POTENTIAL AND USE OF WARM WATERS FROM DEEP ALPINE TUNNELS

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ABSTRACT

Several deep tunnels crosscut considerable sections of the Swiss Alps which drain, especially in permebale fracture zones, considerable amounts of warm water. Utilisation for space heating of such waters, flowing under gravity to the portals, is already underway. The outflow from the 16 km long Furka railway tunnel feeds a local distribution system to heat a part of the village of Oberwald, canton Wallis. The new NEAT project aims at two deep tunnels (Gotthard, 56 km; Lotschberg, 39 km). A preliminary potential assessment, based on predicted rock/water temperatures and inflow rates, yields several tens of MW_{th} for both planned tunnels. Nearby potential consumers have already been identified.

Key *words:* rock temperatures, warm water inflow, potential assessment, heat pumps, district heating

INTRODUCTION

Several deep tunnels crosscut considerable sections of the Swiss Alps. The piezometric surface inside of the mountain range exhibits significant relief between ridges and valleys. Due to the high piezometric level under ridges the deep tunnels can drain, especially in permebale fracture zones, large amounts of warm waters. These can then flow out under gravity, in thermally more or less isolated conduits, to the tunnel portals. Such waters represent an interesting potential for space heating, provided that consumers are situated at or near the portals. Contrary to the use of mine waters for space heating in e.g. in Canada (Sanner, 1983) or Germany (Bussmann, 1994) where electrical energy is needed to lift the warm waters of the drowned mines to the surface, there is no need for pumps in the case of tunnel waters.

In the following, examples will be given for the Swiss Alps: on one hand , already existing utilisation will be briefly described, on the other hand the results of a recent potential assessment for tunnels in construction/planning will be presented.

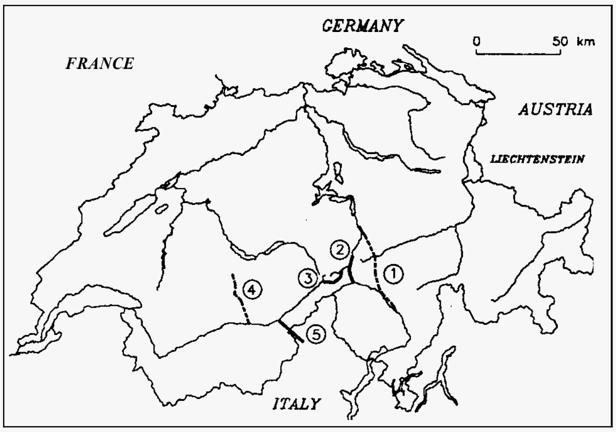

Fig. 1. Location of existing (solid lines) and planned deep tunnels (dotted lines) in the Swiss Alps with geothermal energy potential. 1: NEAT/Gotthard base tunnel, 2: Gotthard highway tunnel, 3: Furka railway tunnel, 4: NEAT/Lötschberg base tunnel, 5: Simplon railway tunnel.

UTILISATION AT EXISTING TUNNELS

There exist already some practical examples of the energetic use of outflowing warm tunnel waters. The office and maintenance buildings at the north and south portals of the Gotthard highway tunnel (16 krn long, in operation since 1980; for location see Fig. 1) are heated by such waters. These installations, although clearly demonstrating the potentialities, are of very small capacity (< 100 kW_{th}). Waters with considerably more potential (25 Vsec at 13 °C, Kaempfen 1994) flow out of the the Simplon railroad tunnel (20 km long, operational since 1906; for location see Fig. 1) unused at its northern end at Brig/VS. The heating of the planned new Brig railway station and some surrounding buildings by the outflowing tunnel waters using a coupled heat pump is technically feasible and economically viable (Kaempfen 1994).

A pioneering village heating system is installed in Oberwald, canton Wallis, at the western portal of the Furka rail tunnel (16 km long, operational since 1982; for location see Fig. 1). The tunnel waters originate mostly from mid-tunnel fracture zones and show constant yield at the portal (90 l/sec, 16 °C). The temperature drop between inflow and portal is small (18 °C vs. 16 °C). The theoretical heat capacity of the outflowing tunnel water (calculated for AT = 10 °C) amounts to 3.5 MW_{th}, more than enough to heat the nearby village of Oberwald. The heating system is in operation since 1991/92.

The essential (and new) feature is the "cold" distribution network with decentral heat pumps (HP) at the individual users, instead of a central HP with subsequent (warm) district heating distribution. The advantages of the "cold" system (the first installation of this kind in Switzerland) are manifold: lower heat losses, smaller initial investments, more flexibility for subsequent developments.

The distribution network consists of polyethylene pipes (250 mm inner and 355 mm outer diameter) buried at 2.5 m depth. With the decentral HP´s, seasonal performance factors > 4.5 (=heating energy delivered vs. electricity of HP over the entire heating season) can be achieved. The economic viability is demonstrated by the cost comparison given in Table 1. This pioneering installation is financially supported by the Swiss Federal Office of Energy, Bern.

Table 1. Cost comparison of tunnel vs. conventional (oil) heating systems for a multifamily house (13 apartments)'

System	Tunnel	Oil
Installation	60'000	60'000
Distribution	18'000	
Difference	+ 18´000	
Running costs	4'500	6'000
Difference		+ 1´500

*) in Swiss francs (1 sfr ≈ 0.7 US $)

The higher tunnel system cost results in a mortgage rate of 8 % which is common in Switzerland.

GEOTHERMAL POTENTIAL OF PLANNED TUNNELS

Recently the construction of a large-scale railway system to cross the Alps, the "AlpTransit/NEAT" project, has been started in Switzerland. This system will include two long base tunnels: the Lotschberg tunnel in the west and the Gotthard tunnel further to the east (for location see Fig. 1). The rock cover can reach 2.5 km; the planned lengths are considerable: 56 km for the Gotthard and 39 km for the Lotschberg base tunnels.

High water inflow rates are expected on geologic grounds in both tunnels. In fact, the amounts of warm water leaving the portals are much too high, when compared to the limits given by water protection regulation, to be disposed directly to nearby rivers. On the other hand, the heat content of such waters can be beneficially utilised at or near the portals, as demonstrated above (e.g. Oberwald/VS at the Furka tunnel).

The authors have performed, for the Swiss Federal Office of Energy, a preliminary potential assessment for the planned Gotthard and Lotschberg tunnels of the NEAT project. The approach and the main results are summarized below.

The heat potential assessment is based on two parameters: 1) the water inflow rate and 2) the water temperature (Rybach, 1994). Both parameters are known only approximatively. The inflow rates have been estimated by the NEAT project hydrogeologists, separately for the tunnel construction and the operation phase (unpublished reports). The construction phase is characterised by high initial inflow rates which usually decrease, more or less rapidly, to stabilise at significantly lower values. For the operation phase (with train traffic), two different inflow rates (constant in time) have been estimated: one ("optimistic") low and one high ("pessimistic") value. The inflow rates are given in the reports of the project hydrogeologists as profiles showing the cumulative flow rate between tunnel culmination point and portal. The temperature of water inflow equals, as experience shows (Keller et *al.*, 1987), the in-situ rock temperature. The rock temperature can be predicted for the deep tunnels with some accuracy (Rybach and Pfister 1994).

The following estimations are based on two simplifying assumptions. First, the temperature of the inflow water was taken constant in time (= rock temperature). This will decrease in time, due to the cooling effect of ventilation (see later). Second, it was assumed that the warm tunnel waters flow under gravity, from their point of emergence, towards the tunnel portals in perfectly isolated conduits (i.e. without heat exchange with the neighbouring rock). Thus the calculated values represent upper limits of the heat potential.

The heat potential P is given by

$$P = c\,Q\,\Delta T \qquad (1)$$

where c is the specific heat capacity of water ($4.2\cdot10^{3}$ J/l,°C), Q the inflow rate (l/sec) and AT the useful temperature difference ($=T_{water} - T_0$). For the calculations, the predicted rock temperature was taken for T_{water}; for T_0 the portal temperatures were taken (mean annual values, 8 - 10 °C, depending on location).

To calculate P, the flow rate profiles have been subdivided in n equidistant length units (for Lotschberg = 500 m, for Gotthard = 50 m) and digitized. The inflow (l/sec) in the section i - (i -1) is

$$\Delta Q_i = q_i - q_{i-1} \qquad (2)$$

where q_i is the (cumulative) water flow at the position i. The total heat capacity can the be calculated as follows:

$$P\,[MW_{th}] = 4.2\cdot10^{-3}\sum_{i=1}^{n}\Delta Q_i \cdot \Delta T_i \qquad (3)$$

where ΔT_i is the useful temperature difference at position i. The ΔT_i values have been determined, in the same way as the flow rates, by subdividing and digitizing the predicted temperature profiles. Figs. 2 - 5 show the estimated inflow rate and predicted temperature profiles for the planned Gotthard and Lotschberg tunnels, along with the inflow rates and the calculated thermal potential. The MW_{th} values found are summarized in Table 2, for two scenarios: A with high, B with low estimated inflow rates).

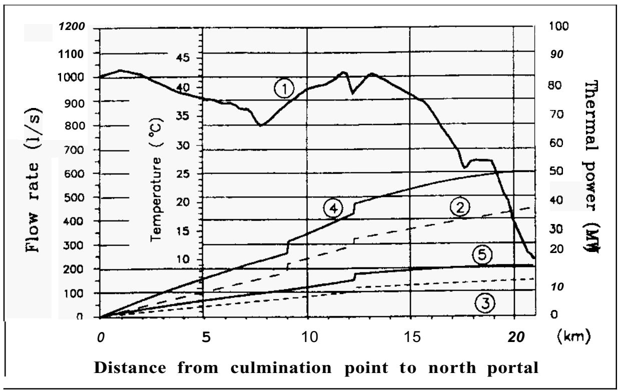

Fig. 2. Rock temperature, inflow rate and estimated thermal power for the Gotthard base tunnel, northern section. 1: Predicted rock temperature; 2: cumulative inflow rate, high flow rate expected; 3: cumlative inflow rate, low flow rate expected; 4: thermal power calculated for high flow rate; 5: thermal power calculated for low flow rate. For further detals see text.

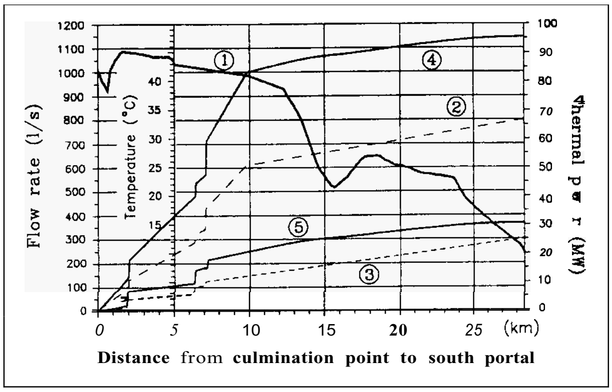

Fig. 3. Rock temperature, inflow rate and estimated thermal power for the Gotthard base tunnel, southern section. Legend same as in Fig. 2.

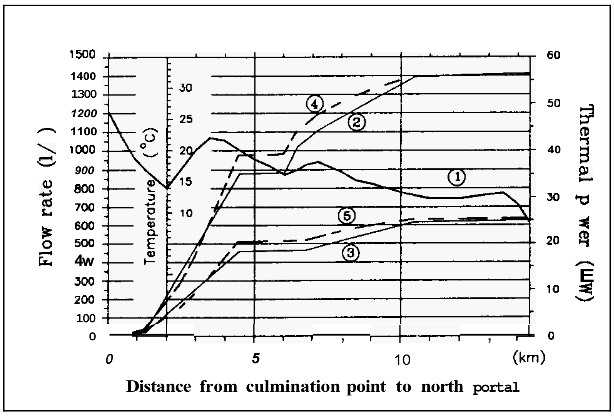

Fig. 4. Rock temperature, inflow rate and estimated thermal power for the Lotschberg base tunnel, northern section. Legend same as in Fig. 2.

Table 2. Preliminary estimates of thermal capacity (in MW_{th}) for the planned Gotthard and Lotschberg base tunnels at their portals

Tunnel	Portal	Scenario A*	Scenario B**
Gotthard	north	50	17
	south	95	30
	total	145	47
Lotschberg	north	56	25
	south	23	18
	total	79	43

*) high rate of water inflow
**) low rate of water inflow

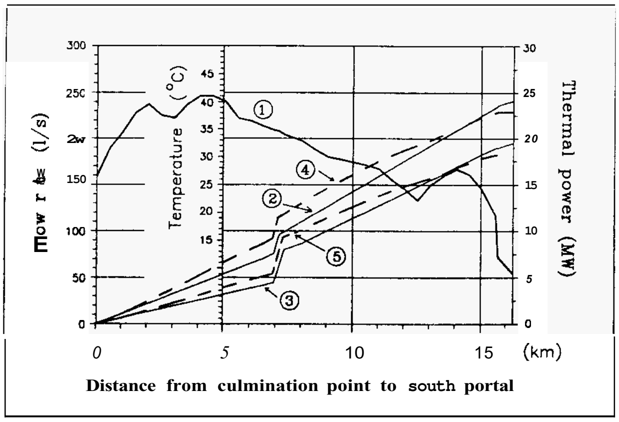

Fig. 5. Rock temperature, inflow rate and estimated thermal power for the Lotschberg base tunnel, southern section. Legend same as in Fig. 2.

The preliminary assessment yields significant figures. Potential consumers located near the portals have already been identified; a more extended study will soon be performed to quantify the demand and the conditions of heat distribution and supply.

CONCLUSIONS, OUTLOOK

Several installations already realized in Switzerland clearly demonstrate the feasibility of using warm tunnel waters for geothermal purposes, especially for space heating. The potential of the planned NEAT tunnels is considerable and can amount to several tens of MW_{th} (cf. Table 2). This potential needs to be investigated in more detail, by taking into account some specific effects which influence the thermal capacity figures. First of all, the development of a transient, nonlinear temperature profile behind the tunnel face due to ventilation needs to be considered; this will lead to lower rock and thus water inflow temperatures with time. The heat loss in conduits, in which the tunnel waters flow to the portals, needs also to be considered, along with possible engineering measures (e.g. injections of cement to seal fissures, cavities in order to reduce the water inflow at critical points along the tunnel).

Besides addressing the potential of the naturally inflowing waters the possibilities to tap nearby water-bearing fracture zones not directly transsected by the tunnels, need also to be investigated. A further idea to be clarifyed concerns the use of the tunnel level for drilling deeper holes from there (especially from the bottoms of vertical shafts) in view of a possible Hot Dry Rock-type utilisation.

At this point, the project SWISSMETRO should also be mentioned in the context of possible future developments. This subsurface transportation system shall consist of high-velocity trains connecting the main Swiss cities, running in several hundreds of kilometers of tunnels, partly at similar topographic and geological conditions as the NEAT base tunnels.

In any case, the deep tunnels offer a most interesting utilisation possibility for space heating and thus represent a unique kind of "Alpine" geothermal potential.

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