Liquid metal as heat transfer fluid – requirements to avoid risks

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Advances in thermal storage technologies, increased performance of structural materials, and the use of high-temperature heat transfer fluids open up new options to concentrating solar thermal power (CSP) ensuring versatile supply of electrical energy at competitive costs (DC&AC), thermal process heat and also buffering surplus solar power in a high temperature storage without considerable additional efforts. Hence realization of a high temperature CSP can be considered as a credible option to increase the share of variable renewable energy sources (VRES).

The key to a substantial reduction of the levelized cost of energy (LCOE) is a significant increase of the receiver temperature of the solar tower. By now mainly the heat transfer fluid (HTF) and the corresponding storage technologies prevented a substantial progress, while commercially available power conversion systems (PCS) have the capability to manage up to 700°C. One option to overcome this temperature limit is offered by liquid sodium being already studied 30years ago in Almeria but subsequently withdrawn after an accident occurring during maintenance operation. Due to their high heat transfer capability liquid sodium allows for considerably more compact receiver designs reducing thermal losses and also a single-phase storage at temperature levels exceeding 800°C reducing additionally the storage volume and thereby the cost. However, at such high temperatures a safe operation of a liquid metal operated CSP necessitates a dedicated safety oriented design taking into account all operational aspects including maintenance. Such a safety architecture formulates the pre-requisite for a successful deployment of liquid sodium based CSP plants at competitive costs.

1. Safety oriented design for Na-CSP

Today, boosted by the efficiency gain in conventional power conversion technology, a renaissance of sodium as HTF is observed worldwide. In turn a successful deployment of sodium based CSP plants requires a safety oriented design with sufficient margins supported by an adequate safety demonstration to attain public and investor acceptance.

Additionally, the utilization of sodium offers a high operational versatility. Not only the temperature range can be flexibly adapted in a range from 300-800° or even higher to serve the PCS without any precautions to the receiver integrity, but also hybrid storage systems can be connected to the receiver loop without substantial additional efforts, which will be outlined in the paper, too. Combining all modules permits state of art optimization to address stakeholder requirements.

Moreover, sodium allows also to transfer by a dedicated integration of a topping cycle directly converting thermal power into electricity by means of alkali metal thermal electric conversion (AMTEC), which is addressed in [2]. The waste heat from the AMTEC still exhibits a temperature level to be either stored in a thermal storage or directly converted in the PCS. Finally, a novel storage technology provided by a frozen thermocline limits the volume of the sodium and large scale sodium piping grids. An exploitation of all these options facilitates for a versatile and highly flexible CSP plant.

This paper describes a safety oriented design as realized in the KArlsruhe SOdium LAboratory (KASOLA) and gives hints for scale up to industrial size systems. Also options for fast return to operation in case of failures are under discussion in order to reduce HTF caused outages.

The excellent heat transfer characteristic [3] and the required safety provision have to be taken into account to design receiver, heat exchanger and storage tanks. Also lessons learned from different accidents in the past and present are discussed and solutions presented.

2. Experimental capabilities within KASOLA

The KASOLA consists of a sodium lab, which holds several small scale facilities: SOLTEC for material characterization [4] and the high temperature ATEFA facility [5], as well as the medium scale facility KASOLA itself (see Figure 1). It allows simulating the sodium infrastructure of a CSP facility, testing all relevant components and systems as well as the control and safety logic close to prototypic scale. The experiences gained during design and licensing are described and discussed, focused on applicability for industrial sodium based CSP. Dedicated experiments are under design to allow for CFD code qualification [6]. Also a topping cycle (AMTEC & CSP) is under development to extend the operation range of tower CSP to the theoretical maximum of 900 – 1000 °C.

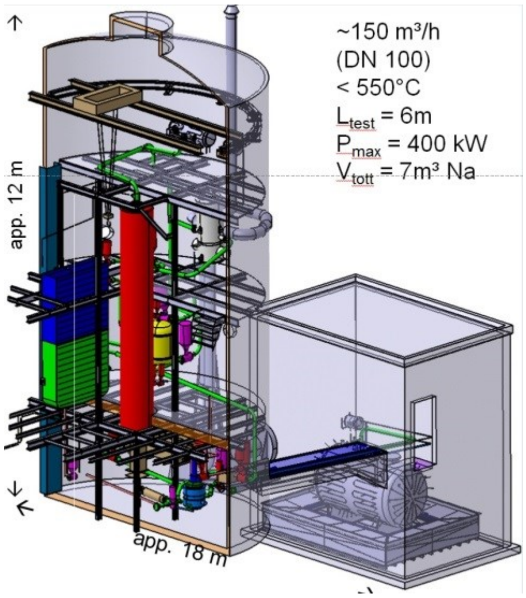

Figure 1 Sketch of the KASOLA facility

3. AMTEC and conventional CSP (A&CP)

Following the concept of combined cycle power plants (GuD) a topping cycle based on AMTEC (Alkali Metal Thermal to Electric Converter) direct energy conversion [5] is proposed and will be demonstrated as part of Helmholtz AMTEC Center at KIT. It comprises an AMTEC cluster and a fast thermal energy storage system in which the excess energy is stored for off light operation [1]. With a small lightweight mirror system and an AMTEC specific receiver all components will be included for an A&CP demonstrator.

The project is funded in the frame of two Helmholtz activities: the Helmholtz alliance on LIquid Metal TECHnology (LIMTECH) and the Helmholtz Energy Material Characterization Platform (HEMCP).

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