Geothermal use of tunnel waters – a Swiss speciality

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Abstract

Switzerland accommodates a substantial part of the Alpine chain. In such mountainous terrain, railway and road tunnels as well as major galleries drain water from their surrounding rock masses. The temperature of this inflow water depends on the cover thickness; in some cases it can reach more than 50°C. The collected water flows under gravity to the portals; provided a sufficient flow rate, various types of installations at or near the tunnel portals can thus be supplied with heat. There are over 700 road or railway tunnels in Switzerland. A potential study screened first 150 tunnels from where 15 objects were selected for more detailed studies. Their heat potential is estimated to be greater than 30 MWth. Six heating systems are already in operation near portals of the St.Gotthard, Furka, Mappo-Morettina, Hauenstein, Ricken, and Grand St.Bernard tunnels, with installed capacities between 0.2 to 2 MWt). Several further projects are at various stages of development. The heat potential at the portals of the two base tunnels under construction for the AlpTransit system (Lötschberg, 35 km long and Gotthard, 57 km) is estimated to range between 4 and 23 MWth, with a total of approximately 29 MWth.

Keywords*: tunnel water inflow, rock and fluid temperatures, heating systems.*

1 Introduction

Tunnels are subsurface constructions to overcome topographic barriers to transportation. They can serve various purposes (highway, railway, pipeline tunnels). Depending on local geologic conditions the tunnels can serve, especially in mountainous terrain, as heat/fluid sources: railway and road tunnels as well as major galleries drain water from their surrounding rock masses.

The piezometric surface inside of mountain ranges exhibit significant relief between ridges and valleys (where the tunnel portals are located). This leads to the development of pronounced, deep-reaching groundwater circulation systems. Due to the high piezometric level under ridges the deep tunnels usually drain large amounts of warm water, especially in permeable fracture zones (Rybach, 1995).

Subsurface rock temperatures in mountain ranges depend on a large number of influence factors: cover thickness, three-dimensional topography, lithologic structure (with anisotropic thermal conductivity), hydrogeology (permeability distribution and water circulation), as well as transient effects like uplift/erosion and past climatic changes. Usually, the inflowing waters are in thermal equilibrium with the surrounding rock masses: the water temperature equals that of the neighboring rock (Figure 1). The inflow rate can change considerably with time: originally strong flows (tunnel construction phase) decrease significantly within the first few years to reach a lower, stable level, corresponding to a new hydraulic equilibrium in the circulation system (Rybach, 1995).

The waters are collected and flow under gravity, from the point of tunnel culmination, towards the portals in more or less isolated conduits. Their flow rate and temperature depend on the natural inflow conditions on one hand, and on technical measures (injections to reduce inflow, isolation conditions during outflow etc.). According to water protection regulation, waters with only a limited amount and temperature can be disposed by discharge to rivers. In extreme cases, the installation of cooling towers would be necessary. Therefore, a possible geothermal use of the outflowing tunnel waters is an attractive option; depending on flow rate and temperature, various types of installations at or near the tunnel portals can be supplied with heat. Usually the outflow temperature shows no seasonal variations. Thus such waters represent an interesting potential for direct use, provided that consumers to use the heat are situated at or near the portals. Contrary to the use of mine waters for space heating e.g. in Canada (Sanner, 1993), Germany (Bussmann, 1994) or Poland (Ustron Conference, 2001) where electrical energy is needed to lift the warm waters form the drowned mines to the surface, there is no need for pumps in the case of tunnel waters.

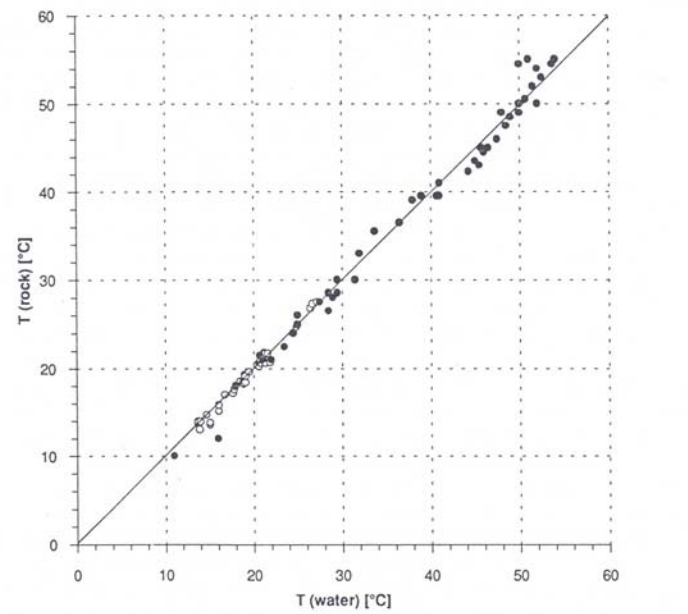

Figure 1: Rock temperature vs temperature of inflowing water. Data from the Simplon railway tunnel (dots), and from the Gotthard highway tunnel (open circles). The black line marks equality, the best fit line through the data points has a slope of 1.01 and an intercept of –0.52°C, the regression coefficient is 0.996 (from Rybach 1995).

In the following, the tunnel water situation in Switzerland will be outlined, utilization examples will be described, and the potential of deep and long tunnels in construction will be discussed. In the concluding remarks the prerequisites of a geothermal use of tunnel waters will be addressed.

2 Tunnels in Switzerland

Switzerland accommodates a substantial part of the Alpine chain; there are over 700 road or railway tunnels in the country! The cover thickness is often considerable which can lead to rock/water inflow temperatures of 40-50°C. A potential study screened first 150 tunnels, from which 15 objects were selected for more detailed studies (Arbeitsgemeinschaft ZEWI, 1995, 1996 and 1998; Figure 2). Their heat potential is estimated to be greater than 30 MWth (Table 1). The flow rates range from 360 liters/minute (Ascona) to 24,000 l/min (Grenchenberg), the outflow temperatures from 11.9°C (Ricken) to 24.3 (Rawyl). Six heating systems are already in operation near the portals of the St. Gotthard, Furka, Mappo-Morettina, Hauenstein, Ricken, and Grand St. Bernard tunnels.

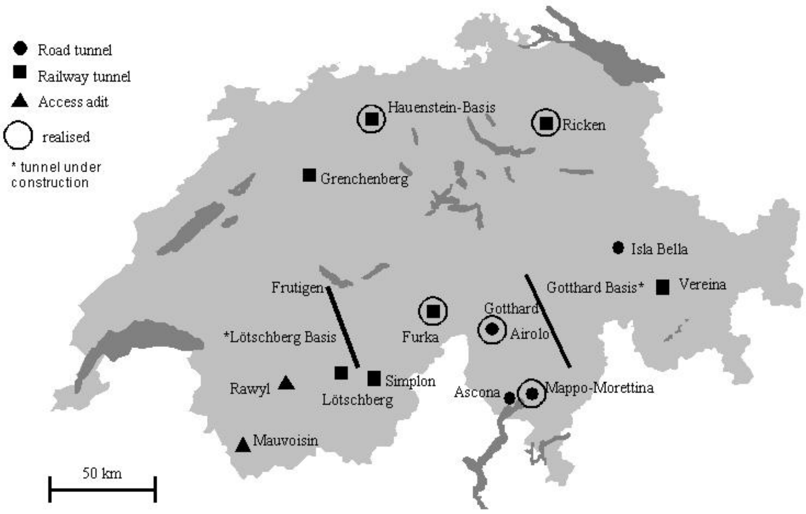

Figure 2: Location of investigated tunnels and geothermal direct use installations in operation.

Table 1: Geothermal potential of 15 selected tunnels in Switzerland (from „Tunnelgeothermie“, SGA / *EnergieSchweiz*, 2002).

Tunnel	Tunnel type	Outflow (l/min)	Water temperature (°C)	Thermal power (kWt)*
Ascona	Highway	360	12	150
Furka**	Railway	5.400	16	3.758
Frutigen (at Lötschberg)	Explor. adit	800	17	612
Gotthard**	Highway	7.200	15	4.510
Grenchenberg (south portal)	Railway	18.000	10	11.693
Hauenstein**	Railway	2.500	19	2.262
Isla Bella	Highway	800	15	501
Lötschberg	Railway	731	12	305
Mappo-Morettina**	Highway	983	16	684
Mauvoisin	Explor. adit	600	20	584
Polmengo	Explor. adit	600	20	584
Rawyl	Explor. Adit	1.200	24	1.503
Ricken**	Railway	1.200	12	501
Simplon (north portal)	Railway	1.380	13	672
Vereina	Railway	2.100	17	1.608
Total				29.927

*) calculated at portal, by cooling down to 6°C
**) geothermal installation in operation

3 Operating examples

The energetic use of warm tunnel waters is most advantageous in the immediate vicinity of the tunnel portals; long transport/distribution piping is a major cost factor. Therefore, the realized heating installations are all situated at the tunnel portals. In addition to five systems, where warm tunnel waters are exploited, there exists also one installation (Gd. St. Bernhard) where the heat content of warm tunnel air is utilized since 1999. For locations see Figure 2.

St. Gotthard highway tunnel

The outflow at the south portal of the St. Gotthard rail tunnel amounts to 6700 l/min with a temperature of 17°C. The water is cooled down by 2.3°C and a heat pump supplies 1.9 MWt heating power to buildings of the highway service center in Airolo/TI. This is the oldest installation, in operation since 1979. By technical upgrade (and especially with a larger cooling ΔT) the system could provide 4.0 MWt.

Furka railway tunnel

The outflow at the west portal amounts to 5400 l/min at 16°C. The water is filtered and then piped to the nearby village Oberwald/VS. There an innovative system is in use since 1991 (Rybach and Wilhelm, 1995): the tunnel water is piped to individual heat pumps, tailored to supply various types of buildings ("cold district heating"). A total of 177 apartments and a sport center are heated, with an installed capacity of 960 kWt (some of the buildings see on Figure 3).

Figure 3: Apartment buildings in Oberwald/VS conneted to the "cold district heating" system of Furka tunnel (for details see text). Photograph by J. Wilhelm.

Ricken railway tunnel

The outflow at the southern portal amounts to 690 l/min at 12°C. The first stage of heating installation is operational since 1998: With a heat pump the tunnel water is used in the village Kaltbrunn/SG to heat a multipurpose building, a gymnastic hall, a civil shelter center and a kindergarten. To date the installed capacity is 156 kW.

Mappo-Morettina highway tunnel

The outflow at the northern portal amounts to 983 l/min at 16°C. The sport- and recreational center of the community Minusio/TI is located right at the portal; it is heated since 1999 with the tunnel waters. During the heating season 2000/2001, the seasonal performance coefficient of the system (including the heat pump) amounted to SPC = 4.0.

Hauenstein railway tunnel

The outflow at the south portal amounts to 2500 l/min at 19°C. In the first stage, three housing complexes with 150 apartments are heated and supplied by domestic hot water in the village Trimbach/SO since 1999. The bivalent system consists of a heat pump for the tunnel water plus two oil burners (total installed capacity 1.0 MWt). The tunnel system including the heat pump has a SPC of 4.0. Further development stages are in planning.

The operating experience with all installations is satisfactory to good; only some minor technical improvements like exchange of filters etc. became necessary. The flow rates and temperatures of the outflowing tunnel waters show little to no seasonal variation, thus this "zero-cost" heat source can be considered as totally reliable and sustainable.

4 Tunnels under construction

Switzerland presently follows the traffic policy of shifting the transport by heavy trucks on roads to railway transport. Towards this goal the capacity of the main traffic axis (north ↔ south) is now greatly extended by the AlpTransit project. The key elements of this project are two long, deep base tunnels: the Lötschberg tunnel in the west and the Gotthard tunnel in the east (see Fig. 2; with exploratory adits Frutigen and Polmengo). The rock cover can reach 2.5 km and the lengths are considerable: 57 km for the Gotthard and 35 km for the Lötschberg. Both tunnels are in construction. Due to the thick overburden and the great lengths the expected geothermal potential is significant.

The geothermal potential largely depends on the inflow rates and temperatures to be expected in the different tunnel sections. Whereas the rock/fluid temperatures can be predicted with relatively high accuracy (Rybach and Busslinger 1999, Busslinger and Rybach 1999, Keller 2002), the forecasts of the water inflows have a considerably range of uncertainty (ATH 1993). Therefore the estimated potentials at the portals can vary over a correspondingly wide range: Gotthard north portal: 4-23 MWt, Gotthard south portal: 4-19 MWt; Lötschberg north portal: 4-12 MWt, Lötschberg south portal: 4-7.5 MWt (Wärmenutzung Tunnelwasser BFE, 2002).

There are limitations by environmental regulation for discharging warm tunnel waters into rivers. The local rivers near the portals have only limited potential for tunnel water uptake; at most places cooling ponds/towers would be necessary to decrease water temperatures prior to disposal. Therefore the construction authorities show significant interest for a geothermal use of the tunnel waters, as well as the local communities like Frutigen at the Lötschberg north portal or Biasca at the Gotthard south portal. Besides space heating, innovative uses like heating of a tropical greenhouse in Frutigen (capacity demand: 2.7 MWt) are currently in discussion.

5 Conclusion, outlook

Switzerland with its mountainous topography has a large number of highway and railway tunnels, and quite a number of them exhibit interesting potentials for direct use. Several installations already in operation demonstrate the technical feasibility.

The potential of the AlpTransit base tunnels Gotthard and Lötschberg, now in construction, is considerable and amounts to several tens of MWt.

Further investigations are needed to better specify the geothermal potential of the deep AlpTransit tunnels. There are several factors which can influence the outflow rate and temperature of tunnel waters and these need to be addressed and quantified: 1) possible construction measures such as cement injections to seal fissures/cavities in order to prevent/reduce the water inflow at critical points along the tunnel, 2) the development of a transient, nonlinear temperature profile behind the tunnel face due to ventilation; this will lead to lower rock and thus water inflow temperatures with time, 3) heat loss from conduits in which the tunnel waters are transported to the portals.

Besides the technical prerequisites for a geothermal use of tunnel waters, there are also additional tasks to be completed for a successful utilization: the economic viability needs to be demonstrated for attracting and motivating potential consumers. Finally, several administrative steps have to be followed to obtain all necessary permits. Nevertheless, the various operating examples in Switzerland demonstrate that all this can be done, even with a relatively low speed of development: at a given location, the addition of a capacity of 0.5-1 MWt needs about one year.

Furthermore, there is still ample space for innovative solutions, especially to utilize the warm tunnel waters in summer time. The planned tropical greenhouse in Frutigen is such an example. Further options are: spa-type establishments for wellness, fun and pleasure, aquacultures and the like. All of these applications are already being considered, but are still in a stage of infancy in Switzerland.

Acknowledgments

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