Building Resilience: Designing well testing equipment and procedures for powerful wells.

Chris Horan[1], Paul von Hirtz[2]

[1]Western Energy, 132 Rakaunui Road, Taupō, New Zealand, 3330

[2] Thermochem, 3414 Regional Parkway, Suite A, Santa Rosa, California 95403

chris.horan@westernenergy.co.nz, paul@thermochem.com

Keywords: *well testing, production wells, LECM, geothermal, flow testing, two-phase flow*

ABSTRACT

Testing geothermal production wells is a key step in the life cycle of a well asset. The owner of the well aims to quantify the value of the asset in terms of; MWe capacity, interaction with nearby wells and geochemistry during the well test.

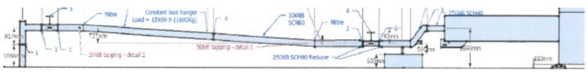
Geothermal wells cost in the magnitude NZD$10M to drill. This large cost drives the asset owner to drill the highest producing well possible. In recent years in New Zealand wells have drilled with larger diameter completions and are producing massive outputs. Well testing equipment has had to keep up with the increased demands. This paper explains how Western Energy and our partner Thermochem have innovated equipment and procedures to handle powerful wells.

Figure 1: Well test initiated by coil tubing air lift on Tauhara Steamfield, Taupo, New Zealand.

1. WELL TESTING FAILURES

1.1 High Pressure Pipework Failures

Wells will produce cuttings (sharp rock pieces from drilling) during the initial hours of a well test. This highly abrasive material mixed with high velocity steam and brine is a recipe for eroding steel pipework. Western Energy has experienced several pipe erosion failures whilst attempting to improve the resilience of the high-pressure pipework entering the



Thermochem Low-Emissions Compact Muffler (LECM).

The original high-pressure pipework had mitered sections and an S-bend as shown in **Error! Reference source not found.**.

Figure 2: Original LECM pipework with S-Bend downstream of control valve.

This was to allow the pipework to be rigged up easily to enter the LECM. These bends caused high wear points where the flow had to change directions. Multiple erosion-initiated pinhole leaks were observed whilst testing powerful wells as shown in **Error! Reference source not found.**. The position of the S-Bend is shown in Figure 4, downstream of the control valve.

Figure 3: S-Bend with pinhole failure.

Figure 4: LECM with S-Bend removed post pinhole failure.

It was suspected that the S-bend having an abrupt change of direction, was causing the steam to erode the underside of the S shape. This however was proven wrong when the pipework was changed for a 'straight-thru' arrangement as shown in Figure 5.

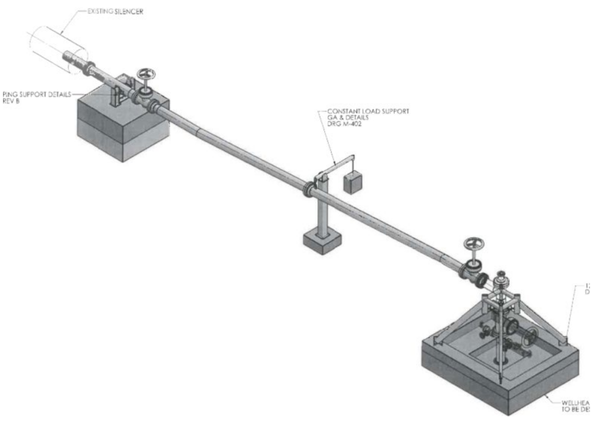


Figure 5: Straight-thru pipe downstream of control valve.

The straight-thru pipe failed due to severe erosion as shown in Figure 6 and Figure 7. The end view photo is the same orientation as the pipe was rigged up. This shows steam and cuttings were directed into the left-hand pipe wall (as looking into the pipe in the direction of flow). The stellite hard facing, that was used to repair and protect the straight-thru pipe from previous erosion events, was fully undermined.

Figure 6: Straight Thru pipe erosion - end view.

Figure 7: Stellite hard facing eroded by high velocity steam and cuttings.

The mechanism of failure was confirmed to be due to velocity increase through the restriction of the control valve with steam with cuttings impinging on the pipe wall. The control valve, when partially open, creates a large pressure drop as the steam squeezes through and therefore the velocity of the steam has to increase.

The control valve type is a segmented ball valve as shown in Figure 8. These valves are good for opening under large pressure differentials as they swivel to open so are easier to unseat than gate valves. Segmented ball valves are designed to throttle flow. However, they have a working envelope and this was frequently being exceeded with powerful wells during well testing. Like most valves however, as it is opening it creates an eccentric, non-centralised flow as shown in Figure 9. The steam accelerates around the opening edge of the segmented ball and impinges into the pipe wall.

Figure 8: Segmented Ball Valve example.

ISSN 2703-4275

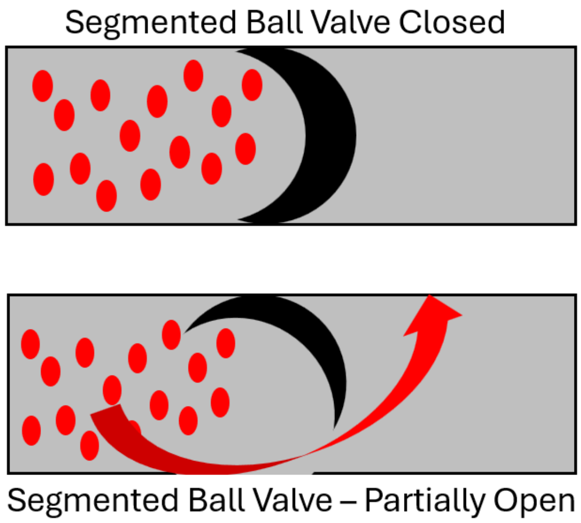


Figure 9: Steam flow direction during partial valve opening.

The bigger and powerful wells were causing havoc with the LECM pipework. The redesign of this pipework is described in section 2.1 Erosion Control Equipment Upgrade.

1.2 LECM Silencer capacity too low

Many steamfields in New Zealand do not allow geothermal fluid to be released to ground due to environmental consent limits. This is to prevent groundwater contamination. Brine carryover is the main risk of dumping geothermal fluid to ground. This is when the silencer is unable to handle the flow of the well and brine is entrained with the steam. The brine flows out of the top of the silencer and onto the ground up to 100 metres away. Other reasons to limit brine carryover are to prevent neighbours close to the well from being covered in brine and silica.

The LECM (Low-Emissions Compact Muffler) is a portable, containerized silencer designed for temporary well testing by Thermochem (Easley, et al., 2018). The base model 40ft LECM is rated for 250 ton/h steam flow and 600 ton/h brine. Many newly drilled geothermal wells in New Zealand are capable of 1000 ton/h or more total mass flow. This far exceeds the capacity of the base model LECM that Western energy owns.

Figure 10 shows significant brine carryover onto the ground from a powerful well. The well had to be throttled in to prevent the carryover and not breach environmental consents. The consequence of this is that the client cannot test the well to its full potential. Thermochem has tested many wells in Indonesia up to the maximum capacity of the base model 40ft LECM without significant brine carryover (Figure 11).

The LECM was redesigned to have a higher capacity before reaching the carryover limit and these modifications are described in section 2.2 LECM Silencer capacity upgrade.

Figure 10: Brine carryover from the base model LECM while exceeding design capacity.

Figure 11: LECM base model in Indonesia at design capacity with no carryover.

1.3 Wellhead growth allowance is too little

Wells are completed, post drilling, in a cold state. The casings are cemented in place whilst the reservoir is under cold water/mud quench. Once the well is flowed for the first time, the steel casing is heated and tries to expand axially. Cement is designed to adhere strongly to the casing and minimize the casing expansion. All wells break some cement bonds, and the wellheads grow taller.

As wells became more powerful and hotter the amount of wellhead growth due to casing expansion is increasing. Cement jobs on wells drilled into high permeability loss zones are more difficult to complete successfully. An incomplete cement job can leave uncemented sections of casing which then expand under heating and cause large wellhead growths.

The original setup of the high-pressure pipework and LECM only allowed for 300mm of wellhead growth. If the wellhead grew more than 300mm the pipework would cause a bending moment on the wellhead. The pipework was fixed to an anchor in the form of a concrete block, as shown in Figure 4, where the control valve is located.

Starting wellhead heights can vary by over 1 metre from well to well and client to client. Geothermal wells are drilled with various drill rigs and the master valves are completed at various heights above ground level. This is usually client specific to allow for the permanent production pipework design.

The solution of catering for large wellhead growths and varying starting heights is described in section 2.3 Wellhead starting height and growth.

2. WELL TESTING EQUIPMENT IMPROVEMENTS

2.1 Erosion Control Equipment Upgrade

Western Energy have re-designed the high-pressure inlet pipework to the LECM to handle high velocity steam and cuttings.

The high-pressure pipework strategy was to make our pipework system more resilient not erosion-proof. The erosion now occurs in a known place which can be monitored. The high velocity flow is centralized as much as possible, not allowing it to impinge on the pipework, to protect the pipes and valves. Certain items of the pipework are treated as consumable and are replaced as needed.

The size of consumable parts are calculated pre-job with expected flow data including total mass flow, enthalpy and wellhead pressure. This process is described in section 3.1 Pre-job data collection and review.

2.2 LECM Silencer capacity upgrade

Thermochem are the designers of the LECM. Western Energy commissioned a Computational Fluid Dynamics (CFD) model to help design modifications to the base model LECM to upgrade its capacity. CFD modelling showed that strategically placed baffles in the bottom container would eliminate channeling of the bulk flow, as shown in Figure 13, and disperse it more evenly.

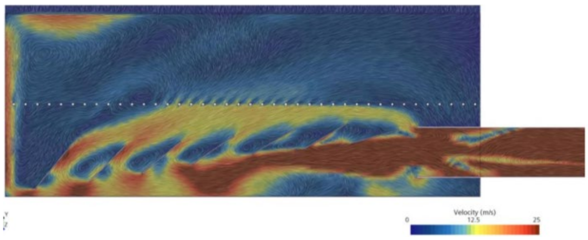


Figure 13: CFD modelling of the bottom LECM container showing channeling at the back of the container.

Thermochem has built 10 LECMs to date since 2010, ranging from a single 20ft. container size to a 20ft. x 20ft. (stack), 40ft. x 20ft. (stack) and the base 40ft. x 40ft. model described here. These LECMs have been used in Chile, Bolivia, Japan, the Philippines, Indonesia and New Zealand. Newer high-capacity designs incorporate an A-frame mist pad configuration to increase the surface area of the pads, allowing for higher volumetric flow of steam at constant velocity (Figure 14). The mesh mist pads are limited to about 4m/s steam velocity before captured droplet re-entrainment occurs, resulting in brine carryover. An A-frame mist pad design was used in the Western LECM upgrade to increase steam-flow capacity.

The current Thermochem A-frame design is used in both the high-capacity 20ft. x 20ft. and 40ft. x 40ft. LECMs, with steam flow capacity increases of at least 150%. Brine flow is seldom a limiting factor in the LECMs, since high brine flow can be accommodated by increasing the brine outlet leg size and quantity. The larger manifold design with up to 4 legs allows a wide range in turn-down for brine flow measurement.

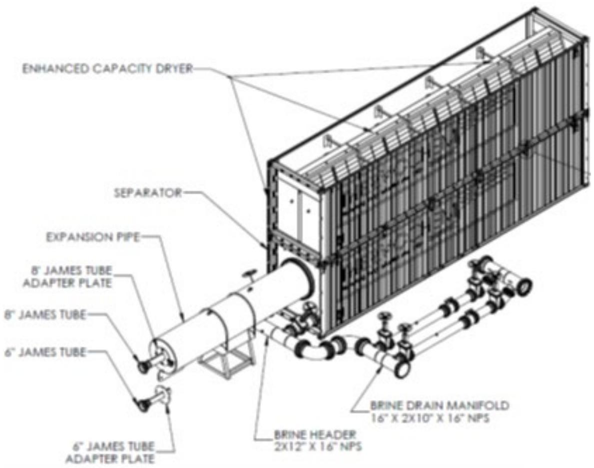


Figure 12: 40ft. x 40ft. LECM A-Frame model.

2.3 Wellhead starting height and growth

The LECM and high-pressure pipework has been re-designed by Western Energy to allow for the various starting heights of wellheads and their potential growth. This allows for starting pipe heights between 500mm to 2000mm+ from ground level. The wellhead can grow 870mm without needing to shutdown and rebuild pipework.

The flexibility of the high pressure pipework allows for rigging up on any well with ease and then allowing a wide range of wellhead growth. As wellheads grow there can be a large bending moment at the casing head flange (CHF) if the pipework to the LECM is fixed. The allowable height span of

Western Energy's pipework mitigates the risk of excessive wellhead growth damaging a wellhead.

It is not uncommon for geothermal wells to have uncemented casing sections due to hitting loss zones during drilling. Wells with uncemented casing sections will grow rapidly as the casing is free to expand, this can cause large wellhead growth. Western Energy's pipework can handle these risks during well testing.

2.4 Telemetry

The main purpose of well testing is to gather data on the well's performance for analysis by reservoir engineers. Western Energy uses a telemetry system that records and displays live data to the client for instant feedback and decision making during the well test. The live data is crucial to optimize the well testing program. Data is recorded to a 1 second resolution and is downloaded for post well test analysis.

A range of sensors records wellhead pressure, lip pipe pressure, brine flowrate with a magflow meter, wellhead growth with a strain gauge and brine pond level, temperature and flowrates. The James calculation is built into the telemetry to calculate total mass flow (brine and stea combined) and enthalpy.

Figure 13: 'Oscar' telemetry unit for data gathering and transmission.

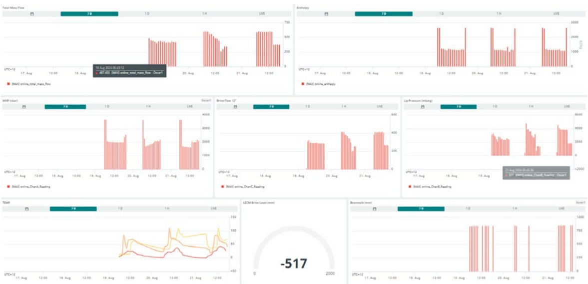


Figure 14: Example of live telemetry data output.

2.5 New Applications and Developments for LECMs

Thermochem LECMs have been used to test severely acidic brine wells with on-line neutralization using caustic injection downhole and at the wellhead without damage to the flow line or LECM (von Hirtz, et al., 2018). LECMs are also ideally suited to perform H_2S abatement using caustic and peroxide injection for minimal corrosive chemical carryover.

Wells producing brine with very high concentrations of salinity and silica will result in substantial scaling when flashed to atmosphere in any type of muffler. In these cases, the use of acid-dosing (pH-modification) must be employed to control silica scaling in the LECM separator and dryer (mist pads) with acid injection upstream in an alloy mixing spool. Deposition of minerals and other solids can impact the efficiency of mist pads over time. The latest Thermochem LECMs incorporate fresh-water spray nozzle manifolds to wash the pads and dissolve silica deposits while operating the well at reduced steam flow for a few hours. Vane packs are also being used to enhance mist pad performance and reduce fouling in the newer 20ft. x 20ft. high-capacity LECMs.

3. WELL TESTING PROCEDURES

The well testing programs have had to adapt to the powerful wells along with the equipment. The outdated theory used by Western Energy was to open the wells to the LECM and the rest would take care of itself. This relaxed strategy was fine for the smaller wells below 400ton/h and around 1100kJ/kg. This was comfortably in the range of the original 40ft. x 40ft. LECM.

Modern wells have much higher flowrates of 700 – 900ton/h plus and are hotter with enthalpies over 2000kJ/kg seen. Well Testing programs have adapted to have two phases: Well Clearing and Well Testing.

3.1 Pre-job data collection and review

To plan the best approach to managing a successful well test, it is key to have accurate expected data including:

- Maximum flowrate
- MDP (Maximum Discharge Pressure)
- Expected Enthalpy

Reservoir Engineers can gather or simulate this data to predict an output curve such as the example described in section 6.5 of Geothermal Well Test Analysis (McLean, Zarrouk 2019). Data from PT (pressure temperature) surveys and any offset wells are used to make the predicted output curve.

The predicted output curve data determines the pressure rating of LECM pipework required, capacity of silencer, size of James tube, size of orifice plates and wear sleeves for the cuttings clearing phase and the brine management strategy.

The PT heat-up surveys can determine the best method to start the well. This is usually either:

- Self Discharge
- Top Heat Method
- Coiled Tubing Air Lift
- Air Compression

The LECM can be used in conjunction with any of these well initiation methods.

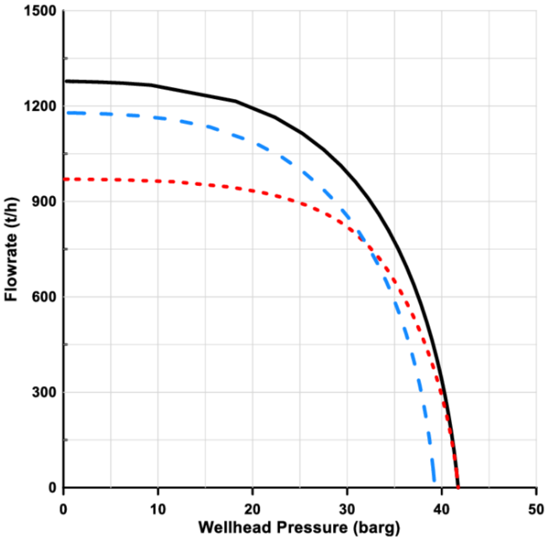


Figure 15: Example predicted output curve with different scenarios

3.2 Erosion Control Procedures

From the predicted output curve data the expected velocity of the steam flow is calculated through the minimum diameter restriction, usually the control valve. This determines the working envelope, it has been found steam velocities over 600m/s through the control valve can erode pipework quickly, especially when cuttings are in the steam flow.

The steam velocity varies according to control valve opening area, steam flowrate and pressure drop through the LECM pipework. High velocities are either avoided with fast opening of the control valve or controlled with the sacrificial parts (mentioned in Section 2.1) taking the force of the pressure drop and centralizing the steam flow to not impinge on the pipe walls.

Downstream pipework is inspected once the well has cleared all the cuttings. This can take anywhere between hours and days. The well is shut in and can be put on bleed for the inspection. The pipework is inspected with a borescope and Ultrasonic Thickness (UT) tester. If excessive wear is seen, the engineer will diagnose the cause and adapt the erosion control strategy.

Monitoring brine returns for colour change and conductivity will determine when the cuttings have cleared. Pipework is then adjusted to allow for highest possible flowrates during the well testing phase. There is still a risk that high steam velocity can erode pipework but the risk is much lower without the cutting present.

3.3 Brine Management

Brine ponds are often the limitation of well testing on powerful wells as the pond fills very quickly with high flowrates. Safely disposing of the brine can involve using a soak pond (if environmental consents allow) or pumping to another pond or into an injection well.

With expected brine flowrates gathered before the well test the pumping strategy can be planned. Large centrifugal pumps with vacuum prime are used primarily as the hot brine is difficult for most other types of pumps to handle. For example, submersible pumps are mostly temperature limited to handle 80°C + brine. Centrifugal pumps have to be de-rated when pumping hot fluid due to the lower NPSH available.

Hydraulic calculations based on pipeline, elevation and hot brine characteristics and are made to size pipeline diameters (if possible), size and number of pumps. Cooling water is often injected near the pump suctions to cool the brine to allow for higher NPSH available to the pump.

The brine pond level and temperatures are monitored with a radar level transmitter and temperature probes. Calculations on pond filling and emptying rates are made to find the limitations of the brine management impacting the well test timeline. Overnight well throttling is an option to manage brine volume. Brine temperature is recorded to protect any temperature sensitive pipeline such as HDPE pipe. Cooling water not only helps the pump but also protects HDPE lines from overheating.

Figure 16: Pumping hot brine with a large centrifugal pump.

4. CONCLUSION

Geothermal asset owners are always striving to reduce costs and make their businesses more efficient. Geothermal well drilling is a large cost to any geothermal project so drilling technology, steamfield modelling and geothermal knowledge have improved to make wells better. Drilling costs are fairly fixed, but the output can vary widely, therefore getting the most output from a well will pay off the drilling cost faster.

Geothermal wells are completed with larger casing and target very high permeability zones to produce massive mass flows and higher enthalpies. Well testing equipment has to keep pace with the requirements of powerful wells.

Western Energy along with Thermochem have worked on improving both the well testing equipment and procedures. Well testing mindset has shifted to a phased approach to first clear the well, then perform testing to gather data. The introduction of resilience with sacrificial parts has proven successful in 100% of well tests since 2022 performed by Western Energy (7 wells and counting).

Well testing equipment and procedures now offer adaptability to any well, to gather data confidently for future decision making. Until wells become another magnitude more powerful in the future!

REFERENCES

McLean, K., Zarrouk, S.J., (2009). Geothermal Well Test Analysis.

Easley, E., Sadji, N., Utami, W., (2018). 6th Indonesia International Geothermal Convention & Exhibition (IIGCE). Geothermal Well Testing Using a New Atmospheric Separator and Metering System in Sarulla, Indonesia.

von Hirtz, P., Easley, E., Kunzman, R., Gallup, D., (2018). 6th Indonesia International Geothermal Convention & Exhibition (IIGCE). New Techniques for Acid Brine Corrosion Control in Geothermal Wells.