Geothermal Use of Warm Tunnel Waters— Principles and Examples from Switzerland

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ABSTRACT

Tunnels drain the rock zones located above them; as a result a considerable amount of warm water flows into the tunnels and subsequently to the portals. On accounts of its temperature this water cannot be released into nearby rivers without previously being cooled down, due to environmental regulation This energy reserve (drained hot water and heated air) can, however, be used at the tunnel portals for various applications. From Switzerland a whole suite of uses can be reported: space heating, greenhouses, balneology and wellness, fish farming (incl. caviar production).

Introduction

Tunnels drain the rock overburden and, depending on its thickness, water temperatures up to 50 °C can be encountered and utilized. In planning the tunnels the following must be considered: higher flow rates and temperatures are better for the energy use, whereas for the geotechnical tunneling works such inflows are more disturbing. Thus a careful consideration/optimization must decide to what extent the water inflows are accepted or retention measures like cementing the tunnel walls are applied.

According to hydrogeological experience the temperature of the inflowing waters corresponds (except from a few exceptions) to the rock temperature at the entry point (see Figure 1). The initially higher inflow rates usually stabilize in the course of time at significantly lower levels (Rybach, 1995).

The most straightforward and cheapest form of tunnel heat usage is to collect and transport inflowing waters via ducts to the portals, with as little temperature drop as possible. The thermal power depends on flow rate and temperature. At or near the portals the heat content of the waters can be used for various applications. When the temperature level of the tunnel water outflows is too low for direct applications (e.g. for district heating), heat pumps are employed.

Available Thermal Power

The thermal capacity and the exit temperature at the portal are decisive for the use of the tunnel water in energy terms. The thermal capacity P (e.g. in Megawatt thermal, MWth) is given by

$$P = c \times Q \times \Delta T$$

where c is the thermal capacity of water (J/l,K), Q the outflow rate (l/s) and ΔT (= T - To) the useful temperature drop. T is the outflow temperature and To the reference temperature, i.e. the temperature of the water after heat extraction.

In the tunnel planning phase the expected thermal capacities and outflow temperatures are usually assessed. Analytical calculations are required for this purpose. Numerical, finite element, three-dimensional, non-stationary simulation models

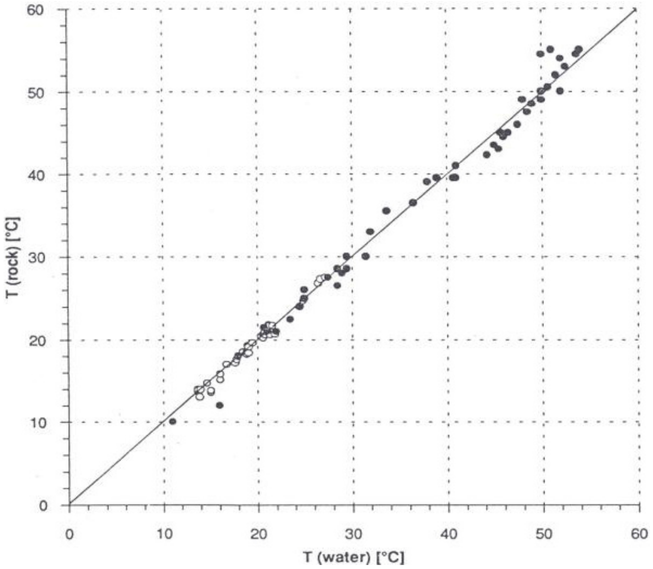

Figure 1. Tunnel wallrock temperature and temperature of the inflowing water. Data from the Simplon Rail Tunnel (points) and the Gotthard Road Tunnel (circles). The line marks 100 % correlation; the best straight line through the measurement points has a regression coefficient of 0.996 (from Rybach, 1995).

Table 1. The geothermal potential and usage of some Swiss Alpine tunnels (from Rybach et al. 2003).

Name	Canton	Type of tunnel	Water discharge [l/min]	Temperature of water [°C]	Heating capacity [kWth] (1)
Ascona	TI	Road	360	12	150
Furka (2)	VS	Railway	5400	16	3’758
Frutigen	BE	Investigation tunnel	800	17	612
Gotthard (2)	TI	Road (N2)	7200	15	4’510
Grenchenberg (South portal)	SO	Railway	18000	10	11’693
Hauenstein (Base tunnel)	SO	Railway	2500	19	2’262
Isla Bella	GR	Road	800	15	501
Lötschberg	VS	Railway	731	12	305
Mappo-Morettina (2)	TI	Road	983	16	684
Mauvoisin	VS	Investigation tunnel	600	20	584
Polmengo	TI	Investigation adit	600	20	584
Rawyl	VS	Investigation adit	1200	24	1’503
Ricken (2)	SG	Railway	1200	12	501
Simplon (Portal Brigue)	VS	Railway	1380	13	672
Vereina	GR	Railway	2100	17	1’608
				Total	29’927

(1) Potential at the portal of the tunnel, without heat pump, cooling up to 6°C

(2) Usage system in operation

are employed for the prediction; in this the hydraulic and thermal boundary conditions are especially essential. Such a prognosis was for instance undertaken for the Koralm Project in Austria (Graf et al. 2002).

A factor influencing the outflow temperature is the way the tunnel water is collected and conducted up to the portal of the tunnel. The general layout and the material of the drainage system, including thermal isolation, the water flowrate, the temperature inside the tunnel are factors influencing the temperature of the drained tunnel water.

The cooling of water flowing in a buried pipe can be calculated by the following formula:

$$T(L) = T_b + (T_b + T_t) \exp [- (K/Qc) \times L]$$

where L is the length of the pipe, T_b the temperature of the water at the beginning of the pipe, T(L) the temperature of the water at the end of the pipe, T_t the temperature in the tunnel, Q the water flow rate (l/sec), K the heat transfer coefficient (W/mK), c the specific thermal capacity of water.

As an example, tunnel water of 35°C flowing at 50 l/sec, in a 70 cm diameter cement pipe, buried 50 cm deep, will be cooled by 5°C over a distance of 20 km, when the temperature in the tunnel is 25°C. The cooling is reduced to 1°C by applying a *Flumrock®* insulation of 5 cm thickness (Wilhelm and Rybach, 2003).

Environmental Aspects

Should the outflowing tunnel water not be used for energetic purposes, it would be diverted to surface waters. Water protection regulations limit such discharge: a river must not be heated up by more than 1.5 °C (=ΔT_{reg}) – given its lowest watermark. The maximum permitted inflow Q_{max} can be calculated as follows:

$$\mathbf{Q_{max} = \Delta T_{reg} \times Q_{rmin}/(T_p - T_{rmin} - \Delta T_{reg})}$$

where Q_{rmin} is the minimum delivery of the nearest river, T_{min} is the minimum river water temperature at that time, and T_p the temperature of the tunnel water at the portal. Often the locally accessible rivers can take up only limited flow rates. As a consequence, cooling ponds or even cooling towers would have to be installed without energetic use, at least during the construction phase. The tunnel company is thus essentially interested in the energetic use of the outflowing water. The prerequisite of thermal use is the presence of heat consumers close to the portals.

Examples of Application

Switzerland has more than 700 road or rail tunnels. Owing to substantial overburden the water inflow temperature can reach 40–50° C. A potential study assessed a selection of 150 tunnels, of which 15 were more closely examined (Rybach and Wilhelm 2003). The thermal potential of these 15 tunnels amounts roughly to 30 MWt. Flow rates vary between 360 l/min and 24,000 l/min, outflow temperatures at the portals from 11.9° C to 24.3° C. The flow rates are practically constant throughout the year just like the water temperatures. As far as the use of energy is concerned, traditional space heating is primarily involved; however, this depends on sufficient thermal consumers located close to the portals. Should these be lacking, other, innovative solutions can be taken into consideration. Both variants will be discussed in the following.

Applications for Space Heating

Currently tunnel heat utilization for heating purposes is taking place at six locations (as indicated in Table 1), in the Jura and in the Alps. These are heating facilities, which utilize tunnel heat by means of heat pumps: the Gotthard Road Tunnel,

Figure 2. Airolo/TI – The Services Centre of the Gotthard Road Tunnel at the southern portal has been heated and cooled geothermally since 1979. Tunnel water temperature: 17° C, thermal capacity with 4 heat pumps: 720 kW (Photo: Geowatt AG, Zurich).

Furka Rail Tunnel, Mappo-Morettina Road Tunnel, Hauenstein Rail Tunnel, Ricken Rail Tunnel, and finally the Grand St. Bernard Tunnel, in which the hot tunnel air is used rather than drained water. Examples are to be found in Figures 2, 3 and 4. At Oberwald at the western portal of the Furka Rail Tunnel, the relatively cold tunnel water (16° C) is conducted in a pipeline to connected buildings ("cold district heating"), where the temperature level required by the heating system is produced by means of heat pumps, designed according to the size of the individual buildings.

Figure 3. Oberwald/VS – a distributor network at the western portal of the Furka Rail Tunnel conducts the tunnel water to the heat pumps for each consumer. Tunnel water temperature: 16° C, thermal capacity: 960 kW (Photo: J. Wilhelm, Pully).

Figure 4. Kaltbrunn/SG – a multipurpose building, a gymnasium, a civil defence facility and a kindergarten are heated with the help of a heat pump at the southern portal of the Ricken Rail Tunnel. Tunnel water temperature: 12° C, thermal capacity with 2 heat pumps: 156 kW (Photo: www.geothermie.ch).

Innovative Solutions

There are two major Alpine tunnels (AlpTransit Rail Tunnels) in Switzerland: the Gotthard Base Tunnel (57 km long, maximum rock overburden 2.4 km; construction nearly completed) and the Loetschberg Base Tunnel (35 km, max. overburden 2.0 km, tunnel construction completed, train services operating). Thermal utilization projects have been designed for both tunnels, which are at various stages of implementation/completion.

The Frutigen/BE Tropenhaus Project solves the discharge problem at the northern portal of the Loetschberg Base Tunnel (cf. section on environmental aspects) in a sustainable manner and in this way uses the geothermal heat with an innovative concept. For this project the warm drainage water from the Loetschberg Base Tunnel (200 l/s, 17° C) is used as the energy base and cooled down after usage to the desired degree prior to being fed into the local Kander River. Fish such as sturgeon and perch, which thrive in warm water, are raised in the Frutigen Tropenhaus fish hatchery basins as well as tropical fruits are grown in greenhouses (Figure 5). Caviar production is also scheduled. The Frutigen Tropenhaus started to operate in November 2009.

At the Gotthard Base Tunnel currently work is forging ahead at

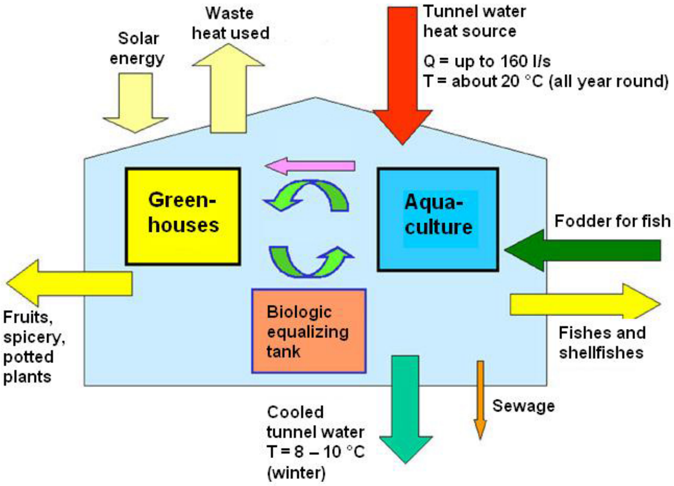

Figure 5. Frutigen/BE – a "Tropenhaus" as well as a fish raising unit is operating at the northern portal of the Loetschberg Base Tunnel. (Source: www.tropenhaus-frutigen.ch).

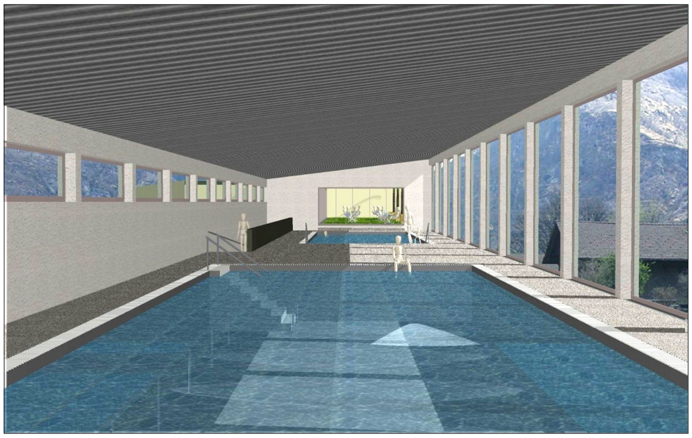

Figure 6. Bodio/TI – planned thermal center at the southern end of the Gotthard Base Tunnel. The annual energy consumption of 1,230 MWh will be covered as follows: tunnel water direct heating (11 %), tunnel water with heat pump (56 %), retrieval from ventilation (22 %), recycling from water (6 %), additional heating (5 %). (Source: ISAAC-DACD-SUPSI).

the southern end (Bodio Portal) in planning the Bodio/TI thermal station. The tunnel's thermal output is still unknown as excavation work is still in progress. As a result, assumptions have to be made for capacity and temperature for the planning stage. Figure 6 shows the energy amounts used for planning.

Conclusions, Outlook

Tunnel heat can be used in different ways. The simplest method directly uses the heat contained by natural flowing water as deep lying tunnels in some cases drain off large quantities of warm underground water. The thermal power and the outflow temperature at the portal are the determining factors for using flowing tunnel water as energy. As far as direct heat utilization is concerned environmental aspects (discharge conditions) as well as economy (heat consumers close to the portals) must be taken into account.

Switzerland with its many tunnels possesses an interesting potential for the utilization of warm tunnel waters; various examples have already been accomplished in different parts of the country. Elsewhere other solutions exist such as in Austria, which rely on the direct extraction of rock heat by means of absorber elements and energy anchors (Adam and Oberhauser, 2008). In the future, the geothermal use option should duly be taken into account during the early phases of planning for every major tunnel project.

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