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Performance analysis of a spectrally selective concentrating direct absorption collector

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Abstract

Spectrally selective liquid filters are proposed as a means of efficiently utilizing majority of solar radiation incident on a given area. This paper reports on the outdoor testing done to verify the thermal performance of a spectrally selective liquid under concentrated light. The design consists of a Fresnel lens based concentrator that focuses radiation on to a glass absorber. Collector thermal performance was measured using Copper Sulfate solution as the heat collection fluid. Effect of various parameters on efficiency is also reported. It was found that parameters such as solution flow rate through the absorber and optical concentration as measured by the spot size have an insignificant impact on the thermal performance.

Keywords: Collector; Direct; Absorption; Spectral; Selective

1. Introduction

It is known that standard crystalline Photovoltaic (PV) materials utilize only a fraction of the solar spectrum resulting in 15–20% of conversion of incident solar radiation into electricity. Majority of the incident energy is lost as heat. In order to maximize the light conversion efficiency for a given area, two approaches are normally pursued. One is to use multi junction PV materials that can capture majority of the solar spectrum. The other option is to extract and use the heat energy that would otherwise be wasted. Multi junction PV cells have been shown to have about 40% cell level conversion efficiencies (King et al., 2007). PVT or hybrid systems normally use a liquid to remove heat from the PV cell, thus maintaining cell temperature, and using the heat elsewhere. Such systems are expected to have a total energy utilization efficiency of 60–80% (Zhang et al., 2012). A less common approach for maximizing the conversion efficiency involves splitting the spectrum, one part being used for electricity generation in a "spectrum – matched" PV cell while the other portion is converted to heat (Chendo et al., 1987; Imenes and Mills, 2004; Osborn et al., 1986 and Otanicar et al., 2011). One approach to spectrum splitting is using an optical element such as a thin film optical filter (Chendo et al., 1987).

Spectrum splitting can also be achieved by utilizing liquids that can absorb a select portion of solar spectrum before it reaches the PV cell and utilizing this heat energy for thermal applications. Such an approach helps decouple the heat generation temperature from the PV material

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Nomenclature

A	area (m^2)
c_p	specific heat (kJ/kg K)
I	solar direct normal irradiation (W/m^2)
Q	heat collected (W)
T	temperature (K)
U	heat loss coefficient (W/m^2 K)
$\dot{V}$	volumetric flow rate (m^3/s)
Greek	
α	absorptivity (dimensionless)
η	efficiency (dimensionless)
ρ	density (kg/m^3)
τ	transmissivity of the lens (dimensionless)
Subscripts	
a	aperture
in	inlet
out	outlet
useful	useful
vol	bulk volumetric
rcr	receiver
col	collector

temperature, thus removing a significant limitation of the conventional PVT approach. By spectrally matching the transmissivity of liquid filter to that of the PV material, it is possible to utilize majority of solar spectrum resulting in higher conversion efficiencies for a given area. Osborn et al. (1986), were among the first to characterize spectrally selective properties of specific liquids including solutions that contain salts of cobalt and copper. Hamdy and El-Hefnawi (1990) studies optical filters with silicon solar cells at low optical concentrations of 1–3 suns. The fluids studies included Cobalt Sulfate and commercial heat transfer fluids such as Valvoline. Nanoparticle based fluids also hold a promise for spectral matching as illustrated in recent studies (e.g. Otanicar et al., 2011; Taylor et al., 2012).

An example schematic for a liquid absorption filter is shown in Fig. 1, which shows a volumetric liquid absorber interposed between the optics and PV material in a concentrated solar system. An ideal liquid absorber will have selective absorption characteristics such that the wavelengths suitable for the PV material are transmitted and the rest are absorbed.

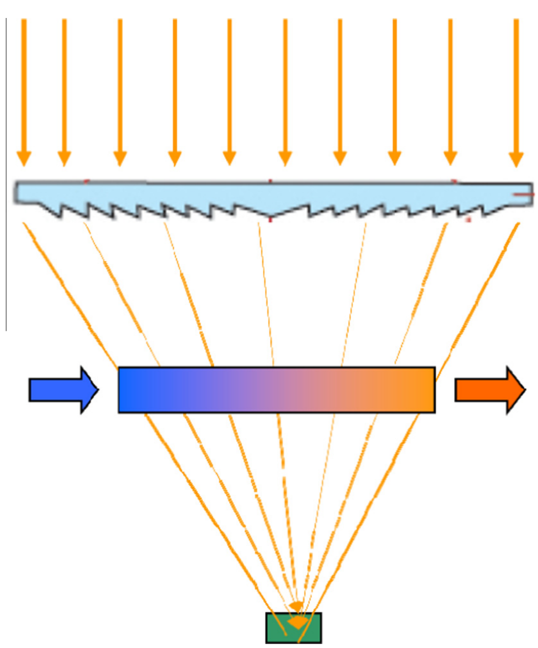

Fig. 1. Spectrally selective liquid absorber in a concentrating PV system.

Though the concept of spectrally selective liquid absorption filters was described a while back (Imenes and Mills, 2004; Otanicar et al., 2011), there is lack of test data using these liquids in a real life scale solar energy conversion device. In this paper, test results of a spectrally selective liquid collector with optical concentration have been presented. As the intention of the testing is to only measure the liquid absorber performance, PV material was not used during the tests to generate electricity through transmitted radiation. Instead, a radiometer was used to measure the transmitted radiation.

2. Experimental details

The testing arrangement consisted of two main components, a concentrated volumetric absorber based collector assembly mounted on a tracker and a collector thermal test facility to measure the thermal performance.

2.1. Test collector

A volumetric absorber test setup built and assembled at our research facility is shown in Fig. 2. The solar radiation is concentrated using a Fresnel lens on to a glass receiver.

Fig. 2. A picture of a partially assembled collector frame mounted on a tracker showing Fresnel lenses focusing light on a volumetric absorber.