STES NEWSLETTER
A Quarterly Review of Seasonal Thermal Energy Storage

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EARTH SCIENCES DIVISION/LAWRENCE BERKELEY LABORATORY/UNIVERSITY OF CALIFORNIA

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A NOTE FROM THE EDITOR

This issue, Volume V, No. 1, represents the first issue of the fifth year of publication for this little newsletter. The consistent support and encouragement from contributors and readers over the years has made it a friendly, informal, but very informative way of keeping in touch with our fellow researchers. We are happy to be able to bring it to you and are grateful for your interest in it.

The subject of subsurface thermal energy storage is continuing as an active area of research and implementation in a number of countries. We are looking forward to the discussions and exchange of information at the International Conference on Subsurface Heat Storage in Theory and Practice that will be held in Stockholm, Sweden, June 6-8, 1983. Interested readers should write directly to Reso Congress Service, S-105 24 Stockholm, Sweden.

Included in this issue is an index of all articles published in Volume IV, during the last academic or fiscal year. We hope this will be useful to the readers.

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 for the next issue, as well as suggestions and changes of address should reach us by February 3, 1983.
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FIRST U.S.-CHINA CONFERENCE ON ENERGY, RESOURCES, AND ENVIRONMENT (November 7-12, 1982, Beijing)

Contributed by: E.L. Morofsky, Public Works Canada, C417 Sir Charles Tupper Building, Riverside Drive and Heron Road, Ottawa, Ontario K1A oM2, Canada.

The first U.S.-China Conference on Energy, Resources, and Environment was held November 7-12, 1982 in Beijing. The conference was jointly sponsored by the China Society for Energy Research, the Chinese Academy of Science, the U. S. Society of Engineering Science, and the National Academy of Engineering. The Conference Chairman and Organizer was S. W. Yuan, Professor at George Washington University and Past President of the Society of Engineering Science. The Co-chairman was Ling Hang-Xiong, President of the China Society for Energy Research.

The keynote address was given by the former U. S. Ambassador to China, Professor Leonard Woodcock. The Director of China's Engineering Thermal Sciences Institute, Wu Chung-Gua gave a talk entitled "China's energy problem and its solution through science and technology." Plenary speakers included Alfred Eggers ("Overview on energy, resources, and environment"), Robert Seamans ("Energy-past and present"), Edward David ("Fossil fuels"), Melvin Calvin ("Biodynamics"), and Ernest Gloyna ("Water and other natural energy"). The conference contained fourteen technical sessions, five plenary lectures, and three panel discussions. The technical sessions dealt with solar; coal; wind; hydro; geothermal; energy economics; energy and environment; energy conservation in industry, transportation, and cities; chemical fuels; and ice storage for cooling. A volume of proceedings has been published by Pergamon Press.

The Ice Storage for Cooling session was chaired by Tony Gorski of Argonne Labs with Yau Fumin acting as co-chairman. Projects discussed included the Argonne heat pipe ice formation method and the use of snow-making machines by the Princeton group. Charles Francis and Arthur McGarity described an earth-freezing method applicable to houses and Edward Morofsky reviewed Canadian ice experiments and plans for large-scale applications to commercial buildings. A Chinese contributor, Lin Fu, described the continuing use of natural ice gathering, storage, and distribution in China and the use of agricultural wastes for insulation of cold storage warehouses. An informal evening session was also held allowing general discussion of ice storage techniques including the annual cycle energy system of Harry Fischer and ice pond technique of Mehdi Bahadori. The Chinese cochairman of the session stated that China would use one of the natural ice formation techniques presented at the session.

The conference also organized several group tours to local universities and to the Solar Research Institute. Pre- and post-conference tours to several Chinese cities were hosted by the Chinese Association for Science and Technology.

AUBURN UNIVERSITY FIELD EXPERIMENTS OF AQUIFER THERMAL ENERGY STORAGE

Contact: Fred Molz or Hoel 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 third and final injection-storage-recovery cycle of the Auburn University ATES (aquifer thermal energy storage) experiments conducted at Mobile, Alabama was completed on November 10, 1982. (See STES Newsletters, Vol. I, No. 4; Vol. II, Nos. 1 and 2; Vol. III, Nos. 1, 2, and 3; Vol. IV, Nos. 1, 2, and 3.) The injected volume was 15 million gallons at an average temperature of 80°C. The native groundwater temperature at the site was 20°C.

Significant convection of the injected water was observed in all the experiments. In an attempt to improve recovery efficiency, a dual well recovery system (STES Newsletter Vol. IV, No. 3) was installed. The production well was screened in the upper 9.1 m of the storage aquifer and the rejection well was screened in the lower 9.1 m of the storage aquifer. This configuration was intended to permit selective recovery of the stratified thermal energy. The upper production well was screened in the zone of warmer water and the pumping rate was maintained at 190 gallons per minute. The lower rejection well was pumped at variable rates in an attempt to minimize any vertical flow of colder water to the production well.

Initial production temperature stabilized at 51.8°C. It was observed that variations in the rejection pumping rate had very little influence on the production temperature from either the upper well or from the rejection well. Evidently, the nomhomogeneity and the anisotropy of the storage aquifer dominates the configuration of the streamlines and the variation of pumping rates can effect very little change in the velocity distribution.

Preliminary aquifer analysis has indicated that the horizontal hydraulic conductivity is seven times larger than the vertical hydraulic conductivity. More importantly, there is a variation in horizontal hydraulic conductivity as a function of depth in the storage aquifer. In the middle of the aquifer the conductivity is larger. Near the upper and lower confining layers the conductivity is smaller.

The heat loss in the just-completed third cycle appears to occur as follows:

(1) During injection, most of the flow occurs in the central layer of the aquifer, causing significant lateral spreading of the injected volume.

(2) During storage, thermal convection in the high-permeability zone is significant, causing more lateral distribution of the heat.

(3) The hot water, having spread over a large area, allows conductive heat loss to the upper confining layer.

(4) The selective recovery system does not have a significant effect because of the aquifer anisotropy and nonhomogeneity (although it increased the production temperature by approximately 5°C during the initial pumping).

The Auburn University field experiments are now complete. Data are being analyzed. Pumping is being continued to restore the aquifer to the original 20°C ambient temperature. The site restoration will be completed in December 1982.

A SUMMARY OF RECENT MODELING STUDIES OF THE ATES EXPERIMENT AT MOBILE, ALABAMA

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

Lawrence Berkeley Laboratory has recently made numerical simulations of the first two cycles of an ATES field experiment being conducted by Auburn University (STES Newsletter Vol. III, No. 4; Vol. IV, No. 2). A comparison of the energy recovery factors indicates a good match between the numerical model and the integrated field results.

	Experimental	Calculated
First cycle (58°C)	0.55	0.58
Second cycle (82°C)	0.45	0.42

The experiment was conducted on a 20-m-thick confined aquifer with an average horizontal permeability of 63 darcies and an initial temperature of 20°C. The aquifer is anisotropic with a vertical permeability approximately 1/7th the horizontal permeability, and heterogeneous with the permeability of the middle third of the aquifer higher than that of the upper and lower thirds.

The difference in the injection temperatures of the two cycles created distinct hot water flow

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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.

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W. J. Schaetzle, W. J. Schaetzle & Associates, Inc., P. O. Box 1523, Tuscaloosa, Alabama, 35403, U.S.A.

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patterns in the aquifer for the two cycles. For the first cycle, with an average injection temperature of 58°C, buoyancy flow was moderate and layering effects were strong--hot water preferentially flowed into the middle (high-permeability) layer of the aquifer. For the second cycle, with an average injection temperature of 82°C, large buoyancy flow was the dominant feature as most of the hot water rose to the upper third of the aquifer despite the lower permeability there.

The numerical model of the system had to be capable of calculating a variety of physical conditions and effects. PT, a computer program developed at LBL, is an integrated finite-difference code that solves the coupled heat and mass transfer equations in a porous or fractured medium. It incorporates all the needed features and was used for the calculations.

The first-cycle numerical calculations were based on well test analysis results indicating a homogeneous anisotropic aquifer. The injection flow rate and temperature histories and the planned production flow rate were made known to us but preliminary experimental results were not. Before the conclusion of the experiment we predicted a recovery factor of 0.62; the experimental recovery factor turned out to be 0.55. Subsequent comparisons of experimental and calculated temperature distributions in the aquifer demonstrated the three-layer character of the aquifer. A calculation using a three-layer aquifer model, with the middle layer having a permeability 2.5 times that of the upper and lower layers, yielded a recovery factor of 0.58 and the calculated temperature distribution in the aquifer matched the experimental data well. This study demonstrated the importance of properly characterizing the aquifer in order to estimate its energy recovery factor.

Using the three-layer model, the second-cycle injection temperature and flow rate histories, and the planned production flowrate, the second-cycle recovery factor was calculated to be 0.40. However, the experiment was not carried out as originally planned. After two weeks of production, using the fully penetrating well that had previously been used throughout both cycles, production was stopped and the well modified to withdraw fluid from only the upper half of the aquifer. Then production was resumed. This modification was made in an attempt to recover more of the hot water in the upper part of the aquifer. This scenario was simulated yielding a calculated recovery factor of 0.42; the experimental value turned out to be 0.45. A detailed comparison of the calculated and experimental temperature contours in the aquifer was impractical because of difficulties encountered with the thermisters. However, a careful comparison of the calculated and experimental production temperatures was made. The production temperature gives an integrated picture of the thermal behavior in the aquifer, so it provides a good basis for comparison with our axisymmetric model.

The overall shape of the experimental production temperature curve is matched by the calculated production temperature. However, for both the first and second cycles the calculated production temperature initially overpredicts the experimental result then decreases so rapidly that by the end of the production period (when a volume equal to the injection volume has been produced) the calculated production temperature underpredicts the experimental value. This initial overprediction even occurred following the second-cycle well modification, when production began after only a two-day rest. Studies are currently underway to determine whether there is a physical process responsible for the discrepancy that could be included in the numerical model.

Although the detailed predictions of the model display some discrepancies when compared with the experimental temperatures, we feel that it provides an accurate enough picture of the thermal behavior at the Mobile site to be helpful in the design of an optimized third cycle. Various production strategies were numerically simulated for a three-month cycle with an injection temperature of 82°C. The results of these optimization studies (STES Newsletter Vol. 4, No. 3) were considered in the planning of the third cycle which was recently completed (see article, this issue).

In conclusion, the repeated sequence of prediction followed by comparison with experiment has given us confidence that the numerical simulation of ATES experiments is feasible and useful and that modeling is a useful tool in the optimal design of ATES field projects.

EVALUATION OF PRECIPITATOR DESIGN FOR THE ST. PAUL, MINNESOTA, FIELD EXPERIMENT

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Injection during the initial warm water storage test (80°C) at the ATES site in St. Paul, Minnesota (May 1982) was halted due to injectivity impairment of the injection well. This impairment was determined to be caused by precipitation of calcium carbonate from the heated ground water onto the well screen and injection zone gravel pack. During subsequent months, acid treatment of the well restored well performance to its original level and an in-line precipitator was installed between the heat exchanger and the injection well to remove calcium carbonate from the injection fluid stream. The precipitator is essentially a fixed-bed reactor which uses a sized gravel as a precipitating agent and is designed to provide sufficient fluid residence time for calcium carbonate to plate out on the precipitating agent.

A series of tests were performed at the St. Paul site to evaluate the effectiveness of the precipitator. These tests were performed using a model heater-precipitator system to simulate the conditions in the full-scale system by control of fluid flow rate, temperature, and particle sizing of the precipitating agent.

Three precipitating agents were tested, including dolomite, red flint sand, and limestone. All agents were sized and washed prior to use in the model precipitator. The fluid stream was sampled at points before and after the model precipitator to measure total suspended solids, particle size, and chemical hardness (indicative of calcium content).

Results showed the limestone to be the most effective agent for reducing the hardness and preliminary estimates are that it removed nearly 80% of the calcium in the water. Dolomite and red flint were much less effective.

Further tests were conducted to determine the optimal particle size for the precipitating agent. Tests also showed that the limestone must be flushed to waste for several hours at temperature to remove formation fines.

The full-scale precipitator was filled with appropriately sized limestone and tested in early November. Results show that the calcium levels in the injection fluid leaving the precipitator are acceptable and warm water injection has begun (November 17).

INITIAL STUDY OF THERMAL ENERGY STORAGE IN UNCONFINED AQUIFERS

Contact: Lance W. Vail, Geosciences Research and Engineering Department, Pacific Northwest Laboratory, P.O. Box 999, Richland, Washington 99352, U.S.A. or Henk M. Haitjema, Department of Civil and Mineral Engineering, University of Minnesota, 1919 University Avenue, St. Paul, Minnesota 55104, U.S.A.

Pacific Northwest Laboratories is directing an initial study of thermal energy storage in unconfined aquifers. The study will be performed by Dr. Henk Haitjema of the Department of Civil and Mineral Engineering at the University of Minnesota. This study will provide a method for evaluating the potential success of a seasonal thermal energy storage system in unconfined aquifers.

The potential for aquifer thermal energy storage (ATES) in unconfined aquifers has not been explored in the United States. Unconfined aquifers are heavily used for municipal and industrial water supply and the groundwater velocity within unconfined aquifers tends to be greater than that exhibited by confined aquifers. These negative considerations are, however, balanced by the economics of drilling and operating in the relatively shallow unconfined aquifers. Drilling, completing, and developing costs for thermal storage wells completed in shallow unconfined systems are much less than for wells in deep confined systems. Thus, there is considerable economic incentive to use unconfined aquifers for ATES.

Theory and models are needed which will allow a preliminary evaluation of unconfined aquifers for potential thermal energy storage. Chill storage would be most appropriate for unconfined aquifers. However, low-level (less than 100°C) heat storage is also being considered.

The study of thermal energy storage in unconfined aquifers will address two major issues:

(1) The efficiency of an injection/extraction scheme in terms of the amount and temperature of the recovered water versus the amount and temperature of the injected water.

(2) The environmental effects of the system in terms of the temperature distribution in both the aquifer and its confining layers.

It is proposed to solve the transient groundwater flow problem by means of a semi-analytical approach employing distributed singularities. The use of triangular surface distributions with a varying sink density in modeling transient flow is a novel approach and is expected to lead to an efficient and accurate solution. The groundwater flow model will be equipped with routines to plot isochrones for residence times at specified times during the injection/recovery cycle.

It is believed that the above initial approach will increase the understanding of the major features of thermal energy storage in shallow unconfined aquifers. Based on that understanding, the priority in future model improvements will be established.

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