Searching for the right specification

The Ultimate Trough collector is the latest and largest model by Flabeg.
Graphic: Flabeg

How much light of each wavelength a mirror can reflect, and in which direction, is information that has been hard to find on manufacturers' technical specifications up to now. SolarPACES Task III is working on a uniform measuring procedure.

The key issue with any CSP mirror is: how much of the sunlight it catches can it direct to the place where it can be used, the receiver? That depends in large part on the surface of the mirror. The variable which describes this characteristic of the mirror surface is called the solar weighted specular reflectance. It is "solar weighted" because some materials reflect different wavelengths of sunlight better than others. It is "specular" because it is an expression of the directed reflection. If the surface of the mirror is ever so slightly rough it can cause some of the reflected rays of the sun to miss the receiver by a hair's breadth. But up to now, there has been no standardised measuring procedure for this important mirror parameter, much less a commercial measuring instrument. Scientists from the American National Renewable Energy Laboratory (NREL), Spain's Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) and Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany, are working within the framework of SolarPACES Task III under the auspices of the DLR to develop a uniform procedure. Up to now, however, the scientists have not been able to agree on which variables should be measured or calculated in order to characterize a mirror with adequate accuracy, or which procedure is suitable for doing so.

Part measurement, part approximation

The DLR has described a method for quantifying a uniform expression of solar weighted specular reflectance. There are three steps. First, the solar weighted reflectance is measured in the laboratory with a spectrometer. The device measures hemispherical reflectance, however. This measurement tells you how well light with various wavelengths reflects, but does not say much about what direction it is being reflected in. The directed reflection of the mirror is therefore measured in a second step with an off-the-shelf portable measuring device and a flap which sets the angle of acceptance, 25 mrad for instance. This device has a drawback, however. It only measures at a single wavelength, 660 nm for instance. So in order to determine how much directed sunlight a mirror reflects, the scientists have to combine the two values. "To do that, we assume that the scattering losses are consistent at every wavelength. That is not entirely accurate, but it does provide fairly good results," explains Stephanie Meyen, who is working on the project at the DLR. After all, the individual wavelengths are weighted according to the solar spectrum. At the end of the process, you get a single value which describes the optical quality of the mirror surface.

Comparable conditions

In the past, even leading research institutions performed measurements under different conditions. That was confirmed by a round-robin test carried out by the NREL, the CIEMAT, and the DLR. In the round-robin test each of the three laboratories got a sample of the same mirror and performed measurements on it. Afterwards, the sample was sent to the next laboratory. Each individual sample is thus tested three times. Because there are three samples of each mirror type, the test yields nine measurements for every mirror.

In the first test, the measurements of the three laboratories were significantly divergent. The standard deviation in specular reflectance was 0.4 %, and in hemispherical reflectance it was a full 0.7 %. The variation was in part due to the fact that the institutes used completely different reference mirrors to calibrate their instruments. The institutes quickly came to an agreement on this aspect of the test. “Today we measure reflection in a comparable way and display the results in a uniform fashion,” says Meyen. Now, however, the more controversial issue has to be dealt with: which measuring procedure and which values best describe a mirror.

Does the value reveal what the scientists want to find out?

Scientists from the American NREL and Italy’s ENEA criticize the procedure presented by the DLR which centres on the solar weighted specular reflectance. Manufacturers of mirror based on film materials, such as SkyFuel and 3M also feel that they are being treated unfairly.

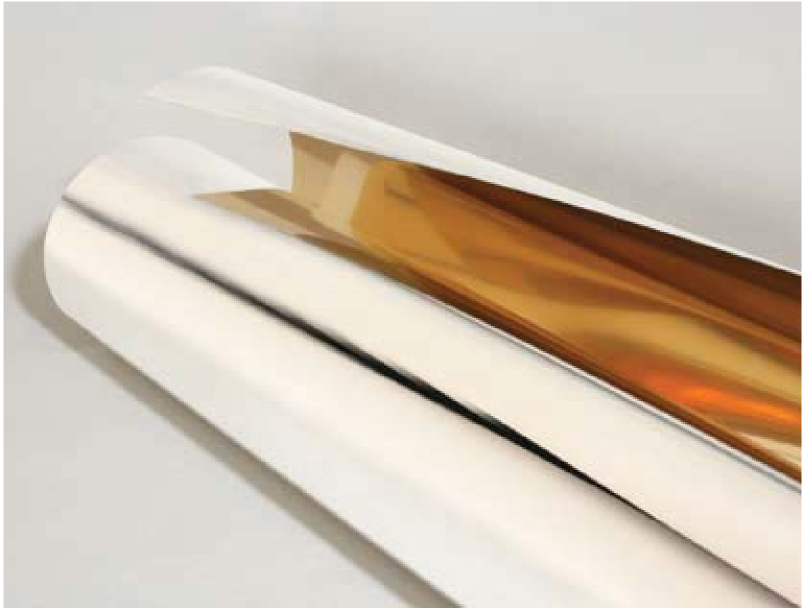
There are three main points of contention. First is the question of whether it makes sense to evaluate a mirror surface at all in isolation from the complete system. After all, a good mirror surface is not the only thing that is needed if a ray of light is to strike the receiver. The mirror also has to be bent precisely into the shape of a parabola, the receiver tube placed exactly along the focal line, and the tracking system has to operate with a high degree of precision. Added to that, in the case of glass mirrors, the parabola always has to be made from several precisely aligned elements. This issue is a particularly important one for mirrors made of film materials because they perform much worse in terms of specularity than glass mirrors. But SkyFuel and 3M counter that their mirrors have other benefits which more than outweigh their less than optimal specularity. Randy Gee, Chief Technical Officer of Skyfuel, points out: “The SkyTrough uses slide-in-place ReflecTech mirror panels that have better contour accuracy, i.e. lower slope errors, than silvered glass mirrors. These mirrors are made from continuous panels that span from rim to rim, thus avoiding the intermediate free edges and panel-by-panel alignment issues characteristic of collector designs that use multiple glass mirrors attached to an underlying support structure.” Suat Akyol, an engineer at 3M, confirms the higher precision. The company has checked the performance of its mirrors in a test loop at a CSP power plant in California and is satisfied. “Our mirrors are also stiffer than glass mirrors. Even in high winds they retain their exact shape,” adds Akyol. He goes into greater depth on the considerations involving the whole system, calling solar weighting itself into question. “At the moment, the tests are weighted to the solar spectrum, but the heavily weighted near infrared range within the solar spectrum is very poorly absorbed by the selective coatings used on receiver tubes. If you want to evaluate the system, you have to take that into account as well.”

Acceptance is a question of definition

The second point of contention is the angle of acceptance for measuring reflection. The DLR measurements are based on an angle of 25 mrad. Rays reflected outside of that angle are considered lost. In reality, however, there is no hard-and-fast angle of acceptance. The angle varies depending on the thickness of the receiver tube and the distance of the mirror from the receiver. Even whether a ray strikes the edge or the centre of the parabolic mirror changes the angle

Solar Mirror Film 1100 produced by 3M. The silver layer can be seen through the PMMA layer that covers the front. Also the copper layer on the back, which is covered by a transparent adhesive layer, can be seen.

Photo: 3M

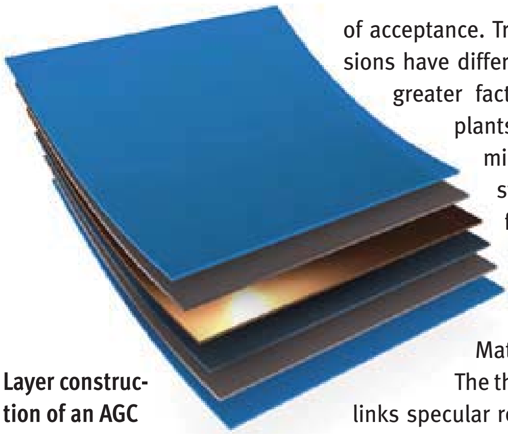


Film premieres at 3M

Solar Mirror Film 1100 was used recently in a full-scale parabolic trough power plant. The test loop is 192 m long; the troughs have an aperture of 7.3 m and consist of two segments. The film is applied to a sheet made of two bonded aluminium plates, which adds stiffness to the elements. Solar Mirror Film 1100 has been in use since the summer of 2010 in an Abengoa process heat system also located in the USA. That system is much smaller, however.

By the end of this year, 3M plans to launch an improved version of its film: Solar Mirror Film 1100+. The new film will be equipped with a hard coat on the front side to make it more resistant to scratching. 3M also wants to improve the bond between the layers. Furthermore, 3M is working on a multi-layer optical film for solar applications. Such films are already used in mobile telephone displays. They are made up of hundreds of layers of plastic with different refraction indexes, and they reflect light better than aluminium – only in the visible spectrum, however. To adapt these films to solar applications, 3M wants to add a layer of silver.

SkyFuel has developed a new coating as well. SkyFuel and ReflecTech announced the commercial availability of ReflecTechPLUS, a high reflectance silvered polymer with an abrasion resistant coating. According to SkyFuel, in November the new film surpassed the 30-year-mark in an ongoing test of durability against ultraviolet radiation using the Ultra-Accelerated Weathering Station (UAWS) at the National Renewable Energy Laboratory (NREL).



Layer construction of an AGC glass mirror

Graphic: AGC Solar

of acceptance. Trough mirrors with different dimensions have different values, but distance is a much greater factor in heliostats for tower power plants. A ray reflected by 25 mrad would miss the receiver by far. “We are strongly encouraging specular reflectance measurement at 7 mrad, which is commercially available and smaller when such measurement systems become available,” says Matthew Gray of NREL.

The third criticism is with the way the DLR links specular reflectance to solar weighted reflectance. “The assumption that the hemispherical reflectance spectrum maps directly to the specular spectrum is not valid for all materials,” says Gray.

Ray tracing as an alternative

Marco Montecchi of the ENEA suggests a ray tracing procedure as a way of dealing with the issues associated with the DLR method. Every ray striking the mirror is simulated to determine whereto it is reflected. Given accurate initial data, the ray tracing procedure provides very precise results. Montecchi’s method aims to determine this initial data. “Unfortunately diffusion depends on wavelength and incidence angle, so the direct experimental characterization is too complex and time-consuming to be adopted,” Montecchi says. He has proposed a new method for overcoming that problem. “I invited everybody to participate and received many samples,” he says. Montecchi measures the spectral hemispherical re-

Overview of mirrors for CSP plants

Company name	Website	Product	Description	Maximum width [m]
Glass mirrors for parabolic troughs				
Flabeg	www.flabeg.com	RP 2	based on LS-2 technology	5
		RP 3	based on LS-3, Eurotrough, Senertrough and similar designs	5.77
		RP 4	based on the HelioTrough design	6.77
		RP 5	based on Ultimate Trough(R)technology	7.51
Flat glass mirrors (for towers, dishes, Fresnel technology)				
AGC Solar (Asahi Glass)	www.agc-solar.com	Sun Mirox Flat	composed of low-iron glass, silver, copper and 3 layers of paint; thicknesses from 2 mm to 4 mm, typically used for tower and Fresnel plants	
		Sun Mirox Thin	thin solar mirror composed of low-iron glass, silver, copper and 2 layers of paint, 0.95 mm thick; highly deformable: can be laminated on collector structures of almost any shape. Typically used for trough and dish systems and for CPV.	
Flabeg	www.flabeg.com	0.95 mm	flat thin glass mirror, ultra-low lead or lead-free paint formulation	
		1.6 mm		
		2.0 mm		
		3.2 mm and 4 mm		
Mirrors from alternative materials				
Alanod-Solar GmbH & Co. KG	www.alanod-solar.com	Miro-Sun PV weatherproof reflective 90	based on an anodized and PVD-coated aluminium, protected additionally by a nanocomposite layer	max width: 1,250 mm thickness: 0.3 - 0.8 mm; length: sheets up to 4,500 mm or on coils
Constellium Singen GmbH (formerly Alcan)	www.constellium.com	Solar Surface® 992	corrosion resistant aluminium mirrors	Thickness: 0.30 - 0.75 mm; width up to 1,250 mm for rolls and 500 to 1,250 mm for sheets; length of sheets 500 to 2,000 mm
SkyFuel	www.skyfuel.com	ReflecTech Mirror Film	silvered polymer film, laminated to aluminum sheets to make monolithic mirror panels, that can be combined with the aluminium SkyTrough support structure	rolls: 1.52 m wide by 122 m long; SkyTrough mirror panels are 1.52 m wide by 6.65 m long.
3M	www.3M.com/solar	3M™ Solar Mirror Film 1100	silver metallized weatherable acrylic film; pressure-sensitive adhesive allows application to recommended smooth substrates	width: 1.25 m; length: on rolls

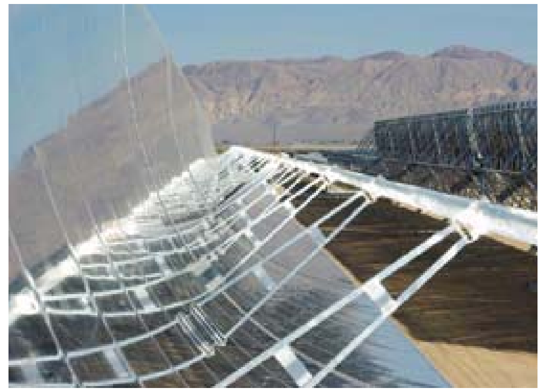
For the reflectance, manufacturers were asked to announce the solar weighted specular reflectance. As this data does not represent well the performance of film-based collectors, for those collectors additional reflection data are shown. For flat mirrors we did not ask for the maximum size as it is usually not a limiting factor.

Source: company data

flectance at near normal incidence. Additionally, he collects experimental data of the near-specular reflectance at near normal incidence on a set of apex-angles and at least two or, even better, three wavelengths. So far, he can rely on common instruments and set-ups. Software models the reflectance as a function of incidence angle and apex angle. It thus uses a model approach that was originally developed for architectural glazing. To determine the slope deviation of the mirrors, the research institutes have developed commercially available measuring procedures, ranging from NREL's VSHOT, to DLR's FRT and the VIS instrument developed at ENEA. "Here the open question is just the standardisation of the outputs in terms of measurement conditions, sampling density, accuracy, etc.," Montecchi says.

How many numbers does it take to describe a mirror?

If any single value, such as the specular solar weighted reflectance, can sum up the many characteristics of a mirror, this is only possible given a set of fixed conditions such as specific collector geometry, for instance. But what if the application is completely different? In that case, you need a set of measurement results that let any user calculate for himself how each mirror would perform in his system. NREL researcher Gray and others therefore advocate separating the measured values and make them more specific. The solar weighted hemispherical reflectance, for instance, should be listed separately, they say. In addition to the wavelength at which specularity is measured, the accompanying hemispherical reflectance should be specified. The standard deviations of the measured values should also not be left out. Combined values, such as the solar weighted specular reflectance, should be left out if they cannot be measured directly.



The SkyTrough is made from one single sheet in the transverse direction. That avoids alignment errors.

Photo: SkyFuel

One step at a time

Meyen of the DLR emphasises that the working group's process, presented at SolarPACES 2011, formed a basis for discussion. "The point was not to find the measure of all things, but to start by using existing instruments to achieve reproducible results at the different institutes and a uniform characterisation," she explains. The discussion is now in full swing. That the measurement results should ultimately provide a precise and realistic description of the mirrors is clear to everyone. After all, reductions in CSP power plant yields, even on the order of a tiny percentage, can lead to millions in losses.

Eva Augsten

	Reference projects	Specular, solar weighted reflectance [%]	Additional reflectivity information
	SEGS II-IV (USA), Nevada Solar 1 (USA), La Risca (ES), Palma del Río 1 (ES)	94.5	
	SEGS V-IX (USA), Andasol 1-2 (ES), Puertollano (ES), Extresol 1-3 (ES), ASTE 1-2 (ES), Valle 1-2 (ES), Manchasol 1-2 (ES), Termosolar 1-2 (ES), La Africana (ES), Genesis (USA), Kuraymat (Egypt), Shams 1 (UAE)	94.5	
	Flagsol test-loop KJC (USA)	94.5	
	Flabeg test-loop SEGS (scheduled for spring 2012)	94.5	
	Aora Solar plants in Israel and in Spain	94.8 *	
	Maricopa field in Arizona (US) - Dish type	95.5	
	several, not named	95.5	
		95	
		94	
		94	
	1.4 MW and 30 MW power plant with linear Fresnel collector technology Murcia, Spain	88	95 % total light reflection
	n/a	83	n/a
	SkyTrough Test Loop at SEGSII, USA	93	solar weighted hemispherical reflectance: 93 %; specular reflectance at 660 nm and 25 mrad acceptance angle: 94 % (2 mrad rms),
	test loop at existing CSP plant in California	93	solar weighted hemispherical reflectance at AM 1.5 = 94 %; specular reflactance at 660 nm and 25 mrad acceptance angle: 95.5 %

* depending on thickness