UTILIZATION OF ABANDONED MINE WORKINGS FOR THERMAL ENERGY STORAGE IN CANADA

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ABSTRACT

The utilization of groundwater from abandoned mine workings for heating and cooling of buildings and industrial processes started in Canada in 1989 when the Town of Springhill created an industrial park where companies could tap into the geothermal energy supply from the local abandoned coal mines. The mines are estimated to have an energy potential in excess of 67,000 MWh/yr. A study of former gold mines in Timmins again found that the mines had a significant potential energy resource of at least 28,000 MWh/yr. Critical issues for the development of successful CTES projects are examined.

1. INTRODUCTION

Canada has a vast variety of mineral resources throughout the country and mining continues to be a major economic engine for the economy. There are literally thousands of old mine workings that have been abandoned over the years and many of these old workings are now flooded by groundwater. Some of the mining communities that originally developed near the mine sites have continued to exist after mine closure, either due to the discovery of new ore bodies nearby, or because of the diversification of employment opportunities through time. Some communities are now regional urban centres, while others are smaller, quieter towns. Due to the locations of the mines, most of these communities are in relatively remote regions where energy costs are high due to increased transportation distances.

Mine development depends on the type of deposit, the distribution of mineralization, depth, and economic factors. The size of the mine workings also depends on the extent and grade of the mineralization and the type of equipment utilized during mining. Communities that continue to exist after a mine closes are often well established and have developed over many years of prosperous mine activity. In some instances, the community was situated beyond the limits of mining activity, while for others an intricate network of tunnels permeates the subsurface beneath their foundations.

As conventional energy costs continue to rise, alternative, renewable energy sources need to be developed, especially for these more remote localities. Flooded mine workings provide an opportunity for the economic development of low-grade geothermal energy for heating and cooling of buildings, which in Canada accounts for roughly 60% of the total energy load (NRCan 2006). In 1989, the community of Springhill, Nova Scotia began utilizing mine waters for cooling and remains the only Canadian community to realize the benefits of this type of energy source. Jessop et al. (1995) discussed the potential utilization of subsurface mine workings in Canada, while Michel et al. (2002) reported on a preliminary study for old gold mines at Timmins, Ontario. Other communities are now interested in examining the potential of their old mine sites and are beginning to evaluate that potential as part of their overall energy reviews. This paper examines the potential for the development of flooded mine workings (caverns) as thermal energy stores (CTES) by subdividing mines into two broad categories; coal mines where workings are contained largely within individual sedimentary strata (usually horizontal to shallow dipping), and hard rock mines where workings tend to be dimensionally more diverse and contain a significant vertical component.

2. COAL MINES

Coal deposits are formed within sedimentary basins containing shallowly-dipping strata that can become deformed at a later time due to tectonic activity. Most coal mine workings are developed within a relatively thick (2-5 m) coal seam that is areally extensive and contained within a relatively stable package of rocks. Mining methods attempt to remove as much of the coal seam as possible without compromising the stability of the workings, which are contained within the confines of the seam. This often leads to the presence of pillars within older workings, while long-wall techniques often result in roof collapse for much of the workings after mining of that particular section has ended. Mining often begins in the near-surface subcrop area and develops the workings down slope, following the dip of the strata. Haulage of coal from the subsurface is also along the slope of the workings, rather than through shafts. The presence of multiple coal seams can lead to the development of multiple layers of workings that are separated by barren rock and have little interconnection between slopes.

In eastern Canada, extensive coal mining has occurred in several sedimentary basins within Nova Scotia. Mining in the town of Springhill ended in 1958 and the town was the first community to develop a CTES system. It serves as a model and case study for future development of abandoned workings in other basins, such as the Stellarton Basin and the Sydney Basin of Nova Scotia. The Nova Scotia government passed legislation in 1992 that declared these coal basins as geothermal resource areas in anticipation of the technological development of this type of renewable energy resource. It is appropriate, therefore, to examine the resource development that has occurred at Springhill as an example for coal mining regions.

2.1 SPRINGHILL GEOTHERMAL DEVELOPMENT

Springhill is situated in north-central Nova Scotia within the Cumberland Basin, which contains sedimentary rocks that include several major coal-bearing units. The Town of Springhill is centered on latitude 45^{o} 39' 00"N and longitude 64^{o} 03' 30"W. An industrial park area has been designated immediately west of the town and overlies the majority of old abandoned mine workings in the area that have flooded since the cessation of mining in 1958.

The climate of the Springhill area is influenced by the water bodies of the Gulf of St. Lawrence and the Bay of Fundy (Atlantic Ocean), which moderate temperatures. The average annual temperature in the area is approximately 5.9^{o}C and precipitation is distributed throughout the year with annual totals of approximately 1100 mm.

Canadian climate normals for the period of 1971 to 2000 for nearby Truro indicate that the maximum and minimum daily temperatures are 24.1°C / 12.7°C in July and -1.5°C / -12.3°C in January (Environment Canada, 2008). Extreme maximum and minimum temperatures have been 33.5°C in July and -34.4°C in February. The average annual number of heating degree-days is 4518 and the number of cooling degree-days is 92.

From the climate data, it would appear that heating would be the primary consideration, however; in industrial and commercial buildings, excess heat is often produced from manufacturing equipment, lighting, and office equipment such as computers. Therefore, there is always an increased demand for cooling and cooling has been the dominant use of the mine groundwater.

Test drilling of wells began in 1987 for the development of independent systems for businesses in Springhill and the industrial park. Several companies now operate mine water systems and in the fall of 2004, Springhill's Dr. Carson and Marion Murray Community Centre began operation of its arena facility with mine water as a cooling source. Interest has also been expressed by other potential businesses and community organizations so that additional geothermal development is expected in the future.

The geology of the Cumberland Basin in the Springhill area has been well documented. Due to the extensive production of coal for nearly 100 years from several seams to depths approaching 1200 m, the subsurface geology has been recorded both within the workings and from numerous boreholes probing coal seam quality and continuity. The mine workings in the Springhill area are in fact the deepest coal mine workings in Canada. More recently, deep borehole investigations by several companies have focused on the generation and recovery of methane gas associated with the unmined portions of the coal seams. Although more than 20 individual seams have been identified, only five were thick enough to permit economic exploitation. This sequence of coal strata is generally found within competent sandstones, although finer grained shales and mudstones also occur.

Most of the mining in Springhill has occurred in the area underlying the western part of the town, including the industrial park, but extends significantly beyond the park area for Seam 2 workings. Systematic mining has created an extensive interconnected network of workings for each of the five mined seams. Seams 1 and 3 contain upper and lower subseams that were mined separately in places so that a total of seven distinct mining levels exist. All of the seams were accessed along slopes that were opened in the subcrop area, with subsurface development work progressing down dip to the west. The degree to which any seam was mined depended on the thickness, continuity and quality of the coal. The mining technique varied with subsurface conditions. The most common method was room and pillar, but included long wall and pillar recovery. Herteis (2006) estimated that approximately 68% of the coal from the No. 2 Seam was recovered within the mining area, but due to collapse within the workings only 25% of the void space remains. Some workings were intentionally collapsed as pillars were removed, while others have subsequently collapsed with time. There have also been a number of cave-ins, fires and explosions through the many years of operation, which have led in some instances to sealing (separating) workings. Mine records have been digitized by provincial government staff and compiled in maps to show the distribution of workings for each seam. Very little mining was conducted within approximately 30 m of surface as a precaution against potential roof collapse propagating to surface.

Test drilling into the old mine workings for development of the geothermal energy systems has been conducted by several consultants, but all of the drilling has been confined to relatively shallow depths of less than 100 m (Ross and Kavanaugh, 1993). The greatest problem encountered was identifying the exact location of the workings. Test wells that did not intersect workings, but rather pillars, generally provided little water and were abandoned. Those wells that did encounter the workings usually had test flow rates exceeding 10 to 15 L/s. Blow back testing with air to estimate yields led to errors due to loss of the air and water into the workings rather than back up the borehole. Pumping tests, or in the case of the community centre wells, injection tests, were required to evaluate true well capacities.

Water chemistry analyses identified the shallower groundwater as similar in composition to the town's former groundwater supply (hard calcium bicarbonate type); however, with increased pumping and/or depth the water chemistry displayed a shift to a hard calcium sulphate/bicarbonate type that contained significant iron concentrations and strongly reducing conditions. The reducing conditions led to the formation of hydrogen sulphide gas and ammonia in the water. The inadvertent introduction of oxygen into mine waters through wells operated by one user caused well clogging with iron bacteria.

Temperature data for the mine waters are limited to measurements taken during the drilling and testing of wells in the 1987 to 1991 period. Initial measurements at the time of drilling indicate that water temperatures were generally between 11.5 and 13.5^{o}C. By comparison, shallow groundwater temperatures were approximately 9^{o}C. During several days of continuous pumping tests, temperatures tended to increase to as high as 18^{o}C. This rise in temperature was attributed to the upwelling of warmer deeper mine waters as the pumping tests progressed. Calculated geothermal gradients for the local Cumberland Basin area average 25^{o}C/km, and are relatively typical for deep sedimentary basins in Canada. Since the deepest mine workings extend to a depth of just over a km and near surface groundwater temperatures are approximately 9^{o}C, it is possible that the deepest mine waters could attain temperatures in excess of 35^{o}C. However, no measurements of deep mine waters are available at present.

Daily well water supply temperatures for the arena facility in the community centre are quite variable, but display an increasing trend since opening in 2004 (average temperatures: 15.5^{o}C for November 2004 to March 2005; 20^{o}C for September 2005 to March 2006; 22^{o}C for September 2006 to January 2007) (Figure 1). The temperatures start relatively high in the fall and decrease to a low in January, at which time they start to rise again. The seasonal fluctuation probably reflects the capture and reuse of the waste heat within the building during the winter when outside temperatures are at a minimum. Although the upward year to year trend might be due to the upward migration of deeper mine waters, the close proximity of the pumping and reinjection wells for the community centre (approximately 30 m apart) and the seasonal variation in supply temperatures could be indicative of a well interference problem.

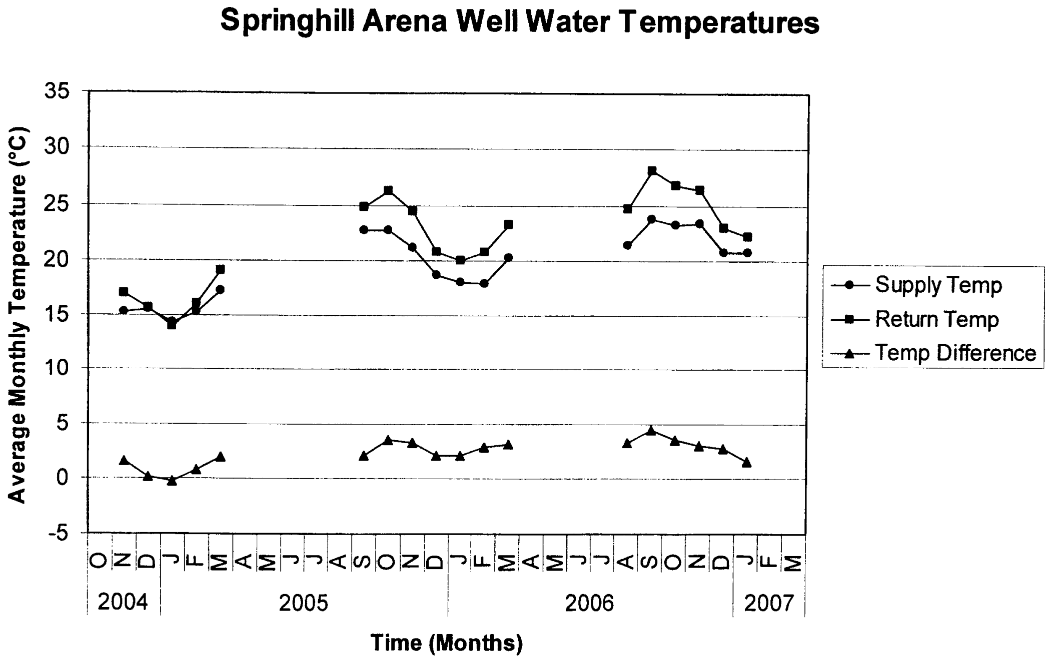

Figure 1: Monthly average well water temperatures for the Dr. Carson and Marion Murray Community Centre area facility.

All of the systems operating to date in Springhill demonstrate that the mine waters do possess potential for providing heating and cooling energy. The total potential of the workings depends primarily on the size (volume) of the workings and in-situ temperatures. Herteis (2006) undertook a detailed GIS analysis of the No. 2 Seam workings and estimated a total of 5,582,588 m^3 of water. No estimates have been established for other mine workings in seams 1, 3, 6, or 7, although operational geothermal wells are tapping water currently from Seams 6 and 7.

One can roughly estimate the energy potential of a geothermal resource for heating and cooling by examining the volume and temperature of the mine groundwaters and the local air temperature records. Calculations based on the volume estimates of Herteis (2006) for the No. 2 Seam and an average water temperature of 15°C yield an estimate of 67,000 MWh per year of heating and cooling energy for an average circulation rate of once per year for the mine water (a continuous flow rate of roughly 180 L/s). Water contained in the other mined seams would add to this total potential.

3. HARD ROCK MINES

Many of the metallic ore deposits in Canada are found within igneous or metamorphic rocks as veins or lenses of mineralization. Underground mining operations are designed to extract these metals with as little waste rock removal as possible. Thus the workings tend to consist of a series of drifts (tunnels) and stopes (caverns) that follow the mineralization on a series of levels and connect back to a main vertical shaft. Workings developed on one level often will extend to other levels such that there is extensive interconnection vertically between levels. Workings can extend to depths of one to two km and in some instances may connect to workings from other mines in the area. After the cessation of mining, the workings tend to flood with groundwater and shallow workings may receive significant infiltrating water in the spring from snow melt. Michel et al. (2002) undertook a study of old gold mines at Timmins, Ontario to examine the potential for development of a CTES resource.

3.1 TIMMINS GEOTHERMAL DEVELOPMENT

The City of Timmins is located in northern Ontario at latitude 48° 29' N and 81° 20' W, and was the center of gold mining activity throughout the 20th century. Many of the old mines lie along the eastern margin of the community and are now flooded. Normal maximum and minimum temperatures are 24°C / 10°C in July and -11°C / -24°C in January while daily mean temperatures for these months are 17.4°C and -17.5°C, respectively. Mean annual temperature is 1.3°C, annual precipitation is 558 mm, and the average heating degree-days is about 6,200 (Environment Canada, 2008). As with Springhill, heating would appear to be the primary consideration, but significant cooling is also required.

The two major mines examined (the Hollinger and McIntyre) were developed on steeply dipping veins. The workings for each mine extend laterally for over a km, while the main shafts extended to depths of 845 and 1260 m, respectively. Drifts were developed at 30 m intervals, while the stopes usually interconnected the levels as the veins were mined. The width of the stope workings averaged 3 m above a depth of 180 m, while below that they averaged 6.5 m. Although no detailed estimate of the mine workings volume is currently available, a 'back of the envelope' calculation with 20% of the original space open would suggest a volume on the order of 1,000,000 m^3 for each mine. Staff from the current mine property owner proved interconnection of the workings for the two mines when pumping of water from one shaft resulted in parallel drawdown in the other shaft, as well as in other adjacent workings on the two properties. Water chemistry from all mine sites had a consistent Ca-Mg-SO_4 composition with a near neutral pH.

Temperature profiling was conducted in the two main shafts and a shallower shaft (289 m deep) at an adjacent property (Canadel). Historical records report measured geothermal gradients in the mines during operation of 0.7 to 0.9°C per 100 m and bottom temperatures approaching 16°C. The Canadel shaft yielded a relatively stable temperature profile, increasing only at a rate of 0.1°C per 100 m. The water level in the McIntyre shaft was at a depth of 24 m and the upper 15 m of water had a constant temperature of 10.25°C (Figure 2). Below 40 m depth the water temperature rose rapidly to 13.3°C and then remained constant to the bottom of the shaft. The profile indicates that warm water from depth is rising up the shaft and flowing out through the near surface workings at a depth of 40 to 45 m. The temperature profile for the Hollinger shaft displays a rapid but variable rise in temperature to 12.7°C at a depth of 400 m, below which it remained constant. This also indicates upwelling of warm water from depth and recirculation into the mine workings at a depth of 400 m. Low temperatures near surface reflect the retention of snow melt water.

An estimate of the energy potential was calculated using the mine water volume estimates, an average mine water temperature of 13°C and monthly air temperatures. For a flow rate of one mine workings volume per year (roughly 60 L/s), the energy potential for the Hollinger and McIntyre mines would be on the order of 28,000 MWh/yr. If the time for the water to re-equilibrate is less than one year, the flow rate could be increased and the energy potential would increase proportionally.

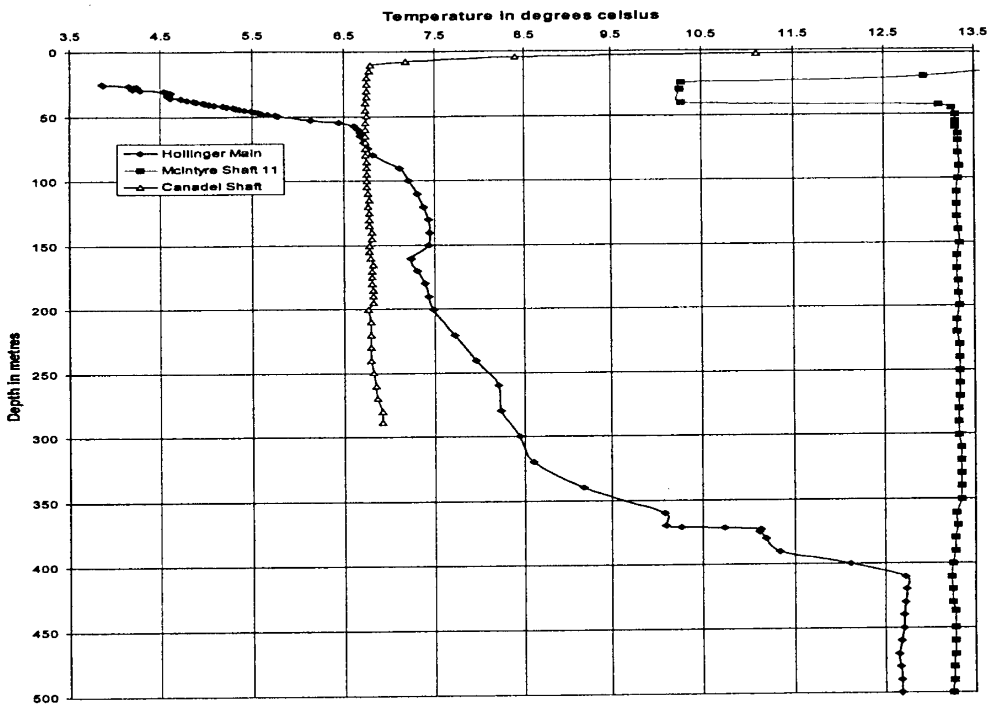

Figure 2: Temperature profiles for the Hollinger Main Shaft, McIntyre Shaft 11 and Canadel Shaft in Timmins, Ontario.

4. DISCUSSION

The two examples described above show that both types of mines contain significant renewable energy potential in the range of thousands of MWh/yr, with average annual air temperatures ranging from roughly 1 to 6°C. The scenarios presented provide theoretically ideal estimates of the energy potential using flow rates of one mine volume per year, but do not consider the additional benefits of storage or the development of distinct hot and cold reservoirs. At both mine sites, warm water has been found at shallower depths than expected based on the geothermal gradient and suggests upwelling of this warm water. The estimates also do not take into account the additional cooling often required by industrial users.

A review of the CTES potential from mined coal seams in the Appalachian region of the U.S. by Watzlaf and Ackman (2006) indicates that annual costs could be reduced by 67% for heating and 50% for cooling compared to conventional methods. If so much renewable energy is waiting to be tapped, one must ask why so few developments have taken place in Canada and on a world-wide basis. What are the stumbling blocks for increased development?

Some of the major issues that need to be addressed include: a detailed knowledge of the positions of the workings and their interconnection, circulation pathways for the mine water, maintenance of water temperatures through time, the potential for rock subsidence and roof collapse propagating to surface if the water levels are lowered, and the coordinated/regulated development of the resource since the mine workings could extend under large areas of the community. Much needs to be done to investigate these issues and well managed demonstration projects need to be developed to showcase the technology and the potential. This requires knowledgeable persons (researchers/consultants) to develop and manage the projects and investors who understand the potential.

5. CONCLUSIONS

The renewable energy potential contained in groundwaters flooding old abandoned mine workings is enormous. Calculations for a single seam of a coal mine in Springhill, Nova Scotia, where a number of small-scale individual systems are operating currently, estimates the total energy potential at approximately 67,000 MWh/yr. A preliminary study for two interconnected former gold mines at Timmins, Ontario estimates the combined energy potential for heating and cooling at nearly 28,000 MWh/yr, assuming pumping at a rate of one mine volume per year. Research is still required to understand many aspects of these systems, especially when it comes to thermal storage, and well developed demonstration projects are needed to showcase the technology and potential.

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