Technology: Sensible Heat Water Storage

GENERAL DESCRIPTION

Mode of energy intake and output

Heat-to-heat

Summary of the storage process

During charging (energy supply), the kinetic energy in the molecules making up the storage material is increased. This results in an increased temperature of the storage content, although no phase transition (e.g. solid-liquid) takes place. Materials suitable for this purpose are non-toxic and inexpensive with a high heat capacity c in kJ/(kg·K), such as water with a c value of 4.2 kJ/(kg·K), for which even a small temperature elevation corresponds to a large amount of stored heat. For water, it is 4.2 kJ (= 1.17 Wh) per 1 litre of volume and 1 degree of temperature increase. For a 300-litre water tank and 70-degree temperature increase (e.g. from 20 to 90 °C), this makes 24.5 kWh of stored thermal energy at 90 °C. Discharging (energy withdrawal) cools down the storage tank's contents. For liquids, density changes depending on the temperature. Hot water is lighter than cold water, thus, buoyancy forces cause thermal stratification in the storage tank. This natural stratification should not be disturbed during charging and discharging, as otherwise the mean temperature in the storage tank will drop to a lower level, at which it may not be usable without additional reheating.

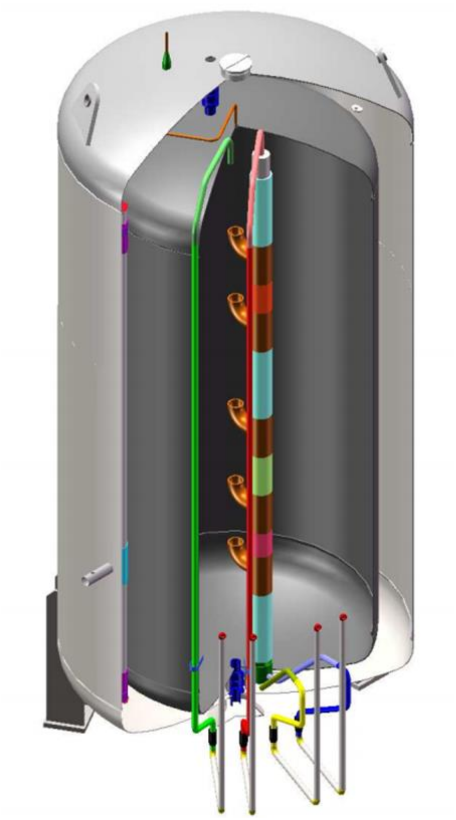

Figure 1: Bivalent sensible vacuum super-insulated-water buffer storage by manufacturer Hummelsberger (2-50 m³, vakuumpufferspeicher.de) with patented stratified loading system and external heat exchangers (not in picture) developed at ZAE Bayern (BMU grant # 0325964 A)

System Design

Generally, storage systems should be distinguished according to whether they hold heating water or domestic hot water. However, a combination of the two is equally possible, as illustrated in Figure 2. For domestic hot water storages, charging and discharging takes place indirectly via an integrated heat exchanger. These spiral pipes, usually made of steel, heat the required domestic hot water through the heating circuit or solar thermal system. Since the hot water is stored directly, the tanks are manufactured from stainless or subsequently enamelled steel for hygienic reasons. Additionally, for legionella protection, the contents of the storage tank must be heated to at least 60 °C once per day.

Storage systems integrated into the heating system mostly employ direct charging and discharging. A typical application would be a buffer storage in a wood combustion system which is equipped with an additional heat exchanger for the solar thermal system, as shown in Figure 2.

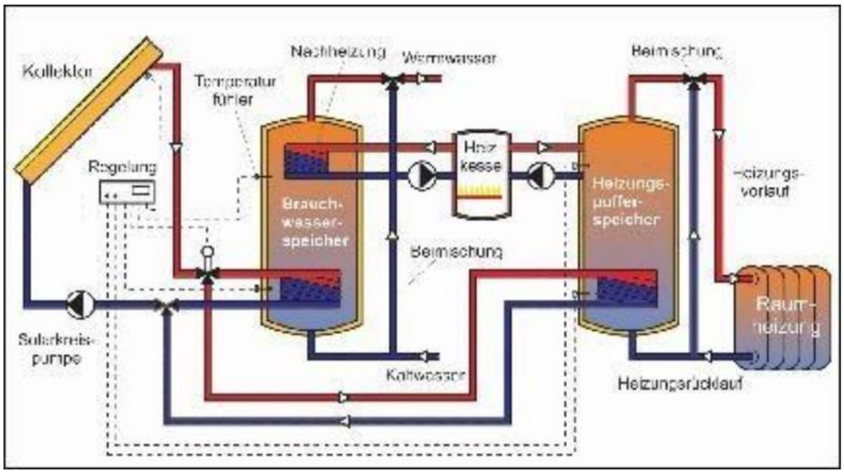

Figure 2: Bivalent sensible domestic double storage system. The domestic hot water tank is made of stainless steel (typically 200 l) and smaller than the buffer storage tank (typically 1,000 l). Both storage tanks are charged indirectly via heat exchangers formed by metallic pipe coils inside the tank. (source: Institute for Thermal Engineering and Thermodynamics (ITW), University of Stuttgart).

The storage tank may therefore be charged by several heat sources. The domestic hot water storage is then again supplied indirectly through a heat exchanger. Due to the physical separation between domestic hot water and heating water, the buffer tanks may be made of less expensive sheet steel. Newer systems usually replace the large domestic hot water tank with smaller systems such as a fresh water station, combined storage tanks (small domestic hot water tank integrated into the heating storage tank) or hygiene coils in the buffer storage tank. Advantageously avoiding the Legionella problem, these systems provide domestic hot water on demand. Maintaining thermal stratification is, however, absolutely necessary with these systems in order to always keep enough energy in the storage. So-called stratified charging units ensure that the hot water is directed to the desired zone in the storage and that mixing of the thermal strata is reduced to a minimum thanks to a reduced flow velocity. This prevents e.g. 70 °C hot water from the solar system from mixing with 90 °C hot water in the uppermost area of the storage tank to reach e.g. 80 °C.

Sensible heat storages use thermal insulation to maintain the storage temperature and temperature stratification and thus reduce heat loss. For smaller storage tanks in single-family homes (500-3,000 litres), this is achieved with 10-20 cm of PU foam or with an appropriate thickness of mineral wool. For large seasonal district heat storage tanks that can hold several thousand cubic metres and supply an entire residential area (Fig. 3), an approximately 1 m thick layer of suitable fill material, for instance perlite, is used for insulation.

Figure 3: Seasonal local heat storage (6,000 m³) developed by ZAE Bayern, charged using solar heat at 48 % coverage (3,000 m² of collectors)

Typical cooling rates for single-family home storages amount to a few degrees Celsius per day. They decrease with a growing heat capacity of the storage medium at a decreasing surface-to-volume ratio and insulation value (thermal conductivity in relation to insulation thickness). Therefore, large, vacuum super-insulated storage tanks provide the best insulation (Fig. 1). Their temperature drops about five times slower than in conventionally insulated storages, making them ideal for long-term applications. For insulating materials like mineral wool, ageing and a resulting deterioration of the insulating effect can occur. Care must therefore be taken to ensure proper installation, avoid moisture penetration and thermal bridges. Therefore, cold storage tanks mostly feature a closed-pore insulating foam to prevent moisture penetration through condensation on the tank surface in case the storage medium's temperature drops below the dew point.

Focus on provision of power or energy

Energy

Suitable fields of application

Water temperatures up to 100 °C (150 °C if pressurised)

Technology-Readiness-Level (TRL)

9

State of development/commercial availability

Market-ready products, commercially available

TECHNICAL SPECIFICATIONS

Specific energy storage density	kWh/m³ 60-100	kWh/t 60-100
Specific power density	kW/m³ 30-500	kW/t 30-500
Typical/feasible storage size	MWh_{out} 0.03-1,000	MW_{out} 0.015-1
Storage efficiency	50-90 %	
Storage duration	Hours-months	
Response time	Minutes	
Service life (maximum)	Cycles 20-4,000	Years n.a.
Loss per time in %	0.5 to 2.5 per day	

Notes on these specifications

The technical specifications depend strongly on the actual application's boundary conditions. Also, due to the very wide volume range of sensitive storage tanks (several litres to 10,000 m³), figures vary widely. The technical specifications depend strongly on the actual application's boundary conditions. Also, due to the very wide volume range of sensitive storage tanks (several litres to 10,000 m³), figures vary widely. The first figure in each given range corresponds to a typical domestic water storage with a volume of 500 l and a discharge pump rated at 500 l/hour. The second figures correspond to a seasonal large-scale storage with a water volume of 10,000 m³ and a discharge pumping capacity of 5 m³/h. 1 cycle per 2 days (domestic) or 1 cycle per year (seasonal) is assumed. Both storage tanks are assumed to be pressureless water tanks, therefore the maximum storage temperature is at 100 °C, the usable temperature difference at 60-100 K. Losses per time depend on insulation thickness, thermal conductivity, and surface-to-volume ratio. Typically, the domestic storage loses about 2 K/day, the seasonal one about 10 K/month.

ECONOMIC SPECIFICATIONS

Investment cost per kW

1-15 €

Investment cost per kWh

0.4-10 €

Notes on these specifications

Due to the numerous and widely different technical designs of such storage systems and with respect to their different applications' requirements, the cost in relation to output and energy varies greatly. The cheapest sensible heat storages available are currently used for seasonal storage in Denmark. An extremely simple design (outdoor earth pit covered with plastic film) can bring the cost of very large storages down to 0.35 €/kWh of installed capacity. If water cannot be used as a medium and highly efficient insulation is required, cost increases accordingly.

For further information, see

ZAE Bayern, https://en.zae-bayern.de/