# Chemical Dosing for Te Mihi Geothermal Station Cooling Towers: Update

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## ABSTRACT

The chemical dosing for Te Mihi geothermal power station cooling tower water had previously been investigated and optimised. This involved continuous dosing of 30% caustic soda for pH control of the cooling water, with periodic shock doses of a quaternary ammonium bio-dispersant/biocide and glutaraldehyde biocide for microbiological control. While initially successful, the caustic consumption and expenditure steadily increased over several years.

This work presents an updated review of the chemical dosing history at Te Mihi power station and performance-based improvement to the caustic chemical dosing system. The results of successful offline biocide dose trails on each cooling tower during a scheduled maintenance outage are also detailed.

## 1. INTRODUCTION

### 1.1 Plant configuration

Te Mihi Uenukukopako (eew-new-koo-kor-par-kor) "Te Mihi" Power Station is a 2 × 83 MWe double flash plant fed by separated steam from the Wairakei geothermal field. The intermediate pressure (IP) turbines operate at approximately 4.6 bar g and the low pressure (LP) turbines at 0.35 bar g. Each unit has a direct-contact condenser and a counter-flow, forced-draught, fill-packed cooling tower, with the capacity of the main cooling water system approximately 4,400 $m^3$. Cooling water is drawn from the cooling tower basin through a single mesh screen by vacuum and then sprayed into the steam exiting the turbine in a direct-contact co/crossflow condenser (Figure 1).

The holding time index (half-life) of the open cooling water system is approximately 20 hours.

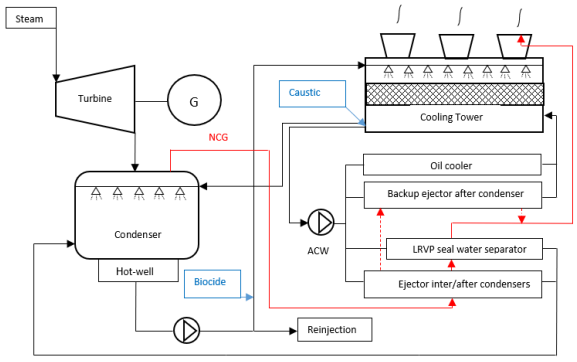


**Figure 1: Schematic of Te Mihi Cooling Water System**

## 2. CHEMICAL DOSING HISTORY

### 2.1 Initial dosing optimisation

Te Mihi Power Station started experiencing cooling water pH control issues within 12 months of operation from May 2015. The original alternating dual biocide programme of dosing a quaternary ammonium bio-dispersant/biocide (quat) for one week and then glutaraldehyde biocide (glut) the following week was no longer able to maintain pH control of the cooling water (i.e., pH ≥ 6.0 in the cooling tower basin). More frequent doses of glut failed to re-establish control. Later successful recovery of pH control through chemical dosing optimisation from November 2016 to 2018 determined that (Young, 2018):

- Biocide dosing alone was not feasible to control pH of the cooling water after the first 11 months of operation once some biofilm inevitably formed on newly exposed surfaces and Sulphur Oxidising Bacteria (SOB) became established, despite their relatively low numbers.
- Too frequent dosing of glutaraldehyde biocide probably resulted in some microbial resistance and biocidal ineffectiveness. Alternative biocides had to be used to regain microbiological control.
- Continuous low concentration caustic (caustic soda/sodium hydroxide) dosing was necessary to control the pH of the primary cooling water at Te Mihi. This was due to the low ammonia levels in the steam available to provide pH buffering to the condensate to counter the sulphuric acid produced by SOB. It was not feasible to control the pH by using biocides alone.

It was also found to be more effective to dose chemicals in particular combinations or sequences than to dose them in isolation. Quat was dosed first at 5 mg/L product (2.5 mg/L quaternary ammonium chlorides) over three days as a bio-dispersant and for its biocidal properties. After the three-day period, this was often immediately followed by a shock-dose of glut at 50 mg/L product concentration (25 mg/L glutaraldehyde). Caustic dosing was briefly increased to raise the pH to 7.5 during and after the glut dose for a few hours to shorten the "kill time" compared to the average target pH control range of 6 to 7 (note these pH values correspond to the basin pH, not the return line where the glut is dosed with a typical pH around 5). There was no observed benefit from going to a higher pH which required significantly more caustic. Sometimes just dosing quat on its own proved sufficient, but the dose concentration was lower than ideal for maximum biocidal effectiveness due to its tendency to foam. There was concern that at higher quat concentrations, excessive foaming in the condenser may compromise NCG extraction and trip the station. Glut


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seemed to work better with a bio-dispersant such as quat, also dosed in the cooling water (Young, 2018).

Based on this optimisation work, an annual chemical budget of 1 IBC of quat (907 kg) and 2 IBCs of glut (2,200 kg) and 100 IBCs of 30% (by mass) caustic (132,500 kg) was set. This was enough for approximately 9 to 10 standard doses of quat, and ten standard doses of glut annually divided between the two cooling towers.

### 2.2 Summary of chemical dosing expenditure over the last seven years

The cost of chemical dosing for the two cooling towers had been steadily increasing over the previous four to five years. The previous optimisation work resulted in reasonable pH control of the cooling water and provided significant chemical cost savings from November onwards during Financial Year 2017 (FY 17), compared to actual chemical expenditure during FY 16 (Figure 2). This lowered the chemical expenditure back to the original budgeted rate, despite having to continuously dose an additional chemical (caustic) that was not initially budgeted. However, for each subsequent financial year from FY 19, the annual expenditure was approximately 20% higher than the previous year. The first three months of FY 21 to September were tracking towards an even more significant increase (Figure 2). This increase in chemical spending was due to the increasing quantities of caustic required to be dosed to stabilise the cooling water pH (Figure 3).

The Financial Year for Contact Energy is July to June, and the data uses the actual value of chemicals delivered to the site each month as a percentage of the original FY 16 (2016) chemical budget - set before problems with the chemical dosing programme were identified and corrected, for comparison.

The following observations were noted (Figures 2 and 3):

FY15; for the first 11 months from commissioning, the expenditure would have followed the dotted FY 16 budget line – (corresponds to the period (1) in Figures 1 and 2 in Young, 2018). For the last two months of FY 15 (May and June), the chemical expenditure would have exceeded the budget once pH control issues began – (corresponds to the period (2) in Figures 1 and 2 in Young, 2018). No caustic was dosed.

FY 16; expenditure was almost twice the budgeted value due to unsuccessfully trying to control the cooling water pH by more frequent and/or more concentrated doses of glut (mainly) plus sulphur dispersant (Nalco 3DT120). There were also some initial trials with slug dosing caustic in July and August. (This falls especially within periods (3) and (4) in Figures 1 and 2 in Young, 2018).

FY 17; expenditure followed the same trajectory as FY 16 until November 2016, when a collaborative effort was made to understand the problem and take a holistic approach to establish microbiological control (Young, 2018). In September, chemical dosing optimisation trials began and from November commenced continuous caustic dosing for primary pH control. After that, the cumulative monthly chemical spending approximately tracked the original FY16 budget. (FY 17 falls within periods (5) and (6) in Figures 1 and 2 in Young, 2018).

FY 18; caustic consumption was low during cooler months until October, biocide tanks did not require refilling before November - hence why total chemical spend was low initially.

FY 19; increase in caustic consumption initially anecdotally attributed to a hot summer that year but was significantly higher in the preceding months also (Figure 3). Only half the regular quantity of glut was delivered in FY 19, but this cost was more than offset by the higher caustic usage.

FY 20; caustic usage significantly increased from October and remained at a similarly high rate for almost the remainder of FY despite cooler seasonal temperatures (Figure 3). Two of the annual three IBCs of biocide were delivered in December and January, resulting in an increase in overall chemical expenditure for these months (Figure 2).

FY 21; caustic consumption remained significantly higher than in previous years and only reduced from October when Unit 2 Station was shut down for approximately one month, then Unit 1 Station the following month for scheduled maintenance (the previous major outage was in 2016). An offline biocide dose was performed on each cooling tower during these periods. The total chemical dosing budget for FY21 was increased to reflect the increased consumption of caustic, with the intent to double the amount of quat being dosed.

FY 22; caustic consumption was acceptable up to October but rapidly increased at a greater rate than previously observed for the remainder of FY 22 (Figure 3). The sharp rise in costs in June was due to a second IBC of quat being purchased (Figure 2).

The continual annual increase in chemical costs due to significantly higher caustic consumption from FY 19 to the present meant that further investigation and optimisation were required.

### 2.3 Cooling water microbial control

The routine grab sampling for monitoring microbial control consisted of a monthly sampling of the basin water for Legionella and Heterotrophic bacteria. No Legionella had ever been detected in the cooling water.

The heterotopic bacteria plate count results from laboratory analysis have mostly been excellent from both units post the 2016 major outage with numbers most commonly <1,000 CFU/mL, none >100,000 CFU/mL and with only a few results above the customised performance limit for these towers of 10,000 CFU/mL. The continuation of low heterotopic bacteria levels, particularly from June 2018 onwards, indicates the effectiveness of the biocide dosing programme for heterotrophic and Legionella bacteria.

The SOB activity was primarily monitored from the continuous recording of the basin water conductivity. The conductivity of the basin water had been used as an effective real-time indication of the activity of SOB activity as an inferred sulphate ($SO_4^{-2}$) concentration at both Nga Awa Purua (Clark et al., 2017) and Te Mihi (Young, 2018). Since there is very little sulphate in the steam (<0.5 mg/L measured in Poihipi hot-well condensate (Young et al., 2020) fresh steam condensate at Te Mihi would be expected to be similar). Any sulphate formed is predominately due to the activity of the SOB in oxidising sulphide to sulphuric acid ($H_2SO_4$). Sulphide will not be readily oxidised to sulphate


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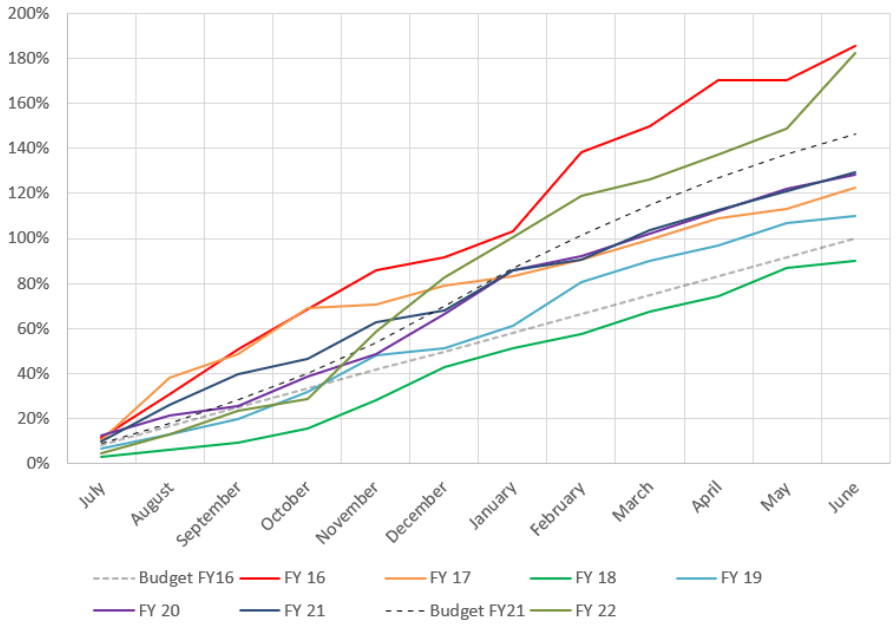


**Figure 2: Cumulative chemical expenditure compared to FY 16 budget for Te Mihi cooling towers**

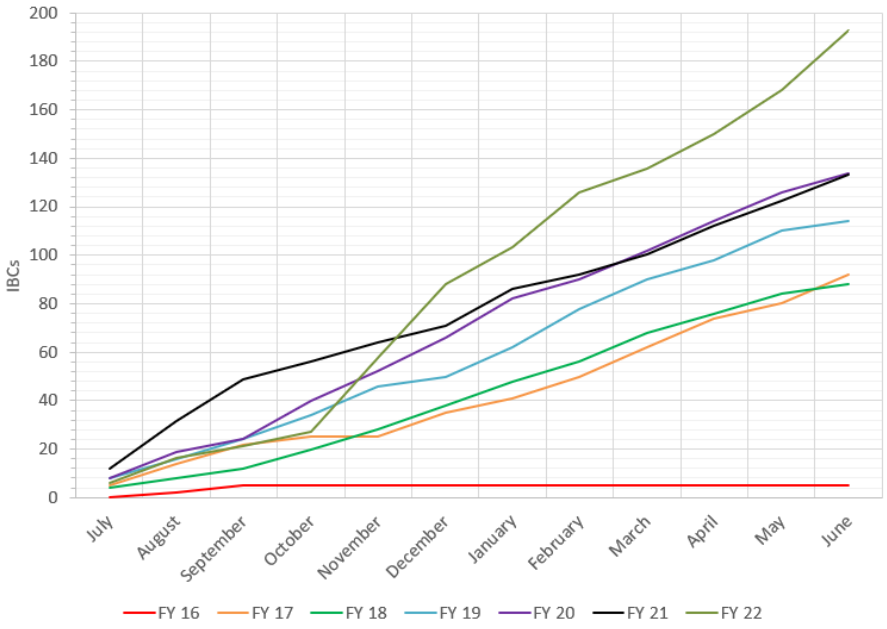


**Figure 3: Cumulative equivalent number of 30% caustic delivered for Te Mihi cooling towers.**


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from atmospheric oxygen alone in the absence of thiobacteria (e.g., SOB) to facilitate this (Webster, 1989). Sulphuric acid almost completely ionises to $H^+$ and $SO_4^{2-}$ ions which readily pass electrical current and hence are detectable through conductivity measurement. The conductivity will also be influenced by the condensate chemistry and any chemicals dosed.

The condensate chemistry and whether a direct-contact condenser or surface condenser is installed will largely determine the normal background conductivity range. At Te Mihi, aside from occasional shock doses with glut, it was observed that regular caustic dosing only varied the conductivity by around 10 µS/cm and quat biocide dosing (at 5 mg/L product) did not have a significant influence. In contrast, SOB (inferred from the sulphate concentration) had a more significant impact on conductivity. The correlation of conductivity with sulphate measured by this method has quite a bit of scattering. There can potentially be a factor of two difference in sulphate readings for the same low conductivity values that are typically seen at Te Mihi and a linear regression correlation of 73% (Figure 4). For comparison at the nearby Nga Awa Purua power plant, the linear regression correlation between conductivity and sulphate was 96% (Clark et al., 2017), but the conductivity and sulphate measurements were over a far greater range: 170 to 670 µS/cm and 10 to 230 mg/L, respectively. Sulphate analysis should be restricted to occasional troubleshooting in future, with conductivity the primary monitor of SOB activity and caustic consumption a secondary indicator.

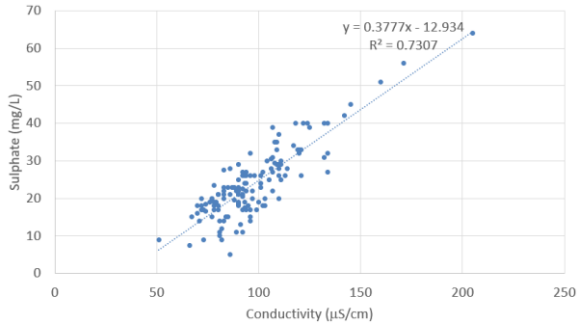


**Figure 4: Correlation of sulphate vs. conductivity for Te Mihi Unit 1 cooling tower basin water.**

At Te Mihi, a high conductivity alarm limit of 120 µS/cm was previously set to indicate that SOB activity was becoming too high, and biocide dosing should be considered within a few days (Young, 2018). This conductivity limit only corresponded to a 30% caustic dosing requirement of 144 L/day. However, from FY20 onwards the caustic consumption significantly increased as the conductivity increased above the alarm limit (Figures 5 and 6).

## 3. IMPROVEMENTS AND FURTHER TRIALS

### 3.1 Caustic dosing

The continuous caustic dosing employed a temporary setup for each cooling tower comprising of a simple dosing pump feed from two IBCs (2 x 1000 L) containing 30% caustic soda. The pump dose rate had to be manually adjusted every few days to keep within a practical, achievable range of pH 6 to 7. There was also no remote tank level measurement or caustic dose rate information available, which meant frequent manual checking of the caustic remaining, and a lot of chemical handling to exchange IBCs.

To address some of these shortcomings, temporary modifications were performed to the existing dosing system until funding could be secured for a permanent caustic storage tank and dosing system. Feedback pH control for the caustic dosing pumps was added in August 2019 using the existing online pH probe in the cooling tower basins and the local chemical dosing controller/data logger/modem equipment. This mainly involved running signal cables to the dosing equipment. After some controller tuning, the cooling tower basins' pH remained stable, generally within +/- 0.1 pH units of the pH set-point. The initial control set-point was pH 6.3, which was later reduced to pH 6.0 to minimise caustic use. An ultrasonic level indicator was also added to each of the two in-service IBCs for each cooling tower, with hourly readings recorded and remotely accessible by the chemical supplier from September 2019. These improvements significantly reduced the requirement for manual monitoring and adjustment of the caustic dosing by the plant operations staff.

With the basin pH under stable control, the daily caustic consumption was calculated from the hourly IBC level measurements. To estimate the daily caustic usage before dosing was on feedback control, manual records of the dosing pump rate-setting were used. The caustic consumption, conductivity, basin pH and biocide doses from FY 18 are plotted in Figures 5 and 6. This shows the caustic usage increasing over time, particularly during FY 20, and higher again in FY 21 until the major maintenance outage. The caustic consumption dropped after the outage due to the draining and drying of the cooling tower surfaces and from more aggressive chemical dosing while the station was offline (Section 3.4). Caustic consumption also drops for a week or two after a successful biocide dose when the station is running. Warmer ambient air temperatures also have an influence with typically higher caustic use and the requirement to dose more biocide during summer than in winter due to increased microbiological activity at warmer temperatures. This seemed particularly the case when ambient air temperatures were above 25 °C. The basin and blowdown maximum daily temperatures tended to closely follow the trend of the maximum daily ambient temperature but are of lower amplitude. Pollen is realised around August to December but does not seem to have a significant impact on the cooling water microbiological control at Te Mihi (or Poihipi from personal experience).

With the pH now stable, changes in caustic consumption will be directly related to changes to acidity either from SOB activity (predominately on the cooling tower fill) and, specifically for Te Mihi, from $H_2S_{(aq)}$ directly discharging into the cooling tower basin from the operation of the 130% backup steam ejector when the LRVP is off. Operating the backup ejector uses an additional 4.5 kg/s of IP steam. After condensing, it is directly discharged into the cooling tower basin (Figure 1) instead of having its $H_2S$ practically all removed in the condenser or cooling tower before entering the basin. Hence the increase in caustic consumption (approximately double) with the LRVP off and decrease once it was operating again (Figures 5 and 6).

Due to the increased caustic demand over time, 50% (by mass) caustic soda in IBCs instead of 30% was trialled in Unit 1 from September 2020. Aside from being slightly cheaper at the higher concentration, it effectively had 1.9 times the neutralising capacity for a given volume (moles per litre), which nearly halved the chemical IBC handling

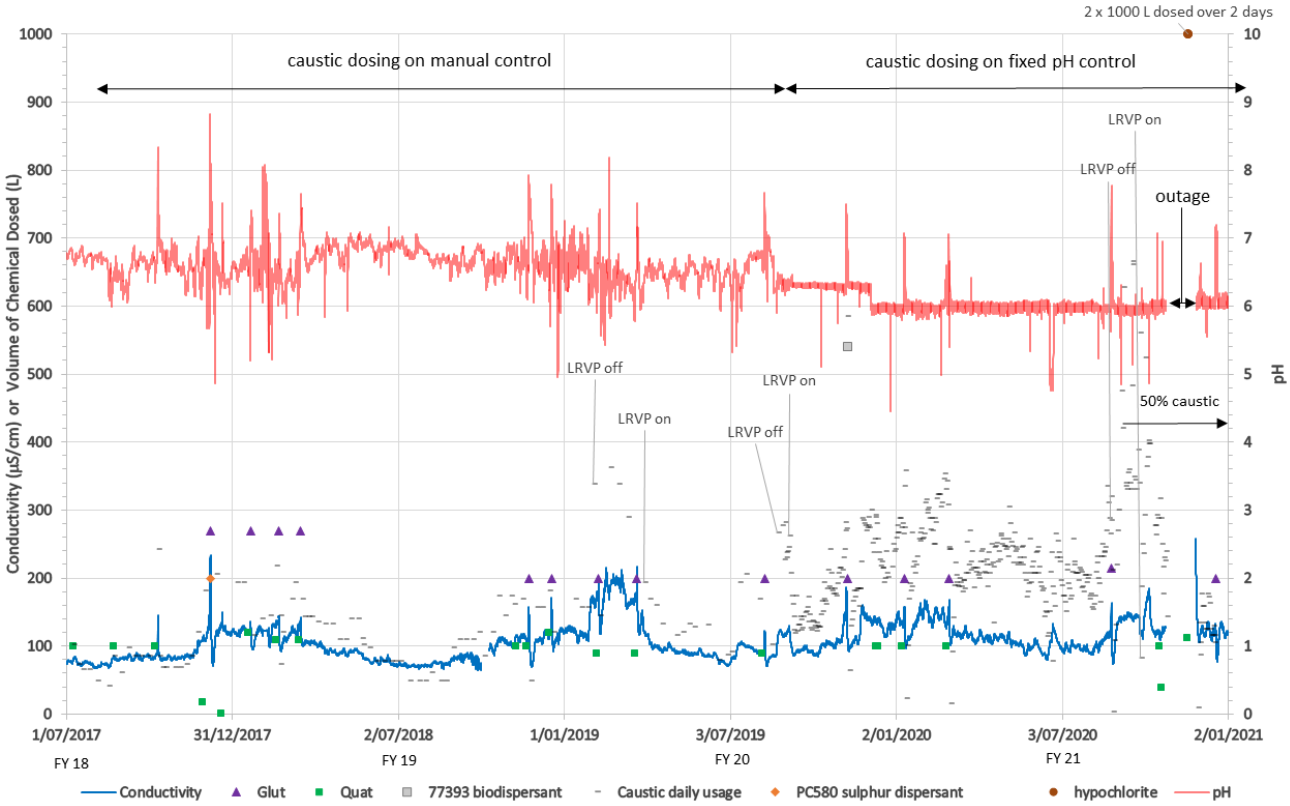


**Figure 5: Unit 1 cooling tower dosing history from 2107 to 2020**

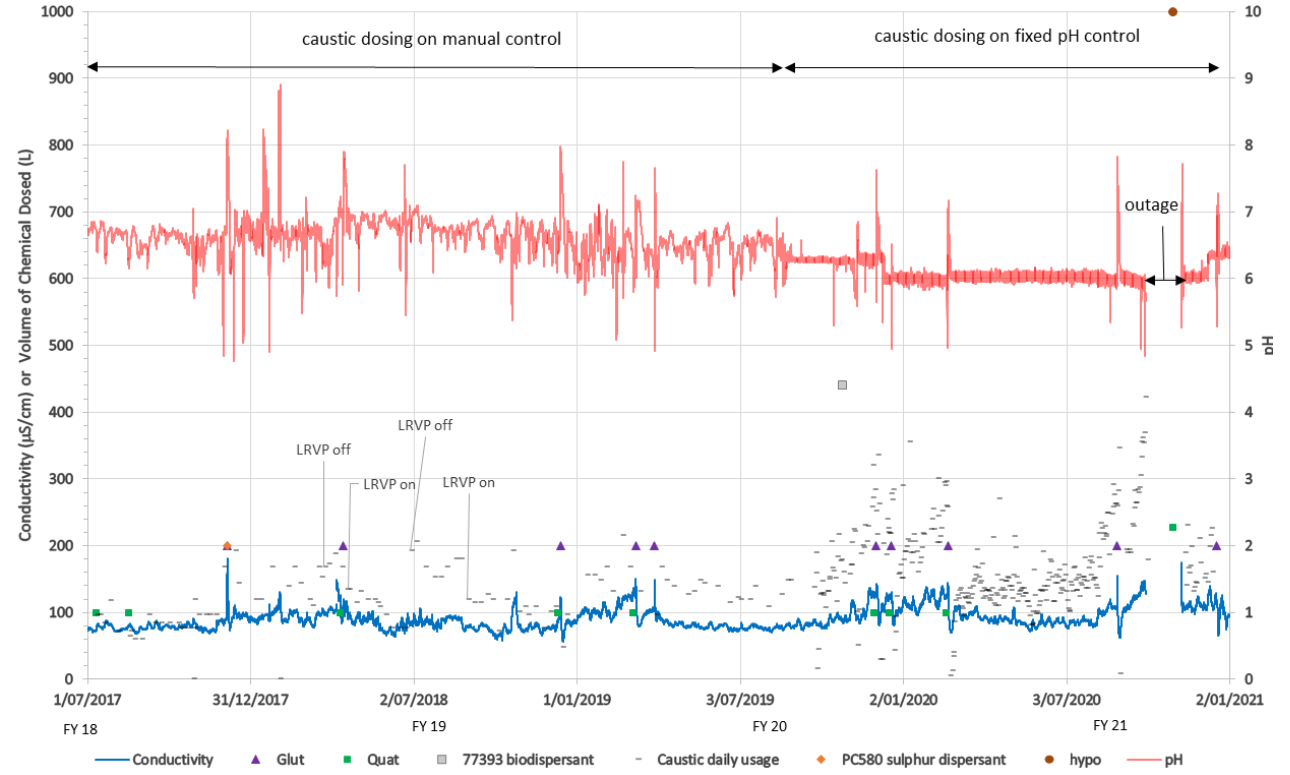


**Figure 6: Unit 2 cooling tower dosing history from 2017 to 2020.**


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requirements. The in-service IBCs on Unit 1 were wrapped with a heating blanket to prevent the 50% caustic soda from freezing (freezing point around eight degrees Celsius), and the plastic dosing lines were later insulated to avoid crystallisation. This worked successfully throughout the calendar year. Trace heating was not required over summer (December to March) when caustic use is highest, enabling Unit 2 also to use 50% caustic during these months. The 50% caustic consumption has been converted to the equivalent amount of 30% caustic volume (Figures 3 to 5).

### 3.2 Bio-dispersant dosing trials

A successful biocide dose should suppress the SOB activity for a week or two from experience at Te Mihi. Unit 1 shock-dose on 8 November 2019 was very successful with two weeks of effectiveness (Figure 5). This shock dose was the first in 78 days and was unique in that a polyglycoside containing bio-dispersant (Nalco 77393) was trialled at 20 mg/L product concentration for four days before glut instead of the normal quat at 5 mg/L product concentration over three days (although it takes the first day to get to the target quat product concentration at the fixed dosing rate). The 77393 has no biocidal properties (unlike quat) but was used to determine the effect of the cleaning action on surfaces alone before assisting the glut biocide. 77393 foams less than the quat, hence could be dosed at a higher concentration without risking tripping the station from loss of condenser vacuum if foaming overwhelmed the NCG extraction system. It is also significantly less hazardous to people and the environment, but this dosage was about three times the cost of an average quat dose.

The 77393 bio-dispersant was also trialled on its own without a biocide on Unit 2 on 25 October 2019 for five days (Figure 6). It was recommended by the chemical supplier to dose the bio-dispersant for an extended period to clean the surfaces of biofilm before summer to subsequently lower biocide and caustic demand. However, this did not seem to achieve any measurable benefit when dosed on its own without a biocide also present – with no significant change to the conductivity and caustic consumption. Hence, quat is recommended as the preferred bio-dispersant (and primary biocide).

### 3.3 Visual inspection of cooling tower

During the 2020 outage for Unit 2, it was observed that there were extensive algae present beneath the fill material all the way to the middle of the tower structure. This was unexpected as little indirect and no direct sunlight penetrate there with the tower in operation. (By comparaison, Poihipi cooling tower only had algae growing on surfaces exposed to direct sunlight but was more enclosed along the sides, being a crossflow design (Young et al., 2020)). It was similar on the side of the tower that gets the morning sun as the other side gets the afternoon sun. There were also “strings” of green biofilm/algae hanging from the bottom of the fill in some locations. The tower had more biofouling than previously thought, which may help explain why the caustic consumption was increasing in recent years as this would allow more SOB to colonise within the biofilm, especially if the fouling extended further up the fill material. Unit 1 cooling tower was similar in appearance (Figure 7). There was also a large amount of sludge in the basin of Unit 2. Unit 2 tower basin took longer to clean than planned, and there was no resource allocated to mechanically clean off all the algae from the cooling tower. Therefore an impromptu offline chemical clean/disinfection trial was carried out instead.



**Figure 7: Unit 1 cooling tower cell A algae and biofilm below fill packing three weeks into outage just before offline chemical clean.**

### 3.4 Offline dosing of the cooling tower during an outage

The offline disinfection plan for Unit 2 was to circulate 20 mg/L of quat biocide through each of the eight cooling tower cells (A to H) individually for one hour, along with 1-5 mg/L Free Residual Chlorine (FRC) sodium hypochlorite. The basin was partially filled with Poihipi condensate and cooling water from the other Te Mihi cooling tower. This provided enough water head to run an auxiliary cooling water pump to circulate the treated water. The (blue) isolation valve on each riser was manipulated to direct the flow to the required cell (same configuration as the Unit 1 tower in Figure 8). There were significant delays in getting the quat pump to run (no local override switch, so it had to be overridden in the control logic program) and the chlorine demand was high, and one IBC (1,000 L) of 15 % (by mass) sodium hypochlorite on-site was insufficient. In the end, only cells B and C received a reasonable dose of chlorine, around 2.6 mg/L but only for 15 to 20 minutes. Cells A, B, C and D got a good dose of quat for at least one hour, but cells E, F, G and H only for ten minutes each.

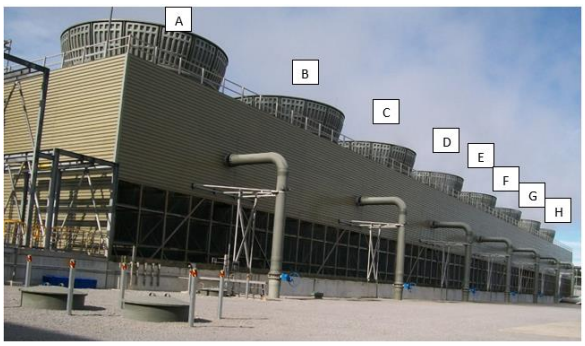


**Figure 8: Unit 1 cooling tower consisting of cells A to H.**

The learnings from Unit 2 were used to improve the dosing in Unit 1. Quat was dosed at 5 mg/L product concentration for five days with the station running, with dosing stopped five days before its outage began. This resulted in a significant reduction in the amount of sludge in the basin that had to be mechanically removed during the plant outage. The quat helped to keep the sludge suspended, so it could be removed with the cooling water blowdown. Dosing quat before a major outage will now be performed as standard


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procedure. The algae and biofouling inside the cells were still evident (Figure 7), but the quat takes time to kill and eventually remove these deposits. The algae will first become brown as it dies, then gradually flack off the surface with weathering and water flow.

During the outage Unit 1 was dosed with 20 mg/L of quat biocide product but could circulate two cells simultaneously as the auxiliary cooling pump discharge valve was opened further than on Unit 2. This time there was 2,000 L of sodium hypochlorite on-site, which was sufficient to obtain 1 to 7 mg/L FRC for approximately one hour for each cell. Each cell also received a second period of circulation with the quat.

It was possible to dose a higher concentration of quat (20 mg/L) with the station offline than the normal operational dose (5 mg/L) as there were no concerns of foaming in the condenser under vacuum. The cooling system was not drained but simply topped up before recommissioning, so there may have been up to 10 mg/L quat in the system at this time without problems. It was possible to dose sodium hypochlorite as there was no detectable $H_2S$ (as total sulphide) in the cooling water with the steam turbine not in service, with any residual $H_2S$ in the cooling water being stripped in the cooling tower as it circulated offline.

## 4. DISCUSSION

Given the significant biofouling evident on the cooling towers during the outage, it is likely that this gradual accumulation over the years has provided more habitat for SOB and required increasing amounts of caustic to counter this to maintain the pH of the cooling water. The biocide dosing frequency should be increased as there have been periods of several months with no biocide dosing (Figures 5 to 6). The primary biocide to dose should be quat as it can be effective against algae. Quat dosing has now increased to nine times a year for each cooling tower since the 2020 outage - although still via the temporary dosing system.

The automated quat dosing system was prone to leaks and has often been unavailable over the last few years. This has compounded the tendency not to dose as often as needed as a temporary manual dosing system must be moved to the required cooling tower and connected each time you want to dose. The problem is due to excessive heating of the dosing cabinet, which has glass doors and receives direct afternoon sunlight, particularly over summer. This heat results in failure of the plastic mac union nut fitting on the dosing pipework allowing chemicals to leak. This external nut is not in contact with the chemical, so it is likely failing due to mechanical stress from the differential expansion of components inside the dosing cabinet. An identical dosing system for the glut has been problem-free, but it does not face the afternoon sun.

There was a considerable reduction in caustic consumption immediately after the 2020 outage on both units, particularly on Unit 1, which had a better offline biocide dose (Figures 5 and 6). We would expect some initial reduction after an extended outage as the biofilm and algae dries out and partially flakes off when water flow resumes. Still, the biocide dosing has resulted in the caustic consumption rate being significantly lower post-outage (November/December 2020) than immediately prior to the outage. This lower caustic consumption rate continued over the summer period (when SOB activity and caustic demand typically increases) and for the remainder of FY 21 and lasted until October 2021 of FY 22 (Figure 3).

However, there has been a very steep increase in the caustic consumption rate since November 2021 (Figure 3). Trials should be performed to determine if a higher concentration dose of quat up to 20 mg/L can be achieved without opertional issues from increased foaming. This concentration of quat has provided good algae control at Poihipi (Young, unpublished data). A repeat of the offline disinfection method should be performed at the next opportunity. A major outage is only scheduled every four years (next 2024) but there are shorter one-to-two day shutdowns annually where a variation of the offline cleaning method may be possible.

## 5. CONCLUSION

The following conclusions were made:

- The increase in caustic consumption over the last several years appears to be the result of increased algae and biofouling of the cooling tower due to insufficient dosing of biocide, particularly quat.
- Adding pH feedback control to the caustic dosing has significantly reduced the need for monitoring and intervention by operations staff. The more precise control automatically accommodates changing demand from LRVP being in service or not and ambient/seasonal conditions.
- Adding remote tank level readings allows caustic consumption rates to be accurately monitored to help monitor SOB activity and management of chemical inventory.
- Trialling 50% caustic soda instead of 30% reduced chemical handling requirements by almost half and proved to be viable over summer without trace heating. It has also proved effective over winter and other seasons when used with trace heating on Unit 1.
- Dosing quat a week prior to a long outage significantly reduces the quantity of sludge that would otherwise have to be manually/mechanically removed.
- When the steam turbine is not in operation, higher dose concentrations of quat (20 mg/L) and an oxidising biocide (sodium hypochlorite) were effective in killing SOB in biofilm resulting in reduced caustic consumption for months afterwards. Oxidising biocides can be used during these outage periods as there will be no detectable sulphide in the cooling water system.

## 6. RECOMMENDATIONS

- Modify quat dosing system cabinet enclosure so it is shaded from direct sunlight to prevent repeated failure of the plastic mac union fittings so it can work reliably without leaking.
- Dose quat more often, at least monthly. Investigate dosing quat at a higher product concentration than the 5 mg/L (preferably to 20 mg/L) and reach the target concentration more quickly; providing


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excessive foaming in the condenser is not an issue. As quat is the primary biocide for algae, these steps should improve its effectiveness.

- Investigate performing the offline disinfection method at the next shutdown opportunity.
- The cooling tower cells should be routinely visually inspected for algae: the water flow through the cell can be briefly stopped for a few minutes via the manual riser valve to permit this without disrupting the operation of the station. Use visual observation of the cleanliness of surfaces and the colour of the algae (brown is good, green is bad) under the fill and cooling tower structure when briefly stopping water flow to individual cells, in addition to monitoring conductivity and caustic consumption trends.
- Install a permanent caustic storage tank and dosing system to further reduce chemical handling and chemical costs.

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