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Improving the performance of arid-zone geothermal power plants using seasonal heat storage

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ABSTRACT

A scheme is proposed whereby the performance of geothermal power plants utilizing low-temperature heat sources in the arid regions of central Australia may be improved through the use of groundwater for direct cooling of the condensers. After use, this water would be reinjected into the aquifer. If ambient conditions permit, heat may be rejected from this water via air coolers prior to reinjection. The current work indicates areas of central Australia where the scheme would have greatest potential, and considers the impact of the scheme on geothermal plants with high, medium and low temperature sources.

1. Introduction

In Australia, large regions of geothermal potential are located in arid areas, and in these environments condenser cooling presents a challenge. Scarcity of water for cooling often makes air-cooling the only option, but high ambient temperatures affect condenser operation and consequently the plant can incur a performance penalty. Solutions addressing this problem have focused on intermittent systems that consume less water than evaporative condensers, such as hybrid cooling (Ashwood and Bharathan, 2011); it has also been suggested that improvements in overall plant efficiency may have as role to play in minimising water consumption whilst using conventional methods (Bliem, 1989).

Collins (2009) presents a novel proposal whereby existing reserves of shallow groundwater could be used to provide direct cooling of a binary geothermal power plant's condensers, and is subsequently re-injected such that no water is consumed in the process. Temperature change in the groundwater is minimized to prevent scaling (Collins, 2009). Water from shallow aquifers in the region is used far less prevalently than water from deep artesian aquifers, which is of high quality. Shallow groundwater, in this case referring to the water table, is frequently saline (Collins, 2009), and thus not as desirable. The proposal notes substantial benefits for maintaining a consistently low condensing temperature, and suggests that this may be achieved by making use of reserves of shallow groundwater with a temperature estimated to be 23 °C. In doing so it uses three separate cooling systems (see Fig. 1).

The first element (A) of the cooling system entails the production of cool groundwater from the aquifer via groundwater production wells *GPW*. This is then passed through a groundwater-cooled condenser *GWCC* where heat from the condensing process is absorbed by the groundwater, a process termed "heat rejection" in this work. The second element (B) is a fan-forced air cooler *AC* which is operated intermittently to reduce the temperature of groundwater prior to reinjection when conditions for cooling are optimal, in a process referred to as "heat discharge". Air cooling capacity is such that storage of heat in the aquifer during hot periods is offset by heat discharge via the air cooler during cool periods. The groundwater is returned to the aquifer via reinjection wells *GRW* placed a substantial distance from the production wells. The proposal suggests a third element (C), composed of a secondary set of production and reinjection wells, and an air cooler. This would also operate intermittently, circulating and cooling the groundwater to remove additional heat as necessary.

When air-cooling of groundwater leaving the condenser is not conducted, the plant incurs a small parasitic load to operate groundwater pumps, and the plant may be described as operating under a "storage regime", as excess rejected heat accumulates in the aquifer. During periods air-cooling is conducted, the plant operation may be termed the "cooling regime", a reference to the removal of excess heat from the aquifer by heat discharge to atmosphere. At these times a higher parasitic load is required to operate cooling fans for the air-cooler.

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Nomenclature

$c_{p,gw}$	groundwater specific heat (J/kg K)
H_p	total pumping height (m)
$\dot{q}_{brine}$	heat input rate from brine (W)
$\dot{q}_{reject}$	heat rejection rate (W)
$\Delta T_{gw,cond}$	change in groundwater temperature (K)
T_{brine}	geothermal brine temperature (K)
T_{cond}	condenser temperature (K)
$T_{gw,condout}$	temperature of groundwater exiting condenser (K)
T_{gwp}	groundwater production temperature (K)
$\dot{w}_{\Delta,out}$	output work rate by triangular efficiency estimate (W)
$\dot{w}_{pump}$	pump work rate (W)

Greek Symbols

η_Δ	cycle efficiency by triangular efficiency estimate
η_{pump}	pump efficiency

Collins (2009) suggests that a plant using air-cooled condensers would produce substantially less net power on a hot day. By comparison, a scheme making use of groundwater would incur minimal parasitic losses in such a situation. This scenario is countered by the times the plant is operating under the cooling regime, when heat is discharged from the aquifer to atmosphere by the second and third cooling systems. During these periods high parasitic losses would be incurred. It is suggested that the proposal's primary benefits are firstly to improve output stability by maintaining a consistent condenser temperature, and secondly to allow heat discharge duties to be carried out when conditions are favorable.

The current work comprises a study of the shallow geology of central Australia, and an analysis of the potential impact on plant performance. Classification of the shallow geology has identified promising regions and formations, and data from existing shallow wells has been obtained to demonstrate the availability of shallow groundwater suitable for cooling. The study region encompasses two geothermal sites, one of which is operational, in Birdsville, and another under development at Innamincka (Chen and Wyborn, 2009). Locally, the Birdsville plant is characterized as utilizing Hot Sedimentary Aquifer (HSA) heat source; the Innamincka site is characterized as an Enhanced Geothermal System (EGS) type resource.

2. Material and methods

2.1. Geological setting

The study area is defined by the bounds of the Eromanga Basin, the largest of the three sedimentary basins (the Carpentaria, Eromanga and the Surat) known collectively as the Great Artesian Basin. This region exhibits some of the highest geothermal gradients found in Australia (Gerner and Holgate, 2010) and two current geothermal projects are located within the basin limits; the Birdsville geothermal power plant, and the Geodynamics project near Innamincka (Fig. 2). The shallowest water-bearing formations in the basin were considered candidates for groundwater cooling as deeper aquifers in the region produce water at temperatures too high for direct cooling. The depositional history, composition, and distribution of the sediments of the shallow aquifers were also considered when determining which might be suitable for producing large volumes of water with minimal pumping.

The composition of the Cretaceous and post-Cretaceous sediments is referred to in many previous studies (Barron and Cox, 1998; Callan et al., 1995; Gray et al., 2002; Wopfner et al., 1974; Wopfner and Twidale, 1967). From these studies it is possible to make general assumptions regarding the water-bearing potential of the candidate layers, as certain lithologies tend to be associated with productive aquifers. The distribution of the shallow Tertiary- and Quaternary-age sediments was mapped using a basin-wide elevation estimate of the Cretaceous Winton Formation developed for the GABTRAN model (Welsh, 2006) and the current 9-second Digital Elevation Model (Hutchinson et al., 2008). The areal distribution of the post-Cretaceous sediments was used to select water bores drawing from these formations. The associated borehole data including yield, temperature and water level measurements was obtained from the Department of Environment and Resource Management (DERM) in Queensland, and from the Department for Water (previously PIRSA) in South Australia. In the case that a single well had been sampled more than once, the most recent sample data was selected. Boreholes located in the sectors of the Eromanga Basin encroaching on the Northern Territory and New South Wales were disregarded. The reduced subset of boreholes drawing from the shallow sediments were compared with more detailed surface geology maps and classified further into depositional zones. These zones were defined being part of the same alluvial system, or as being part of a distinct floodplain or dune field, and improved resolution of regional factors such as yield, water table depth, and temperature.

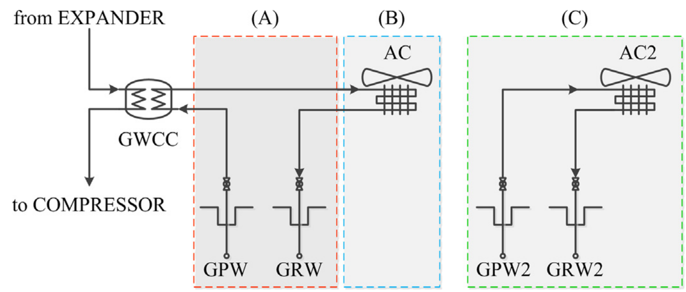

Fig. 1. Groundwater cooling scheme showing (A) production of groundwater for condenser cooling, (B) air-cooler for intermittent heat discharge, and (C) possible secondary air-cooling of groundwater for additional heat discharge.

3. Power plant operation

A report commissioned by the Electric Power Research Institute (Wilber, 2005) presented a case study a fluid being condensed at 55 °C by air with an ambient temperature of 37 °C, an initial temperature difference of 18 °C. This can be taken as typical of a design point that might be implemented in central Australia. In this case study, fan power requirement is approximately 1.3% of the total heat exchanged.

The simplest losses associated with groundwater cooling come from pumping, as few artesian aquifers exist in the target formations. The ratio of pump power to heat rejection rate may be expressed as shown in Eq. (1), where $\Delta T_{gw,cond}$ is the change in groundwater temperature across the condenser (Fig. 3).

$$\frac{\dot{w}_{pump}}{\dot{q}_{reject}} = \frac{gH_p}{\eta_{pump} c_{p,gw} \Delta T_{gw,cond}} \tag{1}$$

Nominal plant efficiency can be estimated using the triangular efficiency approximation as shown in Eq. (2) (DiPippo, 2008). This is more suitable for estimating the efficiency of a power plant using a non-isothermal heat source such as brine.

$$\eta_\Delta = \frac{T_{brine} - T_{cond}}{T_{brine} + T_{cond}} \tag{2}$$