BIOLOGICAL CONTROL OF COOLING WATER IN GEOTHERMAL POWER GENERATION

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ABSTRACT

Mighty River Power (MRP) operates a diverse fleet of geothermal power plants, including two geothermal power plants with condensing steam turbines. The cooling water used to condense the exhausted steam is condensed geothermal steam, recirculated through a mechanical draft evaporative cooling tower. The use of condensed geothermal steam as cooling water presents both opportunities and challenges when compared to the use of surface water or groundwater for cooling. The condensed steam has low levels of dissolved solids, and very low levels of suspended solids reducing the likelihood of mineral scale formation and erosion within the cooling water system. The presence of hydrogen sulphide in the geothermal steam (and the condensed steam) presents several challenges to the management of the cooling water system, including the build-up of sulphur deposits, the management of sulphur metabolising bacteria and the limited choice of sulphide compatible biocides. This paper discusses the implications of these challenges to the management of cooling water systems using condensed geothermal steam including discussion of significant cooling water events resulting from these challenges.

1. INTRODUCTION

Mighty River Power (MRP) operates a diverse fleet of geothermal power plants, including flash plants binary plants and combined flash-binary plants. MRP currently operate two flash plants which utilise condensing steam turbines in the power generation process, the 140MWe triple flash Nga Awa Purua (NAP) power plant and the 100MWe double flash Kawerau power plant. The use of condensing steam turbines increases the efficiency of the power generation process (compared to a back pressure steam turbine) by extracting more energy from the working fluid which results in a lower working fluid exhaust temperature. Condensing the exhausted steam requires the removal of the latent heat of vaporisation of the steam; this is achieved at MRP's plants through the use of an evaporative, re-circulating cooling water system. The use of a re-circulating cooling water system minimises the requirement for an external source of cooling water while also removing the need to discharge large volumes of waste water into the environment.

2. SYSTEM DETAILS

The cooling water system at each of MRP's flash plants consists of a direct contact spray condenser, mechanical draft cooling tower, biocide dosing systems and associated pumps, pipe-work and ancillary equipment. All wetted materials are constructed from corrosion resistant materials including 316 Stainless steel, polyvinylchloride (PVC), polypropylene and fibre reinforced plastic (FRP). The designs and sizing of the cooling water systems at the two plants are very similar with only minor, site specific technical variations. The cooling towers are typical of mechanical draft cooling towers found at fossil fired power plants. Plume abatement systems (dry sections) are not required or fitted to MRP's geothermal cooling towers due to the natural steam venting present in their associated geothermal systems.

2.1 Cooling System Design

Each cooling water system includes a cooling tower basin, which collects cooled water from the cooling tower while also acting as the water storage buffer for the overall cooling water system. From the cooling tower basin cooling water flows to the spray condenser which is maintained under vacuum. The spray condenser operates by spraying cooling water into the condenser to contact and condense the saturated steam exhausted from the steam turbine. The combined cooling water and condensed steam is then pumped to the cooling tower where heat is removed through evaporation and convective heat transfer before the process is repeated. Cooling water is also used to provide cooling to auxiliary systems including lube oil cooling, air cooling and gas extraction system cooling. The basic cooling water process is illustrated in Figure 1.

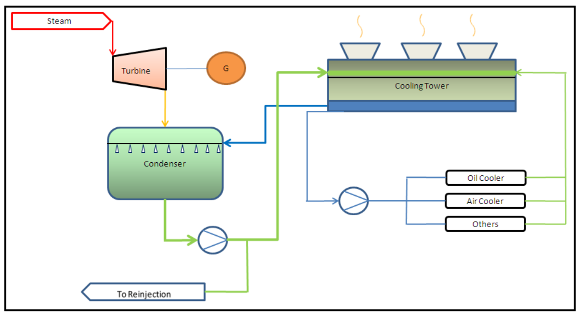

Figure 1: Simplified cooling water process flows at MRP's geothermal power plants.

2.2 Operation

The cooling water system is required to operate continuously while the power plant is operating, potentially running uninterrupted for up to 12 months at a time. The cooling water system utilises condensed geothermal steam exhausted from the steam turbine as make-up water. System make-up is a function of steam flow through the turbine; as such make-up water flow into the cooling water system is not directly controlled. Blow-down or bleed from the cooling water system is undertaken to control the water level within the cooling tower basin, as the make-up water flow exceeds the combined system losses including evaporation and drift. As the make-up water contains a very low level of dissolved solids blow-down is not required to control scale formation within the cooling water system as saturation of dissolved ions does not occur. The almost continuous blow-down of the system to control the water level in the cooling tower basin results in a rapid turnover of water within the system, the entire cooling water volume can be blown-down in less than a day when operating the turbine at full load. MRP's geothermal cooling water systems typically operate at approximately 3 cycles of concentration which is considerably lower than what is normally encountered for other non sea water cooled thermal power plant cooling towers.

2.3 Water Quality

The make-up water to the cooling water system is condensed geothermal steam which is constantly mixed with the re-circulating cooling water in the direct contact condenser. The condensed steam typically has a low total dissolved solids content (TDS) when sulphate is excluded; up to 2mg/L, made up of low levels of silica and boron with trace levels of other impurities including chloride, potassium and sodium.

Cooling water quality is dominated by the concentration of sulphate in the water as shown in Figure 2. Sulphate is formed as a result of the oxidation of hydrogen sulphide present in the geothermal fluid which is transported with the geothermal steam through the steam turbine and into the condenser. While most of hydrogen sulphide is vented from the condenser as a non-condensable gas, a small proportion of the hydrogen sulphide dissolves into the cooling water. This is a continuous process as exhausted steam is condensed, as such the concentration of sulphate in the cooling water increases until an equilibrium is reached between hydrogen sulphide dissolving in the cooling water and oxidising to sulphate and sulphate leaving the system through the blow-down process.

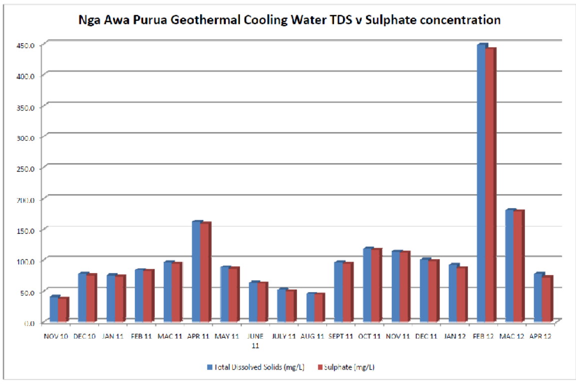

Figure 2: Cooling water TDS and sulphate concentrations.

Not all of the hydrogen sulphide that dissolves in the cooling water is oxidised to sulphate; dissolved hydrogen sulphide oxidises through both chemical and biological processes to sulphate as well as elemental sulphur. Elemental sulphur is insoluble and precipitates from the cooling water, depositing in low velocity areas of the cooling water system as shown in Figure 3. Sulphate and sulphur may be reduced to hydrogen sulphide by biological processes under anaerobic conditions; however these conditions are not usually encountered in MRP's re-circulating cooling water systems. There are many potential oxidation reactions of hydrogen sulphide, both chemically and biologically controlled that lead to the formation of both elemental sulphur and sulphate; it is not in the scope of this paper to go into the detail of these reactions.

Figure 3: Sulphur deposits in a cooling water pipe.

3. BIOCIDE DOSING

Cooling water systems that include evaporative cooling towers can be a breeding ground for pathogens including those from the genus *Legionella* (specifically *Legionella pneumophila* serogroup 1) that may pose a health and safety risk for personnel exposed to the cooling water due to "Legionnaires' disease". Because of this risk the cooling water must be actively managed[i]. The temperature range (approximately 25-35˚C) of many power plant cooling systems are well suited to the rapid growth of microorganisms, coupled with the presence of nutrients found in either the make-up water supply or introduced as dust and contamination, the potential for microbiological growth in an untreated cooling system can be significant. The growth of bacterial populations can result in fouling of heat exchange surfaces and packing material, resulting in reduced plant output and efficiency, while also increasing the risk of damage to plant and equipment due to localised corrosion (microbiologically influenced corrosion, MIC). To reduce the risks to both personnel and equipment, the dosing of biocides is often undertaken to control the growth of microorganisms (including pathogens) within the cooling systems.

3.1 Risk management

Safe operation of industrial cooling towers requires that the risks inherent with the operation of the cooling tower are identified and adequately addressed. AS 5059: *Power station cooling tower water systems – Management of legionnaire's disease health risk* and AS/NZS 3666.3 *Air handling and water systems of buildings – Microbial control Part 3: Performance-based maintenance of cooling water systems* provide guidance on the areas of a cooling water system that require specific attention. The cooling water systems at MRP's geothermal power plants are tested for bacteria populations including *Legionella* on a monthly basis. At the time of writing there is yet to be a positive *Legionella* test result in MRP's geothermal cooling water systems. To date the most effective tool for managing biological activity in MRP's geothermal cooling water systems has been the implementation of effective biocide dosing programs.

3.2 Biocide Selection

The selection of commercially available biocides that can be used successfully in MRP's geothermal cooling water systems is limited due to factors including the cooling water chemistry, the cooling water residence time, the environmental impact of any discharges and the system design.

Cooling water chemistry can have a significant influence on selection of a biocide. Many biocides are sensitive to aspects of the cooling water chemistry such as pH, hardness, presence of dissolved metals and oxidation-reduction potential[ii]. Geothermal cooling water at MRP's plants contains dissolved hydrogen sulphide. Hydrogen sulphide is readily oxidisable and reacts with the most commonly used oxidising biocides such as sodium hypochlorite as shown in Equation 1 below; as a result oxidising biocides are generally ineffective in cooling waters containing significant concentrations of hydrogen sulphide. This has been demonstrated by MRP where the original design basis biocide for the Kawerau power plant was sodium hypochlorite which soon after commissioning was shown to be ineffective. Several non-oxidising biocides are also unsuitable for use within cooling systems containing hydrogen sulphide due to their reactions with dissolved hydrogen sulphide. Such biocides include isothiazolines[iii] and DBNPA (2-2-Dibromo-3-ntrilopropionamide).

Equation 1: $H_2S + 4NaOCl \rightarrow H_2SO_4 + 4NaCl$

The contact time that a biocide requires for effective cooling water treatment has significant implications for biocide selection. Cooling water systems with a rapid turnover of water generally require fast acting biocides to prevent significant volumes of biocide being discharged from the system before they have performed their required function. MRP's geothermal cooling water systems typically operate at approximately 3 cycles of concentration and discharge the entire volume of the cooling water system to reinjection within 24 hours. The use of slow acting biocides in these systems would require higher consumption of biocide than would otherwise be necessary to maintain the required concentration of biocide within the cooling water system for an effective treatment. This would add excessive cost to the cooling water treatment program while also increasing the amount of biocide discharged from the cooling water system.

The environmental impact of a biocide needs to be assessed as a part of the selection process. There will typically be residual biocide contained in water blow-down or bled from a cooling water system which may then be discharged to a receiving environment. A biocide that has detrimental impacts on the receiving environment will not be an appropriate biocide and is unlikely to gain regulatory approval; as such the biocide must be assessed and deemed acceptable to the receiving environment. At MRP excess condensed steam/cooling water is blown-down from the cooling water system and re-injected into the geothermal reservoir so suitable biocides are restricted to those that will readily decompose to benign species in the receiving environment. The biocides utilised by MRP are subject to Resource Consent compliance under the Resource Management Act (RMA) 1991.

Cooling water system design is also a consideration when selecting biocides for a cooling water treatment program. At MRP the use of spray-type direct contact condensers generally requires the use of non or low foaming biocides. Excessive foaming within a cooling water system utilising a direct contact condenser can result in a significant loss of condenser vacuum – potentially leading to a turbine and plant trip. An example of such an occurrence is described in section 4.1 of this paper.

MRP is currently utilising glutaraldehyde and carbamate based biocides supplemented with quaternary amine and polyquat dispersants in its geothermal cooling water systems. Non-oxidising algaecide dosing is undertaken at NAP to complement its biocide program while at Kawerau, algaecide has not been used to date. The application and effectiveness of these biocides is discussed in Section 4 of this paper.

3.3 Shock Dosing

The use of non-oxidising biocides in the geothermal cooling water systems has resulted in the application of shock dosing treatments of the cooling water. Shock dosing involves periodically applying a large quantity of biocide to the cooling water system over a short period of time, rather than continually applying smaller quantities of biocide to the system (continuous dosing). Shock dosing is preferred when applying non-oxidising biocides as these types of biocides tend to require higher concentrations in the cooling water for an effective treatment. Continuous dosing of low levels of non-oxidising biocides is also more likely to lead to the development of biological biocide resistance[iv]. The rapid turnover of water within the cooling water system also results in a shock dosing program being significantly more cost effective than a continuous dosing program.

3.4 Contingency planning

With any cooling water treatment program there is the possibility that a treatment that has been successful in the past may no longer result in the desired outcomes. This can be caused by a change in the cooling water chemistry (pH, oxidation-reduction potential, chemical composition), a change in the cooling water system conditions (e.g. build up of sludge, slime, change of temperature etc.) or the development of microbiological resistance to the biocide[v] (if using a non oxidising biocide).

When developing a cooling water treatment program utilising a non-oxidising biocide the potential for the development of a population of biocide resistant bacteria should be considered. Bacterial populations have been shown to develop resistance to many of the commonly used non-oxidising biocides[vi]. To address the risk of the development of biocide resistance multiple biocides should be used in a treatment program on an alternating basis. At MRP the cooling water treatment programs aim to utilise a primary and a secondary biocide, where the primary biocide is typically used once per week, and the secondary biocide once per month in place of the primary biocide. The purpose of this approach is to utilise the secondary biocide periodically to remove bacterial populations that have survived treatment with the primary biocide. For this approach to be effective it is suggested that the primary and secondary biocides should have clear differences in their chemistry and mechanisms of biocide action.

Changes to the cooling water chemistry, system conditions and biocide resistance are all possibilities in MRP's geothermal cooling water systems; as such two different non-oxidising biocides are available at these plants to provide dosing options should conditions change. MRP are currently investigating the use of a third sulphide compatible biocide to complement the existing biocide program.

3.5 Dispersant Dosing and Sulphur Management

The build up of sulphur deposits throughout low flow areas of the cooling water system as shown in Figure 3 is of concern. These heavy deposits are suspected of harbouring sulphur metabolising bacteria in locations where biocide penetration is poor. Biocide penetration into sessile microorganism deposits (biofilms or "slime layers" is also often poor). These biofilms then provide an ongoing reservoir of microorganisms re-entering the cooling water[vii] making effective microbiological control difficult.

It is common in cooling tower chemical treatment programs to utilise a dispersant with surfactant properties in conjunction with a biocide to enhance the penetration of the biocide[viii] into a biofilm to enable more effective microbiological treatment. When a dispersant is successfully added to a cooling water treatment program a decrease in the requirement amounts of biocide(s) needed to maintain a sufficient degree of microbiological control is often observed. The dispersant may be shock dosed to the system in conjunction with a biocide once a week when utilising non-oxidising biocides. In thermal power plants a dispersant can also be used to help manage suspended solids that may be present in the cooling water, in which case the dispersant may be dosed on a continuous basis. This is not a concern for the MRP geothermal cooling water systems.

The use of dispersants in spray condenser systems must however be treated with great caution. The foaming characteristics of the dispersant being used has to be well understood due to the potential operational issues with the vacuum systems that may occur if large amounts of foam formation occurs within the condenser space. The use of anti-foam compounds in conjunction with dispersants is common as is the selection of low to no foaming dispersants. The selection of a dispersant is often plant specific and is dependant on plant design and cooling water chemistry.

The use of dispersants to reduce sulphur deposits within cooling water systems is also being considered by MRP however the risks of re-injecting precipitated sulphur into the geothermal reservoir need to assessed before the use of a dispersant undertaken. The pH adjustment of the cooling water system to reduce the build up of sulphur is also under consideration, although the cost effectiveness of such an approach is unlikely to result in a favourable cost-benefit analysis.

4. COOLING WATER CASE STUDIES

Two significant events have occurred in MRP's geothermal cooling waters systems in recent years that have been directly related to the cooling water treatment programs. One case resulted in an unplanned forced outage while the other highlights how quickly cooling water system conditions can change.

4.1 Cooling Water Treatment Loss of Control Case Study 1 – Loss of pH Control and Cooling Tower Foaming and Plant Trip

As discussed in Section 3.2 the Kawerau power plant was originally designed and commissioned with an oxidising, sodium hypochlorite based biocide dosing system. During commissioning and early operation an independent review of the cooling water chemistry indicated that this dosing was ineffective and an alternative program was required. A non-oxidising, alternating dual biocide (glutaraldehyde and quaternary amine dispersant/biocide) shock dosing based program was then successfully implemented.

After a successful period of plant operation a small component failure resulted in the draining of a biocide storage tank at the Kawerau power plant. The treatment of the cooling water system with the glutaraldehyde based biocide was not undertaken for several months whilst repairs to the storage and dosing system were designed and undertaken. During this period the cooling water system was treated with only a quaternary amine dispersant/biocide that had previously been successfully used in conjunction with the glutaraldehyde biocide during normal plant operation.

During the period of quaternary amine dispersant/biocide dosing only, the pH of the cooling water dropped significantly, from its normal range of between 7 and 8 to below 3 before the system was eventually brought under control when glutaraldehyde dosing was restored. Prior to the re-establishment of dosing control, an attempt to regain control of the cooling water system was undertaken by doubling the regular dose of quaternary amine that was being added to the cooling water system. This resulted in excessive foaming of the cooling water as shown in Figure 10, which is not unexpected with quaternary amines[iii] but was unforseen and not considered at the time of dosing. The excessive foaming resulted in a loss of condenser vacuum, which then initiated a turbine protection trip and shutdown of the steam turbine. It is unclear whether the loss of vacuum was due to foaming within the condenser itself, reducing the ability of the vacuum system to remove non condensable gases, or due to a loss of vacuum pump capacity due to seal water foaming (cooling water is used as the seal water in the vacuum pumps) or a combination of both.

The plant was successfully restarted following the trip, although the restoration of condenser vacuum required significantly more time than usual and operation at reduced load was required for several hours while the foam within the cooling water system stabilised and then dissipated.

After the plant restart sodium hydroxide dosing was carried out in an unsuccessful attempt to increase the cooling water pH whilst continuing with quaternary amine dispersant/biocide dosing only. Control of the cooling water system was regained only when the glutaraldehyde dosing was recommenced as per the original alternating biocide dosing program.

Figure 10: Foam inside the Kawerau cooling tower basin post unit trip

This event highlighted the critical need for a comprehensive cooling water management plan to be developed and implemented to prevent repeat occurrences of incidents such as these. A root cause analysis investigation was undertaken into the incident resulting in a range of recommendations to improve cooling water system performance. Key recommendations that arose from the investigation included the need for the cooling water management plan to include:

- Online monitoring of the cooling water system to provide an early warning of system changes;
- Clear lines of communication and authority when deviating from the agreed management system;
- Ongoing performance monitoring and reporting of the cooling water system;
- Contingency planning including incident management procedures and documentation.

4.2 Cooling Water Treatment Loss of Control Case Study 2 – Loss of pH Control

Shortly after returning to service after a routine maintenance outage at the NAP power plant, the cooling water pH was observed to drop. The cooling water system had been drained for the plant outage and at the completion of maintenance work the cooling water system was refilled with water from the Waikato River and treated with sodium hypochlorite. At the unit restart the standard cooling water treatment of weekly additions of carbamate based biocide was recommenced. Initially the drop in cooling water pH was thought by operations personnel to be associated with the return to service, however the pH drop accelerated and within a few days the pH had reduced from its normal range of pH 8.0-8.5 down to a pH of less than 4.0, and continued to decrease as illustrated in Figure 4. This rapid decrease in pH was suspected to be the result of microbiological (sulphur oxidising bacteria) activity within the cooling water system, however the subsequent biocide additions to the cooling water system raised some doubt over this hypothesis.

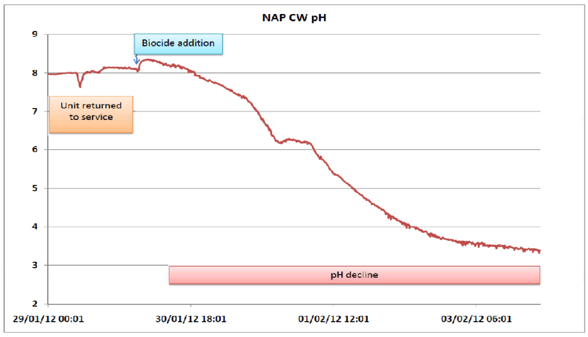

Figure 4: NAP cooling water pH depression post plant return to service

The decrease in pH of the cooling water system was of significant concern to MRP. While the cooling water system was constructed from corrosion resistant materials, these materials are still expected to degrade when exposed to prolonged, highly aggressive environments such as with a low pH as was being experienced. The condensate reinjection system piping and reinjection well casing (where the cooling water blow-down is disposed of) are constructed from carbon steel, and these components were likely to be experiencing high corrosion rates during low pH conditions. The integrity of geothermal wells is of critical importance to MRP due to the potential health, safety, environmental and financial consequences of a well failure.

With limited alternative hypothesis to explain the decrease in pH, extra biocide dosing was undertaken to attempt to restore the cooling water system to its normal operating conditions. The decreased pH was seen as an impediment to the standard biocide program used at NAP, as carbamate biocides are known to have a limited effective pH range[ix], and the biocide efficacy was expected to be poor at such a low pH. Sodium hydroxide was dosed into the cooling water system to raise the pH above 7.0 in preparation for the biocide treatment as illustrated in Figure 5. When the pH of the cooling water exceeded 7.0, 300L of carbamate based biocide was added to the cooling water (a normal dose is 90L). After 7 hours from the biocide addition the station ran out of its supplies of sodium hydroxide and the pH of the cooling water dropped rapidly from 7.5 to less than 5.0 one hour after caustic dosing ceased, to less than 4.0 2.5 hours after sodium hydroxide dosing ceased and to less than 3.0 24 hours after sodium hydroxide dosing ceased, indicating that the biocide addition had been unsuccessful in treating the cooling water.

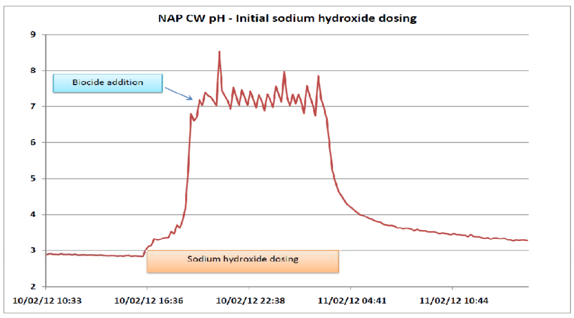

Figure 5: NAP Initial sodium hydroxide dosing pH changes

While more supplies of sodium hydroxide were sourced to increase the pH of the cooling water, a glutaraldehyde based biocide treatment was also sourced as an alternative to carbamate in case the carbamate dosing did not bring about the desired outcome. Glutaraldehyde has been used successfully at the Kawerau power station when its cooling water system has also experienced pH depression.

Sodium hydroxide dosing recommenced after 4 days, by which time the cooling water pH had dropped to 2.6. The pH of the cooling water was raised to above 7.0 with regular addition of sodium hydroxide and the dosing of carbamate based biocide resumed. It became apparent that the carbamate biocide was having an effect in the cooling water, but not to the extent required. Following several carbamate additions, including at dosage rates up to 100mg/L as carbamate in the cooling water (or 10 times higher than a standard treatment at NAP) the decrease in cooling water pH would be slowed, however after several hours the cooling pH would begin to drop rapidly again without the addition of sodium hydroxide as illustrated in Figure 6. It had become apparent that a carbamate based biocide was not the appropriate biocide for this particular situation. A definitive determination has not been made as to why the carbamate biocide was ineffective. The presence of a carbamate resistant bacteria population within the cooling water system has been considered as a likely factor due to the apparent ineffectiveness of the carbamate prior to the initial pH depression. Carbamate biocides are known to have reduced effectiveness at lower pH levels (<7)[ii]. As such once the cooling water pH began to drop the carbamate biocide was going to become less effective. However since the carbamate biocide was likewise ineffective when the cooling water pH was raised with the addition of sodium hydroxide, it also suggests that carbamate resistant bacteria may have been present. As the pH depression commenced shortly after a carbamate biocide addition, the lack of effectiveness of the carbamate is not explained solely by the depressed pH of the cooling water.

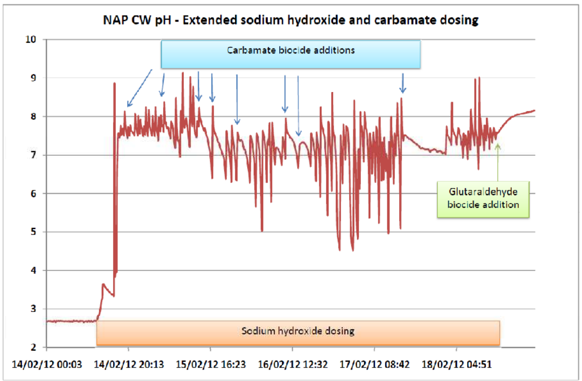

Figure 6: NAP sodium hydroxide and carbamate dosing pH changes

The cooling water system was brought back under control with the addition of a glutaraldehyde based biocide to the cooling water. The addition of glutaraldehyde to achieve 50mg/L (as glutaraldehyde) in the cooling water resulted in the pH of the cooling water system beginning to increase within an hour of the addition, without the need for sodium hydroxide as illustrated in Figure 8. Over the next several days the pH of the cooling water slowly increased back to its normal range without the need for sodium hydroxide addition. Further confirmation that the cooling water pH excursion was due to microbiological activity was received when the biological enumeration testing results for the period were completed, showing elevated levels of *Thiobacillus* bacteria (Figure 7) that are known to oxidise sulphur compounds. The overall pH variation for the NAP cooling water throughout the entire incident is shown in Figure 9.

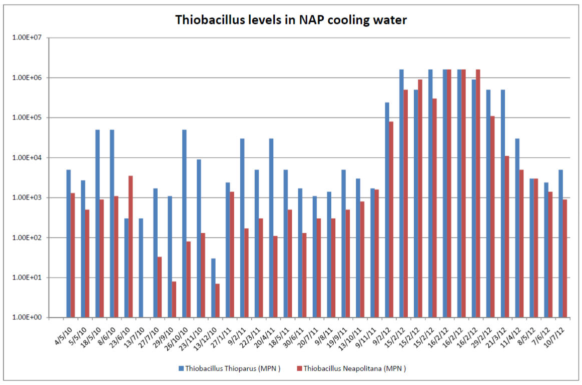

Figure 7: NAP Thiobacillus counts

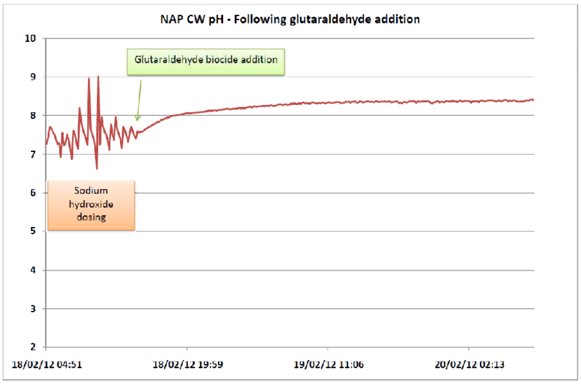

Figure 8: NAP Glutaraldehyde dose pH affects

This incident highlighted the speed with which cooling water conditions can change. A review of the incident was undertaken to identify how to reduce the risk of this type of incident from re-occurring and how to respond to these incidents when they do occur. Key recommendations from the review include:

- An alternating biocide program utilising at least two different biocides is required when operating a non-oxidising biocide program;
- Adequate supplies of the biocides used should be stored on site or where they are readily accessible if needed;
- Clear lines of communication and authority when addressing departures from standard operating conditions are required;
- Automation of early warning systems is preferred when possible (online monitoring and alarming).

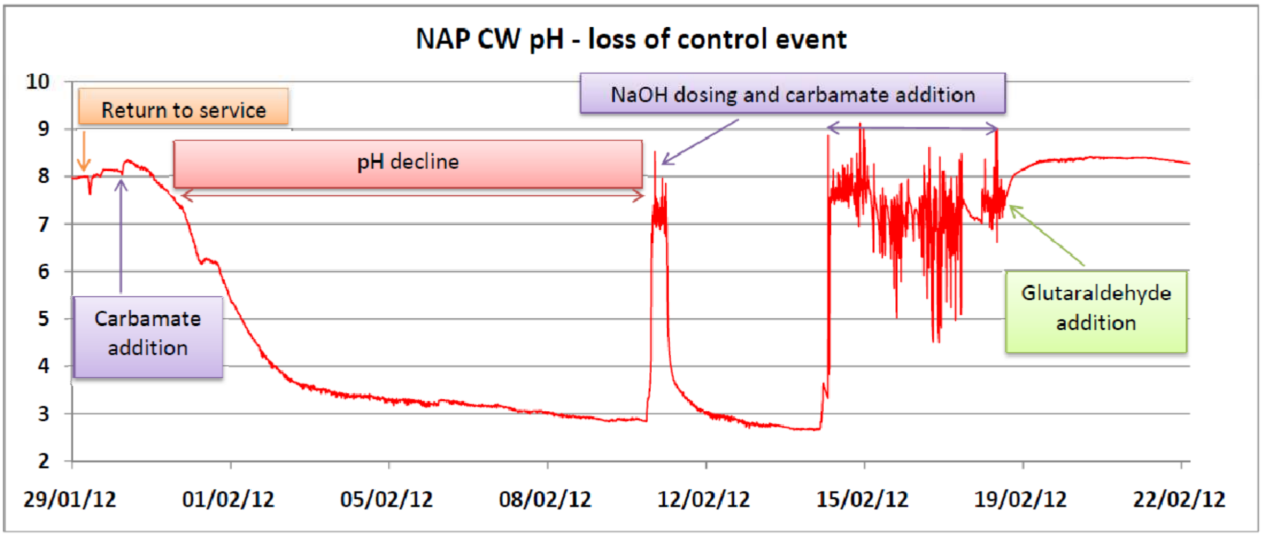

Figure 9: NAP CW system pH during the loss of control incident

5. CONCLUSION

MRP's experience with its geothermal cooling water systems has indicated that while the cooling water has low levels of suspended and dissolved solids and low levels of nutrients; careful attention is still required to maintain biological control of these systems otherwise plant operational problems including plant trips will occur.

As a result of the incidents discussed in the case studies improved control system alarms have been implemented for cooling water pH, with plant operators now receiving an automatic alarm message if the cooling pH goes outside of the normal operating range, allowing corrective action to be taken in a timely manner. Alternating non-oxidising biocide programs are in place for both the NAP and Kawerau power plants with clear procedures and management plans to ensure that deviations from these programs do not occur without detailed risk analysis and assessments being undertaken.

MRP's geothermal cooling water systems have not tested positive for *Legionella pneumophila* contamination since they were commissioned. This is likely due to the make-up water (condensed steam) being free from *Legionella pneumophila* bacteria, while atmospheric dust does collect within the cooling water it appears to be predominantly pollen from nearby forested areas.

Carbamate based biocides have been effective in maintaining biological control in MRP's cooling water systems under regular operating conditions. The pH depression incident at NAP power plant has indicated that carbamate based biocides are not suitable for all conditions that may be encountered in a geothermal cooling water system however and a secondary biocide is required in instances of a departure from normal conditions. Glutaraldehyde based biocides have been shown to be effective in maintaining biological control in MRP's geothermal cooling water systems to date. Conditions in the cooling water systems that would render glutaraldehyde ineffective as a biocide as part of a dual biocide system are yet to be experienced at MRPs power plants. Changes in the composition of the geothermal fluid in the future that would adversely affect the efficacy of the use of glutaraldehyde as a biocide are possible and are currently being monitored by MRP.

A detailed cooling water performance management program should be implemented for any cooling water system to enable the early detection of chemical and biological changes in the cooling water and to provide a frame work for assessing the risks associated with any operational deviations from the prescribed dosing program.

The build up of sulphur deposits throughout low flow areas of the cooling water system is of concern and is suspected of harbouring sulphur metabolising bacteria. The use of a dispersant to reduce sulphur deposits is being considered, however the risks of re-injecting precipitated sulphur into the geothermal reservoir need to assessed before the use of a dispersant undertaken. The pH adjustment of the cooling water system to reduce the build up of sulphur is also under consideration, although the cost effectiveness of such an approach is unlikely to result in a favourable cost-benefit analysis.

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