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Characterization and energy performance of a slurry PCM-based solar thermal collector: a numerical analysis

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Abstract

Flat plate solar thermal collector is the most common technology for solar energy conversion at the building scale. This technology has been established since long time and continuous developments have been achieved as time passed by; significant improvements of flat plate solar thermal collectors are thus now limited.
A novel approach to increase further the performance of this technology is based on the exploitation of the latent heat of the heat carrier fluid. In order to assess this strategy, a previously developed numerical model of flat plate solar thermal collector with slurry PCM as heat carrier is herewith used to simulate the technology. The characterization and energy performance of such a system are herewith presented, based on the outcome of the numerical analysis. The results demonstrate that the novel approach is able to improve the performance of the system under different boundary conditions and in different climates: the improvement in the instantaneous efficiency is in the range 5-10%, while during the winter season the converted heat by the slurry PCM-based system is 20-40% higher than that of a conventional water based solar collector, depending on the climates – the colder the climate, the larger the improvement.

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Keywords: slurry PCM ; flat plate solar thermal collector ; numerical simulation ; parametric analysis ; energy performance

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Nomenclature

A_{col}	frontal area of the flat plate solar collector	[m^2]
c	specific heat of the heat carrier fluid	[kJ/kg K]
Δy_1	length of the virtual section 1	[m]
Δy_2	length of the virtual section 2	[m]
Δy_3	length of the virtual section 3	[m]
G_T	solar irradiance impinging on the flat plate solar collector	[W/m^2]
F_R	collector heat removal factor	[-]
F''	collector flow factor	[-]
η	conversion efficiency of the collector	[-]
$\dot{m}$	heat carrier flow rate	[kg/s]
μ	dynamic viscosity	[Pa s]
$\dot{Q}_u$	useful heat flux	[W]
$\dot{Q}_{u,1}$	useful heat flux in the virtual section 1	[W]
$\dot{Q}_{u,2}$	useful heat flux in the virtual section 2	[W]
$\dot{Q}_{u,3}$	useful heat flux in the virtual section 3	[W]
t	time	[s]
T_a	outdoor air temperature	
$T_{c,in}$	temperature of the heat carrier fluid at the inlet of the collector	[K or °C]
$T_{c,out}$	temperature of the heat carrier fluid at the outlet of the collector	[K or °C]
T_h	upper limit (higher temperature) of the phase change	[K or °C]
T_l	lower limit (lower temperature) of the phase change	[K or °C]
U_L	top loss coefficient	[W/m^2 K]
$(\tau\alpha)_e$	effective transmittance-absorptance	[-]

1. Introduction

Nowadays, flat plate collectors are the most common type of solar thermal collector and they have been investigated since long time [1]. As the efficiency of flat plate solar thermal collectors has been increased by means of different measures (e.g. improving the structure of the system and the properties of its materials), the possibility to further upgrade its performance has become more and more limited, and more expensive – a phenomenon known with the name of *Law of diminishing returns* [2].

Among the main constrains that present-day flat plate collectors show, some of them can be correlated to the mechanism that this technology exploits to remove energy from the flat plate: i.e. the exploitation of the sensible heat of the water-based heat carrier. This means that acceptable efficiencies are only reached when high irradiation levels occur, while with low irradiance their capability of exploiting solar energy is reduced. Moreover, when the water-based heat carrier fluid shows a relevant increase in its temperature (in case of high irradiation), which corresponds to a substantial exploitation of solar energy, the inefficiency of the process also grows due to the enhanced heat dissipation towards the outside.

The widespread adoption of solar collector in general, and of flat plate in particular, is also limited by the time mismatch between solar energy availability and energy demand: in winter time, low or limited solar irradiation can difficulty cover the energy demand for heating, while the abundant solar energy availability in summertime, which may results in a large amount of energy converted by solar collectors, cannot find a direct and profitable use – unless an expensive seasonal storage strategy is adopted.

An interesting concept to overcome the limitations given by present-day flat plate technology is represented by a breakthrough innovation in the architecture of the solar collector: the latent heat of the heat carrier can be exploited instead (or in combination with) the sensible heat of the carrier. This approach has been investigated some years ago [3-5], using a heat carrier fluid that undergoes a liquid-to-gas phase change. However, due to some drawbacks this type of phase change shows – e.g. the great change in the volume of the carrier, the need of dedicated pumps capable of dealing with both liquid and gas state – the interest in such an approach soon faded away.

Nowadays, thanks to the advancements in Phase Change Material (PCM) technologies (terms of both materials reliability and types of PCM), it is possible to conceive an alternative solution based on the solid-to-liquid transition of some of these materials. The idea is to make use of a particular heat carrier fluid (knows as slurry-PCM [5]) that is composed of a microencapsulated PCM (mPCM) suspended in a mixture of water and ethylene glycol. The main feature of this fluid mixture is that it shows constant macroscopic properties (fluid phase) regardless of the state of aggregation of the PCM contained into the microcapsules. In this way, when the heat carrier fluid flows inside the flat plate collector, the latent heat of the solid-to-liquid transition of the slurry-PCM can be exploited while the mixture still shows a fluid appearance.

These new fluid technology shows some advantages as far as both thermal storage and heat transfer fluids are concerned: high storage capacity during phase change coupled with the possibility of using the same medium to transport and store energy, as PCM slurries can pumped by means of dedicated peristaltic pumps. Moreover, they allow the flow rate to be reduced (with a positive impact on the pumping power demand) as a consequence of their higher heat capacity [6].

The analysis of the literature reveals the lack of evidences concerning advantages and disadvantages of the exploitation of solid-to-liquid transition in combination with solar collectors. Therefore, a dedicated investigation was planned, and it is currently ongoing, with the aim of deepening the knowledge and understanding of such a technology. This paper presents the second step of the research activity on a flat plate solar collector based on a slurry-PCM heat carrier fluid: after the first step was done (development of the physical-mathematical model), the characterization and the performance of the system are herewith presented and evaluated by comparison with those of a reference (conventional) flat plate solar collector.

It is worth mentioning that the investigation concerning the flat plate solar collector based on a slurry-PCM is part of a wider research activity, where the solar collector is coupled with a PCM-based heat storage unit and a secondary, water-based circuit aimed at supplying heat to the indoor environment for heating purpose. In this paper, the performance of the solar collector alone is illustrated within a wide range of different boundary conditions, while implications of the coupling with latent heat storage systems and low temperature heating systems are not discussed.

2. Material and methods

2.1. Physical-mathematical model

A dedicate physical-mathematical model of a slurry-PCM based solar thermal collectors have been previously developed by the same authors and implemented in a dedicated environment for numerical solution (MatLab-Simulink). For the sake of brevity, the detailed description of the simulation tool is not herewith given; the architecture of the model and its main assumptions are briefly resumed instead. In-depth explanation and equations of the model can be found in a previous work of the authors [7].

The main governing equation of the physical behaviour of the flat plate slurry PCM-based (sPCM) solar thermal collector is the energy balance equation of the flat plate (Eq. 1), which is based on the well-known Hottler-Willier model (HW):

$$\dot{m}_c c_c (T_{c,out} - T_{c,in}) = A_{col} F_R \left[G_T (\tau\alpha)_e - U_L (T_{c,in} - T_a) \right] \quad (1)$$

where the left-hand side of the equation represents the enthalpy flux of the single-phase heat carrier fluid and the right-hand side the useful heat flux ($\dot{Q}_u$) that is converted and delivered by the solar thermal collector. The main assumptions of the HW model that are adopted also in the numerical model of the slurry PCM-based solar collector, are:

- quasi steady-state (energy storage term is negligible);
- step updates of the forcing parameters at each time-step;
- ignored internal emissions;

- one dimensional heat flux through the covers and the back insulation;
- uniform conditions over the collector;
- all heat losses from the collector surfaces towards the same heat sink, at the outdoor air temperature Ta.

Moreover, as far as the numerical model of a slurry.PCM based collector is concerned, another relevant assumption was made:

- uniform temperature of the heat carrier fluid – i.e. the temperature of the mPCM is equal to that of the mixture of water and ethylene glycol.

The energy balance equation (Eq. 1) has been suitable modified in order to account for the multi-phase fluid, thus allowing the temperature of the carrier not to grow linearly with the internal energy level. The structure of the model has been changed and a new algorithm developed.

The new calculation procedure virtually divides, at each time-step, the solar thermal collector in three segments along the *y*-ax – i.e. along the riser tubes: one segment is that where the mPCM, contained in the slurry-PCM, is complete solid (Δy_1), one is that where the mPCM it is in transition (from solid-to-liquid, Δy_2) and one is that where the mPCM it is completely liquid (Δy_3). The three virtual segments, which in turn depend on the boundary condition of each time-step, are then compared with the real lenght of the riser tubes, and the actual temperature at the outlet (and the heat removed by the heat carrier) is calculated, following the scheme below.

- If the real length is less than Δy_1, then the slurry PCM leaves the solar collector when the mPCM is still in solid state, and the temperature of the slurry is lower than that where the phase change starts.
  The full set of equations of the HW model for the calculation of F_R and U_L are used in this case and the useful heat ($\dot{Q}_{u,1}$) is calculated by means of the left-hand side of Eq. 1, where $T_{c,out}$ correspond to the calculated temperature of the slurry PCM at the end of Δy_1.
- If the real length is less than the sum $\Delta y_1 + \Delta y_2$, then the slurry PCM leaves the solar collector when the mPCM is in the phase change range, and the outlet temperature is within the phase change range. The useful heat is obtained as the sum of the useful heat in section Δy_1 ($\dot{Q}_{u,1}$) and of that in section Δy_2. ($\dot{Q}_{u,2}$). The latter is calculated by means of a slightly different version of the left-hand side of Eq. 1, assuming that the heat carrier fluid temperature increases linearly.[†] in section Δy_2, between the two limit temperatures (T_l and T_h) of the phase change. The temperature of the slurry PCM at the outlet is calculated accordingly.
- If the real length exceeds the sum $\Delta y_1 + \Delta y_2$, (and thus it also includes Δy_3) then the slurry PCM has completely exploited the laten heat of fusion and the temperature of the slurry at the outlet is higher than that correspondent to the upper limit of the transition range. In this case, the useful heat is calculated as a sum of $\dot{Q}_{u,1}$, $\dot{Q}_{u,2}$ and $\dot{Q}_{u,3}$. The latter is again obtained by means of the left-hand side of Eq. 1, where $T_{c,out}$ correspond to the calculated temperature of the slurry PCM at the outlet and $T_{c,in}$ is the upper temperature of the phase change (T_h); the full set of equations of the HW model for the calculation of F_R and U_L are used in section Δy_3 too.

Some additional changes in some subsidiaries equations were also necessary to adapt the HW model to the nature of the heat carrier (a bi-phase, two components fluid). In particular, the formulation of Nusselt number was changed (a typical equation for a pseudo-plastic non-Newtonian fluid in laminar flow is used).

The efficiency of the solar collector was defined as (Eq. 2)

$$\eta = \left[\int \dot{Q}_u dt \right] \cdot \left[A_{col} \int G_T dt \right]^{-1} \tag{2}$$

where A_{col} is the frontal area of the solar collector, G_T is the solar irradiation impinging on the collector frontal area, and *t* is the time.

[†] Ideally, the phase change of a PCM is isothermal, if also isobaric. However, in practice, due to coformulant and additional components contained in the commercial grade PCM, the phase change is not isothermal but takes place within a certain temperature interval.

2.2. Physical proprieties of the slurry PCM heat carrier

The thermophysical properties of the slurry PCM heat carrier were obtained as the mass weighted average of the properties of the mPCM and of the glycol-water mixture (the solution). The most relevant thermophysical properties of the mPCM and of the solution are resumed in Tables 1 and 2, respectively. A carefully analysis of commercially available products was carried out in order to find the best mPCM suitable for the application in a slurry PCM-based solar thermal collector. Ideally, in the solar collector perspective, the lower the temperature of slurry PCM heat carrier, the lower the heat losses to external environment. However, considering that the solar collector is meant to be integrated in a heating system, a minimum temperature is necessary in order to exchange the solar converted heat with the indoor environment. This constrain led to the choice of a mPCM with a nominal melting temperature of (at least) of 37 °C – the combination with low-temperature heating system is supposed.

The selected mPCM (a commercially available produce) is based on a n-eicosane paraffin wax – i.e. the core of the micro-capsule is filled with this wax. The phase change of commercial grade n-eicosane takes place in the temperature range 35 ÷ 39 °C (i.e. T_l =35 °C, T_h = 39 °C). All the thermo-physical proprieties of the mPCM were obtained either from the literature [6] or from the manufacturer datasheet. The other component of the heat fluid carrier is a mixture of water and glycol – the mass percentage is 60% water – 40% glycol.

A detailed description of the features of the slurry PCM and of its nature, as well as of its rheological properties, would require a level of in-depth analysis that far exceeds the scope of this paper. For this reason, the topic is just briefly herewith resumed.

. Both the thermophysical and rheological properties of the slurry PCM depend on the concentration of the mPCM. While the former can be easily calculated as the mass weighted average of the properties of the two components of the slurry, the latter show a highly non-linear behaviour. Moreover, the choice of the ratio of mPCM to solution has a very relevant impact on the efficiency of the system: in fact it affects the relationship between pumping work and heat transfer, which has a deep implication on energy savings in real applications [8]. The concentration of the mPCM and the flow rate were thus chosen in order to reach a compromise between the heat transfer characteristics and the pressure drops of the fluid – a quite tricky trade-off, since the improvement a characteristic may cause the worsening of the other one. In particular, on one hand, a high concentration of mPCM increases the possibility of thermal latent storage of the material; on the other hand, it determines higher pressure drops due to the increased viscosity, which in turn means higher energy demand for pumping. However, higher thermal storage capacity also implies lower flow rate, and thus a reduction in electric energy demand from the pump.

Table 1. Specifications of the microencapsulated PCM.

Specification	Value
Core density	818 kg/m^3
Shell density	1190 kg/m^3
Mass percentage of the core	87.5%
Conductivity of mPCM	0.142 W/m K
Specific heat of mPCM	2025 J/kg K
Latent heat of mPCM	195 kJ/kg
Nominal melting temperature of mPCM	37 °C
Phase change range	35°÷39 °C

Table 2. Specifications of the other solution (water and glycol)

Specification	Value
Water density	1000 kg/m^3
Glycol density	1110 kg/m^3
Mass percentage of glycol	40%
Conductivity of mixture glycol-water	0.369 W/m K

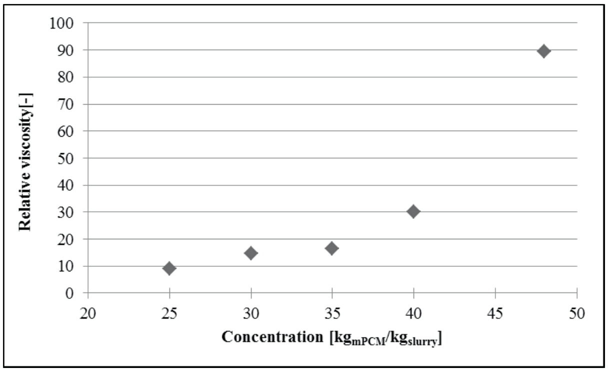

Fig.1. Experimental values of relative viscosity of mPCM n-eicosane in function of mass concentration – pressure drop test circuit results

The choice of the sPCM concentration cannot thus exclude a deep knowledge of the viscosity of the slurry. An empirical model for the prediction of the solid–liquid slurry dynamic viscosity was developed by Vand [9]. This model was used by many previous researchers in PCM slurry applications [10-11]. The law that regulates this phenomenon is non-linear and the viscosity shows a quick rise once a certain concentration value is reached. A dedicate investigation of the pressure drops of the sPCM employed in this paper was carried out in the lab, by means of a pressure drops test circuit. Different concentrations of the sPCM were tested and the results are in line with the behavior predicted by Vand law. Moreover, dynamic viscosity μ was measured, both by means of the above mentioned test circuit and of a reometer, and values found to be in the range 0.009 ÷ 0.09 Pa s, for sPCM mass concentration in the range 25 ÷ 50 %. The trend of the relative dynamic viscosity is shown in Fig. 1, where the non-linear behaviour or the material property is highlighted. The evidence suggests that for concentrations lower than 50% the fluid can flow quite easily, while some problems of excessive pressure drops and pipe clogging appear when higher concentrations are adopted.

The evidences collected during the rheological characterization allows the slurry PCM to be defined as a thixotropic, non-newtonian fluid, with a behavior similar to that of a Bingham fluid

2.3. Simulations

2.3.1. Characteristics of the flat plate solar thermal collector

Two flat plate solar thermal collectors were simulated by means of the codes implemented in MatLab/Simulink environment under different boundary conditions: one makes use of a conventional water-based heat fluid carrier (40% glycol, 60% water), while the other makes us of a n-eicosane mPCM slurry – mass concentration of the mPCM: 50%. The conventional solar thermal collector was modeled by means of the full set of HW model equations, while the one that employ slurry PCM as heat carrier fluid was simulated with the on-purpose developed numerical model [7]. A traditional flat-plate solar collector (Fig. 2), produced by an Italian company, was selected and its characteristics (Table 3) were used as input data in the two models.

2.3.2. Simulation runs and performance parameters

The characterization of the performance of the innovative (and reference conventional) solar collector was carried out by means of different runs of simulations, aimed at pointing out the different features, potentials and limitations of the proposed technology.

Firstly, the instantaneous conversion efficiency η under steady state conditions was assessed as a function of the outdoor air temperature T_a (from -15 °C to +40 °C, with a 5 °C step) and of the impinging solar irradiance perpendicular to the collector plane G_T (500, 800 and 1000 W/m^2). In this round of simulations, the flow rate of the heat fluid carrier $\dot{m}$ in the water-based solar thermal collector was set equal to $8.50 \cdot 10^{-6}$ m^3/s – i.e. the flow rate that determines F'' = 0.9 in case of G_T = 800 W/m^2 and T_a = 10 °C. The tilt angle of the panel was 45 deg.

The determination of the optimal flow rate for the slurry PCM is instead more complicated the PCM shows a non-linear behavior and the extracted heat depends on the combination of solar irradiance and flow rate.

Table 3. Specifications of the flat plate solar thermal collector

Specification	Value
Collector	2.1 m
Length	0.94 m
Width	0.1 m
Number of pipes	8
Internal diameter of the pipes	0.0062 m
Plate	
Thickness	0.0002 m
Absorption coefficient	0.95
Emission coefficient	0.05
Conductivity	390 W/m K
Cover	
Thickness	0.004 m
Emission coefficient	0.8
Cavity	
Thickness	0.24 m
Insulation	
Thickness (bottom)	0.05
Thickness (side)	0.025
Conductivity	0.036 W/m K

Fig.2. Flat plate solar collector used in the simulations

In order to maximise the efficiency in the case of slurry PCM, the criterion chosen to optimise the flow rate was to have the outlet temperature equal to the upper temperature of the melting range (i.e. 39 °C). This way all the material changes phase when it flows through the collector and the temperature does not rise over the melting range. Sensitivity analyses demonstrated that this phenomenon is not related to the outside temperature, but it is strongly dependent on the solar irradiance. Hence, different flow rate for different irradiances were found and used in the simulations – the slurry PCM flow rates were: 7.50×10^{-6}, 5.70×10^{-6} and 3.15×10^{-6} m^3/s, for solar irradiations G_T of 500, 800 and 1000 W/m^2 respectively.

Secondly, a sensitivity analysis aimed at assessing the influence of the nominal melting temperature of the mPCM was carried out. Different simulations were thus performed changing the nominal melting temperature of the mPCM (in the range 27 ÷ 47 °C), keeping a constant the 4 °C phase change range. The flow rate, both in case of the water-based and of the slurry PCM-based solar collector, was the same of the previous run of simulations. The temperature at the inlet of the two collectors and that of the outdoor air were set equal to 10°C. These assumptions were necessary in order to have the same boundary conditions. Nevertheless, this choice has an influence on the final results, since it affect the amount of sensible heat vs. latent heat gained in the different cases – e.g. when the melting temperature is low, a lower amount of solar energy is necessary to reach the melting range.

Thirdly, the yearly and seasonal (winter – heating season: 15 Oct. ÷ 15 Apr.) performances of the two solar collectors were assessed for different climates in Europe: Palermo, Italy (CSA climate), Torino, Italy (CFA climate) and Frankfurt (CFB climate) were the locations chosen for this analysis – the Köppen climate classification is adopted in this paper [12]. In this round of simulations the solar collector was south-oriented and had a tilt angle equal to the latitude of the locations; the nominal melting temperature of the mPCM was 37 °C. The useful heat productions of the two systems were computed and compared. Annual/seasonal efficiencies were also calculated.

Finally, the influence of the azimuth angle on the annual efficiency of the solar collectors was also assessed. For this purpose, simulations were carried out only in one climate (Torino, CFA) and the azimuth angle spanned in the range -90 (East) ÷ +90 deg (West). – tilt of the solar collector: 45 deg.

3. Results

In Figure 3 a) the instantaneous efficiency of the slurry PCM-based and of the water based solar collector are plotted, for different outdoor air temperature and different solar irradiance. The results show that the conversion efficiency of the slurry PCM-based solar collector is always higher than the reference technology. The difference between the efficiencies of the two systems is in the range + 0.06-0.08, regardless of the boundary conditions. This means that the useful heat converted by the slurry PCM system is always higher than that of the reference. As expected, following the behavior of a conventional system, the slurry PCM-based collector (transition temperature of mPCM = 37 °C) shows an increase in the efficiency when the outdoor air temperature rises. Moreover, the improvement with respect to the water based system grows as the outdoor temperature rises too. It holds:

$$\frac{\partial \eta_{slurry}}{\partial T_a} > \frac{\partial \eta_{water}}{\partial T_a} \tag{3}$$

This phenomenon is probably due to the fact that the latent heat of the slurry PCM is more easily reached when the outdoor air temperature is high and that, when the sensible heat alone of the slurry PCM is exploited, the water based solar collector shows a better performance ($c_{water} > c_{slurry}$).

In Fig. 3 b) the different temperature at the outlet of the solar panels are shown. While the conventional technology presents an increase in the outlet temperature as the outdoor temperature rises, the slurry-PCM at the outlet of the panel shows a constant temperature (close to the upper limit of the phase change). This is due to the fact that different flow rates were adopted, as explained in section 2.3.2. It is important to highlight that, even if the outlet temperature of the slurry PCM heat fluid carrier is lower than the water based one, the amount of heat contained in it is higher than that extracted by the conventional heat fluid carrier – $\eta_{slurry} > \eta_{water}$, cf. Fig 3 a). This feature is the key property of the proposed technology, whose aim is to convert more heat at a lower temperature.

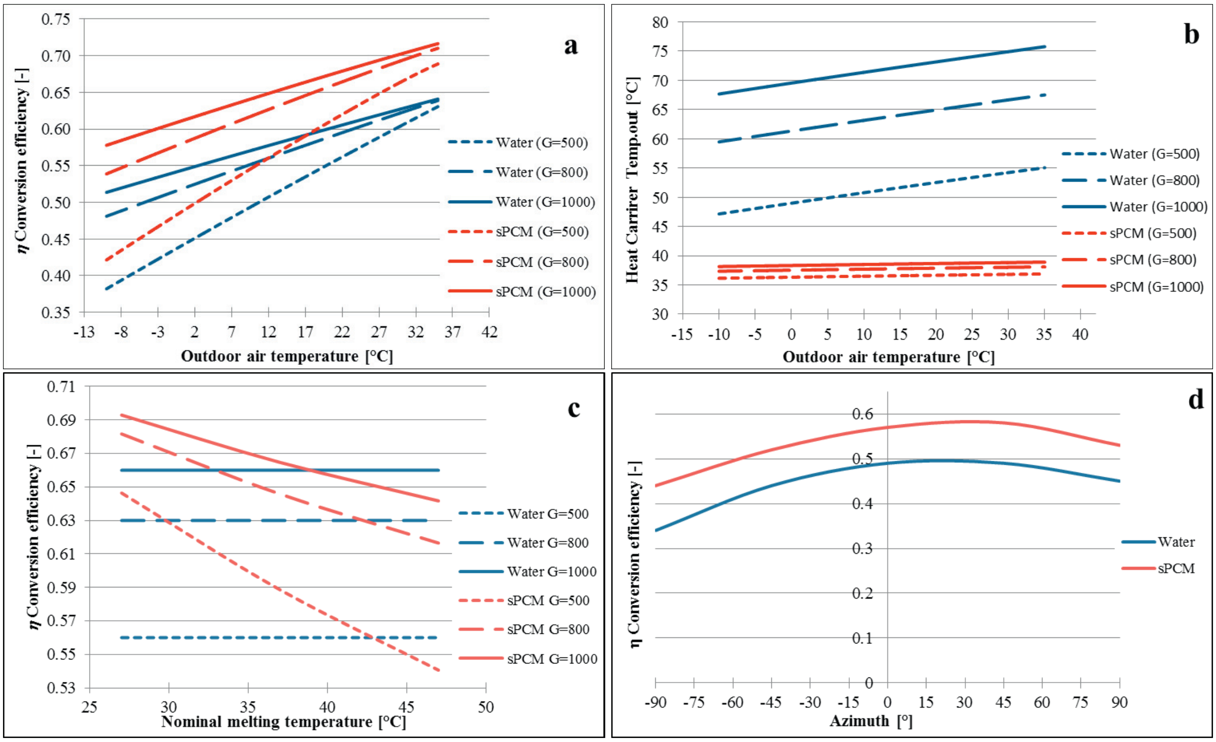

Fig. 3. (a) conversion efficiency ; (b) outlet temperature of the heat carrier fluid; (c) conversion efficiency with different mPCM nominal melting temperature; (d) annual efficiency vs. azimuth angle (CFA climate, Torino, Italy)

In Fig. 3 c) the influence of the nominal melting temperature of the mPCM is shown. It points out that the slurry PCM-based systems can show a better conversion efficiency than the conventional one, but a careful selection of the nominal melting temperature of the mPCM must be done. The optimal value of this parameter depends on the combination of the solar irradiance, outdoor air temperature and temperature at the inlet. In particular, it is shown that the improvement of the efficiency is higher when a mPCM with low values of nominal melting temperature is adopted. However, as mentioned in section 2.2, there is a lower limit of this value below which the practical application of the system for heating purpose is jeopardized. The chart also shows that, for the given boundary conditions, the slurry PCM-based systems shows a better improvement in the efficiency when there are low irradiation levels – a result in line with the expectations and a desired feature of the system. The charts also highlight that, if a non-optimal melting temperature is selected, the efficiency of the slurry PCM-based system may be lower than that of the reference technology. As previously explained, this phenomenon is due to the fact that if the sensible heat of the slurry PCM is primarily exploited instead of the latent heat, the performance of the system is worse than that of the water based system.

In Fig 3 d) the annual conversion efficiency of the slurry PCM and reference collector in Torino (Italy) are plotted as a function of the azimuth angle. The slurry PCM system shows a better performance, regardless of the orientation. It is worth mentioning that the maximum efficiency is reached when the azimuth of the panel is approx. 20 deg. and 35 deg., for the reference and the slurry PCM system, respectively. If the two best orientations are considered, the efficiency of the slurry PCM technology is approximately 0.1 higher than the conventional system.

Annual and seasonal conversion efficiency was also calculated for different locations (Tab. 4). It is remarkable that, while the annual efficiency increase of approx. 0.07 regardless of the climates, the heating season efficiency always shows a higher increase – + 0.14, +0.08 and +0.10, in Palermo, Torino and Frankfurt, respectively. This non-linear beahviour can be due to the combination of nominal melting temperature of the mPCM and of boundary conditions. In Fig. 4 the useful converted heat during the heating season is plotted, for the innovative and the reference technology. The increase in the extracted heat spans in the range +20% ÷ +40%, with the highest increase in the coldest climate (Frankfurt). This reveals that the technology is particularly promising in cold climates, where even if the seasonal efficiency is still lower than in other, warmer location, the highest percentage increase in the converted heat is achieved.

Table 4. Annual and seasonal conversion efficiency in different locations

City	Climate [12]	*η annual*		*η heating season*	
		water	sPCM	water	sPCM
Palermo	CSA	0.46	0.53	0.67	0.81
Torino	CFA	0.45	0.52	0.35	0.43
Frankfurt	CFB	0.38	0.45	0.25	0.35

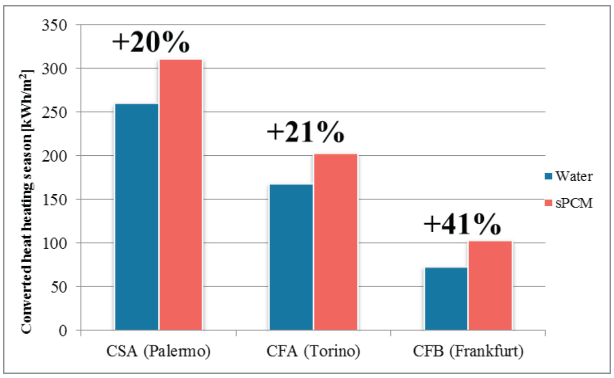

Fig. 4. (a) Converted heat during the heating season for different climates.

4. Conclusion

The results of the numerical characterization and performance analyssi of the slurry PCM-based solar thermal collector demonstrates that this system presents promising energy efficiency improvements, at least from the theoretical point of view. On average, the instantaneous efficiency can increase up to +0.08 if compared to a conventional, water based technology.

A sensitivity analysis on the influence of the nominal melting temperature of the mPCM reveals that a careful optimization of this property should be done – the match between the climate (or boundary conditions) and the nominal melting temperature of the mPCM is very relevant, and a "wrong" value may jeopardize the good performance of the slurry PCM-based collector. Further optimization of the performance is thus possible by searching a better tuning between locations, flow rate and PCM melting temperature.

The converted heat by the innovative system, both during the entire year or in the heating season alone, is always much highe (+20% ÷ +40%) than the one of the reference, water based technology; moreover it is shown that the temperature of the slurry PCM heat carrier fluid is always lower than that of the water solution one (keeping constant the amount of energy stored in the carrier). These features show the promising application of this concept in combination with low-temperature heating systems.

It is worth mentioning that the system also shows some limitations: it is impossible to work with mPCM concentrations above 50 %, pumping energy demand is probably increased compared to a conventional system and technological issues as far as the slurry PCM is concerned (segregation, durability) need to be sfurther investigated.

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