SEASONAL HEAT STORAGES IN DISTRICT HEATING SYSTEMS

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ABSTRACT

There is a rising interest in Sweden for the use of cogeneration power plants in district heating networks, generating both electricity and heat in a coupled operation. This type of cogeneration needs, however, the existence of suitable heat loads. In this study we investigate the use of large long-term heat storages for the cases that the DH-load is not sufficient. For the reason of handling large heat flows, the well established rock cavern technology has been analysed for the use in district heating systems. Two operational cases from real cogeneration systems in Enköping and in Linköping have been studied. Models have been developed for calculation in Excel and operational years have been simulated and economically evaluated with different storage sizes. One is a CHP based on municipality wastes, oil and biomass fuels with oil and biomass-fired top-load plants (Tekniska Verken i Linköping AB) and another one with bio-fuel-fired cogeneration and bio-fuel top-load plants (ENA Energi AB Enköping).

1. INTRODUCTION

District heating system is an optimal way of supplying heat to different sectors of the society such as residence, premises and industries. It gives us the possibility to use a variety of fuels and surplus heat for heat production. District heating is also instrumental in reducing the global and local CO_2 emissions. It offers an enormous flexibility to combine different types of energy sources efficiently. Above other things, the prominent advantage of district heating is that it enables the deployment of combined heat and power (CHP) production thereby enabling the most efficient use of primary energy.

District heating is a common way for supplying space heating and domestic hot tap water in Sweden. The market share of district heating for the whole country is around 40 % but in towns where district heating is well established, the share may reach up to 90 %.

Although district heating is well established in Sweden and the fuel mixture being one of the most diversified, the share of CHP is still low. The current share of CHP in the Swedish district heating system is around 30 % and corresponding figures in Denmark and Finland are well above 60%. The main reason for that is that in Sweden, due to a high amount of hydro and nuclear power, the electricity production is a by-product and have been mostly undertaken in order to deliver heat. However nowadays, with increasing market prices for electricity, there is also an interest to deliver electricity at times where the heat demand is not matching the electricity production (see Swedish District Heating Nets).

One common problem in utilising existing CHP is the rather low heat demand during summer time. The heat demand during summer is so low that it makes it difficult to run CHP during this period. The purpose of this paper is to show how long-term storage can contribute to extended utilization time of CHP.

2. STORAGES IN DISTRICT HEATING SYSTEMS

2.1 Short term storage as operational component

Short-term thermal storages are necessary components in district heating systems. The main purpose of a storage in such system is to balance production in general and during peak load periods. In this context, the need for peak load units can be avoided. The advantages of short-term thermal storages are many such as reduced partial load operation, increased power generation. Furthermore, the storage functions as an expansion vessel for the district heating system. Hence short term water storages in steel tanks are traditional components in CHP systems.

2.2 Rock cavern long-term storage

Dealing with CHP plants, we have to think about both large heating powers and large storage devices. A heating power of 100 MW means a flow of 1600 m^3 water per hour. Therefore the choice of storage in the Swedish perspective is obvious: Rock caverns would be the suitable storage technology. There are many reasons for that: The Swedish ground conditions are very often suitable for rock cavern, there is a large experience for constructing and operating rock caverns in Sweden and millions of m^3 rock caverns have been built for storing oil reserves, very often at elevated temperatures (60 ºC) which means that the heat leak and heat transfer conditions are very well established. (One idea, which is not further treated in this paper, is also to convert not longer used oil storage rock caverns to water storage operation in CHP systems). Furthermore, in the past, a couple of water storage rock caverns have been built, among them the rock cavern of Lyckebo near Uppsala has been a very well known hot water storage, serving a former solar district heating plant (see Figure 2.1).

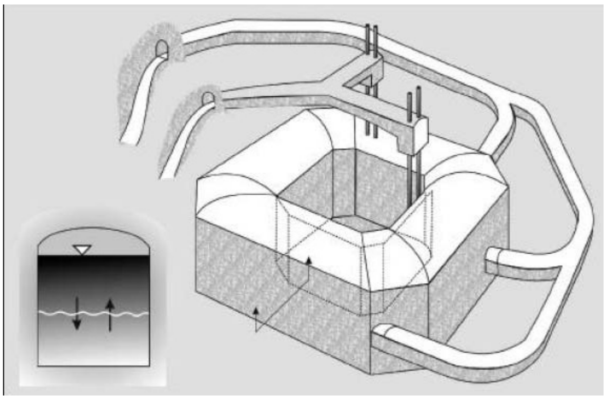

Figure 2.1: Sketch of the toroidal 100 000 m^3 rock cavern of the solar heating plant in Lyckebo

The advantage of the rock cavern storages is that the technique is mature, however, so are also the constructors of it and experience might have been lost and actual prices are uncertain. In our study we relied on older price informations (Hillström, Åstrand) and extrapolation according to the Construction Price Index PBI. The following equation for the storage costs was used:

$$C_{storage} = C_{Reference(V0)} * \left(\frac{V}{V_0}\right)^{eb}$$

[SEK/m^3].
With the following cost parameters:
V_0: 100 000 m^3
$C_{Reference\ (V0)}$: 400 SEK/m^3
eb: -0,3.

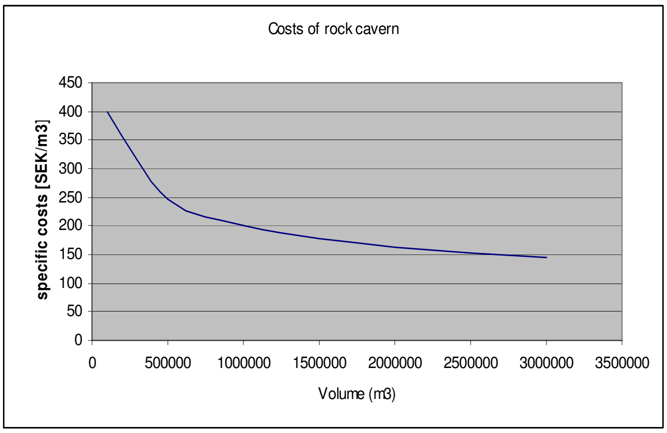

Figure 2.2.: Specific costs of rock caverns.

3. LONG TERM HEAT STORAGES IN DISTRICT HEATING SYSTEMS

CHP in district heating systems are dimensioned with respect to the existing heat demand. This implies that the operation of CHP plant is highly depending on the level of heat demand: The CHP plant can be operated at full load or at technically possible partial load. On the other hand, the plant has to be shut down when the heat demand falls to the point where it is impossible to run the plant. In this situation other production unit has to be run to cover the demand. Running this unit may be expensive and it could also mean environmental disadvantage depending on the type of fuel used.

In these cases one can either produces less electricity or cool away the surplus heat or – evidently - store it in a suitable storage for later use. This later use can either come very soon, for example over a weekend when no electricity would be produced, or some months later, when the heat demand is larger than what the CHP plant can the deliver.

Although power prices in Sweden are generally lower during summer time compared with wintertime, there are times where power prices are high enough that it could be economical to run CHP plants during summer time. This situation, however, demands that there is sufficient heat demand simultaneously. If this is not the case, it could be profitable to run the CHP plants almost like conventional condensing plant (the valuable heat being wasted). To avoid heat dump and at the same time to take advantage of the favourable power price, long-term heat storage could be used. The stored heat can be used in times such as peak load periods. Using long-term thermal storage in district heating system will not only enhance the utilisation of CHP plants but also contributes to improve the environment by reducing the use of fossil fuel.

Therefore, we analysed some practical operating cases from two CHP utilities, in order to find out more about the economics which can be achieved with large seasonal storages based on rock cavern technology.

- Cogeneration based on municipality wastes, oil and biomass fuels with oil and biomass-fired top-load plants (Tekniska Verken i Linköping AB – TVAB)
- System with bio-fuel-fired cogeneration and bio-fuel top-load plants (ENA Energi AB Enköping).

In the following the different operational cases will be discussed.

3.1 Cogeneration based on municipality wastes, oil and biomass fuels with oil and biomass-fired top-load plants (Tekniska Verken i Linköping AB – TVAB)

Table 3.1 summarises technical and economical conditions for Linköping district heating system

Table 3.1: Technical parameters and fuel costs for Linköping

Plant	**Heating power (incl stack gas cooler) [MW]**	**Electr. power [MW]**	**Costs of heat production [SEK/MWh]**
CHP Gärstad P1-P3 (municipality wastes)	66,3	16,1	-326
HOB Gärstad P4 (municipality wastes)	57,3	19,8	-326
CHP Tornby biomass P1	105,6	33,1	-100
CHPTornby Oil P2	105,7	34,9	356
Mjölby wood chips	24,3		223
Ljungsbro wood chips	3,9		170
HOB oil	100		404

The principle of calculating heat productions costs is to calculate the income from electricity sale minus costs for supplied fuel. The interesting feature of Linköping is that people have to pay for delivering waste products, hence we have negative fuel price in the Gärstad waste heating plant. The electricity price C_{el} is taken for 2005 with 450 SEK/MWh. The calculation includes no investments. Additional incomes are the certificates for renewable electricity production $Cert_{el}$ (214 SEK/MWh). The heat production costs in Linköping are therefore calculated the following way and found out to be negative: Totally – 260 MSEK in our example (C_{prod} = Costs of heat production):

CHP Gärstad: $C_{prod} = -142 - 0{,}3*(C_{el} - (-164))$ SEK/MWh (heat)
CHP Tornby biomass: $C_{prod} = 137 - 0{,}45*((C_{el} + Cert_{el}) - (137))$ SEK/MWh (heat)
CHP Tornby oil: $C_{prod} = 384 - 0{,}33*((C_{el}) - (365))$ SEK/MWh (heat).

Figure 3.1 shows the heat duration diagram (sorted after months) for the operational situation based on measured values for 2005 in the Linköping production mix without heat storage.

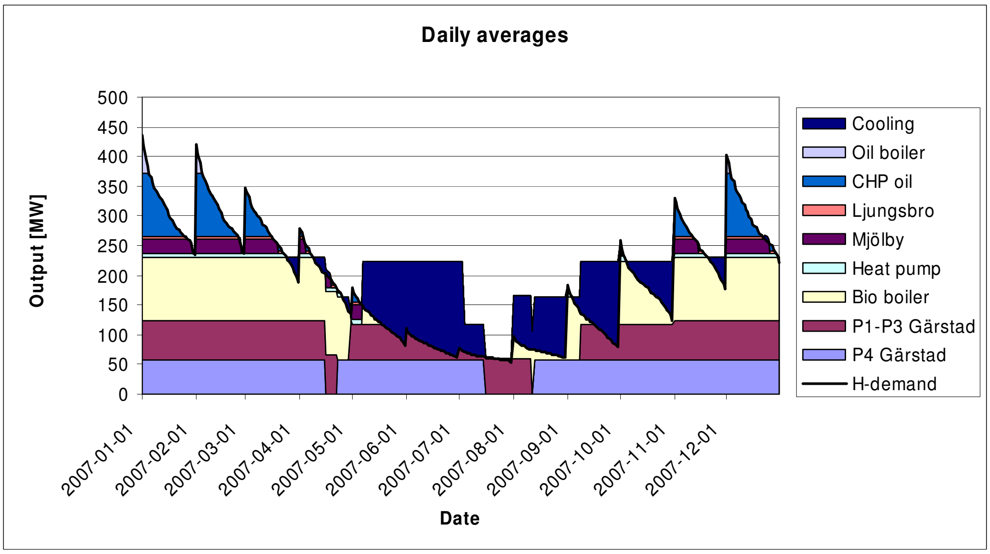

Figure 3.1: Daily averages for the heat demand 2005 in the Linköping DH System – base production (no heat storage)

The total heat demand is 1670 GWh and the maximum delivered thermal power is about 430 MW. The base load is produced with municipality waste plants Gärstad P1 – P4 all the year except some week's closing period for revision (spring and summer). Stack gas condensers are in operation at all the operation time. At higher heat demand, the Tornby biomass plant is put into operation and in the winter, the other boilers are also used. It should be mentioned that there exists also a large cooling potential of about 150 MW for operating the CHP plant in a condensing mode in the case of low heat demand.

By introducing ***a heat storage***, the operation of plants with more expensive fuels (especially oil) could be partly replaced by storing the surplus heat and reusing it another time. The cost analysis was done for a rock storage with costs which were extrapolated from earlier Swedish work on rock caverns. The storage size was varied between 100 000 m^3 and 4 000 000 m^3. Table 3.2 shows the technical parameters and the payback time for different storage sizes. It is obvious that smaller storages can be used more often per year and therefore will be more cost-effective than larger one. This is partially compensated by the anticipated size dependence of the storage costs (see Chpt.2).

Table 3.2: Technical parameter, costs and benefits of the use of long-term storage in the Linköping DH system

Storage size [m^3]	Capacity [MWh]	Annual usage	Oil reduction [MWh]	CO_2 reduction [ton]	Investment [kSEK]	Value of saved oil [kSEK/yr]	Flat pay-back time [yr]
100 000	5 000	4,1	20 000	5 600	40 000	8 024	4,98
200 000	10 000	4,7	30 000	8 300	64 980	11 088	5,86
300 000	15 000	3,0	35 000	9 700	86 306	12 814	6,74
500 000	25 000	2,1	44 500	12 500	123 406	16 308	7,57
1 000 000	50 000	1,6	68 500	19 200	200 474	24 872	8,06
2 000 000	100 000	1,3	93 500	26 200	325 672	37 304	8,73
3 000 000	150 000	1,1	118 500	33 200	432 558	47 541	9,10
4 000 000	200 000	0,9	125 400	35 000	529 056	53 354	9,92

As it can be seen, no optimum for the storages can be found. The smaller the storage, the lower is the pay-back time. This is a trivial solution which should be further commented. A more correct way to calculate the benefit of the investment is to use the annuity for the investment instead of a flat pay-back rate. Therefore in Table 3.3 we compare annuity with the annual value of saved oil. This table shows that with an amortisation time of 10 years, storages up to 300 000 m^3 show positive profit, whereas with amortisation times of 20 years all storage sizes produce a positive result. This is indicated by the profitability factor Θ of the ratio of saved oil divided by the annuity of the investment.

Hence from this comparison, based on an interest rate of 6 %, it can be seen that, in the shorter perspective of 10 years, a storage of 200 000 m^3 could be economically interesting, reducing the amount of oil supply by 3300 m^3 and reducing the CO_2 emissions by 8300 ton. On the other hand, a storage of 3 000 000 m^3 would replace all the 11 000 m^3 oil used in the Linköping CHP- Tornby plant, only the remaining oil of a small HOB (7 GWh) would be still used. However such a storage will have a flat pay-back time of about 10 years and amortisation period of about 15 years and is therefore a very unsafe investment, although it can be expected that the oil price sometimes will surpass the here anticipated price of 75 $/barrel. In order to replace the use of all oil by stored energy we would need a storage size of 4 000 000 m^3.

Table 3.3: Comparison between costs and benefits for different storage sizes, 10 and 20 years amortization time, respectively

Storage size	Annuity [kSEK]		Θ = Value of saved oil/ Annuity	
Size [m^3]	10 [yr]	20 [yr]	10 [yr]	20 [yr]
100 000	5 434	3 487	1,477	2,301
200 000	8 828	5 665	1,256	1,957
300 000	11 726	7 524	1,093	1,703
500 000	16 767	10 759	0,973	1,516
1 000 000	27 238	17 478	0,913	1,423
2 000 000	44 248	28 393	0,843	1,314
3 000 000	58 770	37 712	0,809	1,261
4 000 000	71 881	46 125	0,742	1,157

In Figure 3.2 the operational duration diagram for a storage of 3 000 000 m^3 is depicted.

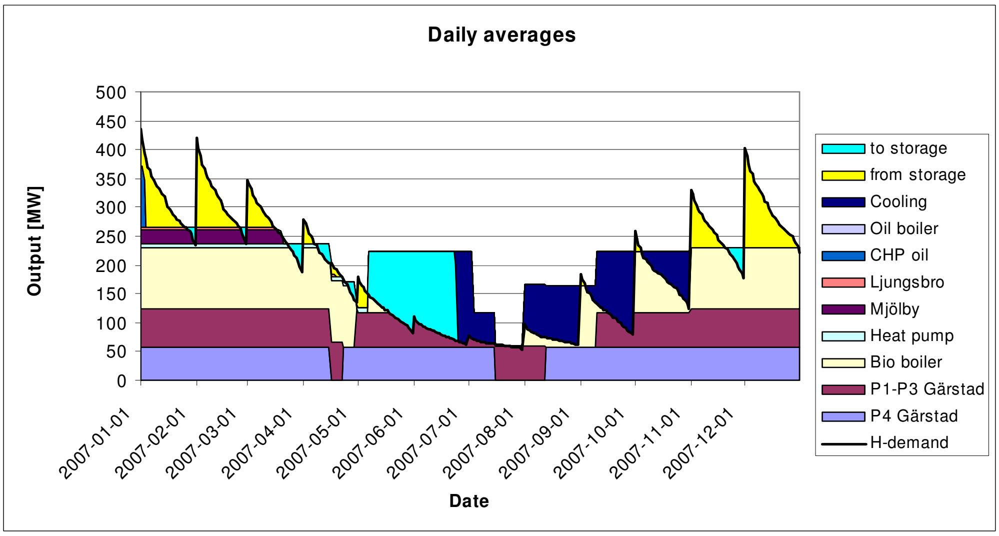

Figure 3.2: Daily averages for the heat demand 2005 in the Linköping DH System – heat storage 3 000 000 m$^{3.}$

It can be seen that heat from the storage is used in wintertime whereas the charging of the storage is primarily achieved in May and June. In Table 3.4 the energy use for the situation without and with two storage sizes is compared.

Hence our first conclusion is that a water storage of 200 000 m^3 could be of interest to be build today, and that larger storages can be motivated at such oil prices as we experienced in spring 2008 (and which certainly will return in a near future).

Table 3.4: Comparison of different system use for three cases

Plant	**Produced heat – base case [GWh]**	**Produced heat 200 000 m^3 [GWh]**	**Produced heat 3 000 000 m^3 [GWh]**
P4 Gärstad	454	454	454
P1-P3 Gärstad	504	504	504
Biomass HOB	836	836	836
Heat from storage	-	47	164
Heat pump	31	35	24
Mjölby wood chips	74	73	46
Ljungsbro wood chips	12	10	7
CHP Tornby oil	118	96	0
HVC Olja	7	0	7
Cooling	-366	-341	-210

3.2 System with bio-fuel-fired cogeneration and bio-fuel top-load plants (ENA Energi AB Enköping).

Another CHP-system of ENA-Energy in Enköping based on bio-fuel was also studied in detail but with less encouraging results. The analysis showed that the results were not stable enough but depending on the instantaneous prices movements for wood chips and electricity. For instance, the profitability factor Θ was larger for electricity prices of 2006 than for 2005 (and 2007) prices. That means that at low fuel costs, such as it is the case with biomass fuel, it is obvious that it would take long time to pay back the investments of even a small long-term storage. However, with some stipulated increase of the electricity price (i. e. 3 % per year) one could think about a 200 000 m^3 storage which could make the operation of CHP more effective. Having today a heat storage of only 10 000 m^3, a larger rock cavern could facilitate the operation of the system running the cogeneration plant in more stable conditions.

4. CONCLUSIONS

The detailed analysis (see references H. Zinko, A. Gebremedhin; J. Andersson, S. Nilsson; D. Sandborg) showed that the long-term storage can replace the heat dump in CHP systems and enable the backpressure plants to work at rated power. This results in increased electricity production during summer operation and of reduced top oil use in wintertime, with corresponding reduction of CO_2 emissions. The profit of this operation has to finance the heat storage.

A good economy has been found when oil is used as fuel in top load conditions. Replacing 60 MW top load oil needs in the Linköping case a storage of 200 000 m^3 rock cavern at a pay-back time of less then 10 years. This storage is turned over in the average 4.7 times a year and there for rather economic. In order to replace the large part of the total oil use, a 3 000 000 m^3 storage would be necessary, replacing about 11000 m^3 oil. Such a storage, although constructed at relatively low costs, is not so effective because it will be use only 1.1 times a year.

In the case that the replaced heat is generated by biomass it was found that the economy is highly influenced by the price difference between biomass and electricity. At low electricity prices, no economical solution was found at 2005 prices, but well at 2006 higher electricity prices. So our conclusion is that we have to wait some years until also these applications can be envisaged.

As a result of the detailed analysis we found that it would be worthwhile to test, if ground coupled storages could be used in district heating systems. Because of the low specific costs of bore hole storages, it would be worthwhile to analyse, how large amounts of heat could be charged and discharged to and from such storages and how the temperature degradation affects the operation in district heating systems.

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