FEATURE

Low-Emission Technologies: A Path to Greener Industry

By Ronald Golden

Solvent-free ultraviolet (UV) energy curing is a low-emission technology that has a proven record of success in many industrial ink, coating and adhesive applications. While the environmental benefits of this technology are well known, it is not so well recognized that the economics also can be very favorable. This paper will report on several case studies of successful industrial applications of these "green" technologies to quantify the achieved environmental and economic benefits.

Low to zero emission ultraviolet (UV) energy curing has been in commercial use for several decades. In addition to performance advantages, the environmental benefits of these technologies have driven their adoption and rate of growth substantially faster than conventional and even water-borne inks, coatings and adhesives.

Techno-economic models can be used to determine whether these technologies are an appropriate option for higher productivity and pollution prevention.

Finally, workplace safety aspects will be considered.

Introduction

Low to zero emission ultraviolet (UV) energy curing has been in commercial use for several decades. In addition to performance advantages, the environmental benefits of these technologies have driven their adoption and rate of growth substantially faster than conventional and even water-borne inks, coatings and adhesives. It should be noted that UV-curing coatings are true "pollution prevention" technologies. There are no emissions to control, destroy or recycle. In contrast, solvent incineration and recovery require additional equipment investment and operating costs, and these technologies generate either incremental greenhouse gases (see Coors Light Case Study, p. 16) on hazardous wastes.

However, while the environmental benefits of UV-curing coatings are well known, many discussions of these technologies have emphasized the investment required to convert existing lines, the higher cost of materials and perceived safety issues. These arguments in some cases have overshadowed the positive economics and improved performance, productivity and safety of these technologies. In the absence of a total economic analysis, it was difficult to quantify these environmental and economic benefits. During the past five years, case studies have been published that provide details concerning the reduced emissions and economics of UV-curing coating installations. Summaries of several of these studies, ranging from a large, world-scale can coating line to a small wood coating shop, are presented here with the objective of providing an overall perspective of the costs, benefits and economic returns to install and operate these green coating technologies.

This broader perspective, combined with existing and emerging economic modeling tools, provide a basis for a rational decision on whether "low to zero emission" technologies are appropriate for a specific application.

UV Curing

UV curing was introduced commercially about 30 years ago, and the advantages are well known:

- Low to zero volatile organic content (VOC) and hazardous air pollutants (HAP).
- Lower capital investment, operating and maintenance costs than conventional ovens (smaller footprint, easy to install or retrofit in existing space, no need to heat and move large volumes of air).
- Lower operating costs and maintenance.
- Increased productivity ("instant" curing, fast-line speed, reduced dust and dirt contamination of wet coating, immediate processing and handling of finished product).
- Special appearance and performance features (wide formulating latitude, high gloss, toughness, high cross-link density, (improved chemical/abrasion resistance).
- Lower energy costs.
- Unexposed liquid coating does not dry or cure in air (viscosity stability, clean-up is easier and requires less solvent, excess coating can be recycled for high-transfer efficiency).
- Reduced fire and explosion hazard.

Disadvantages and limitations of UV curing include:

- Typically higher costs for UV-coating materials.
- High viscosity can impose processing limitations.
- Coating thickness and pigments can limit cure speed or even prevent complete curing.
- Shadow areas and crevices may prevent curing of unexposed coating.
- Acrylate shrinkage may cause adhesion problems on rigid substrates.
- Acrylates can cause skin irritation if not handled properly.

This last point, the potential for skin irritation, deserves some comment. When UV curing first was introduced

TABLE 1

Comparison of solvent and UV-curing materials

Chemical	Flash Point	VOC	Hazardous Waste	Skin/Eye Irritant*	Systemic Toxicity*	Mutagen*
VM&P naptha	<0°F	Yes	Yes	No	Yes	No
Toluene	40°F	Yes	Yes	Yes	Yes	Yes
Xylenes	100°F	Yes	Yes	Yes	Yes	Yes
4-Methyl-2-pentanone	63°F	Yes	Yes	Yes	Yes	No
1-Butanol	100°F	Yes	Yes	Yes	Yes	Yes
2-Butoxy ethanol	160°F	Yes	Yes	Yes	Yes	Yes
1-Methoxy-2-propanol	100°F	Yes	Yes	Yes	Yes	No
2-Butoxyethyl acetate	190°F	Yes	Yes	Yes	Yes	No
2-Ethoxyethyl acetate	117°F	Yes	Yes	Yes	Yes	No
1,1,1-Trichloroethane	None	Yes	Yes	Yes	Yes	Yes
HDODA**	270°F	No	No	Yes	No	No
TMPTA**	>212°F	No	No	Yes	No	Yes
TRPGDA**	>212°F	No	No	Yes	Some evidence	No
PETA**	>200°F	No	No	Yes	No	Yes
3,4-Epoxycyclohexyl methyl 3,4-epoxycyclo hexane carboxylate	245°F	No	No	Yes	No	Yes
Acrylate Oligomers	>>212°F	No	No	Yes	No	No

*) Canadian Centre (1997); Lewis, Sr. (1992); Union Carbide (1993)
**) HDODA = hexanediol diacrylate; TMPTA = trimethylolpropane triacrylate; TRPGDA = tripropylene glycol diacrylate; PETA = pentaerythritol triacrylate

as a commercial technology, a few of the newly developed acrylates were quite irritating, and some of the basic acrylic monomers used were relatively toxic. Workers who were accustomed to frequent direct skin contact with solvents and solvent formulations continued to treat the new UV-curing materials in the same way. While the toxic effects of solvent exposure may not be immediately apparent, the skin rash, which can quickly result from improper handling of acrylates, led to a poor reputation for workplace safety. Most of the more irritating acrylates no longer are used in UV curing, and newer, less irritating materials have been developed. The fact that solvents can be abused without immediate apparent effect is not a benefit; just the opposite. In fact, a rational comparison with solvents (Table 1) shows that, in general, currently available UV-curing materials are actually less hazardous.

Good industrial hygiene practices, knowledge of safe handling procedures and worker training are essential for safe handling of any chemical. When these principles are followed, experience has shown that UV/EB-curing technology can be handled safely in industrial applications.

A guide to safe handling of UV-curing materials is available on the RadTech International North America Web site *www.radtech.org*.

TABLE 2

Total industrial installation and utility source emissions (metric tons/billion cans)

	Process		
Emissions	**Water-borne Thermal, Uncontrolled**	**Water-borne Thermal + Incineration**	**UV Curing**
Nitrogen Oxides	8.1	11.6	6.5
Sulfur Oxides	18	23	18
Particulates	25	29	24
VOC	28	0.56	0.52
HAP	11.5	0.23	0.12
Non-Methane HC	0.048	0.096	0.02
CO	0.52	1.11	0.15
CO2	2,909	5,182	1,727
Ozone	Not Measured	Not Measured	0.0019*

*) At the UV oven exhaust

TABLE 3

Total industrial installation and utility energy usage (million BTU/billion cans)

	Process		
Emissions	**Water-borne Thermal, Uncontrolled**	**Water-borne Thermal + Incineration**	**UV Curing**
Electricity	16,300	19,500	15,900
Natural Gas	23,900	60,100	0
Total	40,200	79,600	15,900

UV-Curing Case Studies

The following case studies provide data on the costs and achieved economic benefits of UV-curing installations over a range of industrial applications. Note that the data will typically show mid-1990s costs for capital, materials and energy.

Coors Brewing Company, Golden, Colorado (Brady et al., 1997)

This is a true total media study. It includes not only an analysis of the emissions and costs of the industrial installation, but also provides data for the emissions from the electric utility and the pollution control solvent incineration unit. It should be noted that the original technology that was replaced was water-borne coatings, and that even these contain substantial quantities of VOC that had to be incinerated to achieve the same emission level as the uncontrolled UV-curing process.

Application: Exterior Aluminum Can Decoration and Coating, One Billion Cans/Year Production Line.

Original Process: Thermal curing, water-based ink, varnish and bottom coating.

New Process: UV curing ink, varnish and bottom coating.

Benefits Achieved: Table 2 shows that although incineration controls with water-borne inks and coatings can achieve the same level of VOC and HAP

TABLE 4

Economic summary ($/billion cans)

	Process		
	Water-borne Thermal, Uncontrolled	Water-borne Thermal + Incineration	UV Curing
Capital*	803,000	1,280,000	428,000
Electricity	171,800	207,000	170,000
Natural Gas	170,600	428,000	0
Raw Materials	1,010,000	1,010,000	1,180,000
Operation/ Maintenance	41,800	192,000	21,200
Total Costs	2,197,200	3,117,000	1,799,200
*) 10 year amortization			

emissions as UV curing, this must be at the expense of increased emissions of hydrocarbons (HC) and carbon, nitrogen and sulfur oxides. Note that ozone emissions are negligible, even directly at the UV oven exhaust.

Similarly, Table 3 shows the substantial additional energy cost for the controlled water-borne system to achieve the same low level of emissions as the UV installation.

Table 4 shows a comparison of the total economics of the three process options.

The following case studies are not so detailed, but equally demonstrate the environmental and economic benefits of UV curing in large and small installations.

Hussey Seating Company, North Berwick, Maine (Northeast States, 1997)

Application: Wood Finishing, Stadium Seating.
Original Process: Brush-applied two-coat solvent polyurethane varnish, slow air drying, 1993 emissions were 45 metric tons/year of VOC (9 metric tons/year HAP).
New Process: Automated UV-cured roll coat sealer, followed by UV-cured vacuum coated topcoat, instant dry and stacking, coating cost 8% higher than conventional material, coating transfer efficiency increased to nearly 100%, 23% less coating used/unit.
Capital And Training Costs: $320,000.
Benefits Achieved (Table 5):

- Production increased 55% from 9,000 to 14,000 units/week without adding extra space.
- VOC and HAP emissions reduced 98% and 90%, respectively to 100 kg/year.
- Substantially reduced clean-up and waste.
- 17% lower coating cost/unit.
- Improved coating durability.
- 67% reduction in labor requirements.

TABLE 5

Economic summary

Factor	Savings/(Cost)
Capital And Training	$320,000
Labor	$280,000/year
Materials	$55,000/year
Expansion cost avoidance	$200,000
Payback period	4.5 months

Kidde-Fenwal, Inc., Ashland, Massachusetts (Commonwealth of Massachusetts, 1996)

Application: Printed Circuit Boards.
Original Process: High-pressure spray, 479 liters of low solids epoxy solvent conformal coating/10,000 boards, 24-hour post cure, 1995 emissions were 13 metric tons/year of VOC (60% toluene), air permit required, regulatory limitations on formulation VOC.
New Process: Low-pressure spray, 15 liters of UV-curing polyurethane/ 10,000 boards, instant cure.
Benefits achieved: estimated greater than $300,000/year:

- VOC emissions reduced by 75%.
- Eliminated 1,530 liters/year of clean-up solvent.
- Eliminated 20 drums/year of flammable waste.
- Eliminated storage of 1,800 kg of flammables on site.
- Regulatory permit fees reduced from minimum $2,000/year to about $150/year.
- Coating material/unit reduced 96%.
- Process cycle time reduced by 24 hours, work in progress reduced by $50,000/year.
- Elimination of masking $75,000/year.
- Labor savings 14,000 worker hours/year.

E&J Industries, Woodridge, New York (EPRI 1999)

Application: Wood Moldings, Brush Blocks, Tool Handles

Original Process: Solvent lacquers applied by spray and gasket dipping, thermal dry, processing time 10 to 20 minutes.

New Process: Vacuum coating, UV cure, line speed 18 m/min.

Capital Costs: $35,000 (used vacuum coater and UV equipment).

Benefits achieved:

- VOC emissions reduced by 99%, greatly reduced workplace exposure to solvents.
- Improved chemical, chip and abrasion resistance.
- More consistent film weight and coating appearance.
- Short coating open time—reduced airborne contamination.
- Reduced surface defects.
- Reduced rejects.
- Process cycle time reduced to less than one minute.
- Coating material costs reduced 61% from $0.04125/piece to $0.016/piece.

Techno-Economic Models

While UV curing can offer environmental and economic benefits, many factors must enter into selection of the optimal pollution prevention or control technology for a specific application. The basis for a decision can range from sophisticated performance and engineering studies to personal preference. Fortunately, some techno-economic modeling tools readily are available or are being developed to help make these critical decisions.

A *UV Powder Resource* CD-ROM (2000) is available through RadTech. It includes a spreadsheet *"UV Powder vs. Liquid Paint Cost Comparison."* It is similar to the conventional powder coating model published by The Powder Coating Institute, but in addition takes into account the special features of UV-curing powder coatings.

RadTech is also working to develop an economic analysis model comparing UV-curing and conventional liquid coatings.

Conclusion

Rapid economic growth and industrialization will continue for the foreseeable future, as a growing world population strives to maintain and improve quality of life. Unless there is a global commitment to reduce and eliminate emissions and wastes, such economic growth will be at the expense of the environment. Unfortunately, it has been a common perception that investment in environmental protection must always result in a net increase in costs or sacrifice in coating performance. Recently published case studies demonstrate that installation of low-emission manufacturing processes can yield substantial environmental benefits and substantial positive economic returns.

There is no one best technology to achieve the lowest possible emissions and wastes in combination with the highest economic return. Each application must be considered on its own. Techno-economic models are just now becoming available that enable end-users to make rational decisions concerning optimal means to achieve environmental and economic objectives. Recognizing and promoting the positive economic benefits of "green" technologies will be essential to achieving greater acceptance and enthusiasm for their adoption. ◗

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