbon dioxide.
3. The use hydrogen donors to quench the peroxy radicals. (amines, thiols, ethers, silanes, phosphites)10
4. The use of waxes in the ink or coating that provides a surface barrier.
5. Short wavelength UV light.

Once you have pinpointed the possible photoinitiator candidates, the application in which the inks or coating is to be examined. If the inks and coating are to be used on food packaging, one must follow applicable regulations for the geographical location. For example, all European regulations must be met for inks and coating which may come in contact with foodstuffs (primary food packaging not intended for direct food contact). This would include all European Council directives and suitable use listings. (i.e. Regulation (EC) No 1935/2004, Swiss Ordinance 817.023.21 Annex 6, Directive 2007/42/EC, Directive 2002/72/EC, Regulation (EC) No 2023/2006, etc.) Along with these regulations, certain end use customers have their own guidance rules for materials used for food packaging inks and coatings. (i.e. Nestle Guidance Note on Packaging Inks11) Looking at the suitable photoinitiators in the above figures and these listings, mixture of BDK/BDMM (CAS# 24650-42-8/119313-12-1), BMS (CAS# 83846-85-9), MBF (CAS# 15206-55-0), DETX (CAS# 82799-44-8), ITX (CAS#75081-21-9), TPO (CAS# 75980-60-8), MMMP (CAS# 71868-10-5), 4-MBP (CAS# 134-84-9) and mixture of HMMP/TPO (CAS# 75980-60-8 / 7473-98-5) cannot be used for products printed for Nestle. This leaves only BAPO (CAS# 162881-26-7), BDMM (CAS# 119313-12-1), Esacure® 1001M (CAS# 272460-97-6) and EMK (CAS# 90-93-7). In addition to these photoinitiators, certain polymeric photoinitiators can be utilized.

**Experimental**

The UV LED curing unit that was utilized for all LED testing was the Air Motion System XP5 and categorized as a 12 W / cm² lamp. The output of the lamp was measured with an EIT Power Puck II equipped with UVA, UVB, UVA2 and UVV filters. The output of the lamp running at 100% power, 7.5 cm from the conveyor belt at a speed of 300 fpm, was measured as 2093.9 mW / cm² – UVA, 3383.6 mW / cm² – UVA2 and 3078.5 mW / cm² – UVV with the smoothing setting on the instrument in the “off” position. The delivered dose of the lamp running at these conditions gave a dose of 26.7 mJ / cm² – UVA, 43.6 mJ / cm² – UVA2 and 40.4 mJ / cm² – UVV.

All inks were printed using a Prufbau Printability Tester equipped with UV rollers at an application speed of 0.5 m / s and a pressure of 700 N. The substrate that was used for printing was a standard 14 point SBS board (*Solid Bleached Sulfate*). The inks were printed to the following densities: Black – 1.80, Cyan – 1.40, Magenta – 1.50 and Yellow – 1.05. (The densities of the prints were read with an X-rite 528 spectrophotometer with Illumination/Observer setting of D50/2°).
The cure of the printed samples was evaluated by using a combination of subjective tests and near-infrared spectroscopy. The subjective testing included: 1) Thumb twist – immediately after curing, the print is subjected to a thumb twist (delivered with great downward pressure) and the amount of ink movement is noted. 2) Scratch resistance – The print is scratched with a fingernail and the damage to the printed surface is recorded. 3) Cross-hatch adhesion was performed on all printed samples to assess the cure of the inks using 3M 610 type tape. 4) Cotton ball test – a cotton ball is rubbed across the surface of the print to check for tackiness of the surface. The amount of fuzz left by the test is quantified. The near infrared spectroscopy is utilized to look at the C-H vibration due to the stretching of the acrylate double bond at 1620 nm. It is the decay of this bond that gives insight as to the extent of conversion of the UV curable materials.

**Results**

Through a screening design of experiment and subsequent optimize design, the above mentioned photoinitiator compounds and amine synergist were tested. A total of four different combinations were identified as having proper cure when utilizing the UV LED 395 nm lamp at the 7.5 cm distance. Each mixture was tested in all four process colors in a UV curable offset formulation. *(See Table 1 for results)*

| Table 1 |
| Lab testing with 12 W / cm² 395 nm lamp at 100%, 7.5 cm from curing surface and a speed of 300 fpm |

<table>
<thead>
<tr>
<th>Mixture A - Black</th>
<th>Thumb Twist</th>
<th>Scratch Resistance</th>
<th>Adhesion</th>
<th>Cotton Ball Test</th>
<th>NIR Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture B - Black</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>62%</td>
</tr>
<tr>
<td>Mixture C - Black</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>68%</td>
</tr>
<tr>
<td>Mixture D - Black</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>72%</td>
</tr>
<tr>
<td>Mixture A - Cyan</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>70%</td>
</tr>
<tr>
<td>Mixture B - Cyan</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>65%</td>
</tr>
<tr>
<td>Mixture C - Cyan</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>72%</td>
</tr>
<tr>
<td>Mixture D - Cyan</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Mixture A - Magenta</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>64%</td>
</tr>
<tr>
<td>Mixture B - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>72%</td>
</tr>
<tr>
<td>Mixture C - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>74%</td>
</tr>
<tr>
<td>Mixture D - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>75%</td>
</tr>
<tr>
<td>Mixture A - Yellow</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>67%</td>
</tr>
<tr>
<td>Mixture B - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Mixture C - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Mixture D - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>74%</td>
</tr>
</tbody>
</table>

5 = Excellent  1 = Poor

These mixtures were then press tested on a commercial UV LED offset press equipped with two 395 nm UV LED lamps at output wattages of 9 W / cm² and 12 W / cm². Testing was conducted at both 10k impressions per hour and 15k impressions per hour. The first test was run with both lamps at 100% power and 15k impressions per hour. The results can be found in Table 2. The second test was performed using the two lamps at 100% power and 10k impressions per hour. The results can be seen in Table 3.
Table 2
Commercial Press testing with one 9 W/cm² and one 12 W/cm² 395 nm lamp at 100%, 7.5 cm from curing surface and a speed of 15k impressions per hour

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Thumb Twist</th>
<th>Scratch Resistance</th>
<th>Adhesion</th>
<th>Cotton Ball Test</th>
<th>NIR Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Black</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>53%</td>
</tr>
<tr>
<td>B - Black</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>57%</td>
</tr>
<tr>
<td>C - Black</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>55%</td>
</tr>
<tr>
<td>D - Black</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>55%</td>
</tr>
<tr>
<td>A - Cyan</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>57%</td>
</tr>
<tr>
<td>B - Cyan</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>C - Cyan</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>D - Cyan</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>A - Magenta</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>55%</td>
</tr>
<tr>
<td>B - Magenta</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>C - Magenta</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>D - Magenta</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>A - Yellow</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>59%</td>
</tr>
<tr>
<td>B - Yellow</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>63%</td>
</tr>
<tr>
<td>C - Yellow</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>63%</td>
</tr>
<tr>
<td>D - Yellow</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>63%</td>
</tr>
</tbody>
</table>

5 = Excellent  1 = Poor

Table 3
Commercial Press testing with one 9 W/cm² and one 12 W/cm² 395 nm lamp at 100%, 7.5 cm from curing surface and a speed of 10k impressions per hour

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Thumb Twist</th>
<th>Scratch Resistance</th>
<th>Adhesion</th>
<th>Cotton Ball Test</th>
<th>NIR Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Black</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>55%</td>
</tr>
<tr>
<td>B - Black</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>62%</td>
</tr>
<tr>
<td>C - Black</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>D - Black</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>60%</td>
</tr>
<tr>
<td>A - Cyan</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>57%</td>
</tr>
<tr>
<td>B - Cyan</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>65%</td>
</tr>
<tr>
<td>C - Cyan</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>65%</td>
</tr>
<tr>
<td>D - Cyan</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>65%</td>
</tr>
<tr>
<td>A - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>62%</td>
</tr>
<tr>
<td>B - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>62%</td>
</tr>
<tr>
<td>C - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>65%</td>
</tr>
<tr>
<td>D - Magenta</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>67%</td>
</tr>
<tr>
<td>A - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>64%</td>
</tr>
<tr>
<td>B - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>67%</td>
</tr>
<tr>
<td>C - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>67%</td>
</tr>
<tr>
<td>D - Yellow</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>65%</td>
</tr>
</tbody>
</table>

5 = Excellent  1 = Poor
From these mixtures, it was determined that the inks developed for offset UV LED printing are a viable option and could be used even for high end packaging applications. A variation in the photoinitiator was then made, utilizing the European Council directives and suitable use listings mentioned above, to see if a primary food packaging UV LED offset ink could be made and pass the migration / extraction testing.

The inks were made in the laboratory and tested according to EN 14338: Paper and Board intended to come into contact with foodstuffs. Conditions for determination of migration from paper and board using modified polyphenylene oxide (MPPO) as a simulant, and EuPIA Guideline on Printing Inks applied on the non-food contact surface of food packaging materials and articles – September 2009. The testing was conducted utilizing both GC/MS and LC/MS to ensure that the lowest possible quantifiable limit of 10 ppb was met for all ingredients in the formulation. Please note: In order to ensure that the cure of the inks are at optimum level, each ink must be cured prior to the next ink being applied. Knowing this and the traditional press sequence of colors, the black ink was cured four times, the cyan ink was cured three times, the magenta ink was cured two times and the yellow ink was cured one time through the lamp at 100% power and 300 fpm. This would simulate the amount of lamps each ink would see on press. The results of the migration / extraction testing can be seen in Table 4.

<table>
<thead>
<tr>
<th>Sample Board</th>
<th>Black</th>
<th>Cyan</th>
<th>Magenta</th>
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μg/kg food corresponds to μg/6 dm2, assuming that 1 kg of food is in contact with 6 dm2 of packaging

Conclusion

UV inks can be formulated to work on high speed sheetfed presses equipped with UV LED lamps. With the new advancements in UV LED equipment, a conventional printer can purchase UV LED lamps to retrofit a press and now compete in the UV curable market. Even though the initial cost of the LED lamps is high, the energy savings, the lack of exhaust, and the lifetime of the lamps makes this proposition very attractive. Traditional UV curing presses can also benefit from these advantages. It is possible to formulate inks and coatings that can be used for high speed sheetfed commercial and packaging applications. With proper testing it is also possible to provide inks that can be used as a primary food package. (for certain food types) As the technology continues to grow, the ability to utilize these curing processes will become more commonplace and the price will continue to decrease. The
lamp manufactures are making great strides by doubling the output lamp energies approximately every two years. At this point, the only lamps that can deliver the output power necessary are based on 395 nm lamp technologies. Work is continuing on lamps whose output spectrum is 365 nm, 300 nm, 285 nm and 265 nm but the efficiency is very low at this time. In addition to the advancements in the lamp technologies, advancements will have to be made in the photoinitiators that absorb in the UV LED wavelengths. Not only will they have to produce free radicals, but they must also provide pathways for low migration / extraction inks and coatings. With the benefits of UV LED lamps, and the continuing innovation, both on the chemistry and equipment side, this technology is poised to deliver great opportunities now and in the future.

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