Experimental Investigation of Sustainable Low-Cost Thermal Energy Storage Materials for Solar Water Heating

Rihab Elassoued, Romdhane ben Slama

Abstract: An experimental study was carried out under climatic conditions of Gabes, Tunisia to evaluate the thermal performance of four innovative materials (sand, clay, concrete, PCM) as storage meduim integrated in a solar water heater. The four solar water heaters prototypes are realized then installed on site. The parameters followed in this study are the outlet water and the ambient temperature and the solar flux received according to two different inclinaison angle. A various temperature and thermal performance curves show the experimental results obtained during the measurement day (summer period). The vertical position of the solar collector shows positive results that ensure the hot water needs in the winter and avoid the overheating in the summer. All tested materials give an acceptable thermal effeciencies above 50% similar to that of the conventional system and reach a high water temperature value of 80°C. More than their thermal performance, clay and concrete have other advantages. Clay can be recycled and concrete can be integrated into the facades of a building. Whence, this investigation proves that the thermal storage materials tested during this work present a promising alternative offering the simplicity of manufacture and using low cost, local and available materials.

Keywords**: *Solar water heater, thermal energy storage, sustainable materials, low-cost materials, Clay, Concrete, Sand, PCM.***

I. INTRODUCTION

Today, the production of domestic hot water is a vital need. However, its production is still ensured by conventional energy (gas, electricity). This form of energy has several drawbacks. It is limited, polluting and harmful to the planet. Regarded this reason, the energy transition towards other sources of cleaner, renewable and free sources becomes a necessity and offers an adequate solution [1]. Especially since the benefits of the use of renewable energy technologies affect various aspects: energy saving, reduction of pollutant discharges to the environment as well as local jobs [2]. Tunisia, with an average solar flux in winter of 3,5 Kwh/m^2/d and 8kWh/m^2/d in summer [3], and all high radiation potential countries are favorable for this energetic transition. One largely used system in thermal applications is the solar water heater. A solar water heater contains essentially two elements: the absorber and the thermal storage. The absorber capture solar radiation, transform it into thermal energy "heat" and transfer it to the heat transfer fluid and the thermal storage allows storing the excess of thermal energy and releasing it at night or during the non-sunny period of the day. Depending on the position of the storage tank, we can differentiate between separate elements solar water heater, thermosyphon water heater and the integrated solar water heater. Several authors have conducted studies on solar water heaters, Smyth (2004) which has summarized their history through the various stages of development of the solar water heater from the water heaters with a simple flat plate collector to the heaters with improved collector [4], as well as the CPC concentration collector and those using an exchanger with a refrigerant ensuring the return of heat to the storage tank [5]. Other researchers have tried to improve the performance of solar water heaters by reducing nocturnal heat losses such as Mohamed (1990) who has introduced a thermal diode to prevent the circulation of water in reverse thermosiphon [6]. The thermal performance of a concentrated solar collector has been evaluated by Souliotis and Tripanagnostopoulos (2003) [5]. Siddiki (1993) [7] and Faiman (2001) [8] have carried out studies on a plate collector with integrated storage. Indeed, several works are performed on the solar collectors and their thermal performances but scarce are the works carried out on thermal storage and the innovation of other ways of heat storage. Heat storage allows removing the major exploitation handicap of the new renewable energy systems particularly solar energy systems and to make possible their use at any time, whenever needed and in particular for the period when the source is intermittent or unavailable regularly. Generally, all conventional solar water heaters use water as storage medium. Khalifa and Jabbar have investigated divers heat exchanger shape[9]. While solar thermal storage can be ensured with two modes either by latent heat or by sensible heat. Researchers have carried out various technologies and materials for thermal storage. However, these materials are expensive [10]. Related to this view, this work aims to evaluate experimentally four innovative materials (concrete, clay, sand and PCM) as storage medium for a solar water heater with integrated storage focused on their thermal performance and to compare them to the classic system which is composed by a metallic absorber surface and a water thermal storage tank.

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These materials have been chosen in fact of their good thermal storage qualities, low cost, ease of handling. The novelty of this work is to use a local available. low cost and durable heat storage materials (Clay, Concrete, Sand and PCM) as an alternative storage medium for an integrated solar water heater, in order to improve their lifespan and to facilitate their use.

II. DESCRIPTION OF THE EXPERIMENTAL SET UP AND TEST PROCEDURE

A. The experimental prototype

In the present work, an experimental study is carried out on four prototypes of solar water heaters with integrated storage. The construction of these prototypes is based on the use of innovative materials to store thermal energy. The main problem with the use of the conventional solar water heaters is that they deteriorate for corrosion and require continuous maintenance of the system. In addition, the use of water in metal tanks to store thermal energy has been replaced by clay, sand, concrete and paraffin used as phase change materials (PCM). The experimental device shown in Figure 1 is a flat plate water solar thermal collector with an integrated storage system, it consists essentially of a double polycarbonate glazing collector with a thickness of 6mm. A gap of 15 mm is maintained from the glazing to the absorber of 50mm of thickness which also represents the storage volume, a layer of expanded polystyrene insulation material are used to reduce thermal losses through the bottom and side walls, (the thermal conductivity and the specific heat of the expanded polystyrene are equal to 0.034 W/m K and 0.36 kJ/kg K). The heat exchanger geometry contains copper serpentine tube with inner diameter of 12 mm and outer diameter of 14 mm immersed inside the storage material. The wood support is designed to hold the solar thermal collector and to enable it to be oriented ($\gamma = 360$ °) and inclined ($0 \leq \beta \leq 90$ °).

Fig. 1. A photograph of one of the solar water heaters.

The novelty of these prototypes is essentially twofold. At the heat exchanger, the conventional collector is equipped with a tubular exchanger, which is welded to two horizontal tubes fixed on the absorber to ensure the flow of the heat transfer fluid, causing leaks at the welding point. Although our prototypes consist of a single serpentine tube immersed in the storage material. At the storage tank which is both the absorber, the water has been replaced by innovative materials which are not corrosive, thus ensuring an equipment with a longer service life and maintenance-free. So we have ensured simplicity of manufacture, use and maintenance. The characteristics of the storage materials are grouped in the table below.

Table 1. characteristics of storage materials [11-15].

Properties	Clay	Concrete	Sand	PCM (solid paraffin)
Thermal diffusivity D (10^{-6}. m^2/s)	1	0,54	0,2	0,2
Thermal conductivity λ (W/m.K)	1,28	1,75	0,27	0,24
Specific heat Cp (J/Kg. °C)	880	880	835	2000
Density ρ (Kg/m^3)	1450	2300	1650	814

B. Test procedure

The solar thermal collector is installed on an open site away from obstacles to avoid the mask effect whose geographical coordinates are:

Longitude L = 10 ° 6'36″

Latitude φ = 33 ° 52'48″

Altitude l =1 m

The collector is oriented to the south with azimuth angle a = 0 ° and inclined in two different positions. The choice of the collector inclination angle is made in such a way as to proceed with an angle equal to the work site latitude incremented by about ten degrees and a vertical position. The inclination angle of the collector is a determining factor which directly influences the density of solar flux received and the heat transfer fluid flow. Thus, most of the collectors operate in an inclined position to intercept the maximum of energy. The test is carried out in June under real operating conditions (fig. 2). For the purpose of experimental testing, K-type thermocouples ± 0.5°C uncertainties are used to monitor the behavior of temperature rise inside the solar water heater and the ambient temperature. In this work, we tested the effect of the collector tilt while making two measurement companions depending on the tilt angle. The 1st test is performed with a 45° slope in continuous measurement for three successive days. In the 2nd test, the collectors are positioned vertically (tilt angle is 90 °) in continuous measurement for two days.

Fig 2. A photograph of the five solar water heaters prototypes on site.

III. THEORETICAL MODEL

A. Solar flux determination

The design and sizing of an installation using solar collectors as well as for the evaluation of the energy performance of an existing installation, it is important to measure the incidental solar energy. However, many laboratories are not equipped with material of measurement of solar radiation received by the solar collector plane which they use in their study. Two solutions are envisaged, either using the closest weather stations data measured on an horizontal plane and adopting them according to conversion formulas for an inclined plane given by various authors such as Afedes Memoso [16], Duffie-Beckman [17] or the estimation of the incident solar flux using a theoretical model. In this work, we used the Bernard-Menguez-Schwartz model [18] which is an empirical model to calculate the amount of energy received by the collectors of our prototypes inclined at an angle "i" from the horizontal. We succesively calculate :

The solar latitude or the height of the sun "h" is given at any moment by :

$$\sin(h) = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos AH$$

(1)

At true solar midday:

$$h = 90 - \varphi + \delta \qquad (2)$$

The angle "u" formed between the normal of the collector and the solar rays at solar midday :

$$u = 90 - (i + h)$$

(3)

The variation of the solar declination is given by equation 4 or by a recapitulatif table (table 2):

$$\delta(t) = 23,45° \sin[0,980(n + 284)] \qquad (4)$$

The direct radiation (coming directly from the sun and not from the atmosphere) under clear sky:

$$I_D = 1230 \exp\left(\frac{-1}{3,8\sin(h+1,6)}\right) \qquad \text{(W/m2)}$$

(5)

Diffuse radiation (emitted by the atmosphere and clouds) received by the horizontal plane under clear sky :

$$D_H = 125(\sin h)^{0,4}$$

(6)

Total radiation received by the horizontal plane :

$$G_H = D_H + I_D.\sin(h)$$

(7)

Table 2: Monthly average solar declination

Month	January	February	March	April
$\delta(t)$	-20,8	-12,7	+1,9	+9,9
Month	May	June	July	August
$\delta(t)$	+18,9	+23,1	+21,3	+13,7
Mo	September	October	november	december
$\delta(t)$	+3	-8,8	-18,4	-23

The diffuse radiation received by the titled plane collector :

$$D(i) = \frac{1+\cos i}{2}.D_H + \frac{1-\cos i}{2}.G_H.a \qquad (8)$$

For a vertical wall (i=90) :

$$D(90) = D_H/2 + G_H.a/2$$

(9)

Finally, the overall radiation received by the titled plane of the collector:

$$G_{(i)} = I_D.\cos(u) + D(i)$$

(10)

To validate the computed values according to the model of Bernard-Menguy-Schwartz, we will compare them with the data measured by the Gabes weather stations data measured on a horizontal plane.

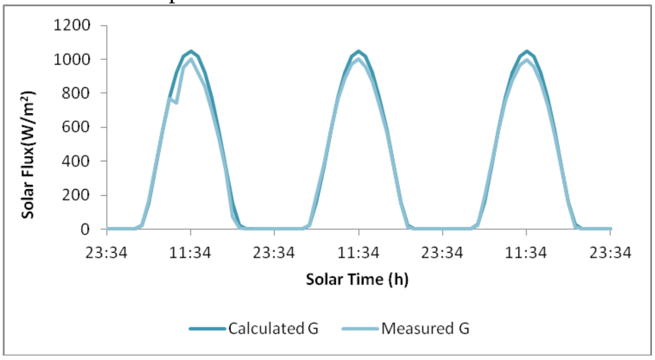

Fig.3. The evolution of solar flux measured and calculated on a horizontal plane for 3 successive days (06-07-08 of June).

As the three days of measurement are successive days, the solar flux values are practically the same. Figure 4 represents the variation of the relative error between the calculated and measured values as a function of time for a measurement day. The relative error can take positive and negative values represented respectively by the overestimation and the underestimation of measured values with those calculated. The time error remains inside the limits of 6% and for the entire day the calculated values exceed those measured by less than 0.5% which is truly satisfactory measurements.

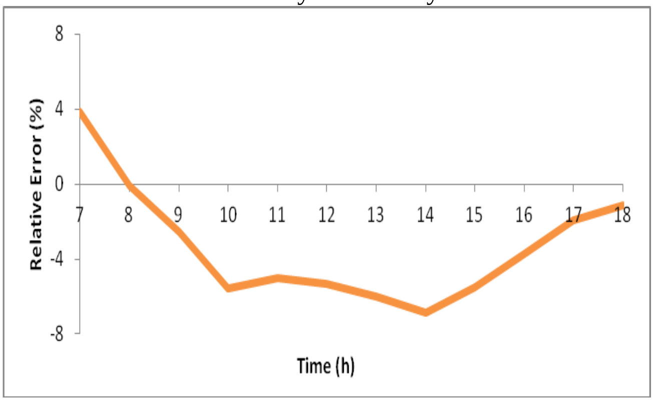

Fig.4. Relative error instant variation..

B. Collector energy efficiency [19]

The collector performance is determined by the Input-Output method. It is called the black box method and consists of letting the collector get hot all the day by solar radiation. outlet water temperature and the solar flux density intercepted by the collector are taken every hour.
The instantaneous energy yield of the collector is defined as the ratio between the energy recovered by the collector (stored heat) and that absorbed (solar radiation incident on the surface of the sensor).

$$\eta = \frac{\text{Useful thermal power per m}^2 \text{ of the collector}}{\text{incident solar flux on the collector surface}} \quad (11)$$

$$\eta = \frac{m.Cp.\Delta T}{S.G.\Delta t}$$

(12)

$$\eta = \eta_0 - U.\frac{\Delta T}{G}$$

(13)

C. Heat loss coefficient [20]

To determine the heat loss coefficient, the system is heated up throughout the day then the hot water and the ambient temperature are measured at 7 p.m. Next, the water cools overnight then the water and the ambient temperature are taken at 6 a.m.

$$U = \frac{\rho.Cp.v}{\Delta t}.\ln(\frac{T_i - T_{am,i}}{T_f - T_{am,f}})$$

(14)

IV. RESULTS AND DISCUSSION

In order to evaluate the solar water heaters efficiencies a two series of experimental trials are performed according to the collector inclinaison angle. These measurements consist on raising the ambiant and the outlet water temperature every hour for three sucssevies days on July for the first test with 45° inclinaison angle and for two successive days in July for the second test with a vertical position under climatic conditions of Gabes, Tunisia.

A. 45° Collector tilt angle

The variation of solar radiation is plotted in Fig. 5. In fact, the solar flux curve followed the same shape during the 3 days of measurement. It increases in the morning and becomes significant between 9 a.m. and 3 p.m. reaching a maximum value of around 1000 W/m^2 at noon, and then it decreases towards the end of the day.

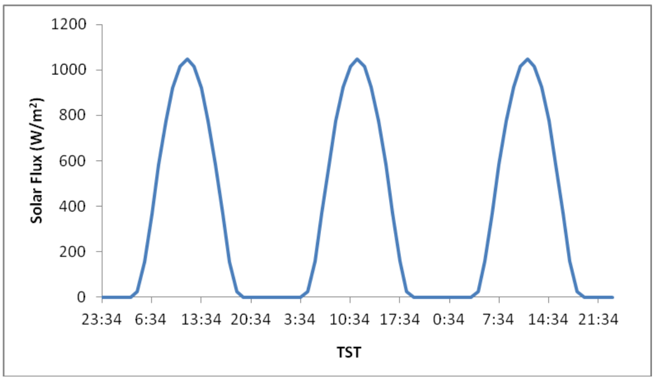

Fig.5. Evolution of the solar flux as a function of TSV for 3 mesearement days (06-08/June).

Figure 6 shows both evolution of ambient and outlet water temperature during three successive days (06/07/08) of June. The ambient temperature varies over time for a minimum of 18.5 °C at 6 a.m to maximum of 29.3 °C at 1p.m. Moreover, the outlet water temperature for the different storage materials increases and decreases in accordance with the shape of solar irradiance curve with a slight shift in the maximum get time however it reach its maximum between 1p m et 3p m depending on the materials.

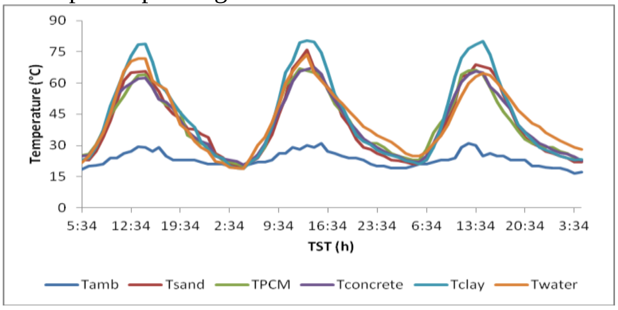

Fig.6. Variation of the ambient and the outlet water of different materials vs solar time.

The difference between the outlet water temperature for the various collectors and the ambient temperature is around 25°C, which is very significant with the simplicity of the system. For most part of the day the solar water heaters with innovative thermal storage materials (Clay, Concrete, Sand, PCM) are having a sufficient temperature for hot water exploitation compared to the conventional system that stores the thermal energy exceed using a water tank. Hot water is available at over than 40°C since the early hours of the day. The maximum temperature values reached by clay, concrete, sand, PCM ant the conventional solar water heater are respectively 80,3°C, 67,6°C, 76°C, 67°C and 73,6°C. The outlet water temperature of the solar water heaters prototypes increases by a few degrees for the 2nd and 3rd day regarding to the first day. The solar water heaters with innovative thermal storage materials don't heat up water with the same temperature evolution shape. Some heat up quickly while others heat up slowly. In addition, some store heat for a long time and there are others that cool down quickly. The thermal storage materials tested during this work don't have the same thermo-physical characteristics; according to Table 1, clay and concrete having a higher diffusivity and thermal conductivity than those of water, sand and PCM and an acceptable heat capacity.

This gives them a strong ability to absorb and transmit heat to the heat transfer fluid. Indeed, the experimental results are in agreement with the nature and the thermal properties of the materials used. This is the effect of the thermal inertia of these materials. Comparing the materials results, some of these materials heat up quickly and they store heat for a long time (Clay, water), others heat up quickly and cool down quickly (PCM, Sand), while there are others that heat up and cool down slowly (Concrete). Fig.7 and 8 compare the performance of the solar water heaters using the different innovative materials to the conventional system that stores thermal energy using a water tank. As it's shown in Fig 7, the maximum efficiency values of PCM, Sand, Concrete, Clay and conventional solar water heater are respectively 50%, 60%, 73%, 86% and 87%. However, according to the Fig.7, the solar water heaters efficiencies get their maximums values at the begining of the day for a low solar flux then, when the solar flux increase over the time, they decrease.

The drop in efficiency is due to the increased losses in the system caused by higher operating temperature. Thus, The higher efficiency is the result of lower losses at lower difference between the ambient and the water temperature. The results show that the solar water heaters with the tested thermal storage materials present a similar instantaneous efficiencies compared to commercial solar water heater. Furthermore, all the solar water heater prototypes are able to reach high instantaneous efficiencies (above to 50%). These positive results prove that the solar water heater prototypes represent an important innovation reaching high efficiency results and using low cost and local materials.

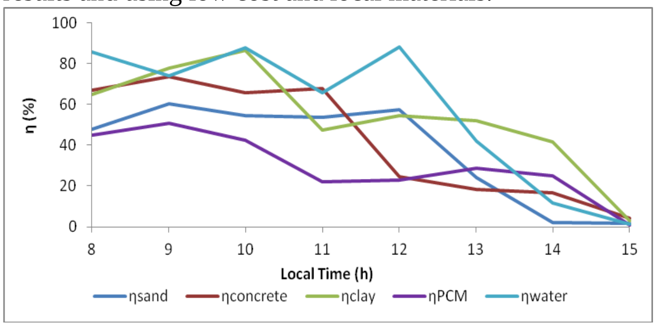

Fig.7. Energy efficiency vs local time (06th June).

According to Figure 8, for a normalized gain value of 0.036 m^2 °C/W, means a water temperature increase equal to 36 °C for a solar flux of 1000W/m^2, the solar water heater with PCM thermal storage material reaches a 28.69% of thermal efficiency and the one with concrete storage material has an efficiency of 24.61% while the solar water heater with sand and clay energetic performances are respectively 53.91% and 47, 59%. For the same normalized gain value, the conventional water heater achieves an efficiency of 65.79%.

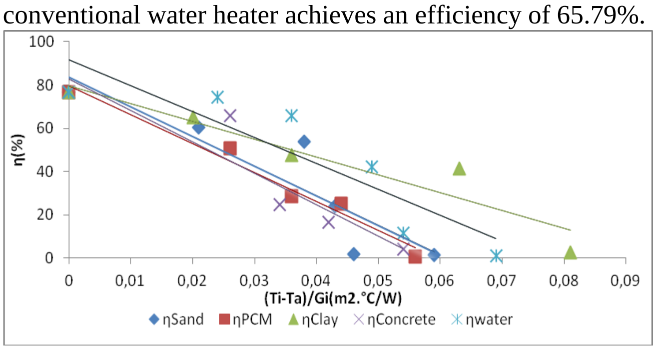

Fig.8. Evolution of energy efficiency vs normalized gain (06/ June).

B. Vertical collector

The same test than the first one just the solar collector inclinaison angle is been changed. The measurements are carried out for two days continuously (12/13-06) with vertical position and southern orientation. According to fig 9, the solar flux curve followed the same shape during the two days of measurement since they are successive days. It increases in the morning, reaching a maximum value of around 340 W/m^2 at noon and then it decreases towards the end of the day. As our collectors are positioned vertically, it is logical that the intercepted solar flux is reduced and weaker than that of the 1st test (for a tilt angle of 45°) due to the measurement period (summer) and the obliquity of the solar rays in relation to the vertical plane of the collector. Indeed, by having relatively high solar latitude at its maximum during the measurement period "hot summer period" and for a vertical collector, the perception of solar radiation is therefore reduced. In fact, the vertical position is the one which minimizes solar contributions in the summer and maximizes them in the winter, which follows the lines of the annual needs of hot water consumer. Besides, especially for the hot countries as Tunisia, the necessity to the hot water is more considerable in the winter than in the summer when the climate is already naturally hot. Therefore, the results offer a better understanding of bioclimatic concept considering how to benefit optimally from the solar flux as regards both winter heating needs and protection in the summer from the overheating problem.

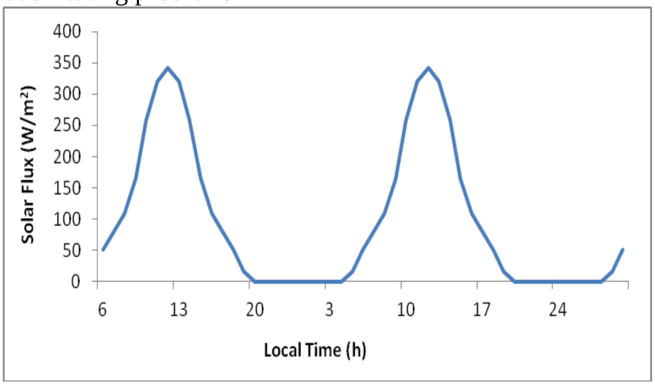

Fig.9: Variation of solar flux vs local time (June 12/13th)

As it's shown in fig 10, the vertical position gives a moderate outlet water temperature compared to those of the first test (45° angle inclination). In fact, the hot water demand in summer is not significant and the water temperature value requested is often not high. The maximum temperature values reached at 2p.m by sand, concrete, PCM and Clay thermal storage materials are respectively 42°C, 43°C, 44°C and 48°C while the conventional solar water heater gets its maximum of 40°C at 3p.m. The outlet water temperature of the solar water heaters prototypes increases by a few degrees for the 2nd day.

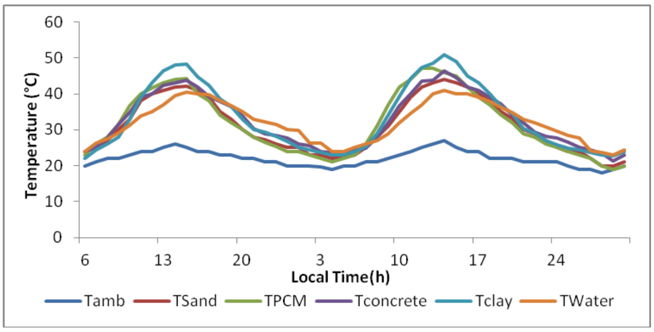

Fig.10. Evolution of ambient and outlet water temperature for the various materials vs local time (12, 13-06).

The variations of the solar water heater performance with the different innovative materials and the conventional system are plotted in Fig. 11 and 12. The maximum efficiency values of Sand, Clay, Concrete, PCM and conventional solar water heater are respectively 73%, 84%, 87%, 72% and 76%, reaching in the first hours of the days. The tested materials achieve similar instantaneous efficiencies that the conventional system and they perform even better in the Clay and Concrete Cases.

As it's shown above and by comparing the results of the two tests, it's obvious that the vertical position gives better performances solar water heaters than those of the 45°.inclined collector. That's explained by lower ambient and outlet water temperatures difference and consequently the heat losses decrease.

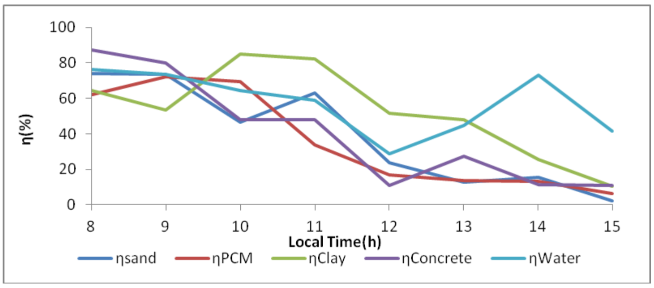

Fig.11. **Evolution of energy efficiency for the various thermal storage materials vs local time (June 12th).**

The solar water heaters performance is shown as a function of normalized gain in fig 12. It has a a linear appearance expressed by equation (13).

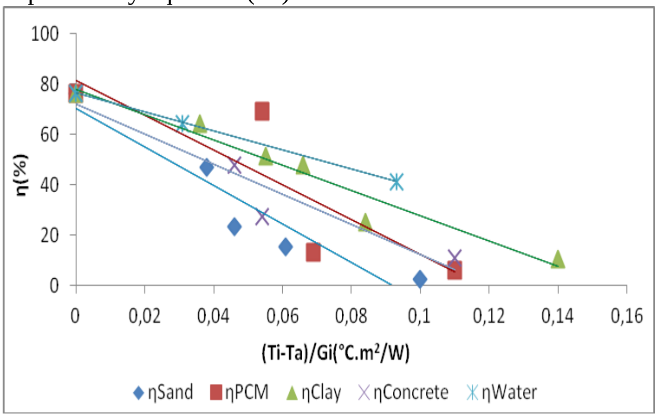

Fig.12: Evolution of energy efficiency vs normalized gain (12-06).

The heat losses coefficient is calculated according to the equation (14) for the different prototypes. The result prove that the heat losses are higher for the inclined collector (45° tilt angle) than for the vertical position (tab 3).That is caused , as it's explained above, by the fact that the outlet water temperature decrease for the vertical position, therefore the ambient and the outlet temperature difference is reduced.

Table 3: Night heat loss coefficient for different angles of inclination.

	sand	PCM	concrete	Clay	Water
i=45°	1,62	1,3	1,55	1,74	1,13
i=90°	0,63	0,57	0,59	0,64	0,53

According to the eq 14, the wind speed has a great effect on the heat losses. The more the wind speed increases the more the heat exchange with the outside increases. The top thermal losses represents the major part of the overall losses and they consist on radiation and convection losses with the external environment. Several remedies can be carried out to correct this handicap, i-e, choice of a good insulator, double glazing, and cover the front face of the collector overnight. Note that the higher thermal losse coefficient is getted by the Sand solar water heaters while the Concrete and the Clay storage materials present an effective alternative with similar thermal losses than the conventional system.

V. CONCLUSION

The solar thermal systems present an effective solution to replace the conventional energy sources. However, the major handicap that prevents the use of its systems is thermal storage. In this context, this study aims to evaluate experementaly four innovative thermal storage materials (clay, concrete, sand, PCM) for a solar water heater. The tested materials have shown very acceptable thermal performance. Indeed, the clay and concrete system show a great thermal performance comparable to that of the conventional system and offer other advantages; the clay could be recycled and the concrete could be integrated into the building facade. The principal results obtained by the experimental tests are :

- A very high water temperature for different materials which can reach 80°C for clay for example and it maintain a satisfactory value even towards the end of the day.
- Very satisfactory energy efficiency for all tested materials compared to that for conventional solat water heater around 80%.
- The inclinaision angle of the solar collector having a very significant effect on the solar radiation received and therefore on the performance of the solar water heater.

Summing up the clay and concrete storage materials contribute to similar thermal performance to that of conventional solar water heater. Storage in sand and PCM shows a satisfactory performance throughout the day but having higher night heat losses compared to the conventional system. Several authors use various solutions to reduce these nocturnal losses as, the use of thermal diode [6], the use of double glazing [21] or cover the front face of the collector during the night [8]. This study allows us to ensure on the one hand, the manufacture simplicity of solar water heaters using cheap, local and available materials. On the other hand, improving the solar water heater lifespan and creating a system that does not require much maintenance while solving the major handicap of the CSI integrated solar water heater; corrosion caused by storage water in a metal tank .

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REFERENCES

1. Ketfi, O., Merzouk, M., Merzouk, N. K., Elmetenani, S., & Lafri, D. (2014). Etude expérimentale d'un capteur solaire plan muni d'un collecteur sous forme de serpentin. Revue des Energies Renouvelables, 17(4), 623-630.
2. Diakoulaki, D., Zervos, A., Sarafidis, J., & Mirasgedis, S. (2001). Cost benefit analysis for solar water heating systems. *Energy Conversion and Management*, *42*(14), 1727-1739.
3. http://www.gabes.climatemps.com
4. Smyth, M., Eames, P. C., & Norton, B. (2006). Integrated collector storage solar water heaters. *Renewable and Sustainable Energy Reviews*, *10*(6), 503-538.
5. Souliotis, M., & Tripanagnostopoulos, Y. (2004). Experimental study of CPC type ICS solar systems. *Solar energy*, *76*(4), 389-408.
6. Mohamad, A. A. (1997). Integrated solar collector–storage tank system with thermal diode. *Solar energy*, *61*(3), 211-218.
7. Siddiqui, K. M., & Kimambo, C. Z. M. (1994). Development of a compact integral solar water heater for Africa. *Renewable energy*, *4*(4), 395-400.
8. Faiman, D., Hazan, H., & Laufer, I. (2001). Reducing the heat loss at night from solar water heaters of the integrated collector–storage variety. *Solar Energy*, *71*(2), 87-93.
9. Khalifa, A. J. N., & Jabbar, R. A. A. (2010). Conventional versus storage domestic solar hot water systems: A comparative performance study. *Energy Conversion and Management*, *51*(2), 265-270.
10. Sarbu, I., & Sebarchievici, C. (2018). A comprehensive review of thermal energy storage. *Sustainability*, *10*(1), 191. **https://doi.org/10.3390/su10010191**
11. http://www.lanniontregor.com/files/CALT_39121_1332771037617_PER_BAT_108_fiche_INERTIE_03_02.pdf.
12. http://entreprises.sig-pyrenees.net/cours/cours1/co/p1s05_effusivite.html.
13. http://fr.wikipedia.org/wiki/Diffusivit%C3%A9_thermique.
14. http://passivact.com/Infos/InfosConcepts/files/QualiteThermique-ComparaisonsMateriaux.html.
15. http://www.diffusivitethermique.fr/.
16. Afedes Mémosol, "Mémento d'héliotechnique", Editions Européennes Thermique et Industrie, Paris, 1979.
17. Duffie, J. A., & Beckmann, W. A. (1974). *Solar Energy. Thermal Processes.(Stichworte Teil 2)*. Wiley & Sons.
18. Bernard, R., Menguy, G., & Schwartz, M. (1980). The solar radiation, thermal conversion and applications. *Technique and documentation, Paris*.
19. Abid, N., Kerkeni, C., & Bouden, C. (2008). Méthodes de test des systèmes de chauffe eau solaires Etude comparative.
20. Tripanagnostopoulos, Y., Souliotis, M., & Nousia, T. (2002). CPC type integrated collector storage systems. *Solar Energy*, *72*(4), 327-350.
21. Slama, R. B. (2012). Experimentation of a plane solar integrated collector storage water heater. *Energy Power Eng*, *4*(02).

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