Heat accumulators

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Previous issues of *News from DBDH* have focused on CHP as an economic and environment-friendly way for a simultaneous production of electricity and heat. This article describes heat accumulators as a tool for further improvement of the CHP concept. Furthermore, the article illustrates different types and different applications of heat accumulators.

Introduction

Heat accumulators have been used in DH systems during the last decades. Practically all CHP plants of the back-pressure type, as well as small-scale plants producing only heat and electricity in a fixed ratio, are equipped with heat accumulators. Earlier, CHP plants of the extraction type have only to a limited extent been equipped with heat accumulators.

The liberalisation of the electricity market has increased the need for more flexibility of the CHP plants in order to operate in the most economical way, serving both the heat consumers as well as the electricity market. In Denmark, we have therefore seen a boost in the development of large-scale heat accumulator systems in the first years of the opening of the electricity market. Today, almost all DH systems in Denmark with CHP plants of the extraction type are supplied with one or more heat accu-mulators.

Function of the heat accumulator

The heat accumulator is used for short-term storage of water-based energy. The water content in the tank by weight is constant, independent of energy content. When charging the accumulator, hot supply water is supplied in the top of the tank simultaneously with extraction of the same amount of cold return water from the bottom of the tank. The hot and cold water separate - due to difference in gravity - with an approximate 1 meter high non-usable separation layer. When discharged, hot supply water is extracted from the top with simultaneous supply of cold return water at the bottom.

Network connection

The heat accumulator is connected to the district heating system between the CHP plant and the DH network (see figure 1). When the production is higher than the consumption, the heat accumulator is charged. The accumulator is discharged when the production is below the consumption. This allows for the CHP plant to produce the DH energy when it is most favourable with respect to electricity prices.

Heat accumulator operation options

The operation options for heat accumulators differ slightly, depending on CHP plant type - extraction or back-pressure.

The extraction plant can produce either electricity in condensing mode or electricity and heat in combination. The electricity capacity is reduced approx. 15% at maximum heat production. This electrical capacity difference is utilized when the heat production is switched off. The main functions of the heat accumulator with this type of plant are the following:

- In periods with high electricity prices, the heat production can be cut off and the heat will be supplied from the accumulator.
- The CHP plant is allowed to operate at optimal ratios of the electricity and heat production.
- In periods with low electricity prices, e.g. at night, the heat can be produced at a low cost and stored in the accumulator. Then, when the price is high, e.g. in the morning hours, the heat can be supplied from the accumulator.

Figure 1. Heat accumulator integrated in a DH system.

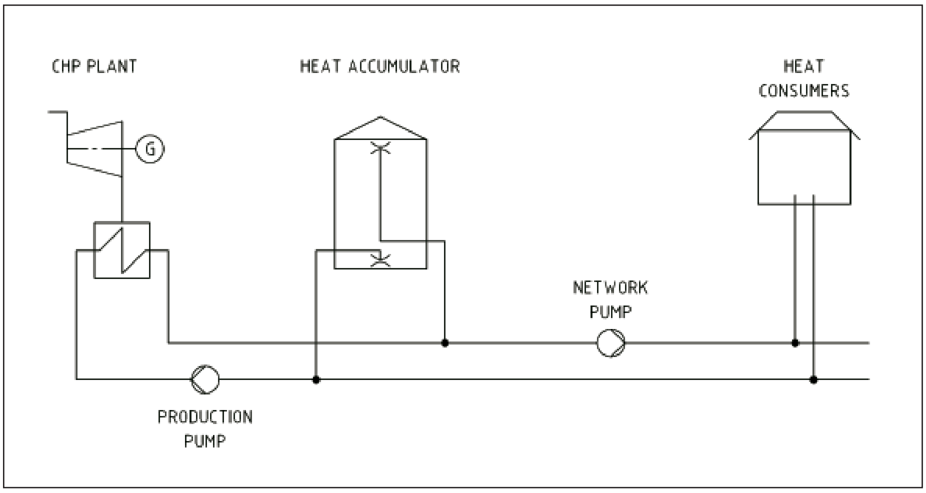
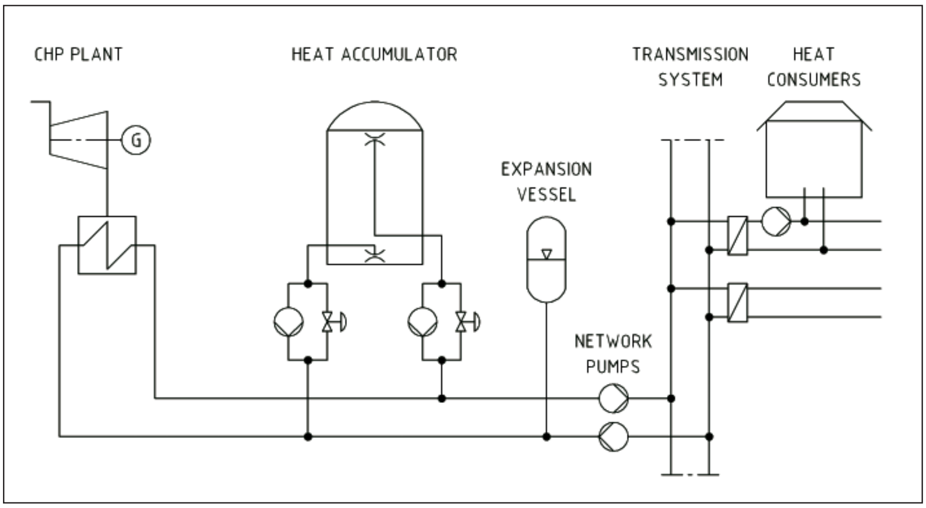


Figure 2. Heat accumulator with hydraulic separation from a DH system.



The back-pressure plant can only produce electricity and heat in a fixed ratio. This is a disadvantage seen from an electricity production point of view. The main functions of the heat accumulator with this type of plant are therefore:

- To supply heat to consumers and allow the CHP plant to produce the necessary heat in periods with the highest electricity prices. This operation mode is especially important in grids with a tariff with time differentiation.
- To allow the CHP plant to produce electricity until the accumulator is fully charged, in case of capacity problems in the electricity grid.

For all types of CHP plants the following applies for operation:

- The heat accumulator may reduce or avoid income losses, if produced electricity is sold below production costs in case of the CHP plant being in operation only for heat production.
- Large accumulators can allow a total stop of the plant during weekends, when the electricity price is often lower than on weekdays.
- The accumulator can compensate for the daily load variations in the heat demand (mainly caused by night setback), and thus reduce start – stop and use of more expensive heat sources in the daily peak load periods.
- In particular the maximum capacity can be reduced if the accumulator can be used for this purpose on the "coldest day".
- The atmospheric heat accumulator tank can maintain the static pressure in the district heating network and also function as expansion reservoir.

How to organize

In the study for evaluation of the benefits of an accumulator, it is important to consider all possible advantages, and how they can be utilised in the various modes of operation in typical periods of the year.

When operating the plant, it is also important that the accumulator is utilised, taking into account the benefits both on the electricity and the heat side on the basis of hour-to-hour, daily and weekly production simulations.

In order to make the right decisions on establishment of heat accumulators and on how to operate them at a minimum cost, it is necessary to look both at the electricity and the heat side. In case the CHP plant and the DH system are owned by different companies, it is of vital importance that the two companies have good relations and are able to collaborate in an open way. This includes analysis of the total benefits and agreements on how to share investments and benefits and also how to operate the accumulator.

Photo 1. Heat accumulators at Avedøre Power Station.

Technical aspects

Temperature and static network pressure

The design of the heat accumulator tank depends on both supply temperature and static network pressure and combinations of temperature and pressure.

Below a 100^{0}C supply temperature, the heat accumulator tank can be designed as an atmospheric tank. Above 100^{0}C the heat accumulator tank must be designed as a pressure vessel. In systems where operation with supply temperatures above100 ^{0}C is limited to a few hours in winter times, it is still possible with an atmospheric tank, either by by-passing the heat accumulator in these periods or by boosting the temperature after the tank.

In systems with static pressure around 7 bar and supply temperature below 100 ^{0}C, atmospheric tanks can be used. Case 4 describes an atmospheric heat accumulator of 65 m height.

Atmospheric heat accumulators are normally designed according to a standard for vertical oil or water storage tanks. Pressurized heat accumulators are designed in line with a standard for pressure vessels.

Network connection

Atmospheric heat accumulator tanks are mostly inserted between the production units and the network, as illustrated in figure 1. This coupling allows the production units to produce heat independent of consumption. When the static pressure exceeds technical tank heights, or local conditions prevent high tanks, or in cases of pressurized tanks, it is necessary with hydraulic pressure separation in the form of a charging and discharging system with double control valves and pumps (see figure 2 on page 4). Such a system is used at the accumulators in the Copenhagen DH system.

Diffuser

In order to secure a good separation between hot and cold water, diffusers are used in top and bottom. Inlet and outlet water velocities may vary between 0.02 – 0.2 m/sec.

Corrosion protection

When the DH water quality meets the requirements, especially with respect to extreme low oxygen content, normally there is no corrosion in the water part of the tank. In order to avoid corrosion of the upper part of the shell and roof construction, an inactive atmosphere shall be maintained in the form of a steam or nitrogen cushion.

Weatherproofing and insulation

Standard insulation up to 130^{0}C is 300 mm mineral wool. Weatherproofing may vary from the cheapest aluminium trapezoid sheet to expensive architectural solutions. Weatherproofing is fastened to the tank shell by a light steel structure.

Dimensioning

Dimensioning of the energy content is a cost-benefit analysis base on both reliable and non-reliable parameters. A non-reliable parameter is e.g. the electricity market price. A reliable parameter is e.g. investment in the tank.

The calculation of the active storage volume between the diffusers is based on energy content and difference between supply and return design temperatures. It should be taken into account that the non-usable separation layer will typically have a thickness of one meter. The choice of temperature is very important, as the temperature has a direct impact on the size of the tank. For atmospheric tanks, deltaT will normally be 30 – 40 ^{0}C. For pressurized tanks, deltaT can be 50 – 55 ^{0}C.

Normally, a height/diameter ratio above 1.5 is preferred, in order to minimize the volume of the inactive separation layer. However, experience shows that ratios down to 0.8 are feasible if the diffusers are split up, as e.g. in the case of using old oil tanks, or the tank in case 2 which has 4 top and 4 bottom diffusers.

The following cases give some indicators of the use and design of heat accumulators.

Case 1. Avedøre Power Station, 8000 GJ – 2 x 22000 m^3
Avedøre Power Station - owned and operated by ENERGI E2 - is located south of Copenhagen. The plant has 2 CHP extraction units. Unit 1 of 250 MW / 330 MJ/s and unit 2 of 560 MW / 520 MJ/s. Together with other CHP plants, Avedøre Power Station supplies heat to the Greater Copenhagen district heating transmission system. The network has a total heat demand of 28,000 TJ.

The heat storage facilities consist of 2 identical pressurized tanks, each with an energy content of 4000 GJ. Due to the pressure difference from the 15 bar DH network pressure and approx. 5 bar tank pressure, the system is equipped with a charging and discharging system. In order to improve operation economy, a water turbine covers 50% of the pressure reduction capacity. The turbine is mechanically connected to one of the pressure increase pumps, thus reducing the electricity consumption. The capacity of the heat accumulator is 330 MJ/s. The investment in the tanks were approx. 5.5 mill. Euro (1992) corresponding to approx. 670 Euro/GJ.

The unique location and architecture of the power station resulted in a unique design of the two heat accumulator tanks (see photo 1 on page 5).

In 2003, ENERGI E2 A/S built a similar 4000 GJ heat accumulator tank at Amager Power Station, which also supplies heat to the Greater Copenhagen district heating network. The objective of this tank is mainly to improve the production flexibility of the CHP plant and a nearby waste incineration plant.

In total, there are 5 large pressurized heat accumulator tanks in Denmark.

Case 2. Power Station Fyn, 13,500 GJ / 73,000 m^3
Power Station Fyn – owned and operated by ELSAM A/S – supplies heat to nearby Odense Municipal District Heating Company (7,700TJ). The plant has 2 units - unit 3 of 285 MW / 325 MJ/s and unit 7 of 400 MW / 450 MJ/s. Furthermore, Odense CHP Plant A/S with 2 incineration units of 10 MW / 29 MJ/s and 14 MW / 35 MJ/s can supply heat to the heat accumulator.

In order to increase the flexibility for the CHP and the incineration plants, a 73,000 m^3 heat accumulator was built in 2003. The district heating system in Odense is operated at a low supply temperature, up to approx. 92 ^{0}C in the winter season. The accumulator is built as an atmospheric tank with a height of 40 m, due to the pressure conditions in the network. With a diameter of 50 m, the height/diameter ratio is only 0.8 against the normal practise of above 1.5. The energy content in the tank is 13,500 GJ and the capacity is 600 MJ/s.

In the winter, the accumulator allows the power station to stop the CHP units at night if the price on electricity is low and to stop the heat production at electricity peak load hours. In the summer, it is possible to close down CHP units for a whole weekend, and in the winter season for approx. 6-8 hours.

The investment (2003) in the tank was approx. 5.5 mill. Euro corresponding to approx. 400 Euro/GJ.

Case 3. Maribo-Sakskøbing Local CHP Station, 720 GJ / 6330 m^3
Maribo-Sakskøbing Local CHP Station – owned by ENERGI E2 A/S - is a small-scale biomass (straw) fired back pressure CHP plant with 10 MW/ 20 MJ/s capacity. The heat is supplied to Maribo District Heating Company (200TJ) through an 8 km transmission line and to Sakskøbing District Heating Company (181TJ).

The energy content in the tank is 720 GJ and the capacity 28.5 MJ/s. The diameter is 18.5 m and height 25 m. See photo 2.

The accumulator is inserted as a buffer between the CHP plant and the DH network – see figure 1. The height of the tank is designed to keep static pressure in the network.

The tank investment (2000) was approx. 550,500 Euro corresponding to approx. 750 Euro/GJ.

Case 4. Asnæs Power Station, Kalundborg, 3000 GJ / 20,000 m^3
Asnæs Power Station (see photo 3) – owned by ENERGI E2 A/S - supplies heat to nearby Kalundborg Municipal District Heating Company (900TJ). The plant has 2 CHP units – unit 1 of 125 MW / 100 MJs and unit 5 of 640 MW / 150 MJ/s. Both units are of the extraction type.

Due to the electricity market conditions, often only one unit will be in operation. In order to improve supply safety and district heating prices, ENERGI E2 and Kalundborg Municipal District Heating Company agreed in 2002 to build a 3000 GJ heat accumulator tank.

The tank was designed as a directly connected atmospheric tank for 98^{0}C. Due to the topographical conditions in the network, 65 mWC (sea water level) was needed for static pressure. This resulted in a tank with 20 m diameter and 65 m height (see photo 3). The extreme height/diameter ratio required an expensive pile foundation.

Photo 2. Heat accumulator at Maribo-Sakskøbing Local CHP Station.

In the winter, the heat accumulator tank can supply heat for up to 3-4 hours. In summer, the tank supplies up to 48 hours, e.g. a whole weekend. The tank investment (2002) including civil works was approx. 3 mill. Euro (approx. 1075 Euro/GJ)

Future trends

Within the last 20 years, many R&D projects have focused on low cost storage facilities, including alternative storages e.g. in ponds, rocks and soil. For the latter it has been difficult to keep a water quality, e.g. low oxygen content, acceptable for the DH system. Seasonal storage has also been subject to R&D study. The studies show that such projects are not feasible as the investments do not correspond to savings.

The electricity market with its differential pricing will prompt CHP and DH operators to build more accumulator capacity in order to benefit from the electricity market. This will result in larger and cheaper tanks, as in case 2. Reconstruction of old oil tanks is also an option.

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Photo 3. Heat accumulator at Asnæs Power Station under construction.