COLD WATER AQUIFER STORAGE

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PROJECT OUTLINE

Project Title: Storage of Cold Water in Ground-Water Aquifers for Cooling

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Organization: Texas A&M Research Foundation
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Project Goals: Design, develop and demonstrate a working prototype system in which water is pumped from an aquifer at 70°F in the winter time, chilled to a temperature of less than 50°F, injected into a ground-water aquifer, stored for a period of several months, pumped back to the surface in the summer time.

Phase I - This phase consisted of construction of the facilities for the study.

- o Drilling of withdrawal and injection wells.
- o Drilling and instrumentation of observation wells.
- o Construction of a cooling pond.
- o Installation of surface piping, pumping, and associated facilities.

Phase II - This phase consisted of project operation and data collection and analysis.

- o Injection cycle.
- o Storage period.
- o Recovery cycle.
- o Data analysis and reporting.

Project Status: Operation of the facility was initiated in October 1978. A total of 8.1 million gallons of chilled water at an average temperature of 48°F were injected. This was followed by a storage period of 100 days. The recovery cycle was completed September 8, 1979, with a total of 8.1 million gallons recovered. Approximately 20 percent of the chill energy was recovered.

Data analysis is now in progress and a final report will be issued by March 31, 1980.

Contract Number: 7386

Contract Period: October, 1978 to April, 1980

Funding Level: $219,000

Funding Source: **Energy Storage Systems Division**
U.S. Department of Energy

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SUMMARY

A cold water aquifer storage experiment was conducted at Texas A&M University during the winter of 1979. Parameters for designing cooling ponds to chill water from 295 K to 277 K were developed. In addition, data on the movement of chilled water through a highly permeable, shallow, unconfined aquifer were obtained. This study provided a least-cost method for obtaining data on chilled water movement in aquifers to verify numerical models and to evaluate problems with chilled water storage. Regional flow in the aquifer and natural recharge to the aquifer during the second wettest year in history reduced the thermal energy recovery from an expected 40 percent to 20 percent. No aquifer plugging problems were experienced during injection and recovery operations. The cooling pond operation was an exceptional success.

INTRODUCTION

Ground water aquifers are available in most sections of the world. Approximately 80 percent of the populated areas of the earth have aquifers capable of delivering over 6.3×10^{-4} m^3/s. These aquifers are capable of yielding or receiving water. Recharge wells have been widely used for years as a water conservation measure.

Space cooling, or air conditioning, is a major energy user in this country. Attempts at solar cooling using the summer sun have not been particularly successful. An available source of low cost cooling is abundantly available in most regions of the country during the winter. If a low-cost storage system could be developed, this natural winter cold could be stored and recovered for space cooling during the summer. Aquifers may be the necessary low-cost storage system to make this system work.

A project to investigate the use of aquifers for storing cold water was conducted by Texas A&M during the winter of 1979. This project had the following objectives:

(1) Develop and experimentally verify design criteria for operating a cooling pond in the 295 to 277 K temperature range,

(2) Collect field data from a cold water aquifer injection experiment for use in verifying numerical models of aquifer thermal energy storage systems, and

(3) Evaluate any well plugging problems caused by injecting a highly aerated water into an aquifer.

This project is not a demonstration project; it is a low budgeted field experiment to evaluate problems associated with cold water aquifer storage. To reduce project costs, the aquifer selected is a very permeable, shallow unconfined aquifer with significant regional movement and natural recharge. A confined slowly-permeable aquifer is available at a deeper depth with characteristics more conducive for aquifer thermal energy storage. However, the shallow aquifer with less favorable characteristics was chosen to allow us to stay within a total construction cost budget of $50,000.

UNITS

Values reported in this report are in SI units. However, the actual measurements and calculations were made in U.S. Customary Units.

COOLING POND EVALUATION

A spray pond 15 m wide, 30 m long and 1.8 m deep was dug and then lined with a 32 mil Hypalon rubber liner to prevent seepage. Spray nozzles are mounted on three parallel 0.1 m distribution pipes supported by a wooden frame. The distribution pipes are 2.1 m above the pond bottom. Each distribution pipe supports 25 spray nozzles on 0.6 m by 0.01 m risers. Pond water is circulated by a 0.038 m^3/s centrifugal pump which supplies about 0.010 m^3/s to the filter and 0.028 m^3/s to the spray nozzles. A drift fence 2.4 m high was installed along each long side of the pond to prevent drift of water.

The spray pond performance exceeded expectations especially at low wind velocities. Data indicated that the cooling capacity of this pond increased linearly with the water circulation rate. This indicated that the pond area was not limiting and that more cooling capacity could be achieved by increasing the size of the recirculation pump.

With a water spray rate of 6.62×10^{-4} m^3/s per linear meter of spray header and no wind, the spray pond produced cooling at the rate of

$$Q = 1.298 \, (T - T_{wb}) \quad , \qquad (1)$$

where Q = cooling rate (kW/m of spray header),

T = temperature of spray water (K), and

T_{wb} = wet bulb temperature (K).

At the present circulation rate (no wind) about 310 kW of cooling was achieved with a 3.9 K approach temperature. This high performance at virtually zero wind speed is especially significant in view of the many cold, clear, still nights in the Bryan, Texas area. Weather records in Bryan indicate that during an average winter, 1300 hours are available when water averaging 280 K could be produced with a 3.9 K approach temperature. Thus, a cooling pond of the size used in this experiment could produce about 1.44×10^{12} J of cooling during a typical Bryan, Texas winter.

The cooling capacity of this cooling pond could be significantly increased by enlarging the recirculation capacity of the pond. We have modified the cooling pond, enlarged its cooling capacity, and plan to operate the pond on a limited basis during the winter of 1980 to evaluate its cooling capacity under the modified conditions.

AQUIFER INJECTION EVALUATION

The field experiment is located about 16 km west of Bryan, Texas. The wells are drilled into the Brazos River alluvium aquifer to a total depth of 17 m. The principal production zone is a coarse sand and gravel from 12 to 17 m. A fine sand 1.5 m thick overlies the sand and gravel zone. A slowly permeable silty clay overlies the sand and causes a semi-confined aquifer effect. However this silty clay zone has sufficient vertical permeability to allow significant quantities of natural recharge to enter the aquifer. The normal static water level is 7.5 m. During 1979, 1.15 m of rainfall occurred (the second wettest year on record) and the static water level increased from 7.5 m to 5.8 m.

A production well was drilled about 700 m west of the Brazos River, and an injection well was drilled another 408 m west of the production well. The production well was test pumped at the rate of 0.028 m^3/s, and the injection well at the rate of 0.013 m^3/s. The production well had a hydraulic conductivity of 180 m/d and the injection well had a hydraulic conductivity of 140 m/d. The hydraulic gradient at the injection site has varied from 0.001 to 0.005. Thus, regional movement of 0.14 to 0.70 m/d has probably occurred in this aquifer during the past year. These conditions are not conducive for demonstrating an aquifer thermal energy storage system in which the recovery of injected energy is the primary objective. However, the objective of this experiment was to inexpensively evaluate field temperature profiles for use in verifying numerical models. From that point of view, the experiment has been a success.

A system of 10 observation wells are located around the injection well and another 10 observation wells are located around the production well. These wells were used to measure the water levels and temperature profiles at various radii from the wells.

The first cold water was injected on January 4, 1979. Water was injected on 24 days during January, 24 days during February, and 11 days during March. The volume of water injected during January, February, and March was 13,625, 12,490, and 4540 m^3, respectively. A total of 30,655 m^3 was injected during the entire 3-month period. The average injection rate during the period was 520 m^3/d; exactly equal to the design injection rate.

The injection temperature fluctuated some during the experiment but was kept approximately equal to 282 K. Colder water could have been easily produced. In an actual demonstration of the cold water system, it would be desirable to inject colder water, but the objective of this project was to establish a measurable temperature difference in the aquifer, and collect data for verifying numerical models. This was accomplished. The average injection temperature throughout the injection period was 282 K.

The resulting temperature profiles around the injection well are shown in figures 1 and 2. Figure 1 shows the temperature profile on January 31, 1979. On this date, the temperature profiles appear to be uniform. An upward bulge in the temperature profile near the injection well is the result of being an unconfined aquifer. Some upward movement into the overlying clays occurred.

Figure 2 shows the profiles on February 28, 1979. The profiles are not mirror images of each other. Regional flow occurs from right to left in figure 2. It can be seen how the regional flow has moved the cold water farther in the down gradient direction. By July 8, 1979, when recovery of water was initiated, regional flow had moved the cold water zone 30 to 40 meters down gradient from the injection well (Fig. 3). A zone of cold water in the slowly permeable clays still existed near the well. But this had little chance of being recovered during the pump out period.

On July 9, 1979, the injection well was pumped at the rate of 6.31×10^{-3} m^3/s. This was continued for 30 days and the pumping rate was then increased to 9.46×10^{-3} m^3/s. Pumping was stopped on September 6, 1979, after withdrawing 30,655 m^3 of water. This water was returned to the original pumping well and reinjected into the aquifer. The temperature of the recovered water was initially 290 K and increased to a final temperature of 292 K.

A total of 1.56×10^{12} J was injected during the winter period and 0.36×10^{12} J was recovered during the pump out. This provided a 23 percent thermal recovery efficiency during the first year of operation. We had expected to obtain at least a 40 percent thermal recovery efficiency; but the large regional flow rate in the coarse gravel zone of the aquifer prevented this from occurring.

NUMERICAL SIMULATION

At the present time, Texas A&M is using two numerical models to analyze the data from this injection experiment. One of these is a finite difference aquifer model and the other is a finite element aquifer model. Work on developing the models was initiated in October of 1979 and only preliminary results are available. Figure 4 shows results of an initial computer model run 54 days after injection was initiated. Qualitatively, the present numerical model shows agreement with the field data. However, some refinement of input data, such as natural recharge rates and vertical permeabilities, is needed before a final match is obtained. We hope to have the two numerical models working by March 1, 1980.

GEOCHEMICAL STUDIES

The aquifer used for this experiment had a very high iron content of 9.1 ppm. When aerated in the cooling pond, an iron precipitate was formed. Much of the iron was precipitated in the cooling pond. However, prior to injection, the water was passed through a sand filter to remove any remaining iron. The iron content of the injected water was not detectable. It was necessary to backwash the filter after injecting every 950 m^3 of water.

During the pump out, we expected the iron content of the recovered water to have increased because of the obvious regional flow problem. However, the iron content started out at non-detectable levels and had only increased to about 0.3 to 0.4 ppm at the end of the pump out. The exact reason for this is not known at this time and is still under investigation.

The important factor is that the injection well did not indicate any signs of plugging during its 3 months of injection. The specific capacity was 2.69×10^{-3} m^3/m at the beginning of the injection period, and it was still 2.69×10^{-3} m^3/m at the end of the injection period. What would happen over a several year period is unknown, but we were encouraged about the first year's results.

To prevent biological contamination, the water was chlorinated prior to injection.

During the injection phase, a total of 29,100 kg of solids were injected into the well. During the pump out a total of 28,800 kg of solids were removed. Although this shows that some solids may be left in the aquifer, the results are well within experimental error, and no significant statistical difference exists between the two.

CONCLUSION

As a demonstration of ATES technology, the first cooling cycle at Texas A&M might be considered marginal because no useful cold water was recovered. However, as an experiment the project was very encouraging. Every aspect of the system operation equaled or exceeded expectations. There were no signs of well plugging during the injection cycle. The cooling pond proved to be an exceptionally efficient and low-cost method of producing cold water; and with the knowledge gained, a further increase in the cooling pond capacity is anticipated.

The simple sand filter worked perfectly, and in conjunction with the oxidation in the spray pond, completely removed the iron from the water. No plugging of the well was indicated during this initial injection cycle. The observation wells gave a complete hydraulic and thermal history of the aquifer during the experiment.

The poor thermal recovery was due to regional flow. This had been expected to a degree, but it was made worse by the second wettest winter and spring on record which raised the water table 1.7 m. During the next few months, this injection cycle will be simulated using computer models of the aquifer system.

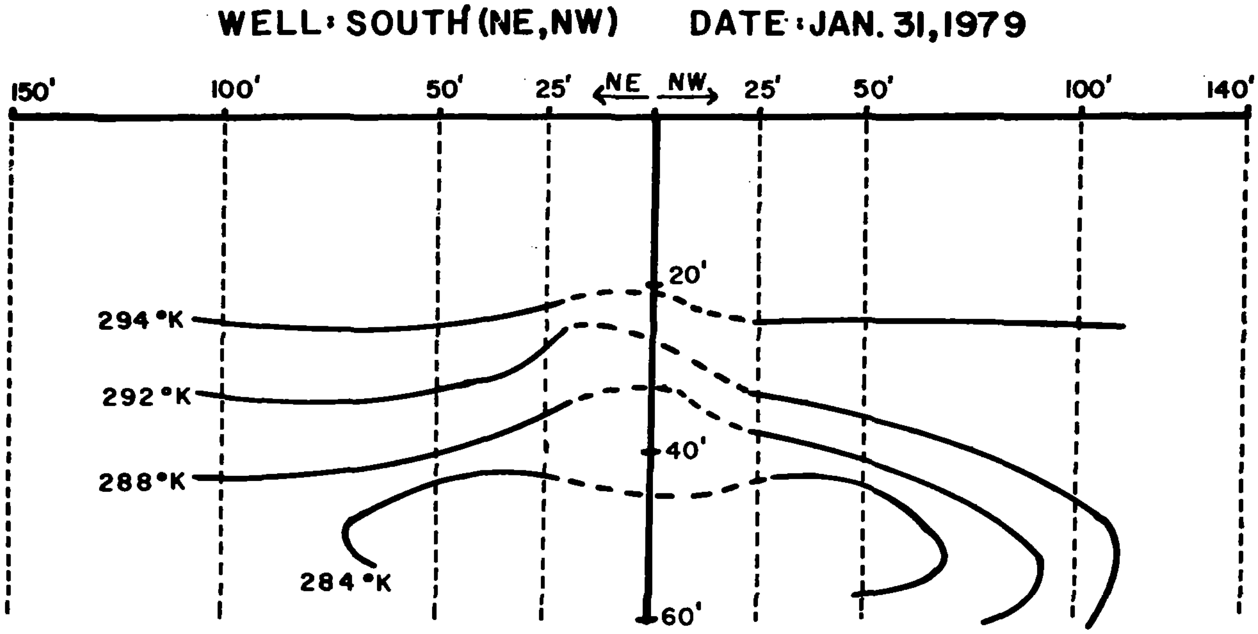

Figure 1. Temperature profiles after injection at 13,625 m^3 of cold water.

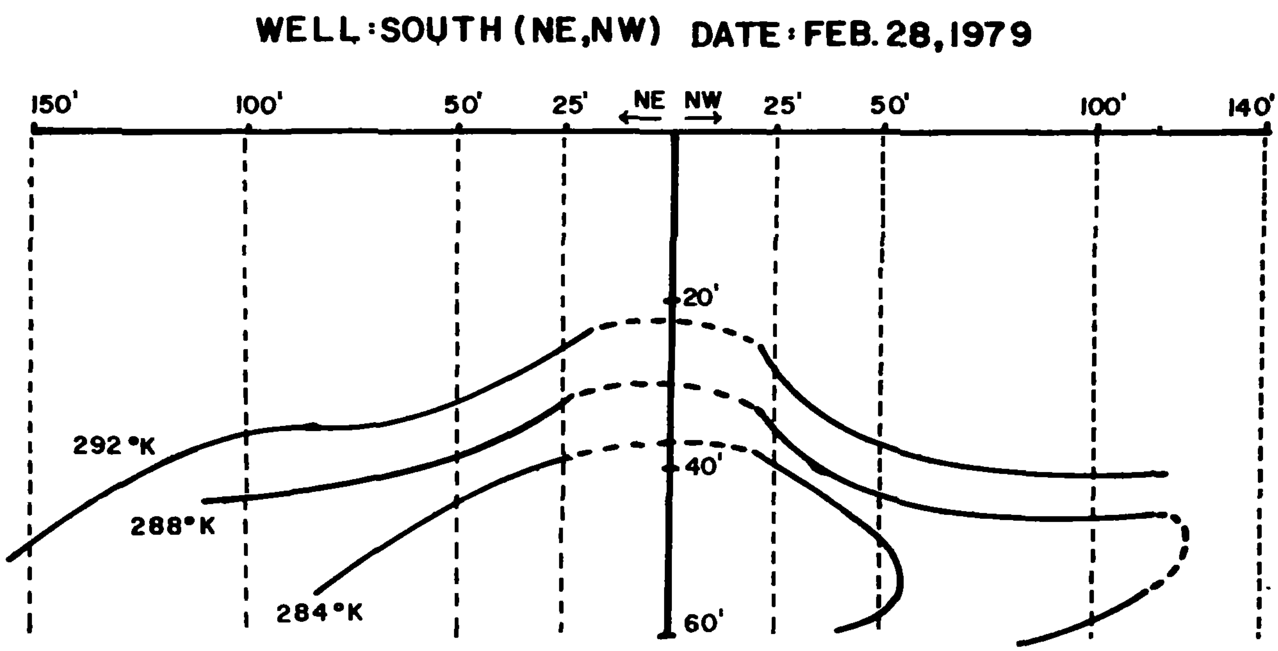

Figure 2. Temperature profiles after injection at 26,115 m^3 of cold water.

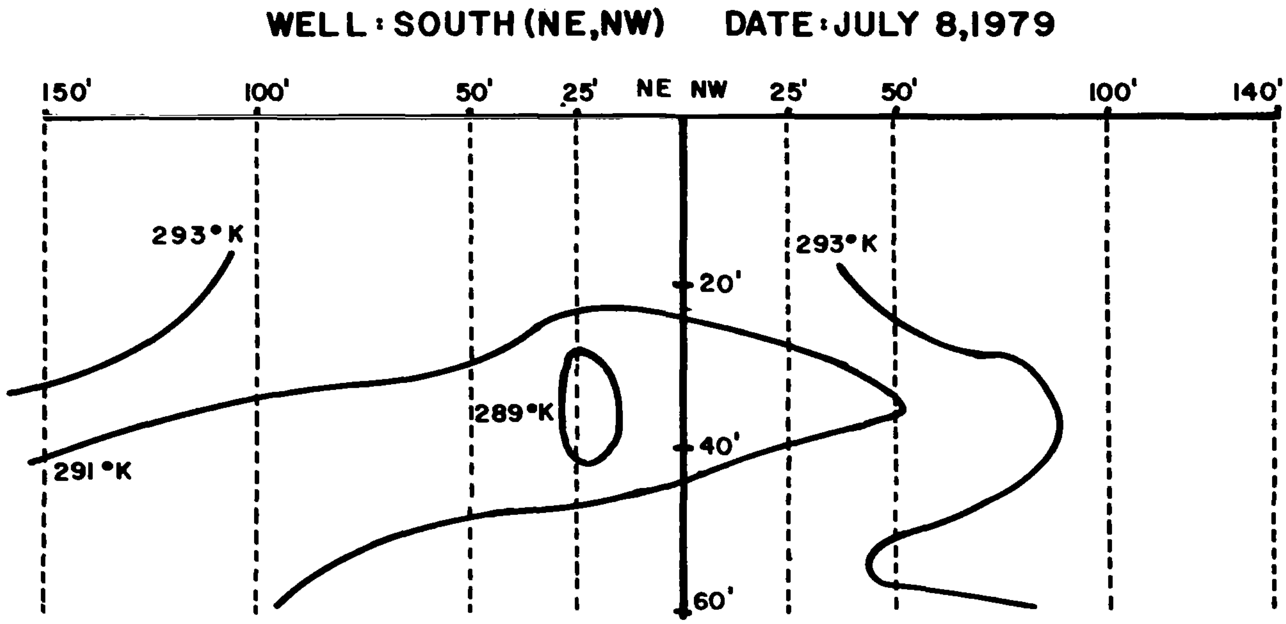

Figure 3. Temperature profiles after a 90-day injection period and a 90-day storage period.

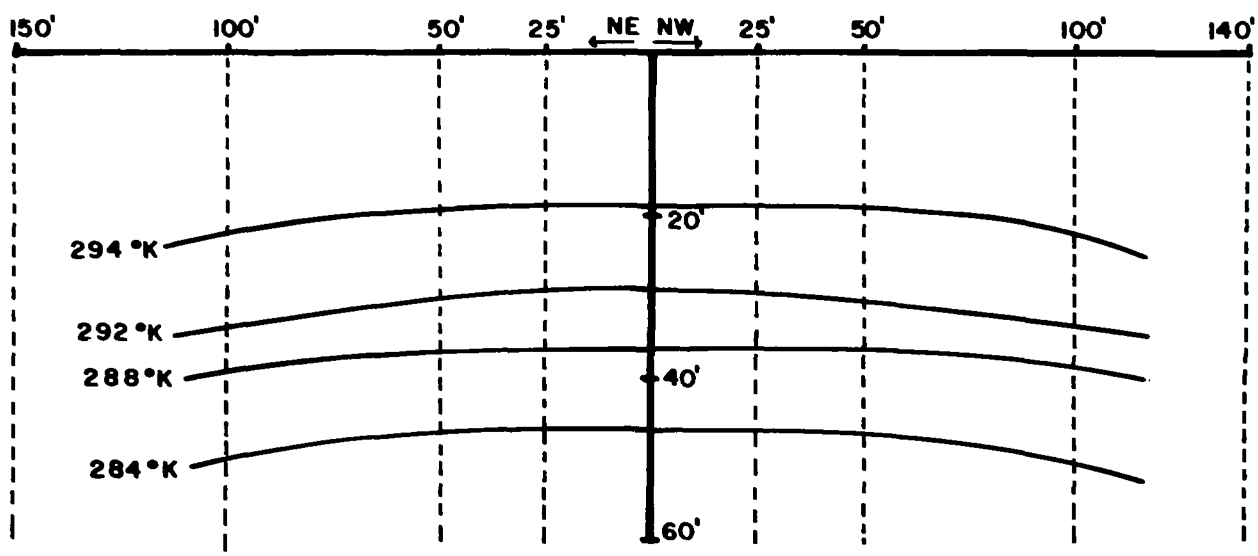

Figure 4. Results from initial simulation of temperature profiles following 54 days of injection.