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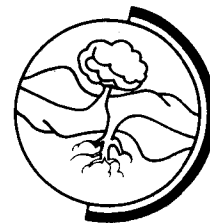
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STES NEWSLETTER

A Quarterly Review of Seasonal Thermal Energy Storage



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Vol. VI, No. 2

March 1984

A NOTE FROM THE EDITOR

Of particular note in this issue is a major article on the Minnesota heat storage project. This is currently the largest project of its kind in the U. S. and the findings should be of interest to all readers. Another noteworthy article is an exploratory study on the possibility of mapping thermal fronts of a hot/cold water plume in an aquifer by means of electrical resistivity measurements. The basic idea of using resistivity measurements to study subsurface structures is not new. However, the authors have performed a three-dimensional sensitivity study and have shown the method to be promising for aquifer heat storage, especially when downhole methods are used. Any interested readers should contact the authors directly.

Recently we have included more articles on ice-chill-storage. Any researchers and engineers in this field are encouraged to submit articles to us. As usual we encourage all workers in STES to submit articles on their plans, current status and/or significant results. Articles in the form of progress reports rather than reports of completed work are quite acceptable. It is a good way of keeping one another abreast of the current status within the field and of fostering possible international cooperation.



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, as well as new developments in this field are welcome.

Contributions for the next issue, as well as suggestions and changes of address should reach us by May 25, 1984.

Send to:

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AN ANNUAL STORAGE SYSTEM FOR NATURALLY FROZEN ICE

Contact: C. E. Francis, Illinois State University,
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Refrigeration and chilling methods usually require rather large amounts of energy for operation. This system uses naturally frozen ice in long-term storage to provide an economical source of ice for any application where a chill temperature of 38° to 40°F is sufficient. Initial research and computer simulations indicate that in areas where the winter is sufficiently cold and of sufficient duration, this system would be a viable option for such uses as simple refrigeration, summer air conditioning, and effective dehumidification.

The concept involves locating a storage mass underground at the location where it is frozen and subsequently used. The storage mass consists of water saturated earth. It is contained in a pit which has been lined with triple 6-mil polyethylene sheet material. The storage mass contains a heat exchanger (HX) consisting of 3300 ft of 1/2" OD polyethylene tubing. Above ground are two additional HX's and a small circulating pump.

During the winter when the ambient temperature is at least 8°F below the mass temperature, the HX fluid is circulated through the system, picking up heat from the mass and rejecting it into the atmosphere. After a period of time depending upon the coldness and duration of winter, the mass becomes completely frozen. A differential thermostat controls the freezing operation. During summer months when chill temperatures are needed, the circulating pump is used to circulate the HX fluid through the frozen mass. However, for this operation the fluid is diverted to a second (summer mode) HX. This HX is an aircoil located in the space to be cooled.

Storage mass dimensions are 40' X 15' X 10' deep with sloping sides. The total storage volume is approximately 5000 cubic feet. By volume, 40% is water and 60% is solid mass. Above the mass is a 4" layer of styrofoam insulation, then 2' of top soil and grass. By oversizing the mass to approximately 150% of that required to deliver the seasonal cooling load, we can account for losses to the surrounding earth due to melting. It should be noted that at this point in time, the required amount of mass oversizing is only an estimate.

UNIVERSITY OF MINNESOTA AQUIFER THERMAL ENERGY STORAGE FIELD TEST FACILITY

Contact: Matt Walton and Marcus C. Hoyer,
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Phase I of the Aquifer Thermal Energy Storage (ATES) field test program at the University of Minnesota ended 7 December 1983 with the completion of the fourth and final short-term test cycle. Planning is now underway for expanding the array of monitor wells. An application is pending for a Phase II program of 90- to 180-day test cycles. Construction of additional monitor wells is scheduled to begin in the spring, and the first test cycle of Phase II will be scheduled to start in early summer.

The Phase I test program was originally conceived as a 5-MW thermal input/output test facility to perform a series of 24-day test cycles, entailing 8 days each of heat injection, storage, and recovery. The purpose of the test cycles is to acquire as quickly as possible the engineering parameters needed to design a seasonal heat storage system for the University of Minnesota heating plant, having a maximum power input/output of 20 MW thermal. The system consists of two primary pumping wells placed 255 m apart, and surrounded by an array of monitor wells. The pumping wells have a design capacity of about 19 l/s, and are connected to a tube and shell heat exchanger. Heat is supplied to the heat exchanger by steam from the St. Paul campus heating plant.

The site is near the center of a large artesian basin containing several major aquifers in well-stratified lower Paleozoic sandstones and dolomites separated by shaly confining beds. Both pumping wells are completed in the Franconia-Ironton-Galesville (FIG) aquifer, which is composed of fine- to medium-grained sandstones with numerous thin shale interbeds. The aquifer is approximately 63 m thick and 181 m below the surface at the injection well and has a head of 125 m. Figure 1 is a schematic block diagram of the system and the underlying geology.

The dimensions of the monitoring well array were determined by the thickness and storage coefficient of the aquifer, the desired length of test cycles and the pumping rate. These parameters dictated a tight array with 2 sets of monitor wells 7 m and 14 m from the storage wells, as shown in Figure 2. The wells are instrumented with pressure transducers and thermocouples at a number of points within the aquifer and in the overlying and underlying beds. This permits changes in pressure and temperature to be measured, as well as the collection of water samples. These instruments are hard-wired directly into a 100-channel digital data logger and tape recorder. A major goal of the program was to test the feasibility of storing and recovering water at relatively high temperatures. The system is designed to inject water up to 150°C and return water to the supply well after heat extraction at a temperature of 84°C. The maximum temperature change of 66°C and pumping rate of 19 l/s give a nominal maximum power input/output of 5 MW thermal.

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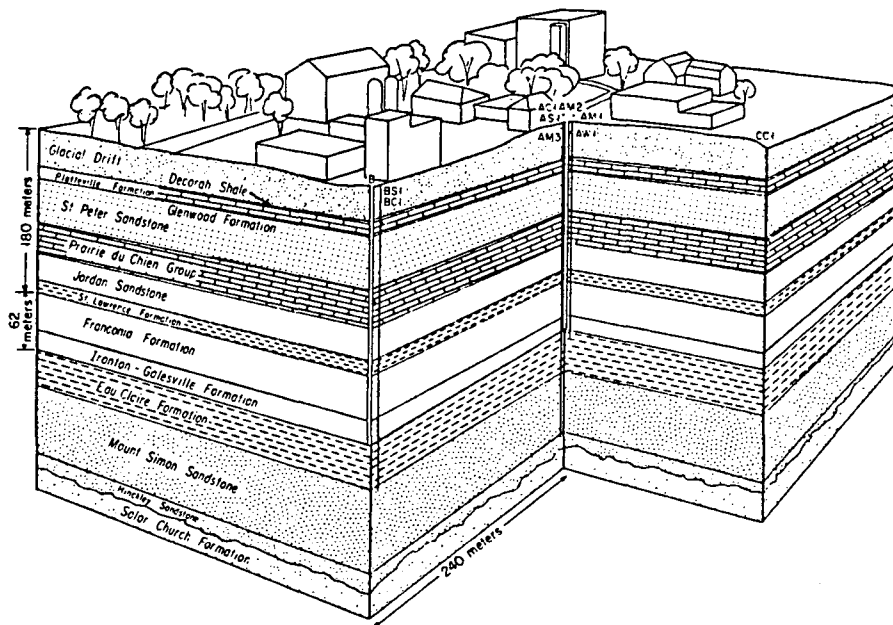


Figure 1. Block diagram of University of Minnesota ATES System, St. Paul campus.

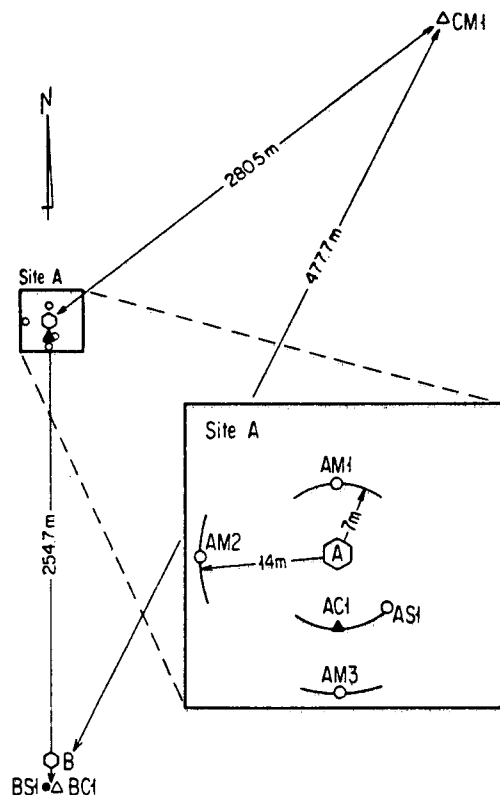


Figure 2. Location diagram of heat storage well (A), source well (B) and monitor wells (AC1, AM1, AM2, AM3, AS1, BS1, BC1, CM1).

Funding for the project was awarded in May, 1980, and well drilling and construction started in September, 1980. Construction, instrumentation, debugging, well development, and hydraulic testing were finally completed in May, 1982, about a year behind schedule. Major delays were primarily due to: i) difficulties with drilling

and well construction in the friable and broken sandstone and dolomite aquifers which overlie the FIG aquifer; ii) repeated failures of the pressure transducers, which required modification for deep immersion in the monitor wells; and iii) injection well clogging due to air entrainment and bubble formation when the backpressure in the injection well was not sufficient to maintain a continuous column of water in the injection pipe. The hydraulic testing procedure ended with the successful 8-day injection of cold water at ambient groundwater temperature (12°C).

The first injection test with hot water (185°C) was started in May, 1982 and was quickly terminated after about 50 hours, when it became evident that severe clogging by the precipitation of calcium carbonate was occurring in the well. An immediate attempt to back-flush the well was aborted when the pump shaft bearings, which were synthetic rubber, failed in the hot water. A long series of delays ensued while a means of handling the carbonate precipitation problem was developed. The pump bearings were replaced, and well A was restored by acid treatment and flushing.

Water from the FIG aquifer is of high quality, containing approximately 235 ppm total dissolved solids, mainly calcium and magnesium bicarbonate. Minnesota law provides that a variance must be obtained from the Minnesota Pollution Control Agency and Department of Health in order to reinject water into an aquifer. In granting a variance for this project, the regulatory agencies stipulated that no chemical additives could be used to treat the water, although water softening and other conventional water treatment processes are widely used within the area. With our first attempt at hot water injection, it became clear that the ATES concept could not work without a means for preventing carbonate precipitation in the well and in the aquifer. Under the leadership of Professor Perry Blackshear, University of

(continued)

TABLE 1. Brief summary of preliminary results of short-term test cycles at the University of Minnesota ATES field test facility.

	Flow Rate (1 sec^{-1})	Mean Temperature ($^{\circ}\text{C}$)	Volume Pumped (10^3 m^3)	Duration* (days)	Energy Recovery Factor
CYCLE I					
Injection	18.4	89.4	8.3	5.2/17.0	0.59
Storage				13.0	
Recovery	18.1	59.3	8.1	5.2/6.0	
CYCLE II					
Injection	17.6	97.4	12.2	8.0/10.3	0.46
Storage				90.0	
Recovery	17.8	55.2	12.3	8.0	
CYCLE III					
Injection	18.3	106.1	12.2	7.7/10.4	0.62
Storage				9.7	
Recovery	17.8	81.1	11.8	7.7/8.0	
CYCLE IV					
Injection	17.9	114.8	11.9	7.7/12.0	0.58
Storage				10.1	
Recovery	17.8	89.1	11.9	7.7	

*Pairs of numbers indicate discontinuous pumping: duration of pumping/duration of injection or recovery period.

Minnesota, a carbonate precipitator was developed. The precipitator consists of an array of 3 pairs of filter columns, having a flow path of 3.7 m, with a total cross-sectional area of 0.26 m², charged with crushed 5 mm median size high-calcium limestone. The precipitator was placed in the system between the heat exchanger and the injection well. Hot water supersaturated with carbonate passes through the filter columns where calcium carbonate is nucleated and precipitated. This reduces supersaturation to an acceptable level in the well but not in the heat exchanger. This device was an expedient which allowed the short-term test program to proceed, but it is not a solution to the problem. Regular shut-downs were required after about 40 hours of operation in order to recharge the filter columns and acid clean the heat exchanger.

Following the installation and testing of the filters, the first test cycle was conducted in November-December, 1982. A second filter array was added before the second test cycle, which was begun in May, 1983. The attempted hot water recovery in June was interrupted by problems with the lineshaft and lineshaft bearings, which were redesigned and replaced by bronze and graphite-bronze bearings. In August the recovery phase was completed after about 90 days of storage. The third and fourth test cycles were conducted from September to December, 1983. Table I summarizes the preliminary results of the four test cycles (I - IV).

Recovery curves for all test cycles reveal that for test cycle II, with the 90-day storage period, the temperature decline of the recovered water with time was at a significantly lower rate than for the test cycles having the planned storage intervals (I, II, and IV). However, peak and mean temperatures are significantly lower with the long storage.

A number of continuous, automatic methods of softening the water prior to heating have been investigated, with the conclusion that conventional sodium-zeolite ion-exchange softening provides the best available solution to the problem. An appropriate variance will be requested from the state administrative agencies. If a variance cannot be granted, the ATES experiment at the University will end. Ion-exchange water softening is widely regarded as benign and not a source of water pollution. Moreover, the treated water is confined within the ATES system with very little dispersion, and if at any time the system should be decommissioned, it would be a simple matter to pump out the treated water and discharge it to waste, should there be any reason to think there is an adverse effect if softened water is allowed to remain and disperse slowly in the aquifer.

****REMINDER****

Contributions for the next issue of the Newsletter are due May 25, 1984.

COMPILATION OF INFORMATION ON ICE STORAGE SYSTEMS

Contact: Anthony J. Gorski, Argonne National Laboratory, 9700 South Cass Avenue, Building 362, Argonne, Illinois 60439 U.S.A.

We are in the process of compiling information on all known seasonal ice storage systems in the U.S. and abroad. We are interested in systems in operation, under construction or in the design stage. If the reader knows of such a system, contact Mr. Anthony Gorski at the above address, or telephone him at (312) 972-6237.



UPDATE ON CANADIAN SEASONAL STORAGE ACTIVITIES

Contact: Edward Morofsky, Public Works Canada, C417 Sir Charles Tupper Building, Riverside Drive and Heron Road, Ottawa, Ontario K1A 0M2 Canada

Construction of a 30,000 square meter commercial office building (the Scarborough Government of Canada Building) is scheduled for completion in December 1984. The building will have an advanced aquifer thermal energy storage facility. Included in the mechanical systems are low temperature water radiation heating, heat pump configured chillers, solar energy collection via evacuated tubes, short-term energy storage tanks, and access to long-term aquifer thermal energy storage. Possible energy sources include the winter ambient temperature (collected by the building cooling tower), building waste heat at 42°C, and solar energy. The aquifer to be used is 50 meters below ground surface and about 10 meters thick. Discharge rates of about 100 liters per second have been selected for two withdrawal wells. A multi-year evaluation will begin after completion of the building.

Construction is expected to begin this summer on an aquifer-based seasonal cooling scheme at the Atmospheric Environment Service (AES) building in Toronto (see STES Newsletter, Vol. III, No. 2; Vol. V, No. 2). The design is the result of several years of field experimentation conducted at the site. The entire cooling load (about 7.4×10^{12} Joules) of this 30,000 square meter building will be provided from aquifer storage. Well field configuration will be three doublets, with about 200 meters between recharge and discharge wells. The USGS thermal simulation model was used in designing the well field configuration.

The FABRIKAGLACE ice fabrication technology has been perfected after several years of development in Quebec City. The technique uses winter ambient temperatures to freeze a large block of ice in thin layers; the rate of growth is controlled by ambient temperatures. In a climate such as Quebec City, ice nearly 20 meters thick can be fabricated in a typical winter. The COP
(continued)

might range between 50 and 75 for such an application. Public Works Canada now intends to test the technology in a large scale field trial on a government building of about 20,000 square meters. This building had been previously scheduled for replacement of its oil-fired chiller. Construction might start as early as September 1984.

The third in a series of international energy storage conferences is being planned for 1985. The upcoming conference will be hosted by Canada; the previous conferences were held in Seattle and Stockholm. Preliminary plans are for the conference to be held September, 1985 in Toronto. The conference will cover daily and seasonal thermal energy storage for building heating and cooling applications.



MAPPING THERMAL FRONTS IN UNDERGROUND THERMAL ENERGY STORAGE SYSTEMS USING ELECTRICAL RESISTIVITY MEASUREMENTS

Contact: C. F. Tsang, M. Wilt and N. Goldstein, Earth Sciences Division, Lawrence Berkeley Laboratory, Berkeley, California 94720 U.S.A.

Because the electrical resistivity of water is strongly dependent on temperature and salinity, it may be possible to locate salinity and thermal fronts in subsurface aquifer storage systems on the basis of electrical resistivity measurements. For example, a sandstone with a porosity of 20% which is saturated with 20°C water has an electrical resistivity more than 2.5 times greater than one which is saturated with water at 80°C. Measurements are typically made by injecting a dc

(very low frequency) electrical current via electrodes on the surface or in a borehole, and then mapping the electrical field on the surface or in a borehole.

A computer simulation study of a resistivity monitoring experiment in an aquifer thermal energy storage system has been made with a three-dimensional resistivity modeling code. The aquifer is 40 m deep and 20 m thick. The injection of 80°C water into a 20°C aquifer is simulated and the ability of electrical resistivity measurements to map the position of the thermal front is evaluated. Four cases are studied: a) sharp thermal front; b) diffuse thermal front; c) stratified aquifer; and d) aquifer with regional flow.

Figure 1 is a plot, from Case A, of the apparent resistivity difference for measurements made before injection and after the thermal front has moved radially 40 m into the aquifer. Measurements are made with downhole current injection and surface voltage measurements. Results show a clear indication of the thermal plume, and using a simple radial model it is possible to predict the position of the front from "half-width" calculations. Thus, the position corresponding to one half the height of the total anomaly is approximately equal to the radial position of the front. In this case the calculation yields 43 m as compared to 40 m for the actual front position.

The simulations show that this method has promise for tracking the thermal and salinity fronts in aquifer systems. There are still some problems in model equivalence (i.e., responses from the different systems studied sometimes appear similar) and in determining the proper electrode arrays to utilize for certain experiments. These problems are currently under study.

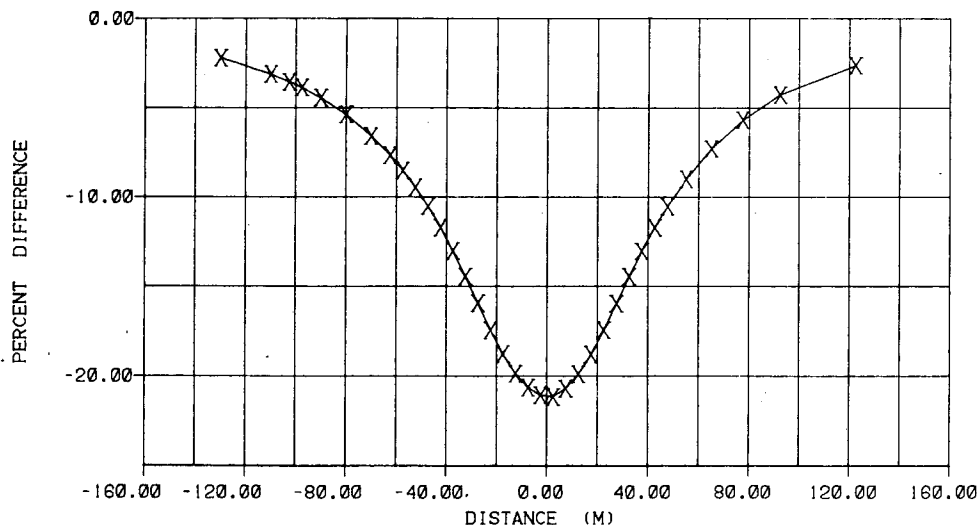


Figure 1. Apparent resistivity difference before and after hot water injection for Case A.

PROJECT SPEOS: SWISS AQUIFER STORAGE PROJECT

Contact: B. Matthey, CH-2205 Montezillon, Switzerland, or B. Saugy, Ecole Polytechnique Federal de Lausanne, Institut d'Economie et Amenagements Energetiques, CH-1015 Lausanne, Switzerland

The general concept of the Swiss aquifer storage project SPEOS has been described in several past issues of this Newsletter (Vol. III, No. 2, 3; Vol. IV, No. 1; Vol. V, No. 2). In the most recent contribution, the injection period of the first cycle of operation was described. From July to November 1982, heat injection at 60°C (200-400 kW) was carried out. Heat extraction then took place from January through April 1983. Extraction temperatures varied between 45 and 23°C. The amount of energy recovered was 42% of that injected. The recovered heat was subsequently reinjected into the lower aquifer.

During the first cycle thermal efficiency corresponded well with predicted efficiency. There were, however, lower exergetic efficiency and lower output temperatures than expected, due in part to manufacturer problems, and in part to problems encountered with the polypropylene sheathing used. From the first cycle we did gain, however, considerable experience in the behavior and reliability of the equipment used.

Prior to the beginning of the second cycle, the following work was completed:

- Placement of six vertical drains to favor vertical heat penetration in the aquifer;

- Installation of a continuous acid treatment system;
- Acid washing of the upper horizontal drains;
- Laboratory testing of heat exchangers;
- Construction of a groundwater by-pass (work in progress).

The second cycle began in June 1983 with a nominal power injection of 500 kW at 70°C. The average power injected during the six months of injection, taking into account the technical interruptions, was about 250 kW. Annual average injection power is therefore 125 kW.

In August 1983 one of the tubular heat exchangers was perforated and successfully replaced by a plate heat exchanger. The perforation was thought to be due to corrosion resulting from the heating circuit water and not to groundwater or acid.

Heat injection continued until November 1983, and extraction began in December 1983. The second cycle will be completed at the end of April 1984. A final report should be available by September, 1984.

The future of the SPEOS site is at present under discussion. An investigation into the economic implications of a system like SPEOS has been carried out. It appears that to be a paying proposition the SPEOS production should be doubled (1 MW instead of 500kW) for the same construction cost. A solution is at present being sought to increase the productivity of the existing site.



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