

Sustainable Energy Storage in Buildings Conference APPLICATION ORIENTED INVESTIGATION OF PCS ON THERMAL AND HYDRAULIC PROPERTIES

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1. INTRODUCTION

Thermal storages are essential for more efficient usage of renewable energies which do not present constant supply [1],[2]. Beside the common application of sensible storages, latent heat storages gained in importance. Phase change materials (PCM) can absorb and release a large amount of heat within a small temperature change while undergoing a phase transition. The most common classes of PCMs are organic and inorganic materials [3]. Low thermal conductivity problems associated with PCM are circumvented by encapsulation. Examples are macro-encapsulated PCM in cold storages or microencapsulated PCM integrated into gypsum plaster boards [4]. Another way of usage is to disperse PCM into a carrier fluid and to use it as heat transfer and storage fluid [5]. These mixtures of PCMs and carrier fluid, which is mainly water, are termed as phase change slurries (PCS). The two main technologies to generate PCS are suspensions of microencapsulated PCM (mPCM) and the direct emulsification of organic PCMs into water. The main requirements for these PCS are high heat capacity in the melting range of the PCM, low viscosity and slow separation speed. Viscosity mainly depends on the fraction of PCS dispersed in water and the amount of additives (thickener). With higher fraction of PCM energy density increases, but also the viscosity rises. In this work two suspensions of different fractions of microencapsulated paraffin will be analyzed and investigated as heat transfer fluid in a cooling application.

The original PCS is delivered by BASF with a fraction of about 40 wt.-% of microcapsules dispersed in water. For the experiments two samples of PCS with fractions of 20 and 30 wt.-% of microcapsules in water were formulated. Both samples were stabilized by adding the same weight-fraction of thickener. The aim of the research was to determine the influence of the capsule fraction in PCS as heat transfer fluid, for active cooling application containing chilled ceiling panels, on thermal and hydraulic characteristics. The samples were characterized with regard to heat capacity, density and viscosity. Furthermore the samples were tested in a hydraulic facility containing a centrifugal pump and plate heat exchangers in order to investigate differential pressure and heat transfer characteristic.

2. MATERIAL PROPERTIES

The 20 and 30 wt.-% sample were characterized and compared to water in laboratory sample scale. The particle size was determined with a laser diffraction particle size analyzer

(Beckman Coulter LS 13320). The measurement obtained a particle diameter between 1 to 15 μm with a median of around 4.3 μm .

The rheological properties were measured by using a rotational rheometer (Anton Paar, MCR 502) with a cylindrical geometry. Figure 1 shows the measured viscosity as a function of temperature at a constant shear rate of 100 1/s. The viscosity was determined in a temperature range between 5°C and 25°C. Viscosity of the 30 wt.-% PCS sample varies between 102 mPa s and 58 mPa s in dependence on temperature. The 20 wt.-% PCS shows a viscosity between 42 mPa s and 28 mPa s.

The change of enthalpy was determined with a Differential Scanning Calorimeter (DSC, SETARAM micro DSC IIIa). Small samples are heated up and cooled down while the heat flux into the samples (about 350 mg) is measured. Figure 2 shows the integrated heat flux over time and thus the change of enthalpy in the temperature range between 10°C and 22°C. The measurement was done for all samples with a linear heating/cooling rate of 0.05 K/min. The heating rate was determined according to the German RAL-standard for PCMs [6].

The paraffin liquefies at around 16°C and is completely molten at around 18.5°C. The solidification starts at around 16.5°C and the PCM is solid at around 14.5°C. The hysteresis is about 2 K. The melting enthalpy is 58.8 J/g for the 20 wt.-% PCS and 69.5 J/g for the 30 wt.-% PCS sample.

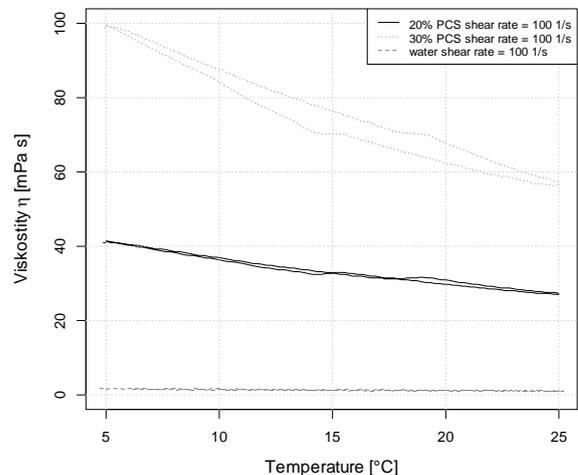


Figure 1: Viscosities vs. temperatures at constant shear rates of 100/s

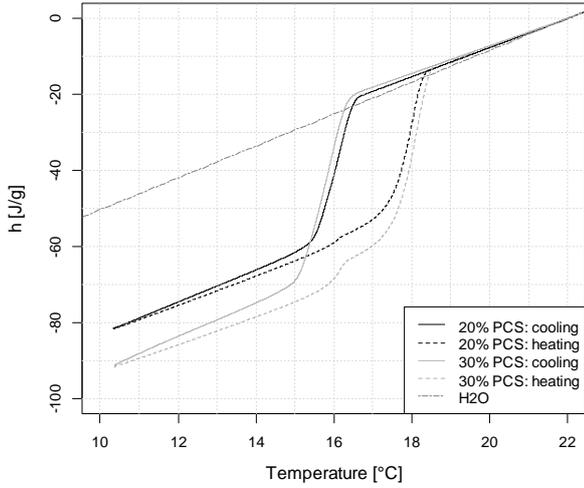


Figure 2: Enthalpies vs. temperatures

The hysteresis characteristics in phase change of PCS can also be observed in density measurements (Figure 3). The density was determined using an oscillating U-tube method density meter (Anton Paar DMA 4500). The density of the fluid changes around 2-3% between solid and liquid state. As the water content is higher in 20% PCS, the fluid is denser than 30% PCS.

EXPERIMENTAL SETUP

Figure 4 shows a sketch of the test facility with three different hydraulic loops. The investigated fluid circulates in the central loop (test loop) and gets heated up by a heater on the left side (heating loop). The heated test fluid is cooled down on the right side (cooling loop). The test fluid is conveyed by a centrifugal pump. Thermal energy is transferred into the test fluid using plate heat exchangers (API Schmidt-Bretten GmbH & Co. KG, SIGMA M 7 NBL). On the heating side the heat exchanger contains 8 plates with a heat exchange surface of 0.4 m², on the cooling side 10 plates with 0.5m²,

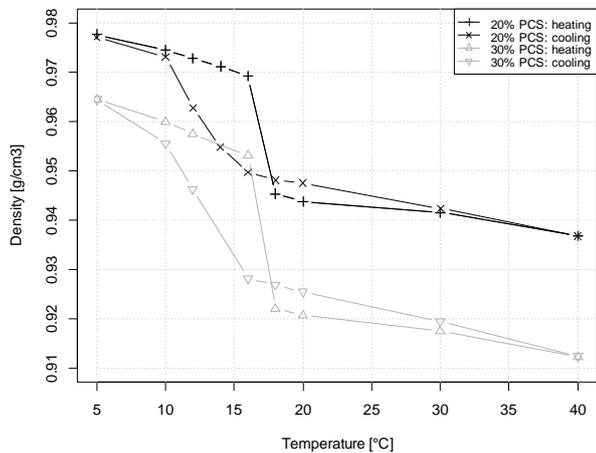


Figure 3: Densities vs. temperatures

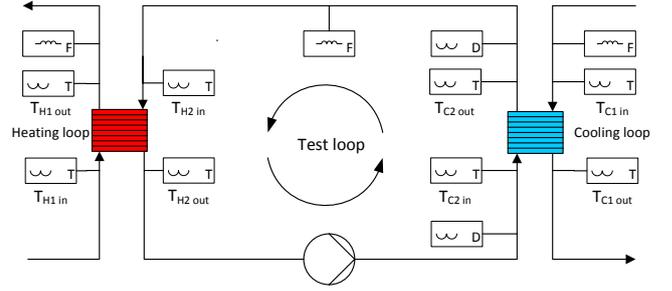


Figure 4 Test bench setup

respectively. Pt-100 temperature sensors are installed on each heat exchanger inlet and outlet. Volume flows are measured in every hydraulic loop by magnetic volume-flow meters. Two pressure sensors are installed on the test loop side of the cooling heat exchanger to determine the differential pressure.

In the heating loop water is used as heat transfer fluid and the cooling loop is operated with a water-glycol mixture. Since the thermodynamic properties of water and of the water-glycol mixture as density (ρ) and specific heat capacity (\bar{c}_p) are well known, heat fluxes (\dot{Q}) can be calculated for the heating/cooling loops by using the measured quantities volume flows (\dot{V}) and temperatures (T):

$$\dot{Q}_{C1} = \dot{V}_C \cdot \rho_{C1 in} \cdot \bar{c}_{pC1} (T_{C1 in} - T_{C2 out}) \quad (1)$$

and

$$\dot{Q}_{H1} = \dot{V}_H \cdot \rho_{H1 out} \cdot \bar{c}_{pH1} (T_{H1 in} - T_{H1 out}) \quad (2)$$

The change in enthalpy (Δh) is calculated as follows:

$$\Delta h = \frac{\dot{Q}_{H1}}{\dot{V}_S \rho_S} = \frac{\dot{Q}_{H1}}{\dot{m}_S} \quad (3)$$

Measurements were carried out first with water as reference fluid and afterwards with the two PCS-samples. For the experiments the heating and cooling loop was controlled to heat the test fluid to 18 °C and to cool it down again to 12 °C. For the experiments the volume flows of the test fluids were varied between 50 l/h and 700 l/h. The data were measured for a period of at least 30 min of steady state. The maximum volume flow of each test fluid was limited by its viscosity.

4. RESULTS AND DISCUSSION

For the design of heat exchangers, the heat transfer coefficient is an important parameter. Figure 5 shows the heat transfer coefficients of the test-fluids in relation to the volume flows. The heat transfer coefficient was calculated on the heating side using the heat transfer surface and the logarithmic temperature difference. The heat transfer coefficients are higher for water due to its low viscosity. At a volume flow of 150 l/h 20 wt.-% PCS transfers heat with 851 W/m²K and 30 wt.-% PCS with 795 W/m²K. The heat transfer coefficient of water is 1545 W/m²K which is about twice as high as PCS.

Although the heat transfer coefficient of PCS is lower than water, PCS can transfer more heat at the same volume flow

Table 1: Comparison enthalpy (sensible and latent) DSC and test bench (volume flow in test bench 100 l/h)

Fluid	Enthalpy change	Enthalpy change
	DSC [J/g]	test facility [J/g]
	12-18°C	
Water	-	25.7
20% PCS	58.8	48.3
30% PCS	69.5	62.6

due to its higher heat capacity in the phase change range.

Table 1 shows the enthalpy change of samples characterized with the DSC and determined by samples measured in the test facility at a volume flow of 100 l/h. The samples measured in the test facility show around 10% (30 wt.-% PCS) to 18% (20 wt.-% PCS) less heat capacity than expected by the DSC measurements. The 20 wt.-% PCS is able to store 1.9 and the 30 wt.-% PCS 2.4 times more heat than water.

Figure 6 depicts the differential pressure of the heat exchanger on the cooling side. As expected from the rheological investigations, the pressure drop of the two PCS samples is higher as compared to water. At an operating point of 150 l/h, water has a pressure drop of 17 mbar, 20% PCS 103 mbar and 30% PCS of about 266 mbar. Due to the viscosity of the PCS, the centrifugal pump conveys in maximum 150 l/h with 30 wt.-% PCS and 450 l/h with 20 wt.-% PCS.

Figure 7 illustrates the transferred thermal power over hydraulic power which has to be provided by the pump. From an operating point of 2 W hydraulic power upwards, the 20 wt.-% PCS suspension (filled triangle) transfers up to 25% more thermal power than water (filled circle). If this PCS is operated only in the sensible range (triangle, 22-28°C) the required hydraulic power is higher than the transferred thermal power compared to water. As PCS shows a lower sensible heat outside the melting range and the viscosity of the suspension is higher than water. With its high viscosity, the investigated 30 wt.-% PCS shows a thermal to hydraulic power behavior below water in the measured flow range.

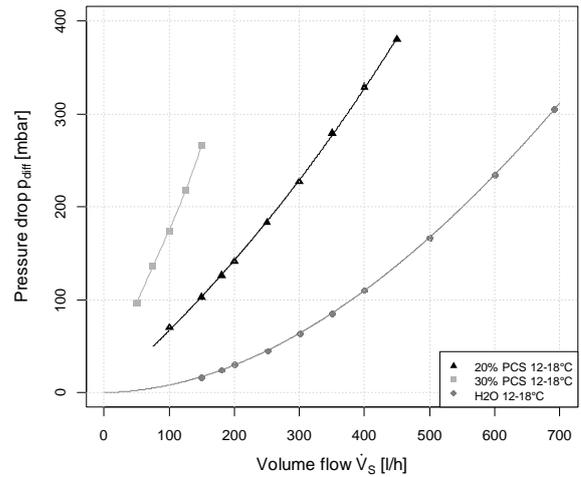


Figure 6: Pressure drop of heat exchanger vs. volume flows

5. CONCLUSIONS

Two PCSs with 20 and 30 wt.-% of microencapsulated paraffin have been prepared and stabilized with thickeners to decrease the separation speed. The viscosities are 28 to 48 and 58 to 108 times higher than water. The PCS suspensions change their density in the melting range of about 2-3% which has to be considered for sizing expansion vessels in hydraulic systems. Due to the viscosities the heat transfer coefficient of the plate heat exchanger reaches about 50 – 55% of the water-performance when operated with PCS. Therefore heat exchangers have to be sized with a larger exchange area to reach a similar performance. In the test facility the two PCS samples offer a heat capacity which is about 10 – 20% lower than expected by the DSC measurement. This might be attributed to the flow characteristics of the shear thinning PCS and/or thermal inertia when heating up the PCM while flowing through the heat exchanger. This will be investigated in more detail in further experiments. The experimental results showed that even a PCS with only 20 wt.-% of encapsulated paraffin can store almost twice as much heat than water. The higher viscosity has to be considered when dimensioning a

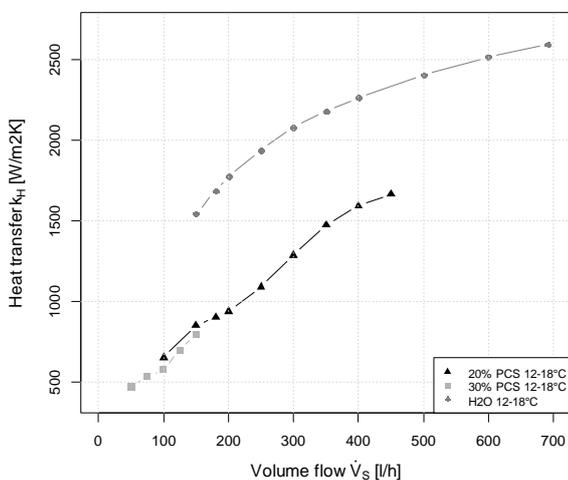


Figure 5: Heat transfer coefficient vs. volume flow

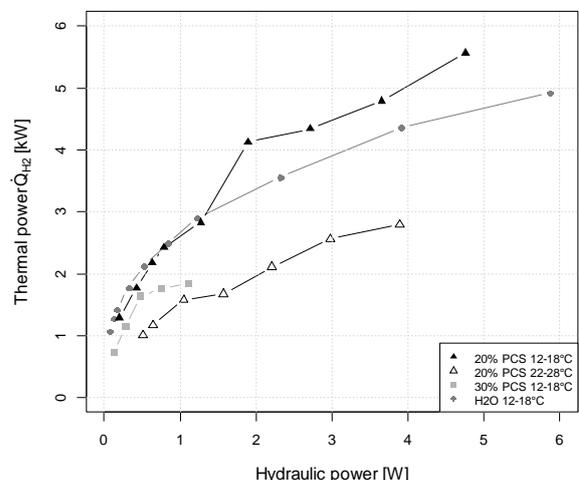


Figure 7: Thermal power vs. hydraulic power

PCS system. Heat exchange surfaces and pressure drop of hydraulic components have to be adjusted to the required thermal power and viscosities. In terms of PCS development further research will be done to develop separation stable PCS with lower viscosities to increase the advantages of these fluids compared to other heat transfer fluids.

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