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Economic efficiency of mobile latent heat storages

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Abstract

In a pilot project an optimized mobile latent heat storage based on a system available on the market has been tested at Fraunhofer Institute for Environmental, Safety and Energy Technology. Initially trials were conducted with the aim of optimizing the process of charging and discharging. A specifically constructed test rig at the incineration trials centre at the institute allowed charging and discharging procedures of the mobile latent heat storage with adjustable parameters. In addition an evaluation model was constructed to further optimize the heat exchanger systems. In conclusion the prototype of the mobile latent heat storage was tested in practical operation. The economic and technical feasibility of heat transportation was shown if not utilized waste heat is available.

Keywords: mobile latent heat storage, thermal energy storage, latent heat, waste heat recovery, phase change material

1. Introduction

The use of waste heat, arising in addition to power generation in biogas plants, other power plants or industrial processes, can contribute to improve energy efficiency and hence reduce the need of primary energy in the future. Not only the time-discontinuous availability, but also the distance between energy source and sink is - due to the absence of a nearby heat consumer - often a major obstacle for the use of waste heat. In this situation, a distribution system based on transportable thermal storage devices can be useful.

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In the agricultural sector there are mainly older biogas plants which usually don't have a comprehensive concept for the use of waste heat in all seasons of the year. Whereas domestic- and barn-heating are potential heat sinks in winter, there is a lack of adjacent heat consumers in summer, so that waste heat cannot be utilized. The amendment to the German Renewable Energies Act (EEG), which was released on 1st January, 2012, emphasizes the utilization of waste heat. New biogas plants have to utilize a minimum of 60-percent of the produced thermal energy, including the own heat demand, to receive payment under the terms of the EEG [1]. However, not only the discontinuous heat demand, but also the distance between biogas plant and the heat demanding side pose obstacles. If the relation between the amount of transported heat and the distance to the heat consumer is inappropriate, the construction of a district heating grid is not profitable, even if there is a continuous heat source [2]. Intermittent decoupling of heat production and consumption can be achieved with thermal storages. Furthermore the combination with mobile applications offers the possibility to use waste heat locally independent. Beside biogas plants the producers of industrial waste heat or biomass heating plants are potential heat sources.

From the consumer's point of view the use of those regionally extended combined heat and power plants (CHP) is useful, if an all-season heat sale can be achieved. Therefore utilization concepts featuring a constant heat demand during the course of the year are primarily focused. Seasonal combinable heat consumers, such as swimming pools in summer and heating systems for schools or public institutions in winter, are potential applications, too.

2. Materials and method

Due to the fact that a large heat storage capacity of the storage material is essential for heat transportation in mobile storages, mainly phase change materials (PCM) are used. The phase change of PCMs from liquid to solid and reverse is used for storing or releasing heat on a constant temperature level. The energy density of latent thermal energy storages is considerably larger than of sensible storages. Within the scope of a pilot project an optimized mobile latent heat storage system based on a system available on the market has been tested at Fraunhofer Institute for Environmental, Safety and Energy Technology. The prototype of the mobile latent heat storage consists of two storage tanks connected in parallel, built in a thermally insulated 20-feet-container and containing about 1.3 MWh of latent heat. Including sensible heat a storage capacity of up to 2 MWh is possible. Salt hydrates working as storage material release the crystallization enthalpy while discharging. Over a defined period of time a constant temperature of about 58 °C is guaranteed because of the storage material sodium acetate trihydrate. The storage parts are equipped with 24 internal tube registers each, operating as tube heat exchangers. Furthermore the tube heat exchanger of one part of the storage system was extended with graphite structures to enhance the charging and discharging processes. To analyse the behaviour of the PCM while charging and discharging, both storage parts are equipped with extensive measurement devices.

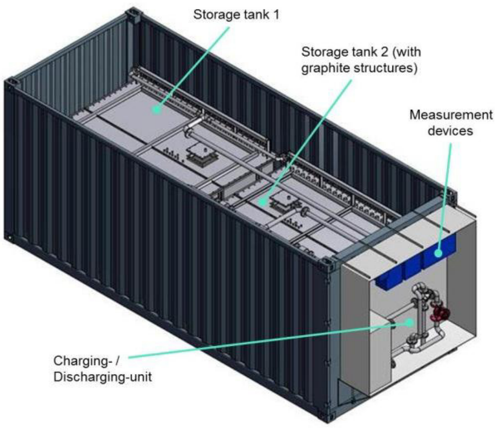

Fig. 1. Structure of the storage prototype with two storage tanks.

3. Results and discussion

3.1. Research at the test rig

Initially thermodynamical analyses concerning the heat transfer and trials were conducted with the aim of optimizing the process of charging and discharging. A specifically constructed test rig at the incineration trials centre at the institute allowed charging and discharging procedures of the mobile latent heat storage with adjustable parameters. Especially a high temperature difference between the inlet-temperature of the heat transfer fluid and the melting point of the salt hydrate improves charging-times. Therefore the primary focus was laid on changing the flow rate at constant inlet-temperatures of 85 °C. A heat content of 750 kWh of each storage tank was defined before executing the trial. In storage part 2, this heat content was achieved after 11.1 hours. In comparison to storage part 1, which was completely charged after 14 hours, the time saved by extending the internal tube registers with graphite structures was 2.9 hours or 18 %. The chart in Figure 2 shows the charging process of storage part 2 in the trial at a flow rate of 5.2 m^3/h.

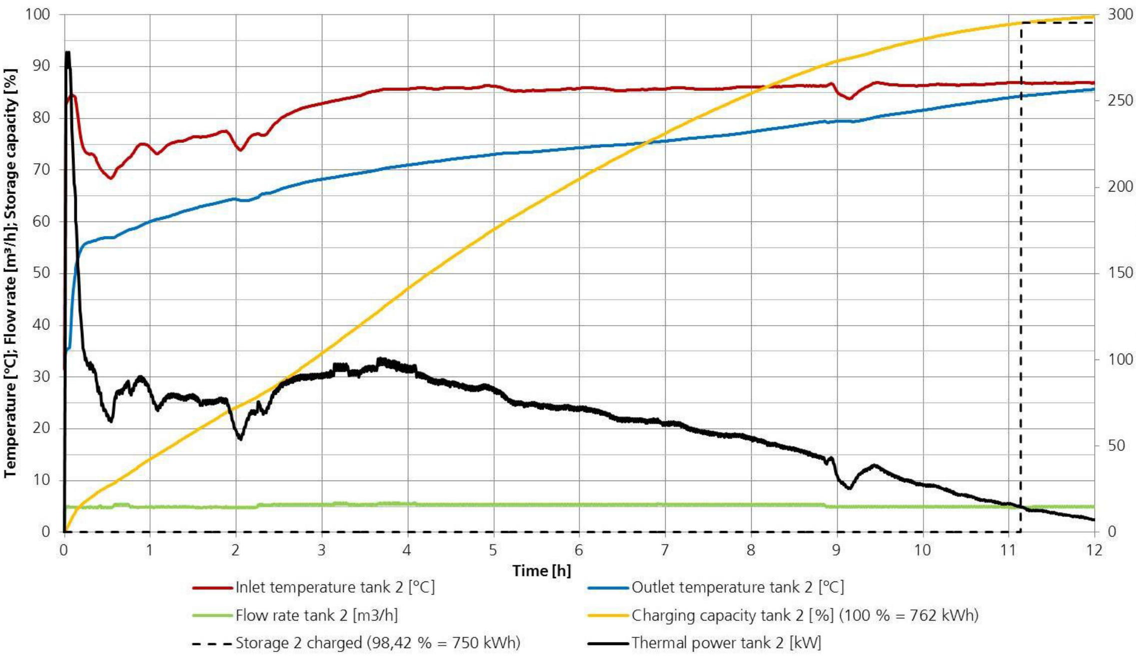

Fig. 2. Charging storage part 2 at the incineration trials centre.

During the discharge process the necessary discharge time and the amount of heat released had to be determined. In general latent heat storages are discharged when the temperature difference between inlet- and outlet-temperature of the heat transfer fluid is smaller than 5 K. By using default values of the flow rate and a constant, recooled inlet-temperature of the heat transfer fluid of 35 °C an ideal consumer was simulated at the test-bed. When discharging no significant time difference between both storage parts was noticeable. At a constant flow rate of 3.5 m^3/h, both storage parts were completely discharged after 15.2 hours. Concerning the storage quality an overall efficiency of 90 % was achieved. In storage part 2, with an amount of 750 kWh of heat stored and 710 kWh of heat released, an efficiency of even 94.5 % was accomplished.

While research at the storage prototype went on, an evaluation model (Figure 3) on a scale of 1:50 was constructed to further optimize the heat exchanger system. The evaluation model is, because of its compact, modular design, easier to modify than the storage prototype in the 20-feet-container. Therefore relevant results were gained in a short time. Based upon these results, recommendations concerning the design and operation mode of the storage prototype were made. A reduction of the charging time of 37 % was achieved by changing the flow rate, the inlet-temperature and the gaps between the tube registers.

Fig. 3. Evaluation model of the storage prototype.

3.2. Practical experiences with the storage prototype

The prototype of the mobile latent heat storage was tested in practical operation during a period of six months to evaluate the economic and technical feasibility of heat transportation. The testing was conducted in continuous mode storing waste heat from a biogas plant and releasing heat in a small district heating system in a distance of 6 km. Usually the district heating system is operated with a woodchip furnace and consists of six single-family houses, an office building and a storehouse. With the objective of providing significant conclusions about the system performance and the influence of user behaviour, the operation parameters of the storage prototype were mapped with measurement devices at each stage of testing. Analyses of the energy balance and the profitability of operation were conducted with the available data and our results. For an inlet-temperature of 90 °C and an average charging-power of 120 kW, the examination of the measurement results showed that the mobile latent heat storage frequently reached its capacity limit after 12-14 hours, meaning it was fully charged. The charging capacity depends largely upon the temperature level to which the mobile latent heat storage was discharged. Through utilization of the low temperature sensible heat by using the storage for operating a drying plant for woodchip it was possible to discharge the storage to a temperature level of 25 °C. Thus in most cases a charging capacity of up to2000 kWh was obtained. Figure 4 gives an example of a discharging process.

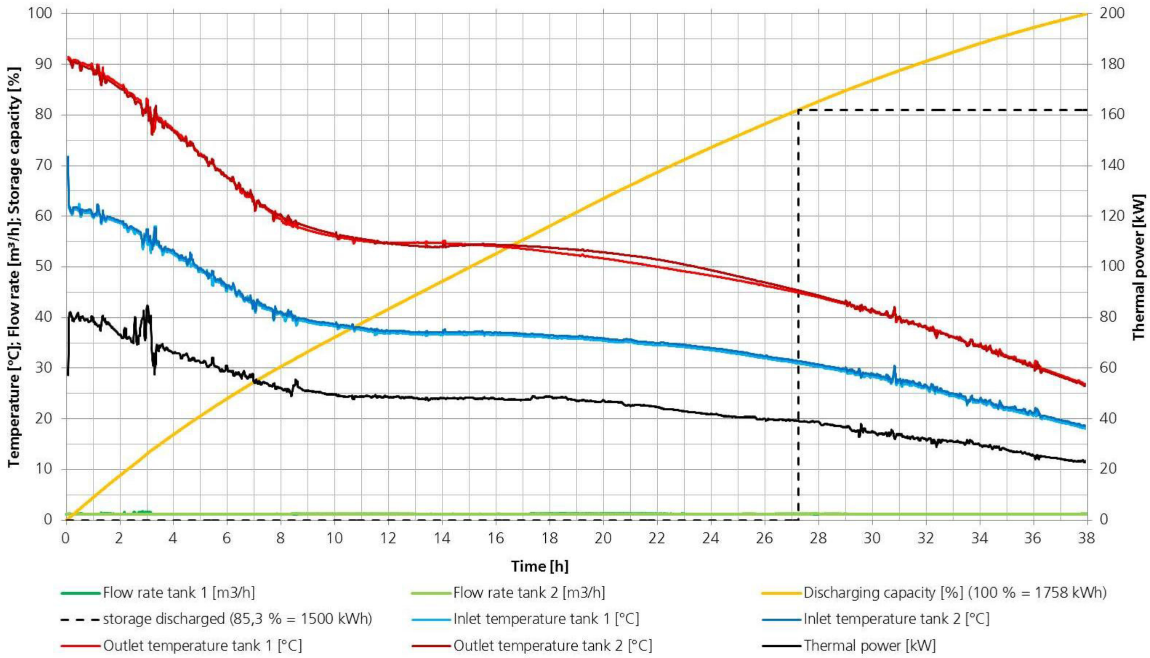

Fig. 4. Discharging of the storage prototype in practical operation.

Beside sensible heat transfer there is latent heat transfer in the temperature range of 50-60 °C, indicating the release of thermal energy over a period of about 16 hours. During the whole discharging process both storage tanks provided almost the same amount of thermal power, which is displayed in similar power curves. Considering the discharging power, there is no significant influence caused by the graphite structures in storage part 2 in comparison to storage part 1. The effect may result from the low consumer's power demand of up to 40 kW over a discharging time of 38 hours.

3.3. Economic efficiency of mobile latent heat storages

In few cases operators have the possibility to use low temperature heat technically. Therefore a realistic discharging time of 27 hours, resulting in 1500 kWh recoverable thermal energy is presumed. Consequently one cycle of charging and discharging, including a replacement period of one hour for exchange and transportation of the mobile latent heat storage is practicable within 40 hours. Provided with an appropriate distribution system, 220 cycles within one year are possible. Nevertheless only 200 cycles per year were assumed in the economic evaluation in consequence of time-consuming factors like maintenance, personnel shortfalls or discontinuous heat demand. The fixed investment cost, transportation and operating costs like motor fuel or electrical power for the pumps have been considered as expenses and broken down to one cycle of charging and discharging. The calculation is based on a service life of ten years and entire self-financing without an interest rate. With an amount of heat of 1500 kWh transported per cycle, 200 cycles per year and a distance of 5.6 km between heat source and heat sink in pilot operation, heat generation costs of 5.0 ct/kWh arise for the use of two mobile latent heat storages in alternating operation (Figure 5). Based upon an average price of district heat of 7.4 ct/kWh, 1 kWh transported generates a profit of about 2.4 ct [3]. The sensitivity analysis indicates that market-adapted systems of the storage prototype result in even smaller heat generation costs, which is shown in Figure 5.

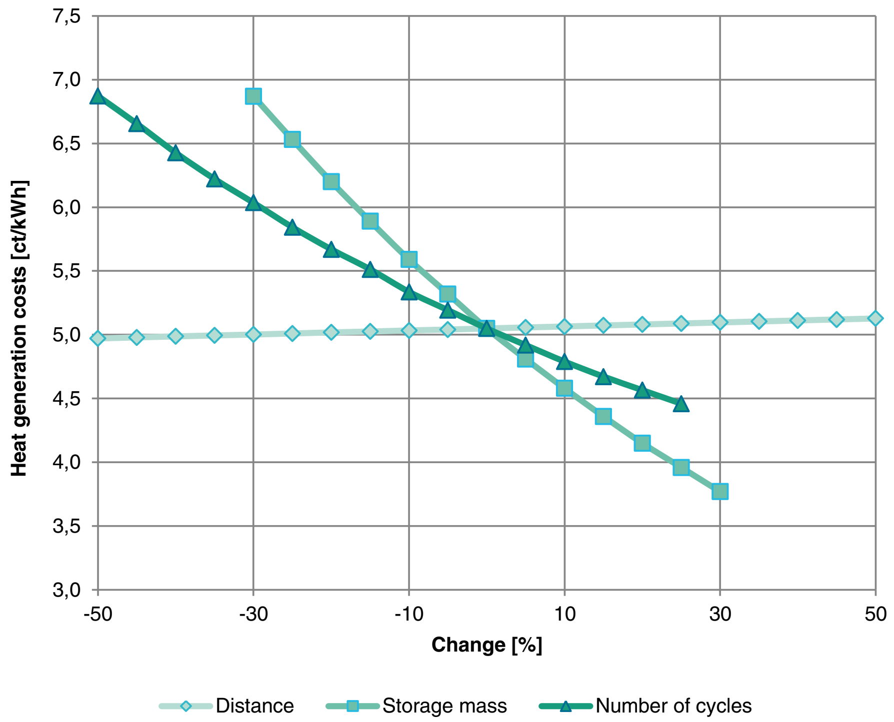

Fig. 5. Sensitivity analysis of the storage prototype.

These storage solutions are designed for the valid maximum authorized weight of the mobile latent heat storage. With a storage mass of 21000 kg heat generation costs of merely 3.7 ct/kWh arise. Another influencing factor is the number of cycles per year, which has to be as high as possible. The transport distance has, in comparison to the storage mass and number of cycles, the lowest sensitivity. For the use of two storages it is 12 km per cycle. Even enlarging the transportation distance to additional 50 per cent just results in a slight increase of heat generation costs to 5.1 ct/kWh. As the chart in Figure 6 shows, heat supply via mobile latent heat storages can compete with conventional heating systems.

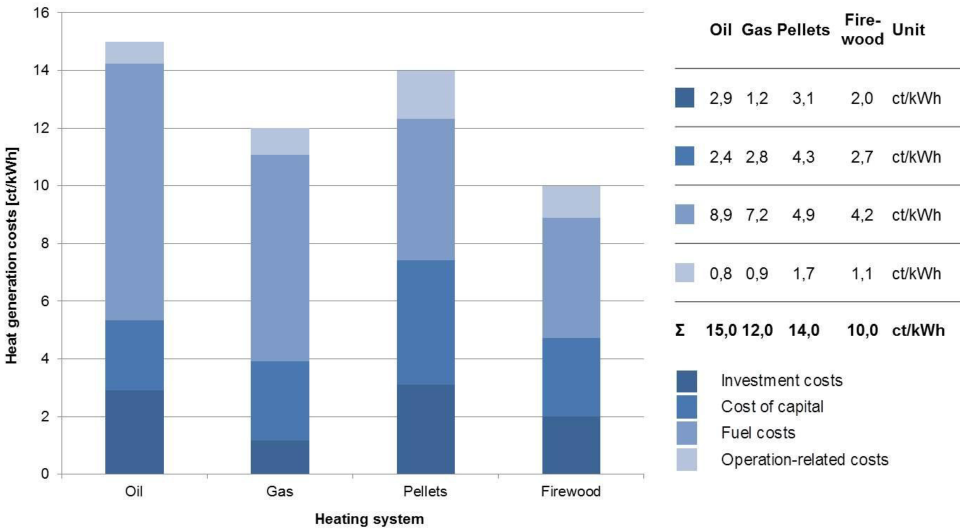

Fig. 6. Heat generation costs of different systems, own calculation [4].

4. Conclusion

Within the scope of testing of the storage prototype the technical and economic feasibility of mobile latent heat storages was proven. The profitability of these systems highly depends not only on the storage capacity but also on the user behavior and on the number of cycles per year. This requires that low-cost, previously not utilized waste heat is available. Furthermore short charging and discharging durations are necessary. Through changing the parameters of flow rate, inlet temperature of the heat transfer fluid, the primary side's power out- and input plus construction material and geometry of the heat exchanger system, optimized charging times of the mobile latent heat storage were achieved. The use of graphite structures had positive influence on the charging time. However, these elements intensely affect the manufacturing costs of mobile latent heat storages. The obtained test results at the evaluation model led to reduced tube distances between the tube registers and consequently reduced the charging and discharging times even further. Based on the gained insights it will be possible to use mobile latent heat storages as a market available system, especially for up to now not utilized waste heat potentials.

Acknowledgements

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