# Completion of Habanero Closed-loop Circulation Test

Doone Wyborn[1*].
[1] Geodynamics Limited. PO Box 2046, Milton, QLD, 4064.
* Corresponding author: doone.wyborn@geodynamics.com.au

Geodynamics has been working towards its "Proof of Concept" Enhanced Geothermal System (EGS) since drilling its first deep well in 2003 into the basement granites beneath the central Cooper Basin, NE South Australia. By 2008 there were two successful wells 560m apart connected by a stimulated fracture system located at a depth of 4,250m where the rock temperature is 247°C.

Initially open loop testing was employed involving production to a pit then re-pressurization back to reservoir pressure with oil industry "frac" pumps. In late 2008 a high pressure pipe line was completed connecting the two wells at surface, and by December 2008, after initial pump failures, a six week circulation was commenced. The circulation involved flow from Habanero 3 using the natural artesian pressure, keeping the fluid at full flowing wellhead pressure through the surface pipeline, cooling the fluid near the re-injection well Habanero 1 with an air cooled heat exchanger, and using a 41-stage centrifugal pump to re-inject the fluid back into the reservoir.

The results of the circulation test and of the associated tracer testing will be presented. The success of the circulation led Geodynamics to announce completion of its "Proof of Concept" in March 2009.

*Keywords*: Enhanced Geothermal System, circulation test, tracer test, stimulated reservoir.

## Background

Geodynamics formed as a single purpose company in November 2000 to develop hot fractured rock (now generally known as Enhanced Geothermal Systems, EGS) geothermal energy from a unique non-volcanic environment represented by basement high-heat-production granites overlain by insulating sediments. Oil industry drilling had identified the central part of the Cooper Basin in an area known as the Nappamerrie Trough as an ideal site for such development. In addition the oil exploration had reported that the stress field is close to overthrust with minimum principle stress vertical. Under such conditions hydraulic stimulation of fractures would in preference take place on sub-horizontal existing natural fractures. These conditions were envisaged to be ideal for large scale multi-well EGS development.

The first well (Habanero 1), drilled in 2003, identified high fluid overpressures in the existing natural fractures, and these overpressures caused difficulty in drilling. In order to control these overpressures the use of heavy drilling mud resulted in mud losses that caused damage to the natural fractures reducing their ability to flow. Habanero 1 was completed to a depth of 4,421m and a fracture system at about 4,250m was stimulated by massive injection in late 2003 where the rock temperature is 247°C.

A second well, Habanero 2 was drilled 500m to the SW of Habanero 1. However difficulty with the existing drilling method and the fracture overpressures resulted in an eventual suspension of a side track in the well with stuck drill pipe left in the hole 79m below the top of the granite at 3,784m. Prior to the sidetrack the well had intersected the stimulated reservoir at a depth of 4,325m and the well flowed at rates up to 20 kg/second with surface flowing temperatures up to 210°C. Pressure responses in Habanero 1 whilst flowing from Habanero 2 indicated strong connection via the fracture system at 4,250m between the wells.

A second massive stimulation from Habanero 1 was completed in 2005 which extended the stimulated reservoir outwards to occupy an area of approximately 4 $km^2$ in plan view. This reservoir resulted from the injection of 40,000 $m^3$ of water in total in 2003 and 2005. It was defined by the location of 45,000 micro-seismic events. The 2005 stimulation proved that stimulation created permanent enhanced fracture flow capacity as the 2005 micro-seismic events commenced essentially where the 2003 events finished.

Habanero 3, the new production well was completed in February 2008 at a distance of 560m NE of Habanero 1 or slightly more than 1 km from Habanero 2. The stimulated reservoir was intersected at the predicted depth at 4,181m, and a pressure response at Habanero 1 was observed before drilling parameters were recognised as detecting the intersection.

Immediately after reaching TD of 4,221m the well was logged with the Baker Atlas circumferential borehole imaging tool (CBIL). The tool was deployed to the fracture zone area as quickly as possible and proceeded to log down. The tool managed to log the whole of the fracture zone before the temperature rendered it inoperable at a depth of 4,207m. Its temperature rating is 205°C, but the tool actually continued to operate to a temperature of 220°C, a very commendable performance. The image through the main part of the fracture is shown in the picture below (Figure 1).

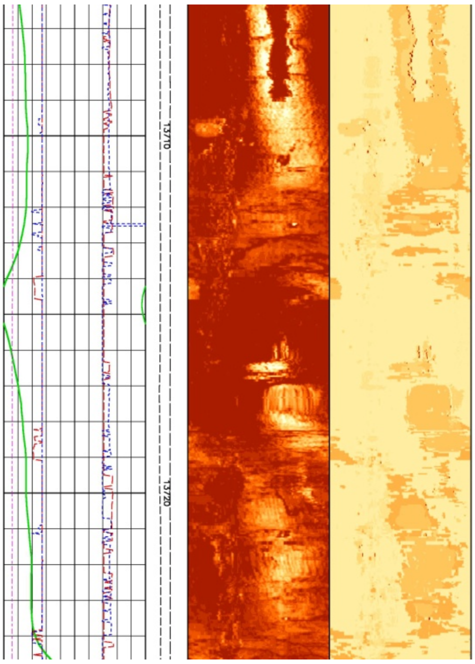

Figure 1 CBIL image of main fracture zone at 4181m (13,716 ft). The dark area in the centre of the image represents a cavity in the borehole formed where a large fracture intersects the wellbore.

## Open-Loop Circulation Test

The open-loop flow test was designed to demonstrate communication between Habanero 1 and 3 along the fracture zone stimulated from Habanero 1 in 2003 and 2005, and to determine the impedance or friction loss associated with circulation between these wells. The impedance governed the pumping requirement for closed loop operation, which in turn dictated the operability of the pump that had been purchased for this phase. If the impedance was too high, the pump would not be suitable and a number of remedial actions would need to be effected.

Habanero 3 was drilled to 40m below the main intersection of the reservoir and completed with a 7 inch perforated liner. The rig demobilised with the well left with a mud weighted to accurately balance the fluid overpressure from the fracture zone. The fracture pressure was estimated at 74 MPa at a depth of 4,181m or 34 MPa above hydrostatic. This pressure is the same as the shut-in pressure observed at Habanero 1.

In order to bring the well on to flow a coil tubing unit was used to progressively clean out the mud to water. By the time the coil had reached about 2,000m depth it was clear that the well was flowing so the coil was removed. The well was cleaned of mud and filled with water derived from the fracture system.

Open-loop testing was based on flowing Habanero 3 through a wing valve and two chokes, a fixed sized choke and a variable choke in parallel, with the fluid flashed to low pressure through the chokes and delivered in an 8 inch pipeline to a steam separator. The fluid level in the separator was adjusted by a control valve on the liquid outlet side. In this outlet line there was also placed a magnetic flow meter and electrical conductivity meter. The steam flow rate was measured by a pitot tube located in the steam vent line.

Figure 2 Mud cleanout with coil tubing

Habanero 3 was opened to flow for the first time on 14 March 2008, and to the separator on 15 March.

The open loop testing can be divided into a number of phases as shown in Table 1 below:

Table 1; Open-Loop Operations in 2008

| **Operation** | **Date (2008)** | **Comment** |
|---|---|---|
| Flow testing from Habanero 3 with Habanero 1 shut-in | 14 to 21 March | A stable flow of 16 kg/sec at a flowing pressure of 27 MPa was achieved with a 14mm fixed choke. Wellhead temperature reached 209°C |
| Main open-loop circulation | 22 to 25 March | Injection 18.5 kg/sec at 51.7 MPa (7,500 psi), production of 20 kg/sec at 27.5 MPa, an increase of 4 kg/sec over the earlier test with Habanero 1 shut-in. Temperature reached 212°C |
| HDC injection | 26 March | Slow injection of HDC chemical barite dissolving agent in Habanero 1 to increase injectivity |
| Post HDC injection | 26 March | Injection at 18.5 kg/sec at 50.3 MPa (7,300 psi), an improvement of 1.4 MPa. Expect further improvements with longer injection during closed loop operation. |
| Stimulation of Habanero 3 | 18-19 April | Injection of 2,173m$^3$ of water at injection pressures up to 64 MPa, resulting in 276 microseismic events close to Habanero 3. Expected increase in productivity |

During the initial flows from Habanero 3 in mid March, Habanero 1 was shut-in, but pressure was monitored with a highly accurate quartz pressure gauge. Any change in flow conditions at

Habanero 3 was immediately recognised by the Habanero 1 pressure gauge indicating ideal connection between the wells in the main fracture zone (Figure 3).

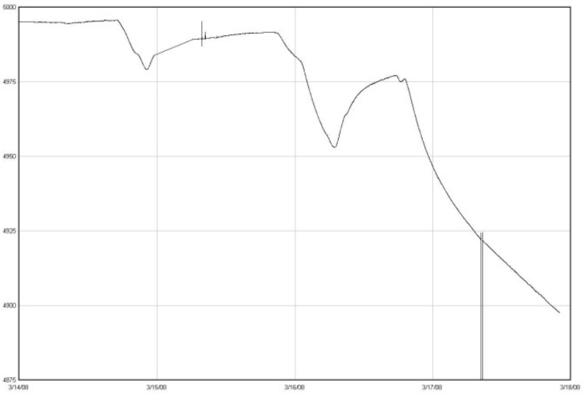


Figure 3. Pressure response of Habanero 1 pressure gauge during flow from Habanero 3 from 14 to 18 March 2008. Pressure on Y axis is in psi.

At the end of the main circulation on 25 March a pressure-temperature-spinner (PTS) logging tool was run to the main fracture and the well was shut-in. The flowing pressure at the fracture was stable during flow at 62.95 MPa, and rose within 20 minutes to 71.5 MPa after shut-in. This rapid rise indicates that most of the friction associated with flow is very close to the well-bore. The bottom hole temperature measured during logging was 244.5°C.

The HDC (barite dissolving agent) injection on 26 March (Table 1) was aimed at the 2,000 barrels of barite-rich drilling mud lost in the fracture system when Habanero 1 was drilled in 2003. Previous well test analysis of Habanero 1 indicated that the mud is inhibiting flow from Habanero 1 into the fracture system. The injection resulted in some improvement in the injectivity of Habanero 1.

## Closed Loop Circulation Test

### Circulation Impedance

The circulation pump was sized according to the understanding that the injectivity of Habanero 1 would be substantially better with Habanero 3 flowing than with Habanero 3 not flowing. This was a view that had been held since before flow testing of Habanero 2 in 2005, but it was never proven.

During the open loop circulation in March 2008 it became apparent that the injectivity into Habanero 1 was restricted and HDC was used to try to improve this. Once the circulation was achieved this improvement was not as good as hoped. Under the conditions at the time, at a pump design pressure differential of 11 MPa the pump could only deliver around 12 kg/second into Habanero 1. It is most likely that the lack of response at Habanero 1 to Habanero 3 flow is caused by the drilling mud lost around Habanero 1 in 2003.

Despite the injectivity problems of Habanero 1, the pump was capable of carrying out circulation operations that would allow the determination of reservoir parameters from injection of chemical tracers, so preparation for the tracer testing phase began. The six-week circulation and tracer test was likely to improve the injectivity of Habanero 1 because (i) longer term cooling of the fractures immediately surrounding Habanero 1 would result in a contraction of the rock adjacent to the fractures and the fractures would open slightly decreasing impedance, and (ii) it was envisaged that the lost drilling mud in Habanero 1 would be gradually washed further into the reservoir with longer term flow, thus reducing the restriction.

### Initial Closed-loop Operations

Start-up closed-loop operations in August 2008 were beset with problems involving (i) blockage of the grit arrestor at Habanero 3, (ii) pump inlet seal failure, (iii) cooling fan vibrations, (iv) generator overheating, (v) leaking plugs, (vi) a flange washout and (vii) gradual loss of efficiency of the air cooler.

The air cooler efficiency loss turned out to be caused by scaling of the antimony sulphide mineral stibnite. The cooling of the formation water from over 200°C to less than 100°C resulted in its precipitation. Fortunately this material is relatively easy to remove as it does not adhere to pipe like other common scales (calcite, anhydrite, and silica).

The pump inlet seal failure required the pump to be sent to Singapore for refurbishment. As a result the circulation test did not commence until December 2008.

### Circulation operations

A data logging unit was installed to collect pressure and temperature readings every 30 seconds at a number of points on the system. Flow rate was measured using an orifice plate set immediately after the air cooler, and before the re-injection pump. The orifice plate was calibrated using two turbine flow meters set on a temporary flow line to a pit. During the calibration, flow was directed to the pit via the flow cross on the Habanero 1 wellhead. A sampling panel on a side capillary line was used to collect fluid samples for tracer analysis. The sampling panel also had installed pH, conductivity and dissolved oxygen sensors.

Between the pump and the Habanero 1 wellhead a 700 ml pressure vessel was installed on a 1 inch sideline for collection of fluid at high pressure and at a defined temperature. The chamber was wrapped in a heating blanket that controlled the temperature. This apparatus was designed to measure the polymerisation rate of silica at re-injection temperature. Fluid samples were left in the chamber for a pre-determined period and then collected and immediately measured for monomeric silica ($H_4SiO_4$) using the ammonium molybdate method. In this way the rate of polymerisation could be determined to asses the potential for silica scaling in the re-injection well.

By 11 December 2008 the pump had been re-installed after its trip to Singapore. The operation was run for several days to assess reliability of equipment and data collection. In the afternoon of 17 December 2008 the system was shut down for 5 hours while 1000 l of fresh water with 100 kg on 1-3-5 naphthalene tri-sulphonate and 50 kg of fluorescein was injected down Habanero 1. The tracer chemicals were injected using a pressure testing injection pump (the tracer story is described in an accompanying paper at this conference (Yanagisawa et al., 2009)). The pump was then re-started and the six week tracer test commenced.

Operating pressure conditions and flow rates were initially as expected, based on earlier understanding of the drilling mud damage at Habanero 1. The stable flow rate was slightly less than 12 kg/second. During the following weeks the system was shut down for short periods and after each shut down the stable flow rate increased slightly. It was noticed that during initial pump start-up with each shut-down that the pump could inject at a higher flow rate whist the reservoir was pressurizing up. The flow rate during these start-ups was greater than 20 kg/second and it was not until several hours later that the flow rate settled to a stable rate once the injection pressure had also stabilised.

Progressively over the circulation test the stable flow-rate increased so that by the end of the test the flow rate was 15.5 kg/second, and was still increasing. The pump differential of 11 MPa remained essentially the same throughout the test so that the overall circulation efficiency increased by 30% over the test period. Barite and fine granite particles were collected from the flow from time to time indicating clean up of the fracture network, and this most likely explains the increasing efficiency. The high flow rates on pump start-up most effectively contributed to the clean up explaining the slight increases in stable flow after each start-up.

The tracer results (Yanagisawa et al., 2009) indicated a tracer swept pore volume of 18,500 $m^3$. On the basis of the modelling of stream-lines (Figure 4, unpublished data from our reservoir analysis consultants Q-con GmbH) it can be reasoned that the pore volume of the whole reservoir (black polygon in Figure 4) is close to 40,000 $m^3$.

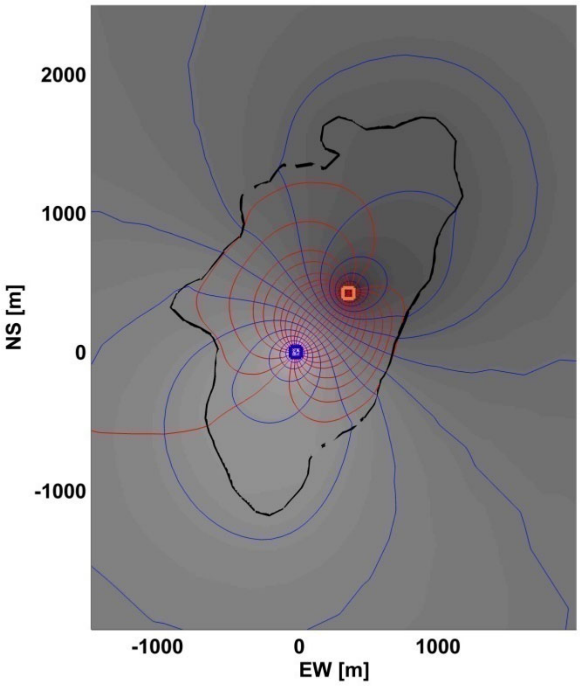


Figure 4; Stream-lines of circulation modelled on the limits of the reservoir based on the stimulation area (black polygon). Red lines represent stream flow, blue lines isobars. Modelling carried out by Q-con GmbH.

The estimated pore volume of the reservoir is approximately equal to the volume of fluid injected during the 2003 and 2005 stimulations. Thus it appears that the stimulation created new pore space about equal to the fluid volume pumped, and that the fracture fluid volume prior to stimulation was quite small. This attests to the effectiveness of stimulation and its necessity.

## Summary

The six-week Habanero closed-loop circulation test took place over the period December 2008 to February 2009. The test enabled Geodynamics to announce its “Proof of Concept” in March 2009. During the test the circulation efficiency increased by 30% and this was mainly attributed to the cleaning out of drilling mud lost into the fractures during the drilling of Habanero 1 in 2003. The pore volume of the reservoir is approximately equal to the fluid volume pumped during the stimulations in 2003 and 2005.

## References

Yanagisawa, N., Rose, P., and Wyborn D., 2009. Habanero Tracer test in the Cooper Basin, Australia: Key Results for EGS Development. Australian Geothermal Conference 2009, Brisbane.