Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 69 (2015) 716 – 725

Energy Procedia

International Conference on Concentrating Solar Power and Chemical Energy Systems, SolarPACES 2014

Modeling of transient cyclic behavior of a solid particle thermal energy storage bin for central receiver applications

H. Al-Ansary[a,*], E. Djajadiwinata[a], A. El-Leathy[a], S. Danish[a], Z. Al-Suhaibani[a]

[a]King Saud University, P.O.Box 800, Riyadh 11421, Saudi Arabia

Abstract

One of the emerging thermal energy storage (TES) concepts is the use of solid particles, which can potentially store thermal energy at temperatures approaching 1000°C. Efforts are underway to prepare on-sun testing of this concept at King Saud University (Riyadh, Saudi Arabia) as a part of the research activities in a SunShot project led by Sandia National Laboratories. A thorough study of this concept has been conducted and a prototype has been designed. This concept involves the use of proppants (CARBO Accucast ID50K) as the storage medium, and a thick, multilayered, cylindrical-shaped TES bin as the storage bin. Due to the complexity of building this first-of-its-kind TES bin, it was necessary to model the thermal performance of this design prior to completing the construction process. For this reason, a numerical model was built for the TES bin which is capable of determining the amount of energy loss. The model takes into account that, during daytime operation, the charging flow rate is higher than the discharging flow rate to allow the proppants to accumulate within the TES bin over about 7 hours. Once the charging process is completed, the discharging phase – whose duration is about 5 hours – is also modeled, followed by modeling the cooling-down process of the TES bin for 12 hours to complete a 24-hour cycle. This modeling cycle is based on an assumed initial temperature in the interior of the bin. This paper extends the modeling effort to more than one cycle, such that the initial conditions at the beginning of each cycle are based on information obtained from the previous cycle, rather than on assumed values.

Results show that multi-cycle modeling is important, since it shows that the assumed initial temperature may not representative and may lead to inaccurate results. Furthermore, lessons learned from the first cycle of operation, especially excessive air leakage into the TES bin during nighttime depletion, help refine modeling of subsequent cycles. Energy loss at the end of the second cycle was found to be 4.3%. While considered large, this value is primarily due to the high surface-to-volume ratio of the prototype TES bin being investigated. Preliminary analysis shows that a utility-scale TES bin using the same concept will have an energy loss of less than 1%, which conforms to the current best practice, and shows that low-cost TES solutions can be used in conjunction with the falling particle receiver concept.

Peer review by the scientific conference committee of SolarPACES 2014 under responsibility of PSE AG

Keywords: thermal energy storage, falling particle receiver, transient energy loss, cyclic energy loss

Peer review by the scientific conference committee of SolarPACES 2014 under responsibility of PSE AG
doi:10.1016/j.egypro.2015.03.082

1. Introduction

Thermal energy storage (TES) is increasingly being deployed in concentrating solar power (CSP) systems due to its favorable economic impacts, including increased dispatchability, capacity factor, and reduced levelized cost of energy [1]. However, one of the main challenges of TES is the upper limit on operating temperature (approximately 560°C), which is currently dictated by the stability limit of commercially available molten salts. For this reason, a multi-national team of researchers is now investigating the feasibility of solid particles as a heat transfer medium as well as a TES medium [2-5]. This concept, called the falling particle receiver, was originally introduced by Sandia National Laboratories [6-13], and it has the potential of pushing the operating temperature limit to 1000°C. Figure 1 shows a sketch of this concept [14]. Solid particles are released within a cavity where they are heated by concentrated sunlight which comes from a heliostat field through the cavity's aperture. Once the particles are heated, they are fed to a TES bin, where some of the particles are stored, while the rest move to a heat exchanger, where their energy is extracted by a working fluid. The cooler particles pass through another bin and are then recirculated to the top of the receiver.

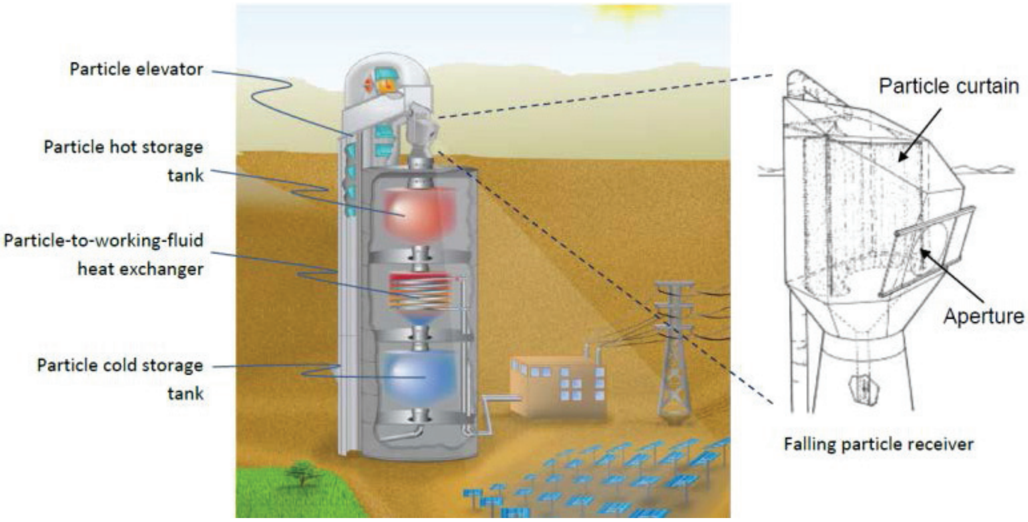

Fig. 1: Sketch of the falling particle receiver concept [14].

Design of the upper (hot) TES bin requires special attention for many reasons. First, the TES bin needs to be built from carefully selected materials and with carefully selected dimensions such that it minimizes energy loss to levels below acceptable limits. Second, the materials of construction need to withstand thermal cycling. Third, the materials of construction need to be inexpensive and readily available. Fourth, the geometry of the TES bin needs to be structurally stable.

The research team had previously conducted experiments on a small-scale TES bin and a medium-scale TES bin [2-4]. The small-scale TES bin was made of three layers consisting of regular firebrick, autoclaved aerated concrete, and reinforced concrete. An LPG burner was used to simulate the presence of hot solid particles inside the bin. That experiment was helpful in identifying issues with the use of autoclaved aerated concrete at high temperatures, since it was prone to cracking. A subsequent medium-scale experiment was conducted on a rectangular-shaped TES bin. The walls of the bin were made of four layers: insulating firebrick, perlite concrete, expansion board, and reinforced concrete. The design showed good mechanical and thermal behavior, and it was deemed suitable for further investigation.

The above mentioned TES conceptual design was included in the research team's plans to build a pilot facility to test the falling particle receiver concept. This facility is currently being constructed at King Saud University in Riyadh, Saudi Arabia, and it is rated at 300 kW(thermal). Figure 2 shows a cut-away view of the upper part of the tower being constructed.