A thermal storage facility can be a cost-effective way to improve the performance and operation of a cogeneration plant. Here, based on experience in Denmark, Jan de Wit discusses the advantages of facilities designed for storing heat for periods of a few hours to a few days and presents a number of heat storage layouts.

Heat storage for CHP plants

adding flexibility, improving performance

With heat storage installed, the production of electricity and heat can be uncoupled for a period of time. Such uncoupling can be very beneficial for enabling maximum electricity production during the hours where electricity is being paid best. The heat that is not needed (surplus heat) during these production hours is then stored in the heat storage facility.

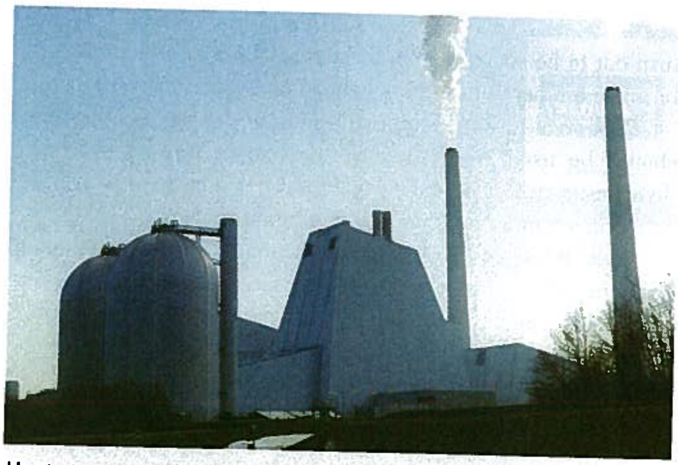
A heat storage facility also makes it possible to run the production units at the most fuel-efficient load. If the prime movers are gas turbines or spark-ignited gas engines, the most fuel-efficient operation is full load; operation at part load will often lead to a less fuel-efficient operation. Heat storage will make shorter outage of units possible (for example for service or minor repairs) with no interruption of heat supply as this can be supplied to customers from the storage. The storage facility will also make production planning more flexible as production units can be stopped during the night and/or weekends if sufficient storage capacity is available.

In liberalized power markets, heat storage facilities in connection with the cogen unit will enable much better conditions for giving bids and production tenders on:

- a spot market
- multiple hours bidding
- power-up or downloading
- back-up reserve production capacity.

STORAGE CAPACITY

The heat storage facilities presented in this article are all insulated, water-based (single-phase) storage tanks (see Figure 1). Water has an excellent heat-storage capacity per cubic metre compared with other liquid substances and is also environmentally friendly.



Heat storage tanks at a multi-fuel (coal, natural gas, oil, wood chips, straw) cogeneration unit

To achieve maximum capacity per volume, the temperature difference between top and bottom should be as high as possible and the mixing layer in between as small as possible. This can be obtained as follows:

- establishing plug-flow in the tank to make the temperature mixing zone as small as possible
- having the heat grid return temperature as low as possible
- having a high feed-forward temperature from the cogen production units.

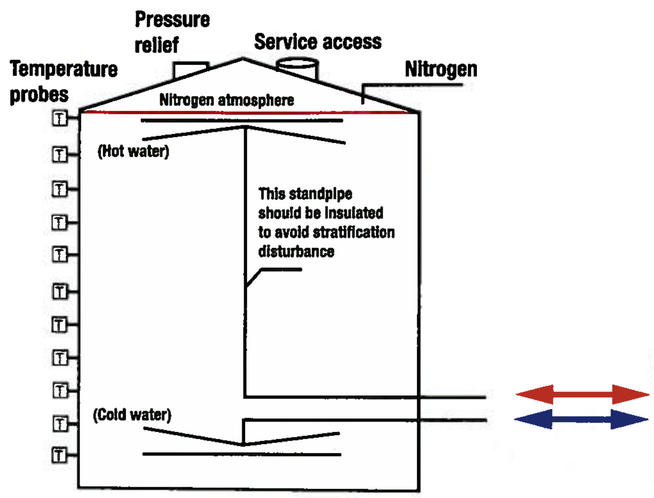


Figure 1. A vertical heat storage tank

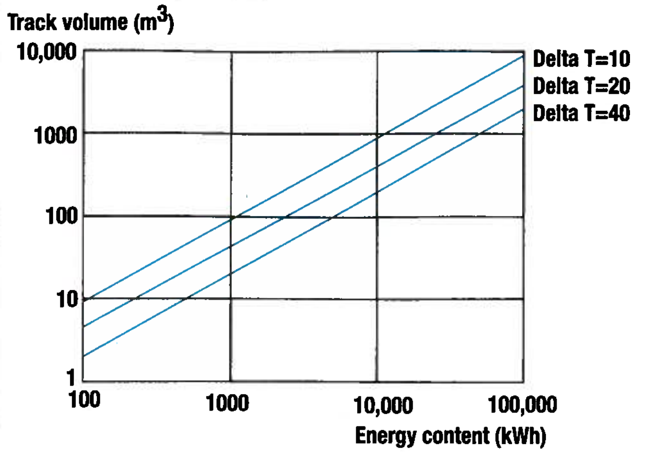


Figure 2. Energy storage in various tank volumes heated 10°C, 20°C and 40°C, respectively

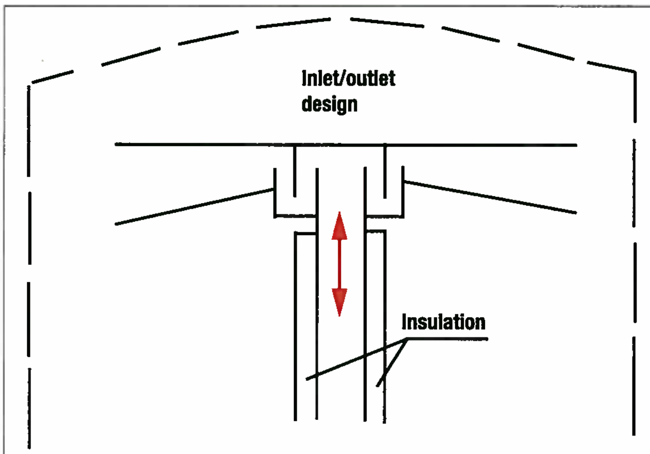


Figure 3. Water inlet/outlet design in a vertical heat storage tank

A number of temperature probes should be installed in the tank to give a precise indication of the actual storage situation in the tank. These probes provide key figures for local and remote production planning.

A low grid return temperature can be obtained by checking that connected appliances are well designed for the heating grid. Having as few grid circulation bypasses as possible will also help to achieve the lowest possible return temperature.

Figure 2 shows the energy storage capacities of a tank heated to 10°C, 20°C and 40°C. In real life, the capacity will turn out to be some 90% of the figures shown since there will be some temperature mixing instead of complete stratification.

High feed-forward temperatures from the production units should be used year-round as the temperature to the heat distribution grid can be controlled through a heat exchanger or by using a temperature control mixing loop.

Water inlets and outlets must be carefully designed to avoid temperature mixing in the tank. The key issue here is to keep water inlet and outlet velocity as low and symmetric as possible to establish plug-flow conditions. Figure 3 shows an example of how this is often made.

To minimize heat losses through tube connections, these are normally made through the lower part of the tank. To avoid the creation of internal heating/circulation in the tank because of the central inner tube, this tube should be insulated as shown in Figure 3.

Storage tanks in Northern Europe often use insulation that comprises mineral wool of thickness 150–200 mm and an outer protection shield.

GEOMETRY

From a production and operational point of view, a cylindrical geometry is often preferred for heat storage facilities. To minimize the ratio of surface to volume, a height-to-diameter (H/D) ratio of 1:1 should be used. From an operational and visual point of view, an H/D ratio closer to 2:1 is often better. As the temperature mixing layer in the tank tends to have a fixed height, the mixing layer in a tall slim tank will take up less volume compared to a wide-body version.

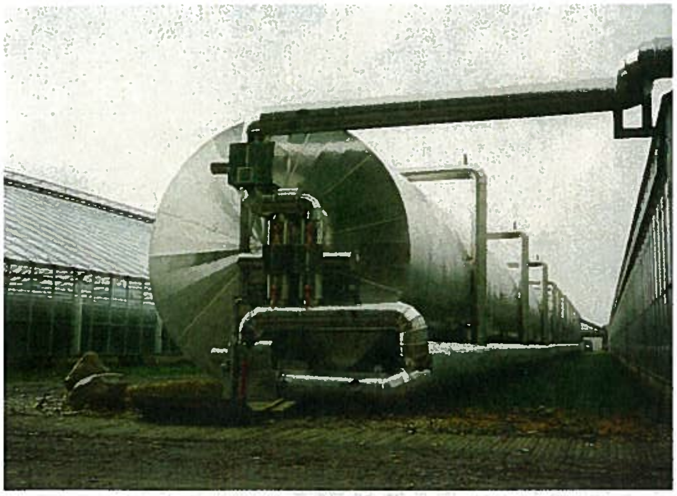
An H/D ratio of 2:2.5 will increase the surface area by only about 5%–10 % compared with an H/D ratio of 1 for a tank of the same net volume.

VERTICAL OR HORIZONTAL?

Heat storage installations can be either vertical or horizontal. From an efficiency point of view, the vertical outline is best. This will generally favour the temperature stratification and favour plug flow through the tank. However, if building restrictions or other circumstances make this impossible, a horizontal outline can also be used, as shown in the photograph on page 80.

If a horizontal outline is used, the inlet and outlet connections can be made at the top and bottom as perforated tubes (long slots/apertures). Operational experience of and measuring programmes[1, 2] for horizontal tanks show that such perforated tubes can provide good results.

Underground horizontal tanks have only been used for small cogen units. Pre-insulated tanks of volume up to about 100 m^3 have been used. Some sites have even used multiple tanks underground in serial connection.



Horizontal heat storage at a greenhouse cogen installation. These insulated tanks were originally for storing heavy fuel oil at a ready-to-use temperature.

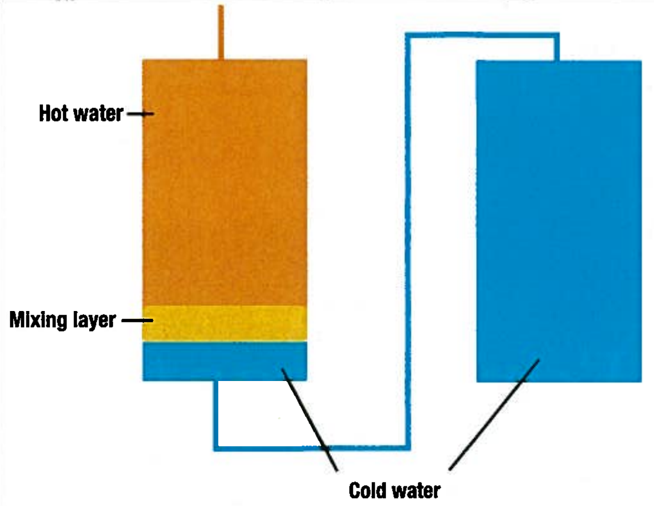


Figure 4. Operation of serial heat storage tanks

MULTI-TANK SYSTEMS: SERIAL OR PARALLEL CONNECTION?

Some cogen plants employ several heat storage tanks next to each other. These installations have been made as both vertical and horizontal solutions, depending on, for example, restrictions imposed by building legislation. Such multiple-tank installations can be connected in parallel or in series. Serial connection will lead to a higher water velocity compared with parallel connection. The advantage is that there should be only one mixing layer between the hot and cold ends (see Figure 4).

Parallel operation divides the water flow among the tanks, which should result in less temperature layer disturbance in the tanks (because of a narrower mixing layer). However, it is difficult to establish absolute parallel operation of the tanks. This means that after even a limited time, the mixing layers in parallel coupled tanks are not in the same position and the capacity and functionality of the tanks will be reduced (see

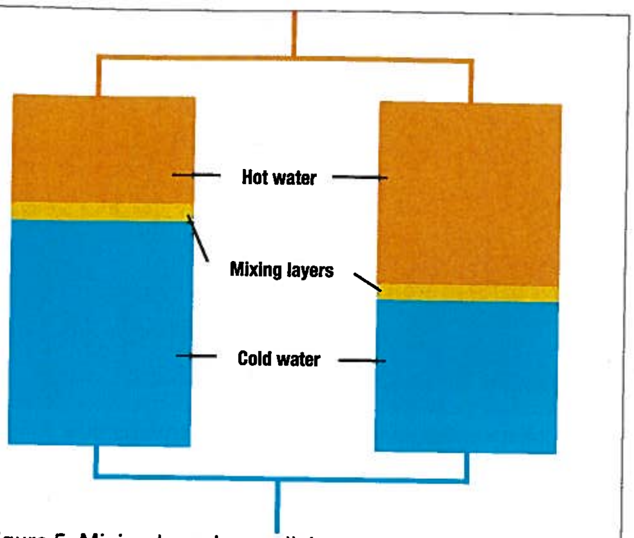


Figure 5. Mixing layer in parallel connected tanks after some charging/consumption cycles

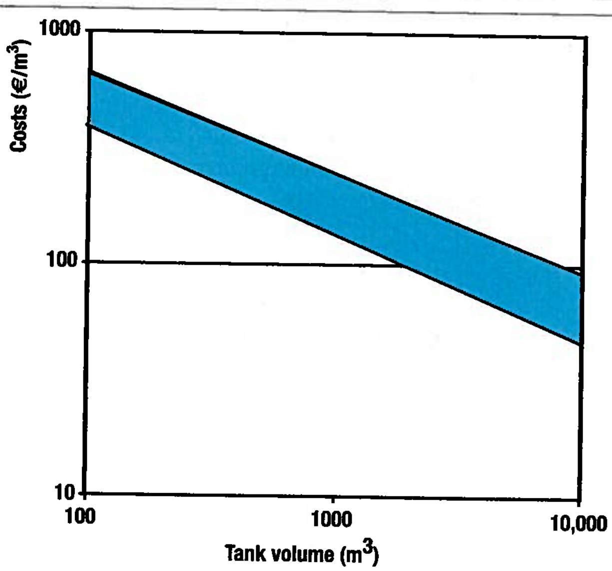


Figure 6. Free-standing insulated heat storage tank costs, including installation works

Figure 5). Measurements[1] and operational experience confirm that the serial tank connection is most advantageous.

INVESTMENT COSTS

Figure 6 shows the costs for insulated heat-storage free-standing steel tanks to be used with cogeneration plants. The costs are based on a number of tanks over a wide volume range.

Underground tank systems are more expensive than those represented by Figure 6. However, if pre-insulated tanks are used, the extra cost connected to the groundworks is, to some extent, compensated by a lower tank price thanks to factory pre-fabrication. Sites in Denmark show that the cost increase for underground tank installations is about 35%.

CORROSION

Corrosion must be addressed when using heat storage tanks. Tank surfaces should be coated to avoid corrosion, and the tanks must

Inspection by diver in a heat storage tank.
PHOTO: J.H. Dyk

Corrosion patterns in heat storage tanks.
PHOTO: J.H. Dyk

Heat storage tank in art painting

use conditioned water. If the top of the tank is used for expansion, a non-water volume will be present here, as shown in Figure 2. Nitrogen or steam can be used to keep out air or oxygen. Most plants tend to choose nitrogen because with steam, there is a risk of 'collapse' and the consequent entry of air or oxygen.[3]

Corrosion must also be addressed in the lower areas of the tank. Inspection doors must be used to enable camera or diver inspection and, if needed, the entry of repair personnel (see photograph above). To monitor corrosion, pieces of metal wire can be lowered into the tank and retrieved at regular intervals for inspection. However, experience has shown that this method does not always give sufficient warning about the precise corrosion conditions in the tank. Experience has also shown that thermal movement, especially in the top end of tanks, may cause coating to slip off the metal surface.

Additional opportunities

Heat storage tanks can be made less visibly obtrusive by a range of means such as painting, which also allows them to be used as billboards, or siting underground, as shown in the pictures (above and opposite).

CONCLUSION

Heat storage facilities offer operational flexibility, enable operation at optimum prime-mover production efficiency and improve the possibility of maximum power production when prices are best. As more and more power markets are liberalized, a heat storage tank as an integrated part of the CHP plant will be even more advantageous.

Heat storage may play an important role in connection with integration of renewables at CHP plants. Renewables supply will not always fit actual demands or may block profitable power production during the hours of the day when electricity prices are best. Heat storage may prove even more profitable if plants offer trigeneration.

It is difficult to estimate the exact return on investment as this would include local prices for the cogeneration units, electricity sales on the spot market, short tenders, long-term contracts and/or tariffs offered for back-up capacity. However, the investment price of a heat storage installation is small compared with the rest of the budget for a cogen plant and enables hours of favourable uncoupling of power and heat year after year.

Various heat-storage designs have proven feasible in connection with power production plants. Examples are: Vertical or horizontal insulated steel tanks, multiple-tank systems, free-standing, in-house or partly/full underground versions.

The tanks can, through their design or painting, act as architectural expressions or be used for branding/advertising. The visual impact of the tanks can also be reduced through their design or by painting them or disguising them an outer covering.

FROM TOP TO BOTTOM: Two vertical tanks frame an outdoor artwork at a sports ground ■ The outer shell of a gas-turbine combined-cycle cogen plant hides a heat storage tank from most angles of view ■ Two underground horizontal heat storage tanks are below this lawn – a few covers can be seen in the grass. The cogeneration unit is in the annex to the house

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