HABANERO PILOT PROJECT – AUSTRALIA'S FIRST EGS POWER PLANT

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ABSTRACT

Geodynamics Limited (GDY) is Australia's leading geothermal exploration company, and is a world leading developer of Enhanced Geothermal Systems (EGS). EGS geothermal systems involve circulating geofluid between two wells drilled into a hot granite body (the "underground heat exchanger") and extracting heat at the surface using conventional shell and tube heat exchangers.

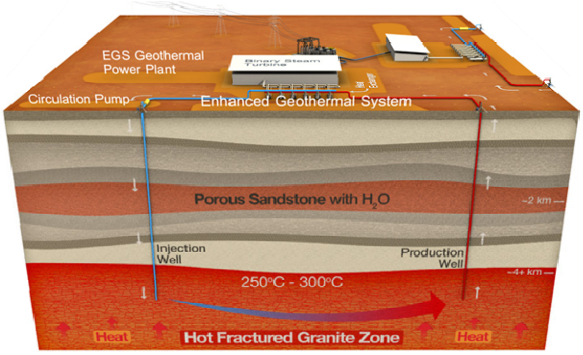

Figure 1: Cross section of an EGS Development (source GDY Internal)

This heat may be utilised in 'Direct Heat' applications, or for power generation. The energy resource potential of EGS is significant, however the proportion that is recoverable depends heavily on the presence of fractures, faults, or other structures that enable fluid circulation throughout otherwise impermeable rock. Technology exists to stimulate such features, however available techniques do not allow such features to be initiated where they do not naturally exist, and the technology for locating natural features is also limited.

For most of the last decade, GDY has focused on developing EGS resources in the Cooper Basin, near Innamincka, South Australia. This resource is one of the best in the world, with measured temperatures up to 264°C at ~4,600 m depth and a fracture system that has, in the course of the Project, been proven to circulate geofluid.

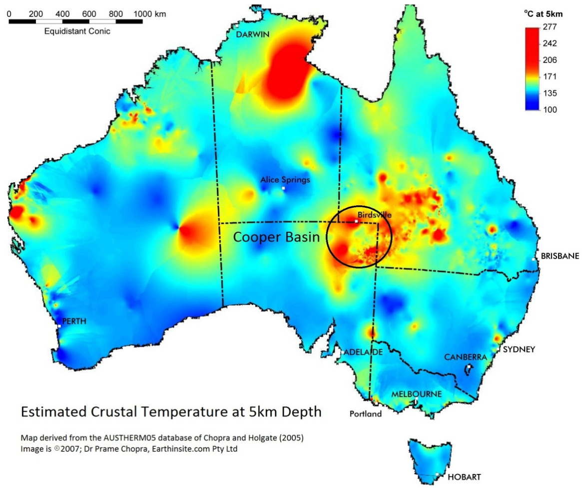

Figure 2: Location of the Cooper Basin EGS Resource (source Geoscience Australia, GDY Internal)

GDY's flagship project is the Habanero Pilot Project (HPP). First electricity was generated in April 2013 and the Plant is currently undergoing operational trials. This paper discusses the trial operation of the above-ground facilities of the HPP and the testing program that will inform the design of future commercial-scale plants.

Figure 3: Habanero Pilot Project (HPP) 1MW Plant (source GDY Internal)

Other papers (Humphreys, 2013) provide more information about the drilling and reservoir stimulation aspects of the Project.

1. HABANERO PILOT PROJECT

1.1 A Recent History

Completion of the HPP project marks the end of a ~10 year program which validated the reservoir as an underground heat exchanger and proved that electricity can be generated from an EGS resource in Australia. This program included drilling six deep, high pressure, high temperature (HPHT) geothermal wells, productivity and injectivity testing of wells and multiple high pressure stimulations to enhance

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well performance. By late 2008, GDY had established a connected doublet of wells (Habanero 1 and 3) and a pilot scale power plant. Over a period of several months, GDY circulated 50,000 tonnes of brine, equivalent to 926 operational hours (Chen, 2010) before Habanero 3 suffered a blow-out and was destroyed. This occurred before GDY was able to commission the power plant. The Company regrouped, completely revised its well design and completed the drilling of Habanero 4 well in 2012. This well has been extremely successful, producing up to 40kg/s in open flow testing, and allowing further hydraulic stimulation of the reservoir.

Figure 4: Open Flow Testing of Habanero 4 (source GDY Internal)

Measured downhole temperature was 241°C and at the time of writing, flowing wellhead temperature was 210°C and climbing towards a predicted long-term temperature of 215°C. In parallel with drilling activities, the Company took the opportunity to re-engineer some aspects of the brine loop and power plant, especially the control system.

1.2 Project Description

The Project was commissioned in February-April 2013 and consists of:

- Habanero 1 well, which was originally an exploration well but which is suitable for reinjection duty, albeit with injectivity compromised by the existence of a ring of drilling mud in the reservoir.
- Habanero 4 well, drilled as a geothermal producer and located approximately 690m from Habanero 1.
- A high pressure flowline connecting the two wells, comprising a Brine Reinjection Pump (BRP) with an associated Brine Cooler (to lower fluid temperature to within the capability of the pump).
- An array of four shell and tube heat exchangers, configured in series, with brine passing through the tube side and "working fluid" (water) in counterflow through the shell side.
- A pilot-scale power station, referred to as "the 1MW Plant", designed to receive hot working fluid, and flash a portion of this to steam for the operation of a conventional steam turbine. The plant is built around a second-hand Peter Brotherhood condensing steam turbine.

Figure 5: The steam turbine of the 1MW Plant (source GDY Internal)

In 2009, the Project was conceived to export power to the nearby township of Innamincka, however by 2013, it was realized that the raison d'être for the HPP was research and development for EGS and that the operating life and possibly the reliability of the Plant would not support an external customer. The limitations of the Habanero 1 well also meant that to generate sufficient power for an external load, GDY must either drill another well or commit to long-term open flows. Open flow refers to the case where brine (and electricity) production is increased without increasing reinjection, and requires a large dam capacity to evaporate the open-flowed brine. Consequently, the HPP project has been commissioned with only token (166kWe) electrical loads to absorb the power that it is capable of producing. The real value of the Project lies in its medium-term closed loop circulation through the "underground heat exchanger".

In the context of geothermal plants, the plant scheme has "binary" (two fluid) characteristics, as well as the flashing water characteristic of a "single flash" plant. The Plant is air cooled, but operates indirectly via a shell and tube condenser with a separate cooling water circuit

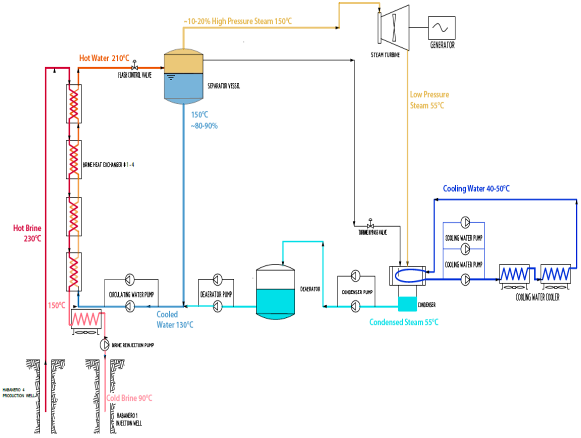

Figure 6: 1MW Plant Schematic (source GDY Internal)

2. DESIGN CHALLENGES

2.1 Sealing High Pressure and Temperature

The brine system in HPP must withstand high temperatures (>200°C) and high pressures (HPHT). At the production wellhead, pressures can rise to 36MPag during hot shut-down and normally occupy the range 33-35MPag. Downstream of the brine reinjection pump, the system is designed for 45MPag and operates close to this limit.

Sealing technology at these conditions is problematic. ANSI flanges become unfeasibly heavy, and were largely replaced on the Project by TechLok clamp connectors, which performed well. Seats and stems on new valves proved to be leak-tight in only about 50% of cases, which requires expensive redundant valving to be specified, especially at wellheads.

Experience in 2009 had shown that mechanical shaft seals for the Brine Reinjection Pump would be problematic. For the 2013 trial, GDY changed from tandem to double seals. Two double seals were custom designed and built. The first lasted 10 days and the second lasted 21 days. GDY then refurbished the circa-2009 tandem seals and heavily modified the supporting barrier fluid system. At the time of writing, a seal of this type has survived for an encouraging five weeks. Future projects will need to continue to invest research in this area.

A key lesson from the 2009 test was that almost all elastomeric materials, in any component, are subject to explosive decompression damage when the brine system is depressurised. By 2013, almost all elastomers had been successfully eliminated from the design.

2.2 Brine Control System

Early trials in 2009 had demonstrated that the brine circulation loop, including the "underground heat exchanger" was capable of:

- Severe water hammer, if valves were operated quickly;
- Brief reverse flows;
- "Over-running" flows, in which the fluid momentum continues to spin the reinjection pump after its motor has stopped, leading to impeller thrust reversals and damage;
- Boiling off of brine to steam and release of dissolved gases when depressurized;
- Causing damaging brine flow into the seal system unless the ratio of seal barrier pressure to brine pressure was carefully managed;
- (Theoretically at least) causing "break-out" damage of the well bore, if wellhead pressure was allowed to fall too low.

This required a distributed control system with numerous protective functions, as well as the ability to control brine demand based on load requirements.

2.3 Mineral Deposits

Geothermal designers are used to dealing with silica and calcite, which deposit in piping and valves at locations where geofluid temperature and pressure are sufficiently reduced. This issue required management in the open flow system of the HPP project, and was handled using polyacrylate inhibitors and occasional acid washing.

Habanero brine is unusual (but not unique) in having up to 4 ppm antimony, which precipitates as crystalline antimony sulphide (stibnite) at certain combinations of temperature at pH. This results in fouling of heat exchanger and brine cooler tubes, which degrades plant efficiency. Since this problem was identified during the 2009 operation, considerable development effort was able to be applied to a solution in time for the 2013 operation. The remedy consists of periodic hot flush with a 10% caustic soda solution (including 5% propylene glycol). A dedicated cleaning system was built to provide this solution to the heat exchangers in the plant.

During the trial operation, optimization of some cleaning parameters was started, but not fully completed. Key outcomes are that effective cleaning time is typically 30 minutes with temperatures down to 40°C (below the theoretically expected value of 70°C).

During the remainder of the test program, experiments will be performed to determine whether satisfactory cleaning can be achieved whilst economizing on caustic soda use and allowing pH to fall below the reference value of 12.

3. PERFORMANCE RESULTS

3.1 Flowrates

Open flow testing of Habanero 4 produced flowrates up to 40kg/s and exceeded all previous GDY wells. As described above, Habanero 1 was a known 'bottleneck' in the closed loop and GDY expected it to absorb a maximum of 15kg/s. After 1700 hours of reinjection, this rate has improved to 17.2kg/s and continues to gradually improve. This is attributed to a probable break-up of the mud blockage, however improvements in Habanero 4 hydraulics and a stronger thermosiphon effect may also play a role (Thermosiphon refers to the natural circulation between two EGS wells due to their differing temperatures, which can occur without mechanical pumping and has been demonstrated to produce a flow of approximately 5.5kg/s in the Habanero 4-Habanero 1 doublet.)

3.2 Temperature

Prior to stimulation, Habanero 4 open flowed at 191°C. Large scale stimulation involved injection of 36ML of cold water, which cooled the reservoir for several weeks. Steady closed loop circulation has gradually improved the flowing temperature from approximately 190°C to 210°C. A small project is underway to partially fill the well's production annulus with nitrogen, thus displacing completion brine. The objective is to reduce heat transfer to the earth as the hot brine ascends the well. This project is expected to result in temperatures above 215°C.

3.2 Reliability and Availability

At the time of writing, the brine loop has operated for a total of 1700 hours since commissioning in April 2013, which is approximately 84% longer than achieved in the 2009 campaign. When the trial is completed in September, it is expected that the loop will have operated for nearly 3000 hours. Despite the difficulties with the brine reinjection pump seal, the brine loop has achieved a 71% overall availability over this period, and since changing to the new seal type, this has improved to 94%. The steam plant has been available as required by the brine system, with the reliability that is expected of proven Rankine cycle technology.

3.3 Power

Plant auxiliary load is dominated by the reinjection pump and remains fairly constant at 650kWe as long as brine reinjection is constant at 17kg/s. The unit is just able to meet its auxiliary demands without any open flow, which has been a major benefit during the trial operation.

Indicative Thermoflex modeling predicted a deficit of 20kWe of generated power at these conditions, which is considered a reasonable correlation given the limitations of the model. Noting the accuracy limitations of the model, it predicts the ability of the as-built Plant to generate net power as a function of increasing open flow (refer Table 1). As explained above, a load bank was not available, however it was possible to use redundant pumps and fans to simulate external loads and approximately confirm the calculated correlation between open flow rate and net power. The last two rows of Table 1 describe GDY's predictions for a commercial project, shown for comparison:

Table 1: 1MW Plant Performance and Scale Up Potential

Open Flow rate	Reinjection Flow rate	Predicted Plant Load (Auxiliaries)	Actual Plant Load (Auxiliaries)	Predicted External Load	Actual External Load	Contribution from Diesel Generator
0kg/s	17kg/s	~650kWe	~645kWe	-21kWe	0 kWe (Plant stable with no load)	0 kWe
2.5kg/s	16.5kg/s	~650kWe	~650kWe	80kWe	150kWe	0 kWe
5kg/s	17kg/s	~650kWe		205kWe	Considerable power available, but no load at Site large enough to absorb this power#	0 kWe
10kg/s	15kg/s	~650kWe		340kWe		0 kWe
15kg/s	13kg/s	~650kWe		513kWe		0 kWe
0kg/s	40kg/s	~700kWe *		2.5 MWe		0 kWe
0kg/s	80kg/s	~1.5MWe *		5 MWe		0 kWe

*(Require much less pumping power if not injecting into Habanero 1 well)

This modeling indicates that the HPP Project could be readily scaled to a 2.5MW plant, with the addition of a single good quality injector well to replace Habanero 1, and that further wells could scale to a 5-10MW project.

4. RESEARCH AND DEVELOPMENT

The brine system was extensively instrumented, including corrosion coupons to test over 12 different metals in various locations. A miniature version of the brine heat exchangers was operated in parallel with the main units, and contained test tubes of SAF 2205, 2507 and 2707 material. These will be destructively tested to assess corrosion and scaling and will inform the choice of materials in a commercial scale plant. The brine is sampled and chemically analysed, at regular intervals, and the brine piping receives in-service ultrasonic wall thickness testing, to assess erosion and corrosion.

5. CONCLUSION

The trial operation phase of the HPP project and 1MW plant culminates a decade of effort by GDY. It demonstrates proof of concept for the conversion of an EGS resource to electricity, and provides confidence to scale the known fracture system at Habanero, and the technology, to a 5-10MW project supplying customers such as the various shale gas companies of the Cooper Basin.

With 1000 square kilometres of hot granite resource, there is the potential to scale EGS technology up to several hundred megawatts, although this requires some development in the exploration technology to identify fracture systems.

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