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T. J. Wendelin
G. Jorgensen
R. M. Goggin

National Renewable Energy Laboratory
(formerly the Solar Energy Research Institute)
1617 Cole Boulevard
Golden, Colorado 80401-3393
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OUTDOOR TESTING OF ADVANCED OPTICAL MATERIALS FOR SOLAR THERMAL ELECTRIC APPLICATIONS

Timothy J. Wendelin
Gary Jorgensen
Rita M. Goggin

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

ABSTRACT

The development of low-cost, durable advanced optical materials is an important element in making solar energy viable for electricity production. It is important to determine the expected lifetime of candidate reflector materials in real-world service conditions. The demonstration of the optical durability of such materials in outdoor environments is critical to the successful commercialization of solar thermal electric technologies. For many years optical performance data have been collected and analyzed by the National Renewable Energy Laboratory (NREL) for candidate reflector materials subjected to simulated outdoor exposure conditions. Much of this testing is accelerated in order to predict service durability. Some outdoor testing has occurred but not in a systematic manner. To date, simulated/accelerated testing has seen limited correlation with actual outdoor exposure testing. Such a correlation is desirable to provide confidence in lifetime predictions based upon accelerated weathering methods. To obtain outdoor exposure data for realistic environments and to establish a data base for correlating simulated/accelerated outdoor exposure data with actual outdoor exposure data, the development of an expanded outdoor testing program has recently been initiated by NREL. Several outdoor test sites will be selected based on the solar climate, potential for solar energy utilization by industry, and cost of installation. Test results are site dependent because exposure conditions vary with geographical location. The importance of this program to optical materials development is outlined, and the process used to determine and establish the outdoor test sites is described. Candidate material identification and selection is also discussed.

INTRODUCTION

Efforts are presently underway to spur commercialization of solar thermal concentrator systems for electric generation applications. A major collaborative venture has been initiated between the U.S. Department of Energy (DOE), state and local public utilities, and private industry to convert the 10 MW Solar One pilot plant to Solar Two, an advanced molten salt central receiver design. A common element in all commercial solar thermal technologies is the need for optical reflector materials that are low cost, light weight, durable, and efficient (1). Consequently, it is important to demonstrate to potential investors and manufacturers the optical durability of candidate reflector materials in outdoor environments representative of prospective sites for solar system installation.

This paper describes work done to date in developing a process to aid in the selection of appropriate sites for such an outdoor exposure network. The goal of this ongoing NREL solar electric research program is to establish and activate two to three outdoor exposure sites by October 1992 and expand the program to additional sites over the next several years.

Solar concentrators represent a significant fraction of installed system cost, and reflector materials are a large portion of the cost associated with concentrators. The cost of existing reflector materials is believed to be too high by industrial concerns interested in manufacturing and marketing solar thermal systems. As a result, recent emphasis has been placed by industry on the development of lower cost reflector materials. A major collaborative initiative has been started at NREL to develop advanced reflector materials having the potential for very low production cost. Because the optical durability of such new candidate materials is uncertain, the demonstration of their longevity during real-world exposure is critical to the reduction of perceived risks associated with this technology. In addition, such a demonstration utilizing a complete outdoor exposure testing network will provide useful data for developing correlations between past, present, and future accelerated weathering data and real-world, real-time outdoor exposure data. Such a program is considered to be an important element in solar, transportation and utility materials research and development (2),(3).

The network envisioned will provide a diverse set of environmental conditions for materials exposure. To determine the best locations, a set of criteria was generated to evaluate candidate sites. It was desired to involve the utility industry to generate interest and support for solar thermal technology and to identify sites deemed suitable for future solar thermal energy production. Thus, initial industry contacts have been primarily directed at utilities that have already shown interest in solar thermal technology as a possible renewable energy source. Initial exploratory contacts have been made with six members of the Solar Two Utility Consortium (4). Each has expressed an interest in assisting with this project. These members include the Los Angeles Department of Water and Power, Sacramento Municipal Utility District, Idaho Power, Utah Power, Southern California Edison, and Pacific Gas & Electric. The information obtained from these initial contacts and others yet to be contacted will be used to select two or three outdoor exposure test sites. A site selection process was developed based upon a set of specific considerations.

SITE EVALUATION PROCESS

A number of factors will be considered in evaluating candidate outdoor exposure sites. The cost associated with installation and operation of the site is of primary concern. Also of interest are factors such as the level of support exhibited by the solar thermal industry and prospective utilities; this includes the identification and recommendation by utilities of specific locations. Some variation in weather exposure conditions is desirable to correlate with samples subjected to accelerated testing in controlled environments. Geographic diversity is important to establish support for solar thermal electric technologies in general and outdoor testing in particular in different service territories.

The total installation and activation cost of a potential site depends on the availability of land (whether or not, for example, an interested utility is willing to provide property or even has an existing suitable exposure test site that they are willing to contribute), site preparation (development, environmental impact, electricity, phone lines, water, security, etc.), operation and maintenance (O&M) costs, the availability and cost of existing meteorological data, and the cost of meteorological instrumentation to augment existing capability. Interested utility companies might cost share any of the above categories thus reducing the overall installation/activation cost.

Of particular importance is the availability of critical meteorological/atmospheric data. To understand the time-dependent environmental effects on optical materials, real-time meteorological and atmospheric data are needed. Some of this information may already be available either on-site or through a local monitoring network. Table 1 lists the meteorological/atmospheric quantities of interest. A good discussion of the various environmental stress factors is provided by Fischer and others (3).

Very few if any existing meteorological/atmospheric networks have all the capabilities of interest. In addition, UV monitoring capabilities are very limited. Recent concerns with atmospheric ozone reduction have spurred an interest in more extensive UV monitoring (5), but stations are slow in coming on-line and locations are few and scattered. This is of particular concern since UV radiation is an important contributor in degrading reflective materials in general (6),(7). Thus, UV monitoring will be performed on site.

The installation of complete on-site meteorological data acquisition facilities would provide the greatest flexibility in monitored data reduction. Necessary hardware would include sensors for each quantity being measured, and a data logger/computer for storing data. Data would be routinely down-loaded to a central data reduction site via a modem communicating link. The system would be capable of collecting and storing up to a weeks worth of data from all channels at a high-resolution data acquisition interval of 5 minutes. The equipment should cost $25,000 to $30,000 for complete on-site data acquisition of all interested quantities. This includes all data acquisition hardware, but does not include the cost of installation of phone and/or power lines.

TABLE 1. LIST OF METEOROLOGICAL QUANTITIES TO BE MEASURED

Ultra-violet (UV) insolation (direct and global)
Total solar insolation (direct and global)
Temperature (ambient and sample)
Humidity
Precipitation (rain and snow)
Pollutants (Ozone, Sulfur, Chlorine and Nitrogen-containing compounds)
Wind (speed and direction)

With regard to land and O&M costs, it is expected that interested utilities will have property available or provide property for installing two exposure test racks. It is also expected that personnel will be available to periodically check the condition of samples and data acquisition instrumentation. Periodic cleaning or washing of samples might also be required. If such support cannot be obtained, then appropriate costs for land, labor, phone and electricity service will be figured into the selection process. There will also be costs associated with the collection and shipping of samples back and forth between NREL and the site.

The actual hardware cost of the test racks is relatively small (approximately $800 to $1000 each), but they will have to be installed with some minor site modifications. The racks are 12 feet long and 4 feet wide and are capable of mounting samples from 4 inches to 4 feet in size. The racks will be installed facing due south and the angle of inclination during exposure will be set to the latitude of the particular test site. The only significant cost associated with installation of a rack would be that two 24-inch-deep cement pillars must be poured to set the rack support posts. It may be possible to modify the racks for installation on a building structure if necessary.

Table 2 summarizes the selection criteria in the form of a matrix. Some data is filled in for three potential sites A, B and C while a certain amount of information remains to be collected. As can be seen, cost is the most significant parameter in the site selection process. Together with the intangible parameters listed, the complete set of data will be used to determine site locations.

TABLE 2. MATRIX SUMMARY OF THE OUTDOOR SELECTION SITE CRITERIA

Criteria	Site A	Site B	Site C
COST			
Land	Provided	Provided	Provided
Land preparation	Some	Some	Some
Meteorological Instrumentation			
Total Solar	Network	On-site	?
UV	No	No	No
Temperature	No	?	?
Humidity	No	?	?
Precipitation	Possibly	?	?
Pollutants	Network	No	No
Wind	Possibly	?	?
Amenities			
Water	?	?	?
Electricity	Yes	Yes	?
Phone	Yes	?	?
Operations & Maintenance	Yes	Yes	Yes
INTANGIBLES			
Utility support	High	High	Medium
Variation in weather	Suburban area	Mountain region	Desert climate
Geographic diversity	High	Good	High
Solar preferable region	High	High	High

MATERIAL SELECTION

A wide range of candidate reflector materials will be tested at the selected exposure sites. The various materials include glass/metal mirrors, metallized polymer reflectors, front surface reflectors, thin glass mirrors, and other advanced/innovative reflectors. Glass/metal samples will serve as benchmark standards to compare with the other candidates. State-of-the-art second surface silvered polymer reflectors will also be included.

NREL is collaborating with industrial partners to develop advanced reflector materials. These materials include front surface reflectors directly deposited on thin metal membrane substrate materials, an all-polymeric reflector concept, and an alternate second surface silvered-polymer reflector. A recent subcontracted survey of candidate alternative reflector materials (8) identified a silvered polyethylene terephthalate (PET, a thermoplastic co-polyester), with a protective hard coat deposited over the silver, as being attractive from both a technical and economic perspective.

Candidate reflector materials either suggested/provided by industry (both commercial and experimental products) or fabricated in-house at NREL will be subjected to accelerated weathering as a screening test (9). Innovative materials that exhibit promising optical durability during accelerated weathering tests will be subjected to outdoor exposure testing as well.

Table 3 lists the reflector materials intended for outdoor testing. Others may be added as new materials are developed through ongoing research efforts.

Three to five replicates of each candidate material will be exposed at each site. Sample size will be roughly 2 inches by 2 inches. Large samples may be included to investigate size dependent effects.

OPTICAL MEASUREMENT TEST PLAN

Candidate reflector materials will by optically characterized prior to initiating exposure testing. Subsequently, samples will be shipped back to NREL for remeasurement every 3 to 6 months and returned to the field for further exposure. Two reflectance measurements will be routinely used to monitor optical durability. Hemispherical reflectance will be measured over the solar spectrum (250-2500 nm) using a dual-beam spectrometer equipped with an integrating sphere attachment. The spectral data will then be used to calculate a solar-weighted hemispherical reflectance, which is indicative of the total amount of sunlight that is capable of being reflected.

Of particular interest is the specular reflectance of mirror materials. This quantity accounts for the fact that only the portion of a reflected beam that reaches the receiver aperture contributes to the collectable energy. A specular reflectometer will be used to measure absolute specular reflectance as a function of collection angle at selected bandwidths (10). Measurements will be made at 4, 8, and 12 mrad full cone angle to allow specular reflectance values to be tracked at collection angles representative of those used in solar thermal electric concentrator applications.

TABLE III. LIST OF REFLECTOMETER MATERIALS INTENDED FOR OUTDOOR TESTING

Reflector Material	Company	Reflective Layer	Reflector Type[1]	Substrate Material[2]
Silvered glass	TBD[3]	Ag	2	Metal
ECP-305	3M	Ag	2	Al, PAl, SS
Silverlux (SS95)	3M	Ag	2	TBD
Alumilux (SA85)	3M	Al	2	TBD
Directly deposited	SAIC	Ag	1	SS
All-polymeric	Dow Chemical	Polymer	Interference	TBD
Silvered Teflon	IST	Ag	2	TBD
Metallized PET	Cummins	Al	1	PET
V1020	3M	Al	2	TBD

[1]Reflector Type: 1=first surface; 2=second surface
[2]Substrate Material: Al=aluminum; Pal=painted aluminum; SS=stainless steel
[3]TBD: to be determined

REPORTING

An NREL report detailing the latest outdoor exposure test data and results will be published annually and made available to industry and utilities. In addition, a paper describing the ongoing testing will be presented annually at relevant conferences such as SOLTECH and/or the ASTM Accelerated and Outdoor Durability Testing Symposium. This will provide industry with ready access to the latest information on the progress of advanced optical materials for solar thermal electric applications.

SUMMARY

The outdoor testing program outlined herein will provide useful data for understanding the real-world mechanisms that affect the durability and performance of solar thermal optical materials. The demonstration of the optical durability of candidate reflective materials at sites of interest to prospective utilities and industry will spur investment and commercialization of the solar thermal electric technology. The site selection process described will lead to quick and thorough evaluation of potential sites and prove useful in establishing future outdoor exposure test locations.

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