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# Numerical studies on thermal and electrical performance of a fully wetted absorber PVT collector with PCM as a storage medium

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ABSTRACT

A detailed mathematical models is developed for a fully wetted absorber photovoltaic thermal (PVT) collector with and without phase change material (PCM) under its absorber channel. Thermal and electrical investigations were carried out using PCM OM37 for typical winter and summer days in Lyon, France. The system is analyzed under energy and exergy performances. PCM incorporation in a water PVT absorber improves the performance of system in terms of electrical and thermal parameters. Enhanced electrical and thermal energy is attributed to dissipation of excess heat of PV module by latent heat absorption mechanism that reduces the PV module temperature and release heat at the night as well, provides better electrical and thermal stabilities to the system. Overall thermal energy and overall exergy of PVT system for a winter day as well as for a typical summer day, are found to be strongly in favor of adding PCM. The effects of mass of PCM on module temperature, outlet water temperature, and PV module electrical efficiency, have also been investigated. During sunshine hours, increment in the PCM mass up to its optimal value decreases temperature resulting in higher electrical efficiency and also allows providing higher water temperature at the nighttime.



## 1. Introduction

There is an urgent need of development of renewable energy sources due to rapid growing demand of energy. In our modern society, inadequate supply of conventional energy sources is a critical challenge. Emission of carbon di oxide and other pollution from the fossil fuels is another a major issue as it is causing climate change [1].

Solar energy is one of the fastest growing sources of renewable energy. There are numerous foremost directions for solar technology growth such as Photovoltaic (PV) panel which directly convert the solar energy into electrical energy. It is a most mature technology but unfortunately typically power of PV module decreases with 0.2–0.5%/°C increase of temperature [2]. Therefore to maximize the performance of PV module its temperature regulation is strongly needed which is usually done by cooling the PV module via some cooling techniques like air cooling and water cooling. An increment in electrical yield by water flow on the front of the PV modules based on crystalline and multi crystalline Si, has been observed before [3,4]. The extracted surplus heat of PV module can be used to fulfil the need of thermal energy for industrial and residential sectors. Such system is known as photovoltaic thermal (PVT) technology: a single unit that can increase the efficiency of PV module by using solar thermal system. In 1978 the first design and performance of a PVT collector was presented, where water and air were used as a cooling fluid [5]. Since then a significant amount of theoretical and experimental research on PVT systems has been carried out [6–15]. A theoretical analysis via use of modified hotel whillier model was presented by Florschuetz [16]. Further Lalovic et al. conducted a theoretical analysis on PVT water collector and suggested that such system can be useful as pre heater for domestic hot water services [17]. Garg at al. also presented the same facets of a PVT water collector [18].

Van Heiden et al. [19]. suggested that PVT systems could be a cost effective solution for applications where roof area is limited. He et al. [20]. carried out a research on PVT system in which natural convection was used to circulate the cold water. They found the

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thermal efficiency lesser than a conventional thermosyphon solar water heater but the energy saving efficiency was found to be greater.

The same hybrid system was dynamically modelled by Chow et al. [21]. They suggested that the performance of the system can be enhanced by insertion of PV cells on the lower portion of collector. Kalogirou and Tripanagnostopoulos [22] stated that PVT is economically feasible for industrial applications in a Mediterranean environment.

Assoa et al. [23] presented a steady-state two-dimensional thermal model for PVT collector based on sheet-and-tube concept whereas the experimental study was carried out by Zondag et al. [24]. Dupeyyrat et al. [25] performed an experiment on PVT collector to enhance its performance. They found the global efficiency of PVT collector more than 87%. Touafek et al. [26] studied the PVT system and PV module separately and found the thermal system cause improvement in efficiency of PV collector.

Shyam et al. [27,28] investigated the N-PVT water collectors connected in series and validated their thermal model with experimental studies. They found the collector partially covered by semitransparent PV module at inlet of PVT water collector gives better result compared to that covered by PV module at outlet of the collector. However they have concluded that both configuration give similar results for large number of collectors connected in series. An experimental study was carried out by Jin et al. [29] on water type glazed and unglazed PV thermal collector. They concluded that the unglazed PVT collector results in lower thermal efficiency and higher thermal efficiency as compared to the glazed PVT collector.

Further Jin et al. [30] performed an experiment on unglazed liquid PVT collector with a sheet and tube type of absorber and other with fully wetted absorber type. They observed that the PVT collector with fully wetted absorber are more efficient.

Solar water heating system is a superior technology that has been widely realized for domestic and industrial applications. Though, still research is being carried out on unglazed PVT water collectors to improve its performance in both senses i.e. electrical and thermal. Recently some of the important studies have been done on the use of phase change materials with PVT systems for minimizing the temperature of PV module [31–38]. PCM can store a high latent heat due to phase change occurs and having a melting point suitable for the application. Therefore in PVT water collector PCM can regulate the temperature of PV module by absorbing the heat on melting and can extend the duration of water heating as well by releasing heat on freezing. Rabin et al. [39] studied a solar collector storage system using salt hydrate eutectic mixture as PCM. They developed a mathematical model for charging process by considering the negligible natural convection. Chaabane et al. [40] presented a numerical study of an integrated collector storage solar water heater with two different PCM (myristic acid and RT-42 graphite) and three radii of this PCM layer. They found that the highest water temperature corresponds to the lowest radius. Bouadila et al. [41] performed an experiment on an integrated solar latent storage collector with two PCM-filled cavities incorporating below the absorber. The results showed that the paraffin increased the performance of the solar collector at night.

This paper aims to understand the effect of integration of OM 37 as a phase change material on the electrical and thermal performance of an unglazed fully wetted type absorber PVT water collector. For that purpose theoretical models have been developed and solved numerically for PVT water collector with incorporation of PCM under the absorber channel, for charging and discharging approach. The results have also been compared with collector without PCM. The numerical calculations have been done for a typical day of winter (20 Feb) and summer (8July) of Lyon, France. For incidence of the maximum solar radiation, the PV module in northern hemisphere are placed south oriented, having inclination with horizontal surface equal to the latitude of the system's station [42,43]. Since the present study is carried out for climatic conditions of Lyon which is located at 45.7600° N, 4.8400° E in France therefore PV module is considered to be south oriented and inclined at an angle of 45° to the horizontal.

A thin layer of PCM below the water tubes of a water collector will store a substantial quantity of heat within PCM during sunshine and at the night duration, solidification cause the discharging of stored heat that will keep the water warm even at night too.

## 2. Thermal analysis

A schematic diagram of the anticipated fully wetted absorber type unglazed PVT water collector with PCM is depicted in Fig. 1.

The present fully wetted absorber type PVT collector set up consists of a frameless mono-crystalline semitransparent PV panel rated at 110 W, having efficiency 18% under standard test conditions (STC). The photovoltaic parameters of the PVT system at STC are shown in Table 1. The detailed structure of fully wetted absorber type PVT collector with PCM is presented in Fig. 2(a).

PV modules used in present PVT collector considered to be semitransparent as higher efficiency is obtained using semitransparent or bi glass PV modules due to the solar radiation incident on non packing area of PV module is transmitted through the glass however absorbed by the blackened plate [44,45]. Hence heat is convected to the water from back PV cells as well as from top surface of the blackened plate.

The area of the PVT collector is 2 $m^2$ which is connected with an insulated water tank of capacity 100 L. A DC pump of the capacity 24 W was used to force the flow of water which is operated by the PV module itself.

In order to maximize the heat transfer area fully wetted channel approach of collector has been used that reduce the thermal resistance between water and collector fluid by allowing rectangular shape channel for water flow [46]. There is no absorber sheet in fully wetted absorber collector as PV module itself makes one face of channel. The heat is transferred from back surface of PV module to the flowing water.

In fully wetted absorber type PVT water collector, a good thermal transfer improves the useful thermal output and reduces the temperature difference between the PV cells and the fluid (water) results better cooling effect and electrical efficiency of PV module.

The PVT collectors are considered to be made up of black painted copper rectangular channel attached to each other and covered with PV absorber as shown in Fig. 2. These collectors are thermally protected with 50 mm glass wool insulation. The bottom and sides of the PVT collector are perfectly insulated. A space is formed between the insulation and absorber plate where PCM is filled via PVC pipe that could be better for the volume dissemination at the time of PCM melting. A bio-based Phase Change Material (PCM) OM37 was used which is an organic material having large amount of heat energy stored in the form of latent heat. It can be absorbed or released when the materials change state from solid to liquid or liquid to solid. Ingredients of OM 37 are from 100% bio based raw materials which are non hazardous, biodegradable and non toxicis usually the most available and cheaper phase change material therefore in the present study OM 37 has been used. The properties of OM37 is also given in Table 1 [47].

The PV panel converts visible and ultraviolet parts of the solar spectrum into electricity but infrared part of spectrum and excess heat of PV module are absorbed by the fully wetted absorber. That excess heat is convectively transferred to the flowing water in channel. The blackened absorber plate or channel absorbs solar