TURBINE WASHING TO REMOVE NOZZLE DEPOSITION AT WAIRAKEI

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SUMMARY-Deposition of steam evaporates on the nozzles of the IP turbines at Wairakei has become more pronounced since the shift in production to "dry" steam wells and operation with superheat conditions within wellbores and pipelines. This deposition, and the outages needed to remove it, resulted in significant production losses. A simple turbine washing system was designed and installed to dissolve deposits with the turbine on load The washing procedure is done for short periods on an as-needed basis. It has been cost effective and there is no indication that the additional water has been detrimental to the life of the turbine.

1. INTRODUCTION

Deposition of evaporates in turbines is a common problem at steam dominated geothermal fields. Tsujimura et al (1980) goes into the problems in considerable detail. Various strategies have been developed to deal with the scaling, most of which involve some form of turbine washing and with varying degrees of success. Triyono (1998) lists the washing regimes at seven fields.

2. HISTORICAL PERSPECTIVE

Historically, Wairakei has not had a scaling problem in its turbines. There has been some deposition on the back of the first stage fixed blading or nozzles in turbines G1 and G4 fed with IP (3.5bg) saturated steam but it has generally been less than 3mm thick and easily removed during surveys. In many cases, the thermal stresses that occur during an outage have been enough to cause any deposition to crack and flake off.

Wairakei has historically been fed by separated steam fiom liquid enthalpy wells. These wells are situated 3 - 4 km from the power station and the long distances, together with poor insulation on the older pipelines, allowed chemical laden water carried over from incomplete separation to be scrubbed out. There was deposition in the HP machines very early on when production was concentrated in the Eastern borefield, but as the production centre moved away from station, the deposition decreased and the scrubbing effect increased. In fact, the scrubbing was so efficient that corrosion in the mild steel pipelines became a major tbreat in the 1980s (Thain et al., 1981). This corrosion was stopped by injecting small quantities of separated geothermal water back into the steam pipelines to maintain <1mg/l of silica in pipeline condensate just prior to entry into the station (Bacon and Stacey, 1984) Most of the blade deposition seen since that time was thought to be related to excessive injection of the silica laden water.

During the past fifteen years, production at Wairakei has gradually shifted from liquid enthalpy wells in the western borefield to "dry" steam wells at Te Mihi, a further 2 – 3 km away fiom station. By 1994, this steam was transported to the station in a large (1.2m diameter) well insulated pipeline (R Line). About 40% of Wairakei's steam comes currently fiom Te Mihi steam wells.

The majority of Te Mihi steam wells that feed into R line are not in fact "dry", although no separators exist At normal operating pressures, the steam is up to about 0.5% wet, the velocity within the wellbore is high and water is carried within the steam in minute droplets. They do not separate out because of their small size and the high velocity. The efficient insulation on R Line also means there is little condensate to provide for scrubbing. Thermodynamically, conditions are such that superheat development occurs either down hole or within surface pipelines.

Under superheat conditions, deposits formed within Surface pipelines. These deposits started to form when the wells and pipelines were first commissioned. The commissioning of new wells caused the deposition rates to increase, particularly within 500 m of the well. Inspections had shown the deposition was up to 100 mm thick on the pipe walls with it being thicker near obstructions like flow measuring orifices. Rough order calculations indicate there could be about 10 tonne of material deposited in the pipes. Attempts were made to wash or waterblast this material off during outages but with mixed success.

In July 1998, two new wells were connected into R line. These significantly increased the velocities in the line and also changed the flow paths where R

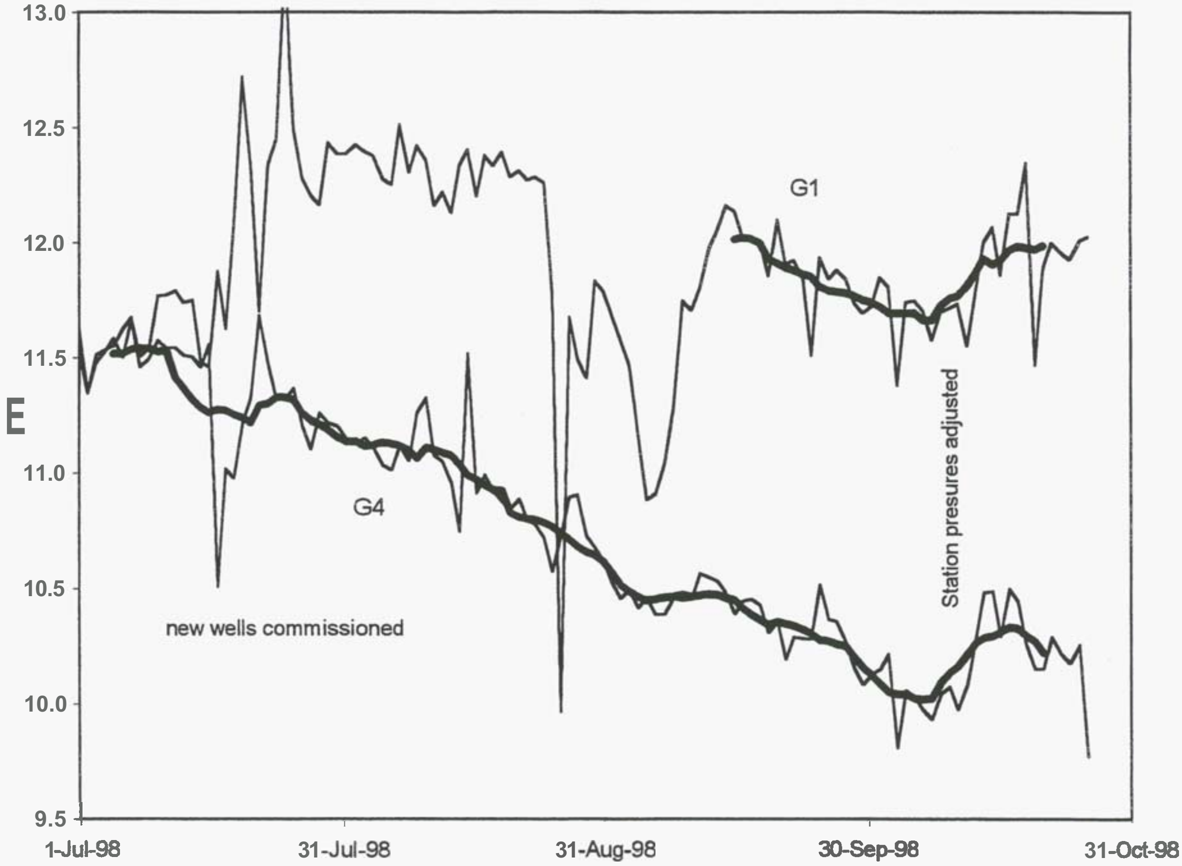

Figure 1. Turbine output decline fkom deposition associated with new wells

line was interconnected with the western borefield wells. Under the old flow regime, the western borefield steam which was wet, flowed into R line at A10. When the new wells were connected, the R line steam flowed into the lines from the western borefield. This change in flow regime meant that as the steam's velocity increased, the dryness of the steam increased. The IP turbines started to clog up the day the new wells were commissioned. G4 is thought to have declined in output first because its machine nozzles were already partially clogged. Within 3 months, one of the turbines had a 20% decline in output. Figure 1 shows the effect of the well commissioning and output decrease. The figures shown are the average generation for the day so are affected by other station and machine activities. Trend lines have been added to remove these day to day fluctuations.

When the steam containing chemicals in the water droplets enters the IP turbines, there is an additional 1.5 bar pressure drop across the nozzles. This provides an additional 30kJ/kg heat to flash any remaining droplet water. The chemicals dissolved in that water will then either be carried through the turbine as dust or deposit on the trailing face of the nozzle blades.

The nozzles are the diaphragms or fixed blades in front of the first stage turbine or moving blades. The turbines consist of a number of stages where, in simplistic terms, there is a pressure drop across the fixed blades and a velocity drop across the turbine blades As well as the velocity drop, the blades extract sufficient energy out of the steam to cause water droplets to form in the steam. This water is centrifuged outwards where it is collected and removed by drains built into the diaphragms. Depending on operating conditions and design, up to 10% of the inlet steam can be converted to water inside the turbine. The reason why the deposition usually forms only on the nozzles is that the water droplets continually wash the other blading. The IP machines at Wairakei are more prone to deposition than the MPs because they have only three stages to drop the pressure from 3.5bg to 0.2bg while the MPs have 8 stages so consequently there is smaller pressure drop per stage.

The evaporate particles also cause erosion of components in the steam path, particularly those that are small or in regions of high velocity. The tenons that fix the shrouds to the tips of the blades are particularly prone to this erosion.

Station operating conditions are such that the IP machines, with clean nozzles, need to be operated with partially closed throttles to prevent overloading of the generators. This operating state adds to superheat development at the nozzles. As the nozzles block, the throttles are opened to bring the output back up. Once the nozzles are fully open, deposition causes the output to gradually drop at a rate of approximately 5% per month. The trigger point for nozzle cleaning is generally at a time when load has dropped by about 10%. Monitoring of the machine outputs indicated that deposition removal needed to be done approximately every three to five months. Machine monitoring has shown sudden improvements in output occurring after the turbines was taken out of service for a day's maintenance. The reason for this is that the isolation valves leak and steam passing the valves provided a source of condensate in the turbines to soften and redissolve deposition.

When turbines were out of service for three months during overhauls, the two wells that caused most of the deposition problems were also taken out of service as their steam was not needed. The turbine nozzles continued to clog up, albeit at a slower rate. This continued deposition was attributed to a change in the flow regime in the steam mains allowing material previously deposited on the pipe walls to redissolve and be re-entrained in the steam flow.

3. EVAPORATE DEPOSITS

During a machine survey in May 1999, samples were collected fi-om the nozzles of G4 turbine. The deposit was relatively soft and easy to break into sub millimetre sized particles The analysis of the deposit (Brown, 1999) showed a mixture of quartz, silicates and burkeite. A condensed form of the analysis is shown in the Table 1.

Table 1 Chemical Analysis of Deposit

Na_2O	42.9%.
SiO_2	15.8%
Cl	9.1%
S	8%
Fe_2O_3	4%
Al_2O_3	2.2%
K_2O	1.8%

No other components over 1%

It needs to be emphasised that such deposits are not precisely representative of the chemistry of droplets at their formation. In this situation, partitioning of minerals may occur within the steam transmission system as a result of the evaporative process causing the least soluble minerals eg amorphous silica, to deposit first followed by the more soluble minerals. The chemical makeup of deposits at any particular location in the system is therefore dependent upon the thermodynamic conditions through which the droplets have passed. If superheat development is rapid then deposits are likely to have a chemical composition similar to the original droplet fluid. In the case of shallow "dry" steam wells near the field boundary the chemical makeup of deposits will be more likely to be closer to that shown in Table 2. This fluid was collected from a well during a long term output test.

Table2 Chemical Analysis (mg/l) of Discharge from 'Dry' Steam Well

pH	8.8
HCO_3	1140
Na	490
K	18
Ca	0.3
Cl	5
SO_4	28
SiO_2	140

4. CLEANING OPTIONS

Analysis of the problem indicated that two solutions needed to be worked on, i.e.

- steamfield thermodynamics and
- turbine deposit removal

The latter was the most urgent. It also offered an immediate solution to generation losses.

The deposition was removed by turbine dismantling on three occasions, two of which coincided with machine surveys. The turbine rotors were removed and the nozzles water blasted with a 3000 bar, 4 l/m water blaster. This proved to be a very effective cleaning method but it needed a three day outage and had a significant impact, both on staff resources and lost generation.

Overseas experience indicated that turbine washing was the most viable option for turbine scale control. A good summary is given in Triyono (1998). It does not however address the thermodynamic or mineral solubility aspects of deposit formation and hence is purely palliative.

Steam line scrubbing in the steamfield was seen as a more suitable long term option. It will be difficult to implement however because of the lack of a suitable water source (to remove superheat) and the steam velocities involved. Initial calculations indicated that about 750 m of lagging needed to be removed from the pipelines to desuperheat the steam. Doing this would mean the performance would be subject to the vagaries of the weather with a significant difference in condensate formation on a cold,

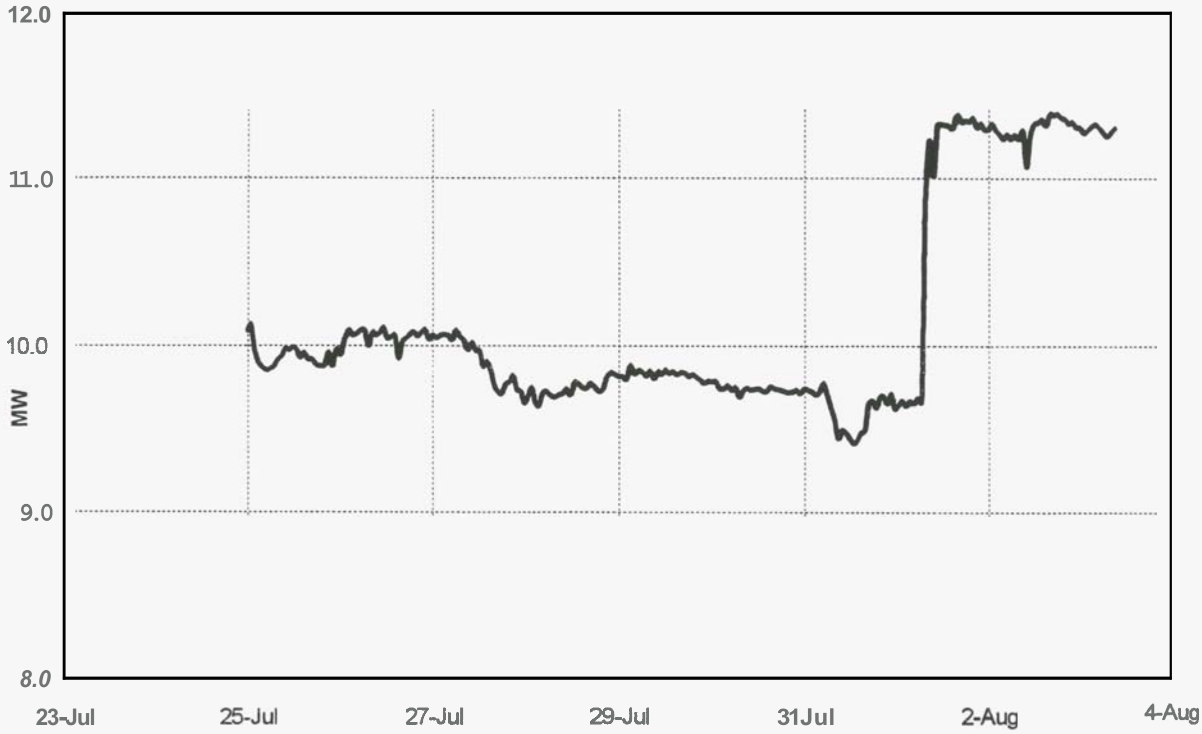

Figure 2 Turbine generation during a turbine wash

windy, wet day compared to a calm one in summer.

There was also not enough condensate flow from any bank of steam traps to provide sufficient de-oxygenated water for pipeline injection. Using ground or tap water would involve significant operating costs for oxygen scavenger chemicals.

5. TURBINE WASHING SET-UP

The decision was made to inject water upstream of the turbine stop valves so that the high steam velocity and turbulence generated by the stop valves and throttles provided thorough mixing of the wash water and steam. No spray nozzles were fitted, eliminating the risk of components breaking and damaging the turbine. The water was injected through a simple port in the pipe wall.

Wairakei was designed to supply steam at a number of pressures from the steamfield. The lower pressure (ILP) steam is produced primarily from secondary flash separators and hence has very low non condensable gases and separator carryover. The LP steam enters the main station manifold at about 0.1bg via a back pressure turbine that also produces about 20t/hr of LP condensate. The decision was made to use this for turbine washing. The water has very little chemical contamination and is already de-oxygenated. The washing system was also designed so that it needed minimal staff input during operation.

Tapping points were fitted to the LP manifold drains pipework upstream of the float traps. From here, water flows through isolation valves into a common sump. This feeds a multistage centrifugal pump sized to provide a shut in head of 11bg and a capacity of 8t/h at 9bg. The discharge line passes to a standpipe between the two IP turbines. Steam hose is used to connect the fixed line to the isolation valves on the inlet bypasses. Small non-return valves have been fitted on the steam hoses to prevent back flow during start up.

The pump motor was provided with a manual starter and there is no installed instrumentation. Running the turbine wash system is therefore a simple matter of connecting the steam hoses to the bypasses, opening five isolation valves and pushing the start button. Monitoring of the washing is done by noting the generation and throttle openings.

6. RESULTS

The wash sequences that have been done to date are without doubt, successful. Payback time for the installation was about one week of the increased generation. There was a full generation recovery within 10 minutes of the washing starting for the first wash sequence. Subsequent washes took slightly longer to get performance recovery. However, the machines were back to near fully clean performance within 12 hours. Figure 2 shows the generation fkom a turbine over a turbine wash. The operators, having to partially close the throttles during washing to prevent generator overloading, decreased the efficiency of the washing and this has meant that it is not possible to "fully" wash the nozzles clean.

The water flowing from the casing drains, especially during the early stages of washing, was silty and particles up to 1mm in diameter could be observed. These were thought to be silica particles that had been left when the rest of the deposition had dissolved. It was noticed during the washing that there was about a slight (< 2%) drop in performance caused by the washing. As the *steam* entering the first stage blades was no longer superheated but wet, this result was not unexpected.

During one washing sequence, a transient vibration alarm came up after about three hours. This was thought to have been caused by debris breaking off and passing through the blades. There have been no other problems so far.

Because of other problems, the turbine cover was removed on one machine just after washing. Careful inspection indicated that there was no visible water damage. The nozzles had no significant deposition restricting the throat area. The trailing faces of the blades had not washed completely clean and were covered with patches of deposition less than 0.5mm high.

7. CONCLUSIONS

Turbine washing on an as needed basis is a simple, *cost* effective means of restoring turbine performance. This confirms the experiences of other geothermal station operators. It is also possible to install a cheap, reliable effective washing system.

However, turbine washing is seen only as a palliative measure. From a station management viewpoint, it would be more effective to remove the material by pipeline desuperheating.

8. ACKNOWLEDGEMENTS

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