New textile-based hybrid photovoltaic/thermal (PV/T) system

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Abstract. This paper introduces a new textile-based hybrid PV/T system utilizing a spacer fabric treated with phase change material (PCM). The PCM absorbs excess heat from the PV modules, which keeps the modules in their optimal temperature range so that their power output is enhanced. The thermal energy stored in the PCM is then used for hot water generation. Cold water, which is pumped through thin capillaries integrated into the spacer fabric, absorbs the heat stored in the PCM and is heated up. The warm water can be used immediately or stored in an intermediate storage tank. Comparing the proposed textile-based hybrid PV/T system to conventional hybrid PV/T systems, the proposed system is less expensive and provides a higher overall efficiency. The textile-based collector is lightweight, thin and flexible.

1. Introduction
Combining photovoltaic and solar thermal components into a single system can quadruple the energy output of a conventional photovoltaic array. Furthermore, such a system addresses the problem of overheated PV modules. Current PV/T collectors are typically bulky and heavy PV panels in combination with solar thermal collectors. It needs to be considered that the hybrid PV/T collectors are currently more expensive than a combined use of a conventional PV panel and a thermal collector based on the same performance [1], [2].

In order to overcome some of the obstacles related to the use of the commercially available hybrid PV/T systems, a textile-based hybrid PV/T system has been developed. In this system, phase change material (PCM) is used for intermediate heat storage.

2. Phase change material
A phase change material (PCM) possesses the ability to change its physical state in a certain temperature range. When the melting temperature is obtained in a heating process, the phase change from the solid state to the liquid state occurs. During this melting process the phase change material absorbs and stores a large amount of so-called “latent heat”. The temperature of the phase change material remains nearly constant throughout this process. In a reverse cooling procedure, the stored latent heat is released into the environment and a phase change from the liquid state to the solid state takes place. This return to the previous state also happens without a change in the material’s temperature. The fact that a large amount of latent heat is absorbed or released without any temperature change makes a PCM highly desirable as a means of heat storage [3].

PCMs are characterized by the temperature ranges in which the phase change takes place and their latent heat storage capacities. Common PCMs are paraffin waxes, salt hydrates, bio-based materials, and eutectics.

3. Containment of the PCM
Before a PCM can be applied to a textile substrate, it needs to be durably contained in a carrier material
in order to prevent dissolution while in its liquid state. For the application in the textile-based hybrid PV/T system, the selected PCM is directly integrated into a silicone rubber compound and durably contained therein by a cross-linking procedure. The cross-linking prevents leakage of the PCM out of the silicone rubber compound while liquid [4].

4. Textile-based hybrid PV/T system

4.1 Collector
The textile-based hybrid PV/T collector consists of a spacer fabric in which capillaries are integrated. The back side of the spacer fabric is covered with a protective coating in order to withstand the elements. The front side of the spacer fabric faces thin film PV cells and is coated with the silicone rubber compound containing the PCM as a thermal storage medium. During the coating procedure, the silicone rubber compound penetrates into the spacer fabric and encloses the capillaries completely. The thin film PV cells are then laminated onto the surface of the silicone rubber coating layer equipped with the PCM. The textile-based hybrid PV/T collector is shown in figure 1.

![Figure 1. Textile-based hybrid PV/T collector.](image)

4.2 Photovoltaic/thermal system
The entire system used for the hot water generation is shown in figure 2. The system comprises the textile-based hybrid PV/T collector, a cold water supply system consisting of a pump and a valve as well as a temperature sensor, and a water tank for intermediate storage of the generated hot water.

![Figure 2. Photovoltaic/thermal system.](image)

4.3 Operation of the system
The thin film PV cells of the textile-based hybrid PV/T collector convert the solar radiation into electricity. As soon as the temperature of the PV cell reaches a given trigger temperature, the excessive heat is absorbed by the PCM integrated in the silicone rubber coating compound. In this way, the PV cell is cooled and can operate at its optimal temperature, staying at its highest possible efficiency and maximum electrical output. Tests have shown that the PCM cooling used in the textile-based hybrid PV/T system is more efficient than the forced liquid or air cooling used in commercialized PV/T systems, because the construction of the textile-based hybrid PV/T collector provides direct contact between the PV cell and the heat absorber.

The temperature measurements carried out by the temperature sensor at the collector location deliver an indication at which point the PCM is ready for a recharge, i.e. when the temperature exceeds a certain value the sensor provides a signal to the valve which normally shuts off the cold water supply. The valve opens and cold water with a temperature of about 20°C is pumped through the capillaries which are integrated into the spacer fabric.

Because of a high temperature gradient between the PCM’s temperature and the water temperature at the beginning of the recharge cycle, there is a fast transfer of the latent heat stored in the PCM to the water, and so the water is quickly heated. The water which is flowing out of the textile composite has a temperature of about 40°C.

The water flow through the capillaries can be automated through a thermostat or operated manually. The warm water can be used instantly and/or can be stored in an intermediate hot water tank. This eliminates the need for a heat exchanger and its components, as well as for a large storage tank which, in turn, reduces costs and saves space.

5. PCM selection

In order to select the PCM which operates in a suitable temperature range, field tests were carried out. In these field tests the temperature development on top of the PV cells were measured over the course of the day. The test results indicate that the temperature rises substantially in the afternoon hours when the PV cell faces in the southwest direction with a maximum temperature of about 60°C.

It needs to be taken into consideration that the optimal operation temperature of a PV module is about 25°C. It has been calculated that for every 1°C above 25°C, the electrical output drops by about 0.5% [5], [6].

Taking these operation requirements into account, an eutectic PCM has been developed and selected which absorbs latent heat in a temperature range between 25°C and 40°C and possesses a high latent heat storage capacity of about 270 J/g. Figure 3 shows a DSC thermograph of the developed PCM.

![Figure 3. DSC thermograph of the developed PCM.](image-url)
A concentration of 50 wt. % of the selected PCM in the silicone rubber compound leads to a latent heat storage capacity of about 540 kJ per one m².

6. Test results

6.1 Cooling of the PV cells

The main purpose of the PCM is the cooling of the PV cell in order to ensure that they remain in the optimal temperature range during the window of operation. Field tests were carried out where the temperature on top of the PV cells was monitored utilizing collectors with and without PCM treatment which were placed side by side. The test results are summarized in figure 4.

![Figure 4. Temperature development at the PV cell with and without the PCM treatment.](image)

The results summarized in figure 4 indicate that the latent heat absorption of the PCM starting at a trigger temperature of 25°C and the recharge of the PCM in consecutive time intervals reduces the PV cell’s temperature by up to 30 degrees.

6.2 Power generation by the PV cells

The cooling feature provided by the PCM leads to a substantial improvement in the power output of the PV cell as it is shown in figure 5. The power output from both arrangements was measured simultaneously with the temperature measurements.
Figure 5. Power output of the PV cells with and without the PCM-cooling.

For instance, the cooling of the particular PV cell provided by the latent heat absorption of the PCM reduced the power output by only 4%. In contrast, without the PCM’s cooling feature the power output of the same PV module dropped by 18% due to the overheating of the PV cell.

6.3. Hot water generation
The latent heat storage capacity of 540 kJ/m$^2$ allows for the heating of about 6 liter of water from 20°C to 40 °C referred to a collector size of one square meter in a single recharge. Multiple recharges are usually carried out over the course of the day.

7. Applications
The textile-based hybrid PV/T collector is lightweight, thin, flexible and weatherproof. The collector fits any roof shape and can be used not only on roofs of residential and commercial buildings, but also for swimming pool and greenhouse covers. Another application can be emergency shelters set up in disaster areas. The system would provide shelter as well as electricity and hot water at the same time and, therefore, can address three major problems in one arrangement.

8. Comparison with conventional hybrid PV/T systems
The textile-based hybrid PV/T collector is roughly 75-80% lighter than a comparable conventional PV/T system. Furthermore, the price of the textile-based PV/T collectors are about 50% of the price of the commercialized PV/T collectors based on the same performance. Moreover, maintenance requirements of commercialized PV/T systems are high and the requirement of continuous pumping of fluid or air though the system leads to high operational costs. The textile-based hybrid PV/T system maintenance requirements and operational costs are lower and its overall efficiency is higher, compared to common PV systems, meaning that the break-even period for a PV/T installation will be much shorter.

9. Conclusions
The newly-developed textile-based hybrid PV/T system provides a solution for enhancing the efficiency of PV modules substantially. The heat which is absorbed and stored by PCM when cooling the PV modules is then used for hot water generation. The textile-based hybrid PV/T collector is much lighter when conventional collectors and fits various roof shapes which make applications other than roofs of buildings possible. In comparison to conventional hybrid PV/T systems, the proposed solution provides substantial cost and space savings.
References

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