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The CellFlux storage concept for cost reduction in parabolic trough solar thermal power plants

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Abstract

Although facility scale thermal energy storage of sensible heat in the range of 200-550°C has achieved a high maturity, state-of-the-art approaches are still not very cost effective. An innovative storage concept is thus proposed that avoids the two major cost-driving factors of the concrete storage and 2-tank molten salt systems. First, the storage volume is comprised of low-cost sensible storage material such as concrete, natural stone or clinker bricks. These materials are several times cheaper than eutectic salt mixtures used in the 2-tank-storage system. Secondly, the system uses an intermediate air cycle, allowing for direct contact with the storage material. The necessary heat exchanger for transferring the heat from the primary oil loop to the intermediate air cycle consists of significantly less steel compared to the tube register inside the concrete storage. Dynamic models of the storage system have been implemented in a Matlab/Simulink environment to analyze its performance theoretically. The investigations show, that the overall performance and profitability of the storage system are mainly linked to the thermal efficiency and pressure drop of the heat exchanger, as well as the operation strategy. To demonstrate the feasibility of the storage concept and to investigate its performance characteristic under realistic conditions, a pilot scale test facility is set up.

Keywords: Sensible heat; Thermal energy storage; CellFlux

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1. Introduction: Current technology for TES

Today's state-of-the-art thermal energy storage (TES) technology used in solar thermal power plants is the two tank molten salt system, mostly applied as an indirect storage system for parabolic trough power plants using thermal oil as heat transferring fluid (HTF) in the absorbers. Further cost reductions of this concept are limited since capital costs for molten salt and corrosion resistant materials dominate total costs and are not subject to any noteworthy reductions.

The thermocline concept [1] suggests the application of filler materials, saving one of the storage tanks and substituting about 40% of the molten salt. Due to the thermocline, however, significantly less storage volume can be utilized, relativizing the cost savings to a certain degree. Furthermore, suitable materials which are inert to the molten salt and can withstand the mechanical stresses still have to be identified.

Steam accumulators are another well developed technology used for short term storage. Their high specific costs are designated by the costs for the pressure vessel. Therefore, no cost reductions can be expected from the economy of scale.

By storing the heat in low cost solid storage material, specific costs can potentially be reduced. The general problem arising here is that the primary working fluid cannot be brought into direct contact with the storage material. The concrete storage solves this constrain by embedding a tube register into the concrete material [2]. Such a regenerator type concept inevitably forms a thermocline inside the storage volume. Since power and capacity are coupled, this leads to a bad utilization of the tube register which raises the capital cost to a close region as the molten salt system.

Nomenclature

D	Storage Volume Diameter	[m]
L	Storage Volume Length	[m]
ε	Porosity	[kg/s]
d_{hyd}	Channel hydraulic diameter	[m]
$d_{particle}$	Particle diameter	[m]
ΔT_{exit}	Maximum change of exit temperature	[°C]
$\dot{m}$	Mass flow	[kg/s]
λ	Conductivity of storage material	[W/mK]
μ	Dynamic viscosity	[Pas]
ρ	Density	[kg/m^3]
Υ	Performance coefficient	[-]
ξ	nondimensional length	[-]
τ	nondimensional time	[-]
Θ	nondimensional temperature	[-]

2. The CellFlux storage concept

The idea behind the CellFlux concept is to decouple power and capacity as in the molten salt concept but still utilizing the advantage of solid low cost sensible material. Possible materials are, apart from concrete, bricks or any other loose packing material which can withstand temperatures in the range of 400°C to 550°C. These materials are likely to be found locally, reducing transportation costs and lifting the local share. Since the primary working fluid still cannot be brought into direct contact with the storage material, an intermediate working fluid has to be applied. The system can be divided into several modules, i.e. storage cells. The working principle of such a single cell is illustrated in Figure 1.