Experimental validation of steel slag as thermal energy storage material in a 400 kWh_t prototype

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1. Introduction

In the search of new generation of thermal energy storage (TES) alternatives, which could provide a cost-effective, high temperature and efficient performance, single-tank storage alternatives have been suggested as a promising solution. These technologies present very attracting advantages beyond decreasing the overall cost of the TES system. Among them, they allow the usage of one tank instead of two, as in current molten salt double-tank TES technology, or an important reduction of the amount of HTF needed. Usually, the HTFs implemented in concentrated solar power plants (CSP) are expensive and demand continuous technical attention to avoid undesired malfunction such as freezing, decomposition, overpressure and other issues. In this regard, the substitution of large amount of fluid by an inexpensive solid material in a single-tank storage could open a new generation of TES alternatives. Aligned with these ideas, packed bed TES systems have been proposed in the last years as one of the most promising TES technologies to reduce the levelized cost of electricity in CSP plants. Packed bed systems are a single-tank solution where the hot and cold fluid zones coexist in the same volume without any physical separation. It consists in the packing of solid individual particles conforming a fixed solid bed. Through the empty volumes of this bed, a HTF is circulated releasing/receiving heat in the charge and discharge operations respectively.

A huge research effort has been done in the last years in the search of high performing and low-cost filler materials, in the analysis of their stability in direct contact with the HTF and with thermal cycling, and in the understanding of the temperature stratification (thermocline) mechanisms that govern the thermal performance of the packed bed [1]. Despite all this work, there is still a lack of clear commercial implementation of this type of systems at real industrial scale. The main limitations that have arisen to this technology are the possible mechanical failures due to the rearrangement of the particles with the thermal cycles, the so-called ratcheting, and the stability/degradation of the thermocline region over time causing a clear exergy loss and a reduction of the storage capacity of the system.

Taking these limitations into account, this work, as well as the European project Reslag, have, as one of the main objectives the experimental validation of the steel slag, the most widely generated by-product in the iron and steel industry, as TES material for packed bed systems. In this regard, this paper presents the results and the conclusions extracted in the experimental campaign carried out in a 400 kWh_t packed bed prototype that implements slag particles as TES medium and air as HTF. In addition to the viability analysis of the selected material and TES technology, this work includes a detailed study of the system performance under different charge, discharge and idle operation conditions. Furthermore, the validation of the obtained experimental results has also been addressed by means of a computational fluid dynamics (CFD) model.

2. Methodology and results

In order to achieve the aforementioned objectives, the *Air Test Loop* facility at CIC Energigune has been used. This lab-scale installation permits the testing of TES systems with a wide flexibility in operational temperature range and air velocities. The main specifications of this facility are reported in the left hand side of Table 1. For this work, a 1 m^3 TES tank has been connected to the *Air Test Loop* (see Figure 1a). Its specific dimensions are collected in the right hand side of Table 1. The investigated packed bed was filled with particles of 1 cm produced within the Reslag project by a mechanical abrasion route carried out in IK4-

Azterlan. This process aimed at the production of slag pebbles with enhanced mechanical stability and improved energy density (lower porosity) in comparison to the raw steel slag [2]. In order to control all the thermal mechanisms occurring inside the packed bed, the temperature inside the bed was measured with K-type thermocouples. In addition to the inlet and outlet temperatures, 9 thermocouples were allocated in the vertical direction of the tank, containing each of them 5 measuring points (radial direction of the tank). The positions of these 47 temperature determination positions are presented in Figure 1.

Air test loop		**Packed bed unit**	
Electrical power	100 kW	Length	1.68 m
Mass flow rate	180 – 360 kg/h	Diameter	0.86 m
T_{max}	800 ºC	Slag mass	2300 kg
T_{min}	Ambient	Void fraction	0.4

Table 1: Main specifications of the experimental facility used in this work.

As already introduced, the experimental campaign consisted of performing charge, discharge and idle periods operations under different conditions of temperature range, mass flow rate and times. An example of one of the results obtained in such experimental campaign is presented in Figure 1. The reported experiment corresponds to a discharge operation starting from the system completely charged. For the shake of clarity, in this figure only the thermocouples in the central axis of the tank are plotted. In addition to the experimental temperatures, the temperatures obtained with the developed CFD model are also included. Comparing both profiles, a good matching between the experimental and model obtained temperatures is observed. A detailed analysis of the error in each thermocouple resulted in a maximum deviation of a 3% of the implemented ΔT.

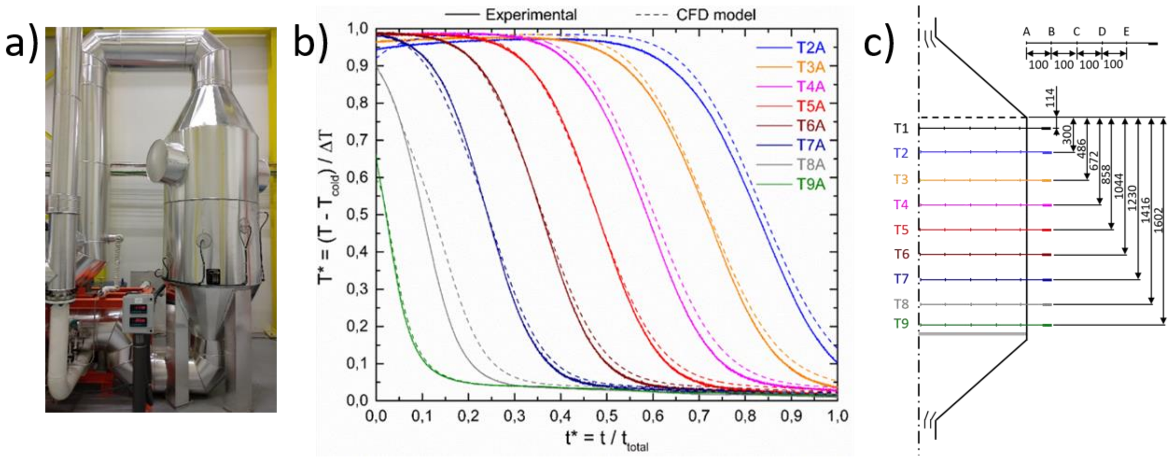

Fig. 1: a) slag-based packed bed prototype; b) experimental and CFD obtained axial temperature profiles in a discharge operation; c) schematic view of the packed bed unit with the thermocouples positions.

Overall, the obtained results in the experimental campaign of the slag-based packed bed have permitted the demonstration of the steel slag as good candidate for this type of TES systems in terms of their thermal and mechanically stability over thermal cycles, together with a high energetic efficiency.

Acknowledgements

This work has been supported by the H2020-WASTE-2014-two-stage (WASTE-1-2014) program through the Project 642067-RESLAG–IA (http://www.reslag.eu/).

References

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