# LATENT HEAT STORAGE FOR PROCESS HEAT APPLICATIONS USING HD-PE IN FINNED–TUBE HEAT EXCHANGERS


## Summary

This work experimentally investigates two finned–tube latent heat storage units for industrial process heat applications in the 110 °C to 150 °C range. The units are filled with either recycled high-density polyethylene (HD-PE) or a commercial HD-PE wax. Differential scanning calorimetry (DSC) is used to characterise the phase-change behaviour and to define suitable operating temperature levels. At a temperature difference of 30 K, recycled HD-PE shows competitive material-specific costs (~18 €/kWh) compared with pressurised-water and thermal-oil storage, while HD-PE wax is considerably more expensive (~117 €/kWh). Charging and discharging tests are performed for two fin spacings (4 mm and 14 mm). For 14 mm fin distance HD-PE wax provides 34 % higher mean thermal power compared to recycled HD-PE. For a reduced fin distance of 4 mm the power is 24 % higher. While recycled HD-PE is more competitive regarding costs, significant deformation of the fins occurred for it during operation.



*Keywords: Latent Heat Storage, Process Heat Application, Heat Exchanger, recycled HD-PE*


*Field of application for the findings: Industrial process heat and waste heat recovery (110–150 °C); design and optimisation of latent heat storage using HD-PE in finned-tube heat exchangers*

*Addressed audience: Researchers and engineers in thermal energy storage and industrial process heat, designers of finned-tube/PCM heat exchangers*

## 1. Introduction

Given the considerable amount of waste heat available in industrial processes, there is great potential for utilizing this heat through suitable storage and heat recovery concepts (Brückner et al., 2015). One promising approach is the use of latent heat storage systems to close the gap between supply and demand. Due to the low thermal conductivity of phase change materials (PCM) (Fan et al., 2013), power needs to be increased by enlarged heat transfer area via encapsulation of the materials or application of heat conduction enhancement structures such as finned-tube heat exchangers. High-density polyethylene (HD-PE) has proven to be a promising PCM candidate due to its suitable melting temperature range, high latent heat capacity, and long-term stability under repeated thermal cycles (Weingrill et al., 2018; Weingrill et al., 2019). The objective of this work is to compare the thermal performance of two finned–tube heat exchangers with different fin distances, filled either with a low-cost recycled HD-PE or commercial HD-PE wax. The comparison can be used later for a determination of a performance map and design guideline.

## 2. Materials and methods

Two different HD-PEs were analyzed in this work. First recycled HD-PE supplied by Nico Kunststoffe GmbH and second HD-PE wax (Licocene™ PE 4201, Clariant). For a temperature difference ($\Delta T$) of 30 K, costs of around 18 €/kWh and 117 €/kWh are obtained for recycled HD-PE and HD-PE wax, respectively. For this $\Delta T$, the material costs for recycled HD-PE are in a competitive range to pressurized water and thermal oil storage systems, with storage costs of around 24 €/kWh and 19 €/kWh (Fraunhofer-Institut für Solare Energiesysteme ISE und Bundesverband Solarwirtschaft e. V. (2025)). Despite the high cost of HD-PE wax, it was selected for the analyses because it has a significantly lower viscosity than recycled HD-PE and is therefore much easier to handle. To characterize the polymers, differential scanning calorimetry (DSC) measurements were performed. Samples were sealed in hermetic crucibles and subjected to three heating and cooling cycles between 90 °C and 150 °C at a rate of 4 K/min, including 5 min isothermal holds at the upper and lower temperature limits.

The two investigated heat exchangers consist of a stainless-steel casing with three meandering tubes each with eight passes on three vertical levels. Additional aluminum fins with a distance of 4 mm or 14 mm are used. Therminol 660® is used as heat transfer fluid (HTF). The 4 mm unit was tested with recycled HD-PE, while the 14 mm unit was tested with an HD-PE wax and afterwards with recycled HD-PE. A trace heating system is applied to minimize losses to ambient. The trace heating temperature was set to the lower value of each range. Temperatures were measured at the in- and outlet of the HTF and in the PCM by calibrated Pt-100 sensors. In the PCM the sensors were located at different heights and distances from the tubes. The mass flow rate is determined via a Coriolis sensor. For all systems charging and discharging tests were carried out. For the 4 mm heat exchanger three mass flow rates of the HTF (0.017, 0.025 and 0.033 kg/s) and three temperature steps ($\Delta T$ = 19, 29 and 39 K) were measured. The temperature levels were chosen relative to the PCM melting and crystallization temperatures obtained in preliminary tests. This resulted in temperature range of 120 °C to 139 °C, 115 °C to 144 °C and 110 °C to 149 °C, respectively. For the 14 mm heat exchanger with HD-PE wax two mass flow rates (0.017 and 0.033 kg/s) and one temperature step of 30 K was investigated. The choice of temperature levels was hereby depending only on the peak melting temperature measured by DSC (15 K below and above). This resulted in a temperature range of 109 °C to 139 °C. For the 14 mm heat exchanger with recycled HD-PE two mass flow rates (0.025 and 0.033 kg/s) and three temperature steps ($\Delta T$ = 19, 29 and 39 K) were measured so far. The temperature was chosen as for the 4 mm heat exchanger. It is planned to measure further mass flow rates for all temperature steps.

## 3. Results

DSC measurement show, that recycled HD-PE exhibits a sharper peak at a higher temperature of 128.2 °C (onset) and a specific melting enthalpy of 203.7 kJ/kg was measured. HD-PE wax shows a broader melting peak at an onset-temperature of 117.4 °C with a specific melting enthalpy of 224.1 kJ/kg. Recycled HD-PE therefore has a 9.1 % lower specific melting enthalpy than the HD-PE wax.

The comparison of the two finned-tube heat exchangers was carried out by a mass flow rate of 0.033 kg/s and a temperature step of 29 K and 30 K for recycled HD-PE and HD-PE wax, respectively. The different selected inlet temperatures are related to the different melting behaviour in the DSC. The temperature profiles of the measurements are shown in Fig. 1. It becomes apparent that a plateau occurs during melting for the recycled HD-PE, whereas this is hardly observed for the wax.

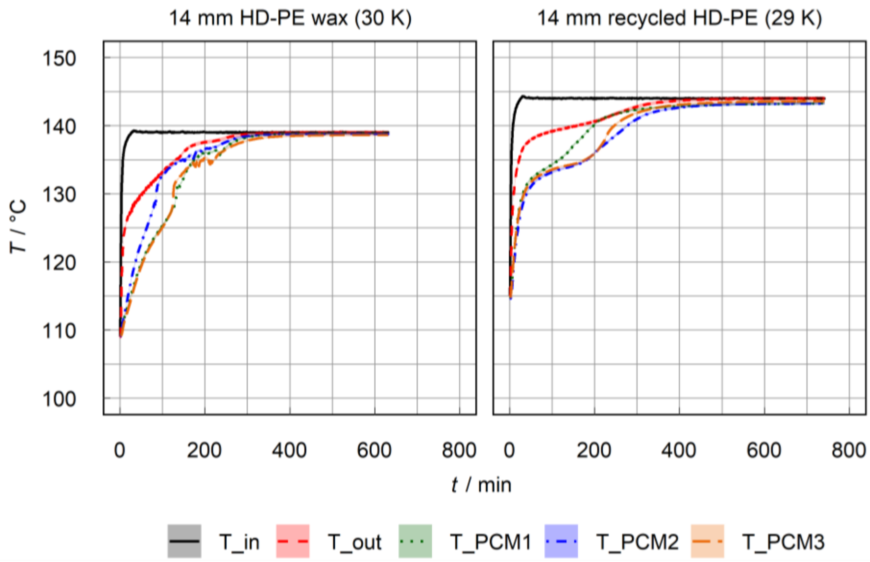
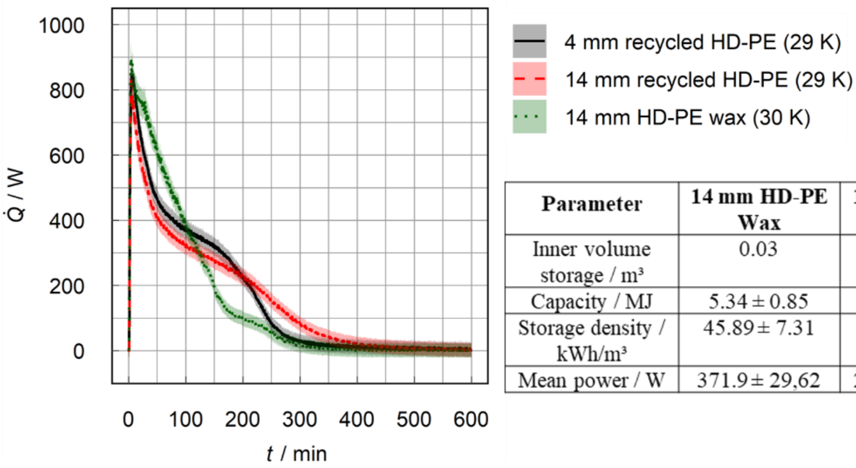



**Fig. 1: Comparison of the temperature profiles**

The average performance of both heat exchanger was calculated for the different measurements. The table in Fig. 2 shows the mean power after 95 % of the total energy is transferred. HD-PE wax exhibits the highest mean power. For 14 mm fin distance HD-PE wax provides 34 % higher mean thermal power compared to recycled HD-PE. With a smaller fin distance and recycled HD-PE, a 24 % higher average power is observed. When examining the power curves, it becomes clear that for HD-PE wax, as in the temperature profile, no melting plateau can be identified. For recycled HD-PE (4 mm fin spacing), higher power is observed in the melting range, but with a 14 mm fin spacing the melting range is longer. The total amount of transferred energy is approximately the same for all three variants (see table in Fig. 2), because the difference in melting enthalpy are not that high and the used mass is for all nearly the same.




| Parameter | 14 mm HD-PE Wax | 14 mm HD-PE recycled | 4 mm HD-PE recycled |
|---|---|---|---|
| Inner volume storage / m³ | 0.03 | 0.03 | 0.03 |
| Capacity / MJ | 5.34 ± 0.85 | 5.67 ± 0.99 | 5.72 ± 1.12 |
| Storage density / kWh/m³ | 45.89 ± 7.31 | 48.72 ± 8.58 | 49.16 ± 9.63 |
| Mean power / W | 371.9 ± 29.62 | 277.72 ± 26.35 | 345.33 ± 28.38 |

**Fig. 2: Comparison of the power evaluation over the time and table with characteristic values**

Visual inspection after the experiments revealed a pronounced displacement of the PCM towards the inlet of the HTF. A possible explanation is that, during discharge at low mass flow rates, the material close to the inlet solidifies first and forms a rigid structure, while the still-liquid PCM in the downstream region is pushed towards the inlet by thermal expansion. Since the heat exchanger was installed horizontally, an inclination can be excluded as the cause of the shift. The large volume change (around 25 %) of HD-PE between solid and liquid state, in combination with its high melt viscosity, led to considerable mechanical stress on the fins. Fins that were initially straight showed noticeable bending after cycling, and the fin spacing locally changed significantly. In contrast, the HD-PE wax is homogeneously distributed after the measurement and did not deform the fin structure. What can be seen, is a color change from initial white to light brown, which could be due to oxidation.

## 4. Conclusion

The results confirm that recycled HD-PE is a technically viable and cost-effective phase-change material for latent heat storage in the investigated temperature range, but it imposes significant mechanical constraints on the heat-exchanger design. Compared with HD-PE wax, recycled HD-PE exhibits slightly lower latent heat and mean power while the melting plateau is more pronounced. However, its large volume change and high melt viscosity cause PCM displacement, fin bending and locally altered fin spacing during cycling, whereas HD-PE wax remains homogeneously distributed and does not damage the fin structure. Thus, HD-PE wax offers better thermo-mechanical behaviour but is economically unattractive at current prices. Future work will address extended operating conditions and improved fin and container concepts to better accommodate PCM expansion and to enable reliable application of low-cost recycled HD-PE in industrial process-heat storage.

## 5. References

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