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Heat Storages for CHP Optimisation

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Introduction

A heat storage facility installation is a very cost-effective way to improve the performance of a cogeneration plant. The storage is basically independent of the prime mover technology or the fuel being used. This paper will discuss advantages, show a number of techno-economic figures and present and discuss a number of different heat storage layouts.

The paper presents design and operational experiences from heat storage facilities for storing heat from hours and up to a few days maximum. Seasonal heat storage facilities are not covered.

Figure 1 Heat storage tanks in connection with a multi-fuel Coal, natural gas, oil, wood chips, straw) cogeneration unit, Avedøre Denmark)

Why use a heat storage facility?

By using a heat storage facility the production of electricity and heat can be un-coupled for a period of time depending on the size of the heat storage. Such un-coupling can be very beneficial for electricity production in 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.

Having a heat storage facility also makes it possible to operate the production units at the most fuel efficient load and to store the surplus heat. 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 lead to less fuel-efficient operation.

Heat storage will also make shorter outage of units possible (e.g. for service or minor repairs) with no interruption of heat supply as this can be supplied from the storage. A 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 present.

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

- Spot market
- Multiple hours bidding
- Power up/down loading
- Back-up reserve production capacity

How to make a water-based heat storage facility most efficient

The heat storage facilities presented here are insulated water-based (single-phase) storage tanks. Water has an excellent heat-storage capacity per cubic meter compared to other media and water is an environmentally friendly component as well.

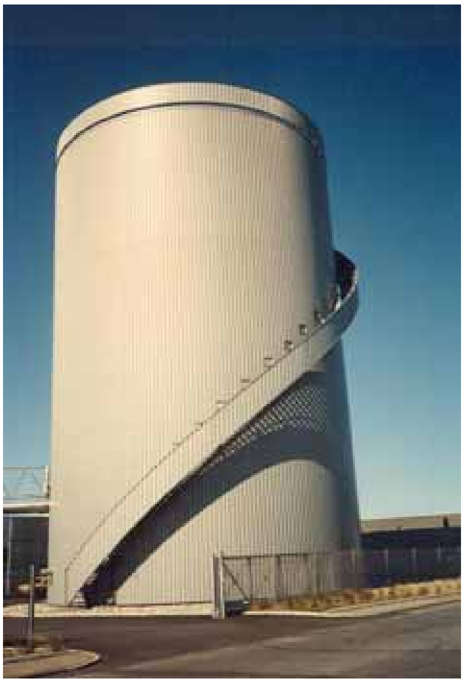

Figure 2   A vertical heat storage tank

To achieve maximum capacity 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:

a) Make sure the heat grid return temperature is low
b) Make sure to have a high feed-forward temperature from the cogen production units
c) Make sure there is as little mixing in the tank as possible

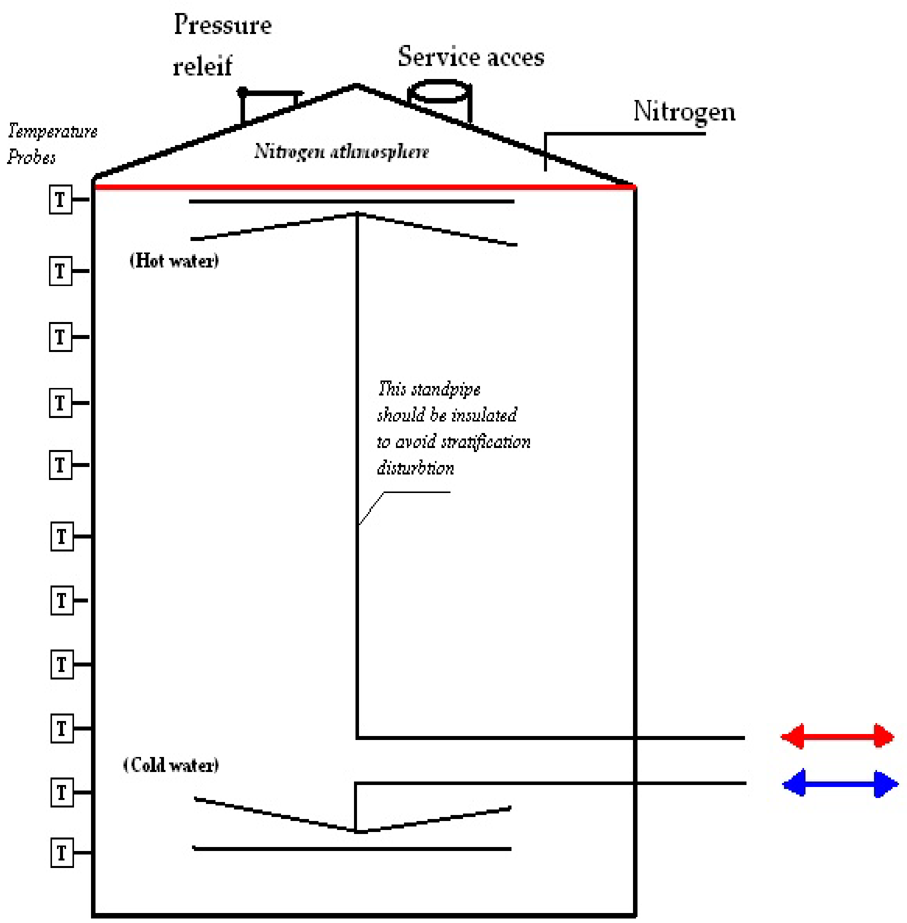

Figure 3 Principle of a vertical heat storage tank

A low grid return temperature can be obtained by checking that the connected appliances are well designed and feasible for such grids. As few grid circulation by-passes will also help to achieve a low return temperature.

High feed-forward temperature from the production units year round may be used as the temperature to the heat distribution grid can be controlled through heat exchanger or through using a temperature control mixing loop. A principle drawing of connecting a cogen unit, peak load boilers to the heat grid and storage facility can be seen in Figure 4.

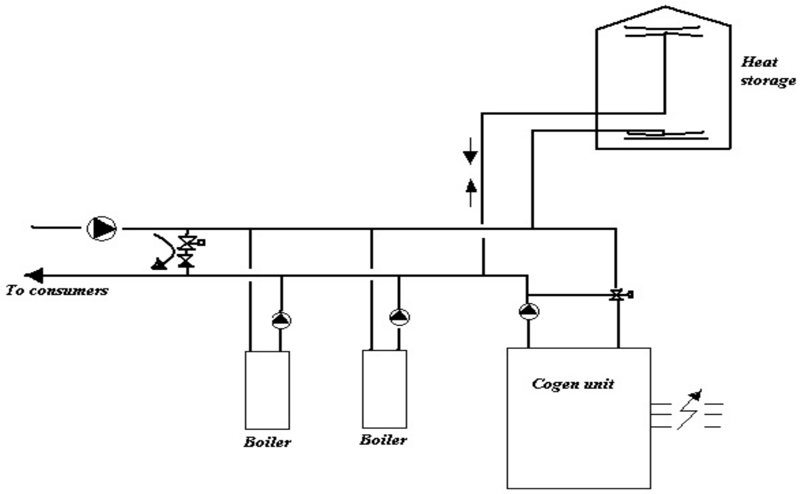

Figure 4 Principle drawing of connecting cogen units, peak load boilers storage facility and heat distribution grid

Temperature mixing in the tank can be avoided by being careful when designing inlets and outlets. These connections should be made in a way so that the water inlet and outlet velocity is as low and symmetric as possible. Figure 5 shows an example of how this can be made.

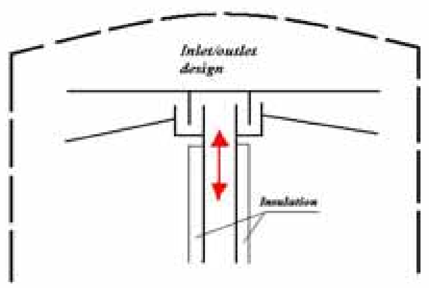

Figure 5 Water inlet/outlet design in a vertical heat storage tank

To avoid heat losses through tube connections they have all been made at the bottom of the tank. This means that hot water will be transported through colder layers to reach the bottom through the central tube. To avoid as much as possible to create internal heating/circulation in the tank the central inner tube is insulated as shown in Figure 5.

If significant temperature mixing in the tank occurs, a situation may arise where the outlet water temperature is too low for the grid and the bottom cold water is too “hot” for cooling the prime mover. This may be the case for engines as prime movers. Gas turbines do not need water cooling for the prime mover; it all goes to the heat recovery boiler. Therefore, gas turbines, in this case, can better “clean up” the temperature mixing/disturbance in the tank compared to engines.

Physical considerations

To minimize surface heat loss area to volume the optimal geometry would be to make the storage spherical! From both a production and operational point of view (low velocity inlets/outlet, plug-flow in the tank) cylinder geometry is preferred. To minimize surface versus volume a height to diameter ratio of 1:1 should be used. From an operational and visual point of view a height-to-diameter (H/D) ratio closer to 2:1 seems 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.

A height-to-diameter (H/D) ratio from 2 to 2.5 will increase the surface area only by some 5-10 % compared to an H/D ratio of 1 of a tank of the same volume.

Insulation with mineral wool of some 150-200 mm is often used.

Heat storage capacity versus volume could be improved by turning to two-phase storages. A medium with a proper melting point and heat transmission properties has not yet been introduced on this market.

Vertical or horizontal?

Heat storages can be made vertical or horizontal. From an energy storage efficiency point of view the vertical outline is best. However, if building restrictions or other circumstances make this impossible, a horizontal outline can also be used, see Figures 6 and 7.

Figure 6   Horizontal heat storage at greenhouse cogen installation. The tanks used are in fact insulated tanks originally used for keeping heavy fuel oil at ready-to-use temperature.

Figure 7   Underground horizontal heat storage tank for a small domestic cogen installation

If a horizontal outline is used the inlet and outlet connections might be made with perforated tubes (with long slots/apertures) as shown in Figure 8. Operation experience and measuring programmes (/3/ and /4 /) made at horizontal tanks show that perforated tubes can be used with a good result.

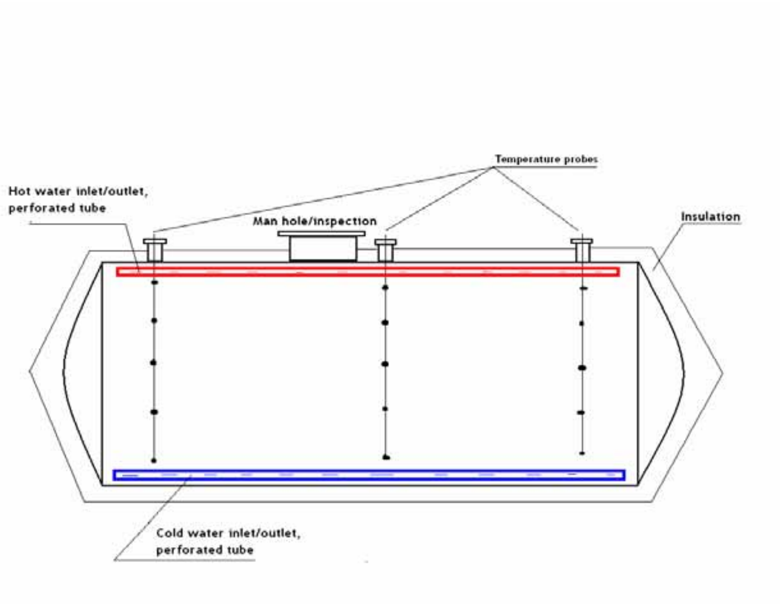

Figure 8   Principle drawing of a horizontal cylindrical heat storage tank

Underground horizontal tanks have only been used for small-scale cogen units. Pre-insulated tanks up to some 100 m^3 have been used. At some sites even multiple- (serial-) tank solutions have been used underground.

Multiple-tank systems, serial or parallel connection?

At some cogen plants several heat storage tanks are installed next to each other. This type of system has been made as both vertical and horizontal installations. This may be due to restriction in building legislation or there may be other reasons. Such multiple-tank installations can be connected in parallel or operated serially.

Figure 9 Two heat storage tanks installed next to each other at a hill-side gas-engine based cogen plant

With parallel operation the water flow is split among the tanks, and inlet and outlet water velocity will be likely to result in less temperature layer disturbance in the tanks (= more narrow mixing layer).

Serial connection will lead to a higher water velocity compared to parallel connection. The advantage is that only one mixing layer between hot and cold end should exist.

Measurements /3/ and operation experience show that the serial connection is most advantageous. It is difficult to establish absolute parallel operation of tanks. This means that after even a limited time the mixing layers in parallel coupled tanks are not in the same position and a “clean up” is needed, as the capacity will otherwise continue to diminish.

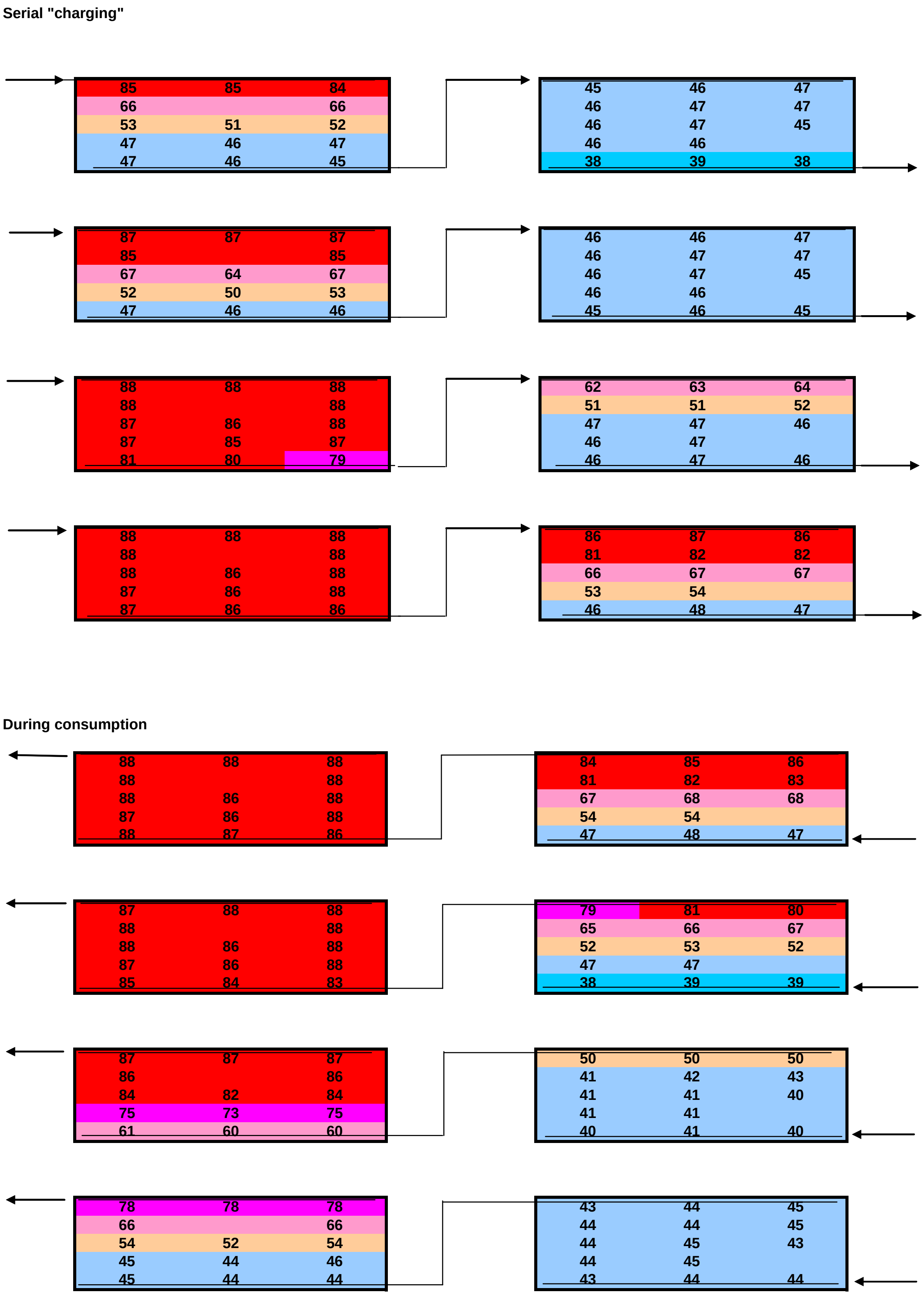

Figure 10 Example of measured temperature distribution in two horizontal serially connected heat storage tanks during a storage situation and heat retrieval situation

Corrosion

Corrosion must be addressed when using heat storage tanks. Tank surfaces should be coated to avoid corrosion even when treated water is used.

If the top of the tanks is used for expansion, a non-water volume will be present here. Nitrogen or steam has been used to avoid air/oxygen here. Most plants tend to choose Nitrogen, as a steam atmosphere has the risk of “collapsing”, thus allowing air/oxygen to enter.

Corrosion must also be addressed in the lower areas of the tank. Inspection doors must be used to enable camera or diver inspection and repair men, if needed.

Figure 11 Diver inspection in heat storage tank (courtesy of /7/)

To keep an eye on corrosion, pieces of metal in wires can be lowered into the tank and taken up for inspection at regular intervals. However, experience has shown that these are not always sufficient to give warning about corrosion in the tanks.

Experience has also shown that thermal movement, especially in the top end at tanks, may cause coating to slip the metal surface.

Figure 12 Various corrosion patterns seen in heat storage tanks (courtesy of /7/)

Capacity and heat loss

Figure 13 shows the energy storage capacity of a tank heated 10, 20 and 40 °C, respectively. In real life, the capacity will turn out to be some 90 % of the figures shown due to some temperature mixing instead of complete stratification.

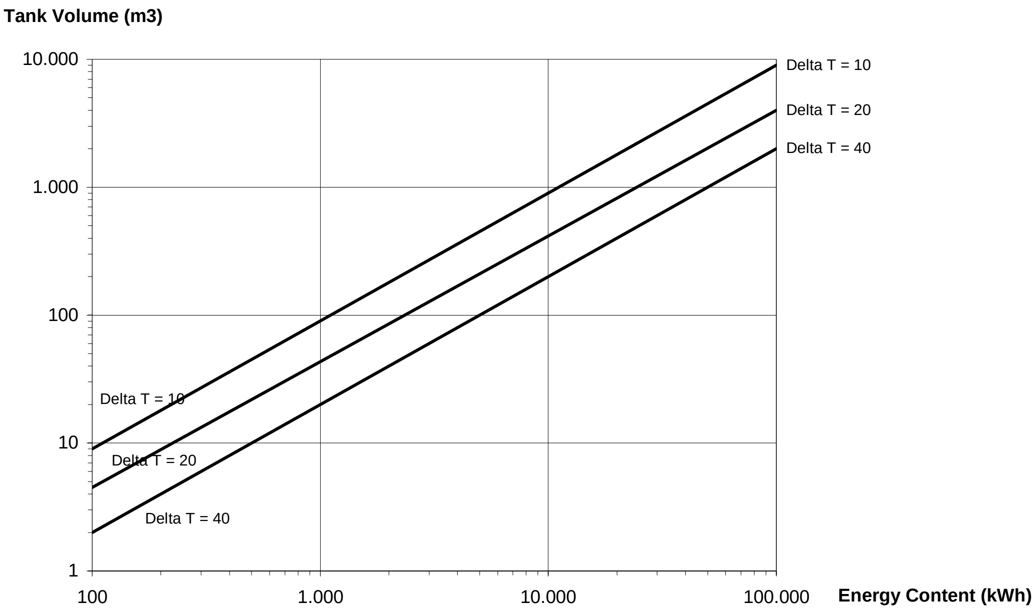

Figure 13 Energy storage in various tank volumes heated 10, 20 and 40 °C, respectively

Figure 14 shows an estimate on calculated surface heat loss from vertical free standing insulated tanks. An outdoor temperature of 0 °C and a water temperature 80 °C are assumed as is a height to diameter (H/D) of 1. Tall slim tanks e.g. with a H/D of 2 will only increase surface losses by some 5 %.

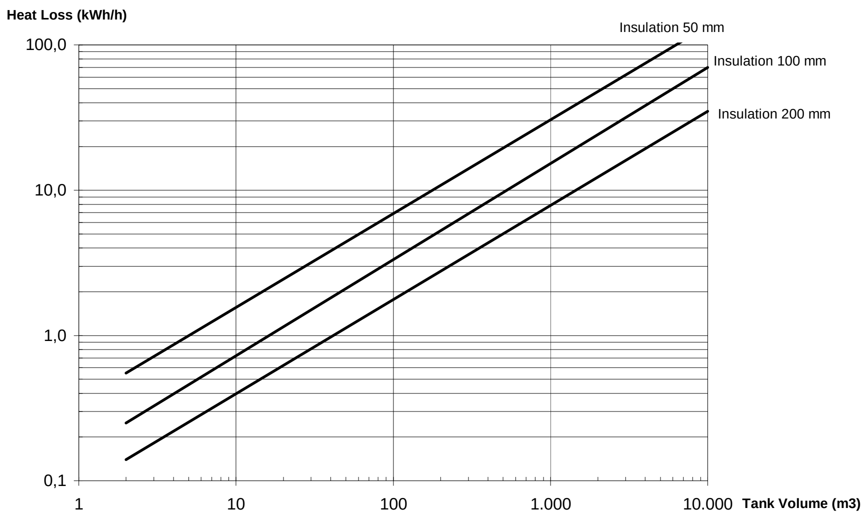

Figure 14 Estimated surface heat loss from free standing insulated vertical cylindrical tanks

Investment costs

Figure 15 shows the costs for the erection of insulated heat-storage free standing steel tanks erected in connection with cogen plants. The figures presented are based on a number of tanks over a wide volume range.

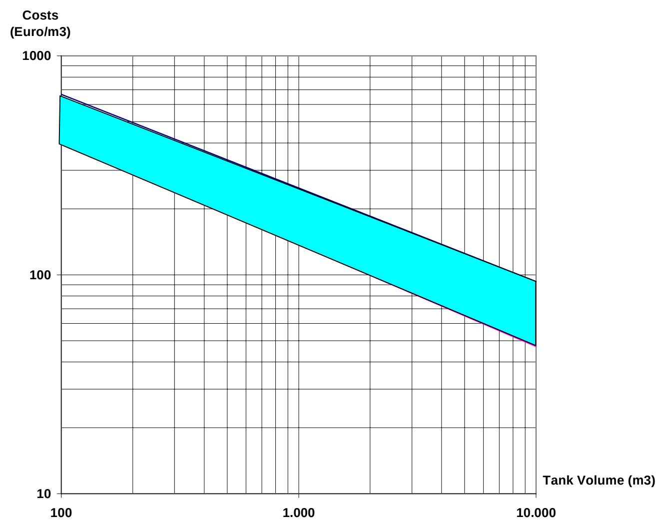

Figure 15 Free-standing insulated heat storage tank costs, including installation works

The underground tank systems mentioned are relatively more expensive than shown in Figure 15. However, if pre-insulated tanks are used the extra cost connected to the ground works is to some extent compensated by a lower specific tank price thanks to factory pre-fabrication. The sites established in Denmark show a cost increase of some 35 % for such underground tank installations

Additional opportunities

Design and painting of heat storage tanks offers many possibilities either to “hide” the tank or to use the tank as a billboard for text or signatures/pictograms, see examples in Figures 16-23.

Figure 16 Two underground heat storage tanks are located below this lawn. A few covers can be seen in the grass. The cogen unit connected is placed in the lower building annex to the house end.

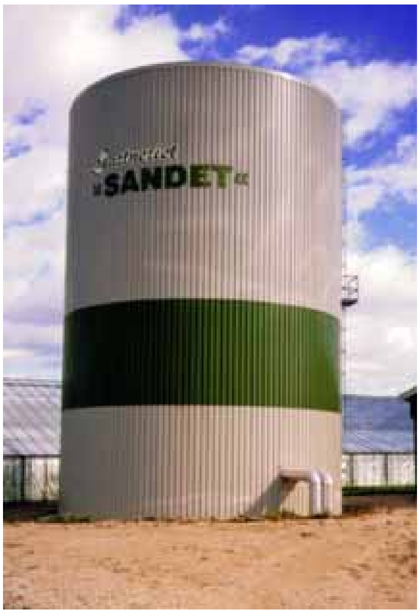

Figure 17 Heat storage tank at the greenhouse ”Sandet” - as clearly shown

Figure 18 Heat storage tank in art painting

Figure 19 Heat storage tank with an artistic geometric design (Helsinge)

Figure 20 The heat storage tank of this gas-engine based cogen plant has a surrounding brick wall for visual reasons

Figure 21 Two vertical tanks framing an outdoor scene erected in connection with a sports ground. A negative attitude amongst locals against such tanks was turned, as this proposal added the outdoor stage and even toilets to be part of the sports ground.

Figure 22 At this gas-turbine based combined-cycle cogen plant the outer shell of the plant hides the heat storage tank from most view angles

Figure 23 A heat storage tank in connection with a large-scale solar collector (18.000 m^2) system; a sand pit storage is used for long term storage (from /8/)

Conclusion

Using a heat storage facility may result in important operational and economic advances for cogeneration plants in today's cost-effective energy production.

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

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

Multiple heat-storage design schemes have been proven feasible in connection with power production plants. Examples are: Vertical or horizontal insulated steel tanks, multiple-tank systems, free-standing, in-house or underground versions etc.

The tanks can - by design or painting - act as an architectural expression, artwork, branding/advertising, or the design/painting/outer cover can be used for making the tank as invisible as possible in the surroundings.

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