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Simulation of thermal behavior of a solid porous medium bed used in heat storage

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Abstract

The thermal energy storage (TES) is not a new concept, but the novelty consists to develop an efficient and inexpensive thermal storage devices.

The present work has been undertaken to study the feasibility of storing solar energy using porous medium (Sand) during the diurnal period and utilizing this energy at the nighttime and overcast periods.

The device is composed by solar plan heater, storage tank and application. The thermal transfer between the storage medium and the energy–carrying fluid heated in the solar cell is assured by an exchanger imbedded into a storage material. The heat energy stored during day is restored at night through the second circuit.

The storage is based on sensible heat concept. The simulation of the thermal behavior of the storage medium shows that the temperature increases during the sunlight period to reach maximal values then it decreases. It corresponds to charge/discharge cycle in storage system.

The realization of this device will be interesting then.

Keywords: *Sensible heat storage, Porous medium, Solar energy, Simulation, Design;*

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1. Introduction

Nowadays with the climate change, increase of demands of energy and decrease of fossil fuels reserves, the renewable energies became a solution for all these problems.

Solar energy is one of the renewable energies that is the most exploited but its irregular character induces serious limitations in many potential applications [1].

As a solution to remedy to these limitations, the storage of thermal energy represents an important alternative [2].

There are mainly two types of TES systems, sensible storage systems and latent storage systems. As the temperature of a substance increases, its energy content also increases. The energy released (or absorbed) by a material as its temperature is reduced (or increased) is called sensible heat.

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On the other hand, Latent heat is associated with the changes of phase (the energy required to the phase change of a material). The other category of storing heat is through the use of reversible endothermic chemical reactions.

The storage medium determines the type of storage. The selection of one of the storage materials depends to temperature range and application.

The number of available materials is more than 150 000, with new ones appearing every year. Materials scientists classify them into four families: metals and alloys, ceramics and glasses, polymers and elastomers, and hybrids that include composites and natural materials [3].

A complete storage process involves at least three steps: charging, storing and discharging. In practical systems, some of the steps may occur simultaneously, and each step can happen more than once in each storage cycle.

Nomenclature

A	surface of sun collector (m^2)	Q_s	stored power (W)
C	heat capacity of storage media ()	Q_u	used power (W)
I	intensity of the solar flow (W/m^2)	T_s	average temperature of storage media (K)
I_c	instantaneous intensity of the solar Flow (W/m^2)	η	efficiency of sun collector
		α	hourly angle.
M	mass of storage media (Kg)		
Q_c	power generated by the collector (W)		
Q_p	lost power (W)		

2. Background

Thermal energy storage is a technology under investigation since the early 1970s [3].

Last years have been characterized by an energy consumption increase as well as a constant rise in prices for energy. Energy storage is not only plays an important role in conservation the energy but also improves the performance and reliability of wide range of energy systems, and become more important where the energy source intermittent such as solar.

Energy system or technology of ES had been developed in order to answer specific needs. They are classified by the form of energy stored, as shown in Fig. 1 [4].

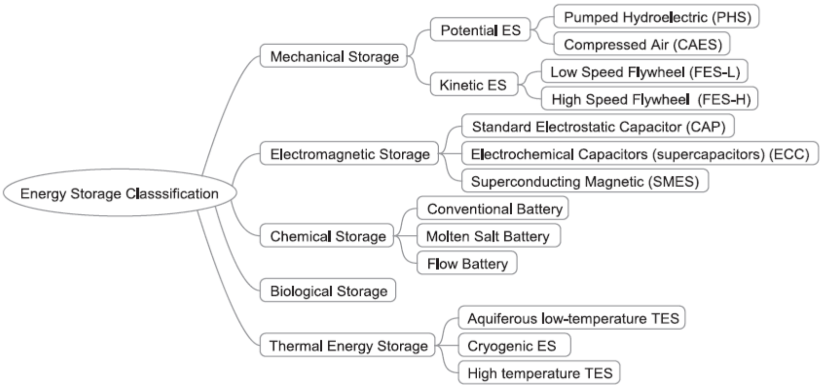

Fig. 1: Classification of energy storage systems [4]

The thermal energy storage can be used in places where there is a variation in solar energy or in areas where there is a high difference of temperature between day and night.

There are mainly three types of TES systems, chemical, latent, and sensible storage, depending on the type of process or property of the material that is profit- able [5].

Many researchers have been interested by sensible storage. In 1987 C. Dang Vu and al. had studied a thermal storage system coupled to an air solar heater and used pebbles like a storage media for a long time. In this study they verified the advantages of sensible storage in ventilated bed of pebbles [6]. Since this year, several experimental and simulation researches have been developed using [3-7].

Because of the interest of the packed bed technology, in 2009 S. Harmeet et al. published a review on. It is concluded that most of the studies carried out are on rocks and pebbles as packing material. A very few studies were conducted on large sized packing materials. Further no study has been reported so far on medium sized storage elements in packed beds [8].

The Thermal Energy Storage (TES) systems cover a large range of temperatures and applications [5]. In the power plants we need the TES that cover a high temperature range. For this raison, in 2009, G. Antoni and al. shown in these studies [9, 10] that Spain is a leader in solar power plants and all thermal storage concepts can be applied in solar thermal power plants with a power range from 10 to 300 MW, and with temperature ranges between 250 and 350 °C. They presented also that there are a new concepts of thermal energy storage systems were developed in DLR in Stuttgart: integrated receiver/storage system, using a fluidised bed storage concept and movable wall concept.

Low temperature thermal energy storage operates in a temperature range below 200°C and has been extensively investigated and developed [4].

In terms of storage media, a variety of choices exists depending on the storage concept, the temperature range and the specific application.

D. Fernandes and al. present in his paper that concrete and cast ceramics have been extensively studied due to their low costs, good thermal conductivities and moderate specific heats [3]. Rock, sand is also used. Liquid media (water, molten salts, mineral oils and synthetic oils) maintain natural thermal stratification because of density differences between hot and cold fluid [9].

Recent studies in USA and Spain showed the interest to use the sand as a storage media (S. Jeter and al., M. Medrano and al.) [10,11].

About latent heat storage system, there are several researches. Latent storage systems based on phase change materials (PCMs) with solid-liquid transition are considered to be very efficient in comparison to liquid-vapor and solid-solid transitions [4, 9-10].

In order to modeling the different storage systems, L. Peiwen and al. has been shown that there is a similarity between the three types of thermal storage systems and that we can generalize the energy storage governing equations. He provided a series of generalized charts bearing curves for energy storage effectiveness against four dimensionless parameters grouped up from many of the thermal storage system properties including dimensions, fluid and thermal storage material properties, as well as the operational conditions [12].

All these previous researches invited us to study the thermal behavior of the sand as the storage media in a solar thermal storage system.

3. Mathematical modeling

The thermal storage system studied in this work is shown below:

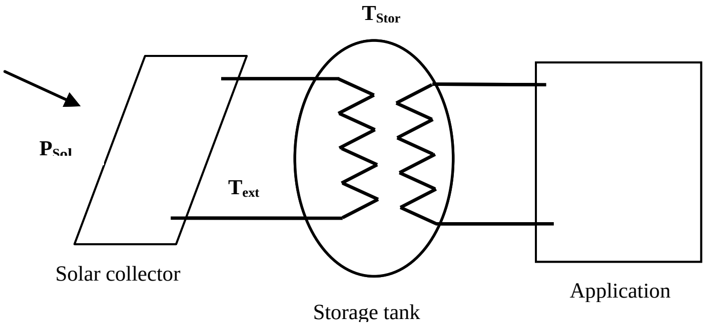

Fig.2: Thermal storage system

The heat balance of the system shown above is:

$Q_c = Q_s + Q_u + Q_p$ (1)

Where:

Q_c: the power generated by the collector
Q_s: the stored power
Q_u: the used power
Q_p: the lost power

By replacing Q_s by its value we obtain:

$M . C . dT_s/dt = A . \eta . I_c - Q_u - Q_p$ (2)

Where:

M: mass of storage media;
C: heat capacity of storage media;
T_s: average temperature of storage media;
Ƞ: efficiency of sun collector;
A: surface of sun collector;
I_c: instantaneous intensity of the solar flow.

For this work, the instantaneous intensity of the solar flow is given by the following relation [13]:

$I_c = I . (1 + \cos(\alpha))/2$ (3)

Where:

I: intensity of the solar flow;
α: the hourly angle.

To obtain the instantaneous temperature of storage media, equation (2) must be solved. For this raison an algorithm of Euler is used [13].

4. **Results and discussion**

The thermal characteristics of sand used for this simulation, as well as other parameters considered, are summarized in the table following:

Table 1. Data used for Computations.

Item	**Value**
Heat capacity of sand (j/kg.k)	835
Sand density (Kg/m^3)	1850
Thermal conductivity (w/m.k)	2
Ensoleillement (w/m^2)	1000
Collector efficiency	0.5

Figure 3 shows the solar power as function of time during 24 hours. The solar power increases from 0 w at the 6 am (hour who correspond to the sunrise) to reach a maximum surrounding of noon (5000 W) then decrease and continuous to decrease until 0 w again at 18 am (the sunset).

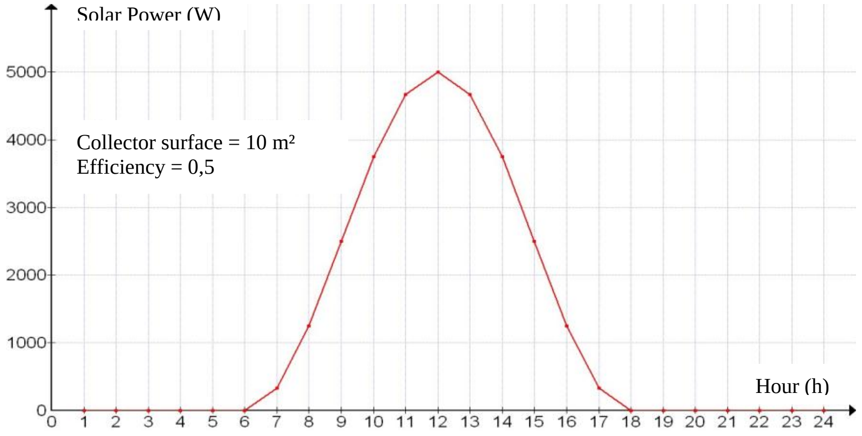

Fig.3: Solar power as function of time during 24 hours

The sand temperature as function of time during 24 hours is shown on the figure 4.

The temperature rises from 20 °C (initial value of sand temperature) to reach a maximum (~55°C), that correspond to the charge phase of the cycle. The sand temperature decreases between 0 am and 6 am, and after 18 am, that is the discharge phase of the cycle. During this phase, the sand loses the energy which it has stored in sunny period.

The thermal behavior of the sand during 5 days is shown figure 5, the minimal value correspond to a non sunny day. This graph shows also the influence of solar collector surface on the sand temperature.

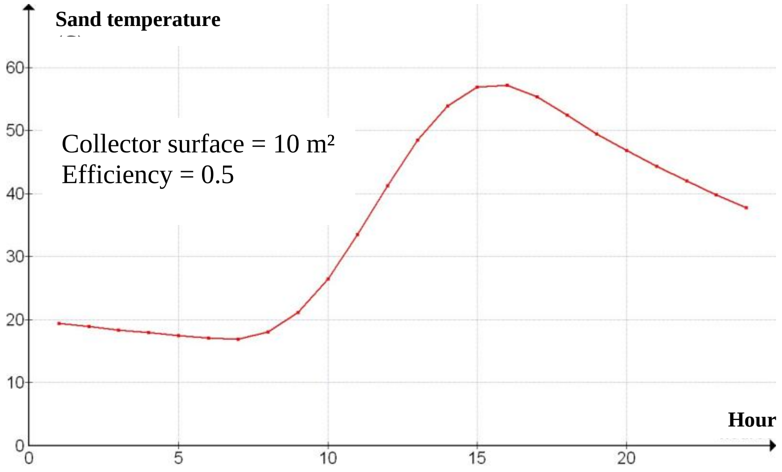

Fig.4: Sand temperature as function of time during 24 hours

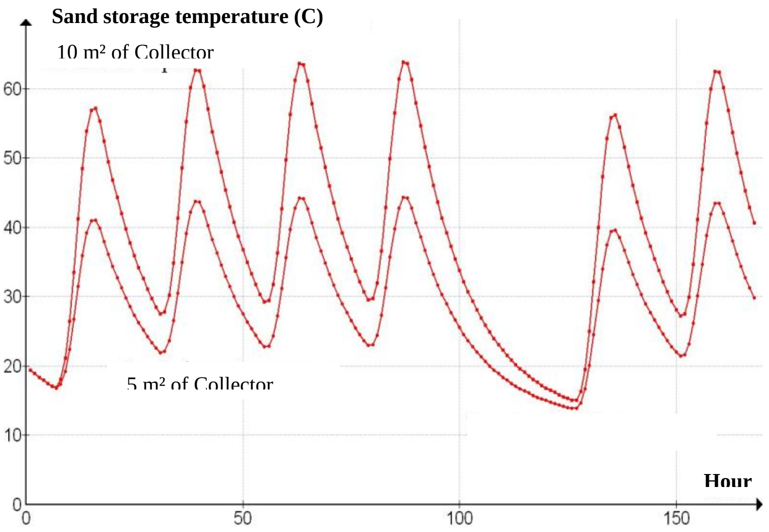

Fig.5: Sand storage temperature as function of time during 5 days

5. Conclusion

According to the results, the following conclusions can be drawn:

- The sand is a good media to store the solar energy (storage temperature ~55°C);
- During a several charge/discharge cycles the themal inirtia of sand remains important;
- The surface of solar collector is proportionnal to the storage temperature.

These conclusions encourage us to desing this solar storage system in the south of Algeria, where is, the solar field is Considerable and the sand is available.

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