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Study on the performance of cooling composite materials for liquid-immersed concentrating photovoltaic systems

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Abstract

According to the aging phenomenon that di-methyl silicon oil working as a cooling material for liquid-immersed concentrating photovoltaic system for long time. In this paper, the method that enhances the weather-resistance of silicon oil by adding additives was proposed. Hydroxy-4-methoxy-benzophenone (UV-9) and a hindered amine light stabilizer named GW-783 were selected as additive to prepare composite materials. The performance of these composites was studied by accelerated life test (ALT). The results showed that the composites can inhibit the aging effect on flow and optic characteristics and did not affect the performance of solar cell. The most efficient one is the composite prepared by adding UV-9 and GW-783 together into silicon oil.

Keywords: Composites; Liquid-immersed concentrating photovoltaic system; Concentrating photovoltaic standard; Accelerated life test

1. Introduction

Concentrator photovoltaic (CPV), as a new technique, is more noticeable for its higher photon-to-electron conversion efficiency and lower power generation cost compared with the conventional flat plate photovoltaic (PV). Only a small part of energy from sunlight can be converted into electrical energy by solar cells, and the excess energy transforms into heat which can cause the increase of the solar cell temperature and decrease of the solar cell efficiency (Radziemaska and Klugmann, 2002). In the latest report of solar cell efficiency from Green (2015), the efficiency of crystalline solar cell was still 27.6% while the multi-junction cell was 46.5%. That is to say, although concentration ration is increased, most part of the solar energy is still existed in cell in the form of heat which makes the temperature of solar cell raise up. In addition, the temperature of cells were increased and thus the efficient were diminished due to the aggregation of heat in the cell. On one hand, the performance of solar cell fell with the increase of temperature (Shaltout et al., 2000). On the other hand, the mechanical property of the cell was affected by the variation of the temperature, especially during the on–off state following the cycle of day and night (Luque et al., 1997). Based on the reasons mentioned above, the temperature of the cells should be reduced timely and effectively to keep a lower cells temperature in a running CPV system.

So far, there are two methods to cool down the cells. One is passive cooling, the other is active cooling. There

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Nomenclature

UV-9	hydroxy-4-methoxy-benzophenone
GW-783	a hindered amine light stabilizer which is mixed by GW-944 and GW-622 by 1:1 mass ratio
V_{oc}	open circuit voltage (V)
FF	fill factor
I_{sc}	short circuit current (A)
P_{max}	maximum output power (W)
R_s	series resistance (Ω)
J_{np}	calculated normalized photocurrent density

Abbreviations

CPV	concentrating photovoltaic
ALT	accelerated life test
PV	flat plate photovoltaic
HCPV	high-concentrations CPV system
GEL	Green Energy Lab
EQE	external quantum efficiency
UV	ultraviolet

was a large thermal resistance which is caused by a low thermal conductivity between the cell models and the glue layer of metal substrate in active cooling (Royne et al., 2005). To solve this problem, a cooling method by flowing insulated liquid has been proposed by Green Energy Lab (GEL) of Tianjin University. This method is called liquid immersed cooling, and its cooling effect can be accepted (Liu et al., 2011). The liquid immersing technology, in which the heat transfer liquid was packaged with bare cells, is a now packaging method. There are two influence factors should be considered in this method. One is the cooling material effect on cells. According to the results of Maiti (2010), Ugumori and Ikeya (1981) and Wang et al. (2009), when the cell was immersed in the liquid, the electrical properties of cell were enhanced for the absorption of non-spectral response band of cell by liquid and the decrease of carrier recombination at surface of cells by polarizable liquid molecules. The other factor is the applicability of cooling material. De-ionized water and di-methyl silicon oil were considered as suitable choice (Zhu et al., 2010). Although the temperature of cells can be decreased by de-ionized water, the stability of cells was reduced due to the galvanic corrosion of cell in the de-ionized water (Han et al., 2012). According to this conclusion, electrical decrease on solar cells immersed by de-ionized water can be restrained by silicone coating (Han et al., 2011). Victoria et al. (2013) studied the optical transmittances of several dielectric fluids under the condition of accelerated exposure to ultraviolet (UV) radiation equaled to that of several years under AM1.5D, the most stable fluids were found to be silicone oil. Silicone oil was exposed at the coupling condition of high temperature and UV irradiance in Zhu's research (2010), an obviously aging phenomenon of silicone oil can be observed and the color of the silicone became yellow. However, the solar cells would not be damaged by immersing in this silicone oil and working for a long time. As mentioned above, silicon oil is suitable for solar cell working in medium and low CPV system as a cooling material. However, it is still limited in a high CPV system.

Among polymer materials, especially those materials exposed outdoor, it is a common way to maintain the performance of materials by adding photo-stabilizer. Many photo-stabilizers had been synthesized to prevent polymer aging (Rabek, 1975; Yachigo, 1992; Jiang and Yu, 2005). Three kinds of photo-stabilizers were classified by their working mechanism: (1) Ultraviolet absorbent; (2) energy quencher; and (3) free radical catching agent. For selecting, stability and consumption of additive are the only two requirements to be considered in most application fields. However, there are no literatures about the method applied in liquid immersed CPV system. So the properties, evaluation methodand evaluation index are particularity.

In this paper, the composites of di-methyl silicon oil adding additive were selected to prevent aging of di-methyl silicon oil working in high CPV system for long time. Protection mechanism of materials with different structure was studied. Additive materials with ideal operation parameters and practical value were selected and tested by accelerated life testing (ALT), performance of solar cell immersed by composite and consumption rate of additive to verify their reliability. For there is no uniform detection index for cooling liquid of concentrator solar cells, the testing items and index from CPV standard IEC62108 (2007) established in 2007 was referenced. This work provides a primary achievement for further study and standardization of liquid as a heat transfer material of CPV system.

2. Experimental

2.1. Experiment materials

(A) Di-methyl silicon oil of Shin-Etsu-kf96 of KF-96L-2cs, whose properties can be referred from literature (Shin-Etsu, 2008), was selected as the experiment material.
(B) TiO_2, white solid, CAS number: 1317-70-0, $M = 80$ g/mol.
(C) UV-9, white solid, CAS number: 131-57-7, $M = 228$ g/mol.
(D) UV-327, white solid, CAS number: 3864-99-1, $M = 358$ g/mol.
(E) GW-783, white mixture solid, average $M = 2600$ g/mol.