Large Capacity Heat Storage for Extended Operation of a Solar Thermal Power Plant

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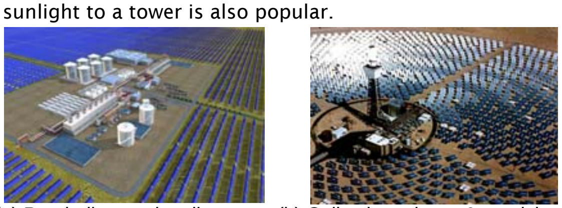
TECHNOLOGY BRIEF OF SOLAR THERMAL POWER PLANT

A solar thermal power plant collects sunlight by its solar collectors and heats up a heat transfer fluid (types of mineral oil that are stable below a certain temperature) to a maximum temperature of around 390 ºC. The heat transfer fluid transfers heat to a working substance of the thermal power plant. From there on, the processes of power generation is almost the same as that of a regular power plant.

There are several major types of solar collectors currently in use around the world. The most popular one is the parabolic trough, which tracks the sun with an variable zenith angle. Using reflecting mirrors to concentrate sunlight to a tower is also popular.



(a) Parabolic trough collectors (www.foreignpolicy.com)   (b) Collecting mirrors & receiving tower (www.global-greenhouse-warming.com)

Figure 1 Different types of Solar collectors

SIGNIFICANCE OF HEAT STORAGE IN SOLAR THERMAL POWER PLANT

A solar thermal power plant has to shut down after sunset, and therefore the capacity of operation of the power plant can only reach less than half of that of a regular fossil fuel power plant. On the other hand, the pick electricity demand regularly occurs during the period from sunset to 11PM. In order to meet the need of pick electricity demand and maximize the capacity of operation of the power plant, an extended operation is necessary for a solar thermal power plant. It will dramatically improve the revenue of investment by 30%-50%.

To have an extended operation of a solar thermal power plant, the needed heat has to be stored at the time that sunlight is available. Therefore, the large capacity of heat storage turns to be one important issue to the economic success of solar thermal power plants.

PROJECT BRIEF

This DOE-funded project is to be jointly carried out by US solar, APS, UA, ASU, and Georgia Tech. US solar leads the project, and APS will endorse a downsized heat storage system developed in this project in their Saguaro solar thermal power plant, as seen in Figure 1. Here the U of A team will carry out research and analysis of the heat storage system based on thermocline technology. Research tasks are 1) sizing of the heat storage tanks, 2) power plant thermodynamic analysis with heat storage considered, 3) flow and control for thermocline heat storage.

(a) Parabolic trough solar receiver   (b) heat exchanger and cooling tower

Figure 2 The APS Saguaro solar thermal power plant

KEY ISSUES OF HEAT STORAGE

■ Minimization of Containers

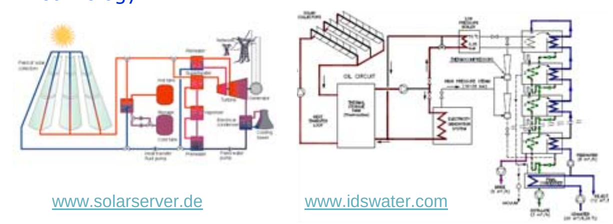
The cost of material construction for heat storage containers can be very high due to the huge amount of heat to store. Since the energy density (ρ Cp) of heat transfer fluid is lower than some solid materials, as seen in Table 1, it is common that the container is filled with solid filler material. Equation (1) explains the relation between the heat to be stored and the volume of storage container.

$$Q = V\rho Cp(T_{end} - T_{start}) = V\left[\varepsilon(\rho Cp)_{fluid} + (1-\varepsilon)(\rho Cp)_{filler}\right](T_{end} - T_{start}) \qquad (1)$$

Material at 300 ºC	Density ρ (kg/m^3)	Specific heat Cp(J/kg K)	Energy density MJ/(m^{3}K)	Thermal Conductivity W/(m K)
Taconite	3200	800	2.56	30
Iron(pure)	7870	455	3.58	81.10
Cast iron	7570	470	3.56	39.20
Aluminum	2700	920	2.48	236
Stone	2600	840	2.18	3.00
Therminol 72 (oil)	1097	1498	1.64	0.14

Table 1 Energy density comparison between solid filler material and heat transfer fluid

■ Reduce Half of the Containers based on Thermocline Technology



www.solarserver.de   www.idswater.com

(a) Two tank system   (b) Single tank system

Figure 3 Two-tank versus one-tank heat storage systems

The earlier version of heat storage for solar thermal power plant employs two tanks; one receives the heat transfer fluid from the other after the fluid gets heat from solar collection field or releases heat to power plant. This results in the fact that one tank is always empty, as shown in Fig. 3(a). As the cost for a tank is expensive, only one-tank heat storage technology is to be used, which is called thermocline.

In a thermocline single-tank discharging process, hot fluid flows out of the tank from the top, and the fluid that released heat flows back to the tank from the bottom. In the charging process, hot fluid flows into the tank from the top, and the cold fluid in tank flows out of the tank from the bottom.

It is important that the hot and cold fluid be stratified or have the minimum mixing so as to reduce the heat loss from the hot fluid to the cold fluid in the same tank.

■ Fluid Distribution and Control in Thermocline

Maintaining a uniform distributed flow at the tank inlet (can be at bottom or top, depending on whether in charging or discharging process) is one important measure to minimize flow mixing in the tank. Fluid flow and heat transfer in the tank will be simulated numerically to understand the mixing.

■ Thermal Protection of the Heat Storage Tank

The state-of-the-art thermal protection technology is to be used to reduce heat loss from the heat storage tanks.

ACKNOWLEDGEMENT

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