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Geothermal cities

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The US Geothermal Energy Association has identified Perth as one of the top 10 'Geothermal Cities' on the grounds of 'entering the geothermal community with a new twist – as the first geothermally cooled city with commercially powered heating and air-conditioning units.' This announcement reports on the proposal of the WA Geothermal Centre of Excellence (WAGCoE) for CSIRO to cool and heat the Australian Resources Research Centre (ARRC) and the adjacent Pawsey Centre with heat from a deep aquifer below the building. This Education Investment Fund supported project is the first demonstration of a novel WAGCoE developed, patented geothermal cooling technology that has the potential to displace 60 per cent of the electricity needed for conventional heating, ventilation and air conditioning for modern cities by a clean geothermal solution. By working with CSIRO on this project, WAGCoE aims to take the first step towards providing geothermal desalinated water, air conditioning and power to our cities with zero emissions. The Centre will achieve this by supporting a series of geothermal demonstration projects demonstrating exploitation of convective geothermal fields in sedimentary aquifers. Successful completion of the ARRC/Pawsey Centre Geothermal Project is expected to lead to adoption of this technology by the wider community, notably in industrial and commercial buildings, schools, shopping centres and government buildings with cooling capacities ranging from 300 kW to several MW. The proposed technology does not occupy a substantial aboveground footprint, thereby making it amenable to existing building retrofit. The standard and existing chillers in buildings simply need to be replaced by adsorption chillers. Installing or retrofitting this technology on to only 300 buildings in the Perth metropolitan area with a required cooling capacity of 1 MW each would lead to 724 000 tonnes of CO2e abatement per annum. The same technology can also be applied in new townships, such as Alkimos with 20 000 dwellings and the township in Pilbara, with 50 000 dwellings being planned. The adoption of the first demonstrator (Figure 1) alone, can in both the Perth metropolitan area and in new Western Australian townships, abate 82 million tonnes of CO2e over 20 years.

Keywords: Geothermal cities, direct heat, power generation, zero emission.

Dual heat abstraction – heat rejection solution

The first innovative component of the ARRC/Pawsey Centre geothermal demonstration project is the novel coupling of adsorption chiller technology to a geothermal heat source. This part of the demonstration hinges on the abstraction of heat from a deep aquifer. Wherever water in excess of 60°C is available (not only from a geothermal but also from another waste heat source), its widespread use in this way can displace a significant amount of electricity use in modern cities.

The second innovation is the new concept of a coupled heat rejection into the shallow aquifer using the method of chaotic mixing. This component is often overlooked but probably the most relevant for broadening the footprint of geothermal worldwide and not only for direct heat use. All geothermal implementations, including so-called high temperature resources, have to tackle the problem that they provide temperatures that are still lower than those obtained from burning fossil fuels. Therefore, the lack of efficiency of geothermal energy is always compounded by the need to reject large amounts of energy as heat. Since most geothermal applications are water-cooled it implies in practical terms that the cooling towers have to often waste twice the amount of water produced by the geothermal system or more. Our below ground heat rejection solution solves this problem.

The proposed ARRC/Pawsey Centre geothermal demonstration project shown in Figure 1 will introduce a tight-knit combination of three components:

(i) deep geothermal abstraction;
(ii) shallow geothermal heat rejection; and
(iii) adsorption chiller as an end-user of this novel concept.

For the geothermal city concept we see the adsorption chiller as interchangeable with any of the cascaded heat solutions from electric power production, to HVAC (heating, ventilation and air conditioning), to desalination and city farming.

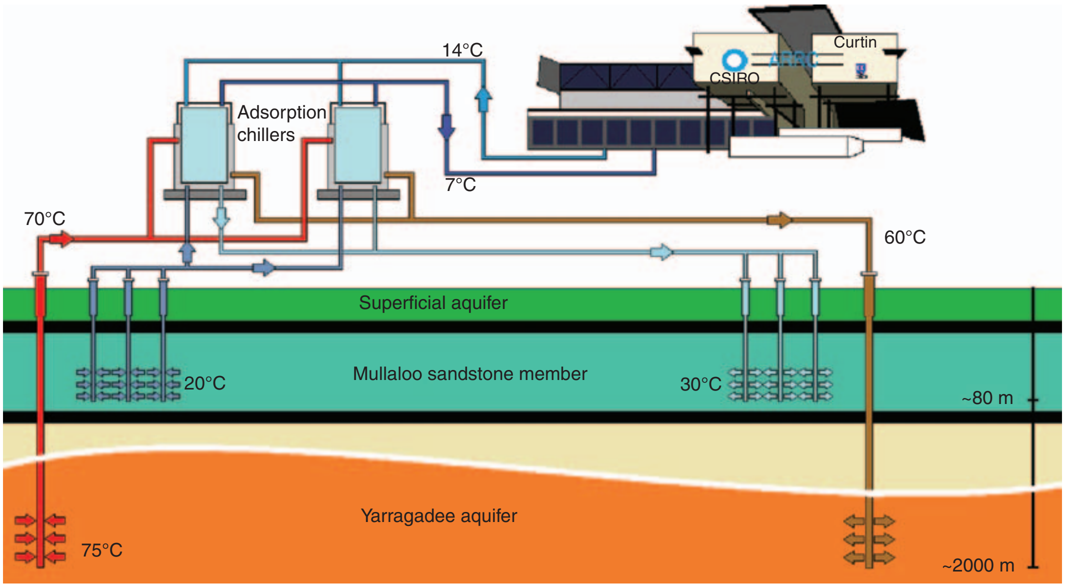

Fig. 1. *Proposed geothermal heating and cooling solution for the Australian Resource Research Centre. Geothermal heat is being harvested from the deeper Yarragadee aquifer to power the adsorption chiller, which provides cooling to the ARRC building, and all the heat is then rejected into the shallower Mullaloo aquifer.*

Heat abstraction

The activities of the WAGCoE in this field have been reported on in previous conferences (e.g. Regenauer-Lieb *et al.*, 2008) and are summarized here in brief. We are focussing particularly on the overlooked potential of hot sedimentary basins, which provide typically lower temperature than the hot rock or volcanic plays. The two key challenges involve geological targeting of the heat sources; and combating the engineering challenges of using the low-grade heat directly. This has been accomplished by:

- assessing the geological and geophysical data from the Perth Basin to identify geothermal targets and thereby construct digital geological models of the basin;
- delivering two patents for utilising heat directly from low temperature geothermal sources and establishing a geothermal desalination facility and a geothermally powered adsorption cooling device (described in more detail later);
- developing a complex system design that combines surface engineering and the underground heat exchanger for optimal tradeoffs and for infrastructure sustainability.

WAGCoE also has a fundamental research program that pushes for hotter and deeper resources. We investigate deeper below the sedimentary cover and address the challenges of extracting heat from the granitic basement. Novel multiscale methods for data assimilation in geosciences have been developed from 4D-synchrotron tomography to large-scale geophysical, geological and geochemical data sets which are reported in one of the premier science journals *Nature* (Regenauer-Lieb *et al.*, 2006; Fusseis *et al.*, 2009; Schrank *et al.*, 2011).

Heat rejection

Recently, a patented technology for efficient heat rejection has been developed based on a controlled laboratory experiment performed in CSIRO's Division of Material and Engineering Science in the Highett labs, Melbourne (Metcalfe *et al.*, 2010a; Metcalfe *et al.*, 2010b). A numerical approach has been developed that allows optimisation of subsurface chaotic mixing which has many potential applications, e.g. for treating contaminant sites, for in-situ leaching, in the petroleum industry, CO_2 sequestration, nuclear waste disposal and geothermal energy extraction and heat rejection.

Heat rejection installations into shallow aquifers are also sometimes known as 'aquifer thermal storage' or 'open loop

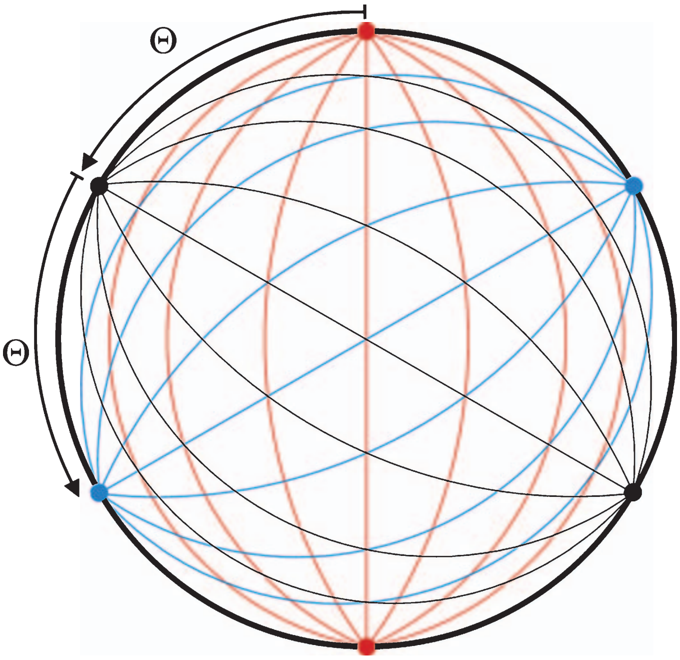

Fig. 2. *Example programmed dipole sequence for a chaotic switching protocol (rotated potential mixing). The red streamlines show the flow regime induced by one well dipole, then, after some programmed duration t, this dipole is deactivated and another dipole at jump angle Θ is activated (black streamlines), then deactivated at time 2t and a third dipole is immediately activated (blue streamlines), and so on.*

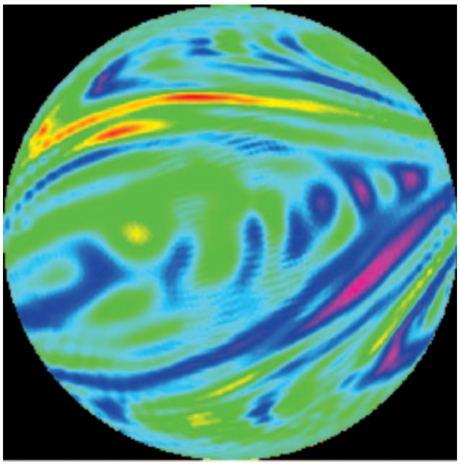

Fig. 3. *Example of optimal mixing eigenmode (Lester* et al.*, 2010).*

groundwater systems'. They classically consist of a pair or several pairs of extraction/injection well dipoles. These are often designed and operated in a loop, where the extraction well and the injection well are considered to be fixed for the lifetime of the operation. Thermal breakthrough, where disposed hot water from the injector reaches the extraction well, poses a serious risk for these operations. This risk limits the optimal design life of the pair. The design life and the maximum amount of heat that can be rejected can be increased significantly through a simple switching protocol that efficiently mixes the water between the dipoles. An example is shown in Figure 2 (Trefry *et al.*, 2011) for an arrangement of injection-extraction pairs verified in laboratory and numerical experiments as shown in Figure 3 (Lester *et al.*, 2010).

This technology is particularly useful for the heat rejection side since, owing to thermodynamic efficiencies, more heat must be rejected than is extracted. The desire would be to operate such a geothermal well field beyond the classical engineering lifetime of 20 years. The lifetime requirement arises because of the substantial capital investment for drilling the wells and the above ground infrastructure. A significant problem on this time scale is the problem of chemical precipitation around the injection boreholes. This is because the deep aqueous chemistry often can be saline/acidic with dissolved gases. The mixing protocol also has the potential to address this problem since the chemical potentials are switched.

Adsorption chillers

Adsorption chillers form a relatively new class of heat driven chillers first patented in the 1980s. Compared with absorption chillers, which are the conventional alternative, adsorption chillers rely on a solid rather than a liquid phase to drive the heat exchange. The solid adsorbent can be either silica gel or zeolite. The key virtues of adsorption chillers are that they can be powered by heat sources with temperatures as low as 65°C and there is no risk of solution crystallization. Compared with absorption chillers, which typically require a heat source temperature of 90°C, adsorption chillers are viable with geothermal resources at shallower depths. This drastically reduces the risk and cost of drilling and improves reservoir performance, which translates to a lower ongoing pumping cost for extraction of the groundwater. There is a trade-off between reservoir accessibility and required flow rate. Being a relatively new technology with a smaller consequent market penetration, the unit costs of an adsorption chiller (currently twice that of an absorption chiller) are expected to reduce significantly over time. However, in terms of net project capital costs they are already competitive because of the below ground advantages.

For installations where space is an issue, the adoption of zeolite-water as the working pair provides a far more compact option than the standard silica gel-water technology, which therefore requires a smaller aboveground footprint. To the best of our knowledge this technology has not been deployed in Australia, but has been tried and tested commercially chiefly in Japan and Europe since the late 1980s in the paint industry, iron refineries and process industry where low grade heat is abundant. WAGCoE's manager of the above ground engineering program, Professor Hui Tong Chua, is an international leader in this technology, and holds an adsorption chiller patent granted in Singapore, US and Europe which has been successfully licensed to the industry since 2003. His adsorption chiller design model is used by Mayekawa, the world-leading manufacturer for adsorption chillers, in its in-house product prototyping. He is currently developing a new generation of compact adsorption chiller which can operate at temperatures as low as 55°C. This will conceivably boost the viability and uptake of geothermal adsorption chiller technology.

Heat driven chillers, absorption and adsorption regardless, reject significantly more heat to the environment than standard electricity driven chillers. In standard engineering design, cooling towers are used for heat rejection to the atmosphere. They consume a significant amount of fresh water, discharge a considerable amount of spent water to the sewerage which produce significant emissions and require ongoing chemical treatment. A key innovation of our proposed ARRC/Pawsey Centre geothermal demonstration project is that we replace this standard design protocol with the novel ground-source heat rejection design described above. So instead of rejecting heat to the atmosphere, the same amount of heat is rejected to a shallow aquifer at a depth of about 80 m. This innovative scenario consumes essentially the same amount of electricity as the standard cooling tower design, but it does not consume any fresh water, nor does it require any ongoing chemical treatment. In addition, the perennially cool groundwater offers 2°C and 6°C temperature drop on top of what cooling towers can offer, in winter and summer, respectively, thereby further improving chiller efficiency.

Research partners

CSIRO, Curtin University, The University of Western Australia.

Industry Collaborators: GTPower, Green Rock Energy Ltd, New World Energy, Geodynamics, BHP, Newcrest, Geowatt (Switzerland).

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The Institute of Earth Science Engineering at the University of Auckland (NZ).

Institutional Collaborators: Geological Survey of WA, WA Department of Water, Institute for Geothermal Resource Management (Germany), Sustainable Energy Association Australia (SEA), Australia–US–Switzerland–Iceland International Partnership for Geothermal Technology (IPGT).

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