Title
STES Newsletter Vol 4 No 1

Author
Lawrence Berkeley National Laboratory

Publication Date
1981-12-01

Pub-393

STES NEWSLETTER

A Quarterly Review of Seasonal Thermal Energy Storage

Sponsored by the Pacific Northwest Laboratory
Operated by Battelle Memorial Institute for the U.S. Department of Energy

EARTH SCIENCES DIVISION/LAWRENCE BERKELEY LABORATORY/UNIVERSITY OF CALIFORNIA

Vol. IV, No. 1 December 1981

Ref,

PUB 393

A NOTE FROM THE EDITOR

This issue represents the beginning of the 4th year of publication of the STES Newletter. Over the last 3 years, the Newsletter has grown into a significant quarterly publication with a circulation reaching 23 countries. Continued interest is evident from the frequent requests for the Newsletter we receive from all parts of the world.

Though the current research funding situation in the U.S. has slowed the energetic effort in long-term underground energy storage here, there is increased interest in many other countries. Indeed, active theoretical, experimental, and practical work is being done in Europe, Canada, Japan, and China. One could hope to learn much from these activities. Several significant research and development problems still remain to be solved in order to encourage large-scale implementation of the concept of seasonal underground thermal energy storage. This newletter serves as a means for the rapid exchange of technical information, plans, and results, and for encouraging possible cooperative efforts among different research groups.

In this issue, we have included a summary of the recent conference held in Seattle, Washington, on Seasonal Thermal Energy/Compressed Air Energy Storage. We welcome reviews of past and future conferences, workshops, etc., and we rely on our readers to keep our list of upcoming conferences up to date.

The STES Newsletter is a compilation of written contributions from researchers working in the field of seasonal thermal energy storage. Articles snd 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 <u>February 5, 1981</u>. Send to:

Dr. Chin Fu Tsang, Editor
STES Newsletter
Earth Sciences Division
Lawrence Berkeley Laboratory
Berkeley, California 94720 U.S.A.

Telephone: (415) 486-5782

ANALYSIS AND MODELING OF GROUND HEAT STORAGE SYSTEMS

Contact: Johan Claesson, Department of Mathematical Physics, University of Lund, Box 725, S-220 07 Lund 7, Sweden

Our current work involves the analysis and modeling of the thermal processes of interseasonal heat storage systems in the ground. The three types of storage under examination are (1) a duct system, (2) a water tank type storage system, and (3) an aquifer storage system. These systems are described briefly as follows:

(1) The duct storage system is characterized by one of three possible designs: the rock is perforated by a large number of vertical boreholes; pipes or latent heat exchanges are driven into clay; or the ground is excavated and layers of horizontal pipes are emplaced. In each case, the fluid used for injection and extraction of heat is circulated in the ducts, and pure heat conduction occurs in the ground around the ducts.

(2) There are several types of water tank storage. The warm water may be stored in a buried water tank, or a pond or pit, which is protected by a layer of thermal insulation. Another option is the use of a rock cavern, where the heat can be stored, for example, in a mixture of water and stones.

(3) In aquifer storage systems, the groundwater is used directly as the heat carrier fluid.

In these types of storages, if the temperature is high enough, the stored heat is used directly for space heating. At lower temperatures it is used together with a heat pump. The combination of heat pumps and ground heat storage systems is attracting increasing interest in Sweden. There are other systems that use only the natural temperature level of the ground or the groundwater. In these cases the natural temperature level may be restored during the summer by heat injection at low temperatures.

The thermal processes of these systems for storage and extraction of heat from the ground share many common features. A rational choice between different possibilities and the proper design of a system require a good understanding of these processes. The need for numerical simulation

CHARACTERIZATION OF HEAT STORAGE IN CONFINED AQUIFERS

Contact: Thomas A. Buscheck or Chin Fu Tsang, Earth Sciences Division, Lawrence Berkeley Laboratory, Berkeley, California, 94720 U.S.A.

Recently Lawrence Berkeley Laboratory conducted an ATES characterization study of confined aquifers. (Preliminary work was discussed in the STES Newsletter, Vol. III, No. 1.) This study included (1) the selection of key dimensionless parameter groups which characterize the hydrothermal processes that determine the energy recovery ratio; (2) the development of a general approximate graphical characterization scheme that predicts the energy recovery ratio; and (3) the validation of the uniqueness of these groups and the characterization scheme using both field data and results simulated by the model PT (formerly CCC).

PT (Pressure-Temperature), previously named CCC (Conduction-Convection-Consolidation), is an integrated finite-difference code which solves simultaneously the coupled heat and mass transport equations for slightly compressible fluid flow in a porous or fractured medium. The code CCC has been used extensively since 1975 for a multitude of aquifer thermal energy storage (ATES) and geothermal problems and has been validated against a variety of analytical solutions and several field experiments. Incorporation of improved mathematical and numerical formulations over the last few years had led to the recent name change to PT. Most of the ATES studies at LBL have been carried out using this version.

For situations where buoyancy flow within the aquifer and hydraulic leakage to the aquitards can be neglected, the governing energy equations can be nondimensionalized, yielding five dimensionless parameter groups. These groups involve only distances, storage-cycle time, and thermal parameters. In order to investigate the effects of buoyancy flow on energy recovery, calculations were made over a wide range of aquifer conditions and injection temperatures, using the model PT. In many of the cases studied, there was a tilting of the hot-cold water interface due to buoyancy flow. This thermal front tilting was shown to significantly affect the amount of energy dissipated as well as the relative magnitude of the radial and vertical heat losses. A closed-form solution of the tilt angle proposed by Hellstrom was adopted for our calculations. It was found to yield accurate predictions when compared with PT-simulated results. Over the wide range of conditions examined, the simulated results indicated the tilt angle to be relatively insensitive to radial thermal diffusion in the aquifer, vertical heat conduction and hydraulic leakage to the aquitards, hydraulic storativity, and the relative duration of the injection and storage times, as long as the total injection and storage time is held constant.

The major effect of the thermal front tilting is its influence on both the vertical and radial heat losses, since the tilting modifies the area over which heat conduction occurs vertically and radially. We introduced empirical shape factors that modify the parameter groups, obtaining Pe^*, Λ^{-1*}, and Bi^*. A wide range of cases were simulated using the model PT and different heat losses were obtained as a function of these parameter groups. These results indicated that the radial and vertical losses can be considered to be uncoupled. Hence, their effects on the total energy recovery ratio may be expressed in a product form:

$$\varepsilon = (1 - E_a)(1 - E_c),$$

where ε is the energy recovery ratio, E_c is the normalized energy lost vertically to the aquitards, and E_a is the normalized energy lost radially within the aquifer.

A consequence of this conclusion is that the energy recovery performance may be characterized by two sets of curves, one for the vertical losses and one for the radial losses. For the vertical losses, a conceptual model, involving only one-dimensional heat conduction, has been used to develop the family of curves for E_c. The radial heat loss may be estimated from a semi-empirical curve relating E_a with Pe^*.

Hence, using values of Pe^*, Λ^{-1*}, and Bi^* obtained from field data, E_c and E_a may be determined and combined to form ε. This superposition method may be carried out without the use of a computer and yields the relative magnitude of the radial and vertical losses in addition to ε. Although not mathematically rigorous, the method has been shown to yield accurate predictions for a wide range of conditions when compared with PT-simulated results.

This work is currently being written up in detail, and will be available as an LBL report.

COMPARISON BETWEEN ATES AND SOIL HEAT STORAGE

Contact: A. Nir, Weizmann Institute of Science, Rehovot, Israel, [Earth Sciences Division, Lawrence Berkeley Laboratory, 90-1106, Berkeley, California 94720, U.S.A. (through August 1982)]

During modeling and design studies of the last two years, a new concept of stratified soil storage has evolved, which, while retaining some similarities to ATES, differs in several qualitative and quantitative aspects.

This article compares the two approaches with regard to several characteristics: (a) mechanism of storage and heat transfer, (b) siting requirements and site availability, (c) stage of development, and (d) cost effectiveness. From this comparison we have obtained preference grading for various applications.

Mechanism of Storage and Heat Transfer

As in ATES, soil heat storge uses ground formations as a sensible heat storage medium and water convection as the main heat transport medium. Special features of the soil storage are: (a) storage is in a relatively shallow (5-50 meters), partially saturated zone; (b) convective transport takes place in a closed pipe system; (c) heat is distributed around the pipe system mainly by conduction; (d) heat may be deposited and controlled in time and space more precisely than with ATES, allowing the application of phase propagation techniques (Nir and Amiel, 1981); (e) diffusive heat flow to the upper soil boundary may be utilized to provide optimal surface temperatures in winter and to enhance air temperatures above it (useful for greenhouses or other similar applications) (f) water content may be controlled in critical areas to enhance heat diffusion; (g) there is no dependence on regional water flow; and (h) phase change material (PCM) may be incorporated in the design with relative ease.

A general description of such a storage concept is given by Nir et al. (1981). Heat-transfer rates to and from storage will be lower than in the case of the aquifer and will require distributed input manifolds.

Siting Requirements and Availability

The preferred site for soil heat storage would be the volume directly below the area of heat utilization, e.g., a greenhouse. This reduces the surface heat losses in winter and protects the storage area from direct infiltration from rainfall, surface runoff, and interflow. Most types of soil are suitable, but the presence of solid rock formations would considerably increase the cost of the installation.

An underlying aquifer can be a source of convective heat losses, therefore a preferred site location would be where the underlying aquifer is several tens of meters below the bottom of the storage volume.

Size considerations allow relatively small areas to act as effective soil heat storage; 2,000 m^2 is an adequate unit size. The storage area can be expanded modularly. The storage capacity is then adjusted by varying the effective storage depth. For an average temperature amplitude of 20°C, the storage capacity would be 300-3,000 MJ per square meter of surface area. For comparison, the siting considerations for ATES are summarised by Meyer and Hausz (1980).

Stage of Development

There are several conceptual and experimental programs under active investigation, but no demonstration facility is operating at present. The experimental sites include various types of ground and climatic conditions; e.g., Sweden, Switzerland, and Israel. Some of these sites were discussed at the Seattle Conference on Seasonal Thermal Energy Storage/Compressed Air Energy Storage, October, 1981.

Cost Effectiveness

The only complete cost effectiveness estimate known to us that seems to indicate positive results, refers to a greenhouse heating project under moderate climatic conditions (Nir and Amiel, 1981). The factors affecting cost effectiveness in this case are: moderate heat demand and therefore small investment in heat storage installation; the direct utilization of the upward heat flux for root zone heating and for increasing the minimum air temperature in the greenhouse. The cost effectiveness of a demonstration project for a new technology such as soil heat storage is influenced by the risk estimate and the amount of geophysical and environmental surveying effort necessary prior to investment. Soil storage is similar to prior experience, as long as the temperatures are limited to those found in natural environments (<55°C). The storage medium is easily accessible to measurement and there is much accumulated data from shallow wells, agricultural activities, construction projects, and general sedimentology of the upper earth layers. The practice of soil heat storage may be expected to advance rapidly, though a more complete description of the coupled heat and mass transfer in the unsaturated zone is still in the process of development. Under some circumstances aquifer and soil heat storage could be used in tandem to make optimal use of their respective advantages.

There are some factors common to both the aquifer and soil heat storage systems that affect relative costs when compared with other storage media. These factors are: (a) no additional land requirements (as for external tanks or ponds); (b) lower construction costs than for tanks, caverns, artificially insulated areas, or external PCM storage (PCM may be integrated, however, into a soil storage system); (c) no dependence on specific features (lakes or natural caverns) allowing the use of least expensive land sites. However, under specific local conditions, alternate storage forms may be more cost effective.

References

Nir, A., and Amiel, A., 1981, Seasonal heat storage in greenhouse soil, paper presented at the International Conference on Seasonal Energy Storage/Compressed Air Energy Storage, Seattle, Washington, October 19-20, 1981.

Nir, A., et al., 1981, Solar heat supply for greenhouses with stratified soil heat storage, Acta Horticulture 115 (in press).

Meyer, C.F., and Hausz, W., 1980, Guidelines for conceptual design and examination of aquifer thermal energy storage, Pacific Northwest Laboratory, PNL-3581

REMINDER

Contributions for the next issue of the Newsletter are due February 5, 1982.

INTERNATIONAL CONFERENCE ON SEASONAL THERMAL ENERGY STORAGE AND COMPRESSED AIR ENERGY STORAGE

Contact: J. R. Raymond, Underground Energy Storage Program, Battelle Pacific Northwest Laboratory, P.O. Box 999, Richland, Washington 99352, U.S.A.

The International Conference on Seasonal Thermal Energy Storage and Compressed Air Energy Storage sponsored by the U.S. Department of Energy and the Pacific Northwest Laboratory was held in Seattle, Washington, U.S.A., October 19-21, 1981. Over two hundred participants from fifteen countries attended the meeting. Meeting participants had an opportunity to discuss application of STES and CAES technologies in a variety of geographical, economic, and political structures and to meet with other professionals who are engaged in research and development activities in these technologies. Forty papers were presented in the four STES meeting sessions, and, in addition, several poster presentations were made.

AUBURN UNIVERSITY FIELD STUDIES OF THE AQUIFER THERMAL ENERGY STORAGE CONCEPT

Contact: Fred Molz or Joel Melville, Principal Investigators, Department of Civil Engineering, Auburn University, Auburn, Alabama 36849, U.S.A., and David Myers, Field Test Facilities Coordinator, Pacific Northwest Laboratory, Richland, Washington 99352, U.S.A.

The second of three injection-storage-recovery cycles in the third series of such experiments is well underway at the Mobile, Alabama field test site. (See ATES/STES Newsletter, Vol. I, No. 4; Vol. II, Nos. 1 and 2; Vol. III, No. 1,2, and 3.) At the present time (November 2, 1981) approximately 59,000 m^3 of water have been injected at an average temperature near 82°C. No clogging was observed during injection. However, the higher injection temperature drove relatively large volumes of gas out of the supply water, which required modification of the piping system to allow for release. This was accomplished by simply adding an open stand pipe near the injection well.

The second injection ended on October 27, 1981. One month of storage and two months of recovery will follow. During this time a third injection-storage-recovery cycle will be designed in an attempt to optimize energy recovery at the 80°C plus injection temperature used during the second cycle.

CHANGES MADE IN THE U.S. DOE SEASONAL THERMAL ENERGY STORAGE PROGRAM

Contact: J. R. Raymond, Underground Energy Storage Program, Battelle Pacific Northwest Laboratory, P.O. Box 999, Richland, Washington 99352, U.S.A.

Changes have been made in the organization of the U.S. Department of Energy's (DOE) Seasonal Thermal Energy Storage (STES) Program. These changes are due to funding restrictions for FY 1982 and reorientation of DOE's role in commercialization of energy-related technologies. The STES Program and the Compressed Air Energy Storage (CAES) program have been combined into the Underground Energy Storage (UES) Program. The Pacific Northwest Laboratory manages the UES Program for the DOE Division of Energy Storage Technology. Dr. Landis D. Kannberg is the UES Program Manager.

Initially, the STES Program was divided into an Aquifer Thermal Energy Storage (ATES) Demonstration Program and a parallel Seasonal Storage Technology (SST) Program. The ATES Demonstration Program was reoriented at the close of FY 1981. The Bethel Alaska Demonstration Project was terminated. Also, the ATES Project on the State University of New York Stony Brook campus is being terminated, with the exception of a proposed investigation on well plugging problems at the site. The St. Paul, Minnesota Demonstration Project is being converted to a high temperature field test facility (FTF), and research work is continuing at the Mobile, Alamaba low temperature FTF.

Research work previously conducted under the SST Program are being carried out in the UES Technology Assessment and Development task.

SUNSTORE - THE COMPLETE SOLAR ENERGY SYSTEM FOR HEATING

Contact: O. Platell Sunstore KB, a subsidiary of Studsvik Energiteknik AB 611 82 Nykoping, Sweden

In Sweden, there are no oil deposits, but due to the cold climate, there is a large demand for heating, which is met at present by imported oil. This provides a strong incentive to develop a system for heating houses which is independent of oil or other exhaustible energy sources. The Sunstore concept is intended to be a permanent solution to Sweden's heating problem using solar energy alone.

The concept is characterized by a very low temperature (less than 35°C) throughout the system, and consists of three main components: heat storage, solar collectors, and indoor heaters. The three components are described below.

1. Heat storage is established deep in the ground. Typically, rock or clay can be used. The ground is penetrated by vertical channels spaced 2 - 4 m apart to a depth of 30 - 100 m. Water flowing through the channels heats the ground during summer and recools it during winter to recover heat for the heating system. Very low costs per m^3 are obtained, giving a low cost per kWh stored, even when the water temperature is cycled within a limited range, e.g., through 10^oC.

2. Solar energy is collected by simple solar collectors, e.g., unglazed roof or facade materials, which perform remarkably well at the low operating temperature used.

3. The heating system distributes lukewarm water over a large surface and therefore requires a temperature which exceeds room temperature by only a few degrees.

The complete system with this low temperature philosophy is being developed by Sunstore KB and has become known as the "Sunstore System". However, other variants of the system can also be used with or without heat pumps, depending on local conditions, and with other heat sources, such as excess summer industrial waste heat.

A small demonstration plant funded by the Swedish Council for Building Research (BFR) and the National Swedish Board for Technical Development (STU) was built for a one-family house in Sigtuna, using a 10,000 m^3 solid rock volume below the house as the heat store. This store was heated initially by electricity. Heating of the store allowed the transfer functions to be checked, confirming the theoretical methods for dimensioning the store.

A research and development program has been carried out on the properties of water channels in clay and rock, and a larger R&D program, comparing the properties and costs for various detailed channel arrangements, has been started with funds from STU. A large scale demonstration plant has been projected. The Sunstore System promises to be competitive with any other heating system in Sweden at a fairly early date.

FIELD INVESTIGATIONS AND RESULTS FROM THE DANISH ATES DEMONSTRATION PLANT

Contact: L. J. Anderson, Geological Survey of Denmark, 31, Thoravej, DK-2400 Copenhagen NV, Denmark

The design of the Danish ATES demonstration plant, located 30 km north of Copenhagen, was described in the June 1981 issue of the STES Newsletter (Vol. III, No. 3). At this time, field investigations prior to the establishment of the final plant have been carried out.

The main hydrogological criteria for selection of the storage site were:

- a confined, porous aquifer with a rather low permeability, 20-25 m in thickness;
- a confined bed with a low permeability, 5-10 m in thickness.

Geoelectric soundings were carried out before the drilling program began. The geoelectric measurements indicated an aquifer of sand with a thickness of 15-35 m, covered by a layer of clay 5-10 m in thickness. In the northern part of the area, the presence of the water table was apparent.

To verify the geoelectrical predictions, five test wells were drilled in the area. The test drillings showed a confined aquifer in the southern part of the area and an unconfined aquifer in the northern part. However, the confined bed had a thickness of only 2-5 m. A perched aquifer was found above the confined bed. A pumping test showed a transmissivity of 1.2×10^{-3} m^2/sec and a storage coefficient of 10^{-3}. The permeability and distribution of the confining bed were of great importance in the selection of the plant site. Therefore, a number of shallow boreholes were augered to a depth of a few meters below the surface. In all of these test holes, the confining bed was present and in the southern part of the area it seemed to be unbroken.

The water table of the perched aquifer was different from the piezometric surface of the confined aquifer. This difference was used to map the extension of the confining bed, and thus determine the final location of the demonstration plant. Based on these results it was decided to accept this site for the demonstration plant.

In August-October 1981 the final five wells for the plant were drilled. The wells are situated with one central well surrounded by four wells placed in a 40 m radius circle. The production and injection wells showed the same stratigraphical sequence as was seen in the test wells.

The hydraulic gradient of the storage aquifer is 2.5%, which results in a natural groundwater flow through the storage area. The confining bed has a dip to the south of approximately 10^o. This will produce an outflow of the hot water from the storage area to the north.

Special care has been taken to prevent leakage around the well casings. After completion of the wells, natural gamma logs were run to obtain a detailed stratigraphy.

In the storage area, drilling of 17 instrumentation wells has begun. After completion of the wells in the winter of 1981/82, a final pumping test will be made in order to determine the hydraulic properties, the leakage, and the boundary conditions of the storage aquifer. Special emphasis will be placed on the determination of the spatial distribution of the hydraulic conductivity in the storage aquifer and the confining bed.

ATES SITE SELECTION IN DENMARK

Contact: L. J. Anderson, Geological Survey of Denmark, 31, Thoravej, DK-2400 Copenhagen NV, Denmark

A desk study of possible sites for aquifer thermal energy storage in Denmark has been carried out. (See previous article for site selection of the Danish ATES demonstration plant). This study started by locating areas where energy, and a need for storage of this energy, are present. Then the Geological Survey of Denmark evaluated the hydrogeological conditions within these areas. The criteria for a possible storage aquifer were the same as above, except for the thickness of the storage aquifer, which was reduced to 15 m.

The evaluation of hydrogeological conditions was based on existing well records at the Geological Survey of Denmark. A special map, the Cyclogram Basic Data Map was prepared in connection with the hydrogeological mapping of the country (scale 1:50,000). It contains well records of most of the water wells, making it possible to determine which sites have storage possibilities. Where warranted, further investigations were considered. A report of the storage possibilities of 22 sites was prepared.

Upon completion of this study, it was obvious that the possibilities for aquifer storage are rather good in most parts of the country. Because the need for thermal storage changes with time, it was decided at present not to prepare a special map showing the hydrogeological conditions for thermal storage for the entire country. This decision was based on the fact that the existing Cyclogram Basic Data Map is sufficient for a quick general evaluation of storage possibilities. Such maps are available for the whole country.

PUB-393 12/81/500 Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48.
Lawrence Berkeley Laboratory is an Equal Opportunitu Employer.