UV-Curable Hardcoats Enter Solar Energy Market

By Gary Jorgensen, Mike DiGrazia, Kristy Wagner and Patrick Peach

After decades of proven performance in the automotive industry, UV-curable hard coats are finding their niche in the solar energy market.

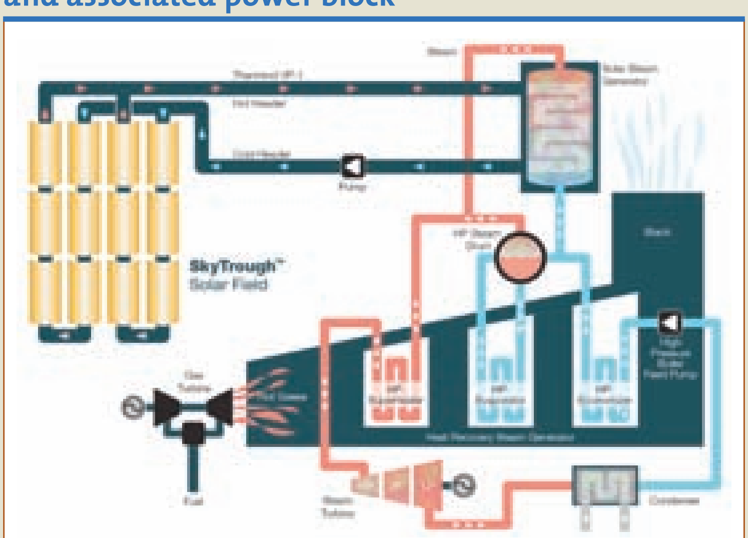
As competition in the solar energy market intensifies, solar energy device manufacturers are seeking out and evaluating new, innovative materials to enhance the performance and overall value proposition of their products. Correspondingly, energy-curable product formulators and raw materials suppliers are being challenged to develop coatings, adhesives and other products that can satisfy the demanding requirements of the solar energy industry.

When people think of solar energy, they typically picture photovoltaics and the framed, glass-fronted modules mounted on rooftops across the country. However, there is another solar technology—concentrated solar thermal (CST)—that is ideally suited for utility-scale power generation and which operates best in arid, undeveloped terrain. Most CST systems utilize mirrors to concentrate the sun's energy and create steam-generated electricity (see Figure 1).

Of the four types of CST technology—parabolic trough, power tower, dish Stirling and linear Fresnel—only parabolic trough systems (see Figures 2 and 3) have the advantage of 20 years of operational experience as a result of utility installations in California during the 1980s. Even so, the end of federal support for renewable energy in the '80s meant that relatively little technological advancement was made in parabolic trough technology until recently.

Figure 1

Schematic of a SkyFuel parabolic trough solar field and associated power block



A Recent Breakthrough in CST Reflector Technology

To date, all of the world's utility-scale parabolic trough systems use glass mirrors because of their high reflectance and 20-year track record. However, glass mirrors are expensive, heavy and routinely fracture and break during high winds. The impact of broken mirrors can create a domino effect; that is, falling shards of broken mirror panels can damage other components such as the glass envelopes of receivers and/or other mirrors. Recently, advances in silvered polymer film technology have enabled the production of outdoor-durable, lead-free mirrors whose performance is equal to or better than glass, while eliminating breakage and greatly reducing system weight and cost.

Mirror films provide several key advantages over glass mirrors; however, there is a market perception that the mirror surface should be more abrasion-resistant than the polymers typically used. Therefore, mirror film manufacturers have been faced with the challenge of incorporating an abrasion-resistant coating or similar treatment into their product.

Through a Cooperative Research and Development Agreement (CRADA) with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in Golden Colo., one such abrasion-resistant, outdoor-weatherable polymer film has been developed. Seven coatings manufacturers submitted a total of 13 different hard-coat formulations to NREL for evaluation of abrasion resistance and compatibility with the mirror film. The candidates were applied to samples of mirror film and then subjected to accelerated UV exposure, condensation cycling and thermal cycling to evaluate the impact of various environmental conditions on the adhesion and abrasion-resistance properties of the coatings. The environmental test conditions are noted in Table 1.

After environmental cycling, the abrasion resistance was evaluated by comparing the mirror film's reflectance after Taber abrasion (post-environmental cycling) to that of both the original uncoated film and the coated, unabraded film (pre-environmental cycling). Adhesion was evaluated with a diamond scribe (6x6, 2mm spacing). Taber abrasion results are summarized in Table 2.

Figure 2

SkyTrough® parabolic trough solar concentrator

Figure 3

Artist's rendition of a solar field and power block

Table 1

Environmental test conditions

Test	Conditions	Apparatus
Accelerated UV Exposure	2x UV light; 60˚C/60% RH	Atlas Ci5000 Xenon Weather-O-Meter
Condensation Cycling	4 hours UV-A fluorescent @ 60˚C/4 hours dark @ 30˚C with condensation	QUV Chamber
Thermal Cycling	8 hours @ 50°C/16 hours @ -5°C	Thermal Cabinet

TABLE 2

Specular reflectance loss after 30 taber cycles (250g) as a function of weathering type

Vendor Formulation	Coating Type	Change in Specular Reflectance [$\Delta\rho\sigma(\theta=12.5$ mrad)] after 30 Taber Cycles as a Function of Type of Weathering			
		Pre-Cycling	Ci5000 (925 MJ/m² UV)	Condensation Cycles (215 cycles)	Thermal Cycles (30 cycles)
B-1	TiO_2	43.9			
C-1	UV-Cured Acrylate	1.1	2.6	7.2	2.5
C-2	UV-Cured Acrylate	0.2	2.9	10.3	2.5
C-3	UV-Cured Acrylate	1.5	3.2	4.7	1.7
C-4	UV-Cured Acrylate	1.6	3.1	1.4	1.6
D-1	UV-Cured Acrylate	0.8	0.2[b]	2.8	1.8
D-2	UV-Cured Acrylate	3.1	4.1[b]	7.5	3.8
E-1	UV-Cured Thermoset Acrylate	7.2	17.3[b]	9.1	4.6
F-1	PECVD SiO_xN_y	13.0[a]			
G-1	Polyurethane	18.5			
G-2	UV-Cured Acrylate	0.0	b		
H-1	Polyaspartic				28.3
H-2	Polyaspartic		c		

a After 10 Taber cycles   b Severe yellowing after UV exposure   c Coating unduly degrades unweathered reflectance

Table 2 shows that UV-curable technology outperforms the other coating technologies across-the-board in terms of post-abrasion reflectance retention prior to environmental cycling (see "Pre-Cycling" column). Further analysis of the data reveals that UV-cured acrylate "C-4" outperforms all other candidates in terms of the combination of UV resistance and post-abrasion reflectance after the various environmental tests, and was deemed the best candidate for further evaluation.

The impact of the hard coat upon the abrasion resistance of the mirror film is demonstrated in Figures 5 and 6. The reflectance of the film at two acceptance angles after varying amounts of intentional abrasion is plotted for uncoated mirror film in Figure 5, and for hard-coated mirror film in Figure 6. The negligible loss of reflectance after Taber abrasion shows the dramatic improvement in scratch resistance provided by the UV-cured acrylate formulation "C-4." In addition, the hard coat exhibits excellent UV resistance, environmental durability and adhesion to the substrate mirror film. Ongoing accelerated outdoor weathering has surpassed the equivalent of 12 years of UV exposure with no loss in reflectance or adhesion.

FIGURE 4

ReflecTech® mirror film

ReflecTech® mirror film can be shipped in rolls of various widths to be affixed to aluminum panels for installation into the parabolic trough structure.

Innovative Formulations Provide World Class Results

Hard coats for CST mirror films must demonstrate optimum UV, environmental and abrasion resistance, as well as a certain degree of flexibility. To achieve optimum long-term UV resistance, lower functionality acrylates are the preferred choice of oligomers; however, these low-functionality acrylates do not provide the abrasion resistance required for the mirror films. Conversely, higher functionality oligomers, used in combination with reactive diluents and innovative additive packages, are known to be keys to improving the abrasion resistance and environmental durability of UV-curable coatings.

The formulator's challenge was to develop an innovative coating that combined the characteristics of the oligomers (low functionality—"soft" with high UV-resistance; high functionality—"brittle" with high abrasion and environmental resistance). To achieve the optimum balance of desired properties (abrasion and UV resistance, environmental durability and coating flexibility) required a new formulation consisting of the most recent oligomer synthesis technologies and reactive diluents, along with an innovative UV absorber, photoinitiator and additive package. Through working closely with various raw material suppliers and conducting a stringent screening process, the proper combinations were identified to achieve the required properties for protecting the solar mirror film.

The Future of UV-Curables in the Solar Energy Market

In order for solar energy technologies to gain widespread use and reduce society's impact on the environment and reliance on dwindling resources, costs must be driven lower while product quality is maintained. The inherent advantages of energy-curable products over many other technologies (in terms of processing speed, overall cost and environmental friendliness) can and will be an important driver for reducing solar device costs. As radcure raw material suppliers and formulators continue to work together to develop innovative products with improved performance and new functionalities, and solar device manufacturers become more aware of the benefits of radcure, the energy-curable materials industry will continue to offer increasing advantages to the solar energy market.

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Figure 5

The reflectance of uncoated mirror film after various numbers of abrasion cycles

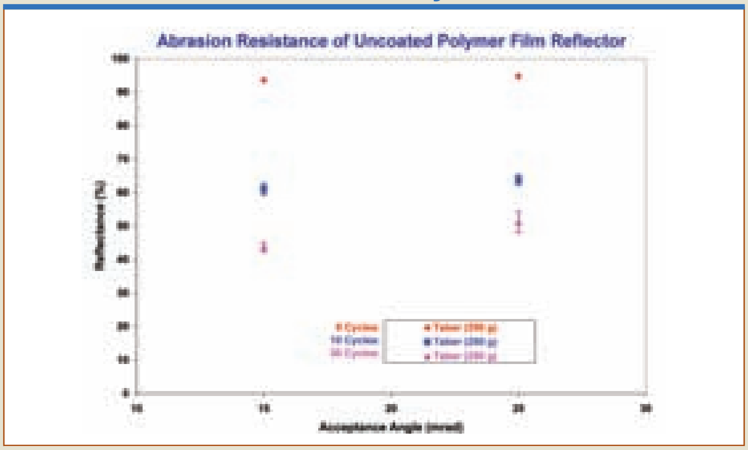

Figure 6

The reflectance of hard-coated mirror film after various numbers of abrasion cycles