Geophysical technologies for geothermal well field development in sedimentary basins

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SUMMARY

Deep sedimentary basins across the globe hold massive untapped reserves of geothermal energy. The economics of developing these resources is yet to be fully understood however it is likely that project scale will be a key factor for success. I investigate the geophysical methods that may be of value in the design and monitoring of geothermal well fields. Such well fields may utilize networks of pumping and injection wells installed in aquifers at multiple depth for heat exchange and or power generation. The Perth basin in Western Australia has at least four distinct expansive aquifers levels below the city. I compute simplified multi-layer hydrothermal numerical models for parameter distributions broadly based on the Perth basin to depths of over 5000m. The possible radial extent of changes in pressure, solute concentration and temperature are considered. The modelling demonstrates that pressure changes spanning hundreds of square kilometres could occur for large projects with a 50 to 100 year life span. Given the above it is clear that surface seismic reflection methods should be routinely used for multilevel geothermal developments in sedimentary basins. The benefit of 2D and 3D seismic is that a robust base-line hydrothermal framework can be developed. This means the entire well field and its impacts can be mapped out over hundreds of years. Australia is highly urbanized and there are good arguments for locating large geo-thermal projects in or proximal to cities where suitable deep basins exist. However cities like Perth tend to be dead zones for deep wells and seismic coverage. So it will be necessary to design and execute seismic surveys within cities. If the geothermal industry is to be a serious provider of energy it will need to build on lessons already learned in the petroleum industry.

Key words: Geothermal, Well-field, Geophysics, 3D seismic reflection

INTRODUCTION

A trio of spectres will confront human habitation on this planet over the next few decades. These include global warming, depletion of fossil fuels and population growth. Under increasingly extreme circumstances previously sub-economic technologies like Geothermal in sedimentary basins start to make sense. However the long term viability of large scale geothermal developments needs to be carefully assessed and all investors and stakeholders adequately informed. Geophysical technologies should be at the forefront of such projects. Of particular importance is developing the correct hydrothermal framework for robust long term predictive numerical modelling that may need to span hundreds or thousands of square kilometres.

Ironically perhaps, the clearest economic case for geothermal power generation is in association with hydrocarbon production at existing oil or gas well fields (see, Zhang et. al. 2009, Erdlac et. al., 2006, and Lyle A., 2010, Davis, et. al. 2009). Such projects would typically be supported modern seismic data and comprehensive well log data sets. However there is also a good case for large scale geothermal development proximal to or in cities. Here heat exchange and power generation can co-exist close to where the energy is required. Here the complications and possibly advantage is that the any geothermal development would need to be integrated with existing public facilities like water supply.

If geothermal is going to be a major contributor to the earth's further energy requirements then large coordinated projects within major cities may need to be developed. Ultimately such geothermal heat exchange and power generating systems would require networks of injection and abstraction wells along with ongoing drilling programs. In sedimentary basins large geothermal developments would likely take advantage of the full range of hydraulic, thermal and chemical properties available from aquifers at many depth levels. Such multi-aquifer basins open the door to a wide range of well field design possibilities.

The Perth Basin is of the order 1000km in length and has considerable potential for geothermal development. It has a permeability unconfined superficial aquifer and several high quality confined aquifers at depths to more than 5000m below ground level. Key formations in Perth Basins are the superficial, Leederville, Yarragadee, and Lesueur Sandstone. The Superficial, Leederiville and Yarragadee formation are major groundwater assets for Western Australia. The Lesueur Sandstone remains as a relatively unknown resource. The deep Lesueur formation is also being considered as a reservoir for CO2 sequestration. The multiple aquifers layers of the Perth Basin present many geothermal possibilities.

METHOD RESULTS

I present a very simple layered hydrothermal model. The model is constructed that to broadly represent the major aquifer layers of the Perth basin below Perth city. The layers are then populated with hydraulic, solute transport and thermal properties, again roughly consistent with what might be expected for the Perth Basin. One example distribution for hydraulic conductivity is represented in Figure 1. This basic model consists of four aquifers layers each separated by a low hydraulic conductivity confining layer. The cube shown has x, y, z dimensions of approximately 8000 by 5000, 5000 m.

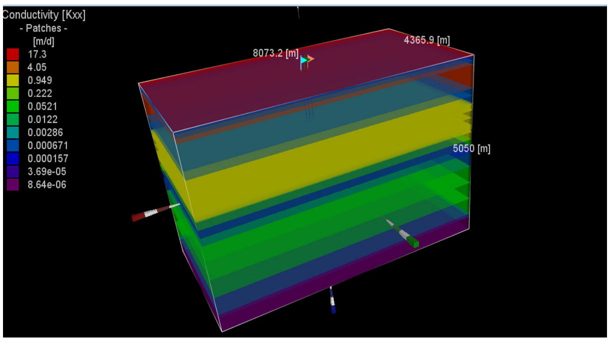

Figure 1. Example hydraulic conductivity distribution for a simple multi-aquifer multi-well hydrothermal numerical model. The model is set up in the FEFLOW finite element software.

Each layer could be used for a range of geothermal applications. For example the upper superficial layer could be used very low grade heat exchange. The economics of such shallow geothermal projects may be under-written existing groundwater applications. For example injection of water could be used to prevent saline water intrusion around the margins of the swan river. The shallow confined aquifers in Perth (i.e. the Yarragadee) are already used for heating swimming pools and could readily be used for air-conditioning. The deepest aquifer (i.e. the Lesueur Sandstone) is likely to be hot enough for heat exchange or direct power production.

Many well field simulations are completed illustrating the changes in distribution of pressure, solute concentration and temperature that may be expected from over more that 20 year production. Figure 2a is a representation of change in pressure for one example. The message from the modelling is simple. Pressure changes rapidly impact through very large volumes of earth compared to radius of impact for solute concentration and temperature. The high volume extraction and injection of more than 8ML/day per well in the deepest aquifers cause impacts well outside the approximately 40 square kilometre area show. In fact from a strict numerical point of view the model domain should be expanded by at least an order of magnitude in area. If the model were to truly represent a location beneath Perth city then it would need to incorporate impacts from large numbers of pumping and injection wells outside the geothermal well field itself. Again the need for good information and integration with an array of stake holders is clear (e.g. The Water Corporation and Department of Water). Geothermal development clearly cannot occur in isolation from other resource users.

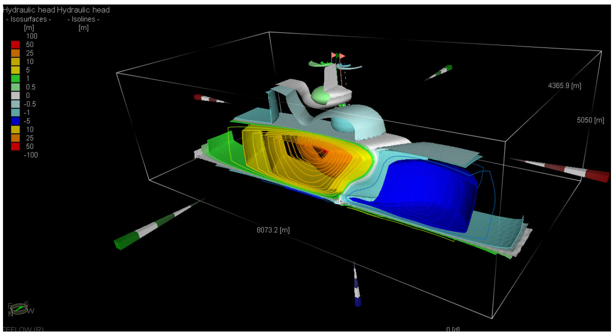

Figure 2. Example hydraulic head change from one geothermal well field simulation. The model is set up and run in the FEFLOW finite element software

CONCLUSIONS

I make five observations concerning the possible future of geothermal in sedimentary basins.

1. The large sedimentary basins of the world represent a massive untapped source of geothermal energy.
2. Economies of scale and integration/co-location of projects are likely to be a key factor in transitioning geothermal developments in sedimentary basins to economic long term providers of energy.
3. Bringing geothermal development to population centres has many advantages.
4. Large sedimentary basins with multiple aquifer levels could have many stakeholders (e.g. groundwater users, hydrocarbon developments, CO2 sequestration etc).
5. Australia is one of the most urbanised countries in the world with several cities located over large sedimentary basins (e.g. Perth and Sydney).
6. Coverage by seismic reflection surveys and deep drilling in high population centres is often very poor. For example Perth city including the suburbs has almost no seismic coverage.

From these observations, combined with the numerical simulation of well field scenarios, stem four conclusions concerning the application of geophysics for large geothermal development in sedimentary basins:

1. The many lessons learnt over centuries of hydrocarbon development need to be transferred to the development of large scale geothermal projects in sedimentary basins. The essence of the problem is not different. That is both often use networks of pumping and injector wells. An example is the application of the highly evolved wire-line logging technologies that recover, hydraulic, mechanical and chemical characteristics of rocks (e.g. Schlumberger's PEX, FMI, DSI, and CMR type logging platforms).
2. Both 2D and 3D seismic reflection should be completed at an early stage of development for large geothermal projects involving deep wells.
3. There is a need for geothermal companies to become comfortable with completing 3D seismic surveys in a modular way in build up areas (i.e. cities). Note that there appears to be an underlying fear of executing seismic surveys in cities. While design may be more complicated there is no technical reason why seismic should not be completed in built up areas.
4. Large sedimentary basins with high quality aquifers are high value assess and may be tapped by hundreds of water wells. For long term geothermal project security comprehensive numerical models should be built. These models may need to span hundreds of square kilometres and require a start hydrothermal framework that would in many cases require seismic reflection surveys to be completed.

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