Slag as Inventory Material for a Thermal Energy Storage (TES): Material investigation and thermo-mechanical consideration

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1. Introduction

Concentrating solar tower power systems use numerous large, flat, sun-tracking mirrors (heliostats) for focusing sunlight onto a receiver, based at the top of a tower. Thus a heat transfer fluid (HTF) is heated in the receiver, which is used to generate steam and therefore electricity. Due to the high conversion temperature, air used as a HTF has a particularly promising potential for a high solar-to-electric efficiency.

One challenge for solar tower power plants is the reduced energy output, when the sun sets or is blocked by clouds, as well as the problem, that there is no sunlight and therefore no energy production during night. To face this issues thermal energy storage (TES) are used.

A suitable heat storage technology is the regenerator storage based on directly heated solid media. It has a simple setup, is applicable to highest temperatures (ϑ > 1000°C) and has best prospects for a deployment in large installations. Here slag from steel industry as an inventory material offers cost reduction potentials (Fig. 1). This is due to the fact that slag is treated as waste and can be turned into valuable low cost feedstock for TES.

However, for a successful market introduction of this technology, efficient and up-scalable solutions for the heat storage are a prerequisite. Regenerator storages are well suited to the needs, but need further investigations to clarify open questions concerning the implementation in large installations in combination with slag-pebbles as inventory. The EU project RESLAG is dedicated to this.

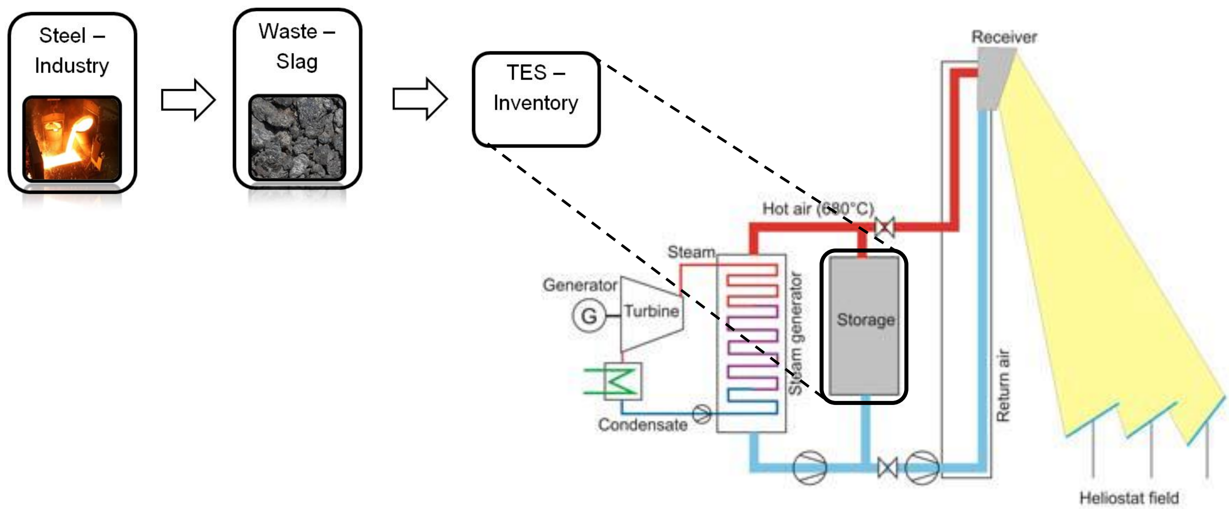

Fig. 1: Flow sheet of slag reuse as TES in CSP.

2. Thermomechanical and slag pebble investigation

Thermo-mechanical challenges arise during thermal cycling of the TES due to thermal expansion of the slag pebbles. This effect causes two major consequences for the pebble bed. Firstly, the contact forces between pebbles increase, resulting in a higher risk of damaging single pebbles. Secondly, the exerted pressure on the surrounding container walls rises, which needs to be considered when dimensioning the container.

For exact thermo-mechanical calculations and to reduce uncertainties during TES operation related to the slag inventory, the slag pebbles needs to be tested under operation conditions. Material modifications and hydration effects resulted in changing inventory strength needs to be determined. Therefore, cyclic furnace tests in hot humid atmosphere with slag and powder samples in terms of hydration were carried out. The evaluation was performed with various supplementary follow-up investigations.

Afterwards thermo-mechanical calculations of the packed bed were performed by using the discrete element method (DEM), where each particle is modelled as its own independent physical object. Since the DEM require high computational effort for large amounts of particles, only a small section of the entire bed was modelled. To gain reliable results a so called worst case scenario was created. Here the boundary conditions were chosen to adequately simulate full-scale setups of specific TES applications. The resulting inter-particle forces were used in a finite element contact model to determine the compressive and tensile stresses of single particles.

The experimental slag pebble investigation results will be presented and discussed in respect to other TES inventory options. Furthermore a comparison of the slag strength with the results of the thermomechanical study will be performed and discussed.