Feasibility of Underground Cooling for Geothermal Power Plant Applications

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ABSTRACT

The efficiency of any thermal cycle depends on the temperature differential of the working fluid in the boiler and the condenser. As such, it depends not only on the temperatures of the geo-liquid, but also on the temperature of the condenser. Most of Australia's geothermal energy resources are found in arid or semi-arid regions where day-time ambient temperatures are high, and where limited access to water will almost certainly prevent the use of cooling towers. This leaves air cooling through large fin and tube heat exchangers (analogous to large automotive "radiators") as the only established alternative option for cooling. However, air cooling in the desert will lead to degraded performance when ambient temperatures are high. The extent of this degradation is illustrated by way of example, based on a flash cycle with a re-injection pressure for the geoliquid of 10MPa and a geo-liquid temperature of 210 °C. It is estimates that a change in ambient temperature from 15 °C to 45 °C, will reduce the output power of this cycle by 44 %, and that this percentage reduction increases with re-injection pressure (Langman et al., this volume). While the magnitude of this effect will depend on the type of cycle and local conditions, it will be significant for all geothermal cycles. Furthermore, the degradation will be most significant during the period of peak summer demand, at precisely the time when the price of electricity is greatest. As such, it could have a significant adverse impact on the commercial return of the plant. To address this problem it is proposed to undertake a preliminary assessment of the potential to use under-ground cooling for the plant.

The broad principles of utilising the thermally cool and stable layer of the soil for cooling are well known (DiPoppo , 2005; Hewit et al., 1994). Underground houses have been used for centuries in desert environments to maintain cool living, and this principal has been extended to provide underground cooling and heating in some modern buildings. This shallow geothermal energy exchange and storage capitalises on the large thermal mass of the soil to damp out temperature fluctuations, provide a semi-uniform thermal reservoir and provide a time lag to avoid the coincidence of peak temperature with peak electricity demand. While the potential to exploit this principle in the cooling of a condenser is therefore evident, some challenges can also be anticipated.

It is well established that below 2 m depth the temperature of the soil is almost constant during the day and changes slightly across the year (Sanner, 2001; Nowak and Satchel, 2005; Hillel, 1998). Both heat conduction and latent heat convection contribute to the transfer of heat in the soil. The thermal properties of the soil depend on its constituents and vary substantially with moisture content. At locations of interest in Australia the likelihood is that a well weathered sandy soil will exist for more than 10 m depth. A sandy soil has a thermal conductivity of 0.55 W/mK (dry) and 2.5 W/mK (wet), porosity of ~40% and thermal heat capacity of ~1.3E6 J/m^{3}K which varies with the compactness of the soil and its density. These characteristics point to a large potential for energy storage, albeit at a moderate transfer rate.

As most sites identified with high potential for geothermal energy have dry weather and hardly any rain the issue of water content need not be considered in a preliminary assessment. Although water drastically improves thermal conductivity it also can cause swelling of the soil (up to 100 times) and introduce substantial directional mechanical stresses. In addition water can enhance the reactivity of the soil and its salts which can cause slow degradation of the buried tubes and heat exchangers.

From the above it is clear that such an underground cooling system can be expected to involve a large network of pipes, and to require significant capital cost. It is also clear that there will be significant potential to reduce this cost by careful design and optimisation. Further, there is significant potential that they may be cost-competitive with air-cooled systems, considering both the capital cost of using fin and tube heat exchangers and the ongoing operational cost of large fans. However, at present, little information is available of the details of such a system, or of the soil and temperature fluctuations on which to base reasonable estimates of its potential. This work aims to address this need.

Although the thermal mass available for storage is large this method relies on temporary storage of the heat during the day for release during the night. The differential temperature during a typical summer day allows for the majority of the heat dissipated from the underground pipes to be released into the atmosphere during the night. Innovative night time cooling methods are being considered to enhance energy release.

A preliminary assessment of a single pipe buried 1m deep receiving liquid at 90 °C has been completed. The average daily temperature for January taken at outback South Australia was estimated to be similar to that at Oodnadatta Airport. At steady state operation it was found that the buried pipe loses 0.25 of the heat compared to a similar pipe in an air-cooled heat exchanger above ground. Considering that no fan power is required and that flexible pipes with moderate heat conduction characteristics can be used in this application, to reduce installation cost, substantial savings in the on-running cost can be achieved through the underground cooling system.

In this talk details of one and two dimensional analysis will be presented highlighting the feasibility of this concept when applied to areas in the outback. In addition a preliminary cost benefit assessment of this concept when compared to air cooling will be presented.

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