Radiation curing of polymeric materials is an efficient and relatively low temperature electricity-based technology with many applications in coating, printing, adhesives, electronics, and communication material. Radiation curing, which includes Ultraviolet Curing and Electron Beam technologies, can improve the overall physical or chemical properties of polymeric materials and produce superior results in bonding, surface finish, and durability to those of other technologies. Speed and controllability in these applications, suggest an increasing market for this electrotechnology in manufacturing worldwide.

BENEFITS

Both UV or EB Curing are highly desirable for processing, owing to benefits of productivity as well as advantages of being "clean" technologies. These radiation processes have a number of key attributes; they are:

- a solventless process -- cure is by polymerization rather than by evaporation, so VOC emissions are eliminated;
- a low temperature process -- heat is not required;
- a high speed process -- cure is nearly instantaneous;
- an energy-efficient process -- energy is invested only in the curing reaction, not in heating;
- easily controlled -- inks and coatings do not "dry," so do not set up in printing/coating equipment.

APPLICATIONS

Radiation-processing technologies offer several major advantages over other production methods. These benefits include rapid curing, low process temperatures, the absence of pollution, and substantially lower energy costs, as well as high-quality and specialized products. Typical product lines involve coatings (on wood, metal, paper, and plastic), inks (for letterpress, lithographic, gravure, and screen printing), and adhesives (for film, foil, or paper substrates). The industries using these technologies are diverse and varied; they include electronics, fiber optics, flooring, packaging, plastics, and printing.
MATERIALS

The essential ingredients of a radiation-curable material are:

(1) Oligomers -- 30-90% concentration; completely reacted upon cure; primarily provide film properties such as flexibility, hardness, and chemical resistance; (equivalent to "resins" of conventional coatings) There are a number of choices of types which provide a variety of features and properties of the uncured and cured material, such as viscosity, cure speed, hardness, toughness, flexibility, weathering, etc.

(2) Monomers -- 10-70% concentration; completely reacted upon cure; controls viscosity and polymer chain formation; (equivalent to "solvent" in conventional materials EXCEPT that it is completely reacted)

(3) Photoinitiator (UV curing only) -- 1-5% concentration; a photo-active material which responds to (UV) light and initiates chain formation.

(4) Additives and pigments -- conventional materials to alter stability, adhesion, tack, or appearance.

TECHNOLOGY: UV CURING

UV lamps are generally of two types: (1) Medium pressure mercury vapor arc lamps (usually called "arc lamps"), or (2) Medium pressure mercury vapor microwave-powered lamps (called "microwave powered lamps" or "electrodeless lamps").

The UV energy produced by the lamp bulb is focussed by a reflector onto a (moving) surface. The UV energy striking the surface causes the photoinitiator to trigger the polymerization reaction. The material is usually solidified ("dry") when it exits the cure zone.

Lamps are characterized by the UV light intensity at the work surface (irradiance), measured in Watts per square centimeter (W/cm²). Cure dose is a function of time (or process speed) and is measured in Joules per square centimeter (J/cm²). By using multiple lamps, the process width can be extended without limit.

A light enclosure is required to eliminate stray UV light and to provide protection to personnel from exposure to UV.
TECHNOLOGY: EB CURING

Electrons generated by a hot filament and cathode are accelerated by a high voltage to produce a flood of high energy electrons which are concentrated into a beam onto a (moving) surface. The energy of the electrons is a function of the accelerating voltage. Electron beam accelerators are characterized by their accelerating voltage: 300 kV or less is referred to as "low energy." Most curing accelerators are in this range. Process width is usually 130 inches or less.

Electrons striking and penetrating the uncured material cause a direct initiation of the cross-linking reaction in the material, and the material is immediately polymerized.

The dose (D), in megarads, received by a material is characterized by the electron current (I), the velocity of the process (S), and a factor (k) which is a function of the accelerator voltage, geometry, width and distance:

\[ D(\text{Mrad}) = \frac{k \cdot I(\text{mA})}{S(\text{m/min})} \]

The curing zone is surrounded by an enclosure to contain an inert (nitrogen) atmosphere. It is necessary to displace oxygen, which interferes with the curing reaction at the surface of high speed materials. Electrons striking oxygen molecules would also produce ozone. The enclosure is also shielded to prevent escape of radiation produced by the high energy electrons.

PRODUCT APPLICATIONS FOR UV PROCESSING

- Printing and Publishing
  - Book and magazine covers
  - Brochures and promotional materials
  - Compact disc boxes and album covers
  - Menus

- Consumer Products
  - Eyeglass lenses
  - Trophies and plaques
  - Tape measures

- Wide web converting
  - Silicone release films
  - Vinyl flooring no-wax finish
  - Solar reflective films
  - Vinyl woodgrain laminating films
PRODUCT APPLICATIONS FOR UV PROCESSING (continued)

- **Business Forms**
  - Direct mail
  - Catalogs
  - Business forms
  - Sweepstakes mailings

- **Narrow web converting**
  - Labels and tags
  - Bar code printing
  - Lottery tickets
  - Stickers and decals

- **Plastics**
  - Headlamp lenses and bodies
  - Decorative caps and containers
  - Auto body moldings

- **Medical devices**
  - Disposable syringes
  - Transdermal patches
  - Catheters

- **Plastic container decoration**
  - Shampoo and toiletry bottles
  - Toothpaste tubes
  - Styrofoam cups and containers

- **Wood**
  - Fillers and sealers for plywood and particle board
  - High gloss finishes on case goods
  - Wood flooring strips and parquet

- **Electronics**
  - Component marking
  - Conductive inks
  - Conformal coatings

- **Metal Containers**
  - Two piece (aluminum) beer and beverage cans
  - Three-piece (steel) cans and containers
  - Metal boxes

- **Telecommunications**
  - Optical fiber coatings
  - Printing on wire and cable insulation
  - Optical ribbons, cables and fiber coloring
PRODUCT APPLICATIONS FOR ELECTRON BEAM PROCESSING

Curing ("drying")
- Inks and coatings in offset lithography (e.g., printing folding cartons and flexible packaging)
- Coatings on wood, Masonite or particle board to produce decorative panels
- Adhesives in laminating operations
- Silicone coatings on controlled-release products (e.g., label stock) and magnetic coatings on recording tapes and discs

Crosslinking
- Plastic films for high strength and temperature packaging materials (e.g., shrink wrap)
- Heat shrink tubing for electronic applications
- Wire/cable insulation to increase chemical resistance and allowable operating temperature

Sterilization
- Medical products

Electron beam (EB) and Ultraviolet (UV) processing are sometimes considered to be competitive technologies, but in most cases, specific manufacturing requirements provide a clear differentiation between the two approaches, and they tend to be complementary. In some instances they may both be required.

RECYCLING OF RADIATION-CURED PRINTED MATERIAL

A study recently conducted by the Beloit Corporation, sponsored by RadTech International, found that all of the (UV/EB) ink/coating combinations were recyclable into board grades.

Furthermore, the study proved that for recycling into tissue grades, all materials require a system containing flotation while most also require centrifugal cleaners.

In addition, UV inks and sheetfed litho inks with water-based coating also require dispersion, a common component in today's recycling mills, for recycling into tissue grades.
For recycling into fine paper grades, most ink/coating combinations require dispersion and additional flotation.

Hence the Beloit study's conclusion: UV/EB printed and coated paper can be recycled into tissue and/or paper grades using commercially available equipment. In fact, UV/EB cured paper is just as recyclable as other materials.

UV and EB MARKETS

U.S. Market for Radiation Curable Coatings, Inks and Adhesives, by End-user Industry

(Value $mm)

<table>
<thead>
<tr>
<th>Industry</th>
<th>1991</th>
<th>1996</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical / Electronics</td>
<td>74</td>
<td>140</td>
<td>90%</td>
</tr>
<tr>
<td>Packaging</td>
<td>67</td>
<td>103</td>
<td>54%</td>
</tr>
<tr>
<td>Graphic Arts</td>
<td>31</td>
<td>49</td>
<td>58%</td>
</tr>
<tr>
<td>Wood furniture &amp; Construction</td>
<td>49</td>
<td>69</td>
<td>41%</td>
</tr>
<tr>
<td>Automotive</td>
<td>8.4</td>
<td>12.7</td>
<td>51%</td>
</tr>
</tbody>
</table>

Source: Frost and Sullivan, Inc. - 1992

RECENT TRENDS AND SHARE

Annual Coatings Market Survey

(percent of total volume)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>47.8</td>
<td>46.0</td>
<td>41.6</td>
<td>32.5</td>
</tr>
<tr>
<td>High-solids</td>
<td>14.9</td>
<td>16.5</td>
<td>16.4</td>
<td>16.3</td>
</tr>
<tr>
<td>Two-component</td>
<td>12.2</td>
<td>12.9</td>
<td>11.6</td>
<td>11.5</td>
</tr>
<tr>
<td>Powder</td>
<td>11.1</td>
<td>11.5</td>
<td>12.8</td>
<td>16.7</td>
</tr>
<tr>
<td>Waterborne</td>
<td>9.1</td>
<td>11.2</td>
<td>11.8</td>
<td>16.9</td>
</tr>
<tr>
<td>Vapor-cure</td>
<td>1.6</td>
<td>.7</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Radiation-cure</td>
<td>1.4</td>
<td>.9</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Other</td>
<td>1.9</td>
<td>3.3</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Source: Industrial Finishing - January 1992
"Radcure coatings today comprise about 3% ($300 million) of the U.S. industrial coating market ($10 billion). Indeed, UV and EB coatings that cure instantly, rapidly and with minimal VOC certainly have a bright future. The share could reach 10% ($1 billion) by 2000". Source: Industrial Finishing - January, 1993

CONCLUSION

Radiation-processing technologies offer several major advantages over other production methods. These benefits include rapid curing, low process temperatures, the absence of pollution, and substantially lower energy costs, as well as high-quality and specialized products. Typical product lines involve coatings (on wood, metal, paper, and plastic), inks (for letterpress, lithographic, gravure, and screen printing), and adhesives (for film, foil, or paper substrates). The industries using these technologies are diverse and varied; they include electronics, fiber optics, flooring, packaging, plastics, and printing. While still minor manufacturing techniques, their industrial use is expected to expand greatly, with a continued annual growth of 15 to 20%.

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