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STES NEWSLETTER
A Quarterly Review of Seasonal Thermal Energy Storage

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A NOTE FROM THE EDITOR

This issue contains articles from Canada, China, Sweden, Switzerland, and West Germany, as well as the United States. It is a pleasure to realize that information on Seasonal Thermal Energy Storage from three continents is brought together in this little Newsletter.

Of particular interest in this issue are the articles from China and West Germany. The former provides a general summary of chilled water storage as it has been carried out in China over the last ten years. It is abstracted from an article available directly from the authors or from the Editor at the address below. The article from West Germany describes in some detail the man-made aquifer concept developed there. It is perhaps worthwhile for us all to consider the advantages and disadvantages of such a system in comparison with natural aquifer storage systems.

We would like again to call our readers' attention to the international STES conference planned for October 19-21, 1981 in Seattle, Washington, U.S.A. The conference should provide an excellent opportunity for further discussion in many areas of STES research and development, including the recent large-scale demonstration experiments in Europe and the United States. Please see the last issue of the STES Newsletter for details.

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 the 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 June 4, 1981, at the following address:

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HEAT STORAGE IN A FISSURED LIMESTONE AQUIFER

Contact: G. Hellström, Department of Mathematical Physics, Lund Institute of Technology, Box 725, S-220 07 Lund 7, Sweden; or C. Gedda, Kjessler & Mannerstråle AM, Kungsgatan 2, S-302 45 Halmstad, Sweden

A field experiment with heat storage in a fissured limestone aquifer has been performed in Landskrona in southern Sweden. The object of the experiment was to assess the feasibility of using the aquifer for the seasonal storage of warm water. The water in the aquifer will be used as a source for heat pumps, which will support nine one-family houses. A glass-covered common yard will provide solar heat.

During the experiment, which lasted for 40 days, 1,700 m^3 of warm water (25°C) was injected. Injection and extraction of water took place in two wells, 40 m apart, at a depth of 30 to 80 m. After an injection and storage period of 10 days each, warm water was produced for 20 days. The pumping rate was the same during injection and extraction. About 29% of the heat was recovered when the extracted volume was equal to the injected volume.

A numerical model has been used to simulate the storage process. The water flow in the aquifer is assumed to be in the radial direction only. The magnitude of the flow rate varies in different horizontal layers. In this way a certain degree of heterogeneity in the hydraulic properties of the aquifer can be modeled. The total effective thermal conductivity in the aquifer, (including dispersion) was determined based on the measured temperature of the extracted water. The calculations were carried out using three different assumptions for the effective thermal conductivity: constant during the entire storage cycle; dispersion proportional to the flow velocity; and dispersion proportional to the square of the flow velocity. The best agreement was obtained using the third assumption.

The results indicate that flow in the aquifer is highly variable. A large fraction of the flow seems to take place in the fissured zones where increased water flow was detected during a preliminary pump test. Further studies will be devoted to the thermal processes and modeling of these strongly heterogeneous aquifers.

THE MAN-MADE AQUIFER CONCEPT

Contact: B. Weissenbach, Messerschmitt-Bölkow-Blohm GmbH, Space Division, Munich, Federal Republic of Germany

This article summarizes a study of large scale, low temperature heat storage that evolved from a cooperative study effort of Messerschmitt-Bölkow-Blohm GmbH, Heilmann & Littmann Bau AG (presently Heilit & Worner Bau AG), and others. These investigations were initiated in 1974 under the sponsorship of the Bundesministerium fur Forschung und Technologie (BMFT), and during the final stages, were also supported by the Commission of European Communities.

The theoretical and experimental studies cover both the technical and economical aspects of the project. After preliminary studies of a variety of heat storage techniques, including hot water tanks and artificial lakes, attention was given to near-surface aquifer storage in artificial layers (i.e., layers of processed material).

Figure 1 shows an example of an artificial aquifer storage unit. It consists of a gravel layer with processed material which is separated from the surrounding ground water by walls and then saturated with water. Heat storage is accomplished by feeding hot water through a drainage system into the upper part of the aquifer. At the same time, an equal quantity of cold water is produced from the lower part through a second drainage system. The water level in the gravel layer remains unchanged. Provided the permeability within the gravel and the difference in temperature between hot and cold water are properly chosen, the device behaves similarly to a hot water tank, in which the hot and cold water remain stratified.

A layer of dry gravel between two layers of bitumen gravel provides insulation against heat losses to the surface. The lower bitumen layer provides insulation for the inner part of the unit; the upper bitumen layer prevents water infiltration from the surface. The reservoir is separated from the surrounding ground water by two walls of bentonite that can be formed either by inserting the tightening material with a ram or by excavation. The annular space between the two surrounding walls serves as a heat barrier with a moderate temperature gradient, thus protecting the surrounding groundwater from thermal pollution.

The soil material of the inner part of the aquifer is excavated and replaced by processed material. By removing loamy components and small-size particles the permeability of the gravel bed is increased and made adequate for high specific loading rates without affecting the stratified temperature distribution. Gravel processing also eliminates clogging caused by swelling of loamy constituents when the quality of water is changed. The entire aquifer construction is based on standard technology. *(continued)*

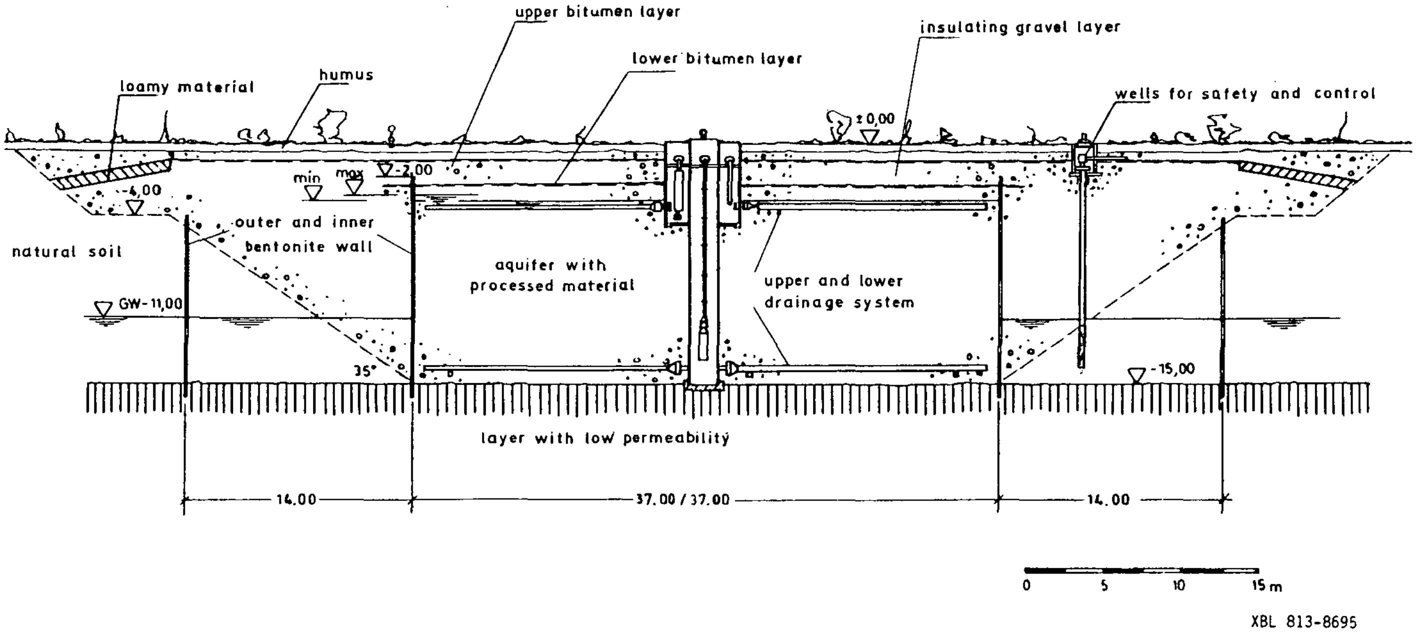

Figure 1. Artificial Aquifer Storage Unit

The water in a gravel bed is more or less in chemical equilibrium with the surrounding material. Since the chemical equilibrium varies with temperature, chemical mass transport may occur in the storage of sensible heat with all its consequences for the whole system. Theoretical and experimental investigations, including testing of different samples of natural soil, indicated that by proper conditioning of water and gravel bed the chemical effects can be kept sufficiently low so that the lifetime of the storage unit will not be reduced.

Besides chemistry and corrosion the biological behavior in a low-temperature system also has to be considered. Employment of biocides is not recommended due to possible pollution of surrounding water. The best way to avoid slime and pathogens is to inject water that is low in nutrients and which has little potential for biological activity. For the same reason the use of organic materials for construction should be avoided. Also, the bitumen layer below the insulation should be separated from the inner part of the storage plant by an inorganic material, such as a layer of concrete.

The design of the artificial aquifer shown in Figure 1 is fairly sophisticated, because it was felt that requirements in crowded areas could not be met by simpler means. Potential benefits from use of the artificial aquifer are as follows:

- exploration costs are low
- the high permeability gained by processing allows high specific loading rates required for economic operation without affecting thermal stratification
- adequate extraction systems can easily be installed in an open pithole
- the artificial aquifer ensures optimal utilization of the storage volume, thus reducing the overall dimensions
- removal of fine particles and loamy constituents during processing can eliminate problems of chemical mass transport and possible clogging
- the artificial aquifer can be built independently of local geological conditions
- the whole storage facility is safe in every respect

Several layouts of aquifer storage units have been drafted and the cost calculated for different site conditions. Facilities larger than 10,000 m^3 (water equivalent) turned out to be cheaper than presently known storage concepts. Economic calculations, however, show that the problem of thermal aquifer storage is part of the general problem of economic structures. To reap the benefits from aquifer thermal storage it will be necessary to consider it as a part of our infrastructure, as are for example, our highways and sewage systems.

LOW TEMPERATURE SEASONAL ENERGY STORAGE IN A SHALLOW GLACIOFLUVIAL AQUIFER

Contact: Clifford Voss, U.S. Geological Survey, 431 National Center, Reston, Virginia 22092, U.S.A.

Field investigations and simulation analyses of a proposed storage aquifer site in Stidsvig, Sweden indicate the feasibility of practical low temperature storage in shallow glaciofluvial deposits.

Field tests involved artificial recharge of warm water in an infiltration basin and measurement of groundwater levels and temperatures at a network of points in the aquifer. These tests provided hydraulic characterization of the system (5 m thickness, permeability approximately $3.0 \times 10^{-10} m^2$, effective porosity approximately 10%), and of its leaky contact with a nearby stream. The tests also provided estimates of transport characteristics of the esker deposit on the scale of a storage system (approximate dispersivity 2-7 m on a 50 m reach).

The field information allowed calibration of a finite element, two-dimensional, transient horizontal groundwater flow and energy transport model with transient vertical heat conduction in adjacent layers. Vertical buoyancy effects on flow for low temperature storage in thin, highly dispersive formations were considered negligible. The calibrated model was employed to evaluate various cyclic storage geometries and design characteristics of the operation of the energy storage scheme in the real aquifer system over a ten year period.

A five-spot storage system was found to provide the greatest system control and efficiency for the field location. Injection and withdrawal take place at the center well of a storage rectangle with four corner wells. The corner wells operate both to maintain a constant amount of water in aquifer storage and to protect against regional flow. A three-month injection of 30°C water at 30 liters/second is followed by a three-month rest period. The sequence ends with a three-month withdrawal period at the same flow rate. Initial production temperatures of 24°C drop to 16°C, 9° above the natural groundwater temperature. Because heat losses are dominated by vertical conduction, there are few practical options for improving temperature output. However, the low return temperatures are acceptable with the use of a heat pump. An increased insulating capacity of the above-aquifer layer (4 m thick) would increase temperatures by only a few degrees.

A complete description of the field project simulation is available in Report 8011, with the above title, by C. Voss, I. Kinnmark and H. Hyden, from the Department of Water Resources Engineering, Royal Institute of Technology, S-10044 Stockholm, Sweden.

THE AQUIFER THERMAL ENERGY STORAGE PROGRAM

Contact: Kenneth Fox, Pacific Northwest Laboratory, P.O. Box 999, Richland, Washington 99352, U.S.A.

The Aquifer Thermal Energy Storage Program, managed by the U.S. Department of Energy's Pacific Northwest Laboratory, supports several site-specific conceptual design studies. The purpose of these studies is to develop conceptual designs for integrated systems containing an energy source, a storage aquifer, and a practical application. In each of these studies, a storage aquifer is being characterized and functional design criteria are being developed for the integrated systems.

At the University of Minnesota, cogeneration steam from the university's heating plant will be used as the heat source. The storage formation is the Franconia-Ironton-Galesville aquifer, which underlies the St. Paul campus. In the summer, high temperature (approximately 150°C) water will be injected into the aquifer. In the winter, the stored energy will be recovered and will then be used for supplying hot water to the district heating system which services many buildings on the St. Paul campus. To date (March 1981), the five monitoring wells are nearly completed and drilling of the production well doublet, which consists of the supply well and an injection well, will soon begin. Following completion of the wells, isothermal pumping tests will be conducted, followed by heat injection and withdrawal tests at increasing temperatures. The U.S. Geological Survey is preparing the mathematical model which will use data from these tests to predict the performance of the full scale installation.

At Stony Brook, New York, chilled water will be stored in a portion of the Magothy aquifer which underlies the campus of the State University. In the winter, a cooling tower will be used to chill water to approximately 4°C. The chilled water will be injected into the aquifer and stored until summer, when it will be used for air conditioning of campus buildings. At this site, all drilling, well instrumentation and isothermal pumping tests were completed in 1980. Chill injection has now been completed and the aquifer is in a quiescent period, after which the chilled water will be withdrawn. Measurements taken at the monitoring wells during these tests will form the basis for determining the efficiency of the aquifer as a storage medium and will provide the data points for mathematical modeling. The model being used, GREASE II, has been developed in the Boston Office of Dames & Moore by Dr. Peter Huyakorn.

REMINDER

Contributions for the next issue of the Newsletter are due June 4, 1981.

THE DEVELOPMENT AND APPLICATION OF AQUIFER STORAGE IN CHINA

Contact: Qi-Sen Yan or Tsen-Fei Woo, Department of Thermal Engineering, Tsinghua University, Beijing, China

In China, the excessive extraction of groundwater in industrial cities, over a period of many years, has caused land subsidence and an annual lowering of the water table. In an effort to solve this problem, an experiment was begun in 1958 in Shanghai, to recharge aquifers through injection wells.

By 1965 it was realized that injection was beneficial not only for controlling land subsidence and raising the water table but for improving the groundwater temperature and quality for later use. At that time, based on the experience in injection and aquifer storage gained from several years of experimentation, large-scale chilled water storage was begun in Shanghai for application in the cotton mill industry. Summer injection for winter temperature and humidity control was also initiated. At present, approximately 10 cities store chilled water in winter for use in summer cooling. Geologically speaking, each of the cities where cold water storage has been used or tested falls into one of three categories: coastal delta plain, river valley plain, or piedmont alluvial plain. Table I shows the amount of water injected and withdrawn in four of these cities.

At present, three injection methods are used in China. These are vacuum injection, gravity injection, and pumped injection. Vacuum injection involves the initial creation of a vacuum in the upper part of an injection pump line. Injection will then take advantage of the siphoning action

City/Place	Period	Winter Injected Amount*	Summer Withdrawn Amount*
Shanghai, 24 cotton mills	65-79	120,540	7,670
Tianjin, 76% of the factories are cotton mills	67-78	1,630	---
Beijing, No. 3 Cotton Mill	70-79	600	560
Nanchang, Jianxi Textile Printing & Dyeing Mill	74-79	260	420

* (X 10^4 Tons)

Table 1. Injected and Withdrawn Water Amount in Four Cities

of the vacuum. This method is used for high-permeability aquifers having a low static water level (10 m below the surface). Because the force against the well screen is not great, this method can be used for old wells where the strength of the screen is rather low. The lower the static water level, the greater the rate of injection.

Gravity injection, utilizing natural gravitational force, is also suitable for aquifers having a low water level and high permeability. This method is advantageous because of its simplicity of operation.

Pumped injection is necessary for aquifers having a high water level and a low permeability. With this method, the injection rate is roughly proportional to the injection pressure.

Because aquifer energy storage was begun rather early in China, there has been a lack of research to date. A field test with many observation wells has not yet been done, and theoretical research is just beginning. Work in hot water storage has been limited to low temperature (39°C) storage, and little work has been done on storage in shallow phreatic aquifers.

AQUIFER STORAGE IN SWITZERLAND - PROJECT SPEOS

Contact: B. Saugy, J.C. Hadorn, Institut d'Economie et Amenagements Energetiques (IENER, ex IPEN) Swiss Federal Institute of Technology (EPFL) Ecublens, 1015 Lausanne, Switzerland.

The Swiss seasonal aquifer storage project SPEOS has been jointly studied, since 1979, by the Center of Hydrogeology of Neuchatel University (CHYN), the Laboratory of Geology (GEOLEP) of the EPFL, B. Mathey, and our institute. The design follows the work which includes field tests in Neuchatel, laboratory experiments and mathematical modeling in Lausanne done with the Laboratory of Geotechnic (LEGEP, EPFL) since 1973 (STES Vol. II, No. 4, G. Bloch).

The general concept is to store hot water (70 - 80°C) from solar collectors or waste heat producers, in an underground saturated porous medium (aquifer), and to withdraw the warm water for space heating. In this way, the use of heat pumps can be limited or avoided.

The aquifer storage concept adopted for this project is based on a vertical water movement (vertical piston) induced by two horizontal levels of radial drains drilled from a deep vertical central well. This system allows control of the thermal front, which is horizontal in this case. Thus, natural convection effects in the main storage zone and vertical leakage effects of the warm water in the disturbed soil around wells are limited. Both of these effects could be important in the single well or doublet system. Moreover, a high maximum flow rate can be maintained during the production period without excessive velocities near the drains, thus limiting clogging effects and transport of solid particles.

A preliminary search for suitable sites (producer-storage-consumer) in Switzerland led our team to choose the Dorigny site near Lausanne for a demonstration project. The pilot plant will be a shallow accumulator (from a depth of 6 m to 25 m) in alluvial deposits, of a 30,000 m^3 volume. Chemical effects will be reduced by using a closed circuit in the storage system (Miserez 1980).

Numerical simulations (3-D finite element models for diffusion and forced convection) showed that for the hydrogeological conditions of the Dorigny aquifers (given by in situ tests, which are not the most favorable for such a system), an average temperature during the first 6 months production period of 32°C could be expected (the injection temperature is 70°C) when a natural regional flow is considered (1% gradient), and 37°C if the natural flow can be by-passed.

The construction phase should begin in a few months. Current studies emphasize:

- influence of free convection effects on the system design
- sensitivity analysis of the thermal and hydraulic parameters
- definition of an optimal geometry (position, length of drains) and an optimal flow control strategy (repartition of withdrawal between drains).

Since the surface impacts are expected to be negligible on the Dorigny site, a small independent field experiment will also be carried out on a representative site very near Dorigny in order to investigate the effects of soil temperature changes upon the surface vegetation and the biological life (important for shallow aquifer storage or wet earth storage).

The project SPEOS was selected in November 1980 as a pilot IEA project by the countries that have signed the implementing agreement for energy conservation through energy storage (ATES, Vol. II, no. 1, B. Mathey).

AUBURN UNIVERSITY FIELD STUDIES OF THE AQUIFER THERMAL ENERGY STORAGE CONCEPT

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

Previous information concerning Auburn University's field research in aquifer thermal energy storage may be found in ATES/STES Newsletters, Vol. I, no. 4; Vol. II, nos. 1 and 2; and Vol. III, no. 1. The present information relates to the beginning of an injection-storage-recovery cycle utilizing a doublet supply-injection well configuration.

After a series of problems involving the failure of a boiler fuel pump and fuel pump motor, injection was started on February 17, at the design rate of 0.76 m^3/min (200 gpm). The injection temperature now averages approximately 61°C, and the bromide tracer concentration is close to 20 mg/1. To date (3/2/81), 8,706 m^3 (2.3×10^6 gal) have been injected at a wellhead pressure of 1.3×10^4 Pa (2 psi). At this stage of the experiment, clogging of the type previously experienced has not been a problem.

At 64 hours into the experiment, the tracer front began to pass the 50 ft observation well. Breakthrough required approximately 25 hours, and preliminary calculations indicated a dispersivity on the order of 0.1 m. At 151 hours, heat was detected in a temperature monitoring well. Heat has now been detected in three other monitoring wells. The middle thermistors registered the hot water first, indicating a relatively high permeability towards the center of the storage formation.

AQUIFER DEMONSTRATION PROJECT

Contact: Stuart Angus and Glynn Williams, Hooper and Angus Associates Limited, 950 Yonge Street, Suite 502, Toronto, Ontario M4W 2J7, Canada

With energy costs rising rapidly, the need for efficient conservation measures increases. Aquifer thermal energy storage (ATES) is one measure which should be seriously considered for use in building heating and cooling systems. A previous study by Hooper and Angus Associates, and others, has shown the technical and economic viability of ATES technology. Canada is a full member of the International Energy Agency (IEA) and a key participant in Task VII, Subtask 1(c) (Storage Systems). Hence Public Works Canada, through its Energy Secretariat, initiated the ATES Demonstration Program in 1980.

The current project represents a preliminary investigation of the Demonstration Program. The joint consulting team of Hooper and Angus Associates Ltd., and Hydrology Consultants Ltd. was asked to select, from a number of federal buildings in Ontario, a suitable building for such a demonstration project. After consideration, the headquarters of the Atmospheric Environment Service (AES), located at 4905 Dufferin Street in North York, was selected as the appropriate site.

The three objectives of the project are to:

a) verify the existence of an aquifer formation near the site and to establish some of its important characteristics;

b) assess the impact of the proposed ATES system on the building loads and physical plant;

c) prepare recommendations for further phases of work, such as well field development, aquifer modeling, aquifer testing, design and construction of building modifications, monitoring, etc.

Because aquifer formations are unevenly distributed and vary widely in composition, a review of well logs, well development and an aquifer testing program are necessary to ascertain the character of any specific aquifer. Under the current plan, three wells are being developed. One of these is a 0.15 m diameter well installed with a submersible pump. This well was drilled using the conventional rotary method. A second well is used for the observation of the water level during pumping from the formation. The thickness of the aquifer formation was estimated to be 9.8 m and to be located at a depth of 42.7 m. Prior to the pump tests, the aquifer showed favorable yield characteristics. The third test hole serves a dual purpose. It has been drilled in such a manner that undisturbed soil samples can be taken in order to determine some of the formation's physical properties by laboratory test. It will also be used as an observation well during the pumping tests. These tests are intended to provide estimates of the yield of the aquifer as well as the size and thermal storage characteristics of the formation.

The AES building, selected for the demonstration project, is being studied in detail to assess the potential for energy conservation using ATES. As part of a continuing program to reduce the energy consumption of federally owned buildings, Public Works Canada has already undertaken an extensive study of the energy demands of the AES headquarters. The results of this study, which involved computer simulation, provided important input to the current investigation. The building is modern in construction, having been completed in 1972. With its large floor area (30,000 m^2) and its diversity of energy usage, the building appears to offer a load spectrum which may in part be supplied by the aquifer. A preliminary engineering assessment of the modifications to the building necessary for ATES implementation is underway.

At this time, indications are that the aquifer and the building can be suitably interfaced. In future phases of the program, detailed designs will be prepared. The aquifer will be modeled using computer programs in order to optimize the placement of wells on the property. Wells will be developed and modifications to the building considered. As this is the first public demonstration of ATES technology in Canada, testing and monitoring of the system will be an important element of the program so that knowledge in this area can be made available to other investigators.

At present there are no insurmountable technical or economic barriers to the use of ATES in Canada. There are numerous aquifers with high yields across the country. With abundant supplies in Canada of "free cold", ATES can be employed successfully (in areas where suitable aquifers exist), in replacing conventional air-conditioning methods. Further, if ATES is coupled with summer solar energy collectors in many parts of Canada, electric or fossil-fuel heat demands can be reduced in winter.

In summary, ATES shows significant promise for reducing our reliance upon off-shore sources of energy, and hence contributes toward the objectives of the National Energy Program.

HEAT RECOVERY FRACTION FROM MULTIPLE WELLS IN AN ATES SYSTEM

Contact: Charles F. Meyer, Consultant, 1141 Cima Linda Lane, Santa Barbara, California 93108, U.S.A.

A key step in designing and evaluating the performance of an energy system employing aquifer thermal energy storage (ATES) is estimating the heat recovery fraction (HRF) - the ratio of recovered thermal energy to injected thermal energy. To maximize the useful HRF (and to conserve water) it is necessary that two wells or sets of wells be used. One well will accept, store, and produce hot water. The other will accept warm water (after heat directly usable by the aboveground system has been extracted from the hot well water), store the warm water, and supply it for reheating when storage in the hot well is again desired.

The <u>useful</u> HRF is determined not only by the hydraulics and thermal properties of a storage aquifer but also by the configuration and operation of the aboveground energy system. The temperature of the warm well as a function of time is particularly important and depends on how the aboveground system is configured and operated. For a given time period, the amount of thermal energy injected into or produced from an aquifer is equal to the water flowrate from well to well multiplied by the water's heat capacity and by the temperature difference between the warm and the hot wellheads.

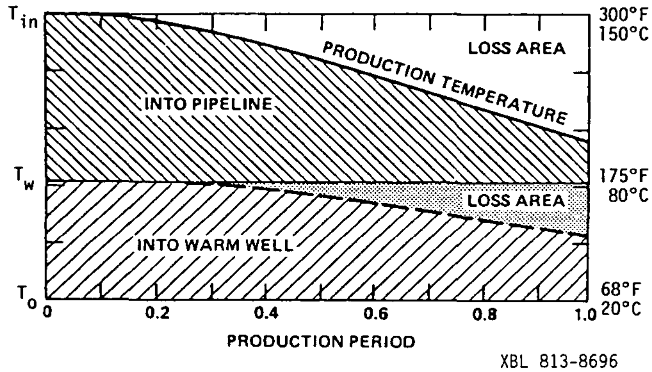

Figure 1. Heat Transferred Into Pipeline and Into Warm Well

Four temperatures, each as a function of time, must be known: the hot well injection temperature, T_{in}, and production temperature, T_{prod}; the well head temperature of the warm well, T_w; and the original ambient temperature of the storage aquifer, T_o (assumed, for simplification, to be the same for the hot and warm wells). T_{in} may vary with the heat load on the aboveground system, daily or seasonally. T_o will presumably be constant. T_{prod} and T_w will drop during the first seasonal production cycle, perhaps as sketched in Figure 1. The behavior of these temperatures will be determined by numerous aquifer and system parameters.

Only during the first period of injection will T_w equal T_o. During the first injection period, the injected heat is proportional to $T_{in} - T_o$ and therefore to the entire area of Figure 1. With reference to T_o, the heat recovered from the hot well during the first production period is proportional to the entire area of Figure 1 minus the "loss area" between T_{prod} and the top of the figure, T_{in}. However, a portion of this heat will not be delivered to the pipeline system. Useful heat can be delivered to the aboveground system only until the hot well water has been cooled (as heat is delivered) to a temperature somewhat higher than the aboveground system return temperature. This is the temperature T_w. During the first production cycle, the portion of heat recovered from the hot well (referenced to T_o) that is stored in the warm well instead of being delivered to the aboveground system is proportional to the area between T_o and the horizontal line through the value of T_w on the lefthand vertical scale of Figure 1.

Using as an example the temperatures shown on the righthand vertical scale of Figure 1, T_w will be 80°C during first-cycle injection of warm water. The heat transferred to the warm well (and not delivered to the pipeline), is about 40 percent of the total heat produced from the warm well. The <u>useful</u> HRF during the first period of production, referenced to T_w, is then less than 0.5, instead of about 0.8 if T_o is (incorrectly) used as a reference.

The situation improves during subsequent cycles. During the second period of injection the dashed line in Figure 1 illustrates water from the warm well being first supplied at a temperature T_w of about 80°C, then dropping to about 55°C by the end of the injection period. The amount of heat required to bring the hot well to a fully charged condition is then proportional to the area between the dashed line and the top of the figure, T_{in}. This amount of heat is substantially less than was required to fully charge the hot well during the first cycle with water heated from T_o (20°C), and continues to decrease with successive cycles as the aquifer system is warmed; both loss areas shrink. Thus, the useful HRF increases with successive cycles.

Further explanation and details may be found in Guidelines for Conceptual Design and Evaluation of Aquifer Thermal Energy Storage, PNL-3581, C.F. Meyer and W. Hausz, General Electric-TEMPO, prepared for Battelle Pacific Northwest Laboratory, October 1980, which is available from NTIS.

STES-RELATED CONFERENCES

The following are upcoming conferences and meetings related to seasonal thermal energy storage that have come to our attention.

April 6-10, 1981. First IEA Conference on New Energy Conservation Technologies and Their Commercialization, Berlin, FRG. Sponsored by International Energy Agency, Berlin Senate and U. S. Department of Energy (COC-Kongressorganization GmbH, Postfach 696, Berliner Str. 175, D-6050 Offenbach am Main 4, FRG)

April 29-May 1, 1981. International Conference on Energy Storage, Brighton, U.K.

May 11-13, 1981. Waste Heat Management and Utilization, Miami Beach, Florida, U.S.A.

May 20-22, 1981. Modeling, Policy and Economics of Energy and Power Systems: Alternative Energy Sources and Technology. Sponsored by the International Association of Science and Technology for Development. (The Secretary, Energy Symposia, P. O. Box 25, Station G, Calgary, Alberta, Canada T3A 2G1)

June 1-5, 1981. Thermal Energy Storage, Joint Research Centre of the Commission of the European communities, Ispra, Italy. A course reviewing the developing technologies for thermal energy storage; designed for both technical and non-technical personnel involved and interested in energy management and technology. (Secretariat "ISPRA-Courses", Centro Comune di Ricerca, I-21020, ISPRA (Varese) Italy)

June 9-12, 1981. Underground-Space Conference and Exhibition, Kansas City, Missouri. (University of Minnesota, American Underground-Space Association, Department of Civil and Mineral Engineering, Minneapolis, Minnesota 55455)

June 15-17, 1981. 1981 International District Heating Association Annual Conference, Otesaga Hotel, Cooperstown, New York 13326, U.S.A.

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)

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)

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)

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