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Spectral characterisation and long-term performance analysis of various commercial Heat Transfer Fluids (HTF) as Direct-Absorption Filters for CPV-T beam-splitting applications

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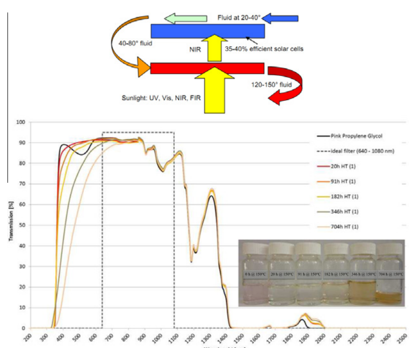
HIGHLIGHTS

- Optical transmittance of 18 different commercial heat transfer fluids has been measured.
- Suitable liquids serving as Absorption Filters are Duratherm 600 and G, Propylene Glycol (PG), pink-dyed PG and Royco 782.
- Long-term degradation tests include low temperature test at 75 °C, high temperature test at 150 °C, and UV light exposure.
- Optimum fluid is the industrial Propylene Glycol adapted with a chemically-inert red dye such as Oil Red 235 inorganic dye.

GRAPHICAL ABSTRACT



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ABSTRACT

Hybrid concentrated photovoltaic – thermal systems (CPV-T) provide simultaneous supply of electrical and thermal energy, using solar cells with cooling systems to avoid high cell temperatures that decrease the system electrical conversion efficiency. Heat transfer fluids arranged in front of the cell, acting as selective beam-splitting filters, may represent a feasible alternative to absorb unwanted solar radiation, preventing the cell from overheating and directly generating usable thermal output. The cooling efficiency and the temperature output of the liquid depend on optical transmittance as well as chemical and physical stability. A research study for the most suitable commercial heat transfer fluid for a direct-absorption beam-splitting CPV-T system is conducted in this paper, analysing the effects of high temperature and exposure to UV light on the optical transmittance of the fluid under accelerated lifetime test conditions.

Optical transmittance of 18 different commercial heat transfer fluids has been measured. The most promising liquids to serve as Direct-Absorption Filters selected for accelerated tests include Duratherm 600, Duratherm G, industrial Propylene Glycol (PG), pink-dyed PG, and Royco 782. Long-term degradation tests include low temperature test at 75 °C, high temperature test at 150 °C, and UV light exposure. Results from the accelerated tests show that the optimum fluid for our application is the industrial grade Propylene Glycol adapted with a chemically-inert red dye such as Oil Red 235 inorganic dye. Propylene Glycol is a liquid used in food processing, with a cost of A$ 2.50/kg.

1. Introduction

Concentrated solar energy technologies are well-known and widely used in centralised power plant applications. The basic idea

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is to collect the sunlight using optical devices comprising mirrors and/or lenses that concentrates the solar energy onto a small area. This leads to a higher solar flux density onto the receiver. The objective of all concentrating systems is to increase the system efficiency and reduce the lifetime energy costs in terms of $/MW h so solar energy systems are competitive on the market. Concentrators can use the incident power for: (a) heat production (domestic solar hot water systems – SHWS); (b) electricity generation converting heat into electricity (thermoelectric systems – concentrating solar power – CSP); (c) electricity generation using photovoltaic solar cells (concentrating photovoltaics – CPV); and (d) heat and electricity generation, using combined thermal-PV hybrid systems (concentrating photovoltaic–thermal – CPV-T) (Fig. 1) [1,2].

Depending on the solar concentration ratio and the design of the thermal application (SHWS/CSP) temperature outputs from a low of around 100 °C to a high temperature around 1000 °C can be provided. Conventional low temperature (SHWS) thermal energy is generally transferred using a suitable liquid circulated through the system to remove the solar energy absorbed by the receiver. The receiver can be a specially coated black tube, for example proprietary black chrome on copper pipe, or evacuated glass tubes using only direct solar power, or tubes situated under a glass plate where they are heated by compound parabolic concentrators (CPCs) with a concentration level of 1.2–2X. These systems are suitable for temperature ranges that cover domestic hot water demand. However high temperature (CSP) is convenient for energy storage, electricity or hydrogen generation, process heat, and some thermo-chemical conversion processes. Operating at this elevated temperature range requires much larger and more sophisticated systems, which are explained in other studies [1].

Concentrated photovoltaic technologies (CPV) aim to reduce the energy generation costs by reducing the cell area, replacing the expensive energy conversion medium with inexpensive collectors and tracking systems. It is important to note that solar cells are capable of converting only a small fraction of the entire solar spectrum into electric power. The fraction depends on the specific type of cell, and is determined by the cell spectral response (SR). Radiation absorbed outside this spectral range is converted to heat in the solar cell, causing stress on the material and a significantly decrease of the electrical conversion efficiency. For mono- and polycrystalline silicon solar cells, this is typically −0.45%/°C in relative terms. The fact that CPV systems operate at an elevated solar concentration level makes the temperature-dependent efficiency loss a crucial issue [3–5]. In order to maintain the highest possible performance, the cell needs to be either passively or actively cooled. The type of cooling depends mainly on the concentration level, the size of the cell, and the absorbed irradiance flux. For active cooling, a heat transfer liquid can be circulated across the rear surface to extract the heat. Instead of dumping this absorbed energy, the heat can be utilised in domestic hot water applications, further improving the energy conversion efficiency and economical attractiveness of the system. This simultaneous supply of electrical and thermal energy is a feature of hybrid concentrated photovoltaic – thermal (CPV-T) systems [1,4] (Fig. 1).

Both CPV and CPV-T systems can obtain additional benefits from spectral-splitting to improve their performance and total efficiency as the cells. The idea is to use bands of the solar spectrum for the applications that are highly efficient in those particular regions. Previous research analysed different methods of spectral splitting, focusing mainly on selective mirrors, combinations of PV cells, and physical films [6,7]. For instance, CPV systems use multi-junction cell technology, which consists of a stack of different cell types which are mechanically and electrically connected. With multi-junction structures, each junction generates electricity within a specific spectral range, successively passing through the unused wavelengths for the cell underneath. In this way, a much larger fraction of the available spectrum can be electrically converted, reaching efficiencies over 41% instead of about 25% for single-junction silicon cells [6,8,9]. The complexity of these structures, their spectral sensitivity, and the need for them to be integrated in CPV with very high concentration levels, currently makes them expensive and less competitive. CPV-T systems can also use spectral-splitting technologies. One method involves the use of a liquid in front of the cell, acting as a selective spectral absorption filter, and directly generating a usable thermal output from the absorbed energy [3,10,11]. This technology is called 'Direct-Absorption Filters for CPV-T'. Simulations conducted by Sabry et al. have shown that a spectral matching fluid drastically reduces the operating temperature of the cell, leading to a higher V_{oc} and to an efficiency increase of about 30%. In addition, about 40% of the incident irradiation was calculated to be converted to thermal energy [3]. Two studies, one from 1986 and one from 2011, reported testing a small number of heat transfer liquids for their optical properties, in particular the transmittance in the original state

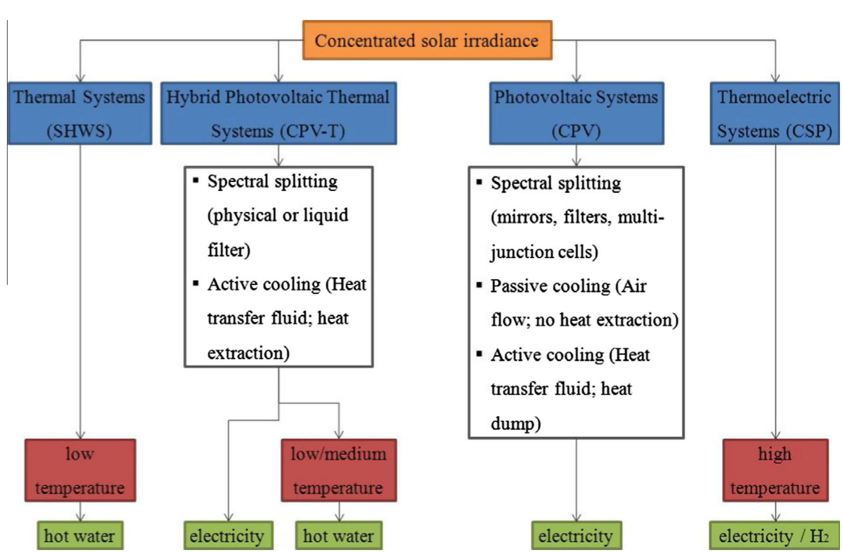

Fig. 1. Classification of common technologies and system set-up for concentrated solar irradiance conversion.