

Use of ethanol as antifreeze in borehole heat exchangers

Swiss market for heat pumps with borehole heat exchangers



Like other European countries, Switzerland is currently experiencing a boom in technology based on heat pumps using borehole heat exchangers. This boom is likely to continue, given the price forecasts and the uncertain mid- to long-term supply situation for crude oil and natural gas, along with stricter environmental rules on reducing CO₂ emissions.

The Swiss Federal Office of Energy (SFOE) predicts that 400,000 ground source heat pumps will be in service in Switzerland by 2020. There are currently some 130,000 systems installed, so that an additional 270,000 or so will need to be commissioned over the next 10 years. This forecast is plausible given current market trends. Assuming conditions remain the same, around 40% of these systems will use borehole heat exchangers.

At the time of writing (2010) total annual production of borehole heat exchangers is forecast to be in the region of 2.3 million linear metres per year (based on 2008 figures), with growth expected to be around 10% p.a. This is equivalent to around 10,000 geothermal systems, each with borehole heat exchangers around 230m long. Even if growth were to flatten off slightly, production of heat pumps with the associated probes would reach at least 100,000 over the next 10 years, bringing the total number of installed heat pumps to at least 250,000. This would be more or less in line with the target of 400,000 heat pumps by 2020.

These heat pumps will require more electricity. Although this extra energy will only equate to a small percentage of Switzerland's overall electricity consumption, it still has to be catered for, and occurs mainly in winter. It is therefore important that as many as possible of these heat pumps are fitted with more efficient borehole heat exchangers in the ground (rather than air). To be competitive, the systems also need to be manufactured as efficiently and as cheaply as possible.

Research project: optimisation of borehole heat exchangers

The Institute for Facility Management at the Zurich University for Applied Sciences (ZHAW) is currently engaged in a research project to examine how borehole heat exchangers can be optimised in order to reduce the power consumption of heat pumps (see www.erdsondenoptimierung.ch). One possibility is to use a technically superior antifreeze in the fluid that circulates around the borehole heat exchanger. Here the focus is on ethanol as a substitute for the ethylene glycol mixture, which is the most common solution used in Switzerland at present. Ethanol/water mixtures have a far better heat capacity and are not very viscous in low concentrations. This makes it possible to reduce the amount of energy required for the fluid circulation pump.

Amount of ethanol required

The borehole heat exchangers typically used require around three litres of fluid per linear metre on average. The total amount of fluid currently required is therefore in the region of 7 million litres. If all the probes were filled with a mixture of 18% ethanol / 82% water, at least 1,260,000 litres of ethanol would be required per year. An average of 120 litres of ethanol would be needed for each borehole heat exchanger. In reality only a portion of this potential volume could be utilised.

Ethanol is in a closed loop

This ethanol stays in a sealed closed-loop system in the probes. Borehole heat exchangers are designed and built to SIA Recommendation 384/6 (2010) with a service life of at least 50 years. According to the manufacturer's specifications, however, the material used for the tubing is supposed to have a life span of more than 100 years. At the moment it's still not certain whether (or when) a borehole heat exchanger reaches the end of its useful life. After around 20-25 years, the heat pump and the circulation pump have to be replaced in any case. At the same time the fluid is replaced in the probe. If the water/ethanol mix is used, it can simply be flushed down the drain, where the ethanol will decompose naturally.

If a leak occurs in the borehole heat exchanger the consequences are also not as disastrous for the environment as when using an ethylene glycol, especially since no inhibitors are required in the case of ethanol.

VOC tax presents an obstacle

A survey of industry representatives showed that the main obstacle standing in the way of using ethanol is currently the high price resulting from the imposition of the VOC tax. This is currently the reason why an ethylene glycol mix (such as Antifrogen N) is mainly used. Furthermore, the ethylene glycol solution is promoted by manufacturers and is widely known, which is not the case for ethanol.

A series of meetings have been held with the Federal Office of the Environment (FOEN), the Swiss Federal Office of Energy (SFOE) and the Federal Directorate General for Customs (DGC) to try and come up with a solution for exemption from the VOC tax. Alcosuisse eventually came up with the solution. It is possible to produce a ready-mixed, tinted brine comprising water and denatured ethanol which is supplied solely for industrial use in borehole heat exchangers and can thus be exempted from VOC tax.

Ethanol helps to save electricity

The current ethylene glycol solution has to be mixed to a concentration of at least 20%, but in practice – and to meet manufacturers' specifications – it tends to be closer to 25%, as this is the only way of ensuring a high enough quantity of added inhibitors to prevent corrosion. The freezing point is therefore actually lower than it needs to be. This higher concentration also increases the brine's viscosity and reduces its heat capacity.

By contrast, ethanol can be mixed to any concentration. According to SIA Recommendation 384/6 on borehole heat exchangers, a probe needs to be designed so that after 50 years in service the temperature of the fluid does not dip below $-3\text{ °C} / 0\text{ °C}$. A mixture of 18% ethanol is therefore certainly enough to provide adequate frost protection (producing a freezing point of around -7 °C). With an ethanol content of 18% no vinegar formation occurs either, which means the fluid has a long service life and is not corrosive.

Because ethanol has a higher specific heat capacity than ethylene glycol, the brine volume flow can be reduced by up to 12%. Since the delivery energy can be cut by the power of three of the volume flow using the same pipe diameter, the energy used to power the circulation pump can be reduced by approximately 40%.

With modern-day systems that have been correctly designed and fitted with new A-class pumps, the auxiliary power accounts for around 5% of the total electricity needed for the heat pump. Using an ethanol/water mix therefore provides energy savings of around 2 % per geothermal system. If new systems have a heat output of roughly 10 kW and need about 2.5 kW propulsion power, this corresponds to an annual energy requirement of 5500 kWh per system. Of this, 250 kWh can therefore be saved.

New product

A mixture of less hard pure water and roughly 18% denatured ethanol should be marketed as "eco-brine" or environmentally friendly fluid for borehole heat exchangers. Exempting this tinted product from VOC tax can create a prize incentive to use the new fluid. The ready-mixed product would be delivered directly to the construction site. This not only helps to keep down building costs, but improves quality assurance because the mixture and the water quality are closely controlled and more consistent.

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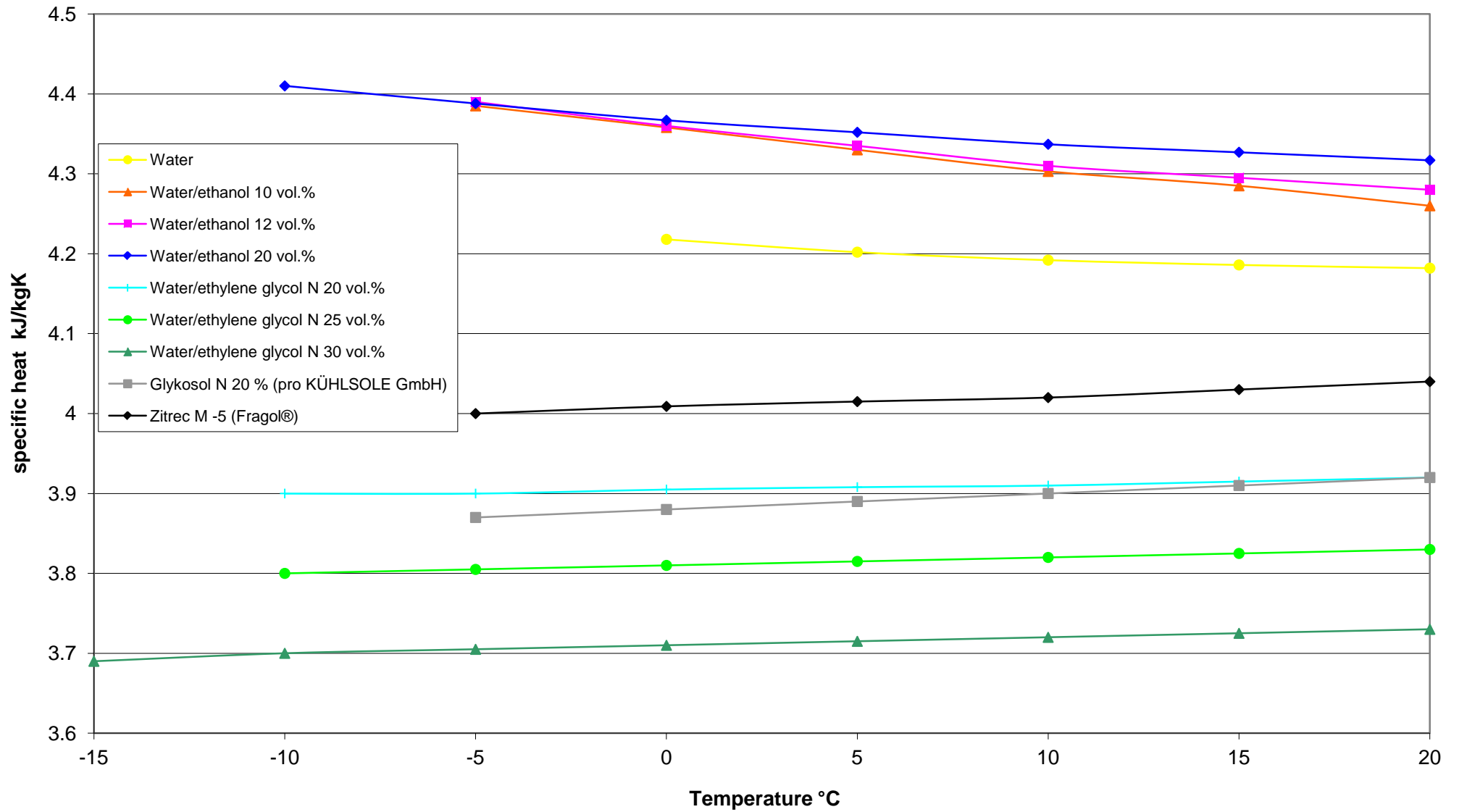
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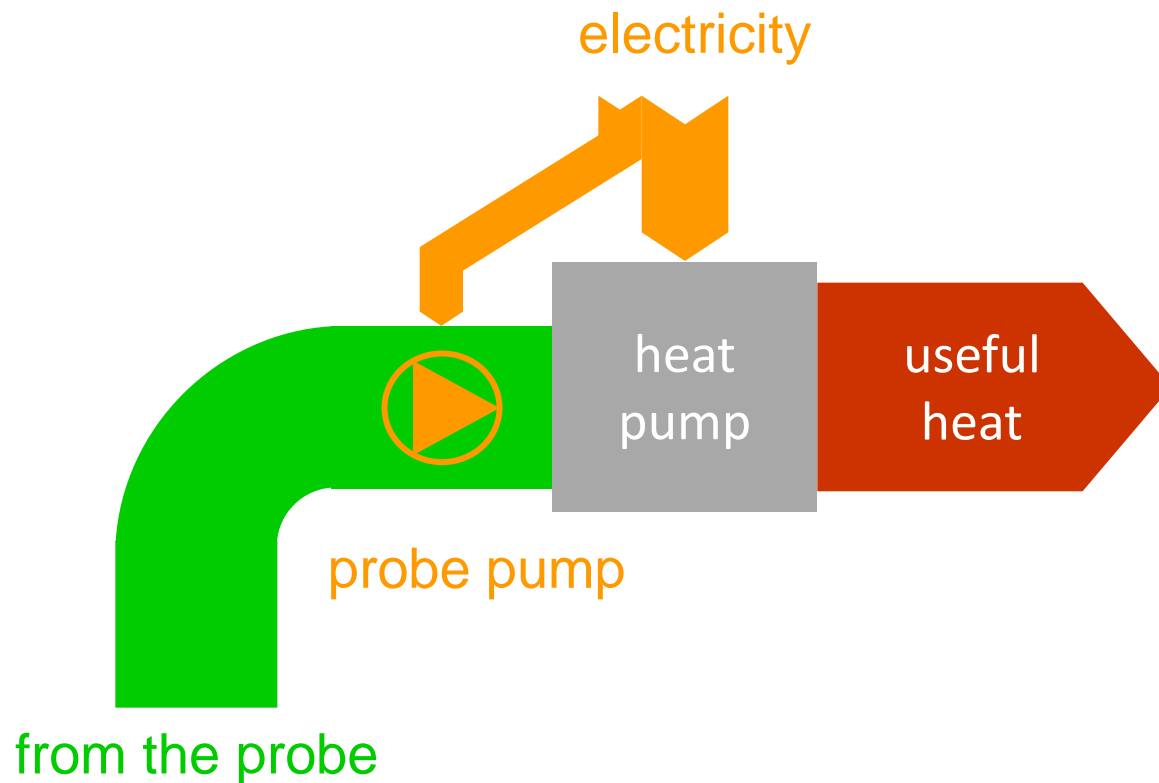
Figure 1: Specific heat capacity of potential fluids for borehole heat exchangers

Figure 2: The seasonal performance factor is a measure of the efficiency of a heat pump system and should be as high as possible

Specific heat capacity c



Seasonal Performance Factor (SPF)



$$\text{Seasonal Performance Factor (SPF)} = \frac{\text{heat output per year}}{\text{electricity per year}}$$