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# A Concept of Making Use of Closed Underground Workings for Heat Recovery in Historical 'Wieliczka' Salt Mine (UNESCO)

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**ABSTRACT**

A concept of exploiting heat from old workings to be closed in the 'Wieliczka' Salt Mine is described in the paper. The monumental salt mine has been uninterruptedly operational since the 13th century. At present this is predominantly a museum of mining industry visited by over a million tourists from all over the world each year. The 'Wieliczka' Salt Mine has been put on the first UNESCO World Heritage List of 1978. The operations performed in the mine are related to maintaining historical workings, the Tourist Route and the extreme Miner's Route. Apart from this, an underground sanatorium was made for curing various diseases, mainly allergies. Part of over 200 km long workings and saline domes were liquidated to maintain the monumental part of the mine. Therefore a concept was proposed, according to which in part of the old workings, prior to the liquidation and backfilling, heat reception systems should be built. Thus obtained heat could be used by the underground sanatorium, e.g. for heating up saline water for balneological purposes and by the underground restaurant. A concept of heat reception from lower levels in the mine to be used on the upper levels is presented in the paper. In this way an underground heat transformer can be put to use instead of taking the energy from the mine's surface. Experience gathered while realizing this project could be used for other tourist-managed monumental mine objects and also for working mines.

## 1. INTRODUCTION

The regular mining activity in a mine can be accompanied by a variety of extra additional operations. While liquidating old workings in underground mines numerous activities may be undertaken (Ostaficzuk 2000), e.g. recovery of the heat from the Earth. Examples of how heat has recently been recuperated from completely or partly liquidated underground are:

- from ventilation air in operational underground mines,
- from dehydration water in active underground or opencast mines (Solik-Heliasz 2002), e.g. from hard coal mines in the Upper Silesian Basin, a total of about 416 $m^3$ of water per minute is produced during dehydration operations. The total heat energy potential included in them has been estimated to be more than 220 MW (Solik-Heliasz 2007, 2009),
- water from closed mines is produced to protect the neighboring mines. The heat of such water can be used for heating purposes (Mutke 2008),
- water from closed underground mines can be used as a heat carrier, e.g. installations in Heerlen, Netherlands; Edinburgh, Scotland; Springhill in Nova Scotia, Canada described by Verhoeven et al. (2014), Burke (2002) and Jessop (1995),
- there are also reports on heat production from underground mines with the use of closed-loop pipe heat exchangers (spirals filled with working agent). They can be installed in workings prior to applying proppants (liquidation operation) and connected with heat receivers on the surface through insulated vertical pipes (Borkiewicz 2002).

Apart from this, old workings can also be used for heating purposes in other ways, e.g. oil&gas wells described by, e.g. Sliwa et al. (2000) or Sliwa and Kotyza (2003).

The heat can also be recovered from partly liquidated workings in underground mines. Heat recovery installations can be disposed in the liquidated parts and used for heating purposes. The heat recovery can be realized through pipes with a heat carrier placed in liquidated workings prior to the proppant application.

The Salt Mine 'Wieliczka' S.A. is the oldest operational salt mine in Poland and one of the oldest in Europe. The unique character of this place has been confirmed by the fact that 'Wieliczka' is on the UNESCO World Cultural and Natural Heritage List.

The first traces of salt production in Wieliczka site date back to Neolithic times (about 4000 B.C.) and are the oldest in Europe. It was there, where the oldest (middle Neolithic) salt-mining sites were discovered by archeologists. The historical origins of the salt mine date back to the Middle Ages. Urged by the necessity to regulate the mining principles, in 1368 the Polish king Casimir the Great pronounced a legal act known as „*Statutes of Casimir the Great*".

## 2. SALT MINE NOW

The end of extraction of the salt deposit in 1996 meant the beginning of other forms of activity of the 'Wieliczka' mine. The salt company modified its profile from production to services. 'A restructuring program' was worked out for the Mine, where the protection activities, financed from the State Budget, were separated from other activities of the company.

The 'Wieliczka' Salt Mine S.A. protects and maintains the historical workings, fights the mining hazards and utilizes brines. The tourist activity and services are in the hands of an offspring company formed in 1997, i.e. 'Wieliczka' Salt Mine Tourist Route Sp. z o.o. Some fragments of the underground Tourist Route have been presented in figs. 1 to 8, including objects saved thanks to the liquidation of deeper workings deposited underneath.

**Figure 1: Salt Chamber of St. Kinga.**

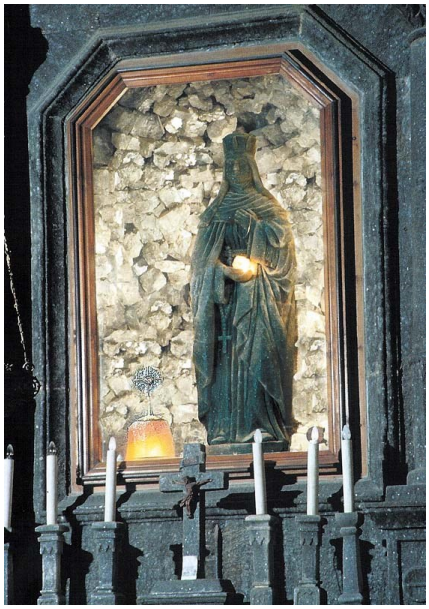

**Figure 2: Salt altar in the Chamber of St. Kinga.**

**Figure 3: Tourist Route – Chamber of Józef Piłsudski.**

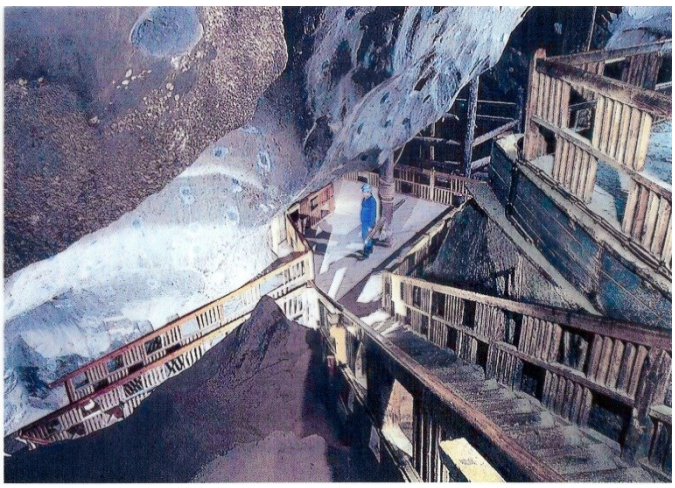

**Figure 4: Fragment of the underground Tourist Route.**

**Figure 5: Fragment of the underground Tourist Route – Chamber of Pieskowa Skała.**

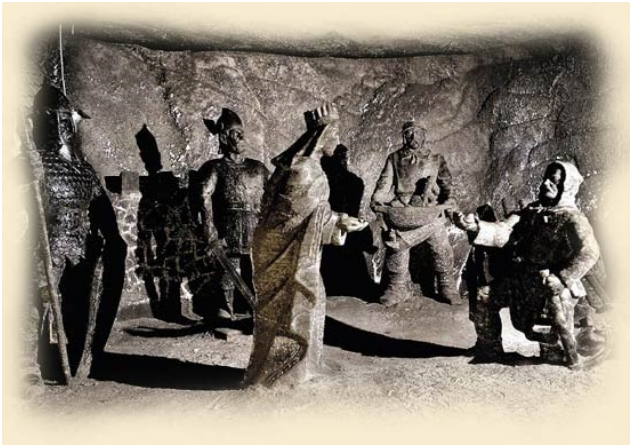

**Figure 6: Salt sculptures on the Tourist Route – Chamber of Janowice.**

**Figure 7: Exposition on the underground Tourist Route – Chamber of Pieskowa Skała - Pater Noster.**

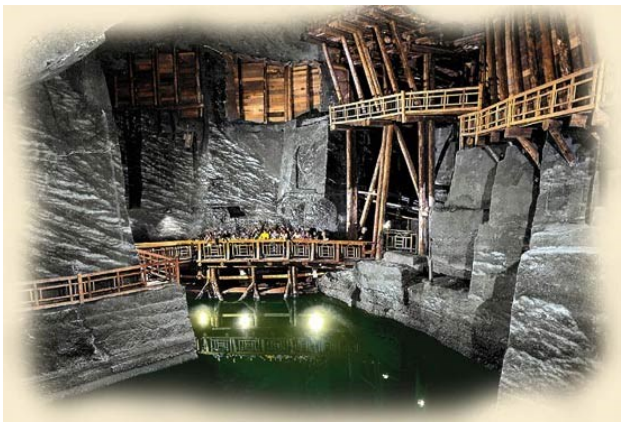

**Figure 8: Tourist Route – Chamber of Erazm Barącz.**

The underground Tourist Route has been open for years (figs. 9 to 11). The visitors have a chance to undertake an active trip along the underground workings, requiring more physical effort. There are more demanding sections with narrow and low passages. Mining traditions and customs are presented along the way.

**Figure 9. Underground Miner's Route – water wheel (kopalnia.pl).**

**Figure 10. Underground Miner's Route – mine's maps (kopalnia.pl).**

**Figure 11. Underground Miner's Route – work underground (kopalnia.pl).**

At 135m depth (level 3) an underground Spa was established (figs. 12 to 14). In the 19$^{th}$ century Wieliczka was a renowned resort where inhalations and brine baths were offered. At present the Spa continues its activity making use of the microclimate of the Mine which has a therapeutic value for treating allergies and the diseases of the respiratory system.

The climate of the 'Wieliczka' Salt Mine basically differs from that on the surface. The saturation of the mines' aerosol with sodium chloride is one of the most important factors for the therapeutic properties of saline chambers. This compound comes from the leaching process and weathering of saline rocks. The underground aerosol is very clean as far as its microbiology and palinology is concerned.

The therapeutic activity of the Mine is mainly focused on curing diseases of the upper and lower respiratory systems, including asthma and allergies. The curing process can be realized thanks to the unique microclimate of the Mine, i.e.:

- exceptional bacteriological purity,
- constant air temperature 15°C to 16°C,
- high relative humidity of air (ca. 80%),
- high sodium chloride content (24 mg/m$^3$) and presence of such elements as magnesium, manganese and calcium.


**Figure 12: Spa – Therapeutic Chamber – Wessel Lake (kopalnia.pl/uzdrowisko).**

**Figure 13: Activities for children in the underground Spa (kopalnia.pl/uzdrowisko).**

**Figure 14: Fragment of Spa – Wessel Lake (kopalnia.pl/uzdrowisko).**

The mine's air does not contain any pollutions which are typical of the natural environment on surface. High humidity of air protects against excessive drying of mucosa in the respiratory system, thanks to which the passages can be cleaned and protected against fungi. The therapeutic properties of chambers depend on natural properties of the saline mass, constantly monitored ventilation and humidity as well as cubature of therapeutic chambers. What is also important about the microclimate is the stimulus character of its changes – everyday a trip down to the level III, 135 m below surface and back up to the surface (kopalnia.pl/uzdrowisko).

Underground workings of the Mine have a historical cultural value, but not only that. They are also an example of inanimate nature. Through the relevant decisions a Natural Preserve was established in the workings of the Crystal Chambers and 40 documentation stands were given special protection. Owing to unique natural and cultural valor (fig. 15), authentic and original character the 'Wieliczka' Salt Mine is the only such mining object on global scale. This mine is one of the most renowned and best recognizable sites and Polish tourist attractions in the World.

**Figure 15. Crystal Chambers – underground Natural Preserve – fragment of a wall.**

A number of events are organized underground, e.g. concerts, performances, dance courses, sport competitions on a full-size underground sport object, film productions, etc. The biggest chamber used for cultural purposes is the Chamber Warszawa (fig. 16) – a result of extraction of 20,000 tonnes of salt.

**Figure 16: Representative and multifunction Chamber Warszawa.**

Presently the protection activities focus on the liquidation of excessive workings and maintaining the historical workings, underground Tourist Route, Miner's Route and underground Spa.

## 3. CONCEPT OF UNDERGROUND GEOENERGY INSTALLATION

The Wieliczka salt deposit basically consists of two differing parts: block and seam deposits. Both complexes were formed about 13.6 million years ago in the Neogene. The geology of the 'Wieliczka' Salt Mine is very complex.

A pilot low-temperature heat recovery installation is planned in a liquidated working (fig. 17). Heat recovered through the heat pumps will be used for heating purposes in other parts of the mine.

Under the notion of 'low-temperature heat' we understand heat with a temperature too low to utilize it directly, i.e. the energy level of this heat has to be increased by heat pumps.

Each year about 100,000 $m^3$ of workings are liquidated in the 'Wieliczka Salt Mine. Typically the workings are up to 5000 $m^3$ of volume, and the total volume of voids exceeds 6 million $m^3$ which gives a considerable potential as far as the recovery of heat of

the Earth is concerned. The temperature of the mine's rock mass ranges from 14 to 16 °C and the expected cubature of workings to be closed is 4 million $m^3$.

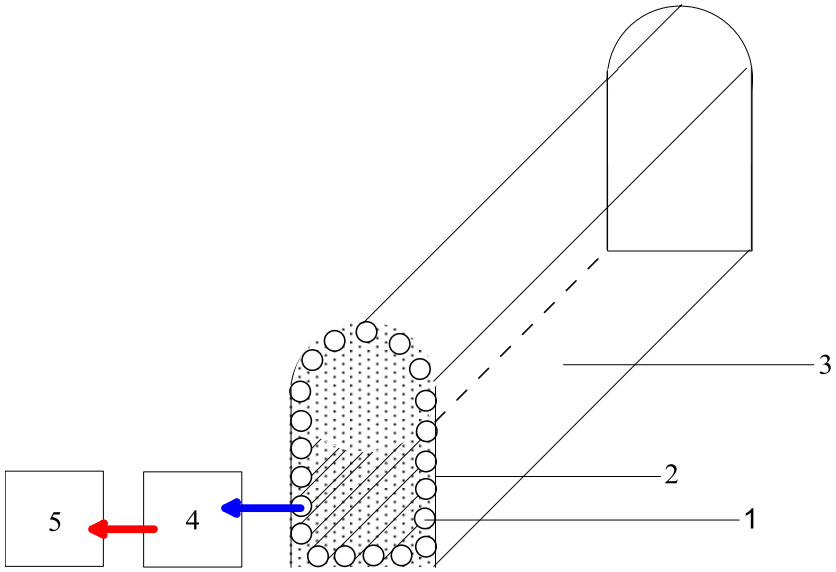


**Figure 17: Schematic of heat recovery installation in liquidated working; 1 – pipes of heat exchanger, 2 – proppant (sand), 3 – corridor, 4 – heat pump, 5 – heat consumer (underground Spa).**

The green layered salt, shaft salt and some types of homogeneous spiza salts will be analyzed for the planned installation. Salt rocks have high thermal conductivity so in this way the heat conductivity in the rock mass making up the 'Wieliczka' Salt Mine can be increased.

According to the presented concept the pipes with heat carrier will be installed in the working prior to its liquidation. What is novel here is a different technical approach to the heat recovery. Commonly the geothermal energy is recovered through the water from flooded workings (Canada, Scotland). In the 'Wieliczka' Salt Mine the heat recovery will rely on the thermal conductivity of the rock mass. The heat exchange system will be closed-loop providing no hydraulic connection with the rock mass. The pipes of the heat exchanger will reside in the working before the proppant material is introduced.

The pipes will be disposed mainly in the workings and corridors as well as in the floor and side walls of the liquidated chambers. The pilot installation project will focus on analyzing the intensification of the recuperated heat and exploitation technology in the aspect of its energy and economic feasibility.

Traditional heat recovery installations installed in the ground consist of pipes disposed horizontally at 1.2 to 1.5 m of depth. A glycol solution is used as a heat carrier. In this system mainly solar energy can be recovered. On a seasonal basis, each summer energy resources are recovered in the near-surface area. A number of guidelines are available for such systems, as provided by the producers of heat pumps.

The situation is quite different in the proposed system as only geothermal heat will be recovered. The resources will be regenerated only on the basis of heat conductivity of rocks, and convection connected with the movement of waters in the rock mass. No practical experience is available in this respect except energy recovery through borehole heat exchangers (Śliwa 2012).

The idea of a linear source of heat is the basis for the analysis of heat recovery in such installations. It is the surface source of heat which should be analyzed in the described situation. This is the way in which will operate the pipes of the heat exchanger disposed on the surfaces of walls of liquidated workings.

The proppant (sand filling up the old workings) will naturally get moist/hydrated. In this way the heat capacity and heat conductivity of the proppant will increase.

In Poland we have a number of mines which are frequently visited by tourists, where the analyzed solution could be implemented. This also refers to the active mines, where the heat can be used locally for various purposes.

The objectives of the research project and the pilot installation are numerous:
- gain experience in the construction and exploitation of this type of installation,
- define economic effect,
- define energetic effects,
- define environmental effects,
- define repeatability of the project in other mines.

## 4. HEAT RECOVERY FROM VENTILATION AIR

The presented installation will in addition manage the heat from the ventilation air and thus the Mine's chambers will be heated with it. Apart from the novel way of managing energy from liquidated workings, a technical and economic analysis of heat

recuperated from ventilation air will be performed. This aspect is known and has been realized in other active mines both in Poland and abroad. The specific character of the 'Wieliczka' Salt Mine lies in the fact that the air used for conditioning the mine is dried beforehand. Prior to introducing the air to the ventilation shaft, it is dried to reduce water condensation in the workings. Such condensation is disadvantageous for the historical interiors and salt.

The analysis will cover the entire technological process in view of economic profitability from drying and heat recovery. Among potential heat receivers are sites on the surface (e.g. Grand Sal Hotel – formerly Saline Baths building) and also the underground Spa (heating of water for baleotherapeutic brine baths).

The stream of ventilation air introduced to the historical shaft Regis (14$^{th}$ century – oldest existing shaft) equals about 300 $m^3 \cdot min^{-1}$. The dried part of the stream is 150 $m^3 \cdot min^{-1}$. For this purpose the air is cooled down to about 15 °C.

## 5. CONCLUSIONS

1. The concept of heat recovery from liquidated underground workings may apply to a majority of mines. They may become a source of low-temperature heat. This especially applies to historical mines where the heat can be used for heating purposes. The 'Wieliczka' Salt Mine, where part of the old workings are liquidated by introducing proppant, is an example. Heat of liquidated and propped workings can be used for, e.g. the therapeutic part of the Mine or on the Tourist Route.

2. The experiences from the realization of the investment will be used for working out a method of managing liquidated workings in underground mines for heating purposes. The heat will be used in other parts of the mine or on the surface. The market potential of the planned investment is high as the gathered experience can be practically utilized in any mine, both active or to be closed (completely or partly).

3. The social aspect of the project is very important. The Tourist Route is visited by over 1 million tourists each year. The number of patients of the underground sanatorium is increasing. The visitors will have a chance to see the way in which part of the heat demand of the underground sanatorium can be satisfied.

4. The environmental effect directly results from the fact that traditional energy sources will have been replaced by renewable ones. The exact value of the environmental effect will be specified after a year of the project's operation. The heat pumps are planned to operate at an efficiency (COP) of over 3.2.

5. The economic aspect is equally important. The realization of the installation will be based on financial support of the Polish Ministry of Science and Higher Education.

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