



High Temperature Underground Thermal Energy Storage

State-of-the-art and Prospects

A review within ECES Annex 12 of the International Energy Agency IEA

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Executive Summary

Heat storage is a crucial issue to match demand for heat with supply of heat, or even with the need to get rid of waste heat. The ground has proven to be an ideal medium for storing heat in larger quantities and over longer time periods, like the yearly seasons. After plants to store summertime solar heat for use in winter heating, storage of waste heat now is emerging. The efficiency of heat storage depends upon the temperature level achieved and upon minimization of thermal losses. While heat storage in the range of 10-40 °C has been demonstrated successfully, higher temperature levels up to ca. 150 °C have caused a lot of problems in experimental and pilot plants in the 80s.

Following a revival of interest in subsurface heat storage, a new activity of the International Energy Agency (IEA) was launched in December 1997 as Annex 12 to the Implementing Agreement "Energy Conservation through Energy Storage" (ECES), to address high temperature underground thermal energy storage (HT-UTES). In a first phase, information from the past experimental and pilot plants was collected, and a survey concerning operational experiences, technical problems, environmental behavior and economic and ecological advantages was made.

The first publications are from the 1960s, and first experiments are reported from the 1970s (KLEY & NIESKENS, 1975; MATHEY, 1977; MOLZ et al, 1979). Around 1982, several pilot plants were constructed, and most are well documented. The depth of wells for aquifer thermal energy storage (ATES) does not exceed 400 m, and is usually much shallower, while depth of borehole heat exchangers ranged between 30 and 100 m. However, the use of deep aquifers (>1000 m) as well as deep borehole heat exchangers (>1000 m) was considered recently. With increasing depth, the ground temperature is higher. This limits thermal losses, but storage changes gradually into pure geothermal heat extraction at greater depth.

The following conclusions from Phase 1 of IEA ECES Annex 12 were prepared in two expert's meetings in 1998 and finished through intensive review in the Annex 12 group and by other experts. Three main areas are covered:

1. What can we learn from the past experiences, be it experimental or demonstration? What were the main problems encountered?
2. What are the key areas, where further R&D is required to solve remaining problems, and what are the concrete topics? (only topics should be addressed, which have a realistic chance to be successfully solved)
3. What are promising system concepts, in what circumstances can HT-UTES best show its potential, i.e., why is it worthwhile to continue with R&D in this field?

A general conclusion can be made: HT-UTES is required to allow direct use of stored heat, without further energy input, e.g. for heat pumps. If high temperature heat is available from clean sources (solar collectors, geothermal) or as waste, the overall result of HT-UTES-operation is always favorable. The remaining problems all seem to be not too hard to be solved, and other limitations may present no drawback for the moment. Some new plants recently became operational, after a longer break, and more new projects are under serious consideration. The Annex 12 expert's group expressed an optimistic view for the future of HT-UTES.

Operational experiences from existing HT-UTES-plants

Some general remarks can be made: Most of the systems under investigation run, but the users usually do not know if they run at optimum or even well. So monitoring and evaluation is crucial to find the flaws in system design, construction, and operation. Good to optimum operation on the other hand is required for long-term sustainable performance. In the demonstration plants, energy demand was mostly not as designed (usually lower), and this affected storage efficiency.

Minimum monitoring required is temperatures, water and energy flows in the surface installation. A monitoring period should last at least 2 loading/unloading cycles. Monitoring may also act as an early warning system, identifying problems like well clogging at an early stage. Storage efficiency and temperature are the key points for economic and energy saving operation. Here it was found through monitoring, that the unloading temperature can be lower than calculated, e.g. due to unexpected buoyancy flow (free convection). Two examples were investigated in more detail:

- Luleå The predicted storage efficiency was not achieved in the first year, the reason was a construction error with the de-aeration system. After fixing, only minor problems occurred.
- Utrecht: Return temperature from buildings was too high, thus minimum design unloading temperature was not met and unloading of the store was less than designed. Energy demand at lower temperature level was not as high as in the design.

User behavior has shown to be a crucial issue; e.g. users made changes without consulting the designer or even telling him. A surprising fact was, that user interference was mostly beneficial (e.g. in Utrecht). User education nevertheless is important, and on the long term, user interference should be limited, to prevent errors.

The experiences with water treatment systems were of particular interest for ATES. Concerning Fe/Mn-scaling, the only possibility is to keep the system under pressure. If mixing of waters in the ground is possible, no ATES should be built. Keeping the system under pressure is also the only possibility to prevent gas clogging, while degassing units may be a solution in future. A selection of methods is available against carbonate scaling, like Na⁺ ion exchange, addition of acids (HCl, but not HNO₃, H₃PO₄ or H₂SO₄, which may act as nutrients for bacteria), addition of CO₂, or the fluidized bed heat exchanger. Only Na⁺ ion exchange and addition of HCl were used successfully in full-scale plants by now.

Main technical problems encountered in the existing plants were:

- Control system (in Utrecht later upgraded by user)
- Deep shaft pumps (better to use submersible pumps)
- Frequency controllers with long cables (electromagnetic noise)
- Sensors (in particular flow meters)
- Surface connections (pipes)
- Problems with Heat Pumps (e.g. in Luleå)
- Cracking of confining layer due to high pressure
- Corrosion, if material is not adequate
- Well clogging problems due to inadequate or not working water treatment system.

Recommendations for further R&D on system studies and technical problems of HT-UTES

A system analysis should be done on the base of a collection of (recent) results of feasibility studies, allowing comparison and evaluation of configurations.

Operational strategies need further investigation, incl. the verification of storage loading etc., and suitable control systems for the storage system in toto have to be optimized. As support, existing simulation models for plant design and for evaluation of operational strategies have to be adapted and used.

There are several R&D-needs concerning individual components and worksteps:

- Drilling, incl. fracturing of rock to increase hydraulic conductivity (for ATES)
- Submersible pumps for high temperatures (at affordable prices)
- Suitable pipe materials for high temperatures, especially plastics
- Material and technique for insulation on top of store, especially for shallow BHE
- Borehole thermal energy storage (BTES): U-tube design is used for low temperatures and low Δt ; modeling and experiments concerning applicability at high temperatures are required, incl. an optimization of design and evaluation of alternatives (e.g. concentric)
- ATES: Well layout optimization
- Fluidized bed heat exchangers have to be made feasible at a technical scale
- For water treatment optimization in ATES plants, some urgent issues have been identified:
 - Automatization of treatment processes
 - For the CO₂-treatment, the importance of stripping of CO₂ in the unloading process has to be investigated
 - Scaling inhibition with natural inhibitors has to be understood better and may be used in practice
 - Mobile Test Equipment for planning of adequate water treatment methods at individual sites should be developed
- Concerning environmental issues, the temperature impact and changes in water chemistry should be considered more closely (in particular long-term effects), and should be investigated through monitoring in existing plants.

System opportunities and chances for increased application of HT-UTES

Possible heat sources and heat users are listed in the table below. Promising systems can be divided into two groups:

- a) From renewable sources:
Heat source can be solar heat (always with buffer store to level short-term changes), with direct heat supply to the district heating network, and backed by an auxiliary heating system, or with heat pumps, where the auxiliary system may not be required. Another option may be the use of geothermal heat, allowing storage of excess

production in summertime and covering of peaks in winter, or for using waste heat from geothermal power plants.

b) From waste or excess heat:

Storage of waste heat from co-generation or industrial processes may be on a seasonal cycle. UTES can also be applied as a back-up in industrial waste heat use, to cover heat load while the industrial process is stopped; the store is always kept loaded, to provide heat in times of production breaks, repairs, etc. Similar is the use for load leveling in a district heating system, where the store is always loaded at times of low heating demand, and unloaded during peak heating periods.

Possible heat sources and heat users for high temperature UTES	
Possible heat sources	Possible heat users
<u>Renewable energy</u> <ul style="list-style-type: none"> - Solar thermal (solar collectors, but also road surfaces etc.) - Geothermal (hydrogeothermal, but also waste heat from geothermal power plants, e.g. Hot Dry Rock) - Others (biofuels?) <u>Waste heat</u> <ul style="list-style-type: none"> - Heat and power co-generation (only with high electrical efficiency!) - Industrial / process heat (paper mills, steel works, and others) - Waste incineration - Others <u>Load leveling</u> in district heating systems (short- to medium term)	<u>Space heating</u> <ul style="list-style-type: none"> - District heating - Large buildings (housing, offices, hospitals, hotels, airports, etc.) <u>Industrial heat</u> <ul style="list-style-type: none"> - Batch or seasonal processes like in sugar refineries - Drying in food industry - Most industries have excess heat, thus no use for UTES <u>Agriculture</u> <ul style="list-style-type: none"> - Greenhouse heating - Drying of grain, hemp, grass (hay), etc. - Aquaculture <u>De-icing and snow-melting</u> on roads, sport centers, airports/run-ways, etc.

Conclusions

The study showed, that technical problems related with higher temperatures in UTES system may be overcome. One main issue still are the changes in water chemistry with drastically changing temperatures in ATEs systems, resulting in clogging, scaling, corrosion and leaching. It is possible to design and build reliable High Temperature UTES plants today, but caution is necessary when working with groundwater. In future, the existence of a choice of suitable methods for various hydrogeological/hydrochemical situations and system requirements is desirable. The investigation of promising system concepts revealed a number of opportunities to make use of UTES for saving energy and reducing emissions.