Separation of power and capacity in latent heat energy storage

H. Pointner[1], W.D. Steinmann[1], M. Eck[1] and C. Bachelier[2]

[1] German Aerospace Center (DLR), Institute of Technical Thermodynamics, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany.

[2] Novatec Solar GmbH, Herrenstrasse 30, 76133 Karlsruhe.

Corresponding author: wolf.steinmann@dlr.de

1. Introduction

Latent heat energy storage is the preferred concept for systems using steam as a heat transfer fluid. Due to cost aspects, nitrate salts are preferred as phase change materials (PCM). The low thermal conductivity requires the development of cost effective heat transfer concepts to overcome these limitations. State of the art latent heat storage system use finned tube heat exchangers embedded in the PCM-volume to compensate the low thermal conductivity by an extended heat transfer surface. Due to the growing layer of solid PCM covering the heat transfer surface during the discharge process this concept is not able to provide thermal energy at constant temperature and power. An increase of the thermal capacity always requires an increase of the embedded heat exchanger. The mechanical separation of PCM and heat exchanger is considered as a promising approach to allow the control of power by the system and to limit the size of the heat exchanger.

2. The PCMflux concept

The basic concept of the PCMflux is to use a thin fluid layer to separate the PCM from the heat transfer surface while a good thermal contact is ensured. For CSP applications, nitrate salts like $NaNO_3$ with a melting temperature of 305 °C or eutectic mixtures like KNO_3-$NaNO_3$ with a melting temperature of 220 °C are PCM candidate materials. Initially, liquid metals with low melting temperatures were considered for the intermediate fluid layer. While the high thermal conductivity of liquid metals is attractive for this application, the high volume specific costs represent an economic disadvantage. Nitrate salts like Hitec with a low melting temperature have been identified as a cost effective alternative Due to the low thermal conductivity, the thickness of the intermediate fluid must be minimized. Two basic concepts for the implementation of the PCMflux have been developed. The first concept uses finned horizontal tubes which are arranged in parallel. The trough-like fin is used as containment for the intermediate fluid. The PCM is filled into thin walled capsules, which are open at the top (open encapsulation). These capsules are arranged in series. During charging and discharging the belt composed of these PCM-filled capsules is driven across the fin according to Fig.2. The intermediate fluid layer between the fin and the bottom of the capsules

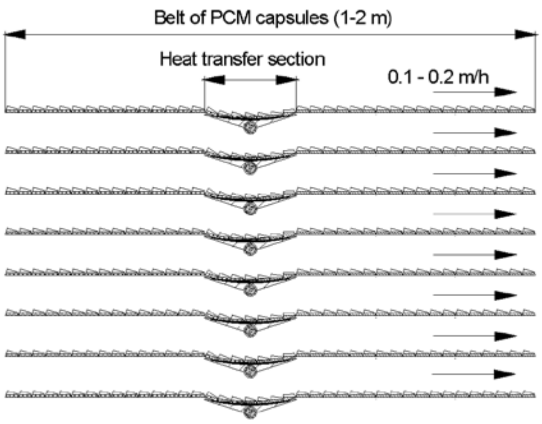

Fig.1: Simplified scheme of the PCMflux storage unit with horizontal tube arrangement

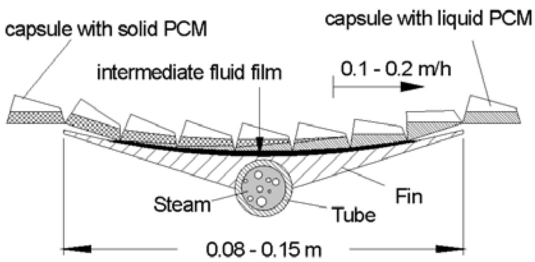

Fig.2: Detailed view of the heat transfer section of the PCMflux storage unit according to Fig.1 (Charging mode)

reduces the heat transfer resistance. The velocity of the PCM is very slow, during a charging or discharging cycle the PCM is moved over a distance of 1-2 m. For a charging process of 4 – 8 h the resulting velocity is in the range of 0.07 mm/s to 0.28 mm/s. The thickness of the PCM layer in the capsules is between 5 – 10 mm.

Using vertical tubes is the second option for the PCMflux concept. The tubes are also extended by fins, the PCM is filled into thin walled containers which are open at the top. The space between the finned tubes and the container is filled again by the intermediate fluid. The containers are floating in the intermediate fluid, so transport is facilitated.

The NextPCM project

The aim of the NextPCM project is the development of an innovative concept for latent heat energy storage at medium and high temperatures. In an initial phase PCMflux was identified as a promising alternative approach to allow a cost effective storage using PCMs. This feasibility of this concept should be demonstrated by a lab scale test unit. The basis for the design of this test unit is provided by a simulation tool which allows the transient simulation of a PCMflux storage unit dependent on geometry and operation parameters. While the calculated results are promising, additional experimental information is necessary to reduce the uncertainties in the physical model. These uncertainties are mainly related to the heat transfer process in the intermediate fluid layer. Experimental activities are organized in several consecutive steps. A first experimental set-up was focused on the evaluation of the contact resistance between the surface of the fin and the bottom of PCM capsules. In these experiments heat was transferred to a PCM volume (eutectic KNO_3-$NaNO_3$) via an intermediate fluid layer (Hitec®) during melting and solidification. The experiments show the significant improvement of the heat transfer by the intermediate fluid layer compared to dry contact, relations for the calculation of the heat transfer resistance dependent on the thickness of the intermediate fluid have been developed. In the next experimental step the movement of the PCM will be introduced. Various geometries for the encapsulation are examined, the transport process of the capsules across the intermediate fluid layer is analyzed. Based on these results, one of the two basic concepts developed for the implementation of the PCMflux concepts will be selected for the test unit.

In parallel to the development of the PCMflux concept, the application of this concept in a CSP plant will be evaluated. For the connection to a direct steam generation solar field the boundary conditions imposed on the storage unit will be determined, criteria for the evaluation of the new storage concept will be defined.

The paper describes the development of PCMflux based on previous findings in latent heat storage. Various options for the implementation of the concept will be presented, results of the theoretical analysis will be given. The results of the experiments on heat transfer across the intermediate fluid layer will be presented and interpreted.