STES NEWSLETTER
A Quarterly Review of Seasonal Thermal Energy Storage

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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 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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