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Use of Polysiloxane Gel as Laminate for Solar PVT Collectors

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Abstract

High temperature resistant polysiloxane gel has been tested for unglazed and glazed solar PVT collector prototypes as a lamination compound. Unglazed and glazed PVT collector prototype with polysiloxane laminate have been compared with state-of-art PVT collectors (based on EVA compound) available on the market. The comparison has confirmed an excellent performance of the polysiloxane gel in terms of optical transparency and heat transfer.

1. Introduction

Solar photovoltaic-thermal (PVT) liquid collectors represent a new technology on the market which combines the electricity and heat generation from the same receiving surface in one device. The hybrid PVT collectors provide both heat and electricity, while the heat generation is several times higher than the electricity. Because of mature and cheap PV manufacturing process the PVT collectors available on the market are based on standard PV laminates from ethylene-vinyl-acetate (EVA) compound. One of the main drawback of EVA copolymer as an encapsulant of PV cells for PVT collectors is its corrosiveness, especially under high temperature exposition (Parretta et al., 2005). Application of EVA laminate restricts the permanent exposition of PVT absorber to temperatures above 90 °C. It has been proved that the long-term thermal load at such temperature levels results decomposition of EVA to acetic acid which causes the corrosion of PV cells contacts, delamination and also degradation of the encapsulation layer transparency (Zondag and Van Helden, 2002; Zondag 2008, Poulek et al., 2012). Because the stagnation temperature in glazed solar collectors could reach 120 to 180 °C the hybrid PVT collectors based on EVA are mainly offered as the unglazed ones so far.

Silicone polymers (polysiloxanes) are more suitable candidates for application as PV encapsulant for PVT collectors. Polysiloxane gel offers several important advantages like large range of operation temperature (from -60 to +250 °C), high transparency for solar radiation (even higher compared to EVA in solar wavelength region), compensation of thermal dilatation stresses due to low modulus of elasticity (permanent gel), high physical adhesion to semiconductors, glass and most other materials without use of sub-layers and good heat transfer from PV to heat exchanger due to higher thermal conductivity (Poulek et al., 2012). Polysiloxane laminate thus opens the application potential especially for glazed PVT collectors development. Silicone gel encapsulation machine available at University Centre for Energy Efficient Buildings (Czech Technical University, CTU) enables to fabricate the solar PVT collector prototypes. The encapsulation technology is based on low vacuum dosing of the gel into the gap between glass pane and flat heat exchanger with immersed strings of PV cells. The encapsulation process is carried out at room temperature. This fact brings a clear advantage for future production.

2. Solar PVT collectors with polysiloxane compound

Two types of solar PVT collectors has been fabricated for the thermal performance testing. Unglazed PVT absorbers has been used to prove the technology of encapsulation and to confirm the suitability of polysiloxane

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gel compound from the aspect of transparency and heat transfer. However, the glazed PVT collector is the target solar component to be developed and which has the economical potential. Recent study (Matuska, 2013) has revealed that unglazed PVT collectors cannot economically compete with combination of photovoltaic and photothermal collectors for usual residential applications. Poor thermal performance of unglazed PVT collectors for domestic hot water preparation has resulted in negative market price of the unglazed PVT collectors to make the system competitive.

The main investigated parameter of solar PVT collectors was the thermal efficiency to prove high heat removal of heat from solar PV cells and low heat loss of the presented concepts for glazed PVT collector. Strong accent of the investigation has been put also to simplicity of the PVT collector design and fabrication (reduced number of elements to compose the PVT collector).

2.1. Unglazed PVT collectors (absorbers)

Solar PVT absorber (CTU prototype) has been fabricated from low-iron solar glazing (thickness 4 mm), polycrystalline PV cell strings and blackened flat heat exchanger with use of the polysiloxane gel lamination technology. Heat exchanger made from 1 mm thick channel structure welded to 2 mm thick flat iron sheet as a face surface for laminate has been used. Total thickness of the polysiloxane gel laminate is approximately 1 mm. Solar aperture area of the PVT absorber prototype was 0.96 m^2. In total 6 x 8 polycrystalline PV cells at size 125 x 125 mm have been used and the aperture area has been filled for 78 %.

State-of-art unglazed PVT collector based also on polycrystalline PV cells has been used as a reference for the comparison. The state-of-art PVT absorber has been produced by commercial company from the laminate of 3 mm thick solar glazing and 2 mm thick iron sheet with encapsulated PV cells in EVA compound in between. Thickness of each EVA layer (upper, lower) is approx.. 0.6 mm. The shaped structure from 1 mm iron sheet has been bonded to back side of the iron laminate to create the channel flow structure. Aperture area of the state-of-art collector was 1.22 m^2. In total 6 x 8 polycrystalline PV cells at size 156 x 156 mm have been used and the aperture area has been filled for 96 %.

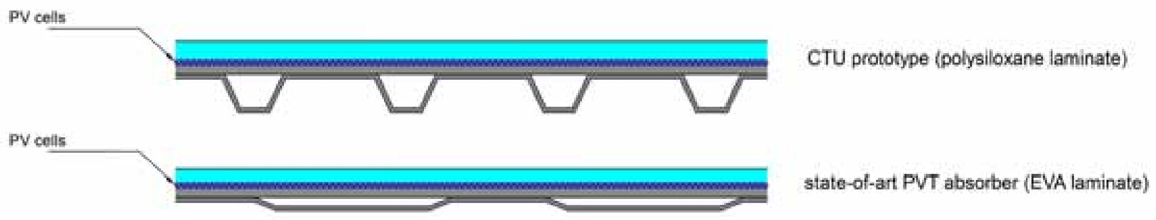

Fig. 1: Layout of the investigated solar PVT absorbers: state-of-art (lower), developed prototype (upper)

Both compared PVT absorbers are almost fully wetted ones and equivalent from the aspect of the heat transfer (2 mm thick iron sheet with a very short distance between the channels). The layout of both PVT absorbers design is shown in Figure 1.

2.2. Glazed PVT collectors

Two concepts of glazed PVT collectors have been developed. First prototype of nonselective PVT glazed collector has been derived from the unglazed PVT absorber immersed into standard aluminium frame box for flat-plate solar collectors with 40 mm of mineral wool insulation at the back side. The edge side has been left without insulation due to complicated immersion of PVT absorber into available collector frame box. Additional low-iron solar glazing 4 mm thick has been used as a collector cover in a distance approx.. 22 mm from the absorber (see Figure 2, upper layout). Aperture area of the glazed nonselective PVT collector prototype was 1.02 m^2. Layout of PV cells at absorber has been identical with unglazed PVT collector (CTU prototype).

For next prototypes, a new concept of solar collectors has been introduced. Double glazing with a gap between glass panes 20 mm filled with argon has been used for encapsulation of PV cells with the iron heat exchanger by polysiloxane gel (see Figure 2, lower layout). Spectrally selective PVT collector has been fabricated from double glazing with a coating with low-emissivity in the infrared part of spectrum. Today low-e coatings have high transparency for visible range but unfortunately significantly reduced transmittance for near infrared region of solar radiation. First prototype of glazed selective PVT collector has been made with commercially available low-e coating without optimization of emissivity and transparency. Fully wetted heat exchanger common to other concept has been used. Aperture area of the glazed selective PVT collector was 0.67 m^2. In total only 4 x 6 polycrystalline PV cells at size 156 x 156 mm have been used due to given size of absorber. Aperture area has been filled for 87 %. Absorber has been insulated by 40 mm of mineral wool on the back and 10 mm of EPDM foam at the edge side and put into wooden frame.

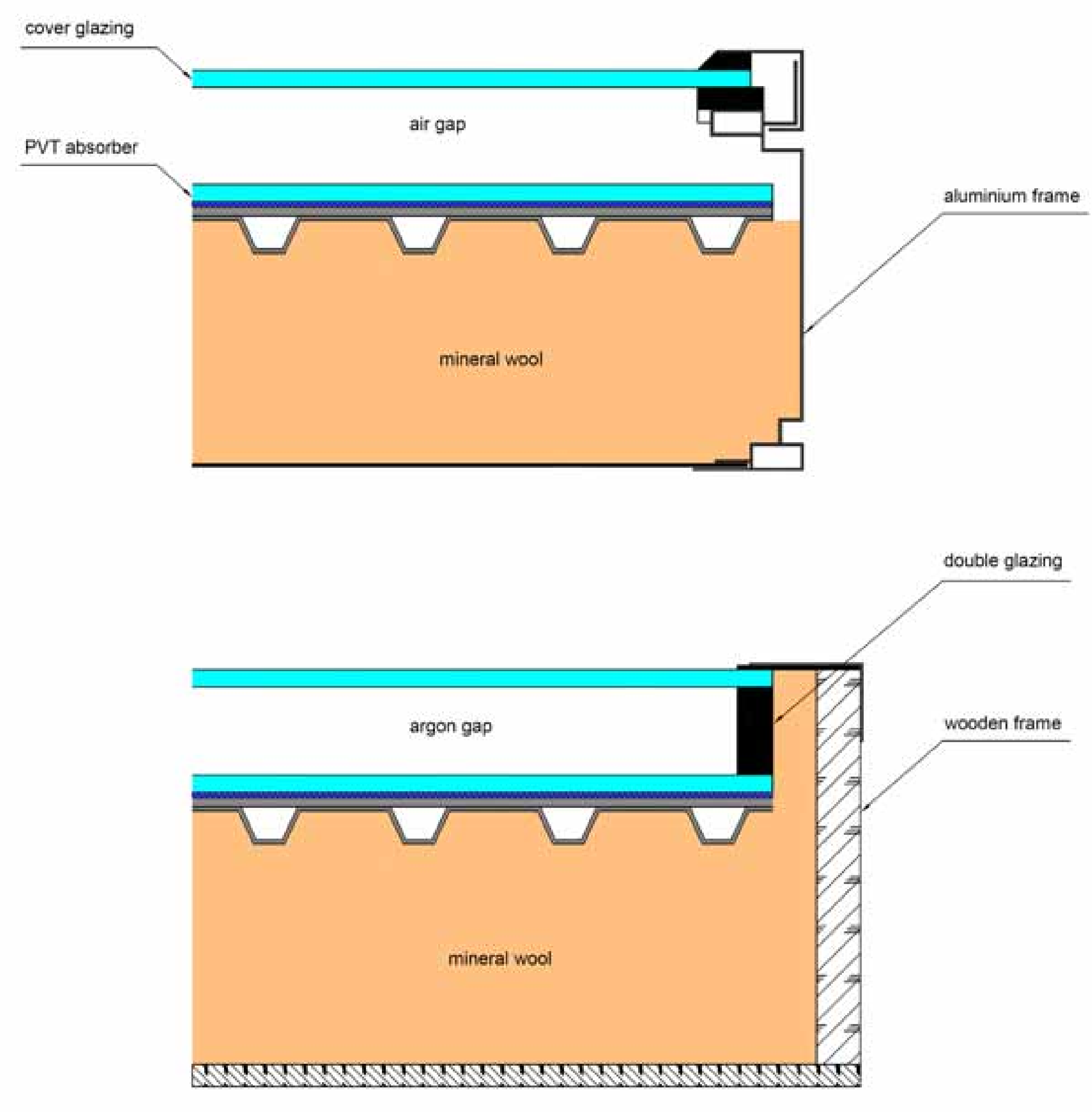

Fig. 2: Layout of the investigated glazed PVT collectors: developed prototypes – nonselective (upper), selective (lower)

3. Testing and results

3.1. Unglazed PVT collectors (absorbers)

Solar unglazed PVT collectors have been tested in outdoor conditions at Faculty of Mechanial Engineering, Czech technical University in Prague (see Figure 3). Tests have been performed in accordance with EN 12975 for open circuit mode (thermal performance test, without use of electricity from PV cells). Figure 4 shows the thermal efficiency characteristics for low and high velocity of ambient air.

Despite the equivalent design of PVT collector absorber (fully-wetted absorber, polycrystalline PV cells), the developed PVT absorber prototype has shown significantly higher zero-loss efficiency $F'\alpha$. Under assumption of identical absorption coefficient for PV polycrystalline cells in both PVT absorbers, it is evident that efficiency factor F' of the absorber (ability to transfer the heat from PV cell to fluid) is significantly higher for the developed CTU absorber prototype than for the reference state-of-art alternative.

Fig. 3: Tested solar PVT absorbers: state-of-art (left), developed CTU prototype (right)

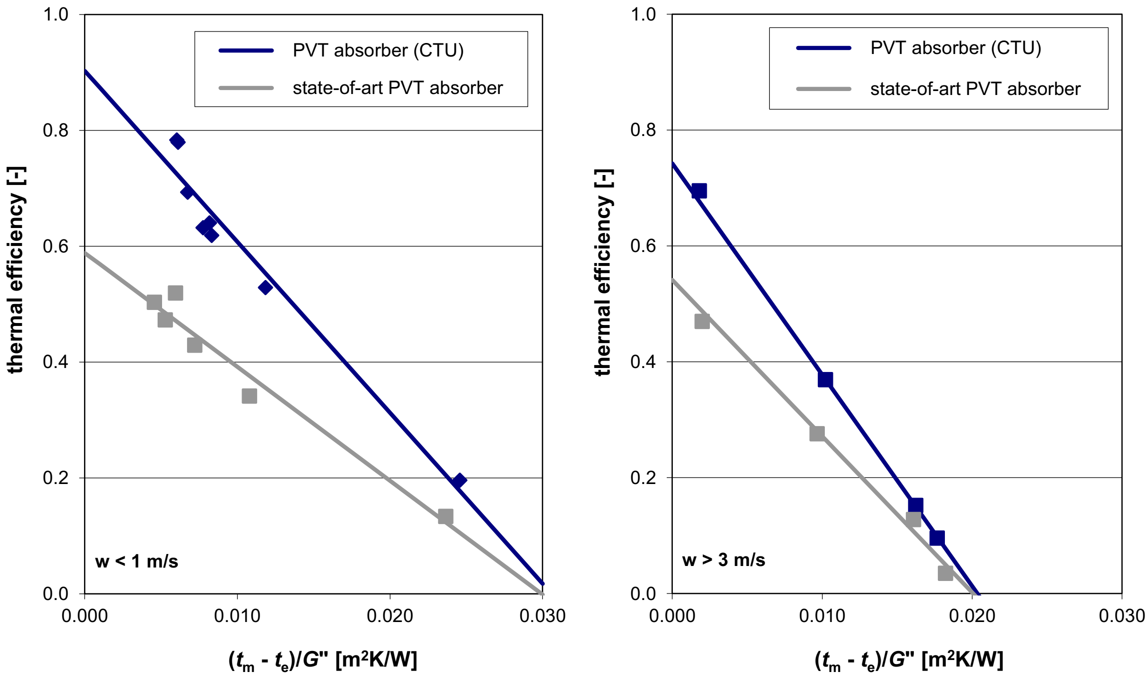

Fig. 4: Thermal efficiency characteristics for the unglazed PVT collectors (blue: developed at CTU, grey: state-of-art on the market) resulted from outdoor testing at different wind velocity levels

3.2. Glazed PVT collectors

Glazed solar PVT collector prototypes have been tested in outdoor conditions (Faculty of Mechanical Engineering, Czech Technical University in Prague) and under conditions of artificial sun at University Centre for Energy Efficient Buildings in Bustehrad (see Figure 5). Tests have been performed in accordance with EN 12975 for the open circuit mode.

Figure 6 shows the comparison of thermal performance characteristics for glazed PVT prototypes with siloxane gel lamination (selective, nonselective), state-or-art glazed PVT collector with EVA lamination and state-of-art solar photothermal (PT) selective collector. All characteristics resulted from the experimental testing. Comparison has confirmed the excellent properties pf polysiloxane gel encapsulation. High zero-loss efficiency for nonselective alternative of PVT prototype indicates the good heat transfer from PV absorber into heat transfer liquid and high transparency of the polysiloxane layer. On the other side, the high radiative heat loss reduces the thermal performance of the nonselective PVT collector at high temperatures.

Results for selective PVT collector prototype have confirmed the assumption of the high reflection losses in the near infrared radiation region due to the low-e coating applied to absorber laminate glass. In any case, the results revealed the area for further improvements of the glazed PVT collector. Main effort should be now concentrated on optimized low-e coating with a very high solar transmittance and low emissivity for infrared region beyond the wavelength value 3 μm.

Fig. 5: Glazed nonselective PVT collector at outdoor testing, glazed selective PVT collector at indoor testing

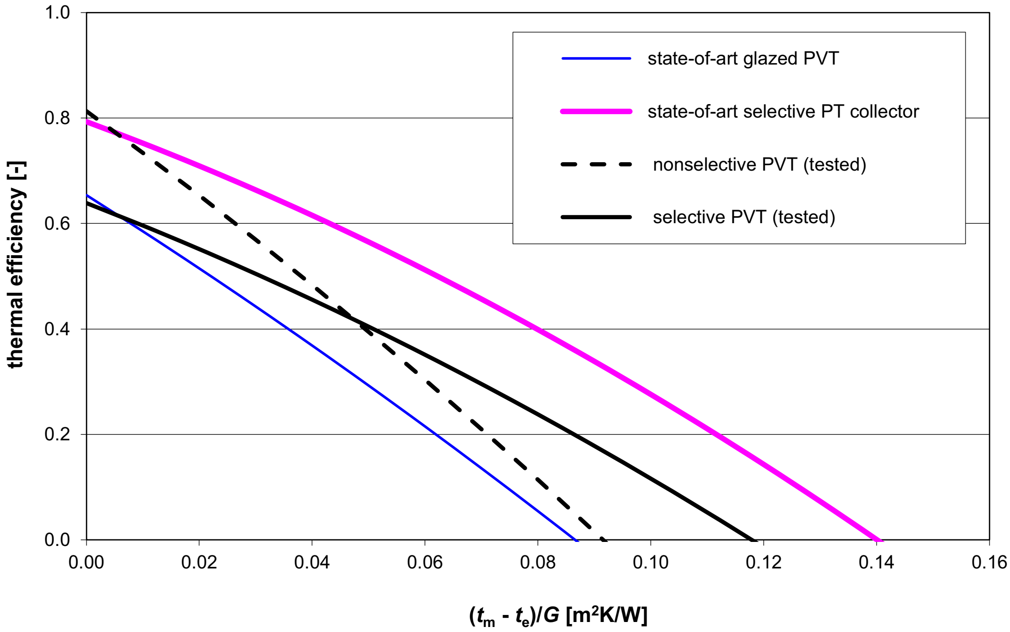

Fig. 6: Comparison of thermal efficiency characteristics for developed glazed PVT prototypes and state-of-art collectors available on the market, characteristics resulted from testing

4. Conclusion

Experimental work on first prototypes of unglazed and glazed PVT collectors has confirmed the excellent optical and thermal performance features of polysiloxane laminate application for solar PVT absorbers. Further improvements should be done in glazed PVT collector design. Application of laminate glazing with a spectrally selective coating highly transparent in the whole solar region but with a low infrared emissivity above 3 μm could reduce the radiation heat loss and improve thermal properties of the glazed PVT collector. Such advanced spectrally selective PVT collector remains as a subject of further development.

5. Acknowlegement

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