ABSTRACT

This paper describes the state of essential demonstration projects of heat and cold storage in aquifers in Germany. Into the energy supply system of the buildings of the German Parliament in Berlin, there are integrated both a deep brine-bearing aquifer for the seasonal storage of waste heat from power and heat cogeneration and a shallow-freshwater-bearing aquifer for cold storage.

In Neubrandenburg, a geothermal heating plant which uses a 1,200 m deep aquifer is being retrofitted into an aquifer heat storage system which can be charged with the waste heat from a gas and steam cogeneration plant. The first centralised solar heating plant including an aquifer thermal energy store in Germany was constructed in Rostock. Solar collectors with a total area of 1,000 m² serve for the heating of a complex of buildings with 108 flats. A shallow freshwater-bearing aquifer is used for thermal energy storage.

1. Energy Supply of the Buildings of the German Parliament

Energy Demand

In Berlin, there are being constructed the new buildings of the Parliament of the Federal Republic of Germany which are grouped around the reconstructed and re-opened Reichstag building. For the four major complexes of buildings with the following energy demand:

- Power 8,600 kW
- Heat 12,500 kW
- Cold 6,200 kW

there was designed and largely implemented already an energy concept including the combined production of power, heat and cold with maximum possible primary energy utilisation.

Description of the Energy Concept

The energy concept focuses on the self-production of power based on power and heat cogeneration units. The eight machines with a total electric capacity of 3,200 kW are operated according to the actual power demand. The heat produced at the temperature level of 110 °C when generating power is for direct heat supply to the high-temperature (90°C/60°C) and, partly, the low-temperature heating networks (45°C/30°C) or to drive the refrigerating machines / heat pumps for the supply of cooling energy in summer and low-temperature heat in winter.

As the heat and power demand curves are not synchronous, there is – in particular in summer – produced surplus heat by the cogeneration units, and at other times, namely in winter, there is a gap in the coverage. That is why the excessive waste heat is stored seasonally in a deep brine-bearing aquifer. The waste heat is fed into this heat store with a temperature of 70 °C and at a later date recovered with a temperature ranging from 65...20 °C. A major share of the recovered heat supplies the low-temperature section of the heating systems in direct heat exchange. More cooling down of the store is done by means of the absorption-type machines in the form of heat pumps.

There is another underground store which is situated in a much lower depth. Primarily, this aquifer cold store is for cooling of the buildings. The water is cooled in winter down to minimum 5 °C. On one hand, this is done by charging the store with cold via cooling towers. On the other hand, the cold store is the source to heat pumps.

The cold stored in winter in the above way feeds in summer the high-temperature cooling systems via heat exchangers at a temperature level of 16°C/9°C. The absorption-type machines driven by hot water from the cogeneration units feed the other low-temperature cooling networks (6°C/12°C). The cooling demand of these machines is covered by air coolers and the cold store, which is charged upon absorption of the cooling load from the high-temperature cooling networks with the waste heat of the chillers up to the maximum temperature of 30 °C. In this way, the heat source to the heat pumps is formed again in the cold store for the next winter.

For the storage of heat, the water is pumped off from the cold side of the store, charged with heat (heat store: waste heat from the cogeneration units, cold store: waste heat from cooling) and fed to the warm side of the store at a distance of about 300 m. For discharging, the direction of flow of the respective system is reversed, i.e., water is pumped off from the warm side of the store. Upon absorp-
tion of the heat from this water (heat store: direct heating or source to heat pump, cold store: cooling towers or source to heat pump), it is fed to the cold side of the store.

Aquifer Store

In a depth of 285 to 315 m, there is a sandstone layer with its pores filled with thermal water (mineralisation 29 g/l). This 30 m thick layer is covered by clay which separates it from the top layers. The hydraulic properties of this aquifer (heat store) allow the production of 100 m$^3$/h of brine via each of the drilled deep wells, to heat it up to 70 °C, and to reinject it.

Moreover, there exist Quaternary/Tertiary water-bearing beds in a lower depth. The hydraulic conditions of these aquifers allow the production of 60 m$^3$/h via one well and to reinject this amount, too. Totally, there were drilled six warm and six cold wells, including necessary redundancy. Operating parameters of the two aquifer thermal energy stores are given below:

**Operating parameters of the heat store:**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Medium Production Temperature</th>
<th>Injection Temperature</th>
<th>Charged Amount of Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Operation</td>
<td>medium</td>
<td>25°C</td>
<td>70°C</td>
</tr>
<tr>
<td>Winter Operation</td>
<td>injection</td>
<td>65 ... 25°C</td>
<td>discharging of heat</td>
</tr>
</tbody>
</table>

**Operating parameters of the cold store:**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Production Temperature</th>
<th>Injection Temperature</th>
<th>Discharged Amount of Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Operation</td>
<td>6 ... 10°C</td>
<td>15 ... 28°C</td>
<td>3,950 MWh/a</td>
</tr>
<tr>
<td>Winter Operation</td>
<td>injection</td>
<td>22°C</td>
<td>Medium Production Temperature</td>
</tr>
<tr>
<td></td>
<td>charged amount of cold</td>
<td>5°C</td>
<td>4,250 MWh</td>
</tr>
</tbody>
</table>

**Effects Expected from the Implementation of the Energy Concept**

With the implementation of the described energy concept – which started in spring 1999 with the commissioning of the Reichstag building – it will be possible to produce 82 % of the electric work and even 90 % of the annual heat demand with block-type heat and power cogeneration units which cover 37 % of the electric peak load. From the cold store, i.e., predominantly from the winter ambient cold, 60 % of the cold demand in summer will be covered.
2. Storage of Surplus Heat From a Gas and Steam Cogeneration Plant in Neubrandenburg

Initial Situation

Within the framework of their district heating system, the Neubrandenburg Public Utilities run two energy generation plants and two district heating networks.

Since 1987, the Neubrandenburg Geothermal Heating Plant supplies heat to a residential area.

Heat supply

- heat generation
  - geothermal energy use in direct heat exchange
    - depth of the two aquifers: 1,200 – 1,300 m
    - thermal water flowrate: 150 m³/h
    - thermal water temperature: 53 °C ... 55 °C
    - mineralisation: 120 ... 130 g/l
  - absorption-type heat pump: 9 MW

Since 1997, both power and heat for the centralised high-temperature district heating system are supplied by a gas and steam cogeneration plant. The system becomes fully effective only when both kinds of energy can be exploited at the time of production. In winter, when both power and heat demand are equally high, this does not represent any problem. However, in summer the heat demand is much too low with the power demand being almost unchanged. That is why considerable amounts of the waste heat have to be discharged via a recooling unit.

Description of the Energy Concept

In summer, there exist problems in both generation plants regarding the utilisation of the existing potential in order to achieve high energetic efficiency and economic profitability. The aquifer thermal energy storage project is to solve these problems through the synergies resulting from the combination of the systems:

- The steam and power cogeneration plant requires a very large thermal energy store for shifting the surplus heat fed hitherto to the recooling unit from the summer into the winter season. This is done by storing the surplus heat in the aquifer of the geothermal heating plant which is not utilised in summer.
- Due to the low thermal water temperature, permanent reheating by gas-driven units (absorption-type heat pump, boiler) is necessary in the geothermal heating plant. With the waste heat of the gas and steam cogeneration plant it is possible to increase the temperature level of the geothermal reservoir up to 80 °C.

In order to achieve the described objective, there will be established two conditions:

- Construction of the hydraulic connection between the central primary district heating system which is fed by the gas and steam cogeneration plant, and the secondary district heating system in the western part of the town which is supplied by the geothermal heating plant.
- Creation of the possibility to reverse the direction of the thermal water flow in the wells and the surface piping systems of the geothermal heating plant.

Then, the plant will be operated as follows:

- The summer surplus heat coming from the gas and steam cogeneration plant fed hitherto into the recooling unit is supplied to the centralised primary district heating network and fed into the geothermal heating plant.
- In the geothermal heating plant, this heat serves two purposes: On one hand, the sanitary hot water supply of the networks in the western part of the town is secured, and on the other hand, the heat is fed at a temperature of 80 °C into one of the wells of the thermal water loop, thus increasing the heat potential existing there by about 30 K.
- In winter, a part of the heat supply is implemented by the geothermal heating plant through discharge of the heat stored in the aquifer. However, the temperature in the system will not be restricted – as presently – to the natural store temperature (52 °C at the well head). The heat demand can be covered from the section where the temperature was increased up to 80 °C in summer.

Effects Expected From the Implementation of the Energy Concept

The described system offers the possibility to store the heat amounting to 12,000 MWh/a just from the summer surplus heat coming from the gas and steam cogeneration plant. Thereof, 8,500 MWh/a will be recovered in winter. Thus, the storage efficiency will be about 70 %.

In addition, also the sanitary hot water demand and – to a less extent – even the heating demand in the “Rostock Street” network will be covered directly by the surplus heat coming from the gas and steam cogeneration plant in summer. This will increase the extent of the surplus heat utilisation by another 3,200 MWh/a.

Retrofitting the geothermal heating plant as an aquifer thermal energy storage system, the environment will be saved from the emission of 1,550 t of CO₂ per year.
3. Centralised Solar Heating Plant in Rostock

Energy Demand

On the site of Rostock-Brinckmanshoehe, a complex of buildings with 108 flats and a total living area of about 7,000 m² was constructed in 1999. 319 MWh/a are required for heating and, in addition, 144 MWh/a for sanitary hot water preparation. The client requested to cover significantly more than 50 % of the heat demand by solar energy.

Description of the Energy Concept

On the roof surface which is aligned towards south and consists of eleven individual roofs inclined by 38°, there are arranged solar collectors with an absorption area of about 1,000 m².

In summer, the installed collectors deliver 400 MWh of solar heat, thus making it possible to cover major parts of the total annual demand of the building. However, the condition is an adequate, i.e., seasonally operated store.

Under Rostock-Brinckmanshoehe, there is a groundwater aquifer in a depth of about 15 ... 25 m which is formed by feldspar-containing quartz sands. It is covered by a 12 to 17 m thick layer of boulder clay. The aquifer is underlain by a 2.5 m thick layer of boulder clay which occurs as silty, clayey fine sand. The aquifer is developed by two wells with an internal distance of 55 m.

The two wells are equipped with pumps and an injection casing allowing both directions of flow with a rate of max. 20 m³/h. Heat exchangers which are integrated into the surface piping system connecting the wells allow charging and discharging of heat. The water produced from the cold well at a temperature of 10 °C is heated up in summer by solar energy and injected into the warm well causing the formation of a so called “heat bubble” in the aquifer. In winter, the heat is produced from this bubble with the direction of flow being reversed, then. Initially, the discharging temperature is 45 °C. In the course of the reversed production, it decreases down to the natural groundwater temperature. Along with the heat exchangers for pre-heating of the return flow in the heating system (low-temperature heating system 45 °C/30 °C, outdoor-temperature dependent) and of the sanitary hot water, an electrically driven 100 kW heat pump is integrated. It transforms the heat from the “bubble” to a usable level. After three years of operation of the store for optimisation of the system, a recovery coefficient of about 63% is expected.

A 30 m³ buffer tank serves for the balancing of short-term oscillations of the solar radiation in the course of the day so as to not overstress the very inert underground store. It is a layered store, and the state of its loading forms the central criterion for the regulation of the entire unit.

On few days during the year (at outdoor temperatures below abt. 5 °C), when the performance of the solar-driven part of the unit alone will not be sufficient, and for the handling of potentially risky situations a gas-fired 250 kW condensing boiler is integrated into the system.

Effects Expected From the Implementation of the Energy Concept

Due to the temporal discrepancy between heat demand and heat offer, about 159 MWh/a of the approx. 400 MWh/a delivered by the solar system can be used directly. Accordingly, the share of the direct solar coverage is 32 %.

234 MWh of heat are fed into the store, about 28 MWh “go lost” during transfer and distribution.

In the phase of heat discharge, 148 MWh of heat are produced from the store at a temperature above the natural one of the groundwater of 10 °C. These have to be added fully to the degree of solar coverage leading to its increase from 32% to totally 62%.

By additional cooling of the groundwater below 10 °C by means of the heat pump at the end of the phase of discharge, the total amount of heat extracted from the store is as high as 222 MWh/a.

Conclusions

All the described demonstration projects are accompanied by comprehensive monitoring programmes which are financed by the Federal Ministry of Trade and Commerce and Technology of Germany. This covers investigations into geohydro- and thermodynamics, geochemistry and microbiology as well as the analysis...
of data of the operation of the plants, energetic balancing and investigations into the economic profitability of the operation of aquifer thermal energy stores.

It is the objective of the investigations to optimise the operation of the plants, to confirm the safety of the applied methods and to advance them, to validate and improve design tools, thus finally contributing significantly to the dissemination of a technology which promises to make possible large-scale heat and cold storage at low specific cost.

КОГЕНЕРАТИВНА ПОСТРОЙКА НА ПРИРОДЕН ГАС ВО СКОПЈЕ

Славе АРМЕНСКИ
Константин ДИМИТРОВ
Доне ТАШЕВСКИ

РЕЗИМЕ

Бо овој труд се анализирани две когенеративни постројки за производство на топлинска и електрична енергија за град Скопје, кои користат природен гас како гориво, од кои едната е со: две гасни турбини, два котли утилизатори и една противпритиска парна турбина, а другата со: две гасни турбини, два котла утилизатори и една парна кондензациона турбина со регулирано одземање на пара за загревање на мрежната вода. Загревањето на дел од мрежната вода се врши и во двата котли утилизатори.

Со оглед на тоа што когенеративната постројка со противпритисна турбина не може да работи во летен режим, извршена е замена на противпритисната со кондензациона парна турбина со регулирано одземање на пара за загревање на мрежната вода. Со тоа се овозможува продолжување на времето на работа на парната турбина и зголемување на производството на електрична енергија и во летен период.

Загревањето на водата наменета за централно грење се остварува во котлот утилизатор со излезните гасови од гасната турбина и во посебен регенеративен загревател со парата која излегува од противпритисната парна турбина, или се одзема од кондензациона парна турбина.

За двете когенеративни постројки анализирано е производството на топлинска (во зимски режим на работа) и електрична енергија (во зимски и летен режим на работа); потрошувачката на природен гас за различни режими на работа на когенеративните постројки и вкупниот коефициент на искористување на енергијата.

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