INVESTIGATION OF COOLING WATER CHEMICAL DOSING: THE OHAAKI GEOTHERMAL POWER STATION COOLING TOWER

Morris Young[1, 2*] and Sadiq J. Zarrouk[2]

[1]Contact Energy Ltd, Wairakei Power Station, Taupo, New Zealand

[2] Department of Engineering Science, University of Auckland, Private Bag 90210, Auckland, New Zealand

Morris.Young@contactenergy.co.nz

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ABSTRACT

The Ohaaki power station is the only geothermal power station in New Zealand with a natural draft cooling tower. The concrete construction of the cooling tower influenced the locations vulnerable to attack from condensate/cooling water pH and from microorganism growth, and this altered the way chemical biocide was applied compared to forced draft cooling towers found in other flash steam power stations. Biocide was routinely sprayed directly onto the internal shell walls of the tower while the basin cooling water was only dosed seasonally.

This work presents a review of the chemical dosing history at the Ohaaki cooling tower, investigation into the effectiveness of the dosing regime and improvements to the understanding and monitoring of the degradation and control mechanisms.

1. INTRODUCTION

1.1 Ohaaki Power Station

Ohaaki power station (Figure 1) was commissioned in 1989 and operated at its full design capacity of 114 MWe utilising two high-pressure (HP) and two intermediate-pressure (IP) steam turbines until 1993. These turbines were referred to as “turbo generators (TG)”. Between 1993 and 1999, output steadily reduced due to declining steam production from the Ohaaki-Broadlands geothermal system, and HP turbine use ceased. Since 1999 output has stabilised around 40 to 45 MWe by just running one of the IP condensing turbines.

The stations’ most distinctive feature is its natural-draft cooling tower at 106 m high, 74.5 m at its base, 40.6 m at its throat and 53.2 m at the top (Figure 2). The shell thickness is 160 mm except at the bottom, where it is 660 mm and the top, where it is 236 mm (Bruce et al., 2020). Although at the time of construction, there was no clear economic advantage between natural-draft and mechanical draft cooling towers, the former was chosen to reduce the contribution to the fog that occurred in the Waikato River valley at Broadlands. The natural draft design also aided the dispersion of non-condensable gases (NCG). For the removal of NCG from the condenser, rotary gas exhausters were chosen over steam ejectors because of the economics of the relatively high percentages of gas to be removed (Brown et al., 1989).

The primary cooling water system volume is thought to be 7,000 m^3, but there were no written records found to confirm this. The cooling water circulation flow rate, while originally around 5,700 kg/s at full station capacity (Figure 1), was approximately 3,000 kg/s when running on just one IP condensing turbine (Table 1).

The wetted materials of the cooling water circuit were manufactured from 316 stainless steel, fibre reinforced plastic (FRP) and high-density polyethylene (HDPE). The condensers were clad in 3 mm 316 stainless steel plates backed by 20 mm carbon steel for structural strength. FRP was used for the barometric legs, buried culvert and cooling water pump discharge pipework and HDPE for the cooling tower film-fill, drift eliminators and the smaller auxiliary cooling water supply lines (Brown et al., 1989). Concrete was also exposed to the cooling water in the cooling tower structure and basin. The fill was replaced in 2014 due to age and sagging, but only a portion of the original packed area was repacked due to the reduced station output, with covers placed over the then empty middle section. The new fill material and water distribution piping was made from polyvinyl chloride PVC, with high density expanded polystyrene (PS) saddles, 316 stainless steel fasteners and polypropylene nozzles (PP). The fill was installed to a depth of 2 m and supported from below by FRP trestles and structural members – this was to reduce the loading on the original horizontal concrete pack support beams, which had reached the end of their service life (Bruce et al., 2020) although one level of support beams still supports the water distribution system. The timber walkway structure inside the cooling tower just above the drift-eliminators is tanalith H6 treated timber, supporting a stainless steel walkway. The mechanism of sulphuric acid attack from Sulphur Oxidising Bacteria (SOB) and the likelihood of associated sulphate attack was considered in the design of the cooling tower concrete by having the following features: using sulphate resistant Portland cement in the concrete, using pozzolan ground fineness 600 in the concrete, and using epoxy-coated steel reinforcing bar in the distribution structure and return channel (Bruce et al., 2020).

Cooling water flows from the cooling tower basin via a set of screens to either the TG1 or TG2 direct-contact condenser by suction, then from the condenser through a barometric leg to the common hot well where 2 x 50% cooling water circulation pumps transports water/condensate back at 10,764 T/h to the cooling tower where it is sprayed overfill material to maximise surface area for cooling. Some of the cooling water can bypass the cooling tower if required to prevent ice from forming on the fill material during winter and potential collapse from the extra weight (Figure 1).

Two 100% duty auxiliary cooling water pumps are used for each turbo generator and draw water from the primary cooling water circuit. Areas of stagnation likely to cause corrosion problems are avoided by providing backflow bleeds in standby coolers, pumps, etc. Auxiliary cooling is used for pump motors cooling, generator coolers, and lubrication oil coolers. There are 3 x 50% condensate reinjection pumps that draw from the hot well.

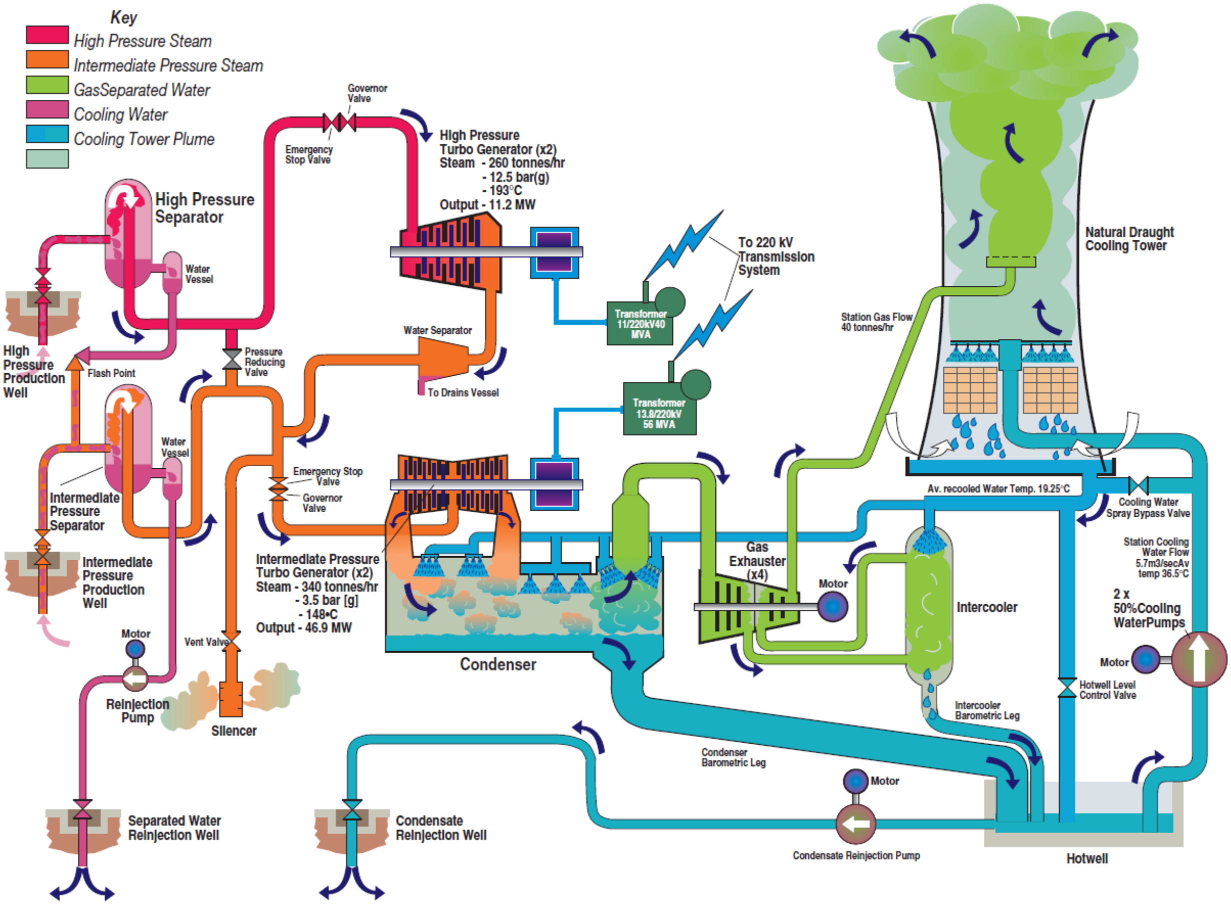

Figure 1: Schematic diagram of Ohaaki power station

Table 1: Ohaaki cooling water system operational data

Operational Data	Typical Value
Station nett power (MWe)	45
Turbine steam flow (kg/s)	80 -100
Steam pressure (bar g)	3.3 to 3.9
Condenser vacuum (mbar)	120
System Volume (m^3)	7,000
Cooling tower blowdown (kg/s)	Not known
Holding Time Index (hour)	Not known
Warm condensate/water flow into cooling tower (kg/s)	3,000
Condenser cooling water inlet temperature (°C.)	23
Condenser cooling water outlet temperature (°C.)	41

2. CHEMICAL DOSING AND MICROBIOLOGICAL CONTROL HISTORY

2.1 Overview

Chemical dosing and microbiological results in internal company records from 1997 to early 2021 were reviewed. There was one service provider supplying dosing chemicals during this period. Some earlier information was obtained from published papers and internal documents.

The performance criteria were to: maintain minimal algal growth, maintain cooling water pH >7 and maintain inner concrete surfaces of the cooling tower (above drift eliminators) at pH >5. In addition, wanted to minimise the accumulation of deposits, to keep the fill pack clean, reduce the potential of anaerobic sites developing and Sulphate Reducing Bacteria (SRB) forming (will produce H_2S and lower pH under solid deposits resulting in corrosion), and to minimise the volume of toxic sludge that was typically removed from the basin every two years.

Monitoring consisted of (weekly measurements unless otherwise noted):

1. Measuring the pH and concentration of SOB from grab (spot) samples of condensation trickling down the inner shell (wall) of the cooling tower near the access doorway approximately 2 m above the drift eliminators. This was done from 1995 onwards, although routine SOB measurements stopped in 2012.
2. Measuring the pH (from 2001), conductivity (from November 2016) and concentration of heterotrophic bacteria (from 1995 via agar plate tests, from 2003 via dip slides) from grab (spot) samples of the cooling tower basin water.
3. Scraping the slime off a stainless steel coupon exposed to the condensate, return water to the cooling tower to measure the wet slime mass.
4. Recording chemical tank levels.
5. Monthly Legionella analysis of a grab sample of cooling water (from 2004).

Concrete corrosion in the Ohaaki cooling tower was observed in 1991 with the erosion of surfaces on the inside of the cooling tower and associated concrete structures – only two years after commissioning. The corrosion was sufficient to be of immediate concern only in areas within the vapour zone of the tower, i.e., at the tidal zone of the basin wall, to the pack support beams and the roof of the return water channel that supplies the distribution pipework for the spray nozzles. An epoxy coating was applied to these areas. The corrosion was attributed to acid produced from the activity of SOB. A similar corrosion mechanism, although less severe, was also observed on the internal surface of the tower shell (Bacon et al., 1995). Applying a protective coating on the inner tower shell was not economical nor practical, so a "rain gun" was installed and commissioned in June 1996 to distribute biocide periodically on the interior tower shell as a means of algae and SOB control – this sprayed at six fixed elevations and rotated horizontally 360° up to approximately the height of the throat of the tower (Figures 2 to 3).

There is a relatively high concentration of particulate sulphur suspended in the Ohaaki cooling water giving it an opaque appearance and deposits on most surfaces in contact with the water. It has been observed that under thick deposits where biocides cannot penetrate, the SOB (and possibly Sulphur Reducing Bacteria if conditions become anaerobic) create a localised low pH environment that attacks the concrete (Bacon et al., 1995). There was a recommendation in the cooling water maintenance manual to clean the tower basin of deposits every two years.

The circulating cooling water was expected to have chemistry parameters within the range listed in Table 2: the composition of the exhaust NCGs was typically expected to be as listed in Table 3[1]. These values were probably related to the early operation of the Ohaaki power station, as most of the concentrations listed in Table 2 have since reduced. It is common for geothermal wells to become less gassy over time as the reservoir is exploited[2]. The higher ammonia concentrations in the steam at Ohaaki compared to Te Mihi power station results in significantly higher natural alkalinity of the condensate/cooling water, enabling the pH to remain stable despite experiencing approximately twice the SOB activity (Young, 2018). This is also indicated by the sulphate concentration in the Ohaaki basin water being 89 mg/L (14/10/2020), compared to 42 mg/L (28/9/20) at Te Mihi.

Table 2: Circulating cooling water

	Condensate	Re-cooled (basin) water
pH	5.8 to 7.0	7.5 to 8.5
Free CO_2 (mg/L)	30 to 100	1 to 12
$H_2S + HS^-$ (mg/L)	1 to 11	0.4 to 1.3
SO_4^{2-} (mg/L)	140 to 290	140 to 290
NH_4^+ (mg/L)	70 to 125	65 to 120
NH_3 (mg/L)	0.15 to 0.5	2.5 to 9

Table 3: NCG composition (% by mass)

CO_2	90.80
H_2S	1.30
H_2	0.01
N_2	2.42
O_2	0.49
CH_4	0.66
H_2O	4.30
Inert gases	0.02

[1] Ohaaki Cooling Tower Operation and Maintenance Manual July 2014, internal document.

2 Personal communication with Contact Energy steam field measurement chemists.

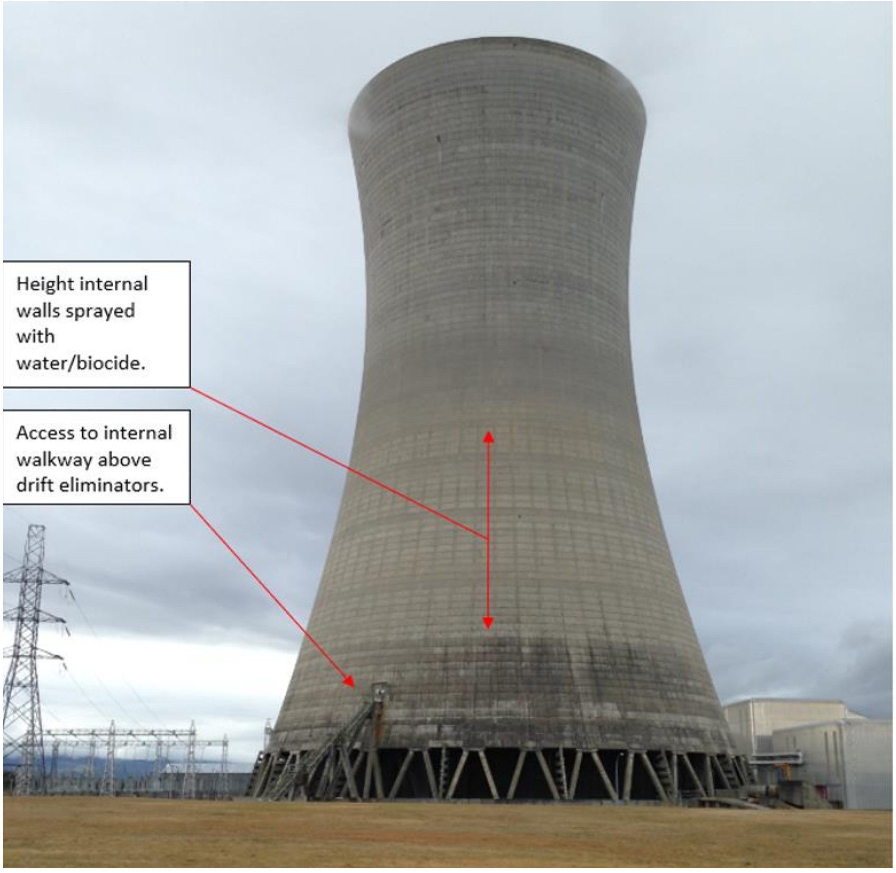

Figure 2: Ohaaki cooling tower

2.2 Biocide dosing

There are two locations treated with biocides:

1. The cooling water itself, where the basin is dosed with chemicals that are intended to treat all the fully immersed/wetted cooling water surfaces around the cooling water circuit, including the film-fill packing in the tower.
2. The interior concrete shell within the vapour space of the cooling tower between the drift eliminators and the throat of the tower (Figure 3).

The initial biocide treatment before 1994 is unclear from internal company records reviewed, although it resulted in high SOB levels and observed slime growth on surfaces around the basin. Before biocide was routinely dosed on the interior tower shell, typical chemistry conditions of condensation trickling down the shell (measured by the access doorway above the drift eliminators) suggested the existence of large populations of both nitrifying and SOB and their ability to produce an acidic surface condensate (Table 4). A trial spray application on a section of the interior shell on the cooling tower with Nalco F1155 biocide at 35 mg/L concentration reduced the numbers of SOB by three orders of magnitude from an initial level of $10^7/cm^2$ (Bacon et al., 1995, Hall et al., 1992).

In 1994 a biocide selection test was conducted on cooling water and slime sample mixture then: treated with biocide, plated on agar plates, incubated and enumerated. This then resulted in continuous dosing of the basin water with Busan 1174 biocide at 5 mg/L product concentration (containing poly[oxyethylene (dimethyliminio) ethylene dichloride] and isothiazolins) combined with periodic shock dosing with Nalco F1155 biocide (a glutaraldehyde methylene bis-thiocyanate mix) (Bacon et al., 1995). A bio-dispersant (Bulab 8002F containing 10 to 30% polyethylene glycol monotridecyl ether phosphate) was also dosed in combination with the biocides as the sessile (surface) organisms were being targeted rather than just the planktonic (free-floating) bacteria.

Table 4: Typical inner shell condensate chemistry before routine biocide dosing (Bacon et al., 1995).

pH	4.1
sulphate (SO_4^{2-})	893 mg/L
nitrate (NO_3^-)	1116 mg/L

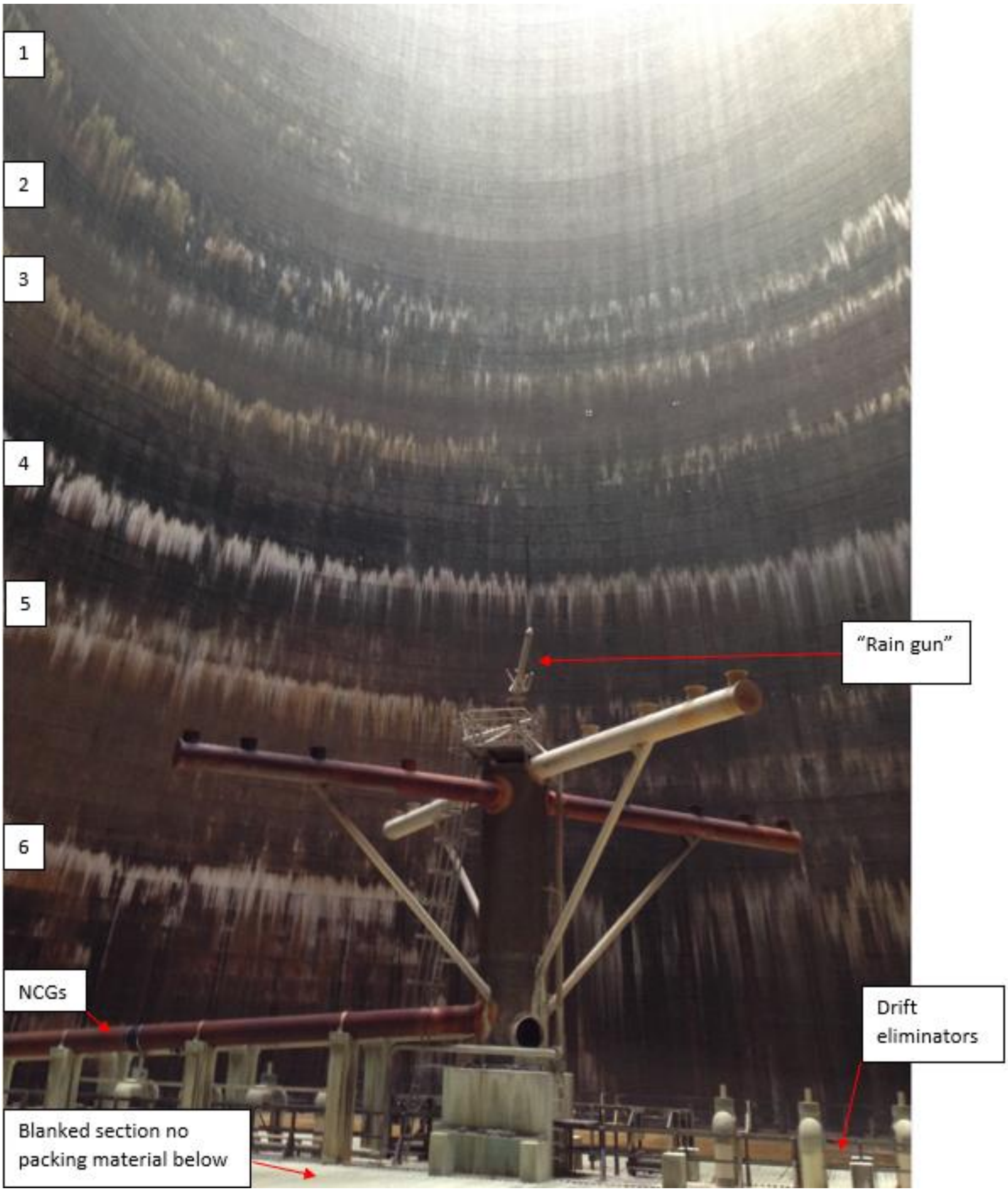

Figure 3: Inside Ohaaki cooling tower. "Rain gun" water/biocide six jet impact locations visible on the shell (labelled).

In June 1997, the continuous chemical dosing to the basin was halted to see what would happen. It was reported that the slime and "heterotrophic" bacteria levels soared. The biocide selection test was repeated, and continuous dosing of Busan 1174 was re-established from October 1997. From approximately 1998, continuous dosing of the basin was replaced by seasonal dosing, with Busan 1174 biocide and bio-dispersant applied during August to December, coinciding with the pollen release during spring/summer. No chemicals were routinely dosed directly into the cooling water during other times.

Non-routine biocide dosing has occurred when the cooling water has dropped to pH 3 on five occasions in January, November, and December of 2016, and twice in November 2017. To recover pH control, 4,000 L of 15% w/w sodium hypochlorite was first shock-dosed to lower the general bacteria population, followed by 1,000 L of Busan 1009 to target SOB. Sometimes additional 1174 biocide dosing occurred when river water was used for refilling the cooling water system post maintenance outages.

The slime consists of bacteria (filamentous or non-filamentous), sulphur particles, algae, pollen and miscellaneous deposits (e.g., insects). It was observed that as soon as pollen was released in spring, the mass of slime would dramatically increase, and the pollen percentage of the slime would increase to at least 50%. From microscopic examination (400x magnification) it appeared that the bacteria would feed on the pollen and hence increase the heterotrophic bacteria levels in the cooling water[3].

From June 1996, biocide was routinely sprayed on the internal tower shell. Initially, this may have been once per week (records are unclear), then moved to twice per week from 1998. Additional doses were applied at times if the tower shell condensate pH was low. From October 2017 to March 2018, the tower shell was dosed thrice per week as a preventative trial on the recommendation of the chemical contractor, following the several low pH events of the cooling water in 2016 and 2017, this was also repeated from September 2019 to March 2020. The biocide used on the tower shells was Bulab 8054, which contained <10% methylene bis(thiocyanate) (MBT) and <10% 2-(thiocyanomethylthio) benzothiazole (TCMBT) by mass. Approximately 40-45 L of Bulab 8054 was used per dose to give an applied product concentration of 470 mg/L. This biocide was changed to Busan 1009 in April 2016 due to inventory consolidation by the supplier – it contained the same active biocidal compounds but no longer included a bio-dispersant, 40-45 L of Busan 1009 was used per dose to give the exact equivalent biocidal concentration as the Bulab 8054. The internal tower shell is sprayed with water daily via the "rain gun". Water flows at 88 L/s for approximately 42 minutes. When biocide is also dosed, it is added 25 minutes into the wash cycle and stops 10 seconds before the end of the water wash. The water pump then stops, and the water in the discharge line drains into the cooling tower basin. The biocide applied to the tower shell should not have any effective biocidal properties once it drips down and is diluted in the cooling water (<0.005 mg/L).

2.3 Cooling water pH, conductivity, macro-biological and microbial trends

Historic weekly grab sample measurements of pH and heterotrophic bacteria from water in the cooling tower basin and slime from a coupon immersed in the return water line to the tower are shown from 1997 to 2020 (Figure 4). Looking over such a long period helps to put some previously reported comments (Section 2.2) in perspective.

It had been stated that both slime and bacteria levels "soared" after continuous biocide dosing of the cooling water stopped in June 1997. While there was an apparently significant increase in slime and bacteria numbers compared to earlier months of 1997, when viewed over many years, it can be seen that the normal variability of these readings is more significant than this one event (Figure 4). Hence these results are not conclusive as to the benefits or not of dosing the Busan 1174 biocide. It also questions the suitability and reliance on these monitoring parameters to indicate adequate biofilm control. The general "heterotrophic" bacteria numbers were overall trending continually higher between 1997 to March 2003, then appeared to drop significantly from April 2003. This drop corresponds to when dip slides were used to replace the agar-coated plates (Figure 4). This was most likely due to the difference in the agar growth media composition being more specific for heterotrophic bacteria in the procured dip slides, whereas the "home-made" agar-coated plate tests may have promoted other types of bacteria or microorganism growth, or their use was simply not conjunctive to reliably monitoring. The significance of the increase in the agar plate tests is unexplained but is not considered to be reliable data in terms of biofilm monitoring.

The basin cooling water pH has generally remained stable between 7 to 8, apart from the low pH excursions mentioned earlier in 2016 and 2017 (Section 2.2). There was no warning from the cooling water monitoring before the first excursion of pH 3.2 was measured on 20th January 2016, with the previous week's reading pH 7.4. Nor were the slime readings anything extraordinary, and the dip slide results had been low at 1,000 CFU/mL for the previous nine weeks of sampling. Although there was a previous low pH reading of 3.2 from the tower shell taken on 5th January, no further samples were taken until 27th January (pH 6.7). A non-routine dip slide of a tower shell condensation sample taken on 20th January returned 900,000 CFU/mL after 48 hours incubation. Shock-doses of 4,000 L of sodium Hypochlorite followed by 1,000 L of Busan 1009 into the cold-well resulted in the recovery of pH of the basin water.

During the second pH excursion event on 16th November 2016, conductivity measurement of the basin water was added to the routine weekly grab sampling after early optimisation work being done at Te Mihi (Young, 2018). Here the conductivity was 1,600 µS/cm at pH 3. After dosing 6,000 L of sodium hypochlorite and 1,000 L of Busan 1009 into the basin on 17th November, the pH recovered briefly, and the conductivity dropped to 800 µS/cm. However, by 2nd December, the pH had dropped again to 3 with a conductivity of 1,200 µS/cm (Figure 5). The conductivity had increased to 1090 µS/cm on 30th November, with the pH only dropping to 6.9, indicating that the biocide dose was insufficient to regain control over the SOB. On 3rd December, 4,000 L of sodium hypochlorite and 1000 L of Busan 1009 were dosed, the pH recovered, and importantly, the conductivity began to decline – although very slowly (Figure 5).

The fourth and fifth pH excursion events on 7th and 21st November 2017 appear very similar to the ones a year earlier. Although, this time it can be seen that the conductivity began to steadily increase from 27th September and exceeded 600 µS/cm over two weeks before the pH dropped to 3. Shock-dosing of 4,000 L of sodium hypochlorite and 1,000 L Busan 1009 was performed on 7th and again on 21st November after the pH dropped again. The pH recovered, and the conductivity slowly trended down (over three months) to below 600 µS/cm. (Figure 5).

It had previously been thought that if SOB numbers got too high on the tower shell, sufficient acid would be produced to not only lower the pH of the tower shell surface but also the pH of the cooling water (or at least by allowing SOB to "seed" the surfaces below). It had been reported that as the pH of the concrete surface declines to about 5, SOB begin to proliferate and produce high concentrations of sulphuric acid, dropping the pH to 2 or less (Rowe, 1991). The tower condensation pH measurements are plotted with the conductivity of the basin water to test this hypothesis. Low pH readings from the tower shell do seem to correlate with high conductivity and low pH of the basin water, but the pH values on the shell are not as low as in the basin (Figures 5 and 6). Also, the

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3 Internal correspondence between chemical contractor and Contact Energy.

shell pH readings do not provide any advance warning (from these weekly measurements) of a pending drop in the basin water's pH, unlike the basin conductivity readings do. There have been over a dozen similar low pH readings from the tower shell in previous years (Figure 8) that did not result in low pH of the basin water. SOB enumeration culturing was being done by the chemical provider but was stopped in 2011 as it was not providing any useful information (Figure 7).

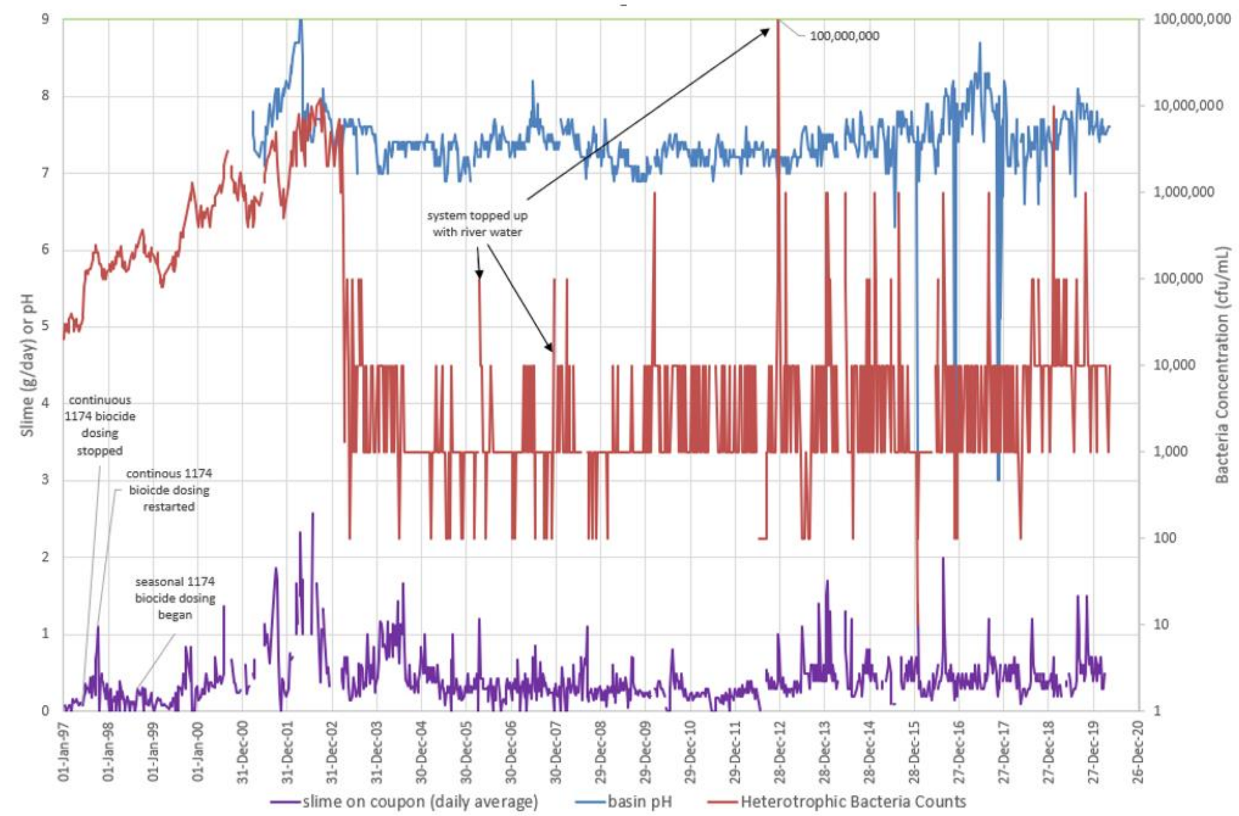

Figure 4: Historical trends of pH, heterotrophic bacteria, and slime of Ohaaki cooling water.

It seems unlikely that the SOB on the tower shell was solely to blame for any low pH excursions observed in the cooling water. The far greater surface area available for SOB and biofilm to proliferate on the film-fill packing combined with the absence of effective biocide dosing of the cooling water would seem a more likely explanation. Biocide was only dosed directly in the cooling water between August and December, providing ample opportunity for biofilm to grow other times of the year. The effectiveness of the Busan 1174 biocide dosing itself is questionable, given such a low dose concentration of 5 mg/L and the product being continuously dosed for four months. This would create a risk of microbial resistance developing to this biocide. One of the active ingredients of the 1174 biocide is isothiazolins which is not suitable for high-sulphide waters like Ohaaki. The frequent dosing and high dose concentration of the interior tower shell with MBT biocide at least twice weekly seems excessive if the objective is to control algae growth to minimise biofilm in which SOB may proliferate.

3. INVESTIGATIONS AND TRIALS

3.1 Cooling water monitoring and dosing

Continuous pH and conductivity monitoring of the basin water was installed and commissioned at the end of March 2018. The conductivity should provide at least two weeks advance warning before the pH drops significantly, with a high alarm limit of 600 µS/cm. The conductivity has varied between 300 to 500 µS/cm (higher in summer) with no low pH excursions over the three years since this instrumentation was installed. In the event of a high conductivity alarm, biocide dosing would be actioned with its effectiveness indicated by declining conductivity over time.

Heterotrophic bacteria enumeration by an accredited microbiological laboratory (HPC at 35°C) was routinely performed from May 2019 to supplement the numbers determined from dip slides. The HPC values were often significantly greater than the dip slides, especially when the dip slides indicated 10,000 CFU/mL while the HPC could be >300,000 CFU/mL (Figure 8). With a target control limit of 100,000 CFU/mL, this was often the difference between considering initiating a shock-dose of biocide or not.

The dosing application to the basin was changed from a 5 mg/L 1174 continuous dose over August to December (last done in 2019) to a periodic 50 mg/L shock-dose of 1174 and bio-dispersant from 2020 (Figure 8). HPC samples were also taken immediately before and a few days after shock-dosing. Although the dip slide results appear to be higher with shock-dosing than before, their accuracy is questionable and are better suited for monitoring heterotrophic bacteria once good microbiological control has been established –

which certainly is not the case here. The HPC counts were no worse under the shock-dosing method but were often higher than ideal. These results are indicative of a cooling water system that is not under reasonable microbiological control. The biocide selected is not ideally suited for this application and needs to be reviewed.

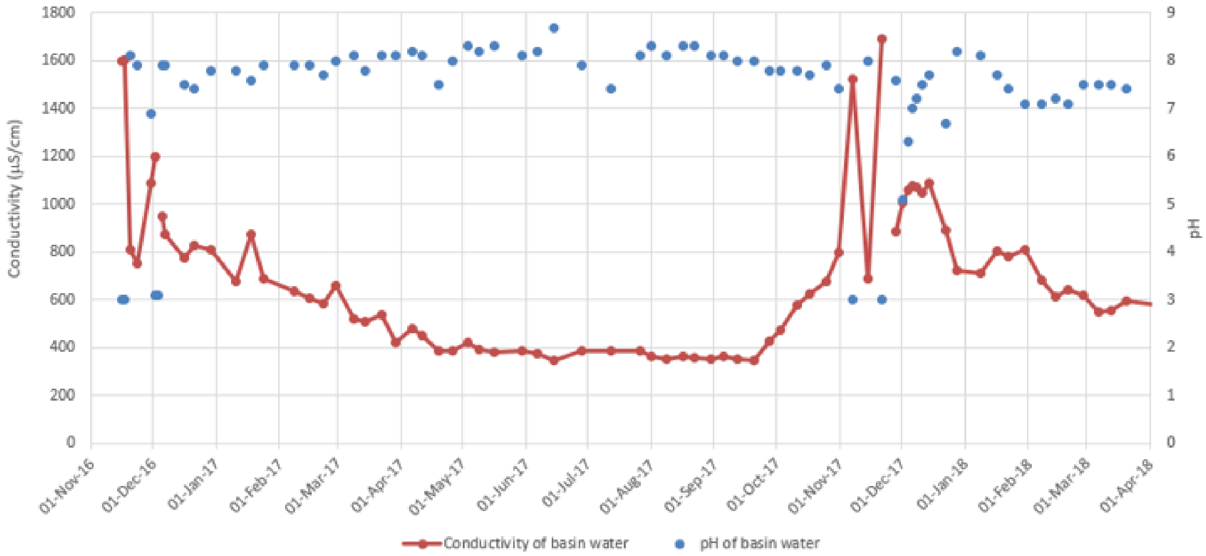

Figure 5: Weekly pH and conductivity measurements of basin water

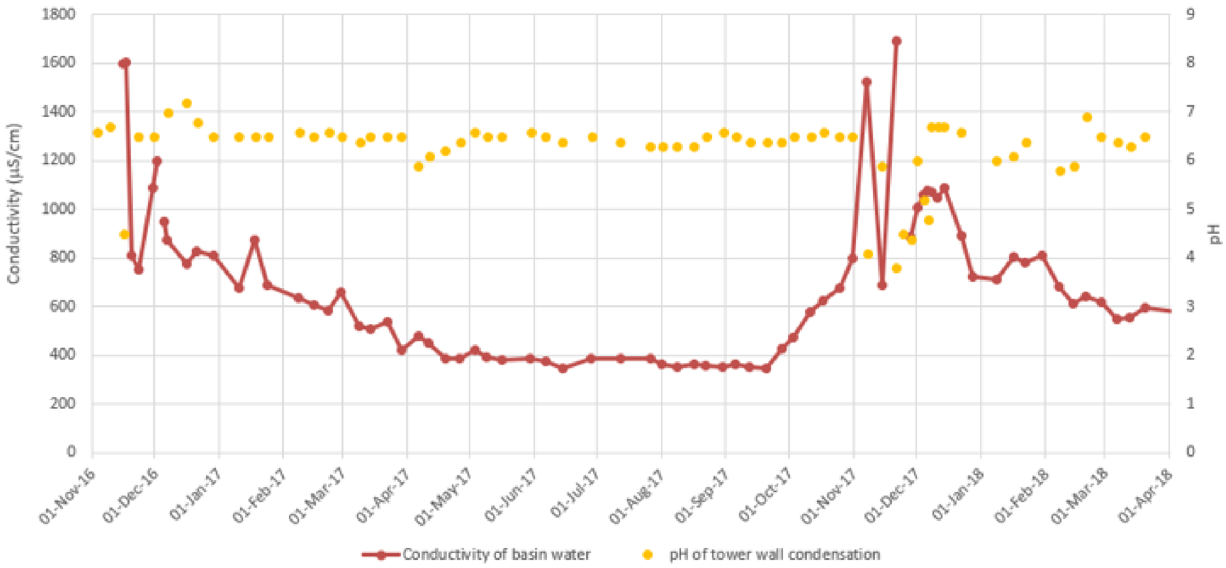

Figure 6: Weekly pH of tower shell condensation and conductivity of basin water

3.2 Tower shell

Of initial concern was the condition of the concrete internal shell of the tower in the vapour zone. The potential exists for even lower pH values in other areas within the vapour zone of the tower (Bacon et al., 1995). If acidic condensation were forming higher up on the concrete internal shell from where it was sampled, then would expect it to be partially neutralised as it reacted with the alkalinity of the concrete surface until this became depleted. Although the alkalinity of the concrete surface would be depleted by now from acid attack from CO_2(g), H_2S(g) and any H_2SO_4 from SOB. There would also be far greater concentrations of H_2S above the height of the NCG distributors (Figure 3), along with greater exposure to sunlight to promote algae growth on the shell, which could provide an abundant food source for SOB to proliferate higher up on the tower shell and above the reach of the biocide "rain gun".

During the May 2018 maintenance outage, there was an opportunity to inspect the inside of the cooling tower. With respect to the concrete tower shell, it appeared to be in good condition from what was visible from the walkway around the circumference, with some "greener" areas but of no discernible thickness. However, there were several localised vertical channels where condensation appeared to have flowed down the shell and severely attacked the cement to the extent aggregate (stones) were being dislodged

(Figure 9). The heights of these attacked channels were not discernible from the walkway, and were concerned that the damage may be more severe higher up on the shell.

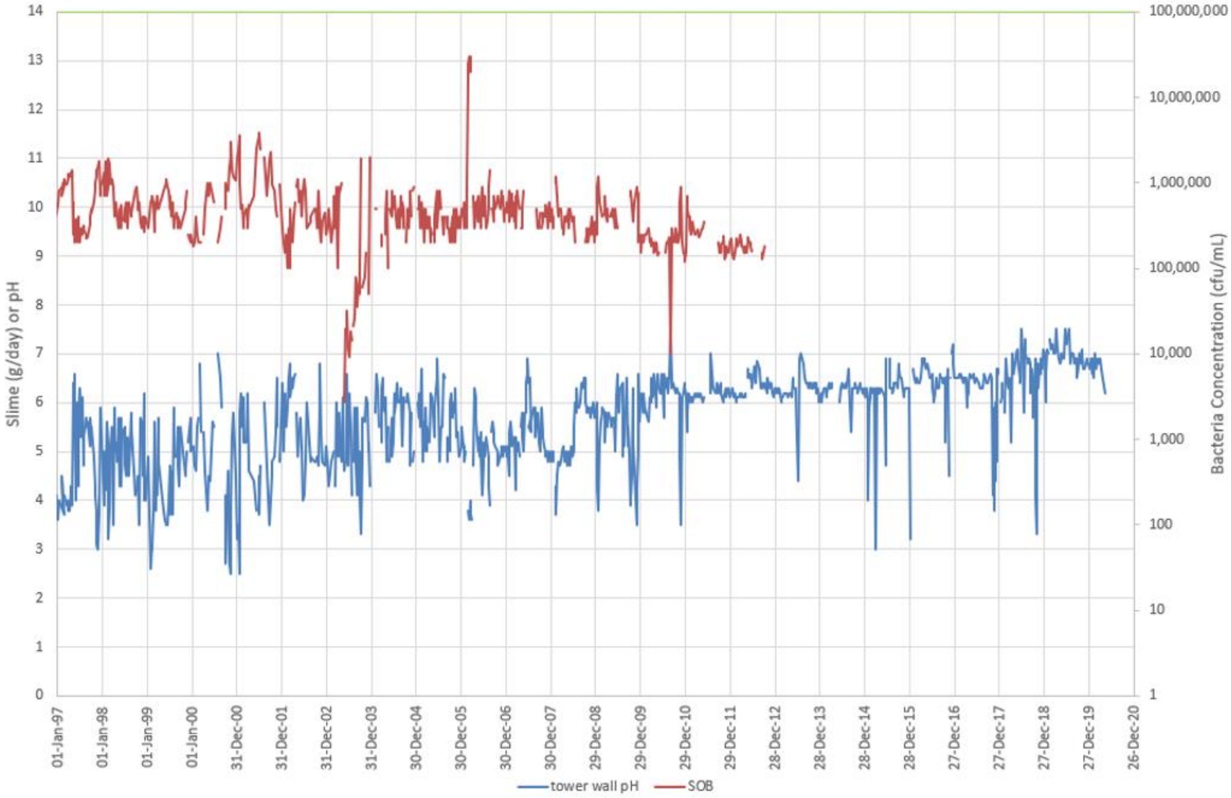

Figure 7: Historic trends of SOB and pH of condensation on cooling tower interior shell

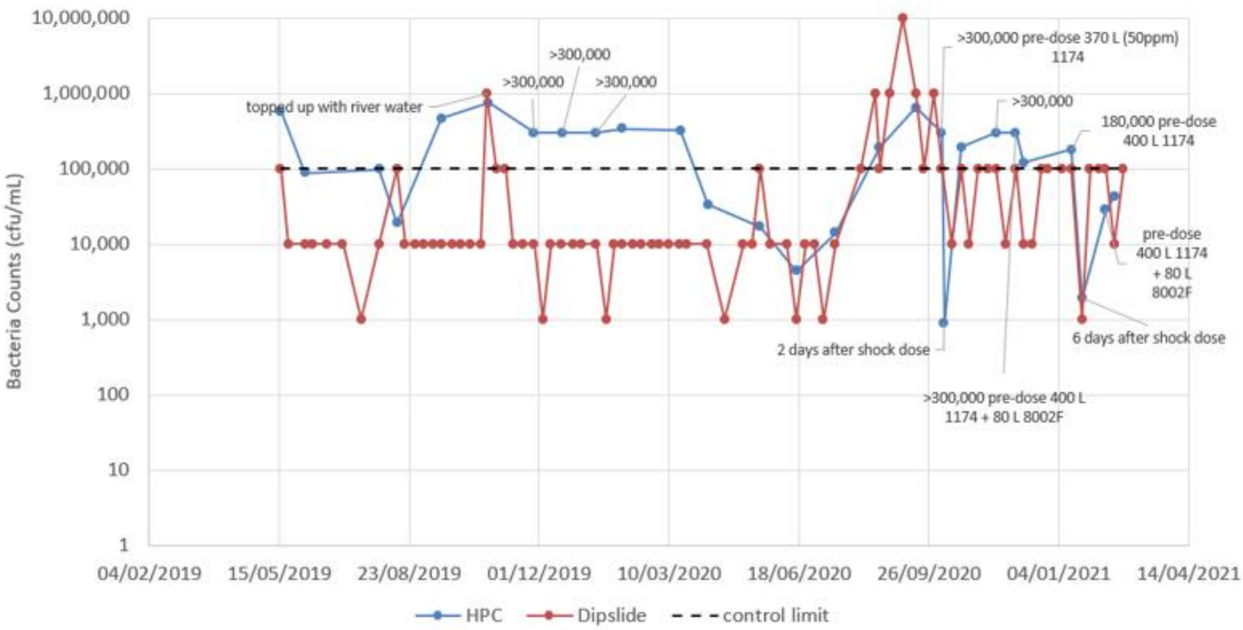

Figure 8: Basin water heterotrophic bacteria

Figure 9: Example of more severely attacked vertical area of tower shell, approximately 300 mm wide (2018 outage inspection)

At the next maintenance outage in August 2020, a drone inspection was performed for the first time to better confirm the condition of the tower shell. This was carried out while concrete condition experts were also present and revealed useful information that had not been previously available. Fortunately, the only attack on the tower shell of note were the few previously observed vertical channels, but these only extended several meters above the walkway and would be accessible with scaffolding to repair at a future outage. Typical examples of the internal shell condition are shown (Figure 10) with apparently better concrete near the top of the tower. There was no difference in surface texture between areas impacted by the "rain gun" jet and the adjacent regions above and below these.

4. CONCLUSION

The following conclusions were made:

- The biocide dosing and monitoring programme for the Ohaaki cooling tower and cooling water is suboptimal with the tower walls being dosed too frequently with biocide while the cooling water is underdosed.
- The concrete attack rate on the inner tower shell is not as severe as originally thought.
- Biocide containing isothiazolin is not suitable for high-sulphide waters like Ohaaki.
- Increasing conductivity of the cooling water should provide an advanced warning (approximately two weeks) before the cooling water pH drops significantly.

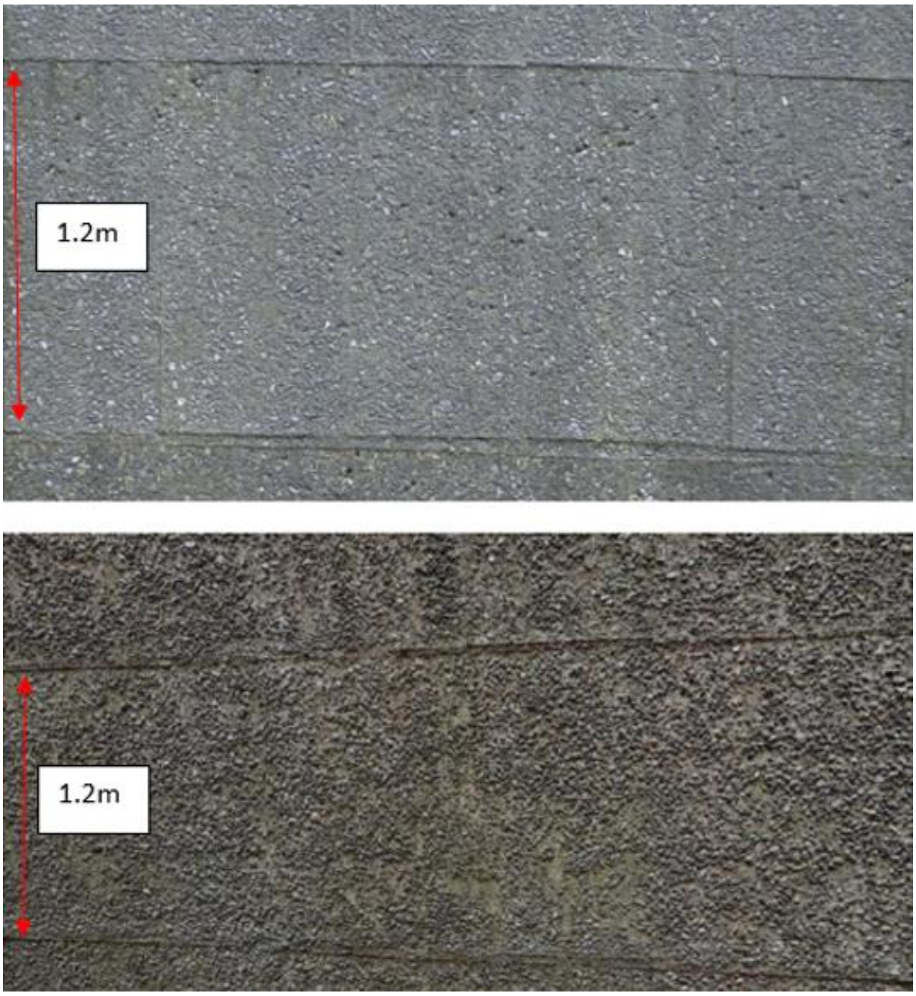

Figure 10: Typical examples of internal shell condition, generally better higher up the tower (Bruce et al., 2020)

5. RECOMMENDATIONS

The following recommendations were made:

- Reduce the frequency of biocide dosing of the tower shell. Initially trial once per week, review, then consider monthly dosing.
- Automatically record and trend the “rain gun” operational parameters (flowrate, biocide and wash steps).
- Select and trial alternative types of biocides for the “rain gun” (one that is less toxic to people) and cooling water (one that does not react with sulphide).

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REFERENCES

Bacon, L., Jordon, J. and Pearson, W.: Microbiology and Corrosion in Geothermal Natural Draft Cooling Towers, *Proc. World Geothermal Congress 1995,* Florence, Italy. (1995)

Brown, D. P. and Hall, N. R.: The Circulating Water and Gas Extraction Systems for Ohaaki Power Station, *Proc. 11th NZ Geothermal Workshop* (1989).

Bruce, S. and Lee, N.: *Ohaaki Cooling Tower: August 2020 Concrete Condition Assessment,* Report No. 5-24000.03/1, Sep 2020, WSP NZ Ltd, (internal report for Contact). (2020)

Hall, J., Hawes, I. and Howard-Williams, C.: *The Potential of Nalco F1155 and Water Blasting to Control Biofilm Development in the Ohaaki Power Station Cooling Tower.* Report for ECNZ, (1992).

Rowe, G. H., *Ohaaki Power Station Cooling Tower: Concrete Deterioration*. Central Laboratories Report 91-23711, Works Consultancy Services Ltd., Lower Hutt, 1991.

Young, M., Optimisation of Chemical Dosing for Te Mihi Cooling Towers, *Proc. 40th NZ Geothermal Workshop 2018*, Wairakei, New Zealand. (2018)

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