State of the art of high temperature storage in thermosolar plants

Antoni Gil, Pablo Arce, Ingrid Martorell, Marc Medrano, Luisa F. Cabeza

Centre GREA Innovació Concurrent
Edifici CREA, Universitat de Lleida, Pere de Cabrera s/n, 25001-Lleida (Spain)
Phone: +34-973 003576, Fax: +34-973 003575
e-mail: lcabeza@diei.udl.cat

ABSTRACT

Thermal energy storage systems have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale switching. They are normally useful for correcting the mismatch between the supply and demand of energy. There are different methods in thermal storage systems for thermosolar plants: two tanks with molten salts, two tanks with synthetic oil, one tank thermocline, one tank thermocline with filler material, etc. In order to enable a comparison among their characteristics, advantages and disadvantages, a classification of storage systems, according to storage concept and media, was done. This classification of plants makes possible to see, at same time, which technologies and materials are more developed, and which others have potential of development. In this work, a complete state of the art of this technology is presented. Over 80 references were reviewed, and a comparison of the technologies and their implementation in real plants was done.

1. INTRODUCTION

Nowadays, the worldwide worry about a global climate change pushes to develop new energetic strategies. And more, after the recent energetic crisis due to the increase of oil price, or the gas crisis arisen between Russia and Ukraine, which left without heating and energy millions of people in centre Europe, solar power is becoming a key issue for countries with high level of solar radiation.

Even the new president of USA has included in the strategic plan for energy presented by his government, to take up the way of renewable energies, and solar power plants are one of the best and fastest choices. The possibility to reduce the dependence of energetic supply on the part of foreign countries, and decreasing the price per kW over the long term seems a good reason to invest efforts in this technology.

A solar power plant requires of many components which need to be optimized for the solar plant to reach high efficiencies. Many of these components are under development. TES is one of them, and is considered of vital importance to make solar power more cost-effective. The objective of this state of the art is to analyze and show the state of development of different technologies used to store energy in thermal solar power plants, and to find out which storing materials are used in each one of them.

2. RESULTS

Energy storage (ES) is the storing of some form of energy that can be drawn upon at a later time to perform some useful operation. Figure 1 shows a large variety of energy storage systems, most of them under development. Thermal energy storage (TES) will be discussed on this document, because is the best method to be applied in solar power plants.

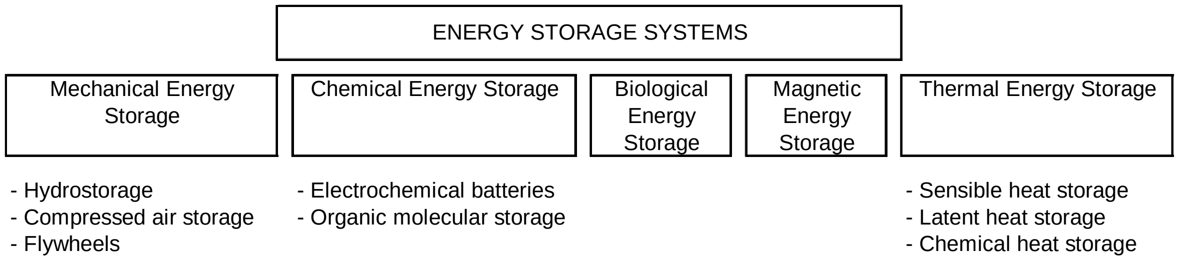

Figure 1. Classification of energy storage systems (Dinçer, 2002).

TES systems can be classified according to the storage media, or according to the concept of storage system. According to the concept of storage, systems can be classified as active or passive storage systems (Figure 2).

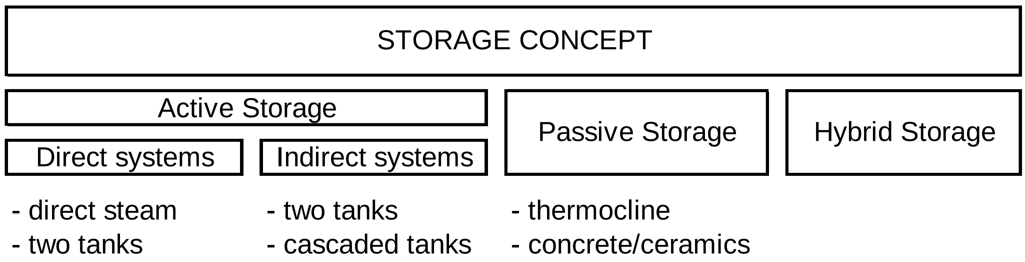

Figure 2. Classification of energy storage systems according to concept (Pilkington Solar International, 2000).

An active storage system is mainly characterized by forced convection heat transfer into the storage material. The storage medium itself circulates through a heat exchanger (this heat exchanger can also be a solar receiver or a steam generator). This system uses one or two tanks as storage media. Active systems are subdivided into direct and indirect systems. In a direct system, the heat transfer fluid, which collects the solar heat, serves also as the storage medium, while in an indirect system, a second medium is used for storing the heat.

Passive storage systems are generally dual medium storage systems: the heat transfer fluid (HTF) passes through the storage only for charging and discharging from/into a solid material, the heat transfer medium. The heat transfer medium itself does not circulate. The HTF carries energy received from the energy source to the storage medium during charging, and receives energy from the storage when discharging. In this case, the two storage medium are sensible heat storage materials.

Hybrid storage systems are also dual systems, but using a combination of characteristics of sensible and latent heat materials, with the target of improving the storage characteristics of the system.

Figure 3 shows with examples of installations the concepts explained above.

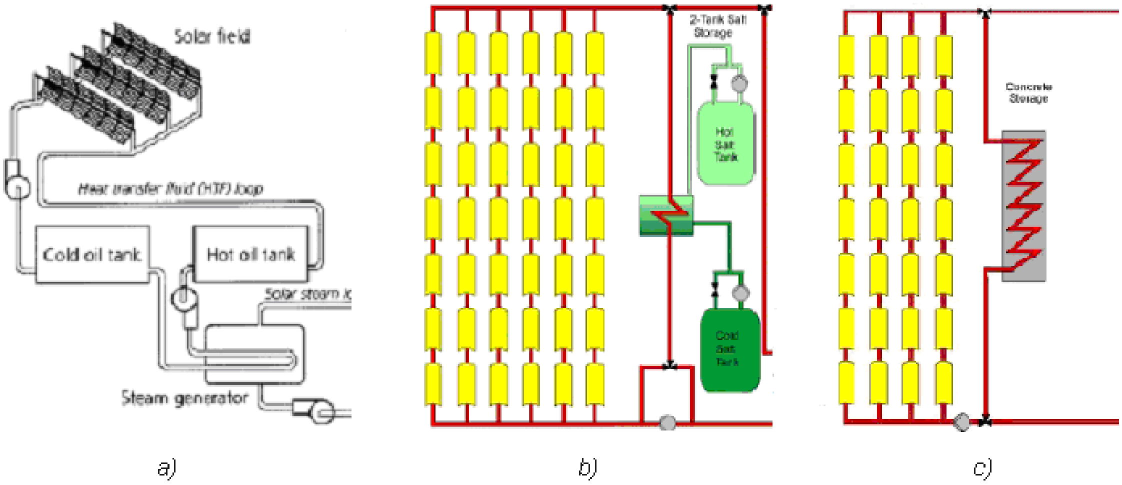

Figure 3. Examples of installations classified according to energy storage concept. a) two tanks active direct system (scheme of SEGS I plant); b) two tanks active indirect system (AndaSol I plant); c) concrete storage, passive system (Herrmann et al., 2006).

According to the storage media, thermal energy can be classified as sensible media (the sensible heat is associate to energy released by a material as its temperature is reduced, or absorbed by a material if its temperature is increased), latent media (latent heat is associated with the phase change) or chemical media (Figure 4). This third category of storing heat is through the use of reversible endothermic chemical reactions.

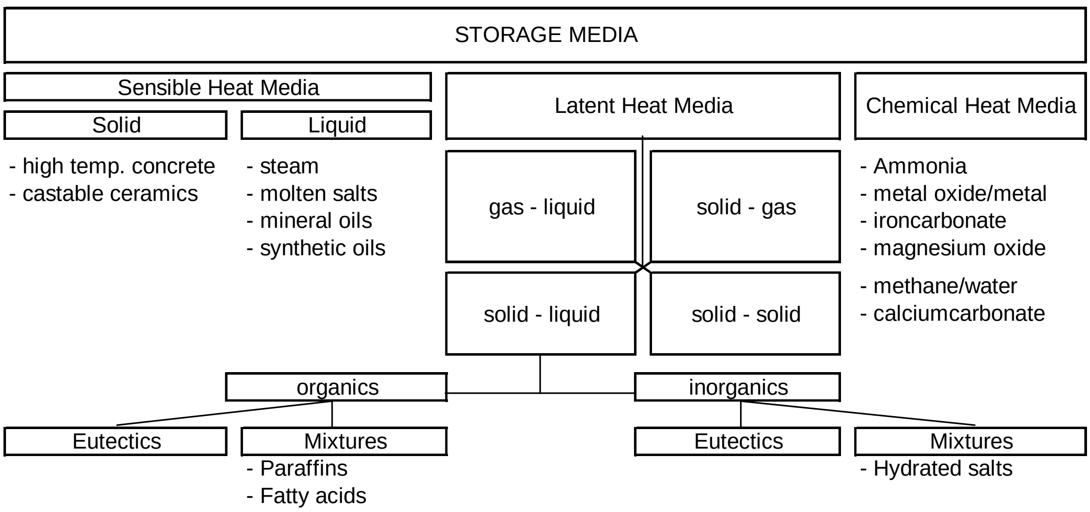

Figure 4. Classification of energy storage systems according to media (Dinçer, 2002, Zalba et al., 2003, Van Berkel, 2005, Lovegrove et al., 1999).

Thermal energy materials will be classified in this study depending on the TES media: materials to store by sensible heat, materials to store by latent heat and materials to store by chemical heat.

The study of appropriate materials to use in thermal storage systems, and their characteristics is ongoing and represented one of milestones of this work, together with of review of the different technologies applied to storage solar thermal energy, described above.

3. CONCLUDING REMARKS

A review of state of the art of high temperature storage in thermosolar plants has been done, consulting about 95 references, with the aim to study and show the technologies applied until the moment in thermal energy storage in solar power plants.

Table 1 shows a classification of the most important solar power plants around the world, in order to present the kind of technologies that are more developed, and which kind of materials.

As a conclusion, Table 2 shows a summary list with the advantages and disadvantages of the different technologies, according to the energy storage concept.

Storage Concept		**Storage Media**					
		Sensible heat				Latent heat	
		Liquid			Solid		
		Steam	Oil	Molten salts			
Active storage	Direct system	PS10 PS20	--	--	--	--	--
		--	SEGS I SEGS II	THEMIS Solar Two Planta Solar Tres	--	--	--
	Indirect system	--	--	SSPS CESA I (PSA) SSPS CERS (PSA) Andasol I Andasol II Extresol I	--	--	--
		--	--	--	--	LUZ proposal for Solar Plant	
Passive storage		--	--	--	SSPS LS3 (PSA)	--	--
		--	SSPS DCS (PSA)	Solar One	--	--	--
Hybrid storage		--	--	--	DLR-ZSW proposal SGL proposal		

Table 1. Classification of existing solar power plants, according their storage concept and media.

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			ADVANTAGES	DISADVANTAGES
Active storage	Direct system	Direct steam generation	· Intermediate heat transfer fluid and steam-generation exchanger is not necessary, improving the efficiency loss in steam generation; · Overall plant configuration more simple; · Lower investment and O&M costs; · Allow the solar field operate at higher temperatures, increasing the power cycle efficiency (Reduction of LEC).	· increase of pipe installation cost (is necessary to work at very high pressures); · Need of auxiliary protective heating systems for start-up, maintenance and recover from frozen conditions; · Instability of the two phase flow inside the receiver tubes (procedures for filling and draining); · Difficult to control the solar field under solar radiation transients.
		Two tanks	· Cold and hot HTF are stored separately; · Low-risk approach; · Possibility to raise the solar field output temperature to 450/500ºC (in trough plants), thereby increasing the Rankine cycle efficiency of the power block steam turbine to the 40% range; · The HTF temperature rise in the collector field can increase up to a factor of 2.5, reducing the physical size of the thermal storage system.	· Very high cost of the material used as HTF and TES; · High cost of the heat exchangers and two tanks due to very large tank size requirements; · relatively small temperature difference between the hot and cold fluid in the storage system; · Very high risk of solidification of storage fluid, due to its relatively high freeze point (that increases the M&O costs); · The high temperature of both tanks drives to an increase of losses in the solar field; · The lowest cost TES design does not correspond to the lowest cost of electricity.
	Indirect system	Two tanks	· Cold and hot HTF are stored separately; · Low-risk approach; · The HTF temperature rise in the collector field can reduce the physical size of the thermal storage system. · TES material flows only between hot and cold tanks, not through the parabolic troughs (decrease the risk of solidification of salts).	· Very high cost of the material used as TES; · High cost of the heat exchangers and two tanks due to very large tank size requirements; · Exchanger between the HTF and TES material is needed; · relatively small temperature difference between the hot and cold fluid in the storage system; · The high temperature of both tanks drives to an increase of losses in the solar field; · decrease of the efficiency comparing with two tanks direct system.
		Cascaded tanks	· Higher utilisation of PCM storage capacities; · More uniform outlet temperature over time.	· Heavy increase of cost, due to a higher number of: storage tanks, heat transfer fluid loops and PCM's; · Further PCMs need to be identified which also offer a sufficient heat of fusion and a satisfying corrosiveness. · not real experiences, only simulation.
Passive storage	concrete/ceramics		· Very low cost of thermal energy storage media, due mainly to the filler cost; · High heat transfer rates into and out of the solid medium (due to a good contact between the concrete and piping); · Facility to handling of the material; · Low degradation of heat transfer between the heat exchanger and the storage material.	· Increase of cost of heat exchanger and of engineering; · Long-term instability.
	One tank (Thermocline with filler materials)		· Decrease of storage tanks cost, due to this system uses only one tank; · Low cost of the filler materials (rocks and sand); · In cost comparisons, the thermocline system is about 35% cheaper than the two tank storage system, due to reduction of storage volume and elimination of one tank.	· Relatively high freeze point of most molten salts formulations (is necessary to maintain a minimum system temperature to avoid freezing and salt dissociation); · More difficult to separate the hot and cold HTF; · The high outlet temperature drives to an increase of losses in the solar field; · Maintaining of thermal stratification requires a controlled charging and discharging procedure, and appropriate methods or devices to avoid mixing; · Design of storage system was complex; · Thermodynamically it was an inefficient power plant; · This system is riskier with respect to the performance.
Hybrid storage	PCM - sensible - PCM		· Increasing of capacity storage; · Better use of PCM storage capacities; · Reduction of costs, comparing with storage systems with only PCM as storage media; · Improve of storage ratio, comparing with systems with only sensible heat materials.	· Necessary to develop technologies to analyze this concept.

Table 2. Conclusions about advantages and disadvantages of different storage technologies, (Hernandez-Guerrero et al., 1999, Michels et al., 2007, Lovegrove et al., 1999, Foster, 2004, Van Berkel, 2005, Kearney, 2006, Brosseau et al., 2005, Tamme, 2003).

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