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STES NEWSLETTER

A Quarterly Review of Seasonal Thermal Energy Storage

Sponsored by the Pacific Northwest Laboratory
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EARTH SCIENCES DIVISION/LAWRENCE BERKELEY LABORATORY/UNIVERSITY OF CALIFORNIA

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A NOTE FROM THE EDITOR

Though the efforts in aquifer energy storage in the United States are somewhat reduced because of budgetary constraints, other countries are increasingly committed to its implementation. We learned recently of new projects started in The Netherlands, the United Kingdom, Poland, and Canada. Of particular note in this issue is the article on the Danish demonstration project whose results should be most interesting to all STES researchers.

This issue of the Newsletter is special in that we have included abstracts on STES from the recent International Energy Agency Conference held in Berlin, April 6-10, 1981. The idea of including these abstracts was discussed internally and with Reinhard Jank who was the Chairman of the Energy Storage Session of that conference. With the kind permission of Bernd Kramer of the International Energy Agency, we have included these abstracts in this issue of the Newsletter. I am sure that they will help to inform the readers of recent international development of the STES projects. Details of these papers will be published and available from the International Energy Agency in August.

Again, we would like to call the readers' attention to the October Seattle Conference (see the article by Minor and Raymond), which should be a good forum for us to discuss all problems related to the STES concept and its implementation.

The STES Newsletter is a compilation of written contributions from researchers working in the field of seasonal thermal energy storage. Articles and reviews of current events, and new developments in this field are welcome.

Contributions and suggestions for the next issue and changes of address should reach us by September 4, 1981. Send to:

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SEASONAL HEAT STORAGE EFFICIENCY IN WATER-SATURATED SOILS

Contact: G. A. M. van Meurs and C. J. Hoogendoorn, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands

A seasonal heat storage project providing heat from solar energy to one hundred houses is being designed in The Netherlands. Heat collected during the summer by a solar collecting system will be used to heat up a cylindrical layer of soil 36 m in diameter and 20 m thick. The heat will be transferred to the ground by vertical tubes (total length 30 km), which will be installed by an in situ method. The heated region will not be bounded by walls.

In general, heat losses by conduction through the soil surrounding a heated region have been well studied. However, in The Netherlands, where the groundwater level is high, convective losses due to density difference of water at different temperatures are also important. In the present study, the combined effects of conductive and convective losses on storage efficiency have been calculated with a numerical model. Using Darcy's law in the flow equations for groundwater and coupling them to the transient thermal energy equation, a set of partial differential equations is obtained. Together with the initial and boundary conditions, these equations are solved by a fully implicit finite-difference method. Some results of the calculations are presented below.

The importance of convection losses is mainly dependent on the permeability of the soil. At lower permeabilities ($< 10^{-12}$ m^2) typical of clays, the effect is small and the heat losses of the reservoir are well predicted by conductive losses. For higher permeabilities typical of sand, the convective losses will considerably reduce the storage efficiency. The introduction of one or two water-impermeable layers around the reservoir reduces convective losses. These layers can easily be introduced by a simple technique. Furthermore, the ground in Holland typically consists of layers of different types of soils. A few horizontal clay layers just below the surface and one just below the reservoir give further protection against thermal losses. Increasing the storage size reduces the relative conductive losses; however, the relative convective losses are little influenced by the storage size. On the other hand, convective phenomena

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will have a favorable effect in spreading out the heat from the heat exchanger in the reservoir.

We have concluded that for water-saturated soils, the convective losses will be important if permeable layers are present. For permeabilities of 10^{-11} m^2 (sand) and lower, the heat recovery efficiencies are about 75%. For higher permeabilities this may drop to 50% or lower.

NUMERICAL SIMULATION OF AQUIFER THERMAL ENERGY STORAGE

Contact: Charles T. Kincaid, Pacific Northwest Laboratory, P. O. Box 999, Richland, Washington 99352, U.S.A.

The Seasonal Thermal Energy Storage (STES) Program has an active research program in the area of numerical simulation of the aquifer environment. In addition to the development of an in-house computation capability, this program is currently coordinating research efforts at both Lawrence Berkeley Laboratory (LBL) and Oregon State University (OSU). Studies at LBL include parametric analyses of confined aquifers for ATES, the development of non-isothermal numerical techniques for partially saturated media overlying an unconfined aquifer, and site-specific analyses of the Alabama field test facility. A preliminary evaluation of mass and energy transport mechanisms in partially saturated media is being conducted at OSU.

A recently completed study conducted by GeoTrans, Inc., of Reston, Virginia, has produced an excellent document dealing with the numerical simulation of the aquifer environment. It is entitled "Review of Simulation Techniques for Aquifer Thermal Energy Storage (ATES)" and is authored by J. W. Mercer, C. R. Faust, W. J. Miller, and F. J. Pearson, Jr. This document reviews the state of the art of simulation techniques relevant to ATES. Included in the document are sections dealing with processes active within the aquifer (physical, chemical, biological), their mathematical description, analytical and numerical solutions of fluid and energy transport, geochemical models, review of field applications, site-specific considerations, and uses and limitations of transport models. This publication will be available through the National Technical Information Service (NTIS). Availability of this document will be announced in a future STES Newsletter.

DESIGN OF THE DANISH ATES DEMONSTRATION PLANT

Contact: J. A. Leth or J. Hagelskjaer, Risø National Laboratory, 4000 Roskilde, Denmark

A Danish ATES demonstration plant is planned to be established during the summer 1981. The storage facility will be located at a site about 30 km north of Copenhagen. It will be connected to a garbage incinerator plant capable of charging the storage aquifer with surplus heat in summer. The stored heat will then be delivered to a district heating network in the neighborhood during autumn.

The 15-m-thick storage aquifer which is located at a depth of approximately 10 m, is confined by layers of clay. A single, five-spot pattern of wells will be used with one central well surrounded by four wells placed in a 40-m-radius circle. During heat injection, cold groundwater will be pumped from the four peripheral wells to heat exchangers and the heated water will be injected into the aquifer through the central well. During the delivery phase, the flow will be reversed and the cooled water reinjected through the peripheral walls.

The plant design requires a storage reservoir volume of 75000 m^3. The injection temperature, which is dependent on the temperature of the heat source, will be about 100°C. There will be a cooling of the storage water during discharge of about 35°C, which is determined by the return temperature of the district heating system. The storage capacity is approximately 2000 Gcal, and the heat flow rate during injection and delivery is about 2 Gcal/h.

The wells are screened with stainless steel to facilitate removal of depositions by chemical treatment. To optimize the temperature field in the aquifer, a mathematical model prescribes flow conditions that put certain requirements on the well screen locations. The peripheral wells must be screened for only the lower third of the aquifer thickness. The central well must be screened differently during the injection and delivery phases. During injection, the well must be screened for the entire aquifer thickness. During delivery, it must be screened for only the upper half of the aquifer thickness. This is achieved by means of a hydraulic valve that closes the lower part of the well for the delivery phase. The flow from each well will be independently controlled.

Because we have to work with a relatively small temperature difference, it is necessary to use high-efficiency heat exchangers. Plate-type exchangers meet this demand because of their large heat-transfer area. The high calcium hardness of the groundwater at the site (16 dH°) could cause problems with scaling on the heat exchangers and clogging of the wells. These problems will probably not be solved until data from the first injection tests have been analyzed and the extent of the problems is known. However, precautions will be taken: the heat exchangers will be cleaned by chemical treatment, and a filtration unit will be used to remove flocculated particles from the water before injection.

There will be continuous measurement of temperature and water level at various points in the aquifer during the injection and delivery phases. For the measurements, sensors will be placed in a number of instrumentation wells distributed over the area. The data will be recorded by a local minicomputer and transferred to a remote computer for further processing. Based on these data, the plant will be automatically controlled so that the hot volume will have an optimum geometry and the heat flow rate will adjust to the demand.

The plant will be operated according to a five-day injection/two-day delivery schedule during the summer. The incinerator plant does not operate on the weekends, and so heat will be produced from the storage facility during the two weekend days to supply the district heating system.

The plant is expected to be ready for preliminary tests by autumn 1981 and the first cycle of operation is due to begin in summer 1982.

THE INTERNATIONAL CONFERENCE ON SEASONAL THERMAL ENERGY STORAGE (STES) AND COMPRESSED AIR ENERGY STORAGE (CAES)

Contact: J. R. Raymond or J. E. Minor, STES Program Office, Battelle-Northwest, P. O. Box 999, Richland, Washington 99352, U.S.A.

The International Conference on Seasonal Thermal Energy Storage (STES) and Compressed Air Energy Storage (CAES) will be held October 19-21, 1981 at the Seattle Marriott Hotel, Seattle, Washington, U.S.A.

Response to the request for abstracts of papers for presentation at the conference has been excellent. Forty-three papers have been accepted for the STES sessions, representing contributions from thirteen countries. STES sessions have been organized to include overviews of seasonal thermal energy storage; Systems 1--Discussion of STES projects; Systems 2--STES Methodology, Modeling, and Economics. In addition, a poster session will be held and will include discussions of solar, rock bed, soil and aquifer STES.

Attendance at the conference will be limited to approximately 300 participants on a "first come-first served" basis. Therefore, if you plan to attend, you should register as soon as possible with the Conference Coordinator, MCC Associates, 8534 Second Avenue, Suite 400, Silver Spring, Maryland 20910, U.S.A. (Phone: (301) 589-8130). Registration fee for the conference is $135 which includes continental breakfast for the three conference days, a luncheon and banquet, and the conference proceedings.

The remaining articles of this issue are abstracts of papers relevant to STES, which were accepted for the International Energy Agency Conference on "New Conservation Technologies and their Commercialization," held in Berlin, West Germany, in April 1981. The proceedings of this conference will be published in August under the auspices of the International Energy Agency. These abstracts are reproduced here with the kind permission of Bernd Kramer, IEA, and Reinhard Jank, Chairman of the Session on Energy Storage.

DESIGN OF THE LONG-TIME STORE IN WOLFSBURG

Contact: Werner Breuer, Rudolf Redecke, and Johannes Strickrodt, c/o Forschungsgesellschaft Wolfsburg mbH, Postfach 100954, 3180 Wolfsburg, West Germany

The Forschungsgesellschaft Wolfsburg mbH has been commissioned by the Federal Minister of Research and Technology to develop a long-time store.

Two terrestrial storages with a volume of 10,000 m^3 each and a maximum storage water temperature of 95°C will be planned. In the planning, it is taken into consideration that the obtained results should be transferable to large-scale storages with a volume of several million cubic meters.

Large-scale stores are only economical when they are built with the condition of equalization of earth quantities, i.e., the excavated earth is used to build a dam around the basin. For reasons of safety the Wolfsburg stores are placed below the upper edge of the surface. Both basins are constructed differently in order to test several materials and operating methods: Basin I gets a thermal insulation on all sides, a sealing of foils, and a floating cover; Basin II gets a thermal insulation only at the surface, a sealing of asphalt-concrete, a reinforced concrete cover, and a test dam. Moreover, both the basins have different charge and discharge systems.

As thermal insulation, only foam glass is suitable. The calculations showed that the insulation layers for the covering, the slope, and the bottom are more or less in the ratio of 3 to 2 to 1. The materials for sealing are a special asphalt concrete with a high softening temperature and different rubber foils. The floating cover consists of rust-resisting steel containers. On them are thermal insulation, the sealing foil, and aluminum profile plates as reinforcement which can be walked upon. The reinforced concrete cover allows a secondary use of the storage area, e.g., as a sport field or parking lot. For charging and discharging, two different systems have been developed: (a) double tubes, the interior of which is provided with holes and the exterior with slits; and (b) baffle plates.

The stored energy shall be used to supply the nearby residential area with low-temperature district heating.

TECHNOLOGICAL AVAILABILITY AND ECONOMIC VIABILITY OF AQUIFER THERMAL ENERGY STORAGE

Contact: Björn Qvale, Laboratory for Energetics, Technical University of Denmark, 2800 Lyngby, Denmark

A number of theoretical and practical questions have to be answered and difficulties overcome before the concept of aquifer storage (ATES) can be accepted as a realistic engineering alternative and available technology.

Among those that will be presented and discussed here is the need for general knowledge of basic chemical, thermodynamic, fluid dynamic, and biological phenomena occurring in aquifers. This knowledge should ideally form the base for designs and the construction of specific storage units. The need also exists for the development of effective exploration methods and techniques so that the cost of the preliminary stages are kept at a reasonable level.

Site-specific methods of analyses have to be available. A number of factors that are of decisive importance to the design of a specific store can only be determined for that given site. Concrete design alternatives have to be offered.

A combination of theoretical models and experimental techniques have to be available in order to monitor and operate the store effectively and safely. Furthermore, in order to assess the economic value of a thermal energy store functioning in a given system, it is necessary that suitable mathematical models should be available.

The paper continues with the discussion of the results obtained by carrying out studies of systems wherein waste heat is being stored. Three applications have been studied: (1) the storage of excess heat from a garbage incineration plant; (2) the storage of low-temperature waste heat from industrial processes; (3) the storage of warm water from geothermal sources. In all cases the application of heat pumps has been considered.

BIG HOT-WATER RESERVOIRS IN DISTRICT HEATING SYSTEMS

Contact: F. Scholz, Kernforschungsanlage Jülich GmbH, Institut für Reaktorbauelemente, D-517 Jülich, Postfach 1913, West Germany

The challenge of saving fossil fuel (liquid or gaseous) can only be met by really important extension of district heating technology, based on cogeneration of heat and power (CHP), the use of waste heat from other processes (e.g., chemical) and eventually, on collected solar energy.

The extension of the well-known and urgently desired CHP technology is hindered by the fact that very often the periods of available heat from the CHP plant do not coincide with the peak demands of the connected district heating system and of the electrical network.

Big hot-water reservoirs can effect a decoupling of the availability and demand of heat or electricity, at least to some extent, and thus the former drawbacks of CHP can be converted into advantages. For example, in periods of peak electrical power demand the bleeding of steam from the turbine for heating purposes can be cut rapidly and the turbine can generate additional electric power. Meanwhile, heat for the district is supplied by the loaded reservoir. When the peak electrical demand is over, heat can again be delivered from the turbine. During the lowest electrical (and/or heating) demand periods, the reservoir is reloaded to the requirements of the heat net. In this way thermal storage can help save primary energy (especially liquid and gaseous) indirectly, since it can stimulate the spread of CHP technology and the use of waste heat.

Because water is normally used as the transport medium in modern district heating systems it can be used as a storage medium too. Big water reservoirs (up to volumes of 10^5 m^3) can be constructed with well-established technology at reasonable cost. It has been demonstrated that it is much cheaper to store heat (hot water up to approximately 95°C) in "pressureless" steel tanks (as used in the oil industry) than in the formerly-used pressure vessels, even though the temperature spread (and thus the specific storage capacity) is much lower. Economic advantages can be gained only in the case of short-term storage (many cycles a year, daily or weekly use) as the high capital investment for the storage system does not permit only a single use in one year. For very big storage volumes and longer storage periods, a multiple-storage container system (with the capability of loading and unloading these containers in parallel or in series) increases the flexibility and availability of the system.

PRINCIPAL POSSIBILITIES OF LARGE-SCALE THERMAL ENERGY STORAGE AND THE PRESENT STATUS OF THE TECHNOLOGIES

Contact: Peter Margen, Studsvik Energiteknik AB, 611 82 Nyköping, Sweden

The Swedish energy R&D programs include work on several thermal storage concepts promising sufficiently low costs to justify seasonal storage of heat in favorable circumstances. Several demonstration projects are initiated, including:

1. Insulated earth pit hot water store
   (640 m^3 unit operated for 2 years)
2. Rock cavern hot water store
   (15,000 m^3 unit under construction)
3. Deep ground perforated by vertical channels,
   (a) rock
   (10,000 m^3 unit being heated)
   (b) clay
   (85,000 m^3 unit, construction complete)
4. Natural aquifer
   (Small-scale tests made)
5. Natural lake
   (15-m-deep model in sea, test in progress).

The paper reviews the concepts, technical problems, and the status reached in demonstration and gives the author's evaluation of their economic promise. This is provided on a common basis with heat storage between 95°C and 5°C, the use of a heat pump to recover the low-temperature part of the stored heat and capitalization of the costs of heat losses and heat pump electricity.

The paper concludes that large stores of type 1, 2, 3a charged with "free" waste heat and discharging heat so that oil is replaced at world market prices are already economic over their life when constructed during the early 1980s, provided geotechnical conditions are favorable. For stores charged by solar heat, break-even comes later and for plants replacing cheaper fuel than oil, later still. Favorable geotechnical conditions and project size would generally be decisive as to which concept would be most favorable.

Aquifers and natural lakes have the potential for even lower costs but require special favorable local conditions to be reached. The extent to which such conditions are to be found requires further study.

The author concludes that the parallel continued development of all the concepts would be justified as each has an important potential market.

THERMAL STORAGE FOR HEATING OF RESIDENTIAL AND COMMERCIAL BUILDINGS

Contact: B. Weissenbach, Messerschmitt-Bölkow-Blohm GmbH, Space Division, RT32, P. O. Box 801169, 8 Munich 80, West Germany

The concept of a near-surface aquifer storage unit with processed material was developed to the state of project definition of a pilot plant. Simultaneously with technical and economical investigations, problems of chemical mass transport in typical soil materials were investigated in laboratory tests. Special attention was paid to the biological behavior of a wet gravel bed in view of the possibility of clogging by slime. Corrosion in connection with the quality of water in aquifers was considered for various materials.

Several layouts of aquifer storage units have been drafted and the cost calculated for different site conditions. Facilities larger than 10,000 m^3 (water equivalent) turned out to be cheaper than present-known storage concepts.

MODEL STUDIES OF DUCT STORAGE SYSTEMS

Contact: J. Claesson and G. Hellström, Dept. of Mathematical Physics, University of Lund, Fack S-220 07, Lund, Sweden

The numerical modeling of a ground heat storage system is discussed. The ground volume is penetrated by a network of ducts for injection and extraction of heat. A numerical model of such a system has to give a good description of both the local thermal process around each duct and the global heat flow in the storage volume and the surrounding ground. It is necessary to treat the local and the global process as two coupled problems, as the number of ducts may be quite large. How to couple these processes is the main problem.

A simple and fast model has been developed. The heat transfer properties between the ducts and the surrounding ground are characterized by a heat transfer length which originates from a particular local thermal process. The heat exchange between the soil and the ducts is represented by a heat source/sink distribution in the storage region.

The influence of different parameters of the storage is studied with this model. These are: the size and the shape of the storage volume, the distance between the heat carrier ducts, the thermal properties of the soil, the duration of the loading period, the lowest and highest accepted temperature of the heat carrier, and the thickness of thermal insulation. The ratio between injected and extracted amounts of heat is given. Comparisons between the temperatures of the injected and the extracted heat are made. The important problem of heat injection and extraction strategies with a suitable choice of temperature levels is discussed.

Finally, a few Swedish demonstration projects are discussed and some dimensioning criteria are given.

APPLICATION OF A DUCT STORAGE SYSTEM FOR A SPACE HEATING SYSTEM FOR 12 FAMILY HOUSES WITH A GAS HEAT PUMP AND SOLAR COLLECTOR

Contact: Bernard Mathey and Bernard Pillonel, CH-2205 Montezillon, Switzerland

The energy production, storage, and heat consumption system described comprises:

(a) 350 square meters of flat solar collectors;
(b) a 4000 cubic meter heat storage system, in undisturbed sandy loams (the accumulator is fed by 400 vertical coaxial tubes with a depth of 6 to 8 meters.);
(c) 2 insulated water tanks (2 · 4500 liters);
(d) a 15 kW electrical heat pump (50-55 kW th);
(e) an electric generator, gas powered, with heat recuperation, TOTEM (Total Energy Module) manufactured by FIAT;
(f) 12 family houses each with a 7 kW heating power at -10°C; and
(g) an electronic control, including microprocessor, specially designed for operating this system.

The originality of the installation, which is due to be put in service in March 1981, lies in the combination of these different elements and in the system's control process.

The main heat storage system works between 0°C and 25°C. The total system should make possible a saving of 60% of the total energy consumed by the houses for space heating and tap water.

The installation has been financed entirely by the owners of the houses, without any State subsidy.

A CONCEPT FOR STRATIFIED HEAT STORAGE IN SOIL

Contact: F. Jäger, Sebastian-Kneipp-Strasse 12-14 D-7500 Karlsruhe 1, West Germany

The storage of low-temperature heat in soil is examined theoretically. In this storage concept, heat is fed in and removed by pumping a working fluid through a series of plastic pipes on spherical and concentric shells within the soil. As the heat conductivity of soil is low and because heat can be stored and removed at different temperature levels, a stable temperature stratification is produced. This stratification, and the low cost of soil with its large heat capacity makes the storage concept especially suitable for an application in active solar space heating systems.

The paper considers the application of an active solar space heating system in a well-insulated single-family house and with heat storage in soil. In order to examine the performance of this system, a computer program for heat conduction calculations (finite difference method) was combined with a simulation model for active solar space heating systems (component-type model). Results of a large number of system simulations using hour-by-hour climate data (Hamburg, FRG) are presented. Simulating the system for several consecutive years of operation shows that the storage design without external insulation has considerable heat losses. A solar space heating system with an insulated soil heat store can supply more than 50% of the annual space heating requirements (13,430 kWh). This is slightly higher than the solar percentage that can be obtained by using the same solar space heating system but with a conventional cost-equivalent store employing water as the storage material. The use of soil in heat storage systems still has a number of problems. These are discussed in relation to the current theory and application, and suggestions are made for further improvement.

AQUIFER THERMAL ENERGY STORAGE: EXPERIMENTAL AND THEORETICAL INVESTIGATIONS

Contact: G. Rouvé and W. Pelka, Institut für Wasserbau und Wasserwirtschaft, RWTH Aachen, Mies-van-der-Rohe-Str. 1, D-5100 Aachen, West Germany

Any use of the aquifer for hot or cold water storage or exploitation of the naturally stored energy implies changes in the thermal field of the aquifer. In order to avoid or minimize negative effects on the environment and to optimize the economical benefit, it is necessary to know how a thermal anomaly will spread in the aquifer.

Heat transport in flowing groundwater takes place by conduction and convection, which can be described by a set of partial differential equations. These equations prove to be highly nonlinear, since the temperature field depends strongly on the flow field by means of the convective term, and the flow and heat transport parameters are functions of the pressure and temperature distribution, especially for saturated-unsaturated flow in shallow aquifers.

Only a few analytical solutions have been found for diffusion-convection problems. All these solutions share the problem of including many simplifications necessary to obtain a solution. The soil and fluid parameters are assumed to be homogeneous, isotropic, and constant in the area under consideration. The geometry of the area and the boundary conditions must be simple, hence analytic solutions are not suitable for most practical problems.

Numerical models are invaluable tools for the calculation of the changes of the flow and temperature field in the aquifer. They enable the designing engineer to evaluate the influence of the thermal anomaly on the environment and to optimize, for example, recharge and discharge processes.

Results from a numerical model based on the Galerkin approach in connection with discretization into finite elements were found to be in good agreement with data obtained from a physical model.

Finally the application of the numerical model is illustrated by calculating the time-dependent flow and temperature field around a two-well storage system for space heating and air-conditioning of residential and commercial buildings.

LARGE-SCALE UNDERGROUND HEAT STORAGE

Contact: B. Saugy, G. Block, J.-C. Hadorn, Ecole Polytechnique Fédérale de Lausanne, Institut d'Economie et Aménagements Energétiques, 1015 Lausanne, Switzerland

Studying the thermal behavior of groundwater has created an interest in interseasonal storage of heat at relatively low temperature.

Trials of hot-water injections carried out since 1975 both in the field and in the laboratory, have identified some properties and limits of groundwater storage. Some results are described.

In the framework of IEA storage projects, a project financed by NEFF (Nationaler Energie Forschungsfonds) is in the course of realization (project SPEOS). Work on the first phase, whose aim is to choose and explore a site, and then to analyze the technical-economical aspects of the complete production, utilization, and storage system, have been achieved. The main results of this study are presented. The pilot project permits us to address some major questions of feasibility and technical-economical constraints related to the realization of an annual sensible heat storage covering the heating needs of a 100 to 1000-person complex.

(Editor's note: A more complete discussion on Project SPEOS may be found in STES Newsletter, v. 3, no. 2.)

ACTUAL APPLICATIONS OF LOW-TEMPERATURE STORAGE SYSTEMS IN SWEDEN

Contact: Björn Svedinger, VIAK AB, Box 519, S-162 15 Vällingby, Sweden

Energy storage and alternative heat sources for heat pumps are of major interest in the Swedish national program for energy conservation. The Swedish Council for Building Research has initiated about 150 different projects up to 1980 concerning heat in soil, rock and water. Results so far indicate that there are technical and economical possibilities to use the ground as a part of heating systems for both old and new buildings. The council has recently published a state-of-the-art report, which includes different techniques and a short introduction to different problems.

The geology of Sweden is extremely variable and the techniques for heat storage are determined by local conditions which must be investigated for each case. Quite a few techniques have been developed which are suitable for various energy-and-effect demands and different geology. Two classes of techniques can be applied.

Techniques for extracting heat which is naturally stored in the ground are often called passive systems. The temperature is relatively low, which is why a heat pump is needed. Different techniques employ heat in the subsoil, groundwater, lake and sea water, solid rock, and geothermal energy.

Techniques for storage of heat in a separated volume on a certain level under the surface, are often called active systems. Storage of solar energy, waste heat water, etc., can be made at high temperatures (100°C), which can be directly connected to a distribution system. Storage can also be made at lower temperatures where extraction is done by means of a heat pump. Different techniques are developed for storage in water (pits or caves), aquifers, and solid rock, clay, or peat.

The report referred to above also includes a short introduction to environmental and juridicial aspects. These aspects are important but so far it appears that there is nothing which prevents development and introduction of heat storage in soil, rocks, and water.

UNDERGROUND ALTERNATIVES FOR THERMAL STORAGE

Contact: U. Lindblom, Chalmers University of Technology, Gothenburg, Sweden

The problem of energy storage is of central importance for an improved energy economy. The two major benefits of energy storage are (i) decreased requirements on the installed capacity of energy sources and (ii) savings of fuel in power plants and district heating systems.

A long-term heat storage requires very low construction costs in order to be economically competitive. Many underground storage alternatives can meet these requirements. On the big scale, hot-water accumulation in rock chambers is an economical solution. On the somewhat smaller scale--one or a few city blocks--inground hot water pools can be competitive where digging costs can be kept low. Direct storage of heat in soil or rock masses is another alternative. The method of heat transfer here is of critical importance.

The paper describes some available techniques for underground thermal storage. Specifically, a more detailed description is given of thermal storage systems which are being developed at the Geotechnical Division of Chalmers University of Technology.

Rock chambers may be constructed as open rooms with the rock walls reinforced by bolts. For low or intermediate temperatures, economical advantages may be gained with rock chambers where blasted rock is permitted to remain in the openings. Low-cost mining methods may then be utilized and no reinforcement is required.

The paper also discusses in some detail how seasonal thermal storage can be arranged for buildings which are founded on clay and clayey soils. Here, piling systems can be designed for the secondary use as heat exchangers to and from the surrounding soil. In cold climates, the solar heat from the summer season may in this way be stored under the building and extracted according to need during the winter season. Other similar methods for exchange of heat to the underground are discussed.

MODEL SIMULATIONS OF AQUIFER STORES AND THEIR APPLICATION TO FIELD EXPERIMENTS

Contact: C. F. Tsang, Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720, U.S.A.

The Lawrence Berkeley Laboratory (LBL) of the University of California has for the last few years engaged in systematic modeling studies of aquifers used for storage of hot or cold water. The goals are to understand the thermohydrological behavior of the system and to make predictions of energy recovery factors and recovery temperatures for given field conditions. These studies follow two main lines of approach:

(1) detailed simulations;

(2) parameter studies.

In the area of "detailed simulations," a numerical model named CCC developed at LBL has been employed. This model is able to calculate three-dimensional fluid and heat flow in a porous or simple-fracture medium taking into account gravity and temperature-dependent fluid properties as well as vertical consolidation effects. Initially, a series of generic studies were performed using this model in order to study the feasibility of the aquifer thermal energy storage concept. Recently it has been successfully applied to the detailed simulation of the Auburn University field experiments (1978-1979). Calculated results agreee well with observed values. Further calculations are currently being carried out to predict the results of Auburn's next series of experiments involving storage of 55° and 90°C water.

In the area of "parameter studies," several simplifying assumptions have been made and key lumped parameters derived. By using a fast numerical model based on these simplifying assumptions, tables and graphs of recovery factors and recovery temperatures have been produced as a function of the lumped parameters. Applications of these results to Auburn, Bonnaud, and other field experiments yield satisfactory results. It is anticipated that we will be able to make rough predictions for field design, and also to provide parameter sensitivity results for optimization and economic considerations.

Results of these two areas of study will be presented in our paper. Discussions will also be made about various key effects which influence the behavior of the system, such as thermal dispersion, thermal front tilting, long-term environmental influence, and regional flow.

** STES-RELATED CONFERENCES **

The following are upcoming conferences and meetings related to seasonal thermal energy storage that have come to our attention.

August 4-7, 1981. Solar Energy Society of Canada National Conference, Montreal, Quebec, Canada. (Benoit Jean, Institute National de la Recherche Scientifique, University of Quebec, P. O. Box 1020, Varennes, Quebec, Canada JOL 2PC)

August 9-14, 1981. Sixteenth Intersociety Energy Conversion Engineering Conference, Atlanta, Georgia. (Peter Fromme, American Society of Mechanical Engineers, 345 E. 47th Street, New York, New York 10017, U.S.A.)

August 24-26, 1981. Mechanical, Magnetic, and Underground Energy Storage 1981 Annual Contractors' Review, Washington, D. C. (MCC Associates, Inc., 8534 2nd Avenue, Silver Spring, Maryland 20910, U.S.A. Telephone: (301) 589-8130)

October 4-9, 1981. Thermal Energy Storage Session, Second World Congress of Chemical Engineering and IX Interamerican Congress of Chemical Engineering, Montreal, Canada. (Congress Secretariat, 151 Slater St., Suite 906, Ottawa, Ontario, Canada, K1P 5H3)

October 12-15, 1981. Fourth World Energy Engineering Congress, Atlanta, Georgia. (Albert Thumann, Association of Energy Engineers, 4025 Pleasantdale Road, Suite 340, Atlanta, Georgia 30340, U.S.A.)

October 19-21, 1981. International Conference on Seasonal Thermal Energy Storage/Compressed Air Energy Storage, Seattle, Washington. (James E. Minor, Battelle Pacific Northwest Laboratory, P. O. Box 999, Richland, Washington 99352, U.S.A.)

November 15-20, 1981. Heat Transfer in Porous Media, 1981 ASME Winter Annual Meeting, Sheraton Park Hotel, Washington, D. C. (Prof. Kenneth Torrance, 289 Grumman Hall, Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, New York 14853, U.S.A., Telephone (607) 256-6253)

February 15-17, 1982. 9th Annual Energy Technology Conference and Exposition, Sheraton Washington Hotel, Washington, D. C. (Martin Heavner, Government Institutes, Inc., P. O. Box 1096, Rockville, Maryland 20850, U.S.A. Telephone (301) 251-9250)

June 7-11, 1982. Thermal Storage Heat Transfer, AIAA/ASME Fluids, Plasma, Thermophysics, and Heat Transfer Conference, St. Louis, Missouri. (Charles E. Hickox, Division 5511, Sandia National Laboratories, P. O. Box 5800, Albuquerque, New Mexico 87185, U.S.A. Telephone (505) 844-0780)

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