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Experimental Investigation of Thermal Discharge Performance of a Metallic Latent Thermal Energy Storage System

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Extended Abstract

Metallic latent thermal energy storage systems are a promising technology for efficient storage of heat with a small foot print in volume and weight. Metallic phase change materials (mPCMs) are characterized by high energy densities and thermal conductivities [1, 2], which allow for fast thermal charging and discharging. These attributes make this kind of storage system attractive for mobile applications. High heat supply rates are required for battery electric vehicles under cold ambient conditions. In opposite to fuel cell or combustion driven engines, battery electric engines reject only little waste heat available for heating purposes. However, the usage of the battery for resistive heating or operation of a heat pump goes along with a reduction in range, which can be more than 50% at cold temperatures [3]. Therefore, a metallic latent thermal energy storage is a possible approach to solve this problem [4] and is currently considered in particular of interest for applications in battery electric buses.

Kraft et al. presented a first experimental demonstrator utilizing mPCM as storage material for vehicle applications, realizing the thermal output by forced convection of air [4]. Lanz et al. proposed a heat transport system for a similar storage concept, implementing the evaporation and condensation of a working fluid in a closed cycle [5]. A recent study by the authors discussed the general impact of a wide operating temperature range on heat transport system design for a mPCM thermal storage unit in mobile applications [6]. Despite the potential of metallic latent thermal energy storage systems, extensive experimental data of the thermal discharge performance of a real prototype configuration is missing.

Therefore, this study describes a small-scale prototype of a novel mPCM storage concept, that was built-up and experimentally investigated for the first time. The focus of the presented work lies on the characterization of the thermal discharge performance and the heat extraction system. The design is based on the mPCM $AlSi_{12}$ as storage material. Caused by the strong corrosive behaviour of this specific material, it is stored in a box-shaped graphite container. The storage container bears on a steel plate, which contains several electrical heaters for charging heat. Integrated fluid channels serve as heat transfer structure for discharging heat. The fluid channels are connected to an air fan in order to achieve a forced convection thermal discharge with ambient air as heat transfer fluid. The test bench accommodates several thermocouples and the possibility to measure the fluid pressure drop and mass flow. Experiments were conducted for full thermal discharge cycles in an operating temperature range from 650 °C down to 100 °C by variations in air fan power or rather mass flow rates.

The results show that the heat output increases with a rise in storage temperature and air mass flow. Around the phase change temperature of 577 °C, an interesting physical phenomenon is observed. In liquid state of the mPCM, the heat output reaches approximately 3.6 kW or 11 W/cm^2, respectively. After solidification of the mPCM, the heat output drops significantly to approximately 2.2 kW or 7 W/cm^2, respectively, and then gradually decreases with falling storage temperature. This observation can be derived to a noticeable increase in thermal contact resistance, when the mPCM changes its state from liquid to solid. At a storage temperature of 300 °C, a heat output of approximately 1 kW or 3 W/cm^2, respectively, is achieved. Numbers reported are based on an air fan power rate of 100%, which corresponds to a ratio of electric power consumption of the fan to heat output of the storage of smaller than 2.5% at a storage temperature of 300 °C, indicating the efficiency of the thermal discharge concept.

The current work proofs the functionality of the novel storage concept and contributes experimental data about the thermal discharge performance and characteristics for the first time. Prospectively, these data can support simulations and new concept development efforts of metallic latent thermal energy storage systems.

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