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Heating and cooling of a hospital using solar energy coupled with seasonal thermal energy storage in an aquifer

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Abstract

A system is being designed, using solar energy in combination with Aquifer Thermal Energy Storage (ATES), that will conserve a major part of the oil and electricity used for heating or cooling the Cukurova University, Balcali Hospital in Adana, Turkey. The general objective of the system is to provide heating and cooling to the hospital by storing solar heat underground in summer and cold in winter. As the main source of cold energy, ventilation air at the hospital and surface water from the nearby Seyhan Lake will be used.

Keywords: Energy conservation; Aquifer thermal energy storage

1. Background

Thermal energy storage systems (TES) can help us avoid the sporadic characteristics of renewable energy resources, like solar energy. Such systems can store solar heat in summer to be used in winter, or during sunny days to be used

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for cool nights. TES can also help us in utilizing our natural energy resources, i.e. summer heat, winter cold. These are actually renewable resources, which have not been fully exploited before. Summer heat is a result of solar radiation heating the earth‘s air, soil and surface water. Storage in summer for winter and/or in winter for summer is the so-called seasonal storage system. These systems contribute significantly to improved energy efficiency of energy use. Thus the use of fossil fuels and CO_2, SO_x and NO_x emissions to the atmosphere can be reduced considerably. When storage of natural cold from winter air is also done for direct summer cooling, the need for prime electrical energy and expensive chillers with ozone depleting gases is reduced.

The large amount of energy to be stored for seasonal purposes requires a large volume, like the underground. Systems using the underground for storing thermal energy are called Underground Thermal Energy Storage (UTES) systems. Among the UTES systems developed since the 1970 s are storage in tanks, pits, rock caverns, aquifers, and ducts. Within the ‘Energy Conservation Through Energy Storage Implementing Agreement’ of International Energy Agency, Annex 8 consists of experts from Belgium, Canada, Germany, Poland, Sweden, The Netherlands, Turkey and the USA who are working on “Implementing UTES Systems”. According to the state-of-the-art report prepared by this group Aquifer Thermal Energy Storage (ATES) and Duct Thermal Energy Storage (DTES) are economically and commercially viable in a number of countries [1]. ATES systems compared to conventional systems can conserve energy reaching the levels of 90–95% for direct heating and cooling, 80–85% for heat pump supported heating and cooling, 60–75% for heating only with heat pump in the system, 90–95% for industrial process cooling, and 90–95% for district cooling [2].

The following work, gives the results of the feasibility study of the ATES system for heating and cooling of Çukurova University Balcali Hospital, in Adana, Turkey. The system stores solar energy in the form of summer heat and winter cold in an aquifer. The hospital has a capacity of 1400 beds that serves about 5,000,000 people living in the region. Currently, the heating system uses 3000 tons of No. 6 fuel oil annually. 10,000 MW of electricity is used annually to run chillers with Freon-12 for cooling.

2. System description

2.1. Basic concept

ATES stores thermal energy in an aquifer (natural groundwater basin). Two groups of wells which are hydraulically coupled and separated by a suitable distance are used for this purpose. Around one of the well groups cold can be stored and around the other heat can be stored. In the basic concept groundwater is pumped from one of the well groups, and then heated or cooled within the building before being re-injected back into the aquifer in the other well group. The groundwater circuit is closed in the sense that the water is produced from a number of warm wells and then injected through the cold wells at the same flow rate and without being exposed to air.

The layout of the proposed ATES system is shown in Fig. 1. There are two modes of operation, namely summer and winter. In summer mode, the cold stored from winter is used as free 'cooling of the hospital'. In winter mode, the system is used for preheating of ventilation air. As the main source of cold energy, ventilation air at the hospital and surface water from the nearby Seyhan Lake are being used. During winter season the groundwater is first used to preheat the ventilation air at the hospital. In this process, it is chilled down to a temperature roughly 3–4°C higher than that of the air. As a second step, cold bottom water is pumped from the Seyhan Lake to a heat exchanger where the groundwater is further chilled to a temperature of 8–9°C. The surface water will then be disposed back to the lake with an increased temperature, while the cold it has provided will be stored around a number of cold wells situated in an aquifer. During the summer season, when there is a demand for cold at the hospital, the cold wells are pumped providing cold water to the cooling system. In return, the groundwater will be heated by ventilation air and this heat will be stored in the aquifer through the warm wells. This heat is then stored in the aquifer to preheat the ventilation air in the coming winter as earlier described. Temperature delivered from the ventilation system (air handling units) will vary depending on the outdoor temperature. However, it is believed that the mean value will be in the order of + 20°C. There are two heat exchangers in the system separating the groundwater loop from the Seyhan Lake surface water (HEX 1) and the cooling loop at the hospital (HEX 2).

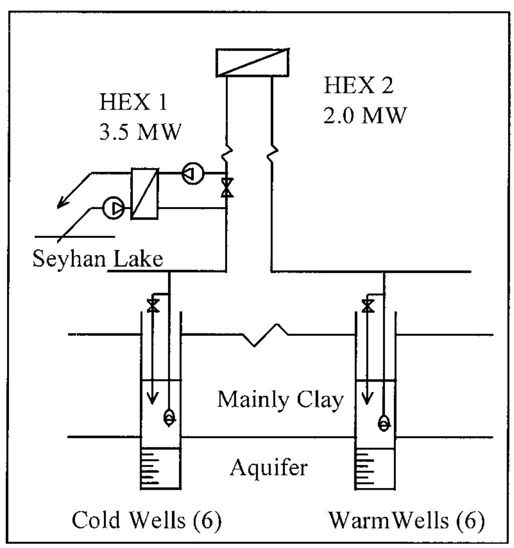

Fig. 1. Layout of the ATES system.

Other concepts to further increase oil savings are connecting solar collectors or a heat pump to the system. The results for the system with heat pump were given elsewhere [3]. In the system with solar collectors (Fig. 2), groundwater returning from hospital after being heated by ventilation air will be circulated through the collectors. Temperature of groundwater may reach to approximately 40°C in this process before being re-injected to the warm wells. The feasibility of this option is still being studied.

2.2. Governing conditions for feasibility study

The governing conditions for the system are hydrographical, hydrogeological and climate. The climate and hydrographical conditions determine the availability of cold for storage and number of running hours of operation in winter and summer modes. The meteorological data on ambient air temperature and temperature measurements in Seyhan Lake reveal the availability of cold for storage for about 4000 h in one year. The hydrogeological condition is essential in determining the suitability of the aquifer for purposes of ATES. These conditions include geology and hydrology. Geological and geophysical surveys together with information obtained from a test well (80 m in depth) drilled in the area show that there is a conglomerate aquifer of total thickness 14 m and a yield of 15 L/s. The aquifer properties like transmissivity (2×10^{-3} m^2/s), porosity (20%) and hydraulic gradient (3‰ towards south) are suitable for ATES purposes.

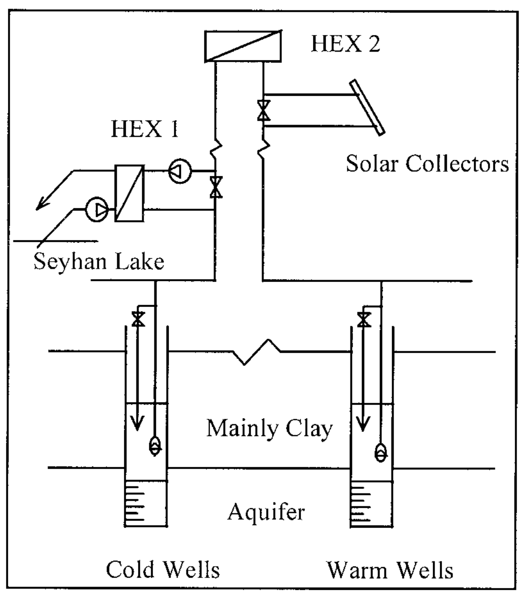

Fig. 2. Layout of the ATES system with solar collectors.

2.3. Operational simulations

Pumping and reinjection of groundwater have to be simulated in order to establish the number of wells, distances between wells and the impact on the surrounding area. In this case a thermohydraulic simulation program by the name of CONFLOW [4] has been used. This program simulates how the thermal front is spread around the wells as a function of time. It is also used to describe the hydraulic head in the aquifer as a function of distance. The later use will show the cone of depression and the cone of uplift under steady state conditions mainly as a function of flowrate and aquifer transmissivity.

3. Results

3.1. Simulation results

One objective with the simulations has been to calculate the well configuration in order to make the storage as dense as possible. One criteria used for this purpose has been to restrict the maximum cone of depression/uplift to 10 m at any point in the well field. A second criteria has been not to let the thermal fronts between the cold and warm well groups interfere with one another. However, within each well group, the thermal fronts are allowed to slightly overlap each other. A distance between straight well groups in the order of 300–350 m is thermally optimal. Between wells of the same group, the distance should be in the range of 60–80 m. From a hydraulic point of view, the calculations show a maximum cone of depression/uplift in the range of 7–8 m which is well below the stipulated 10 m. The results indicate that a square well field of maximum 350×400 m will be enough for the storage of roughly 14,000 MW/year in the form of cold and heat at $+10^{\circ}$C.

3.2. Economic and environmental feasibility

In this ATES system, 7000 MW/year will be stored in the cold part of the aquifer at a mean temperature of $+9^{\circ}$C. This storage is done in the winter during approximately 2000 h. During storage approximately 500 MW will disappear as storage losses and as a result of this the temperature will rise about 1°C to $+10^{\circ}$C. During summer, approximately 6500 MW will be used for cooling the hospital for roughly 3000 running hours (17 h/day). This will replace a major part of the conventional cooling by chillers and save some 3000 MW of electricity. The ATES system will use approximately 250 MW electricity for the pumps in the system. Its assumed that the average COP for conventional cooling is 2.0. For preheating of ventilation air by the ATES system 7000 MWh of energy is pumped from the warm part of the aquifer. To produce that heat, roughly 300 MW of electricity will be used to run the pumps involved. However, the preheating with the ATES system will save oil in the order of 1000 m^3/year.

The environmental benefits from this project will be reduction in energy consumption as electricity and fuel oil and replacement of chillers using ozone depleting Freon-12 gas. The savings in fuel oil (1000 m^3/year) will approximately decrease the CO_2 emission by 2100 tons/year, SO_x by 7 tons/year, and NO_x by 8 tons/year. The replacement of 2 MW of current chillers using Freon-12 will result in a saving of approximately 0.7 tons/year of Freon-12.

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