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Engineering Challenges for the Innamincka Hot Fractured Rock Geothermal Development

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ABSTRACT

Geodynamics Ltd are the first company in Australia to start drilling down to over 4000m to extract the energy from hot fractured rocks at approximately 250°C. Test drilling has been conducted near Innamincka, in central Australia and Geodynamics were startled to find that the resource was a water saturated reservoir at extreme pressure rather than the expected hot dry rock system. Parsons Brinckerhoff has been engaged by Geodynamics to design a closed loop test facility between two wells. The extreme fluid pressures of about 35MPa at the surface, have presented many challenges and the impact that this has on the pipeline design, along with problems associated with the high pressure reinjection pump are presented. The pump has had multiple failures, principally related to the seal design, and these failures are analysed along with potential solutions.

1. INTRODUCTION

The Cooper Basin in central Australia produces significant quantities of natural gas along with some liquids and is an area that has been extensively surveyed since the mid 1950s. Drilling, plus 2D and 3D seismic surveys had indicated anomalous high temperature regions below the sandstone strata of interest to the oil and gas industry and it was apparent that the sandstones capped granite rocks having temperatures at or above 250°C, at depths of approximately 5000m.

Geodynamics Ltd, a publicly listed company based in Brisbane, acquired the rights to approximately 2500 km^2 of geothermal reserves in the Cooper Basin and drilled Habanero 1 to 4,421m in 2003. It came as an extreme surprise for Geodynamics to discover that they had drilled into a highly pressurised aqueous reservoir which yielded well shut in pressures and temperatures of about 35MPa and 250°C. The granite zone was hydraulically stimulated in late 2003 and again in 2005 to produce a fracture zone over ten times larger than projected from their preliminary modelling. Full details of the developments at Habanero 1 are presented by Wyborn et al, 2004. Figure 1 shows the site location.

In 2006 Geodynamics drilled Habanero 2 to 3,852m but this well had to be abandoned due to the loss of a substantial length of drill pipe down the well. In early 2008 a third well, Habanero 3, was successfully drilled to 4,200m, approximately 550 m away from Habanero 1, with the aim of proving the concept of establishing a geothermal heat exchanger through the fractured granites between Habanero 1 and 3. The water chemistry analysis from Habanero is shown below.

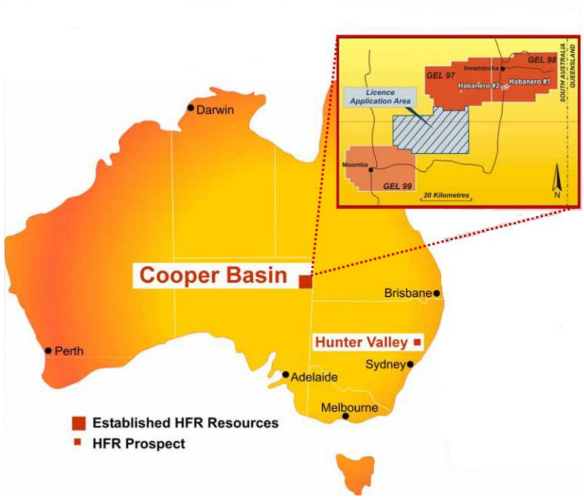

Figure 1: Site Location (courtesy Geodynamics Ltd).

Table 1: Geothermal Fluid Chemistry

Species	Concentration [mg/kg]
pH (at 250°C)	5 - 5.5
Ammonia	2.3
Argon	6.5
Helium	18.3
Hydrogen	0.38
Methane	1,184
Nitrogen	605
Sulfide (as H2S)	0.1
Arsenic	3.0
Boron	240
Calcium	35
Caesium	54
Iron	<1
Lithium	256
Magnesium	0.29
Potassium	870
Rubidium	19.6
Sodium	5,600
Total bicarbonate (1.72% as CO_2 in total flow)	25,000
Chloride	11,200
Fluoride	22
Silica	460
Sulfate	42

A very significant factor that can be seen in the above analysis is the high percentage of dissolved gases. These gases will come out of solution if the fluid is de-pressurised.

Parsons Brinckerhoff (PB) was engaged to design a closed loop test facility to allow long term data gathering on water chemistry and reservoir flow characteristics. The test facility is design to take 25kg/s of fluid at about 250°C from the Habanero 3 well, pass it through a custom engineered cyclone separator to remove particulates and then cool the fluid down to about 100°C via a fin-fan cooler. The fluid is then reinjected into Habanero 1 via a variable speed multi-stage centrifugal pump capable of generating a differential head of up to 9 MPa. A simplified P&ID is shown in figure 2.

2. PIPELINE ENGINEERING

The pipelines were designed and fabricated in accordance with AS4041:2006, Pressure Piping. This piping code uses pipe design stresses similar to ASME B31.3, and are significantly higher than used in ASME B31.1. The piping design conditions are shown in Table 2.

Table 2: Piping Design Parameters

Duty	Size (ND – mm)	Pressure (Mpa)	Temp [°C]	Corrosion (mm)
Pump suction	150	36	265	1
Pump discharge	100	45	125	1

Unlike conventional geothermal piping, there is no significant seismic loading to be accommodated and an elastically responding coefficient of 0.06g was used to comply with local codes.

For both the pump suction and discharge piping, ASTM A106C XXS pipe was selected to satisfy the design conditions. After allowing for mill tolerances and corrosion allowances, there is no reserve of thickness within the piping, which means that the pipeline flexibility analysis becomes significantly more demanding. However, after selecting a pipeline route which minimised significant gully crossings and terrain height variations as well as bypassing the existing camp facilities, we were able maintain the pipeline stresses within the code requirements and keep support reactions at a comparatively low level. The final design incorporated four pipe anchors and the balance of the supports being either guides or vertical stops. Figure 3 shows part of the pipeline during construction.

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Figure 3: Pipeline under construction.

The remoteness of the location and the soil conditions made conventional bored pile supports unattractive. The soil consists of about 1-1.5m of comparatively loose stony clays above a deep layer of hard calcrete, which a naturally occurring concrete-like material. The site is also about 360km away, over very poor roads, from the nearest concrete batching facility and hence it is very expensive to site pour concrete footings. Our solution was to excavate down to the calcrete layer and use pre-cast concrete slabs as spread footings for the pipe supports. Figure 4 shows a typical footing.

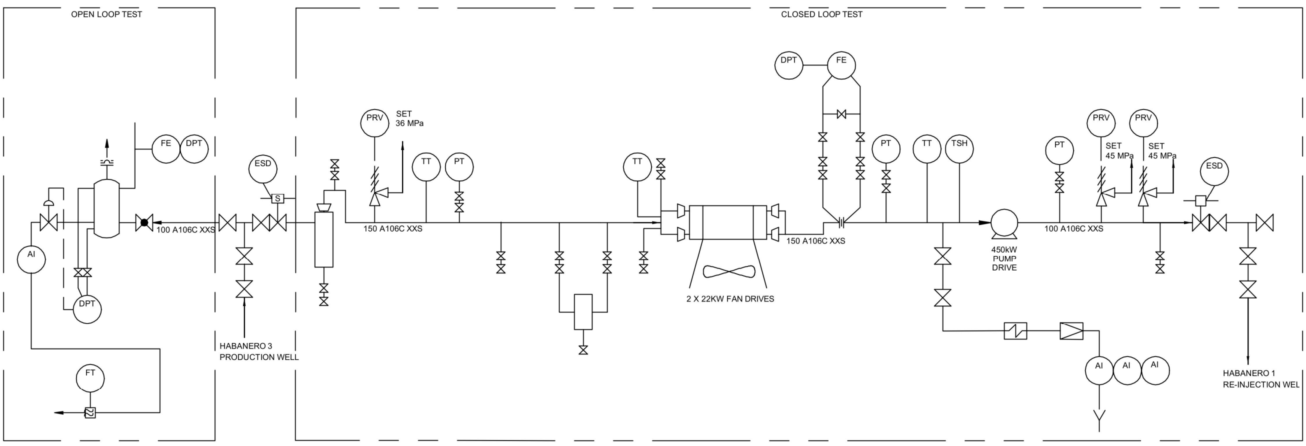

Figure 2: Plant P&ID.

Figure 4: Typical pipe support footing.

The pipeline was being constructed at the same time as drilling and open loop testing on Habanero 3 was being completed.

3. REINJECTION PUMP

Enquiries for a reinjection pump were placed with companies specialising in oil field pumps. The established history of these pumps as either surface, or submersible pumps in dirty, hot and gassy oil pumping duties was impressive and seemed to the best available technology. Unfortunately, we received only one truly commercial offer, but this was from a major multinational company in the field. A summary of their offer is:

Table 3: Commercial Offer

Pump Type	Multistage centrifugal
Configuration	Horizontal surface pump
Number of stages	41 mixed flow
Inter-stage and deliver end	Ceramic
Pump thrust bearing	Three row ball
Suction seal	Tandem mechanical
Seal pairs	SiC/SiC
Seal flush medium	Geothermal fluid
Seal elastomers	Aflas
Pump discharge flange	Grayloc
Peak hydraulic efficiency	76.5%

During the company's sales presentation to Geodynamics and PB, they highlighted that they had pumps successfully operating at similar duties and even had one installation with two pumps in series to deliver pressures higher than we had specified.

After placement of the order, we asked for information on the allowable pump flange loads and we were advised that no piping loads should be transmitted to the pump. We said that this was not possible and asked what was allowed in the oil industry, but the response was that this was never an issue in the oil industry. However, they did offer to undertake an FEA study on the pump to advise the allowable loadings. After many prompts, it was clear that the allowable loading information was not going to be delivered and, as an expediency, we arbitrarily imposed flange loading limits of 50% of API 610 allowables. This was a possibly overly severe restriction, but allowed us to proceed with piping design while still being conservative. The new, self imposed, loadings meant that the pump inlet pipe design was particularly difficult and necessitated a long expansion loop from the fin-fan cooler to the pump, a spring hanger to relieve the pump of vertical flange loads and a sophisticated guide on the inlet piping to eliminate lateral and moment loading in both planes. The discharge pipe design was rather easier due to the smaller bore piping used in this area.

A factory visit to expedite delivery revealed that the pump discharge fitting would no longer be a Grayloc fitting due to onerous licensing requirements for an OEM manufactured item (the pump manufacturer needed to machine the fitting in as part of their discharge connection). The pump company said that they would now offer a class 2500 RF flange, which we objected to as there was no class 2500 flange that satisfied the pressure and temperature requirements. They advised that they would offer an ASME rated 410 grade stainless steel that gave sufficient flange strength for the duty. Due to the late delivery, we were left with few options and asked that they provide a mating flange for us to weld to the pipe.

When the pump was finally delivered we found that the pump mating flange was a custom socket weld flange, which was unacceptable, and further investigation showed that the welding of this flange to the carbon steel pipe would be very difficult and that the flange bolts would also be significantly overstressed.

Within the time available, the simplest solution was to custom engineer a low alloy flange using actual flange loadings and a special spiral wound gasket. This gasket is dimensionally the same as an 80ND gasket, but with a larger centring ring. Even though the gasket surface is the same as an 80ND gasket it still has a bore larger than a 100ND XXS pipe. Using this smaller gasket area reduced the bolt loading below the allowable limits.

During commissioning and the first few weeks of operation, the pump experienced multiple failures that were principally associated with the mechanical seal, pump body seals and the pump impellers. The causes of these failures had to be deduced mainly by the client and PB with little assistance from either the pump or seal suppliers.

Multiple failures of elastomers occurred due to explosive decompression. This is a process where gases dissolved in solution, at high pressure, percolate into the elastomer and will blow the elastomer apart if the seal is de-pressurised. This process can be mitigated by using harder grades of elastomer and more exotic compounds such as perfluoroelastomers and also by depressurising the seal over a very long time to allow the gases to escape from the seal. Figure 5 shows one of the O-rings that has suffered explosive decompression.

Figure 5: Seal failure due to explosive decompression.

There are problems with both mitigation strategies. The obvious issue with a slow decompression (possibly over many hours) is that this does not accommodate the operational need to promptly shut down the pump if there are any safety issues. Using harder elastomers can work for static seals but is problematic for dynamic seals such as are found in a typical mechanical seal assembly where the ceramic must be allowed to float axially. In this case, retrofitting a harder elastomer into existing seal grooves provides too high a radial force on the shaft and is likely to cause the floating ceramic to stick. This almost certainly happened in one instance where disassembly of the seal assembly at the seal company's workshop could find no damage to either the ceramics or the elastomers, even though the seal had been leaking badly.

Multiple failures of elastomers also occurred due to extrusion. This problem was overcome by using harder grades of elastomers and seal back up rings. Seal extrusion at high pressures is very hard to avoid with radial seals as the required minimum radial clearance is very hard to achieve. We believe that the correct solution for all static seals is to use non-elastomer face seals. Figure 6 shows an O-ring that has failed by extrusion.

Figure 6: Seal failure due to extrusion.

Following an early seal failure, the pump was removed and sent to the pump supplier's service facility. Stripping of the pump identified failures of the intermediate ceramic bearings as well has distortion and ruptures in most of the diffusers. It would appear that both failures occurred due to extremely high pressure differentials that could happen due to a sudden loss of pressure at either the inlet or discharge of the pump. In this instance, it takes a while for the pressures to equalise and there will be very high axial forces on the impeller/diffuser stack until pressures equalise. The pump supplier's solution was to use an upgraded bearing design and to drill small holes in the impellers and diffusers to a quick equalisation of pressures.

There also been failures in the seal ceramics without there being any satisfactory explanation of what has caused the failures. It is clear, however, that the existing design is unsatisfactory for the duty. Various remedial measures have been installed by the seal and pump suppliers. These include: fitting of filters on the seal flush water line to reduce the dirt in the assembly and using a manually set pressure reducing valve to achieve an inter-seal pressure at approximately half of the pump inlet pressure. It is not at all clear how the seal supplier expected the inter-seal pressure was going to be maintained in the original design and a manual set pressure reducing valve is a very poor solution as it requires operator adjustment both during start up and shutting down of the pump. It should be noted that SiC/SiC mechanical seal pairs are a common choice for abrasive duties, but are not normally used at pressures above 2 MPa; our duty requires an 18 MPa differential per seal. Figure 7 shows a failed seal ceramic.

Figure 7: Mechanical seal ceramic failure.

4. POTENTIAL SEAL SOLUTIONS

We have attempted to engage other mechanical seal manufacturers in providing a solution, but they are either totally unwilling to be involved or would only get involved in what they see as a high risk venture if they can foresee a long term positive return on their investment. For a mechanical seal to work, we believe that the following is required:

- Total elimination of elastomers exposed to the geothermal fluid
- Use of a clean barrier fluid with good lubricating properties for the seal faces
- Fully automatic control of seal differential pressures

The design is likely to require three mechanical seal faces with the inner seal being bellows sealed to eliminate the need for elastomers. The seal chamber behind this seal would contain the seal barrier fluid at approximately 0.1 MPa above the pump inlet pressure by the use of a differential pressure regulator plus relief valve. The outer two mechanical seals could be of more conventional design and would have ceramics suited for very high pressures.

Another potential solution is to use floating ring seals made from ceramics such as antimony impregnated carbon/graphite. The seal assembly would be similar to figure 8.

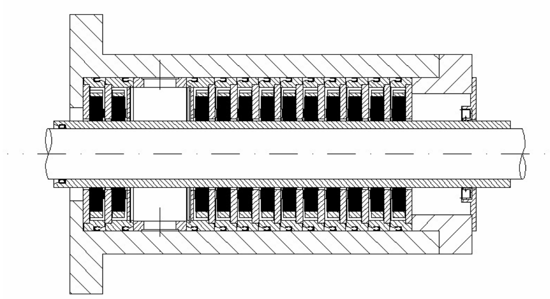

Figure 8: Floating ring seal assembly.

Each of the carbon/graphite rings has an alloy steel "bandage" around the outside to provide mechanical stability and control the differential expansion between the shaft sleeve the bore of the ceramic. Each ring is free to float radially, but is pinned to prevent rotation. The rings bear against hardened and ground alloy steel rings and have wave springs to provide a positive loading at start up. Each seal ring assembly also has a spring activated PTFE seal to ensure a seal against the housing.

Clean water can be used as a barrier fluid and is supplied to the inter-seal chamber at a pressure slightly above the pump inlet pressure. There will be a small loss of clean water through the inner two seals, but there will be a much higher flow to the outside. This water may be cooled and returned to the seal water system.

The floating ring seal has historically been used on boiler feed pumps as metal/metal floating ring assemblies. However, the pressure differentials are lower to minimise the loss of water, the radial clearances would need to be reduced which introduces the risk of wear and pick up on the shaft sleeve to ring interface. There are companies producing carbon floating ring assemblies for gas compressor and turbine duties but they are unwilling to produce a one off design for an unfamiliar application. However, we have been able to interest a local seal manufacturer into progressing this idea and they are in the process of conducting tests on seal ring assemblies.

CONCLUSIONS

The extreme conditions at the Innamincka site have presented problems that have proved to be beyond the current technology of standard commercially available seals. In hindsight, it would have been possible to reduce the risks if we had been fully aware that a mechanical seal assembly for this application was beyond the current commercial technology, but this fact wasn't advised by any of the high end pump manufacturers that were consulted in this regard. We believe that the commercial reality of producing a custom pump configuration, for this difficult application, has resulted in the suppliers not being forthcoming with solutions.

REFERENCES

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