STES NEWSLETTER
A Quarterly Review of Seasonal Thermal Energy Storage

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A NOTE FROM THE EDITOR

The current issue contains articles from France, Denmark, Poland and the United States. They range from modeling studies of field experiments to practical installation of seasonal storage, with very promising results. In the seventh year of continuous publication of this quarterly magazine, it is encouraging to see the current world-wide activities and progress in this field. In spite of various problems encountered, we are learning how to solve or prevent them. We hope that this Newsletter will continue to serve as an effective means of exchanging information and as a catalyst for possible international cooperation.

For the same reason, we encourage all readers to plan to attend the Third International Conference on Energy Storage for Building Heating and Cooling, ENERSTOCK 85, to be held in Toronto, Canada, September 22-26, 1985. Inquiries should be addressed to Conference Secretariat, ENERSTOCK 85, 275 Bay Street, Ottawa, Canada K1R 5Z5.

We have enclosed with this issue an index of articles for the year 1983-1984 (Volume VI, Nos. 1-4).

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. Please keep us informed of research plans, significant results, and accomplishments.

Contributions for the next issue, as well as suggestions and changes of address should reach us by March 1, 1985.

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

COUPLED HOT AND COLD WATER UNDERGROUND STORAGE IN PARIS, FRANCE

Contact: J. Y. Ausseur and J. P. Sauty, BRGM, French Geological Survey, BP 6009, 450 18 Orleans Cedex France

A complex of four buildings, housing the offices and conference rooms of the French Trade Union CGT, was completed in Paris in 1982. The effective habitable area represents 105,000 m^2. The main building is organized around a large central patio (2500 m^2, 30 m high), which, covered with a double glass roof system, constitutes a large solar energy collector.

The total energy system consists of heat transfer between sunny walls and cold walls, general heat balance between the four buildings, and the utilization of hot and cold water underground stores. The stores are coupled with heat pumps by means of a doublet, which involves a pair of wells, one for heat and one for cold. The whole heating system is controlled by a minicomputer center, which monitors the temperatures throughout the buildings. The aquifer, 30 m thick, is mainly composed of a sandy layer (ypresian sand) covered by a chalk formation, the base of which is permeable. During summer, 25°C water is injected into the aquifer. During winter, the water is produced, and serves as a cold source for the heat pump. This water is cooled to about 6°C and stored in the cold well. During summer, the cold stored water is pumped for direct cooling of the air (without heat pumps).

Each season, 200,000 m^3 of water is stored. The heat storage volume occupies around 350,000 m^3 of soil; around 2 GWh will be produced from the underground stores each season.

Exploitation began during the summer of 1982, when 70,000 m^3 of water were stored. The monitoring device, installed in 1983, indicated excellent heat production. Between June and October 1983, 100,000 m^3 were stored at an average temperature of 26°C; the water was pumped back at a temperature ranging between 24 and 20°C (still 22°C at the end of February).

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The production was temporarily slowed during winter 1983-84 due to destabilization of one of the wells. Restoration of the well and new operating procedures (mainly progressive buildup of the pumping rates) are under way, and should allow more regular exploitation. Implementation of 6 observation wells will allow control of storage operations.

THE DANISH AQUIFER THERMAL ENERGY STORAGE PROJECT

Contact: Lotte Schleisner, Riso National Laboratory, Postbox 49, DK-4000 Roskilde, Denmark

Previous articles describing the Danish Aquifer Storage Project have appeared in Vol. I, No. 4; Vol. III, No. 3; Vol. IV, Nos. 1, 2 and 3; and Vol. VI, No. 3 of the STES Newsletter.

The basic concept of the Danish Aquifer Storage Project is shown in Figure 1. It involves the use of a natural aquifer, vertically confined by clay layers. The storage volume consists of a cylinder surrounded by the clay layers. In the storage volume, a central well is surrounded by 4 smaller, peripheral wells.

During storage, cold ground water is pumped from the peripheral wells and heated in heat exchangers. The heated water is then reinjected into the aquifer through the central well. In this manner, the heated volume of water, with a nearly vertical temperature front, propagates until it reaches the peripheral wells. At this time the store is full.

During heat recovery, the flow direction is reversed and the cooled water is reinjected through the peripheral wells.

In the demonstration plant in Hørsholm, the four peripheral wells are located in a circle with a diameter of 80 m. The aquifer has a thickness of about 15 m, and the depth to the top of the aquifer is about 10 m.

The storage volume is about 75,000 m^3, with a storage temperature of 100°C and a return temperature from the district heating system of 70°C. The stored amount of energy is about 1740 MWh.

The first full-scale storage cycle was planned for the summer of 1983, but shortly after injection was started, a leak through the upper confining clay layer was discovered, appearing as a spring of water on the ground surface. An investigation revealed that a crevice extended through the clay from the central well. The leak was repaired by injection of concrete through the upper part of the well screen.

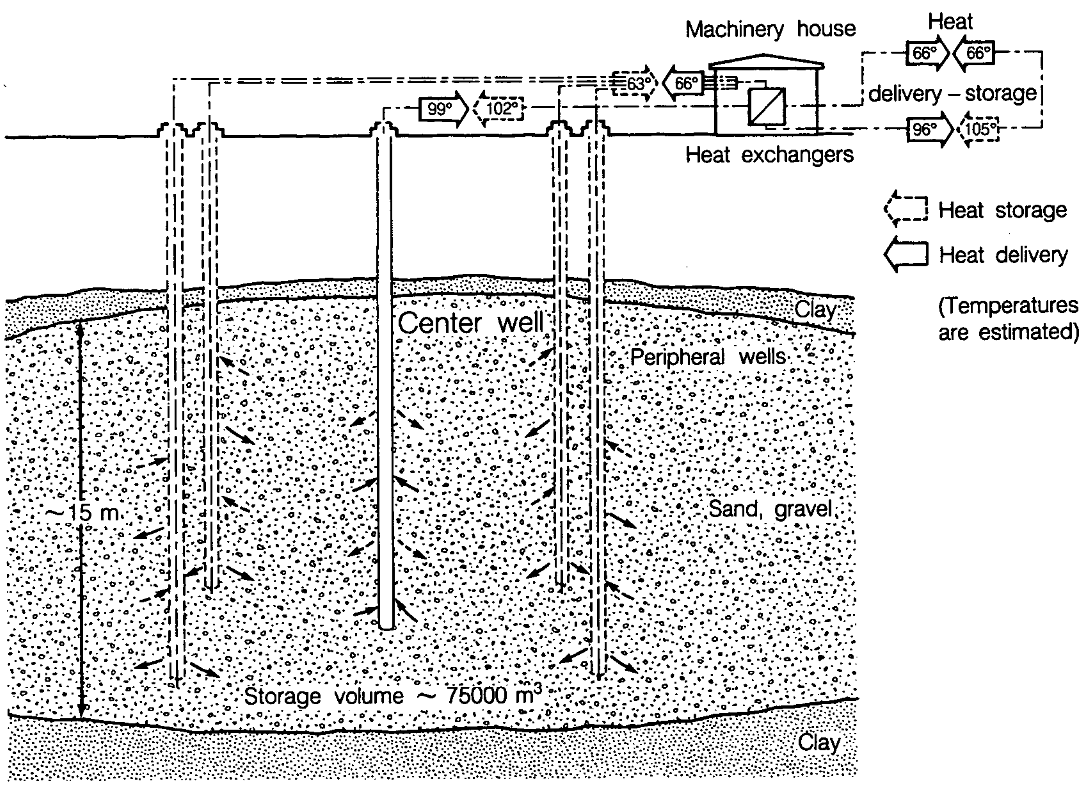

Figure 1. Conceptual model of aquifer thermal energy storage.

After the repair was completed, injection was resumed. However, due to the late time of the season, there was only enough waste heat to fill up about 10% of the store (about 650 MWh).

Heat recovery started in November 1983. After 8 MWh of heat was recovered, the recovery temperature had dropped below 70°C, and recovery was stopped. In spring of 1984, during the testing of the system, another spring of water was discovered about 20 m away from the central well.

To take advantage of the heat season, it was decided to pump cold ground water from the central well, heat it in the heat-exchangers and reinject the heated water through 4 peripheral wells. This process was begun around the end of May, and during the summer, 2058 MWh were stored. Injection stopped in the beginning of October.

At the time of this article (late 1984), the storage volume is not full, and it is not possible to deliver the heat to the district heating system. The heated water cannot be pumped from the peripheral wells, to be cooled in the heat-exchangers and then reinjected in the central well, because leakage will occur again during injection. Therefore, the heated water must be stored until the leakage problem is solved.

In order to solve the leakage problem, which is a very localized geological problem, it has been decided to drill a new injection well. This well will be located about 5 m from the central well. At this distance there will be a drawdown of 1 m with an injection flow of 60 m^3/h.

To get a smaller injection pressure, it is necessary to have a greater screened area. Therefore the new well will have a diameter of 28 in, with a screen of 20 in. The present central well is 12 in in diameter, with a screen of 10 in.

The new injection well will be drilled in the winter, and if there are no further problems, the system will be ready for the first full-scale storage cycle in the spring of 1985.

MINNESOTA ATES SHORT-TERM MODEL SIMULATIONS

Contact: R. T. Miller, Room 702, Post Office Building, St. Paul, Minnesota, 55101 U.S.A.

A three-dimensional, nonisothermal, anisotropic model for ground water flow and thermal energy transport has been developed by the U.S. Geological Survey for simulation of short-term tests at the University of Minnesota's ATES project. Four short-term test cycles have been simulated by the model. The first two cycles were used for model calibration (see STES Newsletter, Vol. IV, No. 4). A summary of field data for the four short-term test cycles was given by Walton and Hoyer in Vol. VI, No. 2, of the Newsletter.

An analytical solution for flow in a doublet-well system in an infinite anisotropic aquifer was employed in the design of a finite-difference grid with artificial boundaries placed in the midst of the flow field. Flow-net analysis was used to determine water flux across an equipotential boundary, and to assign approximate flux values at model boundaries. This enabled simulation of the effects of the entire flow field, although only a small part was modeled.

Areally, the finite-difference grid discretization cell sizes begin at 0.3 m x 0.3 m in the center of the grid at the injection well, and increase in all directions equally by a factor of 1.5 or less to a maximum of approximately 5 m x 5 m. The 5-m-spacing extends to the model's edge. Vertically, the model is divided into six layers, ranging in thickness from approximately 6 to 30 m, in order to represent the aquifer and its confining layers.

The model simulation included the entire period of the four short-term cycles, which was approximately 400 days. The first two cycles were used for model calibration and the last two cycles for model verification. For each cycle, model simulations were compared with temperature data recorded at 12 vertically spaced points at four different radial distances from the injection well, as well as injection well temperatures and aquifer thermal efficiencies. Table 1 summarizes the final injection well temperature at the end of withdrawal, and aquifer thermal efficiency, calculated as total energy recovered divided by total energy injected, for the four short-term test cycles.

Table 1. Summary of final injection-well temperatures at the end of withdrawal, and aquifer thermal efficiencies for field versus computer simulation of short-term test cycles 1 - 4.

Cycle Number	Efficiency (%)		Well Temperature (°C)	
	Field	Computer simulation	Field	Computer simulation
1	59	60	39.4	39.0
2	46	47	39.0	38.5
3	62	58	56.7	58.0
4	58	62	63.9	64.0

MEMBRANELESS GROUND HEAT AND MASS EXCHANGER

Contact: Gerard Jan Besler and Wiesław Kowalczyk, Institute of Chemical Engineering and Heating Equipment, Technical University of Wrocław, Norwida 4/6, 50373 Wrocław, Poland.

A membraneless ground heat and mass exchanger is a new, unconventional device used to gain heat from the ground at shallow depths. Both installation and operating costs are estimated to be relatively cheap and our study has shown the exchanger to be especially suitable for heating and air-conditioning systems. Its application reduces energy consumption, making it environmentally favorable.

The exchanger was designed, developed and patented (1980) by the Research Group No. 1 of the Institute of Chemical Engineering and Heating Equipment, at the Technical University of Wroclaw. Its design is based on the fact that the temperature at a shallow ground depth approximates the ambient air average annual temperature (in Poland, approximately 10°C). Even though annual variations in ground temperature are observed down to a depth of 10 m, the amplitude at a depth of 4 m does not exceed 1.5°C, according to measurements carried out for several years in the vicinity of the main building of the Technical University.

The primary objective of this work, on-going since 1979, is to develop the theoretical fundamentals and optimal technical solutions for industrial applications of the exchanger. Economic analysis as well as the measured thermal performance show that the exchanger can be widely applied to heating, air-conditioning, and refrigeration needs.

There are basically two types of ground heat exchangers; here, we refer to them as membrane, and membraneless exchangers. The first type consists of tubes placed in the ground, through which flows the air that is to be "conditioned." By contrast, the membraneless exchanger is a smaller system, consisting of more effective exchanger units, which are designed as an accumulative bed, located in direct contact with the ground. The membraneless ground heat and mass exchanger is of this type. However, it differs from the earlier exchangers of Sorg and Keller (1940), Vallon (1970), Ohm (1969) and Tomory (1979) both in construction and performance.

Earlier devices were characterized by vertical air flow through different, specially prepared ground layers (e.g., using fillers, stabilizers etc.). Because of the construction and specialized technology (e.g., that of Vallon, 1970), they were expensive and in fact did not perform correctly. This was mainly due to silting, i.e., the movement of rain water impurities down through the layers, causing an unfavorable building-up in air flow resistance. In the exchanger of Valton (1970), the air flow pressure reached 2000 Pa and greater while the inflow velocity was only v = 0.016 m/s. Tomory (1979) experienced the same problem - the inflow velocity was only 0.008 m/s at the similar pressure due to air flow resistance.

In the present exchanger, presented by Besler (1983) and illustrated in Figure 1, the air flows horizontally through an accumulative bed placed directly in the ground. A shower installation for rinsing and disinfection as well as for periodic or permanent increase of the heat and mass exchanger, is located over the bed. The shower installation is covered by thermal insulation and waterproof insulation, which are in turn covered with the native ground.

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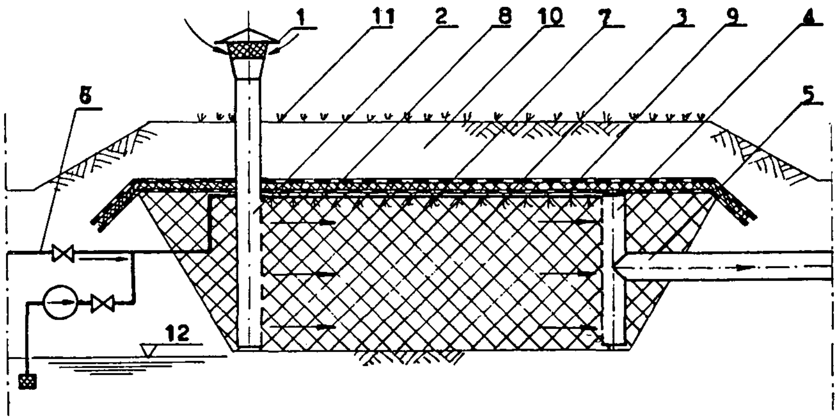

Figure 1. Scheme of the membraneless in-earth heat and mass exchanger. 1-inlet of the ambient air, 2-air distributing duct, 3-accumulative bed, 4-air collector, 5-air duct to the fan, 6-showering water supply pipe, 7-showering installation, 8-waterproof insulation, 9-thermal insulation, 10-native ground, 11-lawn, 12-underground water level.

The basic advantages of the membraneless heat and mass exchanger are as follows:

- Advantageous thermal stratification in the region of the exchanger as a result of the use of thermal insulation. This enables the exchanger to be set at shallower depths in regions of high groundwater level or on rocks;
- Low air flow resistance; i.e., the air pressure is only about 400 Pa at an inflow velocity of 0.1 m/s;
- Performance reliability;
- Capability of rinsing the bed and increasing heat and mass exchange properties;
- Capability to protect the bed against rain-water impurities;
- Exclusion of expensive, special accumulative layers;
- Possibility to utilize the surface over the exchanger.

Due to the complexity of the problem, it was necessary to prepare a broad experimental base. Experimental stations have been built to investigate heat and mass exchange, the spread of water in the bed, and the thermal properties of the bed. Moreover, a prototype of the exchanger has been operating continuously for more than 3 years in a ventilation installation in Polanica Zdroj. At present, two exchangers are in use, with outputs of 20,000 and 10,000 m^3/h, respectively. They are located in the area of the Institute and are available both for use in the ventilation installation as well as for experimental investigations.

These investigations, which have been on-going for two years, consider improvement in heat and mass exchange by water showers, and optimization of the exchanger. The experimental arrangements involve the two accumulative beds with lengths 4.5 and 1.5 m, respectively. The performance time is 16 hrs per day - from 6 a.m. to 10 p.m. The volumetric output has been 300 m^3/h for the 4.5 m bed and 360 m^3/h for the 1.5 m bed.

In the summer, the air is cooled down and dehumidified, and in the winter, heated and humidified. During summer and winter peak periods, thermal transfer of 1500 W/m^3 and greater have been obtained. These are unexpectedly good results. The presented results refer to a 1 m^2 cross section of the bed. For larger beds, results probably will not be as good.

Data analysis shows that when applying the exchanger in air-conditioning installations, it is possible to reduce the power demand during winter peaks by 50%. The cooling units can be completely eliminated since the total demand for cool can be met by that extracted from the ground. The ratio of energy supplied to that gained during peaks is 1 to 30.

Economic analysis by Besler et al. (1982) demonstrates that both investment and running costs of the installation using the membraneless ground exchanger are much lower than those of conventional installations. The investment costs are lower by nearly 50% and the running costs are 10-20% lower.

Processes that occur in the exchanger are very complicated. Even if it is possible to describe them using differential equations, direct solution is practically impossible to obtain. This has been shown by Besler et al. (1984) and Malecki (1984), and is one of the main problems being considered. Until now the Research Group has developed a system of numerical simulation of the exchanger performance, and have plotted the calculated results. Thermal properties of recommended packing materials have also been examined.

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