ECES Annex 12

"High Temperature Underground Thermal Energy Storage"

First report to the Executive Committee
23./24.6.1998

Annex 12, phase 1 was approved during the Executive Committee Meeting in Paris on 4.-5.12.1997. Germany was decided to take the responsibility of the Operating Agent, and the Institute of Applied Geosciences of Justus-Liebig-University, Giessen, will act as Operating Agent.

The objectives of Annex 12, phase 1 are to demonstrate that HT-UTES can be attractive to achieve more efficient economical and environmentally benign energy systems, and to disclose requirements and find problem solutions for reliable long-term operation. The type of UTES-systems concerned shall be confined to Aquifer Storage (ATES) and Duct/Borehole Storage (DTES).

By the time of writing the report, no country beside Germany and Canada had confirmed participation. Some countries expressed they will participate in the immediate future: Netherlands, Sweden. Other countries have a general interest, but do not yet participate: Belgium, France, Turkey.

The preparation of the annex started with a HT-UTES-workshop on June 12, 1996, during the IEA ECES Annex 8 expert's meeting in Halifax, Canada. On April 28/29, 1997, a dedicated workshop on HT-UTES within IEA ECES was conducted in Berlin, Germany, with international attendance. This workshop was a platform for a first review of the state-of-the-art and the future opportunities, and resulted in the recommendation to proceed in establishing a relevant annex. A first proposal was presented to the Executive Committee at its June 1997 meeting in Sapporo, Japan, and after modifications finally approved during the Executive Committee Meeting on 4.-5.12.1997 in Paris as annex 12.

1st Expert's Meeting

The first Expert´s Meeting was held in Giessen, Germany, 17.6.1998, hosted by the Operating Agent. The Senatssaal in the old administration building of Justus-Liebig-University provided a matching backdrop for starting new steps into future R&D. The meeting followed immediately the first Expert´s Meeting of Annex 13, to allow experts to attend easily both events. Due to the problems of some countries to secure funds in time, the workshop with additional participation was postponed to be held in conjunction with the 2nd expert´s meeting in October, and the 1st expert´s meeting was confined to one day only.

The proceedings of the meeting may bee seen from the minutes enclosed with this report. The most important facts are, that work on summarizing the Annex 6 results is well advanced, and identification and collection of material is more or less completed. Canada, Sweden and the Netherlands will provide national reports, Germany will do the rest of the world. Japan contributed to the environmental review, even not participating in the annex.

Workplan IEA ECES Annex 12

January 1998 Meeting of National Workgroups
Start of National Work
- Operation Experiences (Energy/Economy)
- Water Treatment, Environmental Aspects

Collection of information and documents
Work on draft report

June 1998 1st Expert´s Meeting, discussion of first results and adjustments
in further work
17.6.98, Giessen, Germany

Report to ECES ExCom at Meeting # 44 in Chester, UK, 23./24.6.1998

Finalization of state-of-the-art-report
Work on report: - Advantages, System Opportunities
- R&D-needs, Recommendations for Phase II

October 1998 Workshop to discuss first drafts of report in expert´s group and
with people operating or having operated HT-UTES
2nd Expert´s Meeting to discuss the final draft versions of re-
ports of Phase I
14.-16.10.98, Lund, Sweden

Incorporating changes from 2nd Expert´s Meeting into the reports, finalizing and printing of reports

Report to ECES ExCom Meeting # 45 in Albuquerque, USA, December 1998

Minutes of the 1st Expert´s Meeting in IEA ECES Annex 12 High Temperature UTES

17.9.98, Giessen, Germany

Participants:
Abbas Mohamed Abbas, Nat. Inst. Astronomy and Geophysics, Heluan, Egypt
Maurizio Adinolfi, Univ. Stuttgart, ISWA, Stuttgart, Germany
Benjamin Andersson, VBB VIAK AB, Malmö, Sweden
Dr. Olof Andersson, VBB VIAK AB, Malmö, Sweden
Martin Benner, Univ. Stuttgart, ITW, Stuttgart, Germany
Frank Cruickshanks, Environment Canada, Dartmouth NS, Canada
Dr. Paul Dirven, VITO, Mol, Belgium
Dr. Göran Hellström, Univ. Lund, Dept. Math. Physics, Lund, Sweden
Dr. Frank Kabus, GTN GmbH, Neubrandenburg, Germany
Dr. Michael Koch, Univ. Stuttgart, ISWA, Stuttgart, Germany
Dr. Burkhard Sanner, Univ. Giessen, IAG, Giessen, Germany

Begin 9.30

B. Sanner opened the meeting and welcomed the participants to Giessen. After that, the proposed agenda was adopted (s. attachment A).

Round-table for information on recent projects, developments, studies etc.:

Belgium and Canada

- no new information.

Germany

M. Benner reported the latest evolution of the Neckarsulm project:

- 36 borehole heat exchangers in experimental store, the 1. phase of the store will expand the borehole field to a total of 186 boreholes each ca. 35 m deep. In the experimental store heat with >70 °C loading temperature was injected, and a temperature in the store of max. ~55 ° was achieved. The measured results did match the model calculations quite well, only the heat transfer from the pipes to the ground was slightly lower than expected. Hence for the 150 new boreholes a slightly larger diameter >125 mm and spacers were chosen.

F. Kabus informed about some new ATES projects in Northern Germany:

- The heat store for the parliament and offices in Berlin is finished, and a test operation was started, first only for water movement without temperature changes. The water contains 20 g/l of salt. No water treatment is installed, but the system is constantly kept under pressure and free of oxygen. If the operation shows the need for avoiding calcareous scaling, a CO_2-treatment will be added.

- In a planning stadium are three projects: In Neubrandenburg, the existing geothermal doublet serving a district heating net may be converted into an ATES. It will store water of 80 °C in 1300 m depth (and maybe also in 1100 m depth). Up to 100 m^3/h of water with salt content of 120 mg/l will be circulated, and a CO_2-injection is probable. Another store is planned in Greifswald, to be fed by a 1 MW co-generation plant. The aquifer is in 150 m depth, water has 30 g/l of salt. The last project concerns a new CSHPSS activity in Rostock, where 1200 m^3 of solar collectors shall heat the ATES to ca. 60 °C.

Netherlands

Information from Netherlands was provided in writing:

- One new HT aquifer store was set into operation a week before the meeting (Hooge Burgh, Gouda). Finances for evaluation of the Utrecht university ATES are secured and work is beginning.
- As to the other activities, funds are applied for evaluation of the DTES in Groningen and for attending future expert´s meetings. Funds are also applied for testing of water treatment technologies at new HT ATES projects, but activities will be held back until end of Annex 12 phase 1.

Sweden

A short review of HT-UTES in Sweden was provided by G. Hellström:

- The borehole store in Luleå was operated in two phases (ca. 55 °C in 1981 and ca. 80 °C in 1983-89). The results were satisfactory, and the discontinuation of operation after 1989 was due to administrative and not to technical matters. In the Lund university, laboratory experiments are conducted since 1995 to investigate heat transfer between pipes and the ground with various pipe- and grouting configurations and with temperatures up to 50 °C. The assessment of thermal properties by in-situ-measuring and modeling is also further developed in Lund.
- Not yet successful is a project to use open boreholes sealed with rubber hose liners against the rock. 60-70 out of 96 boreholes in this installation in Stocksandstorp leaked; temperatures were up to 70 °C. For 100 houses in the city of Anneberg a borehole store is planned, having 99 borehole heat exchangers each 100 m deep. 1100 MWh will be required, 700 MWh of this shall be from solar thermal energy.
- At the Swedish Geotechnical Institute in Linköping, tests with storage in vertical pipes in clay have been made at temperatures up to 70 °C over 3 years. They have shown, that heat storage in clay is feasible, if the surface of the store is not used for buildings and if other precautions are taken.

- As to cavern stores, three have been built in Avesta (short term storage in a district heating system), Lyckebo (solar heat) and Oxelösund, the latter was closed in 1995. A feasibility study recently was done for conversion of an old rock cavern (oil storage) with 180.000 m^3, to store 12 GWh of heat at 115 °C from a paper mill in Karlshamn.

O. Andersson added information on high temperature tests in the Lomma ATES:

- Within Annex 6 tests were carried out in 1988-89 with water from the Lomma-aquifer. In 5 cycles of 14 days each the temperature was increased, Scaling was monitored on a special tube and also observed in the wells tubing. Corrosion, bacterial growth and geochemical reactions were investigated. The main results are: No scaling was found in the heat exchanger and the scaling measuring unit. Scaling was yet possible, but not likely in the wells. The corrosion potential was 10 times lower than critical, stainless steel was not affected, carbon steel and copper was initially corroded but then formed a protective coat. No chemical clogging was observed, clogging by fine materials (clay) likely. More information in a paper by Anders Banck.
- No ATES with high temperatures exist in Sweden, but several studies. 1991 feasibility study in Ängelholm, co-generation; 1994 feasibility study in Lund, co-generation; 1998 discussion on using deep aquifers for heat storage in Malmö within the community energy planning.

Status of organization and work in participating countries

- Germany started work in January 1998, national workgroup exists, participation confirmed for phase 1.
- Netherlands will start work in August 1998, participation very likely.
- Sweden still has no clear situation due to the re-structuring of the energy R&D landscape, but the prospects improve; national group exists de facto, participation likely.
- Belgium has some activities started, but no decision yet on formal participation.
- Canada has money for 1998 and thus participation confirmed for phase 1.

Presentation and discussion of Environmental and Water Treatment draft

M. Adinolfi summarized the Annex 6 results, as should be included in the relevant chapter of the report:

1. Overview on the activities of Annex 6, main results of the subtasks, water treatment methods.
2. Collection and information about chemical and environmental aspects and water treatment methods at actual HT-UTES sites.

Subtask A: A one-dimensional coupled geochemical model and the two-dimensional model PHREEQM-2 were verified on analytical solutions and validated with experiment. M. Adinolfi asked, if there is any information if these programmes have yet been used at actual UTES-sites.

Subtask B: Geochemical processes were studied in laboratory experiments in Amsterdam, Lund, Stuttgart and Richland, up to temperatures of 100 °C. The results can be summarized:

Problems are mostly caused by precipitation of carbonates or iron/manganese hydroxide. Precipitation of carbonates sometimes is inhibited by polyorganic substances. Problems with silica have not been observed and are not expected under 100 °C.

In several cases cation exchange processes play a major role when the water composition changes, and changes in water composition, not in temperature cause iron and manganese precipitation.

Subtask D: Significant biofouling was not observed, the limiting factor is availability of nutrient carbon. Temperature changes cause a change in bacterial flora, but adverse environmental effects or pathogenic bacteria were not observed. Nevertheless, sampling facilities should be provided in ATES projects for control.

Subtask E: Clogging occurs in injection wells when oxygen enters the system and iron/manganese precipitates, and in production wells, if water with high redox potential is extracted. Clogging also may be caused by fine materials (clay) or by gas bubbles. By temperature rise or escape of CO_2 scaling will occur (see Subtasks B, C and F). Corrosion may be caused chemically by CO_2, O_2, H_2S, sulfide and sulfate, or electrochemically when joining metals with different potentials.

Subtask C and F: Water treatment methods were selected and tested for the main problems: Carbonate precipitation, iron/manganese precipitation and gas bubble clogging.

To solve the carbonate problem, decarbonisation can be done by adding alkaline solutions or acids, by ion exchange (Ca/Na), or by CO_2 treatment. CO2-treatment was tested at SPEOS (Switzerland) and in Canada. Waters with high carbonate contend should be avoided when planning ATES.

Iron/manganese precipitation can only be avoided by preventing mixing of reduced groundwater with air or with water with a higher redox potential. Treatment may be in-situ-oxidation or bioreactors, but this waters are in general not very suitable for HT-UTES.

Geothermal experience is considered, but is not exactly matching, because geothermal plants only cool water from high temperature down (no heating of the water). Problems with biofouling occurred in a deep well in Prenzlau, Germany, where drilling additives containing carbon have been used during maintenance work. The well concerned today is converted into a deep borehole heat exchanger.

For the parliament ATES in Berlin, no water treatment is planned at the moment. The plans to convert a geothermal doublet in Neubrandenburg comprise water treatment with CO_2.

F. Cruickshanks added, that ATES water treatment is tested in Truro, Canada, and that J. Adsett started further work which will be available to the annex.

Presentation and discussion of general layout of report

The general layout was presented and amended with some further items; the new version see attachment B.
Some projects not well covered or only obscurely known should be investigated further, as the Vancouver ATES mentioned by Diana Allen. UTES in France will hopefully be covered by a French partner, otherwise B. Sanner will check. M. Koch / M. Adinolfi will contact L. Mazzarella concerning Italian experience.

Next working steps, "homework", preparation of workshop, next meeting date and place

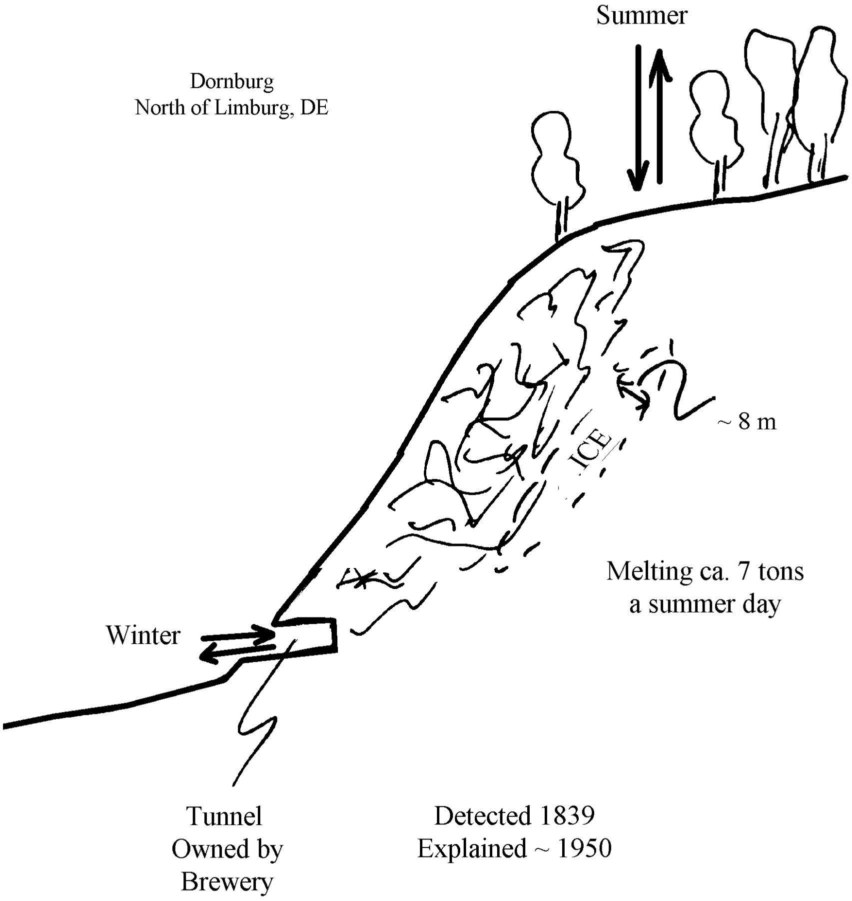
The 2nd expert´s meeting will be at Lund university, Sweden, on 14.-16.10.98, allowing for 1½ days workshop and 1 day expert´s meeting. Local organizers are G. Hellström and O. Andersson. A preliminary workshop invitation shall be made in July, the final invitation end of August.
Deadline for contributions to the draft report (Sweden, Netherlands, Canada) is end of August.
The meeting was closed on 17.6.98 ca. 17.00.

Other activities

Public lecture
Prior to the meeting, a public lecture was held on 16.6.98 at 19.00 in the lecture room of the Institute of Applied Geosciences, Giessen. O. Andersson gave a lecture titled "Seasonal Cold Storage in Aquifers in Southern Sweden, an Energy-Saving Technology for Individual Buildings and District Cooling". The goal was to inform some invited engineers from the area, students and the interested public. A lively discussion was followed by a buffet dinner. The lecture and dinner was attended by Annex 12 and 13 expert´s and was meant to link both events.

Excursion
On 18.6.98, a technical tour was offered to participants of Annex 12 and 13 expert´s meetings. Alas, most of the experts had to leave earlier.

- The first stop concerned cold storage. At the Dornburg hill north of Limburg, Hessen, a unique natural phenomenon can be observed in form of a natural ice storage (s. sketch). The very cold air flowing out of the access tunnel at the base of the slope was sensible even with the poor weather on that day. The main condition for forming of the store is the highly permeable, fractured basaltic rock, covered by an insulation layer of rock debris, and the open areas for air infiltration at the base and the top of the slope. Similar phenomena can be found in carstic limestone environment e.g. in the Salzburg Alps, Austria.



- The second stop was at UEG, Wetzlar. The building, a chemical laboratory with GSHP and direct cooling, was presented in detail in the course of Annex 8 meetings, and now the hardware of the plant could be shown.
- The final visit of the day was to an abandoned iron ore mine now operated as a museum. The hematitic ore in the mine "Fortuna" near Wetzlar was excavated until 1983. The visit included ride in the shaft (elevator) and a mine railway, and demonstration of underground drilling equipment. The Fortuna mine was site for tests with non-conventional drilling techniques in the early 80´s, funded by the Federal Ministry of Research and Technology (then BMFT). Interesting for UTES, the temperature in the mine at ca. 130 m depth is 15 °C (59 °F) year round, which could be observed on a thermometer.

Attachment A

High Temperature Underground Thermal Energy Storage
ECES Annex 12

17.6.1998, Giessen

Proposed Agenda

1. Welcome and Opening of the Meeting
2. Adoption of Agenda
3. Introduction of Participants
4. New developments in individual countries
   (Informal round table information)
5. Status of organization and work in participating countries
6. Presentation and discussion of Environmental and Water Treatment draft
7. Presentation and discussion of general layout of report and of projects to be
   covered more closely
8. Next working steps, "homework", preparation of workshop?
9. Next meeting date and place
10. Any other business

Attachment B

State-of-the-art-review
ECES Annex 12

Contents:

I Introduction
- 1 Historical background
- 2 Overview of storage types
- 3 Early potential studies
- 4 Theoretical considerations

II Experimental plants
- 1 Description of plants
- 2 Lessons learned

III Demonstration plants
- 1 Description of plants
- 2 Problems and experiences made
- 3 Optimization and plants still in operation

IV New plants after 1995

V Economical aspects

VI Thermal and energetic aspects

VII Chemical and environmental aspects
- 1 Results of IEA ECES Annex 6
  - 1.1. Subtask A: Geochemical Transport Modeling
  - 1.2. Subtask B: Geochemical Processes
  - 1.3. Subtask D: Biological Processes
  - 1.4. Subtask E: Precipitation, Scaling and Corrosion
  - 1.5. Subtask C + F: Water Treatment Methods and test of Water Treatment Methods
  - 1.6. Subtask G: General Procedures
- 2 Investigations and results after the end of Annex 6

VIII Other Phenomena
- 1 Thermal parameter changes with temperature
- 2 Effects due to viscosity changes with temperature
- 3 ...

IX Conclusions and recommendations

X Literature

Appendix: Data Summary