UV/EB Equipment for Printing & Packaging Applications

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Applications Specialist

PCT
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Which is better for printing and packaging; UV or EB?

Yes
Solvent Based Inks, Coatings, and Adhesives

- Solvents function as a “carrier” for the “solids” portion of the ink, coating, or adhesive
  - Solvent is a high value material with a low value “temporary” function
  - Solvent costs are increasing with costs of oil and natural gas
  - Most common way to handle solvent emissions is thermal oxidation which produces greenhouse gas (CO₂)
- Solvent based materials are old technology out of step with a sustainable future
Water Based Inks Coatings and Adhesives

- Water – plentiful, low cost, environmentally friendly “carrier”
- Disadvantages of water:
  - High energy needed to remove water
    - Heat of vaporization (calories/gram)
      \[ \text{water} = 540, \text{toluene} = 88, \text{heptane} = 76 \]
  - Dryer energy to remove water results in more CO$_2$ emissions
  - Water based coatings typically have some VOC content (co-solvent or coalescing-solvent)
- Film properties
  - 2-componet systems needed for “resistance” properties
  - Lower gloss
  - Lower print quality due to “dot gain”
Ink Drying Energy Estimates
Assume 60” wide, 6 color press, running 1000 ft/min

- Solvent/Water (conventional thermal drying)
  - Natural gas fired dryers
  - Estimate 30M Btu/h (880 kW) for drier
  - Need to gather actual operating press data
  - Oxidizer energy cost dependant on solvent load

- UV Press
  - Input power = 8 lamps x 600 w/in x 60 in = 288 kW
  - 92% efficient power supply + 30 kW cooling = 343 kW total

- EB Press
  - EB power supply plus cooling = 85 kW
  - Liquid nitrogen to supply 80 scfm inerting uses equivalent of about 100 kW
  - Total = 185 kW
UV/EB Technology Selection

- UV and EB have some similarities and fundamental differences
- Selection of UV or EB should be based on the best fit for the process and application
- Best fit considerations may include:
  - Enabling of end-use
  - Capital cost
  - Operating costs
  - End-use properties
  - Fitness for food packaging
  - Substrate considerations
Energy

**UV**
- Energy in the form of photons
- Wavelength determines energy; typically 250 to 450 nm
- Energy unit conversion; 350 nm photon = 3.5 eV
- Total applied energy typically 0.1 to 0.5 J/cm²

**EB**
- Energy in the form of accelerated electrons
- Accelerating voltage determines energy; typically 80 to 180 kV
- Typical electron energy at substrate; 70,000 eV
- Total applied energy typically 20 to 40 kGy
  - 1 kGy = 1 J/gram
  - For 50 gram/meter² layer = 0.1 to 0.2 J/cm²
Energy

UV
- Energy not sufficient to directly initiate polymerization (non-ionizing)
- Photoinitiator must be used

EB
- Will ionize any organic material
- No photoinitiator needed
Penetration

<table>
<thead>
<tr>
<th>UV</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration depends on the optical density of the material</td>
<td>Penetration depends on the mass density of the material</td>
</tr>
<tr>
<td>Penetration is controlled by the peak irradiance (power and focus) of the UV source</td>
<td>Penetration is controlled by acceleration potential (voltage) of the beam</td>
</tr>
<tr>
<td>Good penetration into clear materials</td>
<td>Easily penetrates into clear, pigmented, filled, and opaque materials</td>
</tr>
<tr>
<td>Limited penetration into pigmented, filled, and opaque materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can cure thick and/or heavily pigmented or filled inks and coatings</td>
</tr>
<tr>
<td></td>
<td>Enables lamination of opaque materials</td>
</tr>
<tr>
<td>■ Effective curing of thin ink films</td>
<td></td>
</tr>
<tr>
<td>■ Effective curing of thick coatings with low pigment loading</td>
<td></td>
</tr>
<tr>
<td>■ Lamination of clear materials</td>
<td></td>
</tr>
</tbody>
</table>
Penetration/Energy Deposition

UV Photons

EB Electrons
UV Equipment

- Medium pressure mercury electric arc powered lamps
- Medium pressure mercury microwave powered lamps
- Pulsed xenon lamps
- Solid state LED arrays
Mercury Arc Lamp Components

- UV Lamp Cassette
- Blower
- Power Cabinet
Microwave Powered Mercury Lamp Components

placed end-to-end for uniform cure, and controlled individually or together.
Pulsed Xenon Lamp System
UV LED Array
# UV Equipment

<table>
<thead>
<tr>
<th>UV Source</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium pressure mercury arc powered lamps</td>
<td>▪ High throughput</td>
<td>▪ High heat output</td>
</tr>
<tr>
<td></td>
<td>▪ Wide widths available (&gt;60”)</td>
<td>▪ Long warm-up time (shutters)</td>
</tr>
<tr>
<td></td>
<td>▪ Broad spectral output</td>
<td>▪ Non-uniform aging</td>
</tr>
<tr>
<td></td>
<td>▪ Printing and converting</td>
<td></td>
</tr>
<tr>
<td>Medium pressure mercury microwave powered lamps</td>
<td>▪ High throughput</td>
<td>▪ Each lamp 10” max width</td>
</tr>
<tr>
<td></td>
<td>▪ Long lamp life</td>
<td>▪ High heat output</td>
</tr>
<tr>
<td></td>
<td>▪ Fast warm-up (no shutters)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Industrial and 3D</td>
<td></td>
</tr>
<tr>
<td>Pulsed xenon lamps</td>
<td>▪ Very low heat</td>
<td>▪ Low continuous output</td>
</tr>
<tr>
<td></td>
<td>▪ High pulse irradiance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Broad spectral output</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Index (stop and go) processes</td>
<td></td>
</tr>
<tr>
<td>LED arrays</td>
<td>▪ Very long life</td>
<td>▪ Narrow spectral output</td>
</tr>
<tr>
<td></td>
<td>▪ Instant on</td>
<td>▪ Low throughput</td>
</tr>
<tr>
<td></td>
<td>▪ Compact – system integration</td>
<td>▪ Low peak irradiance</td>
</tr>
<tr>
<td></td>
<td>▪ Ink jet</td>
<td></td>
</tr>
</tbody>
</table>
EB Equipment

- High energy scanning type
  (300 – 10,000 kV)
- Industrial self-shielded multi-filament type
  (150 – 300 kV)
- Low energy self-shielded multi-filament type
  (70 – 150 kV)
- Low energy compact modular type
  (70 – 150 kV)
Electron Beam Equipment

Industrial Electron Beam Processor

New Generation
Low Energy
Electron Beam Processor
Compact Modular EB Emitters

[Dimensions:
11.5 in x 16.0 in x 34.0 in x 18.0 in x 9.9 in]
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<th>Strengths</th>
<th>Weaknesses</th>
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<tbody>
<tr>
<td>High energy scanning (300 – 10,000 kV)</td>
<td>- Cure through very thick materials</td>
<td>- High capital cost</td>
</tr>
<tr>
<td></td>
<td>- Curing of composites</td>
<td>- Very large size</td>
</tr>
<tr>
<td></td>
<td>- Crosslinking of 3D materials</td>
<td>- Extensive shielding required</td>
</tr>
<tr>
<td>Industrial self-shielded multi-filament (150 – 300 kV)</td>
<td>- Very high throughput</td>
<td>- High capital cost</td>
</tr>
<tr>
<td></td>
<td>- Wide widths (&gt;100”)</td>
<td>- Large size</td>
</tr>
<tr>
<td></td>
<td>- Penetration of thick films</td>
<td>- Potential substrate damage</td>
</tr>
<tr>
<td></td>
<td>- Film Crosslinking</td>
<td></td>
</tr>
<tr>
<td>Low energy self-shielded multi-filament (70 – 150 kV)</td>
<td>- Very high throughput</td>
<td>- Not well suited for 3D applications</td>
</tr>
<tr>
<td></td>
<td>- Wide widths (&gt;60”)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Controlled penetration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Printing and packaging</td>
<td></td>
</tr>
<tr>
<td>Low energy compact modular (70 – 150 kV)</td>
<td>- Lower cost</td>
<td>- Width maximum 16” per emitter</td>
</tr>
<tr>
<td></td>
<td>- Permanent vacuum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Compact modular design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Surface sterilization</td>
<td></td>
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</tbody>
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Equipment Size

**UV**
- Relatively small
- Full interstation installation (lamp after each print deck) is common
- Interstation lamps allow dry trapping of multiple ink colors
- Multiple lamps may be used after last deck for final curing

**EB**
- Original industrial equipment is quite large
- Newer low voltage equipment is much smaller; however, interstation installation still not practical
- Print technologies allow curing with a single EB unit at the end of the press
  - Web offset (lithographic) printing
  - Sun WetFlex™ (flexographic) printing
- Low voltage permanent vacuum type could potentially allow interstation installation
Equipment Safety

**UV**
- UV light can cause skin and eye damage upon exposure
- High temperature lamp could result in skin burns upon contact
- UV lamp units are completely self shielded

**EB**
- Limited penetration of electrons
- Secondary x-rays are primary hazard
- Not radioactive. No radiation can be present unless high voltage is on
- EB units are completely self-shielded
- Interlocked to cut power if shielding is removed
- Continuous monitoring will shut-down unit if x-rays are present
Capital Cost

**UV**
- Relatively low cost for few number of relatively narrow lamps
- High-speed (>1000 ft/min) will typically require 4 to 6 lamps in series
- Wide web (>50 inch) multi-lamp systems begin to approach EB costs

**EB**
- Original higher voltage (>150 kV) units cost greater than $1 MM
- Newer lower voltage equipment has reduced cost 50% or more
- Single EB unit will cure >50 inch-wide web at >1000 ft/min
Operating Costs

**UV**
- About half of the energy input to the lamp is converted to UV light
- Remaining energy is lost as heat
- Additional energy required for lamp cooling (air blowers most common)

**EB**
- More efficient conversion of electrical power to curing energy
- Additional energy requirements for vacuum pumps, water cooling
- Additional cost of Nitrogen
**Inerting**

<table>
<thead>
<tr>
<th>UV</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Free-radical curing inhibited by atmospheric oxygen</td>
<td>- Free-radical curing inhibited by atmospheric oxygen</td>
</tr>
<tr>
<td>- Curing in air can be accomplished for many systems due to high surface irradiance</td>
<td>- Inks and coating require an inert atmosphere to cure</td>
</tr>
<tr>
<td>- Air curing important for sheet-fed printing applications</td>
<td>- Effective inerting limited to web applications</td>
</tr>
<tr>
<td>- Inerting can greatly accelerate cure and/or reduce photoinitiator requirements</td>
<td>- Laminations can be cured without inerting since laminate layer excludes oxygen</td>
</tr>
<tr>
<td>- Inerting may be an attractive option for food packaging</td>
<td></td>
</tr>
</tbody>
</table>
Effect on Substrates

UV
- Non-ionizing energy has limited effect on thermal and mechanical properties of substrates
- Separate UV primer layer may be used for grafting/enhanced adhesion
- Materials that soak into porous substrates (uncoated paper) may limit curing

EB
- May cross-link or degrade polymer substrates
- Low-voltage allows surface curing with little or no effect on inside surface
- Effect may be beneficial
  - Cross-linking film for shrink applications
  - Simultaneous curing and grafting for enhanced adhesion
  - Simultaneous curing on surface and sterilization of food contact layer
Heat Control

**UV**
- Mercury lamps produce significant heat
- Heat control measures needed for many packaging films
  - Dichroic reflectors
  - Hot mirrors
  - Water cooled lamps
  - Chill drums

**EB**
- Cooler process compared to UV
- Many packaging films can be run without special cooling
- EB units available with or without integral chill drums
Food Packaging Considerations

UV
- Properly formulated systems produce little or no taint or odor
- Need to consider migration of residual uncured material
- Methodology available to establish food law compliance
- Need to consider photoinitiator migration
  - Unreacted photoinitiator as well as fragments
  - New systems available to minimize migration
    - Polymeric photoinitiators
    - Reactive photoinitiators
    - Resins with built-in initiators
  - New systems performance limited for dark inks

EB
- Properly formulated systems produce little or no taint or odor
- High conversions may be achieved
- Need to confirm that migration does not occur
- Methodology available to establish food law compliance
- Photoinitiator is not used
Consistency/Maintenance

UV (mercury arc lamps)
- Output can decrease as lamps age
- Decrease not uniform across spectral output
- Decrease may not be uniform across the web
- Systems available that can monitor and adjust output
- Typical preventative maintenance interval 1000 to 3000 hours
- Maintenance interval will depend on process cleanliness and lamp temperature control
- Typical maintenance items are bulbs and reflectors
- Multiple lamp systems allow process to continue at slower speed incase of single lamp failure

EB
- Output is very consistent over time (on or off)
- Cross-web uniformity is constant over time
- Typical preventative maintenance interval is 4000 to 8000 hours
- Maintenance interval will depend on process cleanliness and window/foil temperature control
- Typical preventative maintenance items are window foil and filaments
- Process must be stopped for window foil or filament change
Measurement

**UV**
- Measurement is critical for maintaining a constant process
- Wide range of radiometers are available
  - Probes (inserted, fixed)
  - Radiometer attached to substrates
  - UV sensitive films attached to substrates
- Need to understand limits of each type of radiometer

**EB**
- Measurement is critical for maintaining a constant process
- EB sensitive film dosimeters most common
- Dosimeters traceable to NIST standards
## UV/EB Package Printing
(by printing technology)

<table>
<thead>
<tr>
<th>Printing Technology</th>
<th>UV</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravure</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Flexo - narrow web</td>
<td>Well established</td>
<td>Limited</td>
</tr>
<tr>
<td>Flexo - wide web</td>
<td>Limited</td>
<td>Limited/Growing</td>
</tr>
<tr>
<td>Offset - web</td>
<td>Established</td>
<td>Established/Growing</td>
</tr>
<tr>
<td>Offset - sheet fed</td>
<td>Well established</td>
<td>Limited</td>
</tr>
<tr>
<td>Screen</td>
<td>Well established</td>
<td>Not used</td>
</tr>
<tr>
<td>Digital</td>
<td>Growing (ink jet)</td>
<td>Not used</td>
</tr>
</tbody>
</table>
In-line Flexo with Interstation UV Curing
Wide Web EB Flexo Printing (WetFlex™)
EB Curing In-Line with Web Offset Printing
## UV/EB Package Printing
(by package type)

<table>
<thead>
<tr>
<th>Package Type</th>
<th>UV</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible packaging</td>
<td>Limited</td>
<td>Limited/Growing</td>
</tr>
<tr>
<td>Folding cartons</td>
<td>Well established</td>
<td>Well established</td>
</tr>
<tr>
<td>Multi-wall bags</td>
<td>Well established</td>
<td>Well established</td>
</tr>
<tr>
<td>Ridged containers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Labels</td>
<td>Well established</td>
<td>Established/Growing</td>
</tr>
<tr>
<td>- Cans</td>
<td>Well established</td>
<td>Not used</td>
</tr>
<tr>
<td>- Plastic/composite/lids</td>
<td>Well established</td>
<td>Limited</td>
</tr>
</tbody>
</table>
Conclusions

- UV and EB are environmentally sound technologies well suited for use in printing and packaging applications
- The selection of UV or EB should be based on the best fit for the selected application
Thank you

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Please remember to turn in your evaluation sheet...