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DIRECT HEAT GEOTHERMAL APPLICATIONS IN THE PERTH BASIN OF WESTERN AUSTRALIA

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ABSTRACT

Sedimentary basins offer an ideal target to push forward new technologies of direct heat use. The natural temperature, porosity and permeability of these sedimentary basins may be sufficient to provide usable geothermal power without the requirement of stimulation. A new technology has emerged in which natural hot water motions are targeted. This technology is particularly suited for direct use of heat from extremely deep sedimentary basins such as the Perth Basin (>10 km thick sedimentary sequences). The main opportunity offered by sedimentatry basins is that the drilling costs can be reduced substantially because heat, salinity and topography driven upwellings exist that provide natural transfer of heat to shallower levels. Through this effect geothermal power may in the future become more competitive even in areas with normal or only slightly elevated regional heat flow. The main challenges are that natural convective upwelling zones need to be accurately targeted. The second challenge is that new methods need to be devised to harness the use of low-grade heat; shallow geothermal sources may not reach the temperatures necessary for efficient electricity generation but are ideally suited for direct heat-driven applications, such as desalination, heating and cooling, and dehumidification technologies. We are presenting our methods for improved targeting in the Perth Basin and introduce two direct heat use technologies: geothermal air conditioning via sorption chillers and geothermal desalination. The technologies are not new in their basic principle. However, their engineering art has advanced significantly and their potential for incorporation into geothermal systems is a perfect match.

INTRODUCTION

Sedimentary Basins in Australia

Sedimentary basins offer an ideal target to push forward new technologies of direct heat use. Sedimentary basins occupy a large proportion of the Australian landmass (Figure 1). The Great Artesian Basin (comprising amongst others the Eromanga and Surat Basin), for instance, is one of the world's largest artesian groundwater basins, underlying one fifth of the Australian continental landmass. Groundwater comes out at wellheads at temperatures up to 100 °C. The natural temperature, porosity and permeability of these sedimentary basins may be sufficient to provide usable geothermal power without the requirement of stimulation. A new technology has emerged in which natural hot water motions are targeted. This technology is particularly suited for direct use of heat from extremely deep sedimentary basins such as the Perth Basin (>10 km thick sedimentary sequences).

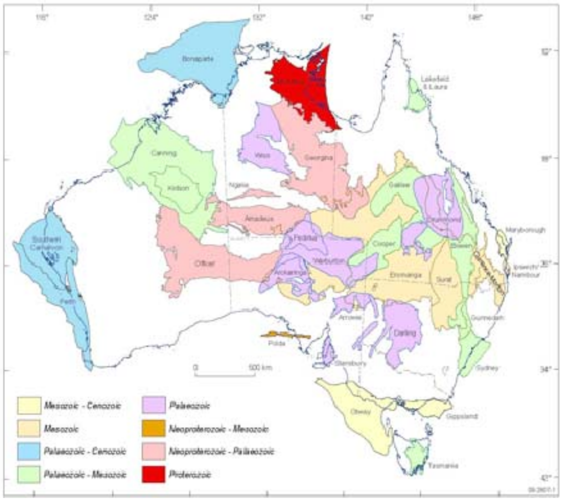

Figure 1: A large portion of the Australian landmass is covered by sedimentary basins. http://www.ga.gov.au/image_cache/GA11137.pdf

THE PERTH BASIN OPPORTUNITY

The Western Australian State Government announced a new $2.3million WA Geothermal Centre of Excellence focussing on direct heat use (e.g. geothermally powered air conditioning and desalination) in populated centres where there is shallow groundwater of moderate temperature.

By exploring for and utilising low-grade heat in a permeable sedimentary environment we address an overlooked opportunity for broadening the footprint of geothermal energy utilisation.

We are particularly focussing on the geological setting of sedimentary basins like the Perth Basin, where exploitable heat is available right where it can be used. In the Perth Basin, Horowitz et al. (2008) argue for the existence of hydrothermal convection cells in thick, permeable, fluvial aquifers. The basin itself is up to 15 kilometers deep, and thermal gradient have been measured in excess of 50 °C/km. In some strata, measured native permeabilites have been recorded to exceed 1 Darcy at 3 kilometers depth.

For 3-D modelling of these geothermal systems the Centre will harness the supercomputers now being set up in Perth. This will make it possible to drive geothermal research into computationally intensive directions that had previously been out of reach in Australia. Because reactive flow simulations are classically performed on single processor infrastructure our parallel implementation will also be a focus of research. The research is organised in three interlinked Programs: 1) Assessment of Perth Basin Geothermal Opportunities using presently available data (including the supercomputer modelling program); 2) Optimal use of geothermal resources; 3) Identification of Future Potential by going deeper.

There are challenges and opportunities. The main opportunity is that the drilling costs can be reduced substantially because the convection cells provide natural transfer of heat to shallower levels. Through this effect geothermal power may in the future become more competitive even in areas with normal or only slightly elevated regional heat flow. The main challenges are that the convective upwelling zones need to be accurately targeted and new methods need to be devised to harness the use of low-grade heat. Shallow geothermal sources may not reach the temperatures necessary for efficient electricity generation but are ideally suited for direct heat-driven desalination, heating and cooling, and dehumidification technologies. In this paper we wish to only present the above ground aspect of this new “geothermal opportunity”. The engineering challenges of using the heat directly will be addressed. The geological challenges of targeting the heat sources will be discussed elsewhere.

The above-ground engineering aspects will be led from the UWA Mechanical Engineering Department in strong collaboration with Earth Scientists from the other institutions in Australia. We are focussing on novel exploitation technologies for low-grade heat. This is an essential step for broadening the utilisation opportunities of geothermal energy in the metropolitan urban environment.

THE DIRECT HEAT USE PARADIGM

A theoretical upper limit on extractable mechanical work from a heat driven process between a maximum temperature level, T_{max}, and a minimum temperature level, T_{min} is the well known Carnot efficiency, given by $(T_{Max} - T_{Min})/T_{Max}$. Here, an efficiency of 1 defines a full but impossible conversion of heat into work. Note that temperatures are expressed in Kelvin.

For illustration of the Carnot principle consider an existing geothermal plant at Mokai in New Zealand which uses an ORMAT Energy Converter binary unit. Mokai uses steam at T_{max} = 219°C (492.15 K) and cools to the ambient temperature of say T_{min} =20°C (293.15 K) thereby allowing a theoretical Carnot limit - which is of course not achieved in the plant - of 40% work extraction efficiency. Because we are targeting relatively low temperatures for T_{max}, obviously the lower difference between the hot and cold sources limits the theoretical amount of electrical energy we can extract from geothermal heat. We therefore suggest a more practical route - that is the direct use of geothermal heat.

The case of the Birdsville geothermal power station illustrates the point. Water at 98°C is extracted from the Great Artesian Basin of Australia, 120kW electric are produced, of which 40kW are lost to pumping and other parasitic causes. That amounts to a total heat-use efficiency of 4%.

DIRECT HEAT TECHNOLOGIES

For Australia we propose investigating two direct heat use technologies. The technologies are not new in their basic principle. However, their engineering art has advanced significantly and their potential for incorporation into geothermal systems has been mostly overlooked. These are:

- Desalination (65°C < T_{max} < 90°C geothermal water)
- Air Conditioning, via sorption cooling (55°C < T_{max} < 200°C geothermal water)

Geothermal Desalination

For geothermal desalination Multi-Effect Distillation (MED) Technology is a perfect match because it is driven with a maximum temperature of about 90°C. Higher temperatures have to be avoided to prevent the precipitation of gypsum which will severely foul the heat exchanger in the distillation plant.

Given a hotter source of geothermal energy, one could drive an organic Rankine cycle (ORC) to produce green electricity, which is in turn used to power a Reverse Osmosis (RO) plant or an MED plant.

The principles of geothermal desalination extend the classical design of an MED technology driven by hot groundwater in the first effect (leftmost box of Multi-effect distillation plant in Figure 2). This hot water is supplied at the highest temperature and highest pressure available from ground source. This hot ground water heats and boils the seawater (green line in Figure 2). Having expended only its thermal energy to the distillation plant the cool ground water will be pumped back into the aquifer so that there is no environmental impact of the MED plant. The steam from the seawater is then condensed and the resulting latent heat released is used at the next effect (the second leftmost box of the MED plant in Figure 2) which is at a lower temperature and pressure. The steam thus condensed becomes the first stream of fresh water (blue line in Figure 2). The same condensation transfer of latent thermal energy to the next effect is then repeated downstream to the other cascading effects at lower temperatures and pressures. When steam temperature is sufficiently close to the incoming seawater temperature the remaining heat is rejected to preheat the incoming seawater. The concentrated brine (green line in Figure 2) can be collected in evaporation ponds for extraction of minerals out of the seawater. This cannot be efficiently done with a reverse osmosis (RO) technology because the rejected brine is not as concentrated and is much lower in temperature.

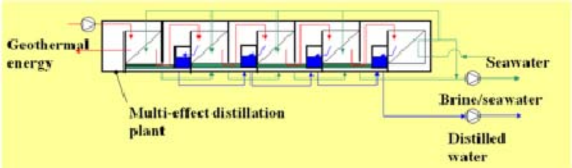

Figure 2: Principle of geothermal desalination.

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The MED technology is commercially available in sizes from 1 m^3 a day (see Figure 3) to 25 000 m^3 a day.

Figure 3: Alfa Laval Freshwater Generator (document No.PD2037-en0109 www.alfalaval.com).

Air Conditioning (Sorption Chillers)

For air conditioning we can utilise geothermal water as low as 55°C. For reference a Perth swimming pool heating system (Christ Church Grammar School) extracts 41.6°C water at 738m depth from the Yarragadee aquifer and reinjects the cooled groundwater without contamination. We believe this to be a strong indication that the economics will be viable for air conditioning via these systems.

Essentially sorption chillers are very similar to vapour compression chillers, the latter technology being the dominant technology in air conditioning. However they are currently electricity driven. Just as with vapour compression chillers, sorption chillers can supply chilled water at the same temperature to a commercial or residential building (see Figure 4,5). We propose to use heat driven sorption chillers to replace the vapour compression chillers so that geothermal heat instead of electricity is the driving energy source. Air conditioning constitutes the bulk of the peak load electricity use in modern Australian cities. Major buildings like hospitals, malls, hotels, office and government buildings can use this exciting technology to replace their existing chillers. In such buildings chilled water from the chillers located in the central chilling plant is piped around the sprawling complexes into the individual air handling units. Therefore, the air conditioning infrastructure is already in place and we propose to simply replace the central vapour compression chiller by a sorption chilling unit hooked to a central geothermal bore which should be sufficient to service a large complex or several customers (Figure 4). Unlike ground source heat pumps this technology is powered by heat directly and not electricity. It is also currently commercially available in up to about 10 MW cooling capacity per unit. It is therefore an order of magnitude larger in cooling capacity than ground source heat pumps. To put this opportunity into perspective we give the potential CO2 savings for one example building using this technology.

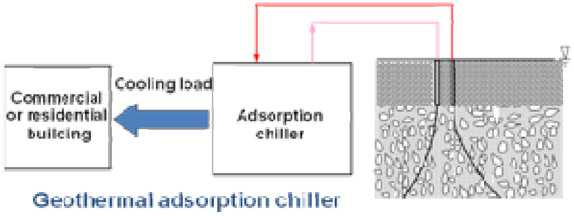

Figure 4: Principle of geothermal air conditioning.

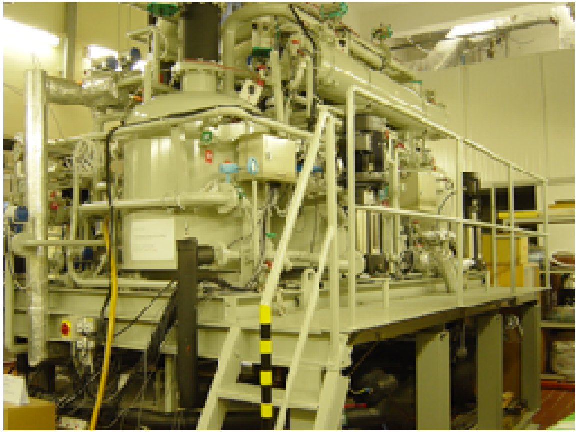

Figure 5: A prototype lab-scale multi-bed adsorption chiller (designed by Assoc. Prof. Hui Tong Chua and Dr. Xiaolin Wang).

As an example, the Australian Resources Research Centre (ARRC) in Perth currently has approximately 2.1 MW cooling capacity of electrically powered vapour compression chillers installed. Over the fiscal years 04/05 and 05/06 the ARRC consumed 5.1 GWh electrical energy and an estimated 3.2GWh equivalent of natural gas. The ARRC's facilities manager estimated 65% of the electricity and 75% of the natural gas went towards space cooling and heating activities during that period. At Western Power's estimated 2004 greenhouse gas emissions rate of 0.85 tonnes CO2e/megawatt-hour, and assuming no electrical transmission infrastructure energy losses, that corresponds to approximately 1400 tonnes CO2e per annum emitted from air conditioning the ARRC. The natural gas component adds about another 70 tonnes CO2e per annum. Those are the potential CO2e savings for one example building using this technology.

SUMMARY

We have described two new archetypal examples for exploitation of the direct heat opportunity. The components interact amongst themselves in a fashion that both advances present day real world needs of the exploitation system and lays the groundwork for a strong Western Australian contribution to a future cooperation with the broader geothermal community in Australia and worldwide. We are particularly excited by the opportunity of intermediate to low temperature geothermal systems to contribute towards a zero emission energy supply.

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