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Levelized Cost of Coating (LCOC) for selective absorber materials

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Abstract

A new metric has been developed to evaluate and compare selective absorber coatings for concentrating solar power applications. Previous metrics have typically considered the performance of the selective coating (i.e., solar absorptance and thermal emittance), but cost and durability were not considered. This report describes the development of the Levelized Cost of Coating (LCOC), which is similar to the levelized cost of energy (LCOE) commonly used to evaluate alternative energy technologies. The LCOC is defined as the ratio of the annualized cost of the coating (and associated costs such as labor) to the average annual thermal energy produced by the receiver. The baseline LCOC using Pyromark 2500 paint was found to be \$0.055/MW h_t, and marginal costs were determined in a probabilistic analysis to range from −\$0.09/MW h_t to \$1.01/MW h_t, accounting for the cost of additional (or fewer) heliostats required to yield the same baseline average annual thermal energy produced by the receiver. A stepwise multiple rank regression analysis showed that the initial solar absorptance was the most significant parameter impacting the LCOC, followed by thermal emittance, reapplication interval, degradation rate, reapplication cost, and downtime during reapplication.

Keywords: Selective coatings; Pyromark; Concentrating solar; Receiver

1. Introduction

Concentrating solar power (CSP) is a renewable energy technology that converts solar thermal energy to electricity via a heat engine and generator. These systems are typically large—capable of generating tens to hundreds of megawatts of electricity. Over 1 GW of concentrating solar power plants have been installed in the United States as of 2014, with over 600 MW of additional CSP plants currently under construction.

Concentrating solar power systems use large arrays of mirrors to reflect and concentrate the sunlight onto receivers that heat a working fluid. Several mirror configurations are possible, including dishes, parabolic troughs, linear Fresnel, and heliostats. One of the most promising CSP technologies is the central receiver (or power tower) system, which consist of a field of large, nearly-flat mirror assemblies (heliostats) that track the sun and focus the sunlight onto a receiver on top of a tower (Pacheco, 2002; Radosevich, 1988) (Fig. 1). In a typical configuration, a heat-transfer fluid such as water/steam or molten salt is heated in the receiver and used to power a conventional steam-turbine Rankine cycle to generate electricity. Excess thermal energy collected in molten salts can be stored in large insulated tanks allowing operation of the steam turbine during the night or on cloudy days.

The efficiency of a power tower can be increased if the energy absorbed by the receiver is maximized while the heat loss from the receiver to the environment is minimized. As materials get hot, energy is radiated away in the infrared wavelengths. Thus, heat loss occurs because

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Fig. 1. Sandia's concentrating solar power tower at the National Solar Thermal Test Facility, Sandia National Laboratories, Albuquerque, NM.

of thermal radiation losses from the hot receiver surface to the environment as well as from convection due to wind and buoyancy effects.

Increased central receiver operating temperatures (>600 °C) are needed to increase power cycle efficiency, reduce material costs for thermal storage, and lower the overall cost of electricity from CSP. However, higher operating temperatures result in increased energy loss due to thermal radiation. Therefore, research is being conducted to identify selective absorber coatings that will maximize solar absorptance in the visible and near-infrared wavelengths (∼400–2500 nm) while minimizing thermal emittance in the infrared wavelengths (∼1–20 μm) (Ambrosini et al., 2011; Hall et al., 2012; Kennedy and Price, 2006). Because these spectra overlap, especially at higher temperatures, development of selective coatings is challenging. Additionally, these selective absorber coatings should be durable at high temperatures in exposed environments to avoid degradation.

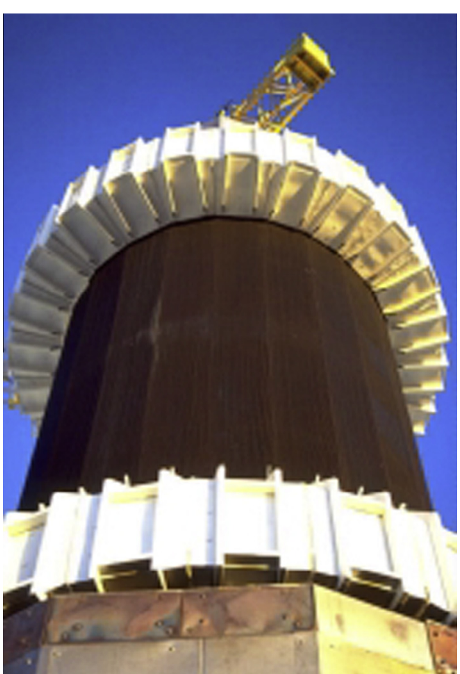

Fig. 2. Pyromark paint was used on the central receivers at Solar One (Radosevich et al., 1988) and Solar Two (Pacheco, 2002) (shown above).

Pyromark® Series 2500 high temperature paint has been used on previous CSP central receivers (Fig. 2) and is considered a standard (Pacheco, 2002; Radosevich, 1988; Ho et al., 2012). Pyromark 2500 is relatively inexpensive, easy to apply, and has a measured solar absorptance of 0.96 (new) (Ho et al., 2012). However, with a thermal emittance of 0.87 it suffers from large thermal losses during high temperature operation. It also showed significant degradation at higher temperatures (>700 °C) when operated in air, causing a decline in performance and potentially added operating costs for CSP facilities (Ho et al., 2012).

The objective of this report is to introduce a new metric, called the Levelized Cost of Coating (LCOC), that can be used to evaluate and compare alternative materials against Pyromark 2500. The LCOC accounts for both annualized cost and performance of the coating.

2. Approach

2.1. Selective absorber efficiency

A significant amount of effort and studies have focused on the development of high-temperature solar selective coatings with high solar absorptance and low thermal emittance (Ambrosini et al., 2011; Hall et al., 2012; Kennedy and Price, 2006; Ho et al., 2012; Cindrella, 2007). Typically, the metric used for selective absorber coatings is based on the net absorptance of energy relative to that of an ideal absorber. Cindrella (2007) and Ho et al. (2012) presented the following definition for the efficiency of selective absorbers, η_{sel}, which is equal to the ratio of the net radiative energy absorbed and retained by a surface to the net radiative energy absorbed and retained by an ideal selective absorber with an absorptance of one and an emittance of zero:

$$\eta_{sel} = \frac{\alpha_s Q - \varepsilon \sigma T^4}{Q} \quad (1)$$

where α_s is the solar absorptance, Q is the irradiance on the receiver (W/m^2), ε is the thermal emittance, σ is the Stefan–Boltzmann constant (5.67×10^{-8} W/m^2/K^4), and T is the surface temperature (K). In this study, we assume the irradiance, Q, is 600 kW/m^2 (600 suns), and T is 700 °C.[1] Currently deployed power tower systems typically operate at a lower irradiance (<500 suns) and temperature (<600 °C). This metric is useful for comparing the performance of different selective absorber coatings, but it does not account for other important factors such as cost and durability.

2.2. Definition of the LCOC

In this work, we introduce a new metric, similar to the levelized cost of electricity (LCOE), that accounts for

[1] With these values, Eq. (1) shows that the relative weighting (importance) of the solar absorptance is over 10 times greater than the weighting of the thermal emittance.