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Measurement and assessment of parabolic trough mirror soiling in an operational CSP plant in southeastern United States.

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Abstract

Soiling of solar collector mirrors in concentrating solar power (CSP) applications is a major factor influencing component and system reliability, thermal efficiency degradation, and minimization of maintenance costs. Research is needed to identify mechanisms to minimize soiling or dust accumulation effects in different geographic and climatic regions as deposition on mirrors is location-specific and modulated by several factors, including soil parent material, microclimate, and frequency and intensity of dust events. With over 300 publications generated in the last five years alone, the effects of soiling and particle accumulation on solar power is a high interest topic. The UL Lafayette Solar Technology Applied Research and Testing (START) lab consists of a large aperture parabolic trough CSP facility in operation since 2013 where spectrometry measurements are taken regularly as part of plant operation and evaluation of the degree of soiling that the reflective surfaces have undergone. Based on operational outcomes, recommendations regarding cleaning procedure and frequency have been developed and are reported. Several models and generations of reflector composition have been evaluated, covering three generations of thin-film polymer chemistry and including several assembly methods. A low-cost gloss meter is used for spectrometry measurements for detecting reductions in specularity which are correlated to the actual plant energy production. This study analyzed solar collector soiling data for three different thin film types: 3M 1100, 3M 2020, and Konica Minolta film mirror. The data, along with parabolic trough cleaning costs and energy pricing considerations, was used to determine the optimal days between cleaning. Analysis of the results reveals that the 3M 2020 film has the fastest soiling degradation rate, and that the mirrors washing rate should be increased from its current standard to optimize cost savings.

Keywords: *Concentrating Solar Power, soiling, reflectivity, O&M,*

1. Introduction

There is a recent emphasis of the improvement of the cost-competitiveness of Concentrating Solar Power (CSP) technology as the Sunshot Initiative of the Department of Energy (DOE) has met its goal for cost-competitive photovoltaic (PV) energy production three years ahead of schedule. As a result of this achievement, the Initiative's new focus is on making CSP technology cost-competitive, with the 6₵/kWh by 2020 goal shown in Figure 1. Achieving this new goal requires research into how to improve the energy pricing of parabolic trough solar concentrators, which are the most mature CSP technology on the market today. Improving the amount of solar resource that the parabolic mirrors can harness, and subsequently lowering the price of energy production, requires a better understanding of how soiling affects the reflectivity of the mirrors over time.

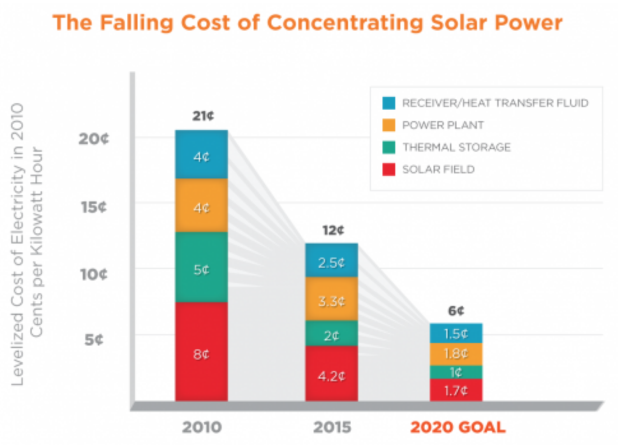

Figure 1: DOE's SunShot Initiative LCOE Goals (SunShot Initiative, 2017).

Parabolic trough systems are most effective when developed on a large scale in open areas with few buildings and ample sunlight. Such areas are often characterized by large amounts of sand and pollen that often accumulate on mirror surfaces as a result of wind and other weather concerns. This phenomenon is known as soiling, and it has the potential to drastically limit the reflectivity of mirrors, which results in less heat absorbed onto the system's heat transfer fluid and a lower overall system efficiency. While soiling in solar power production has been of high interest in the last 5 years, with over 300 being papers being published, research is needed to identify mechanisms to minimize costs due to soiling effects and optimize profit.

Mirror reflectivity analysis is driven by experimental data of the specular reflection of concentrating mirror surfaces. Specular reflection consists of the spectrum of light that is reflected at an angle equal and opposite to that of the incident light beam. The Byk-Gardner micro-TRI-gloss glossmeter, which is shown in Figure 2, is used to measure the reflectivity of the concentrating mirrors. The glossmeter offers a portable, accurate, and easy to use means of measuring reflectivity.

Figure 2. Byk-Gardner micro-TRI-gloss glossmeter

This glossmeter measures the reflectance at an angle of 20° to the mirror surface and is accurate within 2% for highly reflective surfaces (BYK-Gardner GmbH, 2017). It consists of a camera-shaped device and a standard that consists of a true black sample that the glossmeter can be operated against for calibration.

2. Experimental Method

Cleco Power LLC and UL Lafayette completed the installation and commissioning of a pilot solar thermal power plant, the first of its kind in Louisiana, in December 2012. The reflectiveness of the solar collectors at the UL Lafayette Solar Technology Applied Research and Testing (START) Lab, shown in Figure 3, has been monitored since 2013.

Figure 3. START Lab Concentrating Mirrors

The pilot plant has been installed at the UL Lafayette Energy Research Complex, which includes the Cleco Alternative Energy Center and the UL Lafayette START Lab. The pilot plant will provide Louisiana-specific performance and price information regarding the use of CSP technology in Louisiana.

In 2015 a study was conducted on mirror soiling at the START lab. For one year the mirrors were not washed allowing soiling effects to accumulate. Figure 4 shows the results of this reflectivity monitoring, expressed in gloss units (GU), for the year 2015. Although the SMF 2020 had degraded over 20% the mirrors still had higher GU reading that other thin-films tested. After washing the 2020 film was restored back to new specifications within error tolerance.

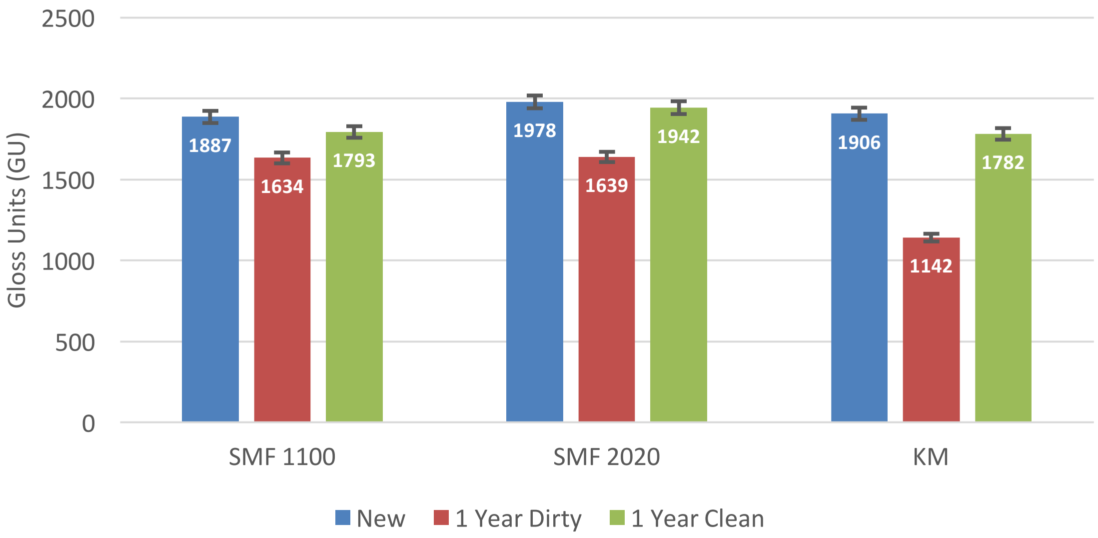

Figure 4. 2015 Mirror Film Reflectivity

The washing procedure currently employed at the plant involves using a pressure washer with deionized water and a microfiber cloth attached to a pole brush designed by 3M.. This brush consists of a long pole attached to a brush head that clamps the microfiber cloth down on a sponge that has running water flowing to it to reduce surface friction. Mirror cleaning consists of an initial spray of water with a pressure-washer, followed by wiping with the brush before the mirrors are sprayed again. Figure 5 shows the equipment and methodology of the mirror cleaning procedure.

Figure 5. Mirror Washing Procedure

Following the May 2017 mirror cleaning, the glossmeter was used to take weekly reflectivity measurement of the entire mirror field. The three types parabolic trough reflector thin film tested in this study are 3M 1100, 3M 2020, and Konica Minolta film mirror. Two measurements were taken per panel, so 480 measurements were taken each week. Each panel has one thin film reflector and the distributions of measurement per thin film type is shown in Figure 6.

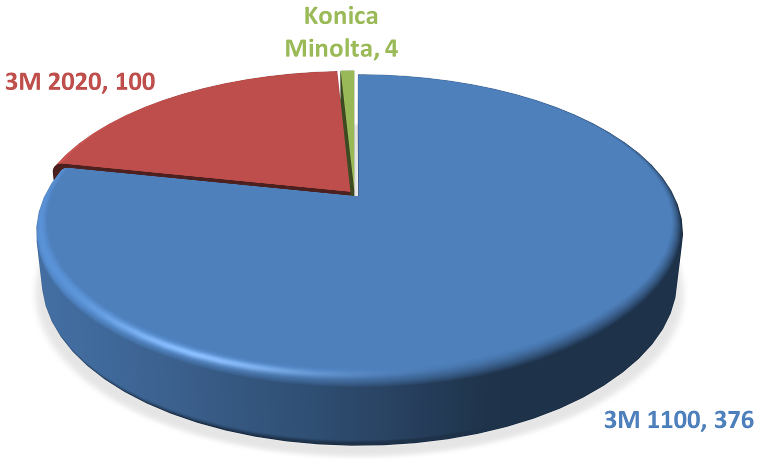

Figure 6. Reflectivity measurement distribution among three thin film types

As shown in Figure 6, the vast majority of panels at the START Lab are 3M 1100 at 376. Only four of the Konica Minolta mirror film are being used for this study. These measurements were transferred to Excel for analysis, with the output consisting of the measurement in gloss units (GU), panel location, and timestamp information.

3. Results and Analysis

The rate of soiling over the summer season of 2017 for the three different types of reflector thin-film used in the plant is shown in Figure 7.

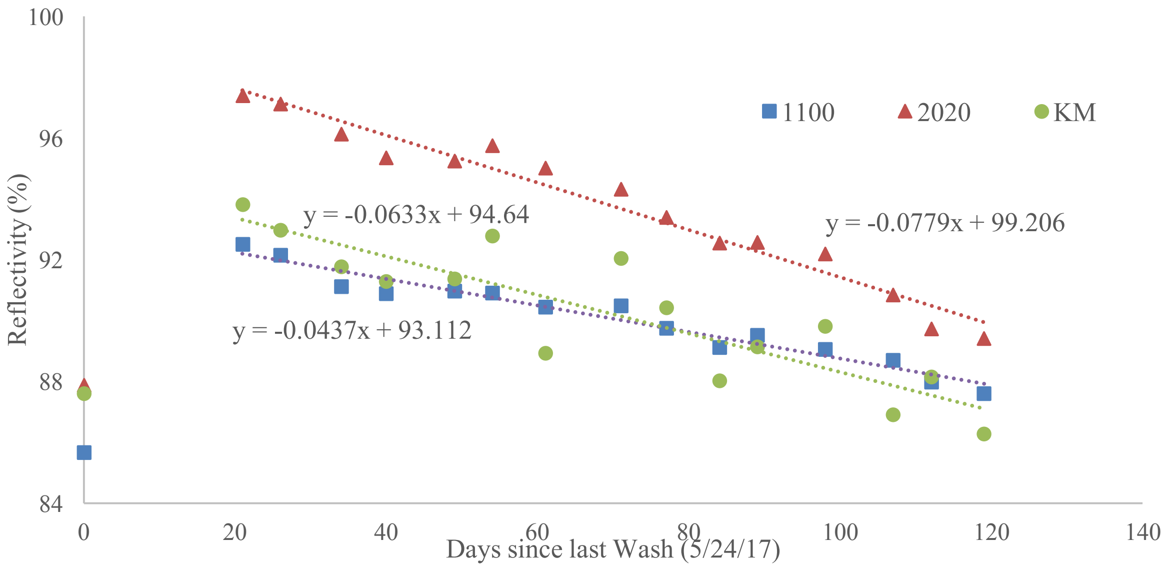

Figure 7. Soiling Degradation Rates for 3M 1100, 3M 2020, Konica Minolta Mirror Films

Analysis of the data shows that the rate of soiling is approximately linear for each of the three films. The soiling degradation rates of the 1100, 2020, and Konica Minolta films are shown in Table 2. This graph shows that while the 2020 film offers higher maximum reflectance values when clean, it also degrades at a rate superior than that of the other two films. The most recent measurement, taken approximately 4 months after the mirrors were washed, shows that the 2020 film is still the most reflective despite its high soiling rate. Based on this analysis, the 2020 is the film with the best reflectance properties for the START lab CSP plant in Crowley.

Table 2. Soiling Degradation Rates

Film Type	Soiling Degradation Rate (%/day)	4 Months Post-Wash (%)	Reflectivity after Wash (%)	Reflectivity when New (%)	Percent Change (%)
3M 1100	0.0437	87.6	92.5	94.4	2.0
3M 2020	0.0779	89.4	97.4	98.9	1.5
Konica Minolta	0.0633	86.3	93.8	95.3	1.6

The soiling rates shown in Figure 5 are one of several parameters that go into the equations derived by Sandia National Laboratories for determining the optimal cost-effective cleaning schedule for concentrating mirrors (Bergeron & Freese, 1981). This equation can be expressed by:

$$\boldsymbol{N_C} = \left(\frac{\boldsymbol{2W}}{\boldsymbol{A_0 I_0 D C}}\right)^{\frac{1}{2}} \qquad \text{(eq. 1)}$$

Where N_C is the ideal number of days between mirror cleanings, W is the cost of this cleaning per square meter of surface area, A_0 is the optical efficiency of the mirrors, I_0 is the average daily solar energy available per square meter of surface area at the location in question, D is the soiling rate of the mirror surface as a percentage of the restored reflectivity value, and C is the energy price, expressed in dollars per kilowatt-hour, at the specified location (Bergeron & Freese, 1981). The energy pricing information is based on the U.S. Energy

Information Administration's commercial pricing data for July 2017 (U.S. Energy Information Administration (EIA), 2017).

For the state of Louisiana, a N_C of 114 days was obtained. This calculated N_C would indicate that the mirrors should be washed every 114 days or about 3 times a year to optimize the system accounting electricity and maintenance costs. Louisiana has one of the lowest electricity cost in the country. Keeping all other values constant, states with higher electricity prices such as California and Hawaii would require 4-6 mirror to optimize cost.

4. Conclusions

The optimal cleaning schedule taking into account efficiency and cost is ever 114 days or roughly about three times a year. The current washing procedure restores reflectiveness to near original specification values with no long-term degradation shown. The 3M 2020 film was found to be the most effective for solar reflection. Although this data is location specific other plant operators can use this methodology to obtain the optimal cleaning time for their local climate and electricity costs.

5. Future Work

Research into the effect weather conditions could potentially has created a need for further experimentation into using light rainfall as a supplementary mirror cleaning. To gain a better understanding of the potential benefits of such a practice, there are plans to experiment to setting the parabolic trough hydraulic system to automatically turn to an angle of 90 degrees (mirrors facing skyward) when rainfall with low wind speed is detected. Achieving such a system requires accurate weather data, specifically rain rate and wind speed data, that is interpreted by the system Human Machine Interface (HMI) in order to automatically turn the mirrors. This will be accomplished through installation and integration of a Davis Instruments Vantage Pro2 weather station. The results of this experimentation will be considered alongside the results described previously to determine whether this automatic washing improves plant profitability.

This experiment also revealed the need for further development of the experiment and advanced analysis. Additional system efficiency data for the plant is necessary to relate efficiency to reflectivity and validate previous assumptions regarding this relation. Weekly interruptions of the apertures' hydraulic tracking system for reflectivity measurements revealed the need for a separate apparatus designed exclusively for soiling studies. A rendered image of said apparatus, which will be used in future experiments, is shown in Figure 6.

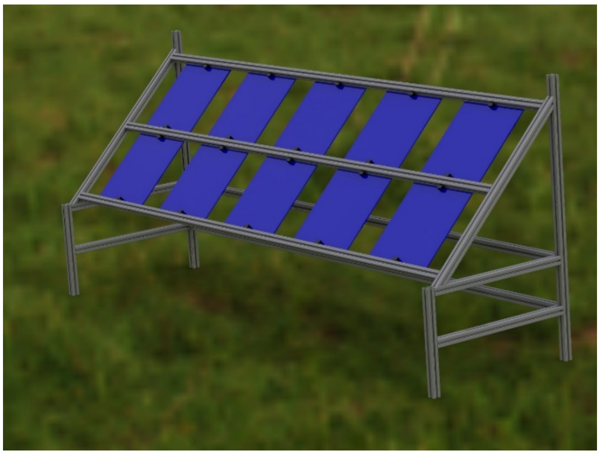

Figure 6. Rendered Image of Aluminum Soiling Study Test Rack

These additional experimental considerations, when combined with the work described in this abstract, will further define the standards of reflectivity maintenance for CSP plants.

6. References

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