Experimental Testing of a Solar Thermal Collector with composite TIM of plastic Honeycomb and Silica Aerogel Polyurethane Containers

Jian Zheng[1], Rafel Febrer[1], Jesús Castro[1], and Deniz Kizildag[1]

[1] Heat and Mass Transfer Technological Center (CTTC) Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Terrassa (Barcelona) (Spain)

Abstract

A new proposal of high performance flat plate solar thermal collector (FPC) based on Transparent Insulation Materials (TIM) combining silica aerogel contained in insulation containers with plastic honeycomb is evaluated and compared with similar state of the art technologies. Thus, the proposed FPC shows better performance than the basic plastic honeycomb collector at high $\Delta TT/GG > 0.074$ while potentially protecting the honeycomb layer from reaching high temperatures. This data is compared as well with a previous version of the FPC with combined TIM of plastic honeycomb with silica aerogel to demonstrate that the performance has been improvedwith a new construction strategy.

Keywords: Silica Aerogel, Flat plate solar thermal collector, Honeycomb

1. Introduction

Solar thermal collectors operated under medium temperatures have different technologies operating in the current market. Besides FPC, stationary compound parabolic collectors (CPC), evacuated tubes collectors (ETC), Fresnel lens collectors (FLC), small parabolic trough collectors (PTC) and cylindrical trough collectors (CTC) are other technological alternatives widely investigated according to Tian and Zhao 2013. Also, Sharma et al. 2013 demonstrated that a solar heated system could be employed in various applications depending on the temperature and working fluid. Many authors, e .g. Sokhansefat et al. 2018 used TRNSYS16 software for a thermoeconomic analysis of two different solar hot water systems with FPC and ETC in cold winter Iran. Their results showed that the ETC system is 41% better than the FPC systems and applying ETC in cold climates is recommended. (see Osorio el al. 2017) used TIMs in the FPCs, PTCs, and CR, then the results presented that TIM could dramatically increase the thermal efficiency at high absorber temperature. For the FPCs, when the extinction coefficient of TIM $\mu = 8\text{m}^{-1}$ and the absorber temperature $T_{abs} > 103^{\circ}\text{C}$, the FPCs with TIM have higher efficiency than the conventional ones. High performance honeycomb flat plate solar collector (FPC) using honeycomb plastic Transparent Insulation Materials (TIM) has been established as a commercial market solution (an example of that is TIGI's collector, Klier et al. 2014)) that achieve a good tradeoff between high efficiency in the high temperature range $((T_m\text{-}T_a)/G>0.08)$ with a reasonable cost compared to evacuated tube collectors. Beikircher el al. 2014 presented that optimized mounting insulation with 30mm film should yield the same results as mineral wool with 50 mm insulation thickness. Besides, the film does not store moisture, and could avoid fogging and corrosion. Zhou et al. 2019 also studied FPCs with TIM using numerical methods, and the results show that if the transmittance of TIM is below 80%, the collector with TIM shows no advantages. Bellos and Tzivanidis 2018 introduced nanofluid with solar-driven absorption chiller with nanofluid to enhance the thermal performance. Ranjith and Karim 2016 used alternate working fluid for the solar thermal system, including propylene glycol(PG). Ammar el al. 2022 used transparent insulation material parallel slats (TIM-PS) to prevent air convection in a flat plate solar air collector for industrial agriculture drying. In order to reduce the thermal loss in the collector, TIM is widely used and in works of (see Ammar el al. 2022, Kizildag et al. 2022, Kessentini et al. 2014), simulations and experiments of FPC with TIM were carried out. In order to protect TIM from the high temperature of the absorber, in Kizildag et al. 2022, an overheating protecting ventilation channel based on shape memory alloy is used in the FPC, which can ventilate the FPC and preventing the TIM from igniting. (Wu et al. 2021) introduced aerogel to the PV/T

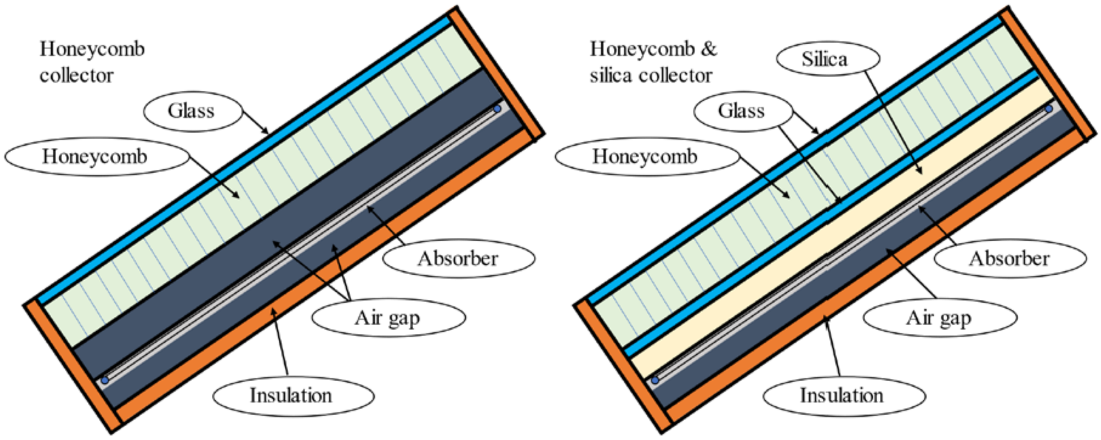
doi:10.18086/eurosun.2022.12.03 Available at http://proceedings.ises.org

collector and found that the heat loss of the PV/T at 70°C could be reduced up to 75% and the thermal efficiency increased by 46%. The coefficient generally has a linear relationship with solar radiation and ambient temperature. To acquire better thermal insulation, aerogel is introduced in the solar collector due to its high transmittance and low thermal conductivity, which also has an ultra-low density. In this part, several versions of FPC are demonstrated including the manufacturing details. The experimental data is compared with each version and simulation results.

The current study intends to validate a new proposal of collector with a compound TIM cover of plastic honeycomb and a silica aerogel layer contained using insulation containers which are implemented using polyurethane. The FPC has been tested in the summer days. The design aims to reduce the thermal loss in the relatively high-temperature T_{abs}>90°C. Additionally, it is compared with state-of-the-art honeycomb and silica layer collectors from Kizildag et al. 2022.

2. Collector concept

The previous collectors developed that have been taken as a reference to evaluate the new proposal efficiency are schematically represented in Figure 1. In contrast, the collector proposed in the current study is presented in Figure 2.



(a) Previous high performance FPC (Kizildag et al. 2022) **(b)High performance FPC in this work with TIM and aerogel**

Fig. 1: Honeycomb collector (Left), Honeycomb and silica aerogel collector (right)

Important details to assess properly the efficiency of the collectors depicted in Figure 1. Are the following:

- Both collectors have the same thickness of honeycomb (75mm)
- The glass layer of the honeycomb collector has a transmittance of 0,96 and the honeycomb and silica collector a transmittance of 0,92 for both glasses
- The silica layer of the honeycomb and silica FPC is 20mm thick
- Both collectors are equally insulated
- Both collectors have the same absorber design

Regarding the new collector, the main differences are that the silica will be distributed using polyurethane containers and vertically stacked between the honeycomb layer and the absorber. Moreover, the glass layers for this collector will be a 0.96 transmittance glass. The remaining properties will be kept the same to simplify the comparison between solar collectors.

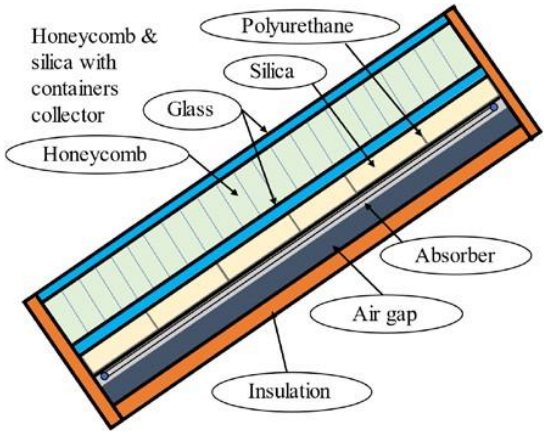


Fig. 2: Honeycomb with silica aerogel containers solar thermal collector

The test bench used to obtain the steady-state efficiency of the solar collectors compared in the current study is presented in Figure 3. The results have been recorded in accordance with ISO 9806-1:1994.

The flat plate solar collector with TIM in this work is addressed as a further development of the collector proposed at Kizildag et al. 2022, and the main difference is the insulation with aerogel. The ventilation channel is set behind the absorber since there will be barely an air gap inside the collector. The TIM used is cellulose triacetate, which has a melting point of 120-160◦C. And yellowing and embrittlement can already be observed at temperatures above 100 ◦C (see Kizildag et al. 2017). The aerogel used here has a thermal conductivity of 0.01 W·m−1K −1, a density of 0.1 g/cm3. After the absorber is fixed above the insulation, the aerogel will be tiled above the absorber with a thickness of 2 cm. Since the aerogel is in the shape of particles and the collector is inclined, an auxiliary structure should be placed to fix the aerogel layer. Seven polyurethane barriers are attached above the absorber with the same thickness as the aerogel, and another tampered glass (same as the cover) is placed on top of the aerogel and barriers, as shown in Fig 4a. And the TIM material is glued to the cover, then the cover will be fixed with the support structure. The cover should not be directly placed above the first layer of glass since the absorber may form curvature and affect the horizontal level, a small air gap (<1cm) between the first layer of glass and TIM should always be considered. Finally, the collector should be well insulated. Finally, the collector should be well insulated, as shown in Fig 4(b). The picture was taken several days after the installation of the solar collector, from which it shows clearly the aerogel above the absorber is fixed well.

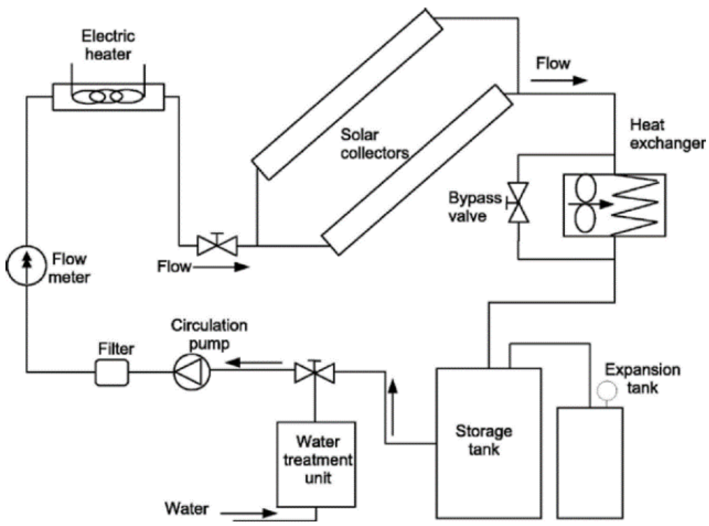


Fig. 3: Test bench used for the characterization of the solar thermal collectors

(a) (b)

Fig. 4: Solar collector with TIM and Silica aerogel, (a) shows the silica above the absorber with a thickness of 2cm (b) represents the collector with TIM after insulation and installation.

3. Experimental Results

The experimental results of the previous solar thermal collectors depicted in Figure 1 and the new proposal shown in Figure 2 can be seen in Figure 5. The honeycomb with silica layer without containers (previous version) has worst performance in the comparison since the reduction of the optical efficiency is not compensated with the reduction of the first and second order coefficients. In other words, the reduction in the transmittance produced by the glasses of 0.92 transmittance and the silica layer cannot be compensated with the reduction of the heat losses produced by the silica aerogel. Moreover, the silica aerogel presented important problems related to compactness that will be discussed later in section 4.

The proposed collector, represented in Figure 4, overcome the honeycomb collector when $(T_m - T_a)/G > 0.08$ area. This important finding demonstrates the applicability of the silica aerogel to obtain high efficiency collectors and that the technical difficulties could be overcome using containers to maintain silica compactness and shape.

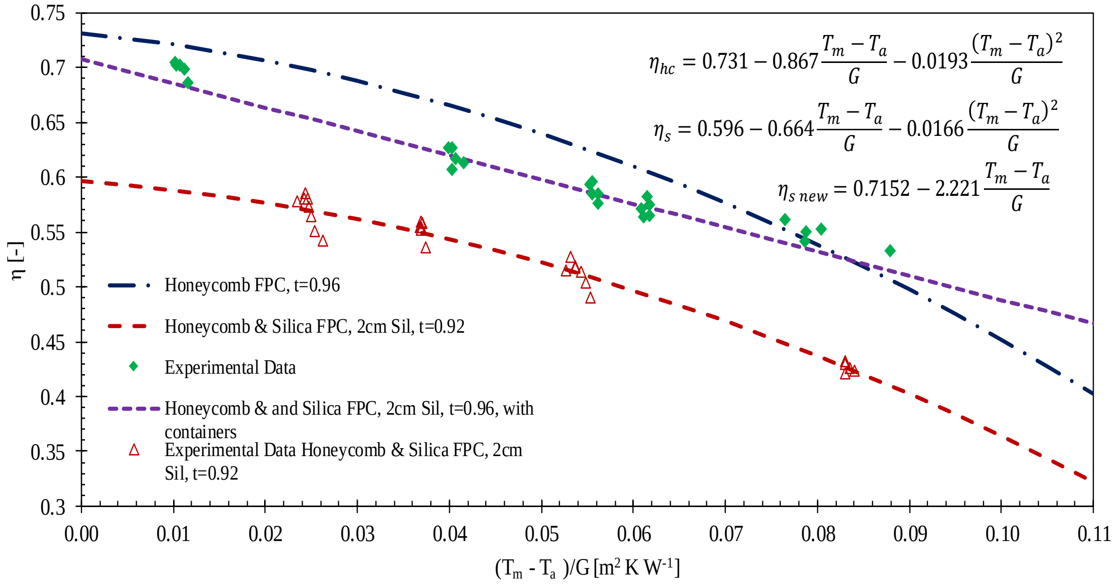


Fig. 5: Efficiency of the honeycomb FPC and the honeycomb with silica FPC collectors based on aperture area

The curve is flattened quite importantly due to the silica effect on the heat losses. Additionally, the improved compactness of the silica played a vital role in the results as will be discussed in the following section.

4. Discussion

The first version of silica aerogel with honeycomb FPC presented silica compactness related issues consequence of manufacturing the FPC without considering the movement of the silica aerogel granulates inside the collector. The implementation of containers to strategically locate silica for the second version is justified with Figure 4, since the flatness of the curve is improved. Previous design without containers struggled in containing properly the silica on the top side of the collector. Thus, the heat losses in the hottest part of the FPC were high. During the manufacturing of the new version of the collector the air-silica compactness ratio was taken importantly in consideration. The higher the stability of the silica inside the collector and the less air contained inside, the better the efficiency to be achieved.

It can be observed that although the silica-honeycomb collectors' optical efficiency is low when compared to the pure plastic honeycomb TIM collector, its efficiency becomes greater in the $\Delta T/G > 0.08$ region.

When the performance of the two versions of combined silica aerogel/plastic honeycomb TIM high performance FPC are compared. It cannot be neglected the relevant effect of using high transmittance glass in the present collector (0.96) compared to the one in the previous version (0.92).

An important aspect to be improved for the next versions of the new collector, is the optimization of the useful area, as the polyurethane bars that contain the silica aerogel occupy part of the collector area (now about 15%).

5. Conclusions

In this work, the performance of a new concept of high performance Flat Plate Collector (FPC) based on Transparent Insulation Materials (TIM) combining silica aerogel contained in insulation containers with plastic honeycomb is evaluated. The current study demonstrates that including silica aerogel without considering its compactness is not a success approach. Thus, properly compacting the silica can improve efficiency of a previously developed plastic honeycomb TIM for high temperature applications (at $\Delta T/G > 0.08$). Another important lesson learned is that a high transmittance glass cannot be avoided since the silica aerogel decreases optical performance, which is not enough compensated flattening the efficiency curve at high temperatures to have a competitive FPC.

6. Acknowledgments

Sponsored by the SUDOKET – SOE2/P1/E0677 project under the Interreg-Sudoe program.

7. References

Ammar, M., Mokni, A., Mhiri, H., Bournot, P., 2022. Parametric investigation on the performance of natural convection flat plate solar air collector with additional transparent insulation material parallel slats (TIM-PS). Solar Energy, 231(November 2021):379–401.

Beikircher, T., Berger, V., Osgyan, P., Reuß M., Streib, G., 2014. Low-e confined air chambers in solar flat- plate collectors as an economic new type of rear side insulation avoiding moisture problems. Solar Energy, 105:280–289.

Bellos, E., Tzivanidis, C., 2018. Performance analysis and optimization of an absorption chiller driven by nanofluid based solar flat plate collector. Journal of Cleaner Production, 174:256–272.

Kessentini, H., Capdevila, R., Castro, J., Oliva, A., and Bouden, C., 2014. Three dimensional heat transfer analysis of combined conduction and radiation in honeycomb transparent insulation. Solar Energy, 105:58–70.

Kessentini, H., Castro, J., Capdevila, R., Oliva, A., 2014. Development of flat plate collector with plastic transparent insulation and low-cost overheating protection system. Applied Energy, 133:206–223.

Klier, S., Klier, Z., Adel, M., Efron, R., TIGI LTD., 2014. System and method for temperature limiting in a sealed solar energy collector (US Patent Number 8857426B2) Mark M. Friedman. URL: https://patentimages.storage.googleapis.com/48/43/73/b224ddbdaebbc0/US8857426.pdf

Kizildag, D., Castro, J., Kessentini, H., Rigola, J., Oliva, A., 2017. Development, optimization and test performance of highly efficient flat plate solar collector with transparent insulation and low-cost overheating protection. In ISES Sol. World Congr. 2017-IEA SHC Int. Conf. Sol. Heat. Cool. Build. Ind. 2017, Proc, pages 2031–2042.

Kizildag, D., Castro, J., Kessentini, H., Schillaci, E., Rigola, J., 2022. First test field performance of highly efficient flat plate solar collectors with transparent insulation and low-cost overheating protection. Solar Energy, 236(December 2021):239–248.

Osorio, D., Rivera-Alvarez, A., Girurugwiro, P., Yang, S., Hovsapian, R., Ordonez, C., 2017. Integration of transparent insulation materials into solar collector devices. Solar Energy, 147:8–21.

Ranjith, V., Karim, A., 2016. A Comparative Study on the Experimental and Computational Analysis of Solar Flat Plate Collector Using an Alternate Working Fluid. Procedia Technology, 24:546–553.

Sharma, K., Sharma, C., Mullick C., Kandpal C., 2017. Solar industrial process heating: A review. Renewable and Sustainable Energy Reviews, 78(January):124–137.

Sokhansefat, T., Kasaeian, A., Rahmani, K., Heidari, A., Aghakhani, F., Mahian, O., 2018 Thermoeconomic and environmental analysis of solar flat plate and evacuated tube collectors in cold climatic conditions. Renewable Energy, 115:501–508.

Tian, Y., and Zhao CY., 2013. A review of solar collectors and thermal energy storage in solar thermal applications. Applied Energy, 104:538–553.

Wu, L., Zhao, B., Ao, X., Yang, H., Ren, X., Yu, Q., Guo, K., Hu, M., and Pei, G., 2021. Performance analysis of the aerogel-based PV/T collector: A numerical study. Solar Energy, 228(September):339–348.

Zhou, L., Wang, Y., Huang, Q., 2019. Parametric analysis on the performance of flat plate collector with transparent insulation material. Energy, 174:534–542.

Appendix: Units and Symbols

Table 1: Symbols for properties

Preferred name	Symbol	Unit
Temperature	T	K
Thermal conductivity	K	W m^{-1} K^{-1}
Thickness	E	m
Efficiency	η	
Solar irradiance on FPC	G	W m^{-2}

Table 2: Suffixes for properties

Suffixes	Symbol
Flat plate collector	FPC
Stationary compound parabolic collectors	CPC
Fresnel lens collectors	FLC
Small parabolic trough collectors	PTC
Cylindrical trough collectors	CTC
Sil	Silica Aerogel
Honeycomb	TIM
Absorber	abs
Ambient	a
Absorber fluid inlet	i
Outlet	o