75 KM OF DRILLING FOR THERMAL ENERGY STORAGE

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ABSTRACT

A borehole thermal energy storage system was put into operation in 2004 at Durham College and the University of Ontario Institute of Technology (UOIT) in Oshawa, Ontario. The UOIT/Durham College campus includes eight new buildings that are designed to be heated and cooled with renewable energy in order to minimize greenhouse gas emissions. Test drilling programs were carried out to determine the feasibility of thermal storage in the overburden and bedrock formations at the UOIT/Durham College site. In-situ tests were conducted to determine the groundwater and thermal characteristics. An almost impermeable limestone formation was encountered from 55 m to 200 m below surface. The homogeneous, non-fractured rock proved to be ideally suited to thermal energy storage since there is virtually no groundwater flux to transport the thermal energy away from the site. The total cooling load of the campus buildings is about 7,000 Kw. Using the thermal conductivity test results, it was determined that a field of 370 boreholes, each 200 m in depth, would be required to meet the energy demand. In addition, 5 temperature monitoring boreholes were installed, increasing the total drilling for the project to 75 km. The borehole drilling was carried out using three drilling rigs, operating 24 hours per day. Steel casing was installed in the upper 58 m of each borehole to seal out groundwater in the shallow formations. Design changes were made to the borehole heat exchangers (BHEs) as a result of the lack of groundwater flow in the rock. The Swedish practice of water-filled BHEs was utilized instead of the North American practice of grouted BHEs. Water-filled BHEs improve the efficiency of U-tube installation and extend the life of the boreholes indefinitely. The BTES field occupies the central courtyard of the new UOIT/Durham College campus. The field is divided into four quadrants in order to optimize seasonal energy storage. The BHEs are located on a 4.5 m grid and the total field is about 7,000 m^2 in area. A string of temperature probes in each of the 5 monitoring wells will monitor the growth of the thermal store within and outside the BHE field. Monitoring of the fluid and energy flow in the first few years of operation will also be required to optimize the long-term performance of the BTES system. Start-up of the system is scheduled for the fall of 2004.

RESUME

Un système de stockage thermique en puits a été mis en service en 2004 au Collège de Durham/Institut de technologie de l'Université de l'Ontario à Oshawa, Ontario. Le campus du collège/institut inclut huit nouveaux édifices conçus pour être chauffés et climatisés à l'énergie renouvelable dans le but de minimiser l'émission de gaz à effet de serre. Des programmes tests de forage ont été entrepris afin de déterminer la faisabilité du stockage thermique dans les morts-terrains et les formations rocheuses du site du collège/institut. Des essais sur place ont été menés afin de déterminer les caractéristiques de la nappe souterraine et les caractéristiques thermiques. Une formation calcaire presque imperméable a été rencontrée entre 55 et 200 mètres sous la surface. Le roc non fracturé homogène s'est révélé idéal pour le stockage de l'énergie thermique étant donné qu'il n'existe virtuellement pas de flux des eaux souterraines pour transporter l'énergie thermique à l'écart du site. La charge calorifique totale des édifices du campus est d'environ 7 000 Kw. En utilisant les résultats des tests de conductibilité thermique, on a déterminé qu'il fallait un champ de 370 puits de forage de 200 m de profondeur chacun pour rencontrer la demande énergétique. En outre, 5 puits de surveillance de la température ont été aménagés, augmentant le forage total du projet à 75 km. L'opération de forage a été effectuée à l'aide de trois appareils de forage fonctionnant 24 heures sur 24. Un tubage d'acier a été installé sur les 58 premiers mètres de chaque puits pour sceller les eaux souterraines à l'extérieur dans les formations à faible profondeur. Des modifications ont été apportées à la conception des échangeurs de chaleur de puits en résultat de l'absence de flux d'eaux souterraines dans le roc. La pratique suédoise des échangeurs de chaleur de puits remplis d'eau a été utilisée au lieu de la pratique nord-américaine des échangeurs remplis de béton à remplissage. Le fait d'avoir des échangeurs de chaleur de puits remplis d'eau améliore l'efficacité de l'installation des tubes en U et prolonge indéfiniment la durée de vie des puits de forage. Le système de stockage thermique en puits occupe la partie centrale de la cour du nouveau campus du Collège de Durham/Institut de technologie de l'Université de l'Ontario. Le champ est divisé en quatre secteurs afin d'optimiser le stockage saisonnier de l'énergie. Les échangeurs de chaleur de puits sont distancés sur une grille de 4,5 m et le champ total occupe environ 7 000 m^2 dans la zone. Une chaîne de sondes thermiques dans chacun des cinq puits de surveillance surveillera la croissance du stockage thermal à l'intérieur et à l'extérieur du champ d'échangeurs de chaleur. La surveillance du flot de fluides et d'énergie durant les premières années d'exploitation sera également requise afin d'optimiser le rendement à long terme du système de stockage thermique en puits. Le démarrage du système est prévu pour l'automne 2004.

1. INTRODUCTION

The University of Ontario Institute of Technology (UOIT) is Ontario's newest university and the campus has been constructed at Durham College in Oshawa, Ontario, Canada (Figure 1). Figure 2 shows the campus location on the northern boundary of the City of Oshawa. The initial phase of the school will comprise eight buildings clustered around a 72 m by 132 m central courtyard.

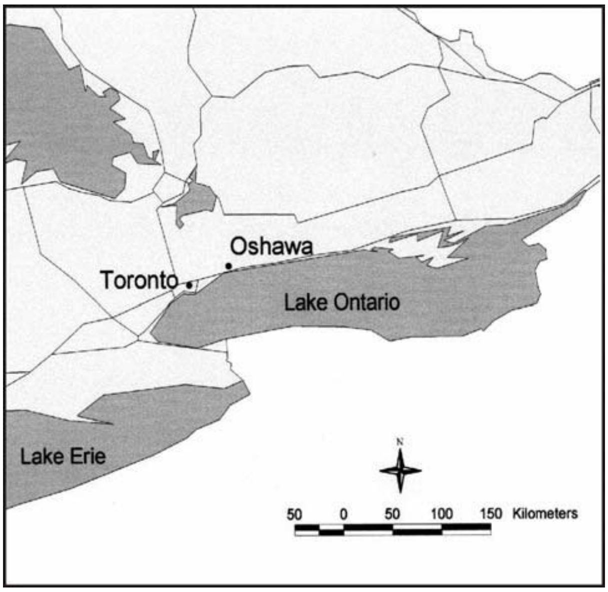

Figure 1. Location of Oshawa, Ontario

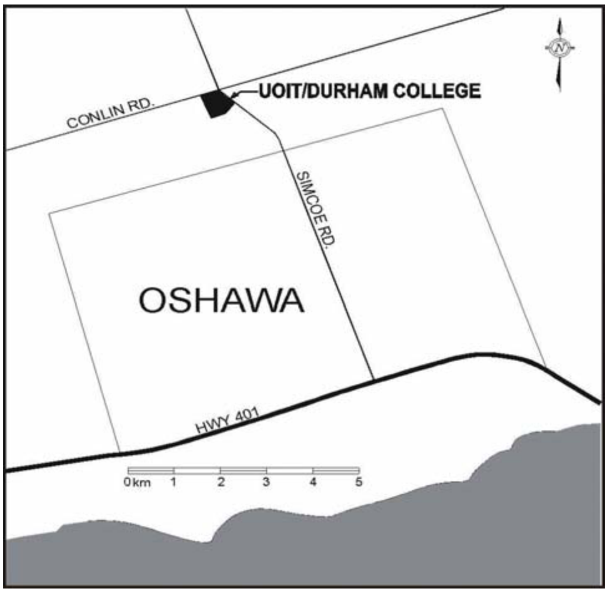

Figure 2. Location of UOIT/Durham College Campus

UOIT selected a geothermal energy system to heat and cool the campus buildings. A central plant on the east side of the courtyard houses the heat exchangers and delivers heating and cooling to the campus buildings. This paper describes the testing, design and installation of the geothermal energy facility that was installed at the university.

2. HYDROGEOLOGIC SETTING

A background study of the hydrogeologic setting revealed there was over 40 m of unconsolidated overburden deposits overlying shale bedrock in the vicinity of the site. Groundwater resources in the general Oshawa area are limited to isolated, thin sand deposits. Water well and geotechnical records in the study area indicated there were no regionally extensive aquifer systems. This ruled out groundwater as a geothermal energy resource (Michel et al., 2002). Municipal water services have replaced a few dozen low-yielding bored or drilled overburden wells near the campus. There were no records of bedrock wells, confirming the absence of deep rock aquifers.

A test drilling program was carried out to confirm the groundwater conditions and the geology at the site. The overburden comprises layers of glacial till, clay, silt and silty fine sand. No water-bearing sand deposits were found in the 44 m of deposits. Two Paleozoic sedimentary bedrock formations were encountered: 14 m of shale and 142 m of limestone. The stratigraphic log of the pilot test hole is shown in Figure 3.

The shale belongs to the Upper Ordovician Georgian Bay Formation, which underlies the eastern half of the Greater Toronto Area. Test pumping of the shale indicated that it yielded less than 0.1 L/s and had a hydraulic conductivity in the order of 10^{-8} m/s. The shale groundwater was saline (chloride of 15,000 mg/L) and contained traces of natural gas.

As a result of the small seepage of poor quality groundwater and natural gas into the test well, it was decided to seal off both the overburden and shale with a 150 mm diameter steel casing. The casing facilitated rapid drilling in the underlying limestone by an air-driven down the hole hammer drilling rig.

The deeper limestone belongs to the Lindsay Formation of the Upper Ordovician Simcoe Group. Video logging showed no visible fractures in the limestone and no evidence of groundwater seepage into the test hole. The hydraulic conductivity of the limestone is estimated to be less than 10^{-10} m/s. Figure 3 shows the geological conditions at UOIT/Durham College.

The background temperature of the geologic formations at the site is 10°C. Considering the ground temperature, the poor quality shale groundwater and the lack of a measurable groundwater flux in the limestone, it was concluded that the site was ideally suited for a borehole thermal energy storage (BTES) system.

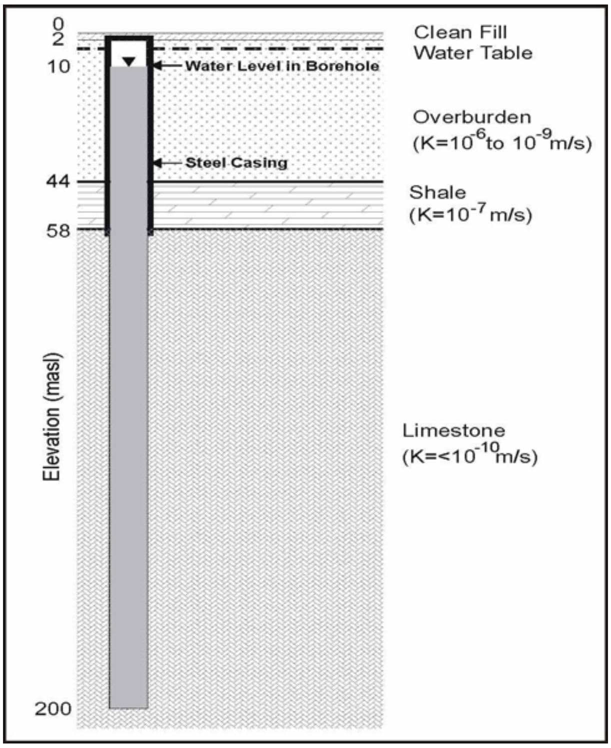

Figure 3. Site Geology and Borehole Construction

3. TESTING FOR BOREHOLE THERMAL ENERGY STORAGE

In accordance with the guidelines set out in Canadian Standards Association (CSA) No. C448.3-02 for BTES installations for institutional buildings, an insitu Thermal Response Test (TRT) was conducted in the pilot test well. The test was conducted with a Canadian-built mobile test rig, which was supplied and operated by Earth Energy Systems Inc., Halifax, Nova Scotia. The rig and test procedures were developed at the Lulea University of Technology, Sweden (Eklof et al., 1996).

The TRT involved the installation of a closed loop in the pilot test well. The well bore had to be filled with municipal water, since there was no groundwater recovery in the limestone formation.

Water was circulated through the closed loop at a rate of 0.75 L/s, with a constant heat injection of 3.2 Kw. The heat injection test was conducted for 72 hours, followed by a 72-hour recovery period. The power input, flow rate, and the loop inlet and outlet temperatures were recorded during the heat injection and recovery period.

The thermal conductivity was determined from the relationship between the heat rate, the test hole length and the slope of the mean temperature data vs the natural log of time. The “apparent” thermal conductivity of the geologic media encountered in the test well was calculated to be in the order of 1.9 (W/m)/K.

4. DESIGN OF THE BTES FIELD

The design of the BTES field began with modeling of the seasonal heating and cooling loads for the campus buildings. This work was done by Keen Engineering Ltd., mechanical consultants for the project. The model results indicated that a slight imbalance existed in the annual heating and cooling loads. The cooling load was dominant, with a peak requirement in the summer period of approximately 2,000 tons (7,000 Kw).

The higher cooling load means that there will be more heat rejection to the ground than heat extraction. The slight imbalance in heat rejection vs heat extraction can cause a gradual heat build-up in the ground over time. The potential for heat build-up can be determined by modeling software and contingencies developed to mitigate any loss in system efficiency.

The preliminary test drilling and hydraulic and thermal conductivity testing demonstrated the heat content of the geologic media should be targeted for the BTES system. The energy supply for the heat exchangers in the building will come mainly from horizontal conduction within the upper 200 m of the overburden and bedrock matrix. The lack of any significant groundwater flux at the BTES site means that advective transport of energy via groundwater does not have to be considered.

Determination of the size of the BTES energy reservoir was based primarily on the peak cooling load (2,000 tons or 7,000 Kw), the vertical geothermal heat flux in the geologic matrix and import of heat to the reservoir by conduction. Earth Energy Designer, a numerical model developed by the Universities of Lund, Sweden and Giessen, Germany (Hellstrom et al., 2001) was used to estimate the required number of boreholes in the BTES field.

The final design of the BTES field included a total of 370 boreholes and 5 observations wells drilled to a depth of 200 m. The central courtyard provided space for a 14 by 28 grid of boreholes at a spacing of 4.5 m. The layout of the 0.7 hectare BTES field is shown on Figures 4 and 5.

The CSA guidelines for BTES systems (No. C448.3-02) require grouted boreholes to *“arrest the downward percolation of potentially contaminated surface water into the rock stratigraphic units and aquifers pierced by the borehole” (Section 5.6.2, C448.3-02).* Since no bedrock aquifer exists at the university campus, there was no need to grout the boreholes. The use of steel casing in the overburden and shale formations and the absence of a measurable groundwater flow in the limestone, however, eliminated any concerns of downward percolation of contaminants.

In other countries where similar unfractured rock is found, such as Sweden and Norway, it has become standard practice to utilize water-filled boreholes in BTES fields (Anderson et al., 2003; Lund et al., 2003). Based on the Scandinavian experience, the UOIT/Durham College BTES boreholes were designed to be water-filled rather than grouted. This cost-saving measure is believed to be the first application in North America.

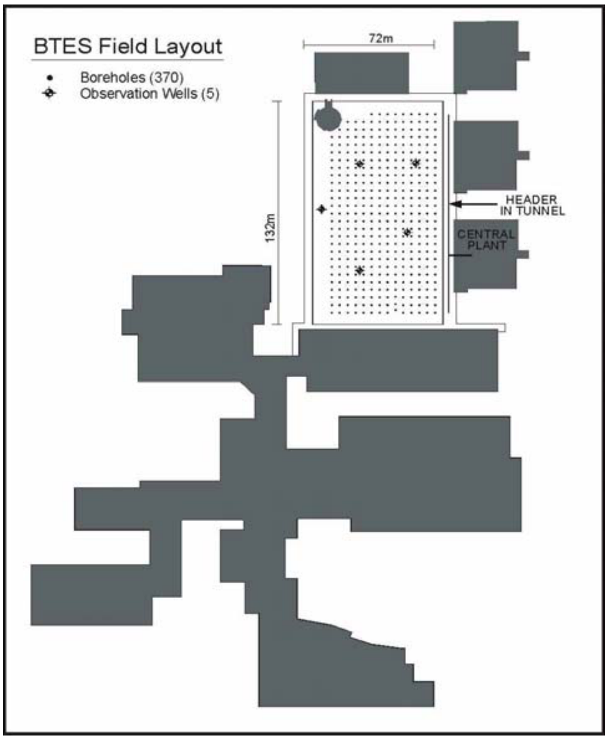

Figure 4. UOIT/Durham College Campus and BTES Field Layout

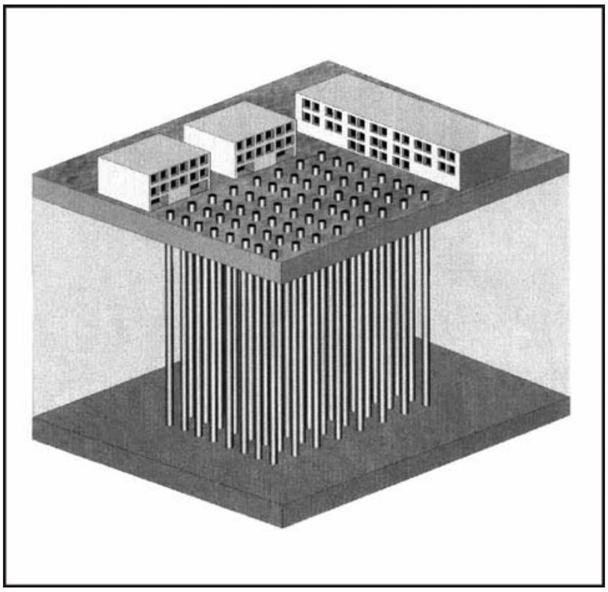

Figure 5. Schematic of BTES Field

5. CONSTRUCTION OF THE BTES FIELD

Prior to commencing the borehole drilling, about 2 m of soil was removed to make a level base for the BTES field. A 300 mm drainage layer of crushed stone was placed over the glacial till soils to provide a working base for the heavy drilling rigs. The stone bedding also provided an effective drainage layer for precipitation and drilling fluids.

The drilling program was carried out by SDS Drilling Ltd. (SDS), a division of the Boart Longyear Group, of Calgary, Alberta. SDS provided three Ingersoll Rand Model T-90 drilling rigs for the project. Drilling commenced in mid-July, 2003 and proceeded on a 24 hour per day, 7 days per week basis until the project was completed at the end of October.

Six, two-man crews carried out the drilling program, working on 12-hour shifts. Periodic shift rotations were used and crew replacements were made every few weeks to avoid driller fatigue. Three to four boreholes were drilled each day by the six drilling crews.

In order to achieve the high drilling production rate, all components of the operation had to be carefully planned in advance. Adequate working space had to be scheduled daily for drilling materials, well casing, supply of water, and drilling mud circulation tanks. The three drilling rigs were serviced daily with fuel trucks and vacuum trucks to remove the borehole cuttings.

The nature of the site geology required two different drilling techniques. Hydraulic mud rotary was used in the upper 58 m of overburden and shale. The boreholes were cased with 150 mm diameter steel casings with threaded couplings. Drilling proceeded in the limestone with an air-driven down the hole hammer (DHH). With the DHH technology, high-pressure air is supplied to a drill bit through the drill string to remove the drill cuttings. This method achieved average drilling rates of about 15 m per hour.

The steel casings were seated about 1.5 m into the limestone bedrock in each BTES borehole. The surface annulus around each casing was sealed with bentonite grout to prevent downward seepage of surface drainage.

Daily inspection of the BTES drilling program was carried out to log the stratigraphy, monitor groundwater conditions in the boreholes and confirm the borehole depths. About 10% of the boreholes were video-logged to evaluate the borehole plumbness and examine the limestone formation for fractures and groundwater seepage. The inspections indicated that homogeneous geologic conditions existed throughout the BTES field.

The boreholes were left dry at the completion of the drilling. The water level recovery rate was monitored in three of the 200 m deep observation wells, and averaged only about 2 cm per day over a 200-day period. Few fractures or fissures were noted in the limestone video logs, which explained the extremely low groundwater flux in the rock.

6. INSTALLATION OF U-TUBE HEAT EXCHANGERS

The manufacture, installation techniques and operation of borehole heat exchangers has become standardized around the world. They involve the circulation of a heat-transfer liquid through polyethylene U-tubes installed in each borehole. The only design variations are the type of heat-transfer fluid (water or antifreeze) and the borehole filling materials (water or grout).

The U-tube material used for the UOIT/Durham College BTES project complied with CSA Standard B127.1. The 32 mm ID piping was factory stamped with the “C448” code. The high density polyethylene (HDPE) pipe was PE 3408, with a minimum cell classification of 345434, as specified in ASTM Standard D 3350. It had a DR11 (160 psi) rating which meets the CSA requirement for vertical heat exchanger pipes.

The use of water-filled boreholes resulted in several cost-saving adaptations to conventional U-tube installation practices. First, the U-tube installations were campaigned separately from the borehole drilling work. This procedure improved the time-efficiency of each operation. The U-tube installations lagged about six weeks behind the drilling operations, allowing separate material storage and working areas for each task.

The HDPE pipe was delivered to the site in large reels of 2,100 m rather than the smaller, custom-length reels that are normally supplied for individual boreholes. The long reels, which were pressurized and sealed with fusion caps, reduced the on-site material storage areas and significantly improved the U-tube installation time. The combination of dry boreholes and large reels allowed as much as 6,000 m of U-tubing to be installed per day.

The heat exchanger tubing was pressure-tested on delivery to the job-site and kept sealed until insertion in each borehole. The U-tube installations were carried out by Groundheat Systems International and included the following steps:

- uncoiling adjacent twin reels to attach the U-band by a socket fusion;
- attachment of 90 kg of 2 cm-diameter iron sinker bars to the bottom 20 m of the U-tube to counteract the buoyancy of the tubing in the water-filled borehole;
- insertion of the entire 200 m long U-tube assembly into a dry borehole;
- simultaneous filling of the U-tube and the borehole with treated Lake Ontario water from the Oshawa water supply system;
- installation of fusion caps on the pipe ends to prevent entry of any surface water or debris.

Each heat exchanger assembly was pressure tested after installation in compliance with the CSA standards. The pressure test involved compressing the water in the U-tube with compressed air to at least 690 kPa (100 psi). The pressure was maintained for 1 hour. The U-tube was considered to be leak-free if there was no significant pressure loss at the end of the 1 hour test period. Two of the 370 U-tube installations were found to have excessive pressure loss due to leakage at the U-band fusions. These U-tubes were removed and replaced by new installations.

After the heat exchangers were installed, each borehole was topped-up with municipal water and an air-tight sanitary well seal was secured into place on top of the borehole casing. A custom-made steel cap was then installed over the sealed U-tube extensions. This protective cap prevented any vehicular damage prior to connecting the U-tubes to the horizontal distribution pipes.

The 370 U-tube installations were done by a 4 man crew over a 50 day period. The installation rate averaged about 7 boreholes per day. At peak efficiency, however the crew installed up to 14 heat exchangers per day. In total, the BTES field contains over 148 kms of heat exchange pipes.

After connection of the heat exchanger pipes to the horizontal distribution pipes, the BTES field was backfilled with about 2 m of clean fill. The casings on the 5 observation wells and one of the heat exchange boreholes were extended to the final grade to permit future instrumentation and monitoring.

7. DISCUSSION

BTES installations have grown rapidly in the United States, Sweden and Switzerland over the past few years (Lund et al., 2003). In Canada, however, there are very few operating BTES systems. The UOIT/Durham College BTES system is the largest water-filled borehole field in the world and will become a showcase for renewable geothermal energy projects in Canada.

BTES systems have been in operation in Europe and the United States for over 10 years. They have proven to be a very reliable energy source for heating and cooling large buildings. The experience to-date indicates that BTES systems require a minimum of maintenance.

The UOIT/Durham College BTES system is scheduled to start-up in the fall of 2004. Careful monitoring of the ground temperatures will be required for the first few years of operation to assess the efficiency and performance of the BTES field. It also takes a few years to streamline the building heating and cooling control and data processing systems.

The annual energy load for the campus buildings is cooling dominant. This means that there will be more thermal energy released to the ground than is required by the annual heating load. Experience with other large BTES systems indicates that it may take 2 to 3 years of operation before a new stable thermal equilibrium is established between the ground and the borehole heat exchangers.

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