BINARY PLANT CAUSTIC DOSING TEST RIG DEVELOPMENT

Evan Erstich[1], Arnel Mejorada[2], Keith Litchi[3] and Kevin Brown[4]

[1]MB Century, 166 Karetoto Road, Wairakei, 3351, New Zealand

[2] Newcrest Mining Limited, Lihir Island, Papua New Guinea

[3]Quest Integrity NZL Ltd, PO Box 38-096, Lower Hutt, 5045, New Zealand

[2]Geokem, PO Box 30-125, Barrington, Christchurch, 8244, New Zealand

eerstich@mbcentury.com; arnel.mejorada@newcrest.com.au; k.lichti@questintegrity.com; kevin@geokem.co.nz

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ABSTRACT

This paper is a case study of the design and development of a test rig to assess separated geothermal brine for power production at the Lihir geothermal field in Papua New Guinea.

The test rig was constructed to gain an understanding of the brine chemistry from the field and how it might behave in a binary power plant. The outcomes of the testing will give Newcrest Mining Limited additional design criteria to better manage and control mineral scaling and corrosion.

The test rig incorporates two independent test lines for delivery of geothermal brine: one allows for pH-modification by dosing the brine with sodium hydroxide (caustic), and the other is an undosed control line. The two test lines are fully instrumented and controlled via a Programmable Logic Controller (PLC) on the test rig.

The detailed design for the rig is discussed in this paper, with particular focus on the implementation of a heat exchanger to simulate a binary plant, as well as pH control methodology, equipment packaging within the confines of a shipping container, caustic delivery, brine flashing problems and operating philosophy.

1. INTRODUCTION

Newcrest Mining Limited was considering the construction of a binary plant to take advantage of available waste heat in separated water (brine) from the steam power plants at its Lihir Island site in Papua New Guinea. They wished to optimise the use of this brine yet minimise possible mineral scaling and corrosion problems in reinjection pipelines and reinjection wells.

Consequently, it was decided to experimentally investigate a variety of design parameters by building and operating a test rig that would simulate possible pH modification arrangements and material options within a full scale binary power plant.

In order to maximise the power output of the future power plant, it was decided that the final outlet temperature would be below the silica saturation temperature, and pH adjustment would be required to prevent silica scaling. The use of acid pH adjustment was considered high risk because of the relatively high chloride content of the Lihir brines which would result in pitting corrosion of many common construction materials on-line and could become severe under shutdown conditions. In addition, acid dosing can be difficult to control with varying flows and differing chemistry of wells. It was therefore recommended to trial caustic dosing to prevent silica scaling. Caustic dosing is easier to control operationally and avoids many acid corrosion problems. It also dissolves the excess silica, rather than delaying the polymerisation. The test rig was designed to measure the degree of mineral scaling and corrosion one might experience in a binary plant, and to explore methods to prevent or minimise these.

2. DETAILED DESIGN AND BUILD

2.1 Preliminary Design

The project involved a number of stakeholders, with their own individual requirements for the design. The test rig needed to be capable of assessing corrosion using on-line monitors such as electrical resistance probes (EPR) and linear polarization resistance (LPR) probes as well as the more traditional mass loss coupons (Lichti et. al, 2000). The scaling build-up would be measured on test heat exchanger tubes (Brown and McDowell, 1983) that accurately mimicked the conditions in a binary plant heat exchanger. In addition, the rig designers had to ensure the pipework network had sufficient expansion loops to safeguard it from thermal overstressing of the system. Lastly, the client required that the test conditions replicated their site and fluid chemistry.

2.2 Detailed Design

2.3.1 Heat Exchanger Design

In the binary plant, there are numerous tubes within the heat exchanger depending on the total brine available. The test rig was designed to simulate just one of these lengths to ensure accurate replication of the conditions it might encounter. The diameter, velocity and residence time were the primary variables to be replicated. The rig was designed for a 5 bar inlet pressure.

The heat exchanger design required targets for these three variables, i.e. 14.8mm ID tubing, velocity 1.5-2.8m/s and residence time 10-50s.

Carbon steel pipe (ASTM A106 Gr. B) was selected to model the diameter requirement; the velocity requirement would be maintained using a flow control loop, and the residence time would be controlled by the length of tube installed.

The heat exchanger tube needed to be removable so that it could be cut into sections for shipping and lab analysis of silica/calcite deposition rates. As a result, the shell and tube heat exchanger was designed with a gland on each end so it could be easily removed or replaced.

The brine enters the heat exchanger tube at one temperature and exits at a lower temperature (the more heat that can be taken out of the fluid the more power can be generated; however, this increases the scaling risk). It was important to have a linear temperature drop as the fluid cools; a counter flow heat exchanger was nominated which ensures this requirement was achieved (Figure 1).

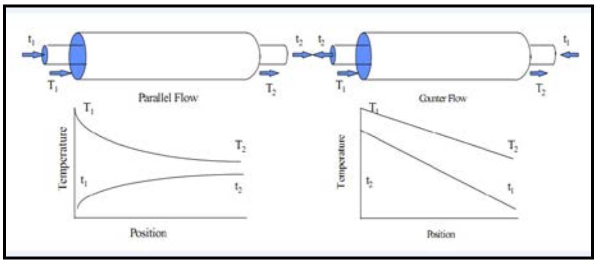

Figure 1. Parallel Flow versus Counter Flow Heat Exchanger

2.3.2 3D Model

The test rig was designed to fit within the confines of a 40 foot flat rack to allow it to be easily transported both overseas and between locations once onsite in Lihir. First, 3D modeling was necessary to ensure the 'packaging' could accommodate the requirements of the complex piping network that included bypass loops, corrosion test point upstream requirements, heat exchanger lengths, pH measurement, numerous pumps, storage tanks and safety shower while additionally allowing the operators adequate access to sampling points, test sections, control panel, instrumentation and valves. Transport of supplemental equipment was also packaged; this included the silencer, roof and associated onsite piping.

The test rig included an Endress and Hauser pH measuring system, control cabinet with PLC, datalogger and touch screen Human Machine Interface (HMI) (Figure 2).

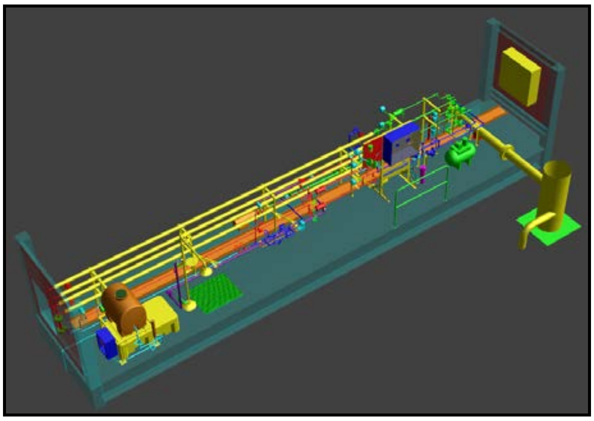

Figure 2. 3D Representation of Test Rig

2.3.3 Dosing Pump Sizing

Using chemical data from sampling at Lihir the silica saturation index (SSI), calcite saturation index and titration curve were calculated for addition of caustic to brine lowered to 80ºC (Figure 3). This shows that at a SSI of 1.0 (pH ~ 9.45) the amount of caustic required to prevent silica depositing would be 225ppm of 100% Sodium Hydroxide (caustic) solution. It also shows that calcite will likely be oversaturated and could deposit. However, it was hoped that calcite anti-scaling dosing into the production wells would prevent calcite deposition.

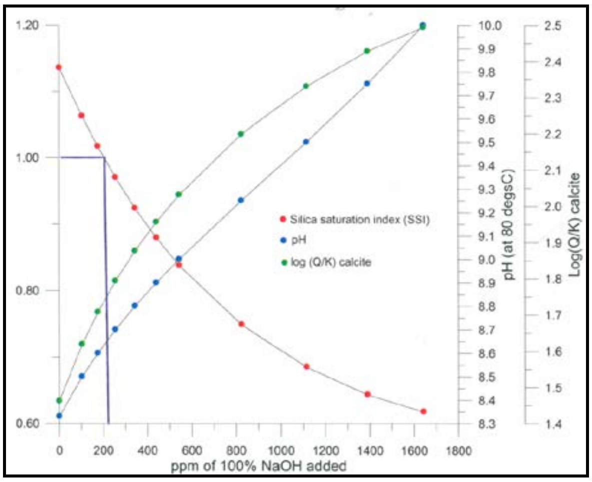

Figure 3. Caustic Requirement Determination

The optimum brine flow rate of 1.0ton/hour was determined from the velocity requirement (See 2.3.1 above), while the caustic was to be mixed with a 10% concentration. With this detail known, the size of the dosing pump, 2.1LPH was determined.

The dosing pump selected was an electronically 4-20mA controlled dosing pump -/+1% accuracy. Downstream was a pulsation dampener to ensure pulseless flow.

2.3.4 pH Control Loop

The test skid had two independent lines which in each case had the brine flow controlled and brine temperature out of the heat exchangers controlled with the use of control valves. In addition one of the lines, as discussed previously, had a pH control loop.

Early on it appeared sensible to simply control the dosing pump by taking the pH measurement and change the dosing rate up and down to achieve the pH set point; however it was understood there would be a significant lag to stabilize this if for instance there was a fluctuation in brine flow rate. It was determined (*Brown, K and Rock, M: 2010*) that the best method for controlling pH would be to control the dosing pump at a rate directly proportional to the brine flow rate to eliminate any lag. To achieve this, the brine flow was multiplied by a pump rate constant and this value was used to drive the dosing pumps stroke rate.

In addition, it was known that the brine chemistry could change over an extended period and the pH value could float above or below the set point. The pH value was used in a control loop to adjust the pump rate constant and therefore adjusts the dosing pump stroke rate to achieve the desired pH set point. See Figure 4.

3. COMMISSIONING

3.1 Isolated site

Once the test rig had arrived via container ship to Lihir Island it required multiple contractors to fully install it, and a number of weeks for commissioning works.

3.2 Flashing

The brine for the commissioning and first series of corrosion testing was taken from the brine outlet of nearby 30MW separators. This soon proved to be problematic, as the takeoff water was below the test rig elevation and the brine had no margin above its saturation pressure. When it was delivered to the test rig, there was flashing. This flashing caused a volatile brine flow rate, which prevented the temperature control loops and pH loop from stabilizing thereafter.

A number of solutions were considered to improve the quality of the brine being delivered, and it was decided the addition of an elevated mini-separator was the optimal solution. The intention was to take brine from the bottom of the nearby two-phase line and deliver this to the mini-separator elevated 6 meters above the test rig. The valve controlling the steam out of the top of the separator was opened until there was a small amount of brine, which indicated the separator was flooded. There was flashing as the brine travelled up and into the separator before delivering brine to the test rig from the flooded separator chamber. With the added margin above the saturation pressure the pressure drop along the brine lines on the test rig wouldn't result in flashing, thus delivering a stable brine flow rate.

In addition the mini-separator also allowed the test rig to have flexibility for future testing. It can be used to directly tap into a well or a two phase line and separated at a condition that you want tested.

3.3 Stable control

Before the test rig could function as designed, the control loops on the test rig needed to be stable. To achieve this, it was critical to ensure that the brine supply, cooling water supply and caustic supply were constant.

The flow control loops were the first loops adjusted, and before checking how stable the loops were, a 'bucket' (volumetric) test was performed to validate the flow rates' accuracy. With this validated, the loops were ready for checking and from the HMI, the operator had the ability to operate these loops in MANUAL and AUTO. In addition, the operator could access the controller tuning constants using Kp (Gain) and Ki (Integral).

Once the brine flow was stable, the pH control loop was adjusted. From the HMI, the operator had the ability to operate this loop in MANUAL and AUTO. The loop had two interacting controls: the "stroke" of the caustic pump which was set as a varying function of the brine flow rate, and the "trim" which was a + or – value used to change the stroke to a finer degree using the actual pH measurement as a controller input as discussed in 2.3.4. The operator could set the tuning constants of the pH controller using Kp (Gain) and Ki (Integral) boxes, and the "trim" which determines the relative magnitude of the pH controller output. For example, setting the "trim" to 30%, would mean that the dosing pump output would vary by +30% to -30%, thus if the "stroke" was set at 50%, the "trim" could be used to vary this from 20% (50% stroke - 30% trim) to 80% (50% stroke + 30% trim).

The temperature control loops were the final loops adjusted, and these were dependent on the incoming cooling water supply. Similar to the flow control loops, the operator has the ability to operate the temperature control loops from the HMI.

In MANUAL mode, the brine temperatures were stable; however, in AUTO mode the temperature loops did not settle within a reasonable time (<12 hours). At the time of this writing, further testing was being performed to improve this time by reducing the fluctuations in the cooling water supply.

4. FUTURE ACTIVITY ON LIHIR

Two distinct test programs are being planned. The first of these is mineral scaling and would involve initial silica polymerization testing followed by continuous operation. Afterwards, the heat exchanger tubes would be removed and assessed for silica and calcite deposition rates.

The second test program will involve corrosion testing, in two parts: firstly online testing using LRP and ER probes. The second part is continuous operation with mass loss coupons of varying materials from which corrosion rates can be assessed.

With these two test programs, complete recommendations will be proposed to control and manage mineral scaling. In addition, advisement on the relationship between pH, scaling, corrosion, and subsequent material selection will be given.

5. CONCLUSION

pH modification technology continues to develop as a solution to control mineral scaling from brine; acidifying brines has typically been the primary constituent used for pH control. This study aims to prove the viability of caustic dosing for the particularly special brines at Lihir.

The purpose of the test rig was to model process conditions at Lihir Island and quantify the quality of the brine, its behaviour in an operating binary power plant and its impact on material selections. Consequently. This would help flag any design issues that should be considered in equipment selection.

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REFERENCES

Lichti, K, Brown, K and Ilao, C: *Scaling and Corrosion of pH Adjusted Separated Water*, Proceedings of 22nd New Zealand Geothermal Workshop, pp 169-176.

Brown, K and McDowell, G*: pH Control of Silica Scaling*, Proceedings of 5th New Zealand Geothermal Workshop, pp 257-261.

Brown, K and Rock, M: *Test Rig Experiments for Silica Scaling Inhibition.* Proceedings World Geothermal Congress, Bali (2010).

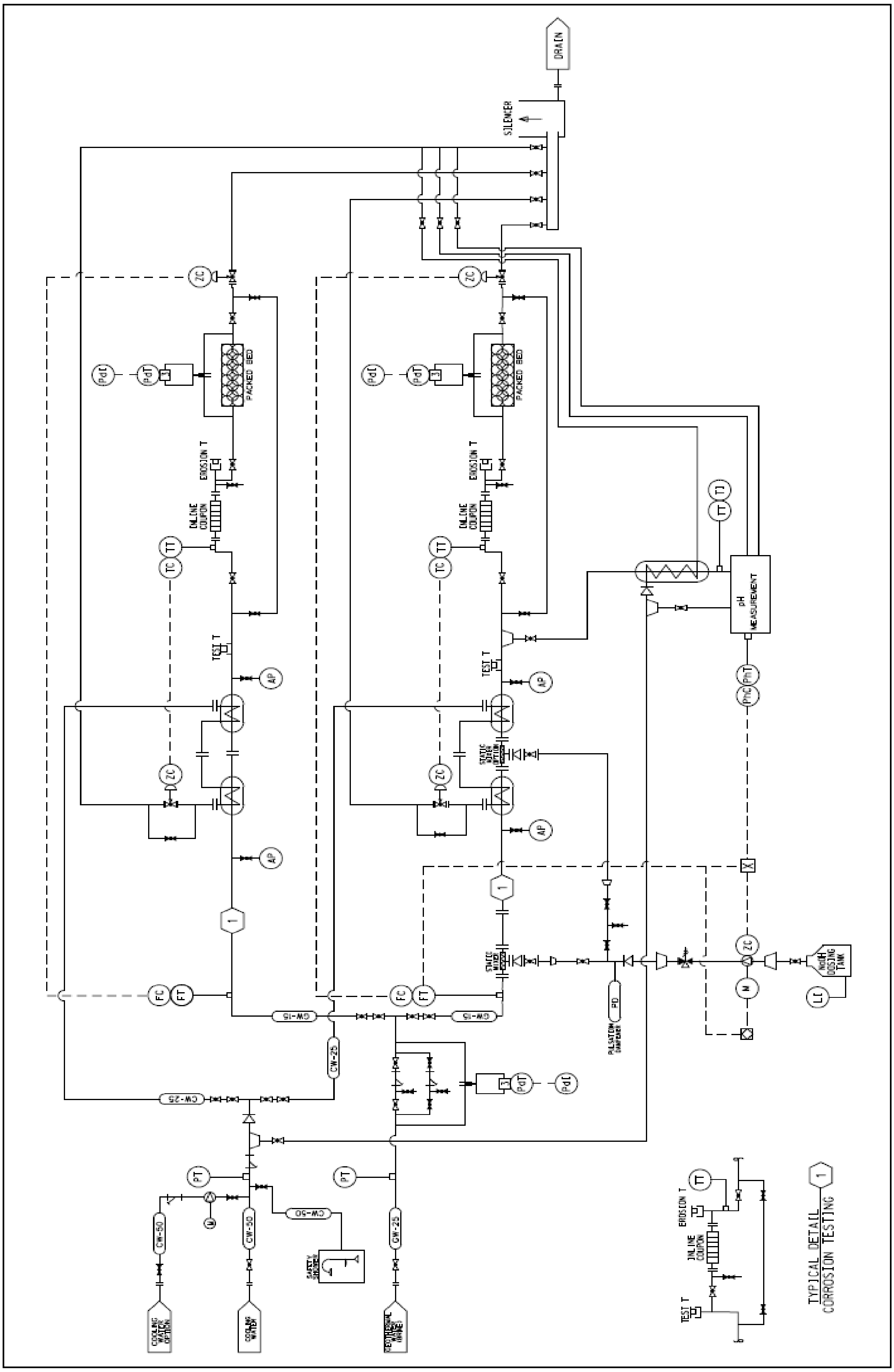

Figure 4. Test Skid Schematic