Accelerated Corrosion on Roof Purlins

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Abstract

One of the Water Corporation's Tanks is currently experiencing an accelerated rate of corrosion on its steel roof purlins. Corrosion weakens the structure and causes an ineffective seal to the outside environment. As this poses a potential health and safety risk, the roof must be replaced more frequently, increasing the cost of the asset. This project uses a root cause analysis approach to determine the most likely cause of the accelerated corrosion and provide recommendations to how it can be avoided. Both environmental and design/construction factors were assessed. It was found that Tank A had a high free chlorine residual concentration and an undersized ventilation system by 8%-38% (depending on the time of year). Combined, these factors create a harsh internal tank environment and poses as the most likely cause of the accelerated corrosion. Recommendations include testing the internal void space for chlorine concentration and humdity to allow for a higher cause certainty, and changing design standards to have a greater focus on the correct sizing of ventilation.

1. Introduction

Corrosion is an electrochemical reaction that causes the deterioration of a material over time. Although it may be difficult to fully prevent, it can be controlled/delayed. Several Water Corporation water storage tanks are constructed using a steel roof design. This includes Tank A, which is currently exhibiting signs of accelerated corrosion on its steel roof purlins (secondary roof beam supports). Water Corporation have a set of standards that govern tank design and construction. If correctly followed, roof purlins are given a lifespan of 25 years and fasteners are given an approximate 10 years (Water Corporation, 2017).

Tank A has been in operation for 13 years, with significant corrosion present. The extent of the corrosion can be seen in Figure 1. With deterioration occurring around the bottom edges and connection points of the purlins, as well as the tek screws (screws that hold the purlins in place).

Corrosion decreases steel strength, causing the purlins to loosen and break off, creating an ineffective seal to the outside environment. This exposes the internal tank water to contamination sources such as external fauna and flora. With potential health and safety factors arising, the roof is required to be replaced or maintained more frequently. The higher the corrosion rate, the more time and resources are spent on the tank, increasing the whole-of-life cost of the asset. The aim of the project was to determine the source for the accelerated corrosion on Tank A and provide recommendations to how it can be avoided in the future.

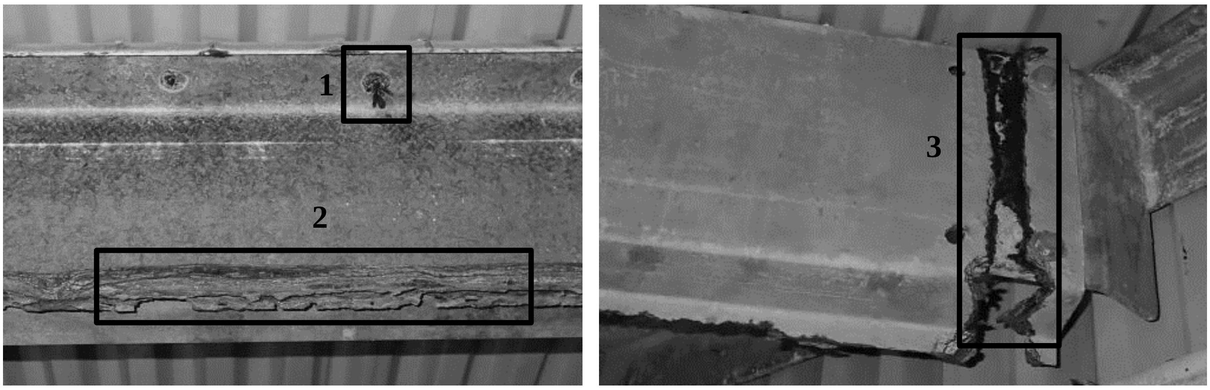

Figure 1 Tank A internal steel roof photos taken from an inspection report in 2020, showing an advanced state of corrosion on the purlins tek screws (1), bottom edges (2) and connection points (3).

2. Process

To effectively analyse the source of the accelerated corrosion, a root cause analysis approach was undertaken. This approach aimed to systematically identify the underlying issue rather then just treat the effects. The method was performed by gathering a collection of principles, techniques and methodologies that were leveraged to identify the root cause event. The process invloved the following steps seen in Figure 2.

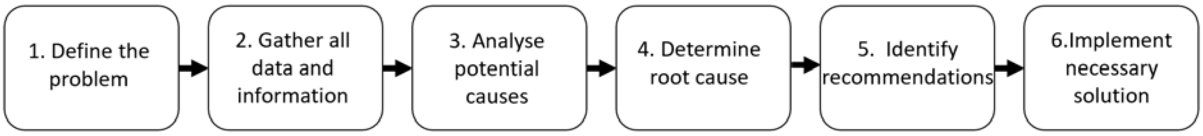

Figure 1 Root cause analysis approach.

In step 2 of the root cause anaylsis mehtod, a variety of factors were found to influence the rate of corrosion, which in turn determine the asset lifespan. In line with Water Corporation’s design standards these factors include location, corrosivity of the environment, design details, quality of the material and construction, residual chlorine concentration in the stored water and roof ventilation (Water Corporation, 2017). These aspects could be divided into two main investigation areas: environmental and design/construction factors. Environmental factors assessed included the free chlorine residual concentration in the water, hydrochloric acid fumes and temperature. Design and construction factors included analysis of the materials used, inlet and outlet positioning and ventilation sizing. Each potential cause of corrosion was assessed by comparing Tank A to other various tanks experiencing a normal rate of corrosion, to determine any outstanding trends.

3. Results and Discussion

3.1 Free Chlorine Residual Concentration

Chlorine gas is used as a disinfectant in potable water systems, with the reaction described in Equation 3.1.1 (Leaist, 29186). The hypochlorous acid (HOCl) then further dissociates into hypochlorite ions (OCl^-) as in Equation 3.1.2 (Gray, 2014). Together HOCl and OCl^- are referred to as free chlorine. Free chlorine residual refers to the amount of free chlorine that has not reacted in the system.

$$Cl_{2\,(g)} + H_2O_{(l)} \rightleftharpoons HOCl_{(aq)} + Cl^-{}_{(aq)} + H^+{}_{(aq)} \qquad [3.1.1]$$

$$HOCl_{(aq)} \rightleftharpoons OCl^-{}_{(aq)} + H^+{}_{(aq)} \qquad [3.1.2]$$

The inlet and outlet water free chlorine residual were assessed for 4 tanks including Tank A, seen in Figure 2. The solid filled symbols represent the inlet concentration while the outlined symbols represent the outlet concentration in each tank. Tank A and Tank B inlets have the highest free chlorine residuals. This may be a result from both tanks being located in close proximity to the water treatment plant (where the water is dosed with chlorine). As chlorine decays with time, the less distance travelled the higher the concentration should be. The tanks used for comparison vary in multiple ways. Tank B was used due to it having the same approximate distance to the water treatment plant as Tank A. Tank C and D are located in the same approximate region with Tank C being a secondary chlorination site and Tank D is a primary chlorination site, the same as Tank A.

Tank A outlet points from the end of 2014 to the start of 2018 have a zero chlorine concentration. This may be a result of the analyser being broken or turned off but have not been taken out due to uncertainty

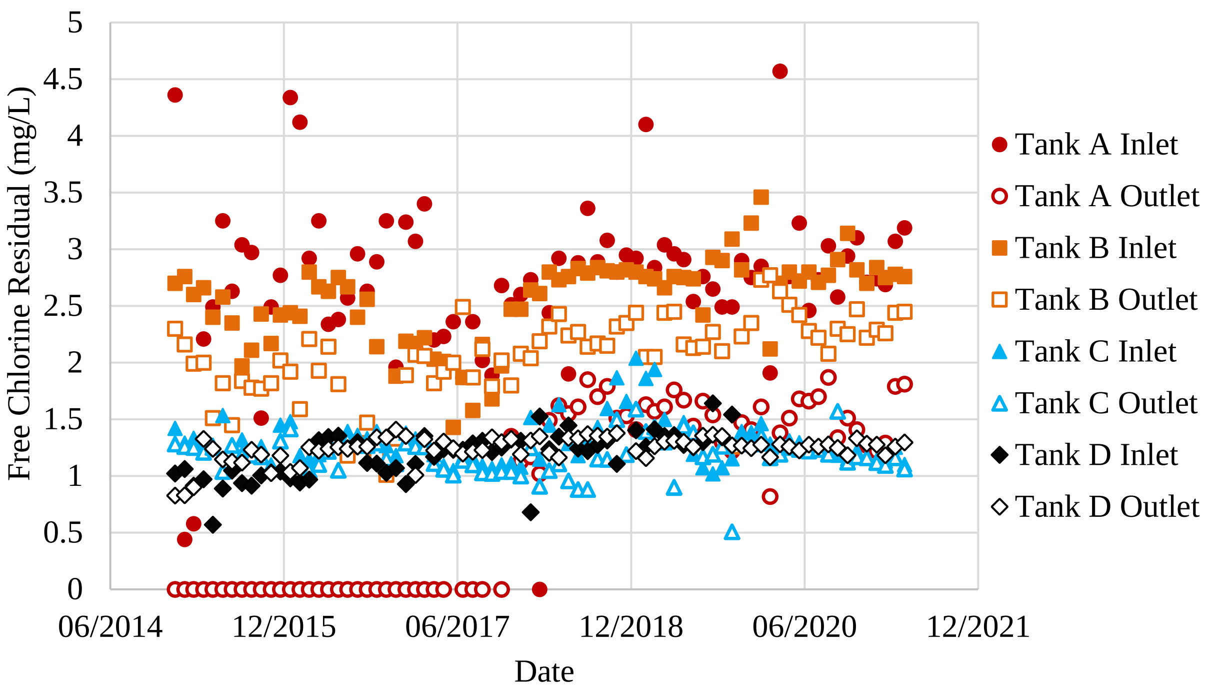

Figure 2 Free chlorine residual concentration for Tanks A-D for both the inlet and outlet.

To further analyse the trends in the free chlorine residuals the difference between the inlet and outlet concentration for each tank was taken. This was to determine the change in the free chlorine residual occurring within the tank. Each point was taken as an average per day concentration obtained from Water Corporation's database. Hence the difference for each point was taken from the average inlet concentration from that day minus the average outlet concentration for that day. This graph can be seen in Figure 3.

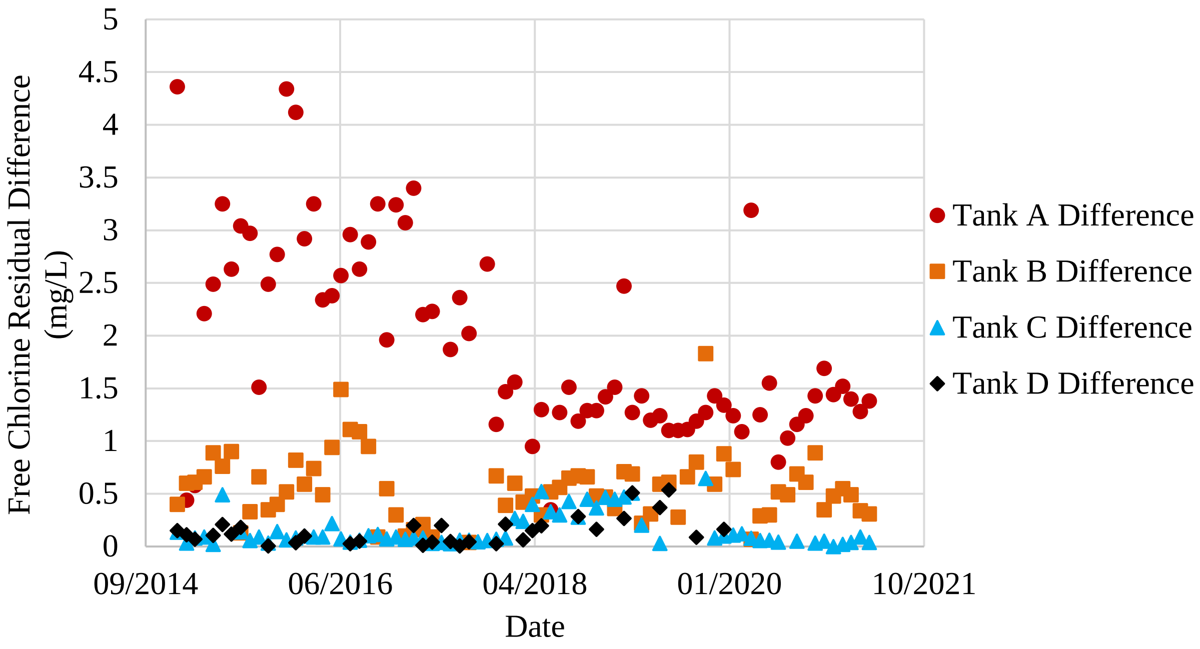

Figure 3 Free chlorine residual difference for Tanks A-D.

Tank A chlorine points from the end of 2014 to the start of 2018, are significantly higher than the later half of the trend due to the outlet zero value and should be noted when looking at trends. Taking this into account Tank A still has a significantly higher difference, with its average concentration lying in the 1-1.5 mg/L range. Tank B has a slightly high concentration averaging from 0.4-1 mg/L. While Tanks C and D have the same approximate difference of about 0.1-0.2 mg/L.

There are many possible reasons for the large difference in Tank A's free chlorine residual concentration. The first is the distance from the chlorine analyser to the tank. For example, the inlet analyser may be located only a meter or kilometres away from the actual tank. As chlorine decay is influenced by time, the longer it has to the travel the more decay will occur. The difference in free chlorine concentration was deemed to be too difficult to further investigate given the projects time constraint.

From further discussions it was concluded that best representation of the free chlorine concentration in the tank is given by the tank outlet. From Figure 2, Tank B's outlet concentration is high. There are many reasons for this difference including the different climate and distance to distribution tanks. As this isn't the tank at interest these possible outcomes aren't further explored. Tank A's outlet concentration is slightly above those of the other same geographical location tanks (C and D).

3.2 Ventilation Sizing

According to Water Corporation's design standards, the ventilation should be compromised of at least 0.2% of the total roof area and be sufficient to cope with the tank's water inflows/level changes (Water Corporation, 2017). To assess the size of the ventilation, vent area was found as a total of the roof area, seen below in Table 1.

	Tank A	Tank F	Tank G	Tank H
Vent to Roof ratio (%)	0.531	0.371	0.788	0.230

Table 1 Vent to roof area percentage for Tanks A, F, G and H.

Each tank analysed exceeds to the vent to roof percentage of 0.2% as required in the design standards. To how much it exceeds the target by, varies. This is due to each tank varying in water level changes and different inlet and outlet flow rates. To further investigate Tank A's ventilation size the water inflow and humidity generation were assessed to determine if the appropriate dimensions were chosen. Humidity generation was calculated using equation 3.2.2 (Evaporation from Water Surface, 2004) which led to the air filtration required to remove the humidity to be determined by 3.2.1 (Required Air to Remove Moisture, 2010). Along with the average water flow into the tank Equation 3.2.3 is able to assess the overall air filtration required by the ventilation system.

$$L = \frac{G}{(X_i - X_o)} \quad [3.2.1]$$

$$G = 25 \times (19 \times v) \times A \times (X_s - X_i) \quad [3.2.2]$$

$$\Delta Air\ Filtration\ (in\ and\ out) = \Delta Tank\ Inflow + \Delta Humidity\ Generation \quad [3.2.3]$$

Two different months for Tank A were assessed to determine a range of the air filtration required. These months were June and November as they displayed the largest temperature difference. The results can be seen in Table 2.

	June	November
Air Filtration Required (L/s)	203.8	306.0
Ventilation Capacity (L/s)	188	190
Difference (%)	7.8	37.9

Table 2 The air filtration required for Tank A with the capacity of the ventilation for the months of June and November.

Hence the ventilators are undersized for the air flow required, by 7.8% in the colder month and 37.9% in the hotter month. Even though Tank A ventilators occupy more than 0.2% of the roof area as required, they are inadequate to handle the humidity build-up within the tank.

The increased humidity inside the tank due to inadequate ventilation in combination with the slightly higher free chlorine residual concentration creates an unfavourable environment. This environment is a likely cause of the accelerated rate of corrosion that the steel purlins are currently experiencing.

4. Conclusions and Future Work

Significant environmental and construction/design factors were assessed for the Tank A to determine the cause of the accelerated corrosion on its steel roof purlins. It was found that the concentration of the chlorine residual for Tank A was slightly higher at the outlet compared to other tanks in the same geographical region. It also experienced a large drop in the concentration from the inlet to outlet, but was not further due to complexity and time constraints.

The design features of the tank were also compared to other tanks, including the sizing of ventilation. Although, ventilation area for Tank A occupied 0.531% of the tank roof area, obeying the standard of at least 0.2%. Further investigation found that to handle the humidity and water inflows of the tank it was 7.8%-37.9% undersized depending on the time of year. The reduced air flow to the outside tank environment with combination of the slightly higher outlet free chlorine residual creates a harsh environment. This is a likely cause of the accelerated corrosion on the steel roof purlins.

The most obvious and effective solution to reducing Tank A's rate of corrosion, is to increase the size of ventilation when a roof replacement is required. To effectively account for inflows and humidity the new ventilation system would need to double in size.

Potential work that could also be of use is to test a purlin for composition and coating, when a replacement is required. This would eliminate the uncertainty that the construction and manufacturing was done incorrectly. To allow higher certainty, an experiment could be conducted on the humidity and chlorine concentration in the void space (water to roof level). Ventilation size could also be placed at a higher focus when the tank is designed and standards can be changed to represent this.

5. Acknowledgements

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