IEA ENERGY STORAGE PROGRAMME - ANNEX VI: "ENVIRONMENTAL AND CHEMICAL ASPECTS OF ATES AND RESEARCH AND DEVELOPMENT OF WATER TREATMENT METHODS

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ABSTRACT

In the period 1982 - 1987, experience with completed aquifer heat storage projects clearly showed that precipitation of chemical substances is the principal technical problem. The reliability of the water treatment methods applied was also questionable because of the lack of information on slow underground chemical reactions. The environmental impact of water treatment could present a serious obstruction to the implementation of larger scale underground thermal energy storage projects.

As the storage of thermal energy in aquifers is both technically and economically feasible, high priority is attached to improving the reliability of the storage system.
Therefore, in 1987, eight IEA countries started a new R&D Task. The objectives of this Task are:
* a systematic analysis of the chemical, microbiological and environmental aspects of ATES, and subsequently;
* to develop reliable, environmentally sound water treatment methods.
The preliminary results from this R&D Task are presented in this paper.

1 INTRODUCTION

In the early eighties, several projects concerning high temperature heat storage in an aquifer were implemented. Most of these projects started as a pilot project with the aim of gaining experience with this new technology, to be able to integrate the aquifer storage in an energy system later on. Examples are the SPEOS project in Lausanne, Switzerland (Saugy et al, 1988), the Hørsholm project in Denmark (Qvale et al, 1988) and the St. Paul Field Test Facility in USA (Hoyer et al, 1985).

From experience with these high temperature aquifer thermal energy storage (ATES) projects, the following is known:
- heating groundwater often results in precipitation of dissolved minerals. This precipitation mainly consists of carbonates and occurs inside and after the heat exchanger.

- precipitation of iron and manganese hydroxide can be avoided by preventing oxygen from entering into the system. However, iron and manganese hydroxide may precipitate when different water types are withdrawn from the same well.
- the application of a precipitator for calcite prevents well clogging, but does not solve the clogging problem in the heat exchanger.
- current water treatment methods, like addition of hydrochloric acid or ion exchange, are effective against calcification. However, the reliability of these methods over a longer period may be questioned because there is insufficient information on the interaction between the treated water and the aquifer material.
- the addition of chemicals to groundwater may deteriorate the groundwater quality, and render the water unsuitable for other purposes. This applies particularly when heat is stored in an aquifer which is used also for the production of drinking water.
- the addition of hydrochloric acid as a water treatment method has resulted in system operation failures due to corrosion.
- well clogging due to biomass, as encountered for instance at infiltration of surface water into aquifers, has not occurred at high temperature ATES projects so far.
- there is lack of knowledge on the effect of heat storage on the development of (pathogeneous) micro-organisms.

Figure 1 shows the relationship and interaction between the processes which occur during heat storage. In the aquifer, there is an equilibrium between the chemical species in the solid phase and the solution. Heating the water disturbs this equilibrium. Moreover, there is a balance between the micro-organisms in the aquifer and the available nutrients. This balance is also disturbed by changes in temperature and groundwater flow.

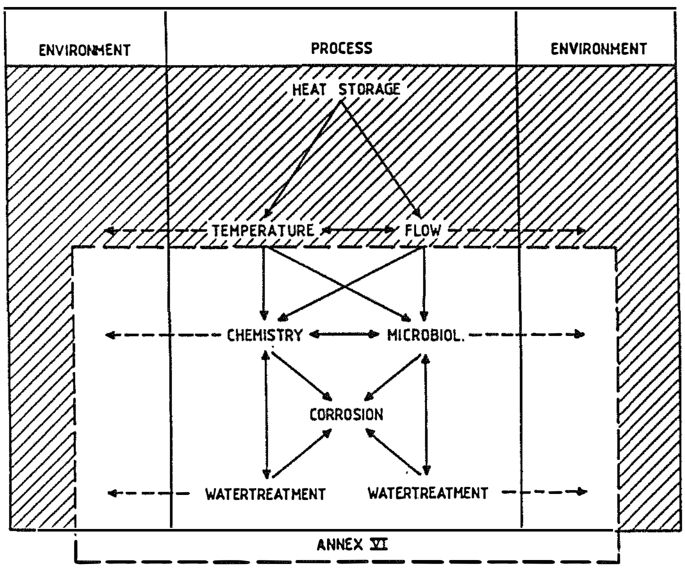

Figure 1: Relationship and interaction between the processes during aquifer heat storage.

2 IEA RESEARCH

In 1987, as a result of the experience with the pilot aquifer heat storage projects, eight IEA countries decided to start a systematic investigation into the chemical, microbiological and environmental impacts of ATES and to subsequently develop reliable, environmentally sound, water treatment methods. This research is being conducted in the framework of the IEA "Implementing Agreement for a Programme of Research and Development on Energy Conservation through Energy Storage". The countries participating in what is called "Annex VI" (the sixth R&D Task under the Energy Storage Agreement) are Canada, Denmark, Finland, Germany, The Netherlands, Sweden, Switzerland and the United States of America.

The objectives of the first phase of Annex VI are:
* to analyse (both by modelling and experiments) the chemical, microbiological and environmental aspects of ATES;
* to evaluate of different water treatment methods for heat storage, including both existing techniques and new concepts.

The second phase the following objectives:
* to test, both in the laboratory and in the field, the most promising water treatment techniques selected during phase I;
* to develop two generically applicable procedures, one to select the best water treatment method for a given new ATES site, and the other to assess the environmental impacts of a new ATES project.

The transport of groundwater and heat in the soil is no part of the research within the framework of Annex VI (see also figure 1) because there is sufficient information available from other sources.

Phase I started in 1987 and most of the work has been completed now. Chapter 3 gives the preliminary conclusions of this phase. The evaluation and reporting of the experimental data is still under way. The second phase started at the end of 1990 and will take about two years.

3 ACTIVITIES AND PRELIMINARY CONCLUSIONS PHASE 1

3.1 Development coupled model

The two-dimensional coupled model that has been developed, describes the transport of heat, groundwater and solutes. Solute concentrations may change due to mineral equilibrium dissolution and precipitation processes and cation exchange. For this coupling, the HST2D code (Hagoort, 1989) was used to describe the transport processes, and the PHREEQUE code (Parkhurst et al, 1980) to simulate the geochemical reactions.

The above-mentioned transport code is able to describe the transport of groundwater and heat in the aquifer and the confining layers, including the buoyancy flow. To provide a correct description of the processes during heat storage, the geochemical part of the coupled model had to be expanded. A geochemical database which describes temperature dependency is required, because of the temperature fluctuations of the groundwater during the heat storage and production cycle. This temperature dependency not only applies to equilibrium constants, but also to cation exchange capacities. With the coupled model the equilibrium dissolution and precipitation for up to 20 minerals simultaneously can be calculated as well as the kinetic dissolution and precipitation for one mineral. Extension of the model with respect to kinetics is foreseen, because it is important to know when and where precipitation will occur in order to predict clogging.

The coupled geochemical-transport model was used during the IEA Annex VI research to simulate and extrapolate the results of the geochemical experiments and to predict the effectiveness and environmental impact of several water treatment methods over a longer period of time.

3.2 Geochemical research

Field and laboratory experiments have been performed in the geochemical research. For the laboratory experiments, flow columns were constructed and used to study the geochemical interactions between water and sediment at flow velocities relevant to ATES and temperatures up to 100°C. The column experiments were carried out for geochemically different combinations of sediment and groundwater, as can be found in aquifers suitable for ATES.

Some conclusions from the geochemical research are:

- Precipitation of iron and manganese hydroxide can be almost completely ascribed to the entrance of air into the installation or to the withdrawal of different, chemically-incompatible water types from the same well. In the latter case, water treatment seems the only solution to avoid clogging due to iron and manganese.
- The precipitation of carbonates sometimes appears to be dominated by the formation of (Fe, Ca, Mg) solid solutions. The prediction of the equilibrium composition of the solid solutions is still not a completely resolved problem.
- Carbonate precipitation is inhibited in groundwater containing organic matter or phosphates. A saturation index for calcite up to one is found without precipitation of carbonates occurring.
- Depending on the sediment, cation exchange may become an important process when the water composition is changing, for instance due to water treatment.
- At high temperatures dissolution of silicates takes place. Problems due to silicate precipitation at decreasing temperatures have not been encountered.

3.3 Water treatment

The research on water treatment methods has started with an evaluation of conventional water treatment methods applied until now in ATES systems. This evaluation addresses the efficiency, the cost and the environmental impacts of these treatment methods. Furthermore, the applicability of several other water treatment methods, whether commercially available or not, to ATES was studied. This study implied some laboratory-scale tests also.

The efficiency and the environmental effects of conventional treatment methods may differ significantly, not only as compared to each other, but also as a result of local factors, like the chemical composition of sediment and groundwater, and the natural groundwater flow velocity (Willemsen, 1990). For instance, an increase in the chloride concentration due to water treatment may render fresh water unsuitable for human consumption, but might be considered an acceptable environmental consequence when an aquifer contains brackish or saline groundwater.

Under circumstances when it is impossible to avoid iron and/or manganese oxidation, both in situ oxidation and iron/manganese removal by a bioreactor seem to be environmentally sound techniques for water treatment.
To avoid precipitation of carbonates, some water treatment methods with minor environmental effects have also been selected, mainly because chemicals are not added to the groundwater permanently; for example: periodical and automatic cleaning of the heat exchanger in situations where only little precipitation is envisaged; temperature-dependent addition and removal of CO_2 to and from the groundwater; controlled carbonate precipitation using an integrated fluidized bed water treatment/heat exchanger.

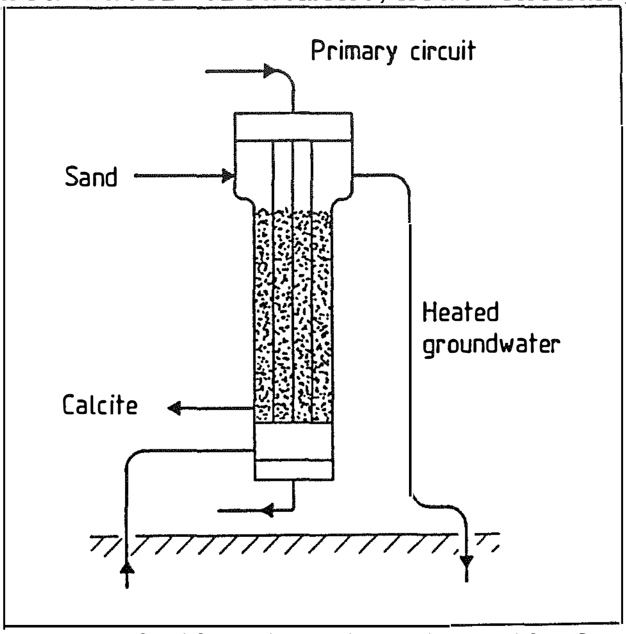

Figure 2.
Fluidized bed water treatment/heat exchanger for precipitation of scale on pellets.

Some of the treatment methods selected during phase I, are based on new concepts and require further development in the laboratory. Pilot installations will be designed for the most promising techniques,constructed and tested in the field. Existing field test facilities will be used. These activities, starting with the laboratory development up to the evaluation of the results of the field tests, are covered by phase II.

3.4 Microbiological research

For the microbiological research too, both laboratory and field experiments were carried out. The main objective of the laboratory research was to quantify the influence of temperature and groundwater flow on the development and change of bacteria populations. The field research focused on the presence and development of pathogenic micro-organisms at existing ATES projects.

Although the final results of the microbial research are not yet available, some preliminary conclusions may be drawn:
- Normally, the availability of nutrients (assimilable organic carbon) is the parameter restricting the development of micro-organisms in aquifers. Organic carbon is often mobilised at higher temperatures, so an increase in the number of micro-organisms may be expected. However, the fluctuating groundwater temperature on the other hand seems to suppress bacterial growth.
- Excessive biomass growth (resulting e.g. in biomass clogging) was not observed during the experiments, not even when assimilable organic carbons were added to the groundwater.
- Until now, the development of pathogens has not been observed. Additional laboratory experiments are scheduled with groundwater that is artificially contaminated with pathogenic micro-organisms.

3.5 Scaling and corrosion

The scaling and corrosion part of the Annex VI research has started with the assessment of the experience in related branches of industry, such as the oil industry, geothermal industry, and district heating. Furthermore, laboratory and field tests were carried out to determine corrosion and scaling rates under different circumstances relevant to ATES operation.

The inhibition phenomenon, mentioned already in paragraph 3.2, was confirmed by the fact that at some experiments no scaling was found, although it was expected.

Anaerobic conditions, as often found in groundwater, are favourable with respect to corrosion: corrosion rates are much lower than in oxygen-containing water. However, although corrosion may be acceptable from the system lifetime point of view, it may not be acceptable for system operation: corrosion products easily clog infiltration wells (Fouillac et al, 1988).

4 PROSPECTIVE

One of the main obstructions to the large-scale implementation of this technology was formed by the adverse environmental effects of conventional water treatment methods. The inhibition of carbonate precipitation, that is found in many natural groundwaters, will reduce the necessity for treatment and thus the adverse environmental impacts of treatment. It is expected that in the presence of inhibitors, a reduced treatment will be required for heat storage at higher temperatures (above 40°C) and no treatment at all at low temperatures (below 40°C). Furthermore, several promising water treatment methods to prevent problems due to precipitation of carbonates, iron and manganese, without the addition of undesirable chemicals to the groundwater, will be tested in the near future.

No operational nor environmental problems due to micro-organisms were found until now. Further research will be conducted on the survival of pathogens in a contaminated aquifer, because such an aquifer might be used for ATES in future. Well clogging due to biomass is not anticipated at higher temperatures (injection temperature over 50°C). At lower temperatures, the conditions for biomass development are more favourable (less change in temperature over the storage cycle), although excessive biomass growth has not been observed so far.

The final reports from the IEA Annex VI research will be available for the participating countries after clearance by the IEA. It is envisaged that the results presented in these reports, will be applied to other fields of science and technology.

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