Group: Karlsruhe Liquid metal LAboratory (KALLA)

Concentrating Solar Power with Liquid Metals as Heat Transfer Fluids

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Introduction

Liquid metals are investigated as heat transfer fluids in concentrating solar power systems due their excellent heat transfer properties [1,2]. In the SOMMER test facility at KALLA, lead bismuth eutectic (LBE) is used as heat transfer fluid in a so-called thermal receiver in the focal point of the solar furnace [3]. During 2019, the SOMMER test facility has been put up into operation and tests were performed under direct concentrated sunlight conditions. The thermal receiver – efficiently cooled by LBE – withstood maximum heat flux densities of 4 MW/m² without any failure.

Figure 1: Solar furnace arrangement consisting of a heliostat mirror (front, outside) and a parabolic mirror (back, inside the laboratory) (Foto: J. Flesch).

Thermal receiver tests in the SOMMER facility

At the location of the SOMMER facility, peak DNI values of up to 950 W/m² have been measured. The sunlight is reflected by the heliostat mirror (32 m²) and onto the parabolic mirror (16 m²) inside the SOMMER laboratory, where the solar power is concentrated. The solar furnace arrangement without the liquid metal loop is shown in Fig. 1. The installed shutter blinds in front of the parabolic mirror can be adjusted for tests under part-load conditions. For safety reasons, a curtain has been installed that drops into the light passage driven by gravity in case of a power outage or other irregular conditions. Additionally, the heliostat mirror is moved automatically into stow position if there is a power outage.

The liquid metal LBE can be pre-heated in an electric heater before entering the thermal receiver to allow for a wide measuring matrix. After leaving the thermal receiver, the heated liquid metal is again cooled down before entering the pump tank. The pump is a submerged mechanical gear pump delivering 0.1 L/s at 1000 turns/min and is designed to operate up to a temperature of 380 °C. It is located at the highest point of the SOMMER liquid metal loop. During down time or in case of an emergency, the fluid flows down into the sump tank due to gravity. The sump tank has capacity for 130 L of lead-bismuth (Fig. 2).

Figure 2: The sump tank of the SOMMER test facility; top: insulated (Foto: Amadeus Bramsiepe/KIT); bottom: before insulation with electric trace heating (Foto: F. Fellmoser).

The thermal receiver, which is cooled by the LBE flow, is installed in the focal point of the parabolic mirror. It is designed as a spiral tube of 10 mm outer diameter with a wall thickness of 0.5 mm. The area being heated by the sun is 100 mm x 100 mm. The inlet and outlet temperatures of the receiver are measured with thermocouples to determine the thermal power that is absorbed by the liquid metal flow. In total, the thermal receiver has a thermal power input of max. 13 kW. Figure 3 shows the thermal receiver connected to the liquid metal loop. The tubes are coated with Pyromark 2500 to improve the absorption of the sunlight. A large copper plate is installed around the receiver to prevent damages on other components in case of a tracking error of the heliostat. The copper plate will then absorb the heat and the light source can be cut off in this time.

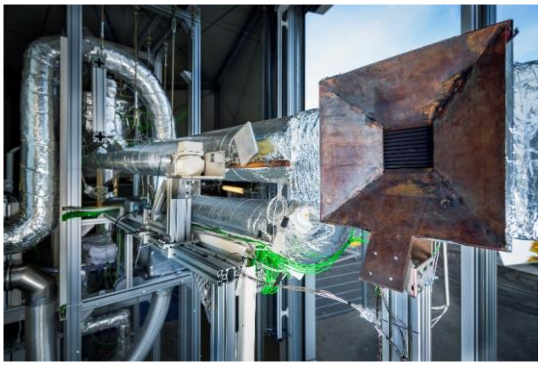

Figure 3: The thermal receiver of the SOMMER test facility with copper shield (Foto: Amadeus Bramsiepe/KIT)

In order to determine the incoming solar power on the receiver a heat flux measurement device was developed [4–6]. It uses a heat flux micro sensor that moves across the focal area on a circular path superimposed with a linear motion. In the SOMMER test facility, the liquid metal loop's position – and thus the thermal receiver's position – is fixed. The parabolic mirror, however, can move along a distance of 0.5 m driven by a linear motor and thus, the focal area can be shifted for the heat flux measurement. Heat flux density (q') values of up to 4 MW/m² were measured and successfully cooled by the lead-bismuth flow, as shown in Fig. 4.

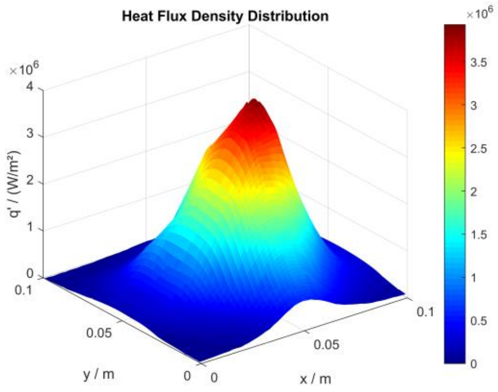

Figure 4: Heat flux distribution measured 28.06.2019 with open shutter blinds

In addition to the experimental investigation in the SOMMER facility, thermal energy storage options for liquid metal were compared [7] and a dual-media thermocline storage system was theoretically investigated in detail [8]. High-temperature thermal energy storage with liquid metals was also investigated regarding the application in energy-intensive industries with waste heat at high temperatures [9, 10]. Experiments for such high temperature thermal storage and liquid metal based process technology are ongoing in KALLA [11].

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