CLEAN IN PLACE OPTIMISATION
FINAL REPORT

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Purpose

The purpose of this document is to provide a summary of the outcomes for the clean-in-place (CIP) optimisation project focussing on Dryer 3's CIP system within the Dunsandel site. This project was completed by Hugh Paterson, a Master's in Engineering Management (MEM) student), on behalf of Synlait, over the period from 1st of October 2018 to the 1st of February 2019.

Acknowledgements

I wish to express my gratitude to those who supported me in completing the CIP optimisation project at Synlait Milk Limited.

Special thanks go to Cameron Dellar and Ken Wong for their support and supervision through-out the project. I would also like to thank Adrian Coursey and Gareth Owens for helping me understand Dryer 3 and being extremely open to making changes to the status quo. I would also like to thank Ray Struthers, Alan Jonkers, Tony Mienis and Perry Buist for the time they have donated to the project.

This project would also not have been possible without the help of the wider Plant and Process team, Dryer operators, Laboratory, Quality and Change Control team.

Executive Summary

Project Scope

The purpose of this project was to investigate the optimisation of the CIP system within the newest of Synlait's three spray dryers, Dryer 3 (D3). The evaporator's CIP process commissioned by Tetra Pak in Synlait's third dryer has not been optimised. There is a large opportunity as the evaporators CIP process runs every day and any time savings will result in significant increase in D3's availability. The project delivers two outcomes:

1. Optimise the current CIP system for immediate and tangible results.
2. Investigation into a novel sensor-based CIP system to identify potential opportunities for improvement.

The Toyota A3 approach[1] was taken to outline each of the project outcomes using a modified PDCA method [2]version of the A3 template. These can be found on the following pages

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[1] https://www.lean.org/Search/Documents/406.pdf

[2] https://asq.org/quality-resources/pdca-cycle

CIP Optimisation of Synlait's current System

Sponsor: Cameron Dellar

ISSUE

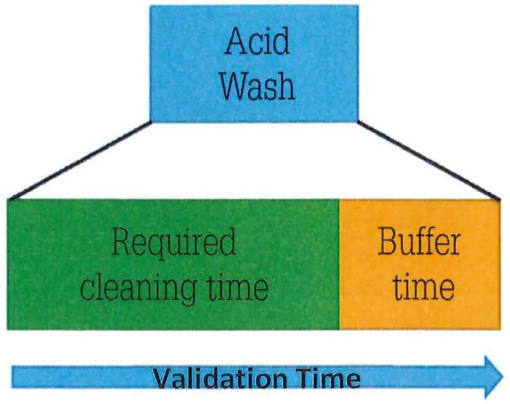
Every minute a Synlait dryer is under CIP is a minute it cannot manufacture milk powder. The current Dryer 3 (D3) CIP process being used by Synlait has not received many changes since it was commissioned in 2015, and there is plenty of opportunity for optimisation of this process.

BACKGROUND

This project will look into optimising D3's evaporator CIP. This CIP contributes the most time to the critical path in the D3 turnaround. The evaporator CIP runs after every milk powder run, so it runs almost every day. This means that any time savings can contribute significantly to the amount of product that can be manufactured by D3 every season.

CURRENT SITUATION

D3's Evaporator CIP consists of a 33-step process that runs for an average of 2.6 hours. Most system steps are validated so that it cleans for the worst case scenario every time. Once the step has run for its validated length of time, the process moves on to the next step. This results in a very long and similar CIP running every time the system is cleaned, regardless of how much fouling exists within the system. This means there is always excessive cleaning time as the cleaning is completed well before the validated time is up. This contributes to lean manufacturing waste within the process, while the plant waits for the CIP to end. The graphic to the right displays a step's time broken down. The actual required cleaning time varies depending on several factors and the buffer time is the excessive cleaning performed on the system.



GOAL

- The goal of this part of the project is to optimise the system to run more effectively and validate that shorter step times can be implemented with no additional risk to the product. Identified opportunities will be implemented throughout the project for immediate savings for the company.

OPPORTUNITIES

Acid Recirculation

- This step is the longest within the CIP, taking up to 25 minutes.
- Literature and CIP experts suggest that this step completes it cleaning very early in the process.

Who?	Acid recirculation length
Endress + Hauser[16]	10 minutes
IXOM[17]	10 minutes
Dept. of Dairy Science, Mannuthy Kerala Veterinary and Animal Sciences University[18]	5-20 minutes
Suncombe[19]	5-15 minutes
SPX[20]	10 minutes

- Initial testing suggested the step could be reduced by half and still effectively achieve its cleaning goals.

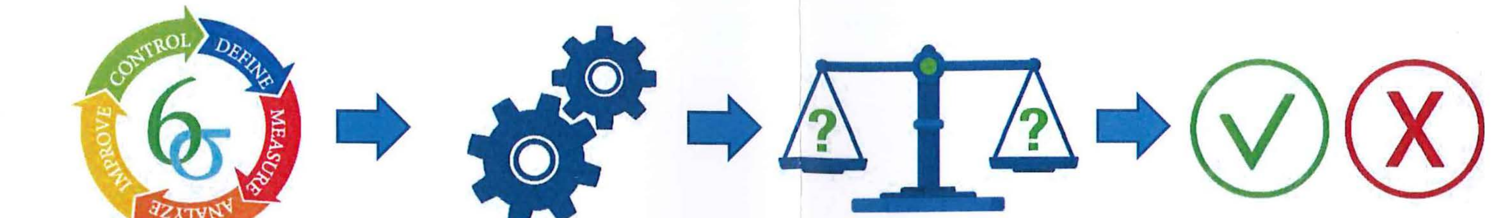
Flooding

- The mechanical vapour recompression (MVR) calandria floods during CIP.
- The reservoir of caustic chemicals built up by flooding takes a long time to dilute and flush out when the system needs to purge.
- This issue adds an additional 15 minutes to the CIP time.
- This is caused by excess fouling remaining within the system. The initial caustic flush is not completing its job correctly.
- It is worth noting that the flooding does not affect the quality of the clean.

Evaporation Rates

- The MVR fan that drives most of the evaporation in the evaporator was running much faster than it should.
- The caused more evaporation of the CIP solution resulting in flowrates within the system that were below the recommended 1.5m/s.
- The evaporation of the fouled CIP solution caused excess fouling on the MVR turbine meaning it needed to be water blasted around twice a month.

IMPLEMENTATION METHOD



Plan	Do	Check	Act
Analysed each problem using DMAIC to find issues and create action plans to fix or mitigate them. And established the baseline performance of a CIP.	Started the change control process and implemented trial runs of the changes, after all stakeholders had given their consent.	To determine if the change had worked the trial run performances were compared with the baseline performance of a standard CIP.	The change was determined be either successful. And change control was complete Or unsuccessful, and the changes were dropped.

COUNTERMEASURES

Change control: This process documented the change, from planning right through to completion and outcomes. This process provided insights from throughout the business each step of the way to mitigate any unintended consequences.

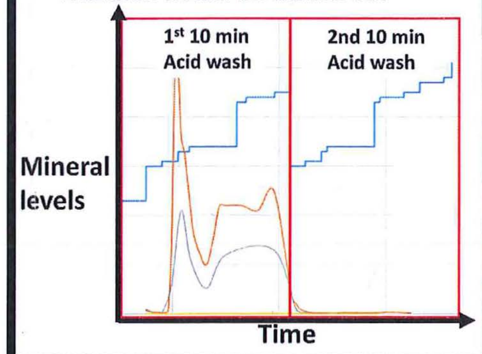
AB testing: Due to the complexity of the system one change was implemented at a time. This meant that any effect on the system could be directly attributed to a specific change after three test runs.

Full day CIP: The changes that had the most risk attributed to them were tested on the first CIP of one of D3's full CIP days. These meant that if anything went wrong with the new CIP settings there was plenty of time for the plant to recover without losing any manufacturing time.

OUTCOMES

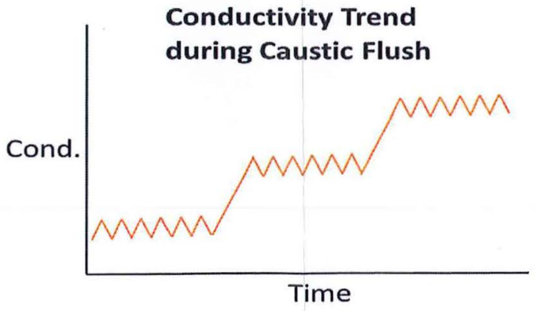
Acid Recirculation

Tests confirmed that the acid recirculation could be reduced by **10 minutes.** IXOM has also recommended that even 15 minutes could be achieved.



Flooding

The caustic flush was altered to remove more of the fouling before the system started recirculation. The conductivity settings were stepped to remove fouling piecemeal, instead of all at once. This resulted in a **10 minute** reduction of flooding time.



Evaporation Rates

The MVR fan speeds were dropped by 4% during the CIP.

This resulted in a 14% increase in flowrates across the system.

The increase in flowrate improved the performance of the CIP by around **8 minutes**.

Time saved per CIP = **28 minutes** Additional plant availability = **163 hours** Additional milk powder per season= **1,308 MT**

COST

Cost of automation changes, lab testing and student. **NZ$ 25,700**

BENEFIT

1,304 MT of additional product, contributing at NZ$ 879 per MT to the EBIT. **NZ$ 1.1M**

FOLLOW UP

To realise the full NZ$ 1.1 million, all CIP time savings need to go into additional manufacturing time. To ensure this the D3 turnaround will need to be looked into, as the evaporator CIP is no longer the critical path.

To better increase the turnaround speed the Feedline CIP will also need to be optimised in a similar fashion.

Proposal to install a Sensor-Based CIP System on D3's Evaporator

Sponsor: Cameron Dellar

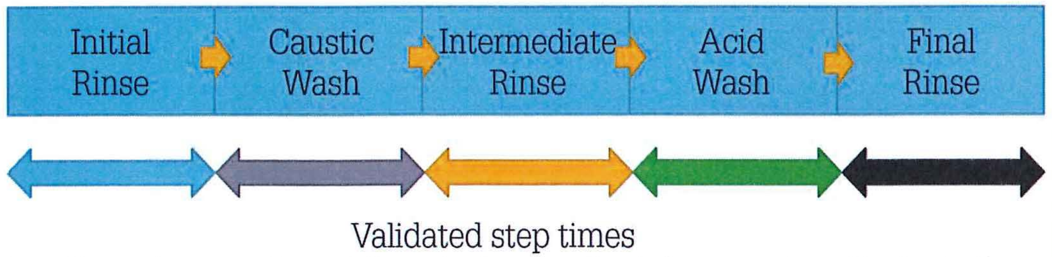
ISSUE

The current timer-based CIP systems that Synlait uses are unable to detect when the systems are clean or not. The CIPs are run off conservative timers that have been validated to confirm system cleanliness. This results in the CIP cleaning for worst case scenario every run, regardless of the fouling levels. Meaning there is excessive cleaning every production run.

BACKGROUND

The evaporator CIP of D3 was chosen as the system to investigate implementing sensor-based control on. This was to share resources and learnings between both goals of the MEM project. The sensor-based system investigated current automation logic, utilising current sensors, and installing new sensors within the system to determine system cleanliness.

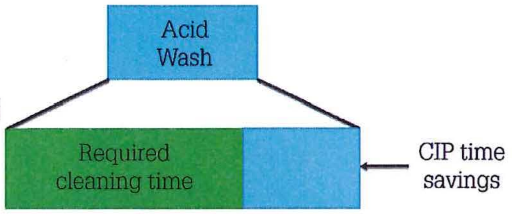
CURRENT SITUATION



Currently the system does not know when it is clean. The only confirmation of cleanliness comes after the CIP is completed through the manual critical control point (HACCP) tests completed by the D3 operators. The system runs through its main steps, outlined above, not transitioning to the next step until the timer is complete. The sensors that currently monitor the system are used a safeguard to not transition a step if certain conditions are not being met. These sensors can only trigger alarms, emergency stops or extend the length of a CIP if the system is not behaving correctly. Currently, they cannot reduce the CIP length.

GOAL

The end goal of CIP optimisation is to run the system for as little time as possible, using as little resources as possible, while still maintaining a clean system that meets regulations. To meet this goal a sensor-based system will be investigated that can detect when the evaporator is clean, removing all the excessive cleaning that is done by the current system. The time savings will be significant with the removal of "buffer" time from the system.



ROOT CAUSE ANALYSIS

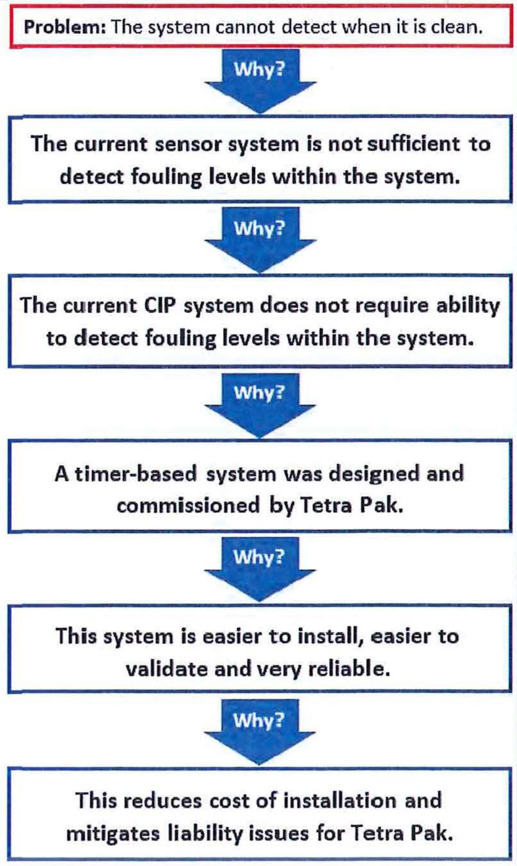
Looking into the reasons at why the current system exists in its current state was good exercise into looking at the incentives for each company. Synlait wanted a system from Tetra Pak that worked and was reliable, and Tetra Pak wanted to deliver this system for as little cost to them as possible. This resulted in the timer based system being implemented.

This system was the best option for Tetra Pak, but not the best option for Synlait. The excessive over cleaning each step does results in an extremely reliable process. The timer-based system is also very simple to implement and understand, requiring minimal additional assets to monitor. So even though Tetra Pak delivered a robust system, it has cost Synlait millions of dollars in lost production time. It is important note that when D3 was constructed, Synlait did not have had the milk supply to support this additional production, so initially this long CIP was not an issue.

With Synlait's rapid growth over the past few years this discrepancy in required CIP time and actual CIP is adding up. For some perspective, one hour of D3 on product will result in a NZ$ 8,000 contribution to Synlait's EBIT. So the potential savings over a season are in the millions of dollars.

The potentials savings are large enough for Synlait to invest in modifying their current system to something that can benefit Synlait and support the growth they are undergoing by getting more from their assets.

5 Whys



Problem: The system cannot detect when it is clean.

Why?

The current sensor system is not sufficient to detect fouling levels within the system.

Why?

The current CIP system does not require ability to detect fouling levels within the system.

Why?

A timer-based system was designed and commissioned by Tetra Pak.

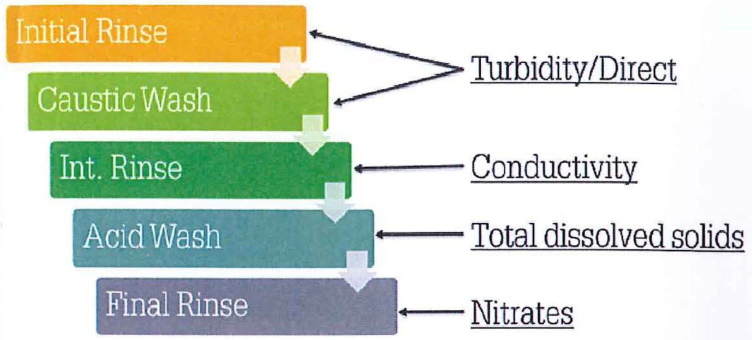
Why?

This system is easier to install, easier to validate and very reliable.

Why?

This reduces cost of installation and mitigates liability issues for Tetra Pak.

TARGET CONDITION



- Remove all excessive cleaning time from the CIP system.
- For each step within the CIP to transition based on a sensor value/s relating to system cleanliness and the cleaning goals of the specific step.
- To remove all unnecessary steps from the CIP system, such as the initial rinse.
- To have an accurate measure of system cleanliness that can be used to assess system health for preventative maintenance purposes.
- Have a self-validating system, instead of a system that is validated on a set of results from over a year ago.

COUNTERMEASURES

Redundancy: Double up on all critical sensors and have them constantly compare values. If one sensor fails, the system can run off just the other sensor. The error should be flagged immediately so the issue can be remedied before the next CIP.

Diversity: Having different types of sensor measure the same critical parameters is key for exceptional situations. The situation might affect one sensor method of function, but not the other. A good example is in the final rinse, nitrate sensors can be combined with the conductivity meters.

Positioning: Make sure redundancy sensors are placed in different areas. If an issue affects an area, then the likelihood of both sensors being taken out of action is minimised.

PDCA implementation plan: The first round of planning has been completed by the Gap Analysis, appendix 10. It important whilst implementing the system, one change is checked at a time. So any changes in system behaviour can be attributed to said change. This will make needed adjustments easier to discover and implement. Once the change is working as expected, move on to the next change. However, this will not assist with identifying any holistic issues with the system due to changes.

PDCA IMPLEMENTATION PLAN	Who	Outcome	Time
1. Low Hanging Fruit	• Automation • Process Engineer	Tidies up the system removing errors and unnecessary steps. Saving **10 minutes** for no additional capital expenditure.	2 months
2. Acid Wash	• Automation • Process Engineer • Maintenance • Laboratory • Dryer Management • Validation • Quality	The largest potential time savings of **17 minutes** are within this step. These changes are being actioned early to maximise the effect of the time savings.	1 month
3. Final Rinse		Installing an additional sensor to measure the CIP step most critical to product safety. This will increase product safety and will save around **3 minutes**.	1 month
4. Caustic Wash		No time savings on this step. However, this will complete the sensor-based system meaning the system will be self-validating.	1 month

See appendix 10 and 11 for details on action plan and implementation recommendations.

COST

Cost of system implementation and validation. **NZ$ 174,000**

BENEFIT

1,428 MT of additional product contributing at NZ$ 879 per MT to the EBIT. **NZ$ 1.2M**

FOLLOW UP

PDCA is that the iterative four-step method is a useful tool for continuous improvement of the system. This will keep the novel sensor-based system relevant if competitors develop something similar. The first audit with this system will be very thorough due to the change in system. So a lot of planning will be required to explain and provide proof of validation to the auditors. However, after this initial time investment the audit process will be much easier due to the systems self-validation.

Contents

1.0 Introduction

In the production of milk powder the equipment becomes fouled and needs to be periodically cleaned for the final product to reach its food grade specifications[3]. Synlait has both legal and ethical obligations to maintain the quality of their product[4]. The equipment is cleaned at the end of each individual run by using a CIP process that pumps large quantities of water and chemicals through the system. The CIP is an expensive process and contributes as a large operating expenditure within the manufacture of milk powder. The main expense is for every minute the system is being cleaned, is a minute that the dryer is not manufacturing milk powder. See **Figure 1** for a breakdown of expenses.

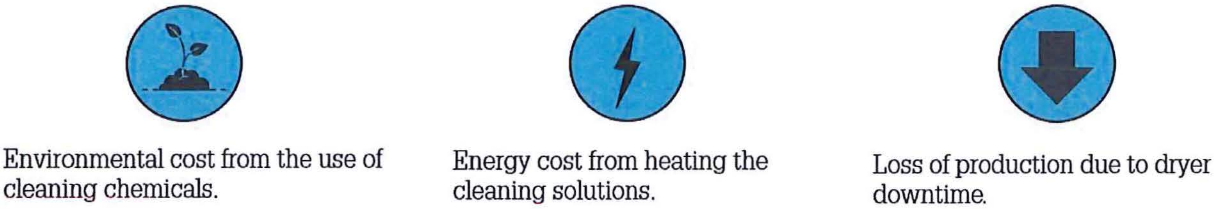


Figure 1: Factors contributing the high cost of the CIP process.

This project was assigned to Dryer 3 (D3), Synlait's newest dryer to speed up the dryer's time to transition from one milk powder run to the next run. During this time, it needs to be emptied, cleaned and prepared for the next run. This process is known as turnaround time. D3's current turnaround consists of two main work streams detailed in **Figure 2**. The evaporator CIP was targeted by the project as this CIP is the longest part of the turnaround, and according to the Theory of Constraints it classes as the 'Drum' of the process[5]. So, the goal of this project is to optimise and provide future recommendations for speeding this step up, increasing the 'drumbeat'.

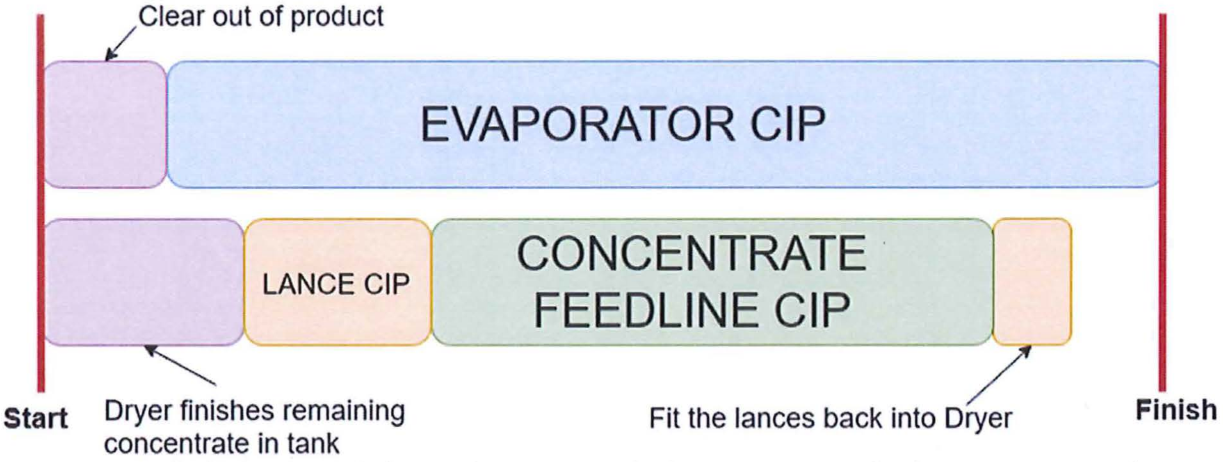


Figure 2: Standard D3 turnaround, showing the two main paths that occur concurrently. The evaporator currently contributes the most to the critical path (not to scale).

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[3] https://www.mpi.govt.nz/dmsdocument/10145/send -DPC 1: Animal Products (Dairy): Approved Criteria for General Dairy Processing, 2011.

[4] https://www.mpi.govt.nz/food-safety/food-act-2014/ - Food Act, 2014.

[5] http://www.lean-manufacturing-japan.com/scm-terminology/dbr-drum-buffer-rope-theory.html

The project was quickly identified as an operations issue within Synlait. This issue has not yet been identified by Synlait as there has been little effort so far to solve this problem. Synlait lack of dedicated resources to the CIP area also highlights that they do not believe it is a quality issue, taking the stance of "if it is not broken, don't fix it". However, this was an issue that directly related to quality as there is a lot of variability in the process that is not accounted for by the current system. The system over compensates for this variability, creating unnecessary waste within the non-value adding steps of the CIP process. To problem solving that was required to tackle this issue was centred on lean manufacturing,[6] and the Six Sigma methodology, DMAIC.[7]

2.0 Project Overview

This project was broken into two parts:

1. The first was optimisation of the current timer-based system to reduce CIP time.
2. Investigating a sensor-based system to further reduce CIP time, and determine its feasibility.

Figure 3 displays a high-level overview of both work streams within the project.

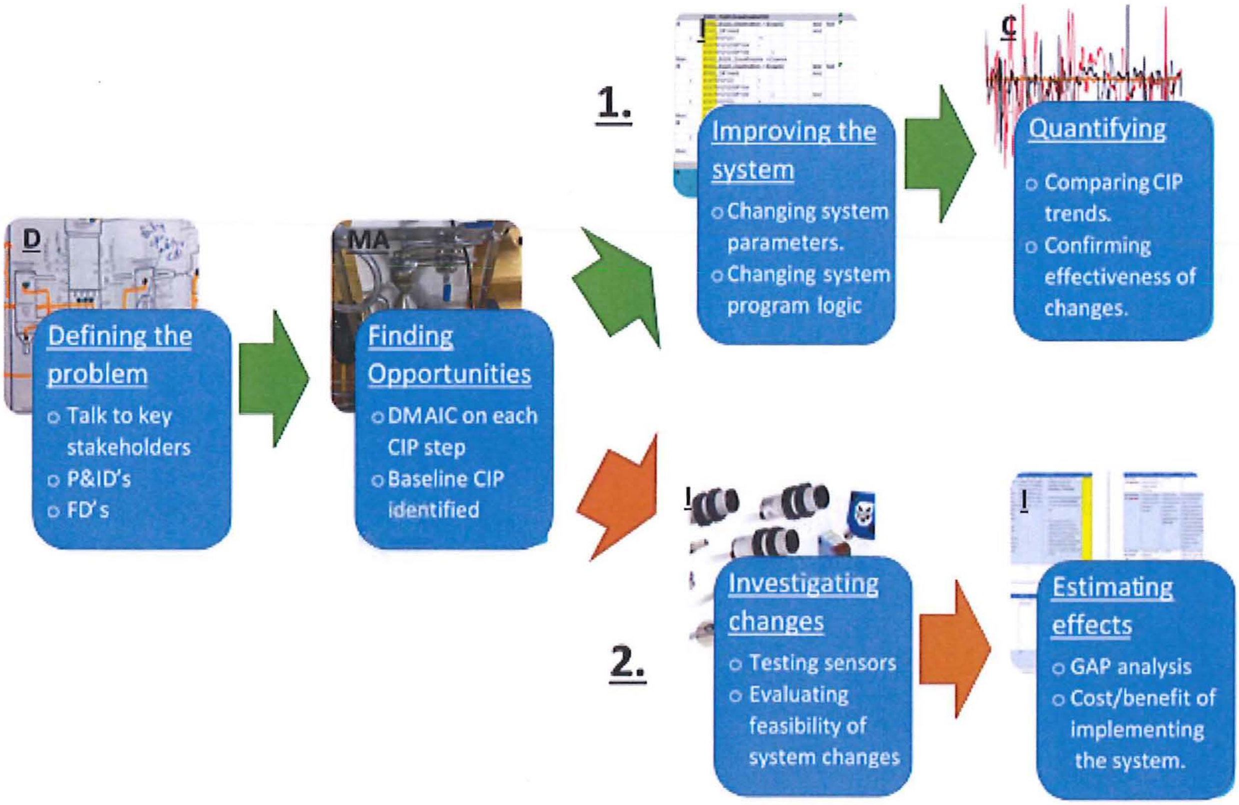

Figure 3: High level overview of both work streams from the project.
1. Optimising current system. 2. Investigating the sensor-based system.

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[6] https://www.leanproduction.com/

[7] https://www.isixsigma.com/new-to-six-sigma/dmaic/six-sigma-dmaic-roadmap/

3.0 Define – The Problem

A standard CIP is run using five main steps including rinses, caustic and acid washes, see attached pdf appendix 1 for the fundamental details of CIP and a summary of evaporator performance. D3's Evaporator CIP consists of a 33-step process that runs for an average of 2.6 hours. Most system steps are validated so that if the step runs for a certain amount of time it has achieved its goals. Once the step has run for its validated length of time, the process moves on to the next step. This results in a very similar CIP running every time the system is cleaned, regardless of how much fouling exists within the system. This means there is always excessive cleaning time as the cleaning is usually completed well before the validated time is up, this contributes to the waiting waste within the process.

This method is simple to implement as it does not need to measure when it is clean, only that if it runs for a certain period, it is clean. However, this creates the necessity for buffer time, which is a direct metric for the excess non-value added process time. **Figure 4** shows the breakdown of a CIP step, the buffer time is required as the actual cleaning time is different for every CIP. Some parameters affecting this are; length of previous run, recipe and seasonality. So, this buffer time is required to ensure a clean system when considering the variability of the actual time required to clean the system. The bigger the buffer time the less the risk, but the greater the waste. Most of the current optimisation is proving, through testing and validation that some of the step timers have excessive amounts of buffer time in them and that reducing the step lengths will not increase the risk to the system. Part of this project investigated optimising the current-timer based system to reduce the wasted non-value added cleaning.

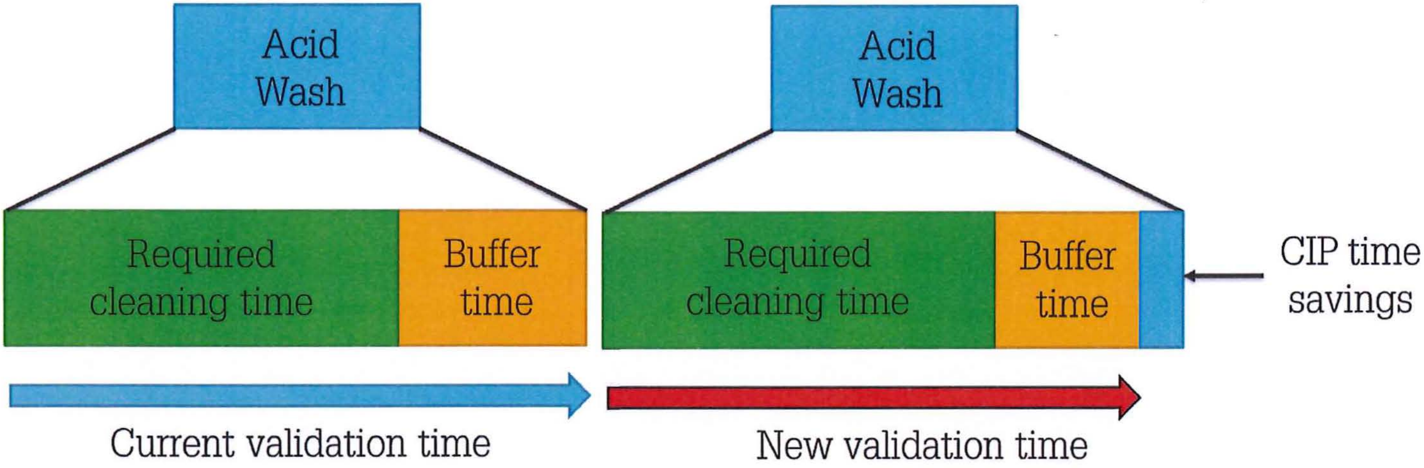

Figure 4: Time within CIP steps can be broken down into two types. The time required to actually clean the system and the time required to minimise the risk of a failed clean. The right image shows how the system is usually optimised

The second problem that this project set out to investigate was the problem that the timer-based system **must** always have waste in the form of excessive cleaning. A solution is that the system should be able to detect when it is clean and progress through the CIP process after it has detected that each step has done its job, **Figure 5**. This part of the project focused on investigating the feasibility of transitioning from a timer-based system to a sensor-based system with the goal of removing all non-value added cleaning time.

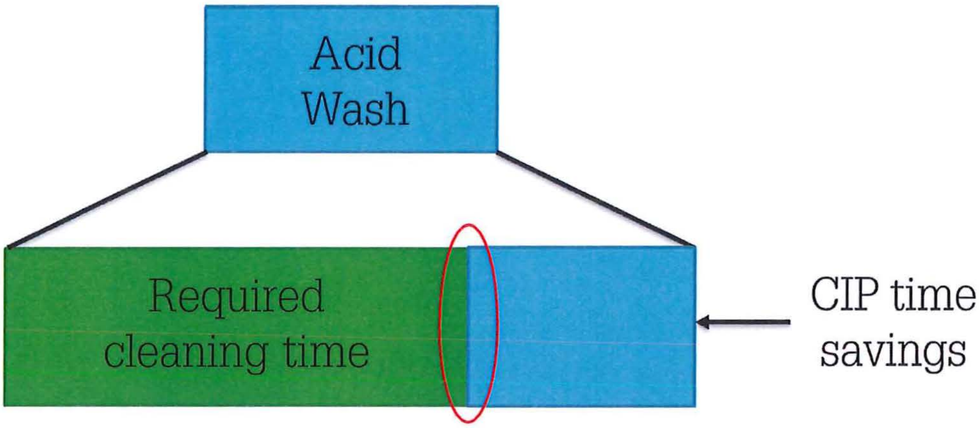

Figure 5: Buffer time in a sensor-based system can be directly attributed to time savings and decreasing the plants downtime.

4.0 Measure - Data Collection

The CIP is a complex process with the main sequence containing over 100 steps. The sensors and software that monitors the CIP is displayed through a human-machine-interface (HMI) accessed within the plant or the automation office. There are dozens of data points measuring a large variety of variables that are being continuously monitored throughout the process. Data that was relevant to the project needed to be determined early in the project so there would be adequate time to collect and analyse it. The way data was prioritised was using pipe and instrumentation diagrams to see where sensors were placed within the system and the functional

Conductivity

- To measure the concentration of the chemical throughout the CIP.

Flow rates

- To determine the mechanical effect of the solution running through the system.

Temperature

- Temperature is a key measurement as it is a source of delays within the CIP as sometimes the system must wait for the temperature to increase within the system.

Step times

- The key variable in determining time savings.

Level sensors

- For the analysis of the tank levels, to see any effects of any flooding throughout the system.

Figure 6: The main sets of data that were collected from the HMI.

descriptions to determine what sensors were used to control the CIP process. The main types of data that are relevant to the CIP are displayed in ***Figure 6***.

Another source of data was Synlait's portable CIP analyser, also known as the "Black Box", see appendix 3. The Black Box was a modular instrument that was hooked into the main CIP circuit to gather additional data on the CIP solution within the system. Additional data gathered from the Black Box is shown in ***Figure 7***.

Suspended Solids

- To measure the turbidity of the CIP solution.

Conductivity

- An additional point within the circuit where conductivity can be tested.

pH

- Testing the pH to give another measure on how acidic or basic the soluton is.

Nitrates

- To detect the amount of nitrate levels present in the CIP solution

Figure 7: The main sets of data that were collected from the Black Box

5.0 Analyse - Data Analysis

A baseline profile of a standard CIP was constructed on Excel from current and historical data. This baseline profile included overall and step time lengths, conductivity, temperature and flow trends, see appendix 4 for insight into the EV03's baseline profile. Two baselines were created due to the two main types of powder D3 produces, whole milk powder (WMP) and infant formula (IF). These products have the same CIP process used to clean them. However, the IF is slightly easier to clean than WMP and runs around 15 minutes faster. The CIP was broken down into its individual steps and the data was collected and compared to the steps cleaning goal.

The methodology that was used to discover and prepare changes to be implemented was DMAIC[8].

1. Define the purpose of the step or process.
2. Determine what data is relevant to step performance and collect it from the HMI and "Black Box".
3. Analyse the data and decide whether a step is achieving its goals. If it is not, then find the root cause of the issue.
4. Find an optimal solution to the problem, using data, literature, and stakeholder experience.
5. Identify where to compare success against the baseline CIP profile.
6. Take the proposed changes to change control.

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[8] Define, Measure, Analyse, Improve, Control. https://asq.org/quality-resources/dmaic

6.0 Improve

This next section is where the project splits into its two parts mentioned in the **Project Overview.** Both project paths will be outlined individually in the following section.

6.1 Summary of CIP Changes

The following section outlines the changes that were made to the current system to optimise the process. To discover opportunities for change a literature review on the critical CIP parameters was completed, as was an extensive summary on the baseline performance of the CIP. The time savings were determined by comparing the changed CIP to the baseline CIP.

Table 1: Summary of the main changes made to the CIP system.

Change	Details	Time savings
MVR fan speeds	• The fan speed drives evaporation within the system. • The fan speed was discovered to be running faster than it should during the CIP process. • The fan speed was slowed by around 4%, reducing how much evaporation was occurring. • Flowrates within the system increased by 14% and the transitions between the steps were faster. • This decreased the overall CIP time. See appendix 5 for details.	8 minutes
Acid recirculation	• When reviewing the literature and talking to CIP experts, it was discovered that the acid wash step in the CIP may do its cleaning very early in the step. • The acid wash was tested and analysed, and this was determined to indeed be the case. • Synlait's chemical supplier IXOM confirmed that there was up to 15 minutes of savings to be had. • Automation change was implemented to validate these changes. • Step reduced. See appendix 6 for details and appendix 7 for IXOM's evaporator report.	10 minutes
Caustic Flush	• The main evaporator column in the CIP is flooding every CIP. This is abnormal behaviour for the CIP as the other dryers do not suffer from this. • The flooding was analysed to determine how much of an impact it was having on the quality of the clean and the overall CIP time. • It was determined that it added 10-15 minutes to the overall CIP time but did not affect the quality of the clean. • A root cause analysis was conducted to determine the reason for flooding and after several theories one was decided upon. • The issue is likely to be that the caustic flush is trying to clean too much fouling from the system at one time, which cavitates a pump in the column.	10 minutes

	• The caustic flush was then changed to step up its cleaning effectiveness from very low, to very high to spread the fouling removal out across the step. • Attempt so far have decreased the flooding time by 15 minutes. Settings still need to be adjusted and optimised within this caustic flush to completely remove the problem. • Appendix 8 details part of the analysis to achieve this result, this gives an idea of the complexity of the problem.	

6.2 Sensor-based System[9]

The second part of the project consisted of investigating the feasibility of a CIP that can run and be validated by sensors. The initial familiarisation stages of this project were key in both optimising the current system and learning the exact goals of each CIP step, how it functioned, and how it was monitored to have achieved them. The critical parameters for each step were determined and methods of measurement were investigated and tested to determine feasibility of such control. The suggested sensor-based system works on the five main principles displayed in **Figure 8**. Information on these sensors and how they function within a CIP can be found in appendix 9.

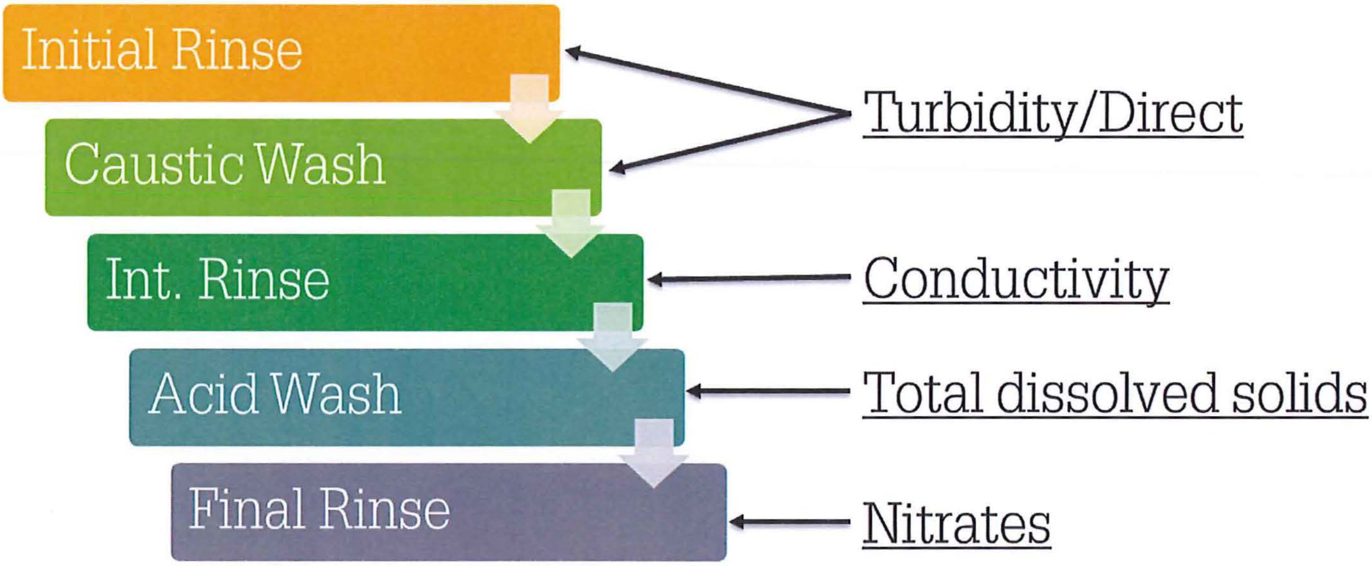

Figure 8: Sensors that measure the effectiveness of each step, relating to system cleanliness.

The benefits of a sensor-based system over a timer-based system are as follows;

- Removes unnecessary buffer time from each step with no additional risk to the system's cleanliness.
- Decreases the overall CIP time.

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[9] Note: Since writing this recommendation, implementation of this system has started as of 25/1/19.

- Reduces excessive cleaning, which reduces water and chemical usage within the plant.
- The system is flexible and adapts to changes with fouling conditions. For example, if the system is very lightly fouled the CIP will be very short. Whereas currently the same standard CIP is run in all situations[10].
- Allows operators to assess the system health more effectively with additional data.
- Auditors will be able to assess the effectiveness of the system with much more accuracy and ease. Critical cleaning parameters will be measured and viewed historically.
- The system can be implemented in steps, is does not need to be commissioned all at once.

A risk with this system is that sensors can malfunction, or exceptional circumstances could cause a systematic error in their readings. This could cause the CIP system to not function correctly and the system may not be clean at the end of it. Mitigation techniques for sensor unreliability are;

- **Redundancy:** Double up on all critical sensors and have them constantly compare values. If one sensor fails, the system can run off just the other sensor. The error should be flagged immediately so the issue can be remedied before the next CIP.
- **Diversity:** Having different types of sensor measure the same critical parameters is key for exceptional situations. The situation might affect one sensor method of function but not the other. A good example is in the final rinse, nitrate sensors can be combined with the conductivity meters.
- **Positioning:** Make sure redundancy sensors are placed in different areas. If an issue affects an area, then the likelihood of both sensors being taken out of action is minimised.
- **Watchdog timers:** Watchdog timers are usually long timers that progress a step gets stuck in a loop, even if the transition conditions are not met. If a system hits a watchdog timer the operators must be notified immediately for them to determine if any action needs to be taken. Essentially the step is finished when the sensor says so OR when the watchdog timer expires.

6.1.1 Gap Analysis

A gap analysis was completed and can be seen in appendix 10. This broke down a standard CIP into its discrete steps and analysed the current performance of the step and the potential performance should it run off a sensor set point. It also outlined a high-level action plan to implement each step. To tie this together this, an implementation guide was completed with some notes and suggestions on the best way to implement this system, appendix 11.

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[10] Emphasising this point is the fact that a completely clean system takes 2.5 hours to CIP in the systems current state.

6.1.2 Cost Estimate

A cost estimate of implementing all these changes is given below, there are many ways of implementing this system that will cost different amounts, this costing is based upon the high-level implementation plan suggested in appendix 10 and methodology in appendix 12.

CAPEX Cost

The following table outlines the costs for the sensors required to control this system, ultrasonic sensors potentially will not be required if the suspended solid sensors are effective. These costs were obtained from the CAPEX and Plant and Process departments within Synlait.

Table 2: Material cost summary

Sensors	Cost $NZD	Quantity (unit)	Total cost $NZD
Nitrate	2,200	2	4,400
Conductivity	3,000	2	6,000
Suspended solids	19,000	2	38,000
Ultrasonic	3,000	4	12,000
Total	27,200	9	**60,400**

- Included in the $3,000 price of the ultrasonic sensor is the cost of the temperature probe required for the method of fouling detection to function correctly.

OPEX Cost

This project will take a significant number of labour hours to complete. The problem is a lot of the hours will be attributed to automation department, who have a high workload. The automation team finding time to implement the system will be a challenge and the labour will likely be passed on to an automation engineer from a contractor such as Industrial Controls, this could increase costs. The following table gives an approximation of the labour costs. Again, the values were obtained internally.

Table 3: Labour cost summary

Type of labour	Cost per hour $NZD	Number of hours	Total cost $NZD
Automation	150	100	15,000
Project engineer[11]	50	800 (5 months)	40,000
Maintenance/ Instrumentation	-	-	27,000 for 9 sensors installations.
Total	-	-	**82,000**

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[11] Assuming a 90k salary

- Implementing 13 code changes of varying degrees of difficulty. This will take some time as it cannot be all completed at once as each section needs to be commissioned and tested before moving onto the next.
- Nine new sets of sensors need to be installed by the maintenance and instrumentation team.
- The Plant and Process engineer managing and performing the system analysis of this project will contribute the most hours to the project, as there will be lots of sensors and processes to check and validate.

Validation Cost

The cost of the lab tests sent to AsureQuality to validate changes is displayed in the following table. These values were obtained from the pricing of previous tests within the project.

Table 4: Validation cost summary

Test	Cost per sample $NZD	Quantity per batch	Cost per batch $NZD
Mineral Test	10.40	50	520
Nitrate Test	16.64	15	250
Total	27.04	65	**3 x 770 = 2310**

- Usually three batches are required to confirm finding so the total cost would ideally be **$NZ 2310**, but if something doesn't work as predicted some phases may need to be revalidated, increasing this cost.
- Any lost production time due to the validating processes would contribute to the validation cost, this is undesired and would happen due to a mistake. Costs like this are covered by the contingency funding allocated to the project.

Total Cost Estimate

The total estimated cost of the system will take the previous estimates and add a 20% contingency.

Table 5: Total cost summary

Type of cost	Cost $NZD
Material Cost	60,400
Labour Cost	82,000
Validation Cost	2,310
Total Cost	144,710
Total Cost + 20% Contingency	**173,652**

The fully implemented system will pay for itself very quickly with a return on income (ROI) for one milking season of 605% and a payback period of two months.

7.0 Control - Change Control

Synlait is a rapidly expanding company. Due to their fast growth, the plant and systems have had some undocumented changes made to them in the rush to get things working. These unknown changes have, and will lead to further complication in future projects. To mitigate this issue Synlait has implemented the change control system. Each change that was made to the CIP in this project was submitted through change control and the process is outlined in appendix 15. Essentially, a committee of employees from around the business track changes to the business, determine their success and provide important insights of changes that may have been missed during the initial planning.

To see an example of an approved change summary report, see appendix 5.

8.0 Expected Benefits

8.1 Optimisation of the Timer-Based System

The main CIP changes that yielded significant time savings in the project can be attributed to the savings and benefits outlined in ***Table 6***. The main costs that are associated to CIP is the opportunity cost of the dryer. The dryer contributes an average of NZ$ 8,000 to Synlait's earnings before income tax (EBIT). The actual value depends on what type of product is being manufactured at the time. D3 produces most of the higher value IF for the company so its time is worth more than the other dryer's. So, every minute saved on a CIP is worth a considerable amount as it increases the output of the asset.

Table 6: Expected benefits from the implemented CIP changes.

Major change	Time saved per CIP	Production time per season	Additional product per season	Potential EBIT per season, NZD
MVR fan	8 min	47 hours	376 MT	$330,504
Acid Recirc	10 min	58 hours	464 MT	$407,856
Flooding	10 min	58 hours	464 MT	$407,856
Total	28 min	163 hours	1304 MT	$1,146,216

- In the 2018/19 milking season D3 has 450 CIPs that have been either completed or scheduled. If 350 are standard CIPs then the production savings are 163 hours.
- To be conservative the metric tons values were based off the slowest rate that D3 produces milk powder, which is 8 tons an hour.
- Synlait's 2018 financial report stated that the average EBIT per ton was $879 this year. So, the additional product that can be manufactured from these time savings is worth over $1 million NZD.
- Synlait also gets more utilisation out of its asset as the amount of production can be increased without incurring significant capital expenditure.

8.2 Implementation of the Sensor-Based System

This sensor-based system will not have the same time savings each run, it depends on many factors such as what type of product was run, how long the run was, what time of the year it is, etc. These factors make it difficult to estimate time savings. However, the benefit this system has is that it can handle all these changes as it has the flexibility to only clean the system as much as it needs. For example, if the dryer was testing a new recipe it may only have a short 6 hour run. The resulting CIP will also be a lot shorter as there will be much less fouling compared with a standard 20+ hour run.

An approximation of time savings can be given by using the average step lengths from the 15 CIP's used to quantify the 'current performance' of the gap analysis. To work out potential savings the step times were compared to the estimate step times from the proposed changes, again from the gap analysis. The following tables breaks down time savings estimates into its individual steps.[12]

Table 7: Breakdown of each CIP step, and its estimated time savings from the gap analysis. Green is time savings to a step, red is time addition.

Step	Savings (s)	Step	Savings (s)
3	-180	48	0
18	+180	60	+360
20	+300	62	-300
22	-300	64	0
24	0	66	0
26	-60	68	--600
28	-300	86	0
32	0	88	+120
34	+100	90	-200
36	-400	92	0
40	0	94	-60
44	0	96	-200
46	-300	98	0

Caustic wash

Intermediate rinse

Acid wash

Final Rinse

= 30 minutes of savings

Table 8:Expected benefits from the implementation of the sensor-based system.

Major change	Estimated time saved	Production time per season	Additional product per season	Potential EBIT per season, NZD
Sensor based system	30.6 min	178.5 hours	1,428 MT	$1,255,212

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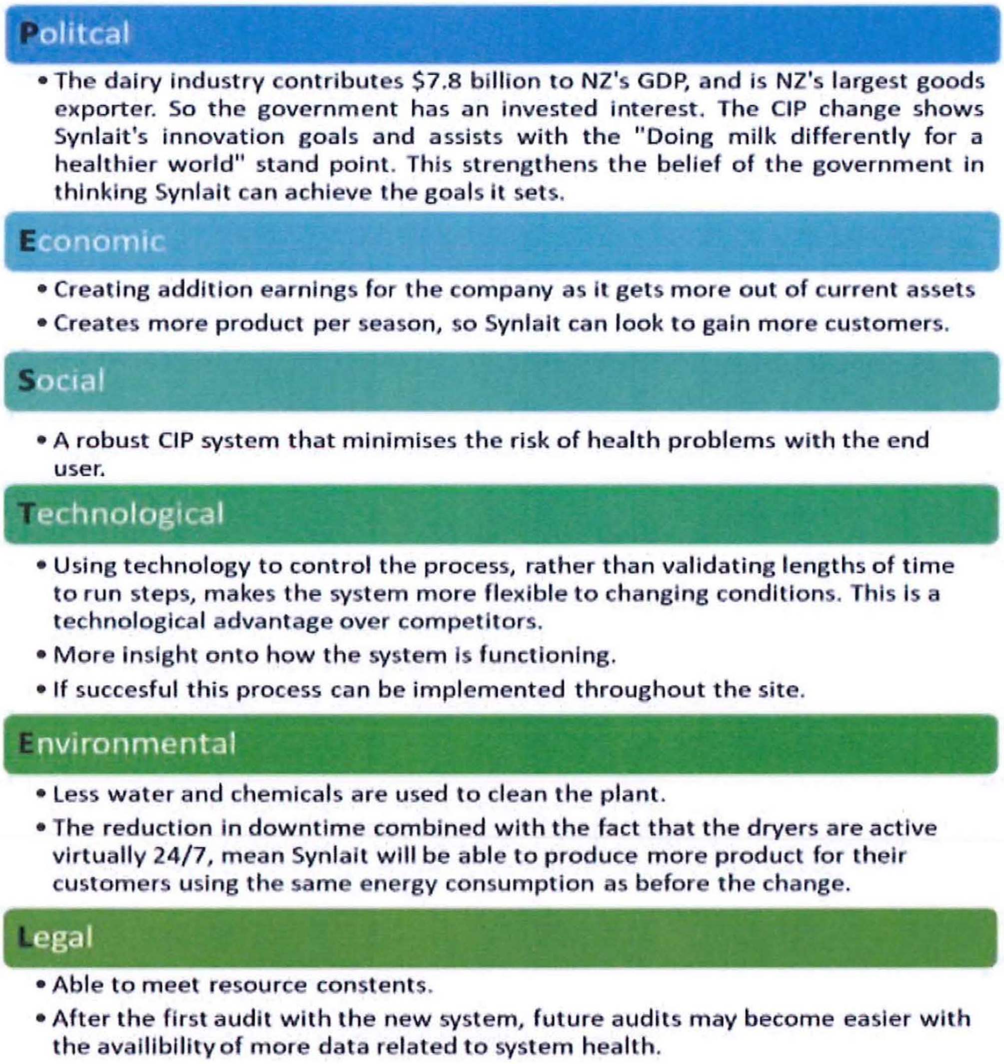
[12] The same assumptions are used as in the previous section, 350 CIPs, 8 MT per hour and $879 per ton.

9.0 Conclusion

Synlait is primarily a manufacturer, and they practice lean principles on their manufacturing side of operations. However, CIP is not considered to be part of manufacturing within the company, so the process is not subject to Synlait's lean methodologies. CIP is required to manufacture milk powder; however, it does not directly contribute to adding value to the final product. The process results in the plant waiting to be free to begin manufacture again. CIP contributes to the single biggest waste in Synlait's manufacturing process, taking 12.5% of potential manufacturing time per day. Yet it is not included as a manufacturing process, so it is not regularly optimised to reduce this waste. One of the biggest takeaways from this project is highlighting to the company the extent of the savings to be had, and how much additional product they can extract from the dryer per season. This short three month project identified and fixed issues that will contribute up an additional 1300 tonnes of product being manufactured per season. With recommendations that are estimated to add another 1400 tonnes if implemented. The company will now see the value in taking the CIP process seriously and may take some ownership on improving this often-overlooked process.

As automation and data collection continues to become more embedded throughout industry, it is important to keep up. Automation is ubiquitous over the dairy industry and continuous improvement on these systems is required for companies to just to keep being competitive with their competitors. Due to Synlait's size. Synlait has a unique opportunity to capitalise on slow-moving competitors such as Fonterra. Synlait can be flexible and make lots of changes to its systems and processes without a huge logistical effort to coordinate across many locations and employees. During the transition to industry 4.0, Synlait can perform several rapid iterations to perfect their process before they expand into something too big to be able to perform rapid changes. Then as Synlait grows they can apply these new processes and systems to new sites as they are constructed, rather than having to change systems in existing sites. This allows Synlait to improve their systems faster than competitors. If successful Synlait will be able widen the gap between their competitors and gain an edge in the dairy industry.

This applies especially to CIP systems as they are often overlooked when it comes to manufacturing ability. So, it is a good time to implement this projects idea of smart sensor-based system as most competing companies are likely stick to the best practice method for a while longer or will be slow to roll out changes due to the company size. This system will cost around $NZD 170,000 to implement and generate an estimated $NZD 1,250,000 of additional product per season. The fully implemented system will pay for itself very quickly with an ROI for one milking season of 605% and a payback period of two months. This would be a good investment, and a good example of Synlait's new vision statement of "Doing milk differently for a healthier world", as not only is the control process novel but it will also reduce chemical and water usage so to align with their sustainability goal. See **Figure 9** on the following page for a PESTEL analysis highlighting the range of major impacts if Synlait was to implement a sensor-based CIP.



Politcal

- The dairy industry contributes $7.8 billion to NZ's GDP, and is NZ's largest goods exporter. So the government has an invested interest. The CIP change shows Synlait's innovation goals and assists with the "Doing milk differently for a healthier world" stand point. This strengthens the belief of the government in thinking Synlait can achieve the goals it sets.

Economic

- Creating addition earnings for the company as it gets more out of current assets
- Creates more product per season, so Synlait can look to gain more customers.

Social

- A robust CIP system that minimises the risk of health problems with the end user.

Technological

- Using technology to control the process, rather than validating lengths of time to run steps, makes the system more flexible to changing conditions. This is a technological advantage over competitors.
- More insight onto how the system is functioning.
- If succesful this process can be implemented throughout the site.

Environmental

- Less water and chemicals are used to clean the plant.
- The reduction in downtime combined with the fact that the dryers are active virtually 24/7, mean Synlait will be able to produce more product for their customers using the same energy consumption as before the change.

Legal

- Able to meet resource constents.
- After the first audit with the new system, future audits may become easier with the availibility of more data related to system health.

Figure 9: PESTEL analysis on changing to the new CIP process.

An implementation plan for this system can be found in appendix 11. This gives a summary of implementing the system with a PDCA method[13] and highlights some of the key resources and time required to realise all the potential savings and benefits from the system.

Further conclusions regarding system implementation can be found in the attached pdf, Appendix 2: Gap Analysis, section 6.

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[13] https://www.mindtools.com/pages/article/newPPM_89.htm

10.0 Recommendations

10.1 Implement this System throughout the Site

The proposed system was tailored to D3's evaporator. However, like D3, D2 and the new Pokeno evaporators were designed and built by Tetra Pak, so they are almost identical systems. Once this system is validated on the D3 system it would be quite straightforward to apply the same sensor-based system and learnings to these other evaporators. This system has the potential to decrease the turnaround time of all four dryer's that Synlait operates.

Most CIP circuits within Synlait run with the exact same five step structure and cleaning principles[14]. The sensor-based system suggested by this project measures critical metrics based on this structure and principles. With minor modifications the system could be implemented to virtually any CIP circuit onsite. The key part of widespread adoption of this system would be identifying critical CIP steps that could hold up manufacturing time or increase the effect of bottlenecks.

It is worth noting that current practice for dairy companies[15] is to still use these timer-based systems as CIP doesn't fall directly under manufacturing optimisation so it generally gets overlooked. This is an opportunity for Synlait to get ahead of the competition and continue with their goal of being disruptive.

10.2 Hire a 'CIP champion'

As previously mentioned, CIP systems are generally overlooked. This is surprising as the benefits of optimising these processes can be significant for the company. The evaporator CIP optimisation currently falls under the jurisdiction of the dryer's department. Unfortunately, they are generally flat-out with their current workload and have little to no time to dedicate to improving their CIP system. The system currently works with little issues so there is no incentive to divert resources to optimise it. The Plant and Process department have a few projects on CIP, but these are generally one project among many for the project engineer assigned to it. So not a great amount of time can be dedicated to it. As there are dozens of CIP circuits on the site and most haven't been looked at since commissioning, more resources need to be allocated to looking at them. Furthermore, due to their positioning between processes it can be unclear whose jurisdiction the CIP falls under. The potential for savings generated by optimising CIPs is demonstrated by both current and previous projects.

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[14] Sinners Circle, appendix 1.

[15] This is not confirmed as the main tool dairy companies keep their best practice safe is by using trade secrets. However, past employees that worked for competing dairy companies have suggested this statement is correct.

Hiring, or giving a current employee a fulltime role as 'CIP champion' is recommended. Keeping with the role of a "champion" to drive change[16] [17], they would be managing the CIP projects across the site and coordinating efforts and energy towards areas where the most savings can be realised. Ideally, they would be part of the plant and process team, with a primary focus on CIPs. The cost of having such a role would be negligible to the company, when compared against the millions of dollars of savings they can coordinate within the system.

10.3 Increase INSQL capabilities

The control system that runs Synlait's plants is run on an internal system that cannot be accessed by external channels, unless they are approved and secure. The normal office system that performs the day to day operations cannot access the internal control system. Industrial Controls has created an interface that snapshots sensor readings within the closed system and uploads the data to be accessed externally. The problem is that they have only added the sensors deemed critical for manufacturing. As a result, most of the sensors required to analyse the CIP are not present, this means that the employee looking at analysing the CIP trends must walk to the other side of the site, to the automation team to access the internal system. Or they can cross the red-line and access the data from within the plant. Both are time consuming exercises and they could be cut out more if more sensors readings are added to the INSQL list. Sensors that would be useful to be added are;

- Level sensor within the evaporator feed tank.
- All the flowmeters in the evaporator.
- Temperatures throughout the system.
- Total solids reading.

10.4 Re-use of Caustic Recirculation chemical

Currently all the chemicals within D3 are single use. The logic and systems are already set up to be able to re-use the chemicals, however it is not applied. Ideally the recirculation chemical should be reused in the next CIP's caustic flush. However, due to the flooding, the amount of fouling currently in the caustic recirculation, the chemical is too heavily loaded to re-use, IXOM stated it was over three times the recommended levels. When the flooding is completely gone the recirculation fouling levels will be diminished. Another issue is that there are several tasks and validations that would need to be completed before the system could re-use chemicals and it is not seen to be economically viable at this stage.

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[16] http://639969719114303356.weebly.com/definition-and-the-role-of-a-champion.html

[17] https://www.processexcellencenetwork.com/lean-six-sigma-business-performance/articles/defining-the-role-of-champions-in-business-excelle

Synlait has set a very aggressive sustainability strategy and re-using this chemical will reduce the total amount of harmful chemicals used to clean the system, aligning with their goals.

Another consideration is that there are currently some consent issues with the amount of sodium being released onto the neighbouring farms through Synlait's waste disposal strategy. These issues have resulted in the testing of different potassium-based cleaning chemicals. If the current sodium based chemical usage can be reduced by re-using some of the chemical, then it is possible that the consent can be met and Synlait will not have to switch over some of their systems to using a more expensive potassium-based chemical.

10.5 Summary of recommendations

Table 9: A GIDA analysis highlighting the recommendations of this project.

GO	**IMPROVE**
• Implementing and trailing the sensor-based system to D3. • Implement the system to Pokeno during commissioning, to avoid unnecessary work or replacing a system. • Re-use the caustic recirculation chemical.	• Improve the usability of the INSQL system by increasing the amount to data that can be accessed from it. This will reduce the engineers time in motion. • The process of optimising CIPs needs to be more centralised. Hiring a 'CIP champion' would help to coordinate optimisation efforts.
DEFEND	**AVOID**
• Defend the reliability and validation of the CIP. • The willingness of the dryer managers to make changes to their system. • Defend the robustness of the system. Each step must have a fail save within the process logic, to ensure a clean system every time.	• Avoid implementing sensors for the sake of it. Make sure that installed sensors are essential to the process. Data saturation is a real issue onsite. • Avoid adding risk to the product. The sensor system is not to be used to cut corners on the effectiveness of the CIP.

11.0 Appendices

The following appendices are a combination of essential information and critical aspects extracted from milestone reports, such as key deliverables like the Gap Analysis and the high-level implementation guide. Also appended are the milestone reports themselves in Appendix 1 and 2.

Appendix 1: Literature Review on Critical Clean in Place (CIP) Parameters and Evaporator 3 Performance Summary

Attached as a pdf named:

Paterson_Hugh_Appendix_1_Lit_Review_and_Evap_Summary

Appendix 2: Gap Analysis

Attached as a pdf named:

Paterson_Hugh_Appendix_2_Gap_Analysis

Appendix 3: Synlait's "Black Box"

Also referred to as the "Black Box", this system is the small portable circuit on wheels depicted in ***Figure 10***. The circuit connects to sampling taps, ideally positioned at the very end of the CIP line to determine the properties of the solution after it has passed through the entire system. This is a useful tool to provide additional CIP data from sensors that are not currently installed in the line. These sensors measurements are stored and controlled by Quadbeam technologies MXD75, this system provides a HMI that allows users to calibrate, trend and store sensor data to a SD card. This rig also allows for a trial of sensors without an expensive installation into the main line during maintenance shuts.

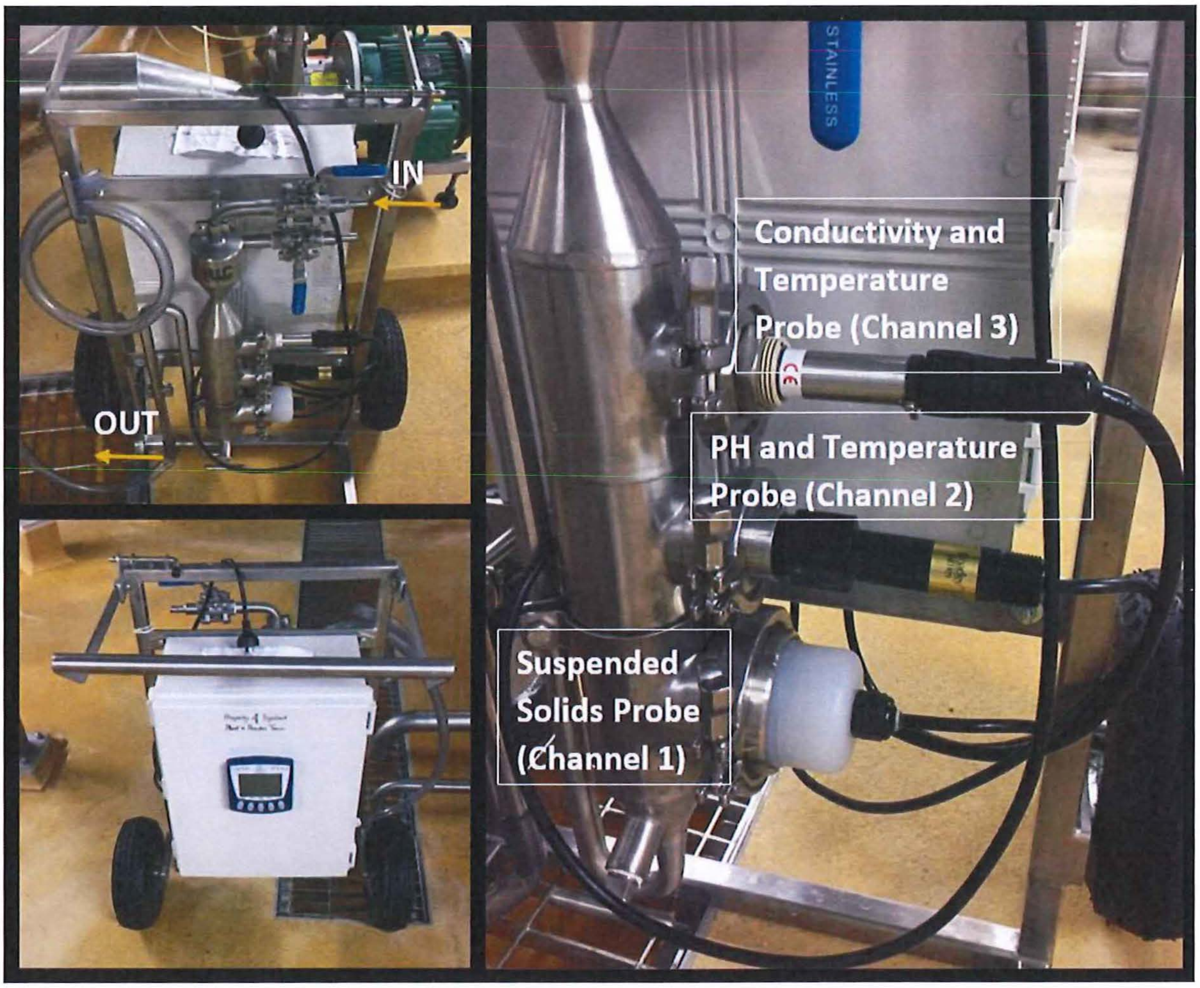


Figure 10: The Synlait "Black box" description.

Appendix 4: Baseline CIP Profile

The baseline profile for each recipe was determined from gathering historical data from the HMI. 15 individual instances of CIP were used for determining the average step times. The same was method was used for the data trends.

Process Step	Date/Time EV03	Set Point Setting		EV03 Ave	
Type				WMP	IF
	CIP Duration (hr)		2.00	2.59	2.40
	CIP Duration (sec)		7216	9326	8638
3	Initial Rinse	<=	180	217	180
6	Request Chem - Caustic	=	0	0	0
18	Caustic Flush	=	900	900	900
20	Caustic Circuit Fill	=	300	300	300
22	Caustic Circuit - Monitor Cond.	=	300	296	300
24	Caustic Circuit - Cond. Chk Alarm	=	2	2	2
26	Caustic Recirc Temp/Cond. Hold	<	0	60	7
28	Caustic Recirculation	<	1200	1498	1447
32	Empty Feedtank	<	2	114	113
34	Purge Caustic	<	550	581	582
36	Purge Caustic - Monitor Cond.	<	10	486	460
40	Purge Caustic - Cond. Chk Alarm	=	2	2	2
44	Intermediate Rinse	=	300	300	300
46	Int Rinse - Monitor Cond.	=	600	566	473
48	Int Rinse - Cond. Chk Alarm	=	2	2	2
60	Acid Circuit Fill	=	300	300	300
62	Acid Circuit Fill - Monitor Cond.	=	300	279	300
64	Acid Circuit Fill - Cond. Chk Alarm	=	2	2	2
66	Acid Recirc Temp/Cond. Hold		0	201	198
68	Acid Recirculation	<	1200	1602	1321
86	Empty Feedtank	<	2	126	132
88	Purge Acid	<	450	532	535
90	Purge Acid - Monitor Cond.	<	10	241	259
92	Purge Acid - Cond. Chk Alarm	=	2	2	2
94	Final Rinse	=	450	450	450
96	Final Rinse - Monitor Cond.	<	150	265	150
98	Final Rinse - Cond. Chk Alarm	=	2	2	2

Figure 11: Time profile of a standard WMP CIP

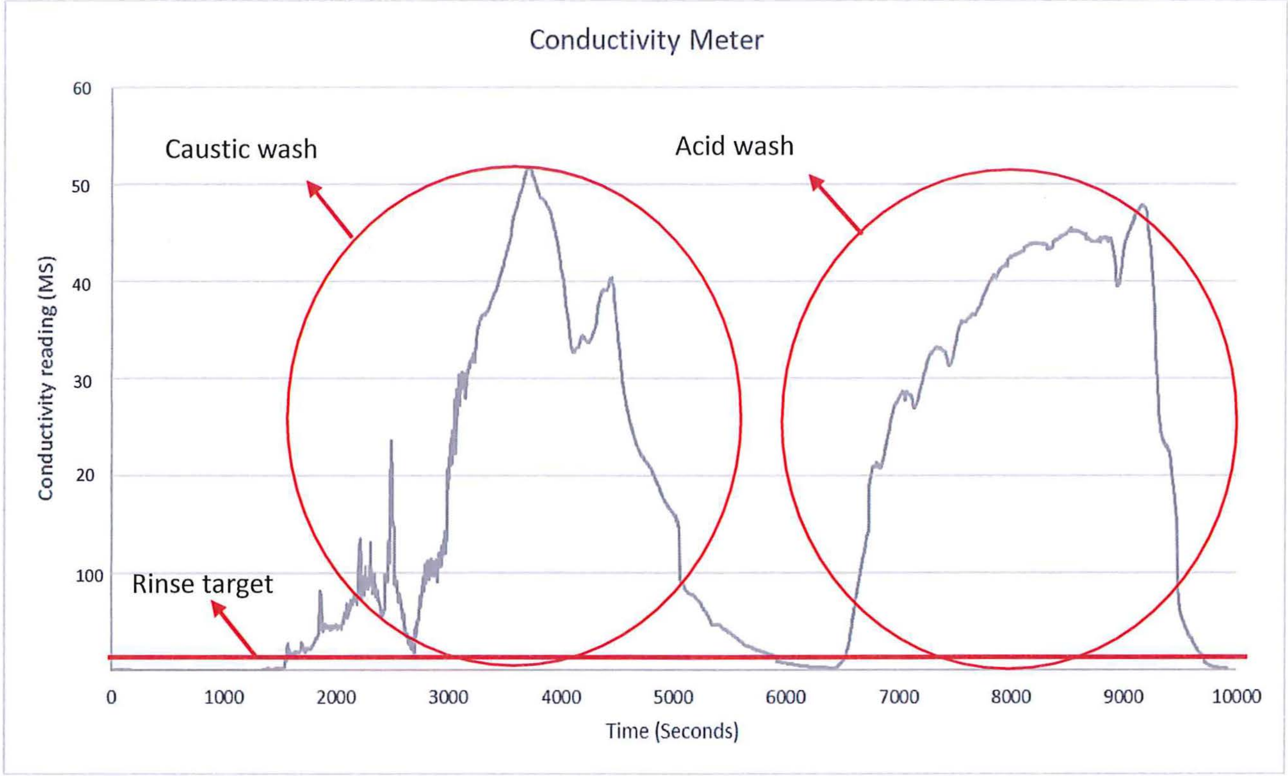


Figure 12: Conductivity profile of a baseline CIP.

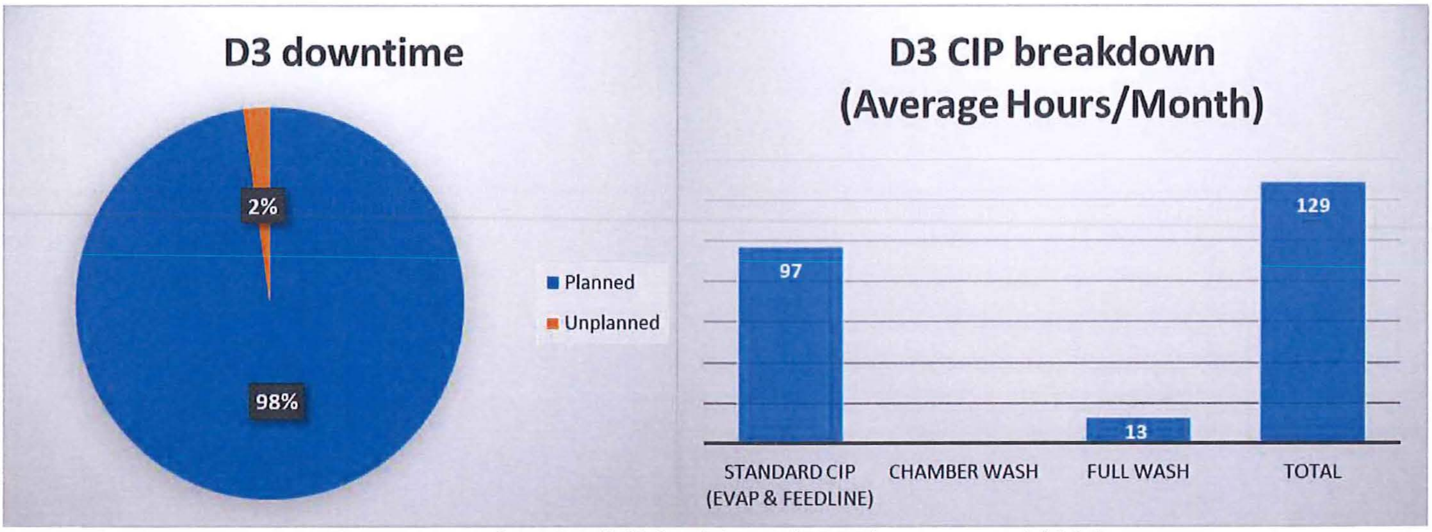


Figure 13: Dryer downtime (left), breakdown of D3 CIP hours per month (right).

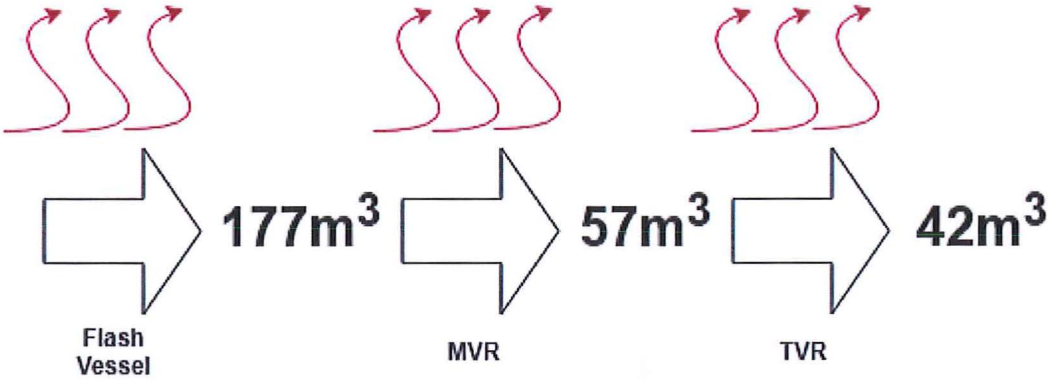


Figure 14:The volumes of solution that pass through the flowmeters during a standard CIP set calculated from the flowmeters within the line.

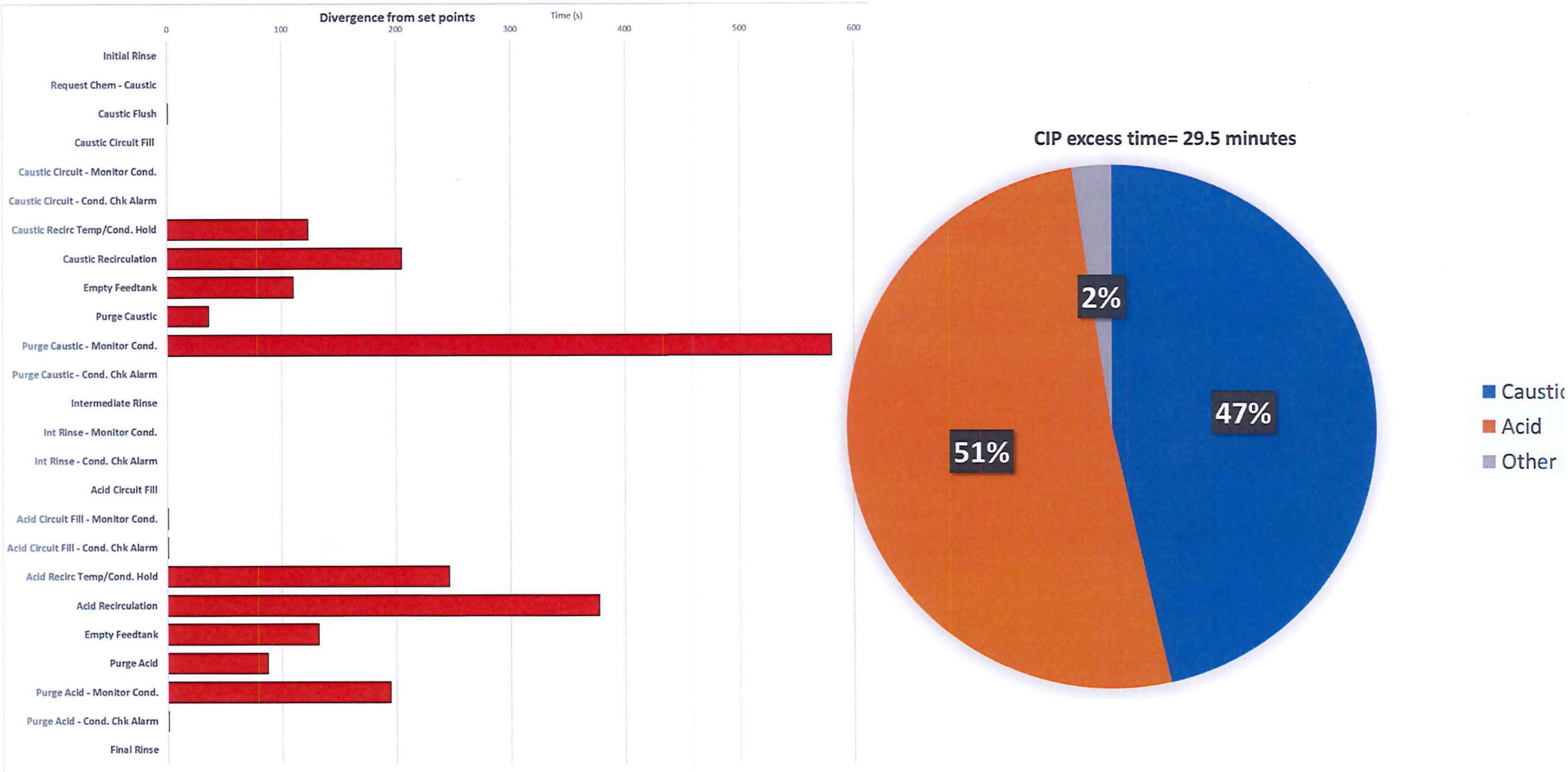


Figure 15: A list of the CIP steps within a general CIP process and a comparison of their actual runtimes against their set point runtimes (left). The contribution of each phase to the additional seconds within the CIP (right).

Appendix 5: MVR Fan Speed Change Report

Description of Change

Reduction of Evaporator CIP MVR fan speeds via HMI set points during the CIP

FD: EVAP3_CIP

Step number: Whole CIP

Set point:

MVR Fan CIP Operating OP - E3SC052121 SP106

MVR Fan CIP Caustic Operating OP - E3SC052121 SP107

MVR Fan CIP Acid Operating OP - E3SC052121 SP108

	MVR Fan CIP	MVR Fan CIP Caustic	MVR Fan CIP Acid
D3 values	2180	2190	2160
D2 values	2190	2125	2090
New D3 values	**2120**	**2125**	**2090**

Purpose

Reduce evaporation during the CIP to increase the flow rates throughout the system. This will assist in the draining of the flooding and increase the performance of the CIP in general. Reducing the fan speed may also help assist with slowing the fouling buildup on the fan impellor.

Justification

The MVR fan set points in EV03 are higher than EV02, the fan speeds are going to be lowered to similar levels to D2's. See **appendix 1** for a visualization of the set points over a CIP cycle.

Risks

1. Not enough evaporation occurs, and the flooding gets worse as the inflow increases.

Mitigations

Watch the flooding levels using the sight glasses and level sensors within the separator. If additional flooding occurs the CIP can move back to the original set points mid-CIP, via the HMI.

Change Plan

1) Change set points

2) Monitor several CIP with the new set points.

3) Compare the new CIP behavior between recent CIP's using the old set points and similar recipes.

4) If the CIP behaves better, accept the change, else revert to original set points.

Results

The change was made before the CIP on the 27th of November and has remained active till now.

As expected, **the flow rates improved** with the reduction of MVR evaporation, **appendix 2**;

- A **total increase of 12% flowrate through the MVR** with new fan settings,
- and a **total increase of 14% through the TVR** with new fan settings.

The flooding time was reduced slightly suggesting that the change helps with the symptoms of the flooding rather than affecting the root cause. See **appendix 3** for a comparison of before and after.

- Average flooding time on infant formula was **58 mins**, it was **53 mins with the new settings.**

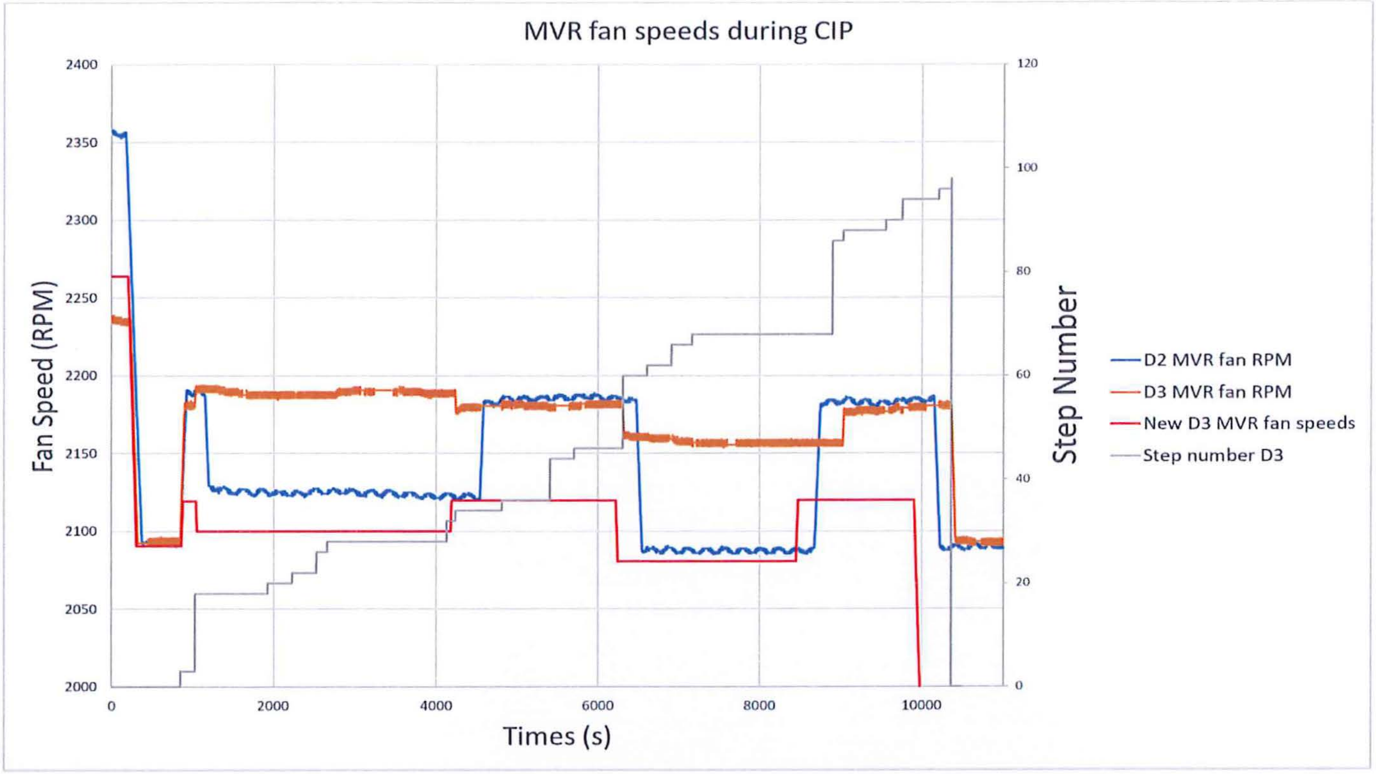
The overall CIP time was improved because of the reduction in flooding times. The caustic recirculation performed much better due to better flow rates. This resulted in less conductivity holds and conductivity came down faster after the step was finished. The CIP improvement is as follows:

Type	Before change (hour)	After change (hour)	Improvement (min)
WMP	2.62 (10 runs)	2.49 (7 runs)	8
IF	2.47 (8 runs)	2.36 (7 runs)	6

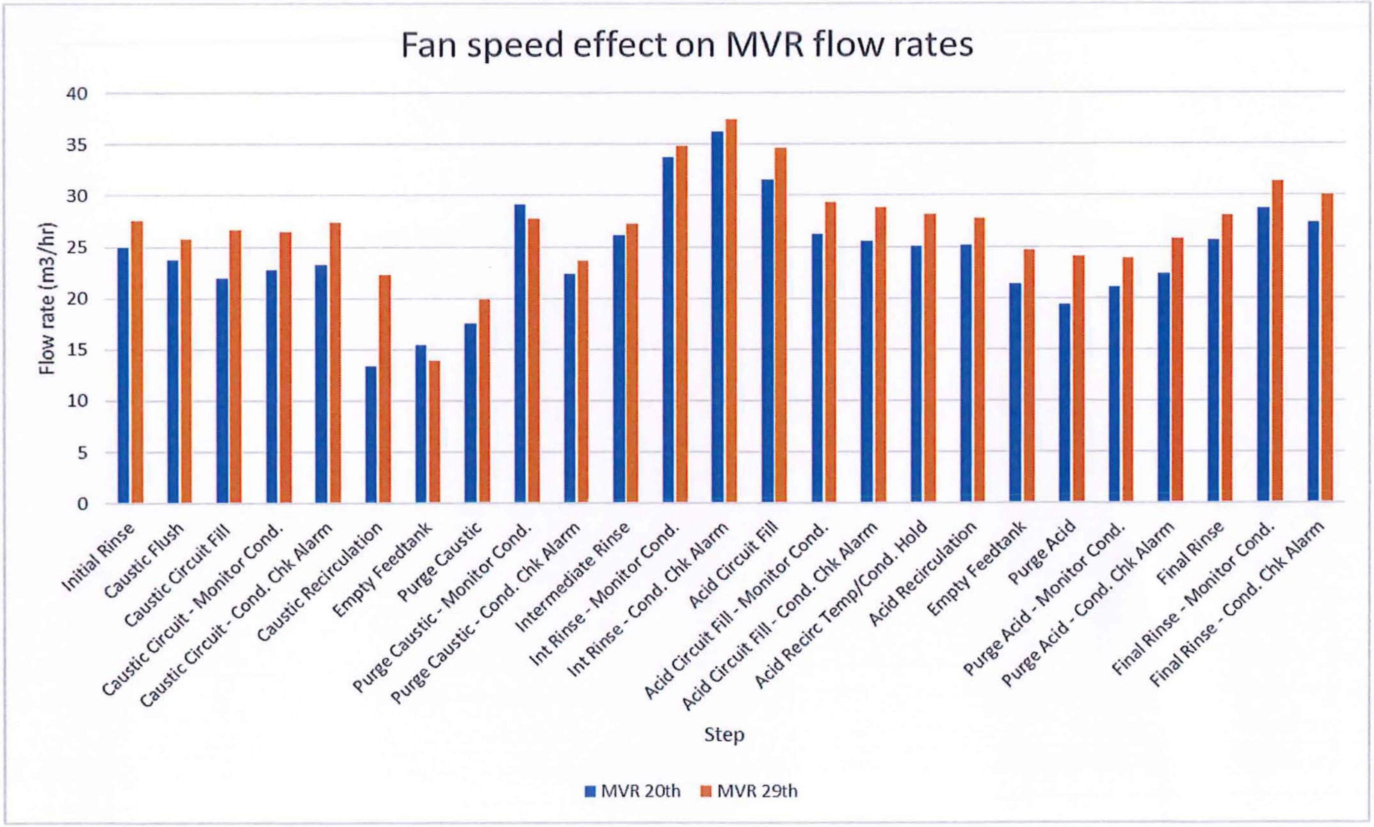
One test was also tried with further reduced RPM speeds, reducing SP107 and SP108 further to 2080 and 2050 RPM respectively. However, the CIP performed poorly, and the set points were put back. Still waiting to see if the slower fan speed has any effect on impeller fouling rate.

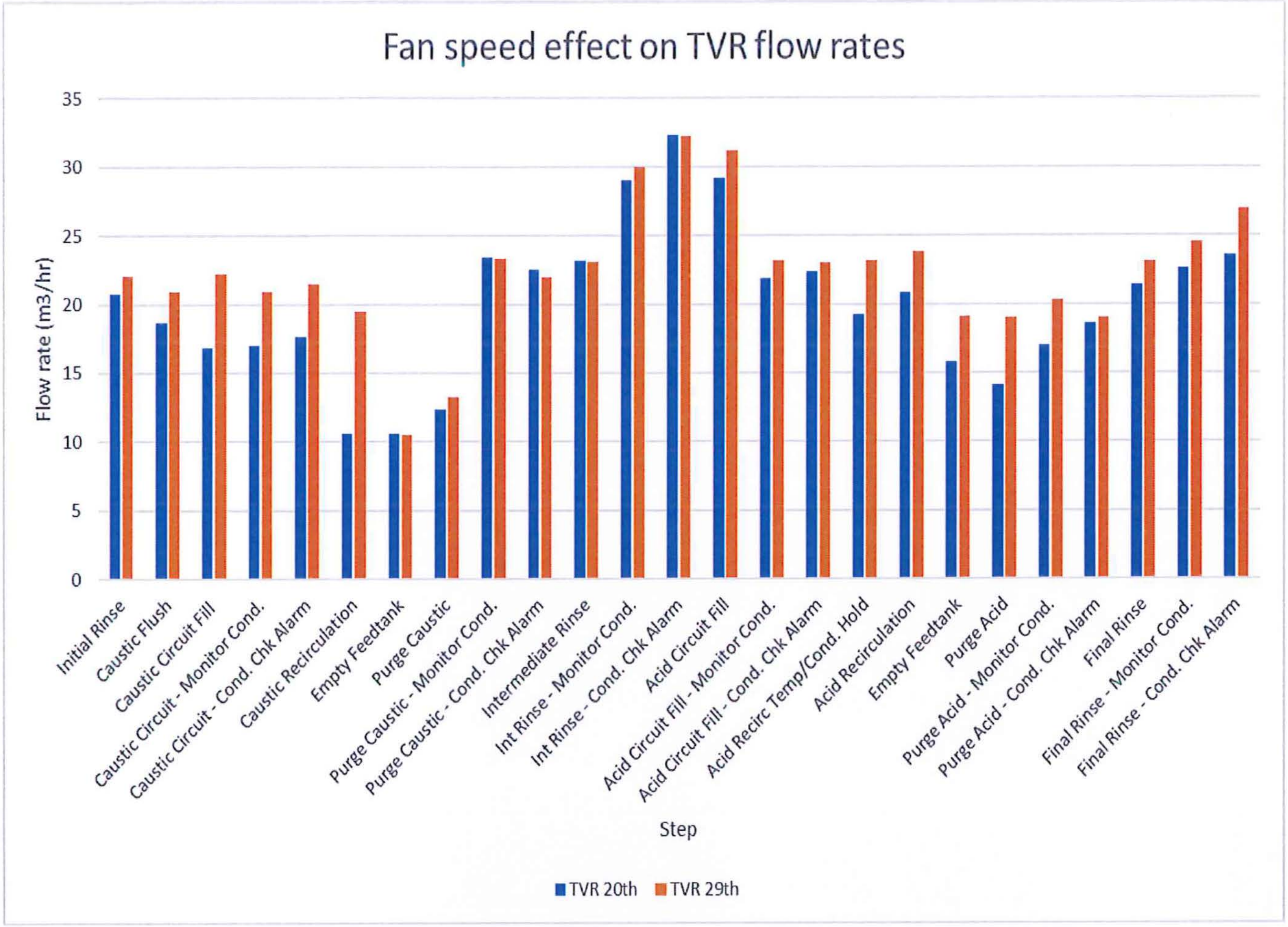
Appendices

Appendix 1: Fan speeds across the CIP

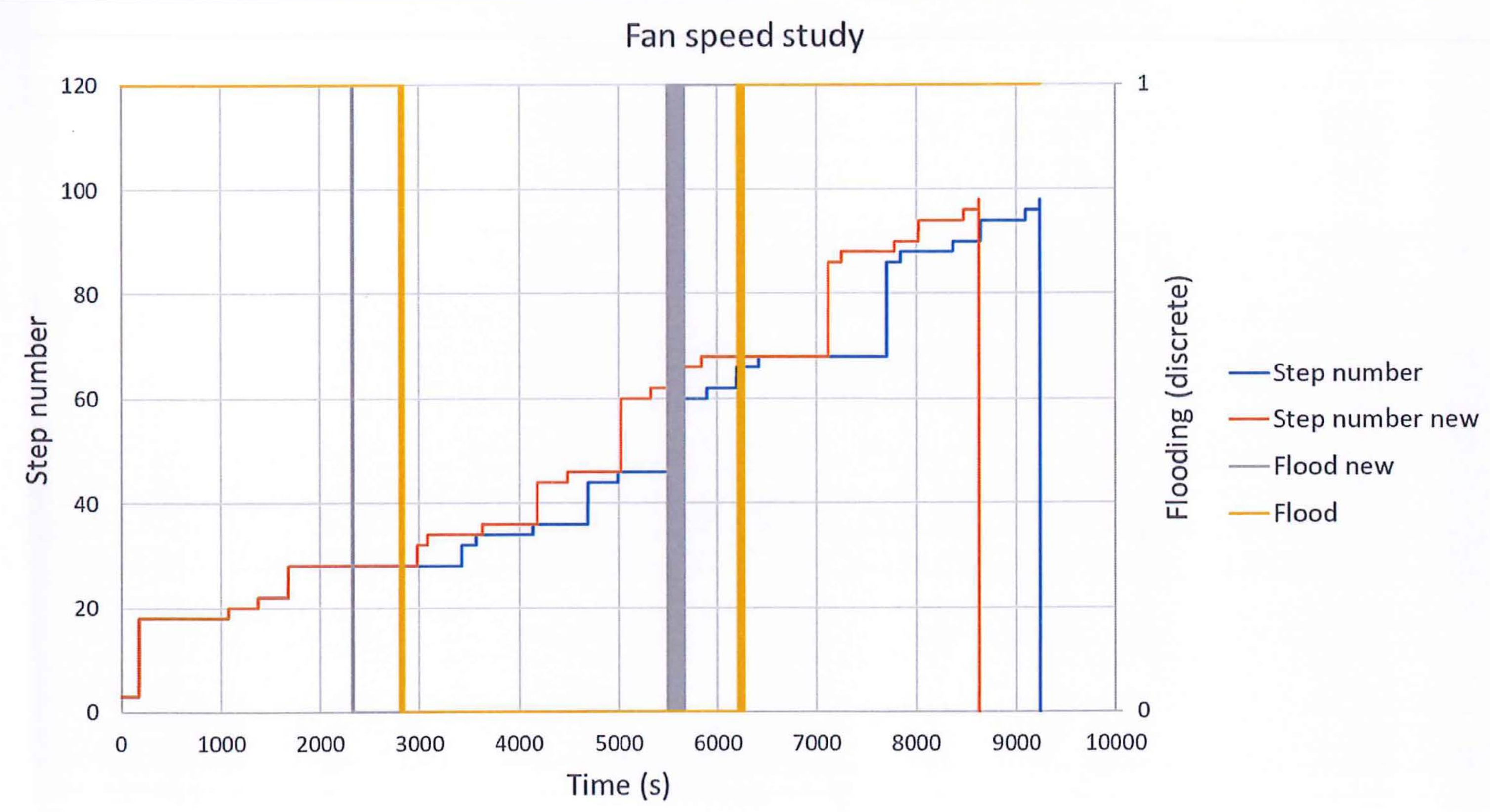


Appendix 2: Flow rate comparison.





Appendix 3: Before and after CIP change



Appendix 6: Acid Recirculation details.

The length of the acid recirculation was 20 minutes with the whole acid wash process contributing to almost half of the length of the CIP. The potential for time savings is the greatest in this step. The following table shows the literature suggesting that the 20-minute step is excessive.

Table 10: Recommendations from several organisations for acid recirculation time.

Who?	What and where?	Acid recirculation length
Endress + Hauser[18]	Process automation company, Australia	10 minutes
IXOM[19]	Chemical Supplier for Synlait, New Zealand	10 minutes
Dept. of Dairy Science, Mannuthy Kerala Veterinary and Animal Sciences University[20]	CIP dairy plant review, India	5-20 minutes
Suncombe[21]	CIP, bio-waste & process company, United Kingdom	5-15 minutes
SPX[22]	Process engineering company, America	10 minutes

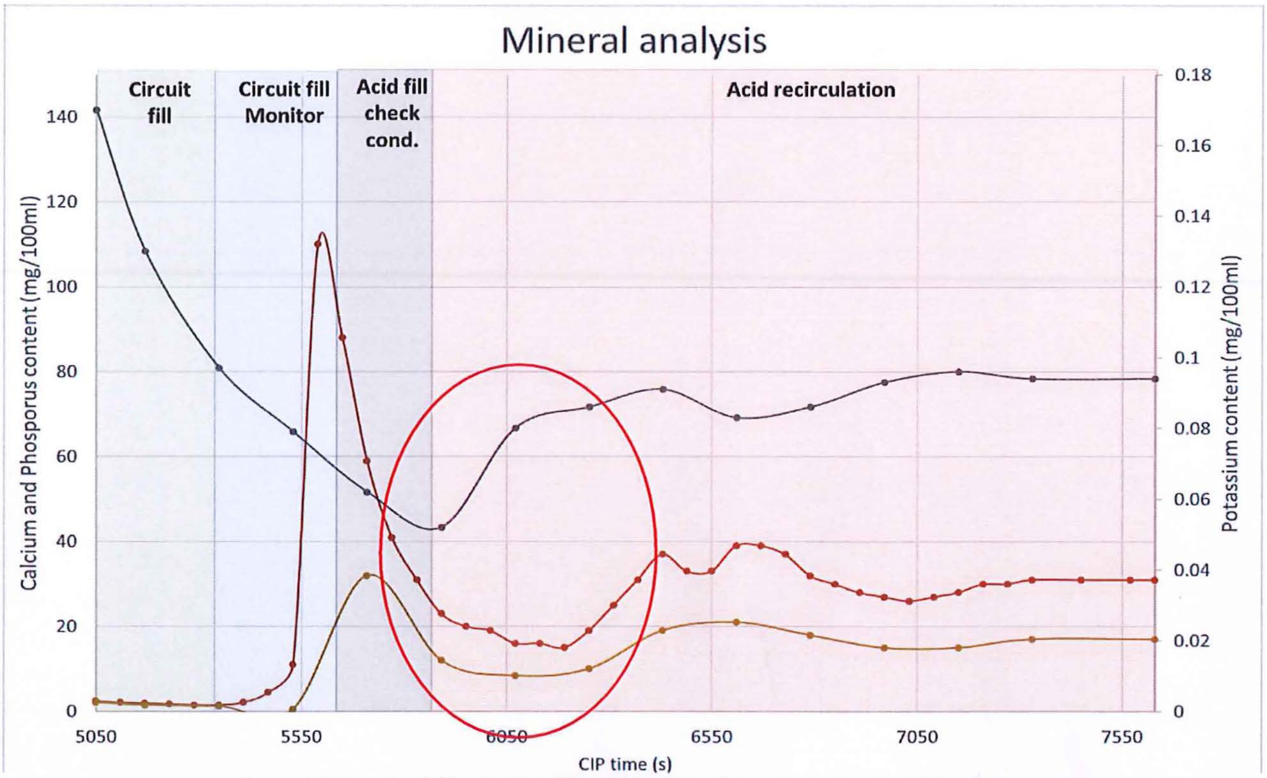


Figure 16: Levels of dissolved solids within the acid wash during the CIP process.

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[18] https://www.endress.com/en/industry-expertise/food-beverage-productivity-quality-cost/cip-process-efficiency

[19] Interview with Ray Struthers, Ixom report in appendix 6.

[20] https://www.researchgate.net/publication/271254246_Cleaning-In-Place_CIP_System_in_Dairy_Plant-_Review

[21] https://www.slideshare.net/KyriakosMichalaki/suncombe-cip-overview-presentation

[22] https://www.spxflow.com/en/assets/pdf/CIP_Systems_22003_05_02_2013_GB_tcm11-7665.pdf

This potential for time savings needs to be validated for this specific system so several samples were taken over the course of several CIP acid washes, to determine whether it was appropriate to implement this time reduction. The result of the testing can be seen in **Figure 16**, where it highlights that mineral removal is completed only a few minutes into the acid wash. The reason the levels increase after this step is because the acid recirculation recycles the solution back through the system. So the mineral laden initial solution is passing back through the system and being sampled again. It has been mixed in its path through the system and so the concentration of minerals has been spread through the solution resulting in a slight lower 2nd peak. A second and third test was also completed to confirm these results. They showed the same trend, so the acid recirculation was reduced by 10 minutes.

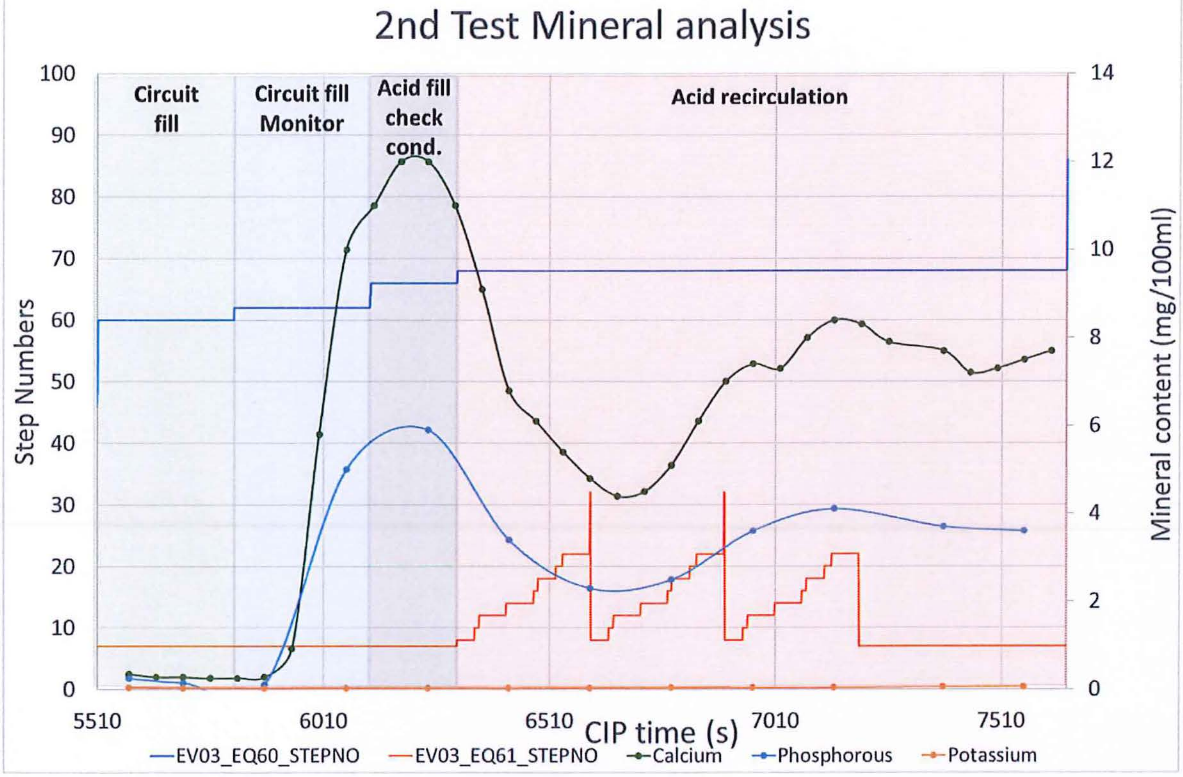


Figure 17: Acid wash validation to confirm the effectiveness of the step and justify a reduction in step time.

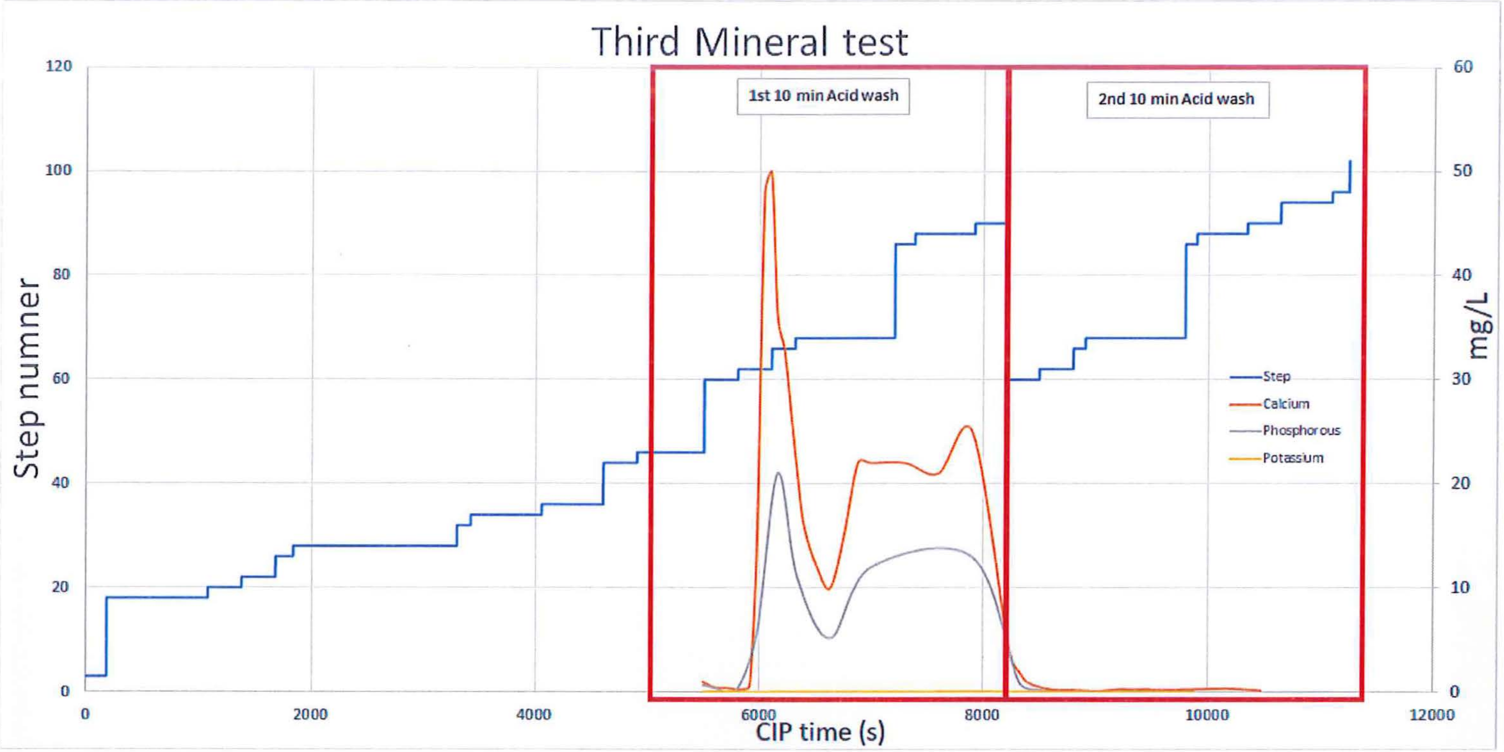


Figure 18: Third test showing that a 10-minute wash is sufficient to clean the system.

The third test run on a CIP that completed two 10 minutes acid washes, **Figure 18**. These washes had a purge in-between. So, in total it still was a 20-minute wash, but it was possible measure the effectiveness of the first half of the wash and the second half. The test showed that there were no minerals remaining in the system for the second wash meaning that all the cleaning was done in the first 10 minutes.

Appendix 7: IXOM Evaporator Report

Evap 3 Acid Streamline

To: Adrian Coursey
Copies: Antony Moess
Assessed by: Ray
Audit Date: 7.11.2018

Date received: 9.1.2019

OVERVIEW

Assessment and analysis of samples from the Synlait Evap 3 CIP were carried out to determine if the acid recirculation stage could be optimised through Ixom's Acid Streamline programme.

SUMMARY AND RECOMMENDATIONS

The evaporator seems to be cleaning up well although there are some minor issues that may need addressing.

The key concern in this plant is the timing of the CCP diverts which occur during the caustic recirculation stage. There is a lot of cold water being added whilst the CCP diverts are being done which dilutes down the caustic. During this stage, the drain valve also opens allowing the loss of the caustic solution to drain. Feed temperatures during the Caustic recirculation fluctuated about 84°C to allow the operators perform the CCP diverts. These CCP diverts should be done at the end of the CIP during the final rinse or after the CIP to minimise caustic losses whilst not adding any time to the overall turnaround of the evaporator. Changing the CCP divert timing also provides better stability during the caustic recirculation stage, ensuring flow and coverage across the evaporator during this critical stage of the evaporator.

Evaporator Feed Tank levels could be increased to above 50% on all steps to reduce the likelihood of a vortex forming in the feed tank.

The Spray Ball sequence currently starts during the recirculation step, this should begin during the Caustic Pre-flush to ensure that all areas are getting contact throughout the CIP process.

Caustic Pre-Flush may need to be extended another 300 seconds as the COD levels were still high when then evap went into recirculation step.

This is a 700 second circuit and the dosing setpoints of 300 s are too short although the circuit is dosed to conductivity. Coarse chemical dosing may need to be investigated, it appears there is not enough chemical going in at the start of the chemical dose steps. Fine dosing should be used to control conductivity.

CIP OBSERVATIONS

The CIP performed was a Rinse/Caustic Pre-flush/Caustic Recirc/Rinse/Acid/Rinse.

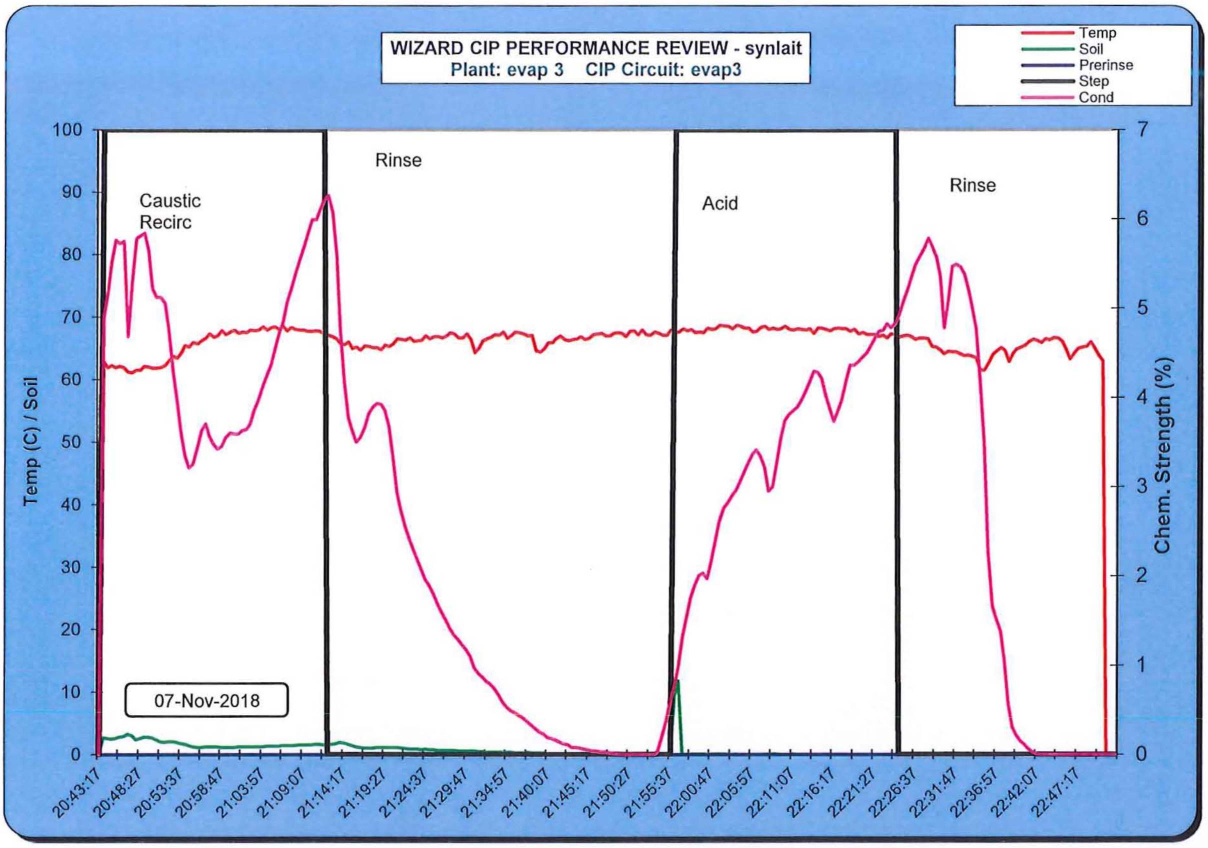
Flow rate on product:	64m^3/hr
Total actual CIP time:	2 hour 42 minutes
CIP Lap time:	Approximately 700 seconds
CIP flow rate:	70m^3/hr
Caustic product:	D-Zolv
Acid product:	Nitric Acid

Off Product
Off product at 7.47pm
Flushing to drain

Rinse
CIP started at 8.04pm - Rinse to drain for 180 seconds.

Caustic Pre-flush step
At approximately 8.07pm – 900 seconds, conductivity was fine at 20 to 25ms. This could be extended as COD analysis showed that there were still high levels of soil before the caustic recirculation began.

Caustic Recirculation
Caustic recirc fill plant with caustic 8.22pm – 300 seconds.
Caustic fill waiting for conductivity
Caustic Recirculation started 8.33pm – 1200 seconds.
Conductivity hold due to no backend flow. CCP's may have coincided with this occurring. There was also cold water addition during the caustic recirculation. It is uncertain as to where this water addition took place as it was not added to the balance tank. Hugh is to investigate further. The wizard graph below shows that the conductivity drops while the CCP's are done and the evaporator struggles to dose enough additional caustic before the step is finished.
Caustic temperature going into the first effect is at 84°c. This may need to be lowered to 75 to 80°c.
Empty feed tank 9.04pm



COD levels began high and remained high during the caustic recirculation averaging >4100 mg/L. An increase in the caustic preflush timer would render this recirculation stage more effective. Ideally a COD level of 1500 mg/L is targeted for caustic stages and this evaporator shows 2-3 times that level.

Intermediate –rinse
Purge Caustic 9.05 – 550 seconds. This may need to be extended to 700 seconds
Monitors Conductivity 9.15
Intermediate rinse 9.30pm – 600 seconds
Rinse end 9.40pm

Acid step

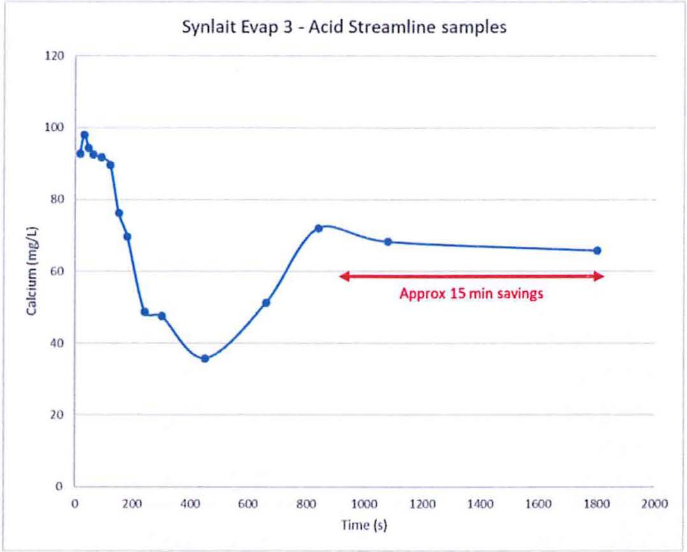
Prime Plant with Acid 9.40 – 300 seconds. This may need to be extended to 600 seconds
Feed tank level 61%.
Took the Acid streamline samples.
Acid recirculation finished 10.18
Empty Feed tank 10.18

Final rinse
Purge Acid
Rinse to Conductivity

CIP ended at 10.46pm

SAMPLE ANALYSIS

Analysis of samples taken during the acid recirculation stages are as depicted below. These results indicate that approximately 15 min of time savings can be achieved during the acid recirculation stage.



ACKNOWLEDGEMENTS

Thanks to the night shift staff for their assistance with this CIP review.

Disclaimer: Ixom has prepared this report on a fee free basis using information and data made available by or through your organisation and its personnel. To the extent permissible under New Zealand law, Ixom, its related companies and personnel of each of those entities disclaim and exclude all direct and indirect liability, whether in contract, tort, commercial law or under any statute, for any loss, damage, expense, cost, claim, incident or outgoing that results from or in connection with: (i) your organisation's reliance on any of the information or recommendations provided by Ixom in, or in connection with, this report; and (ii) the report's contents or the suitability, accuracy or completeness of any of the contents or recommendations contained or referred to in it. In adopting any recommendations or advice contained in this report your organisation does so at its own risk. By accepting or using this report or its contents your organisation acknowledges and agrees to this disclaimer and its terms. To the extent that this disclaimer is contrary to any New Zealand statute, Ixom its related companies and personnel of each of those entities limit their liability in the manner (if any) permitted under the provisions of the relevant statute.

Appendix 8: Flooding Analysis

The effect of the flooding can be seen in the ***Figure 19***. The flooding could be contributing to up to 15 minutes of delays per CIP run. The delay is caused as the caustic reservoir built up from the flooding is slowing down the steps between caustic purge and intermediate rinse. This is because additional water needs to be pumped in to dilute the reservoir enough for it to not show up on conductivity reading from the back end sensor. The flooding is caused by fouling as there is no flooding when a CIP

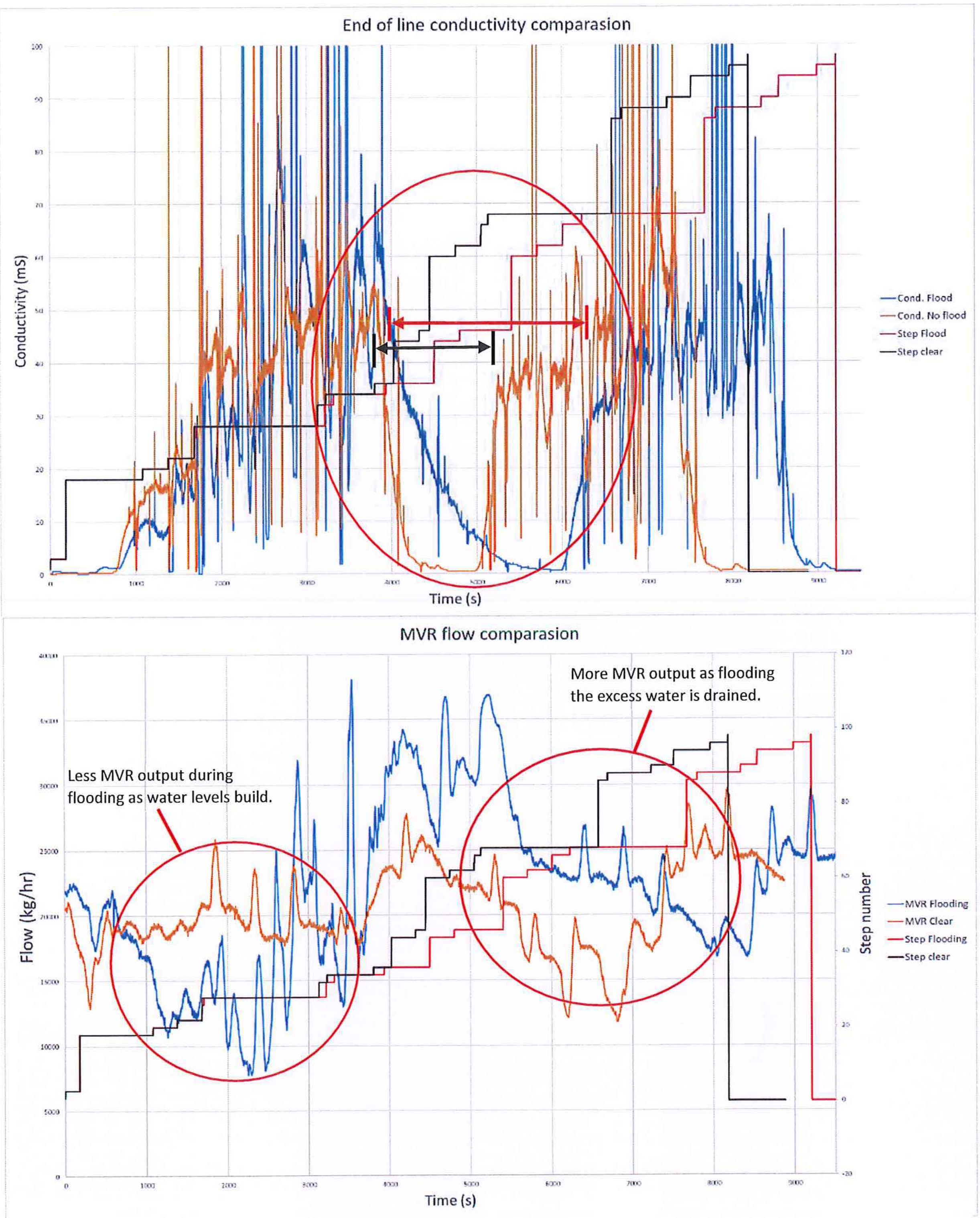


Figure 19: Graph comparing trend between flooding (blue) and non-flooded (orange) CIP sets.

is run on a clean system. As demonstrated in the 2nd evaporator CIP that occurs during the chamber wash. The flooding has been first detected as early in the process as step 18 – Caustic Flush, and floods through until it starts draining during step 68 - Acid Recirculation, with it all drained by step 88 – Purge Acid after 114 minutes.

Flooded: as determined by sight glass.		**Time flooded(minutes)**
🟥	***Pass A***	**74**
⬜	***Pass B***	**114**
🟧	***Pass C***	**68**
🟩	***Separators***	**95**

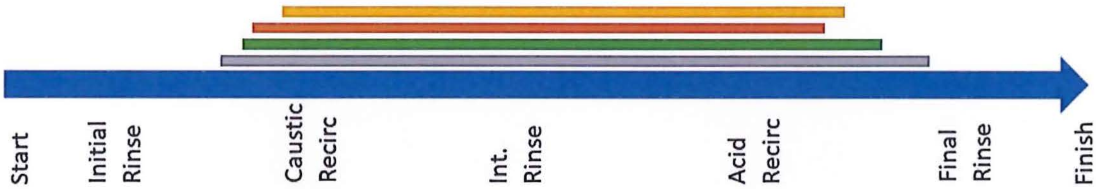


Figure 20: Flooding time details.

Flooding occurs main MVR calandria and the separators, see **Figure 21** for details and sequencing. For the emergency stop to trigger the flooding will need to filling faster than pass F can pump out and will require around 13 cubic metres of liquid.

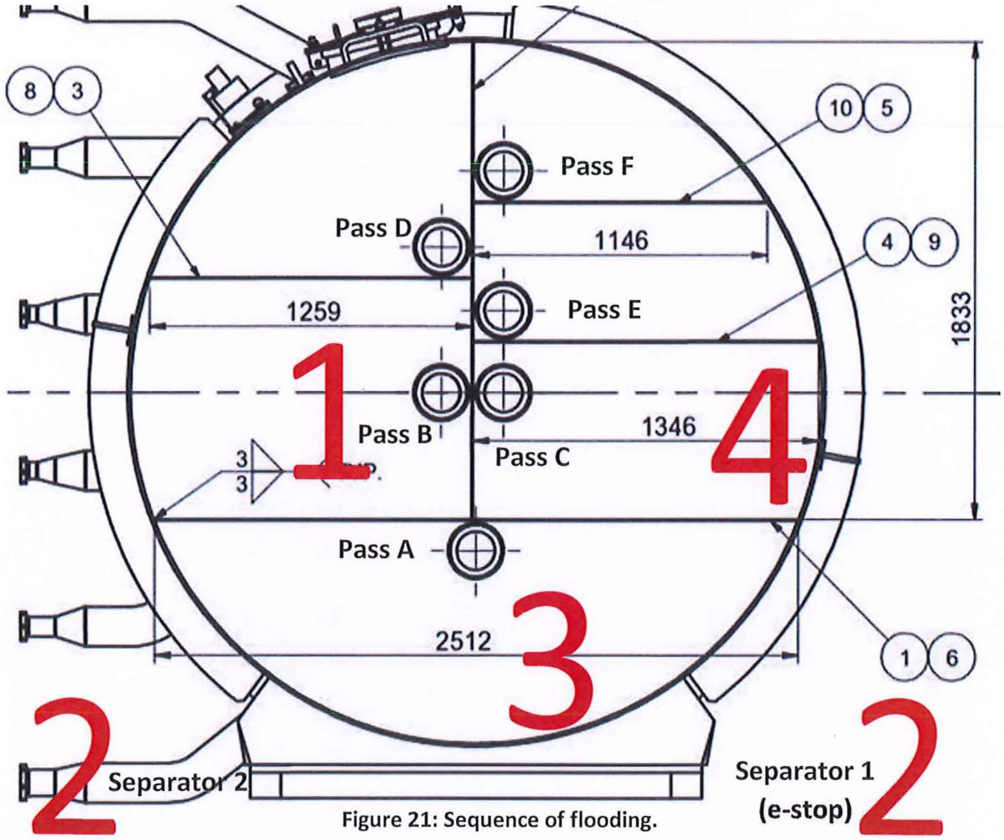


Figure 21: Sequence of flooding.

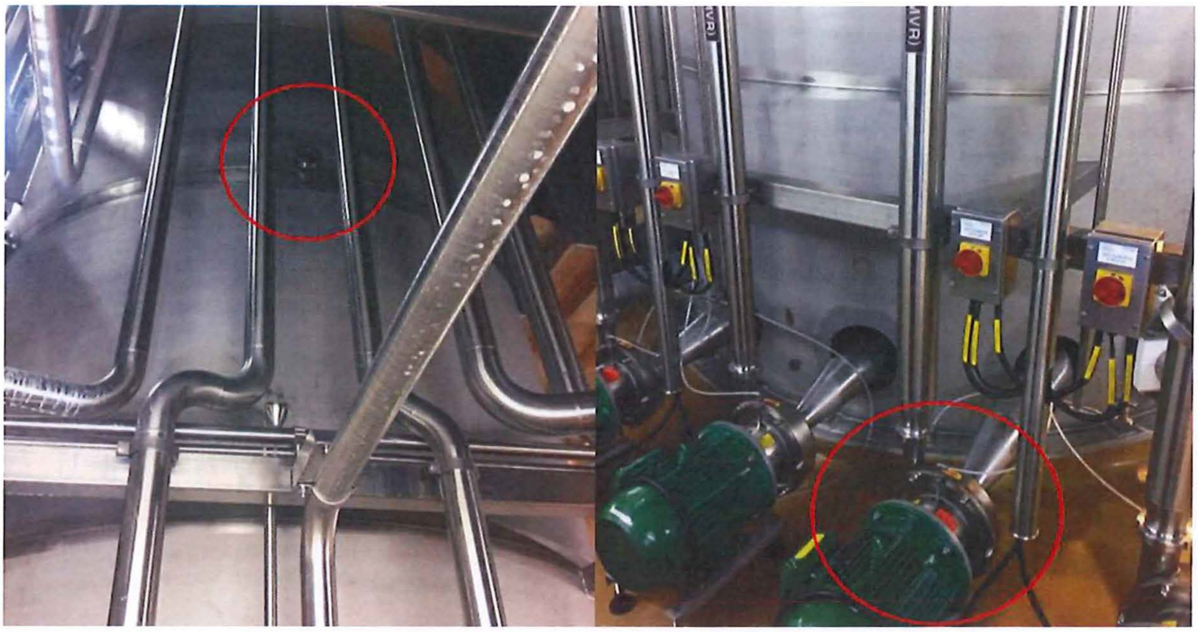
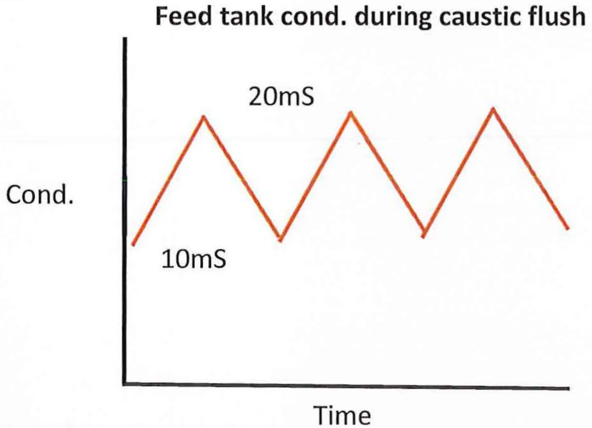


Figure 22: Flooding is spotted during the CIP through the sight glass. The highlighted glass and 7.5 kW pump are the first to flood.

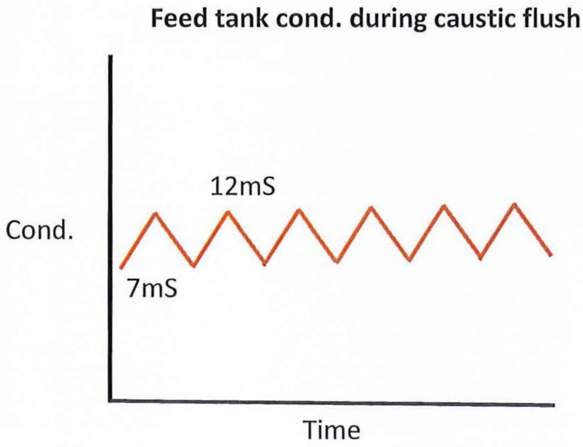
The solution was changing the caustic flush settings.

Current



Feed tank cond. during caustic flush

Tested



Feed tank cond. during caustic flush

Conductivity controlled by the setpoint:

E3CT012123_SP101

When the conductivity gets below this setpoint the system will dose caustic solution into the feed tank.

The amount of caustic solution is determined in litres by the setpoint:

EV03_CIPparSP101

The current system was set at 10mS and dosed 1.5l of caustic into the feed tank. The target of the caustic wash is 10mS and as you can see in the first graph it never was 10mS.

The set points were changed in a test to:

E3CT012123_SP101 = 7mS

EV03_CIPparSP101 = 0.7l

The trend can be seen on the left. Closer to the target.

This automation project would like to add two additional set points (editable from the HMI) and two additional enables to the caustic flush, so the conductivity can be stepped up during the caustic flush. This will help with the flooding issue as the differing concentrations of caustic solution will remove the fouling in parts, rather than all of it at once. See below for a graphical representation.

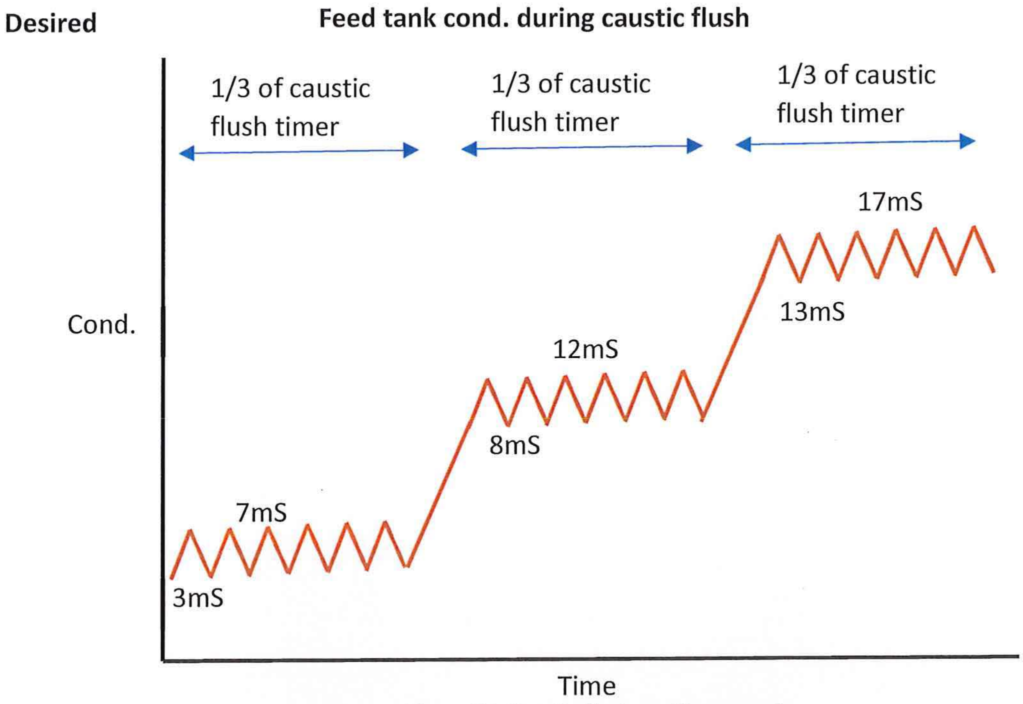


Figure 23: Caustic flush profile example.

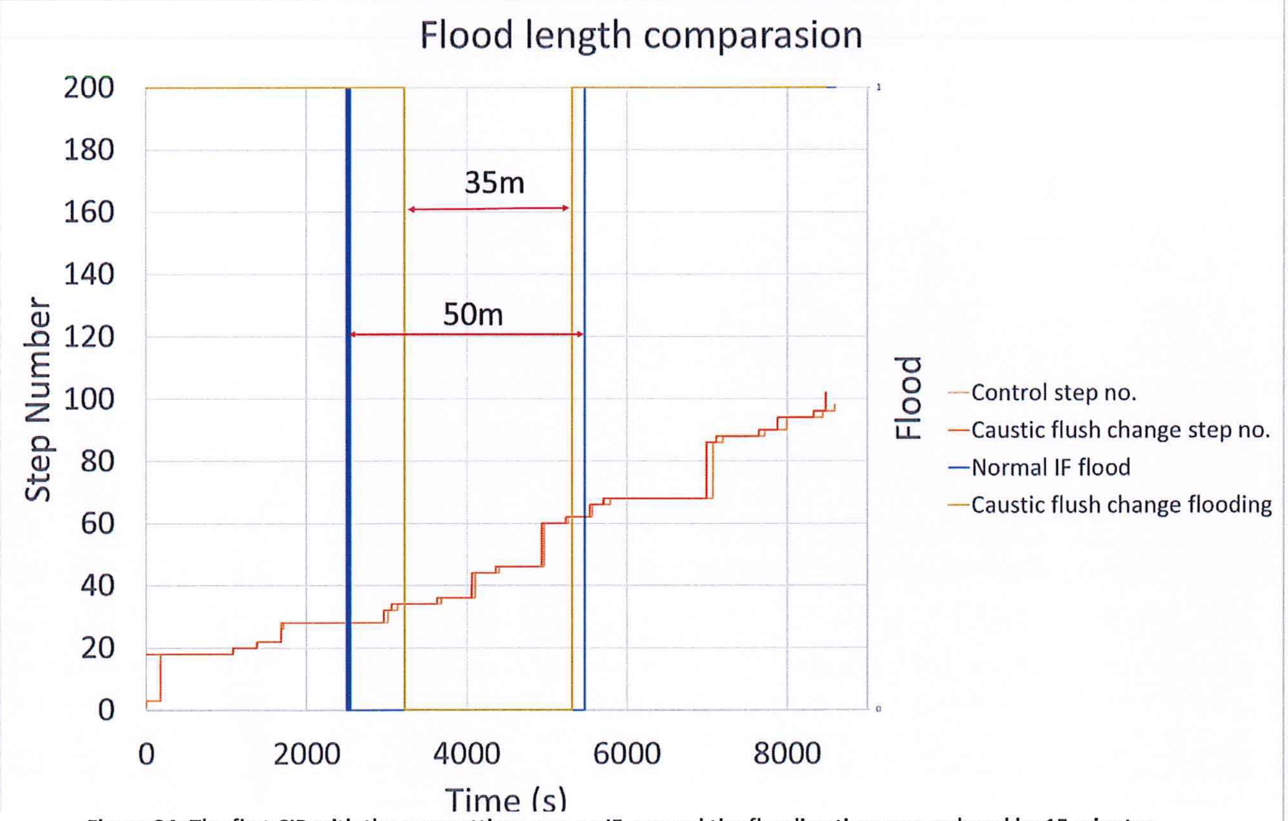


Figure 24: The first CIP with the new settings was an IF run and the flooding time was reduced by 15 minutes.

Appendix 9: Sensor Summary

9.1 Initial Rinse and Caustic Wash

Goal: To clear the main foulant out of the system which consists of milk fats and proteins.

Turbidity Measurement

Suspended solids meter

The turbidity measurement is a measure of the solution's clarity. If there is fouling being removed within the system, the solution will be saturated with small particles. These particles can be measured by a suspended solids meter that can determine the level of fouling being removed during the wash. The more particles in the water, the more cleaning that is occurring, conversely if the suspended solids meter is reading close to zero then the water is clear and either there is no more fouling to be removed by the caustic solution or, the caustic strength isn't enough to break the bonds binding the remaining fouling to the interior stainless-steel walls. See appendix 7.1 for more information of funtionaility.

Steps looking at cleaning milk fouling will be able to transition on based on readings from this sensor. I.e. If suspended solids falls beneath a certain setpoint for a certain amount of time then the step can transistion. This sensor needs to be posistioned on the back-end of the system as it will measure a representation of the solution that has passed through the entire system. So once the solution has

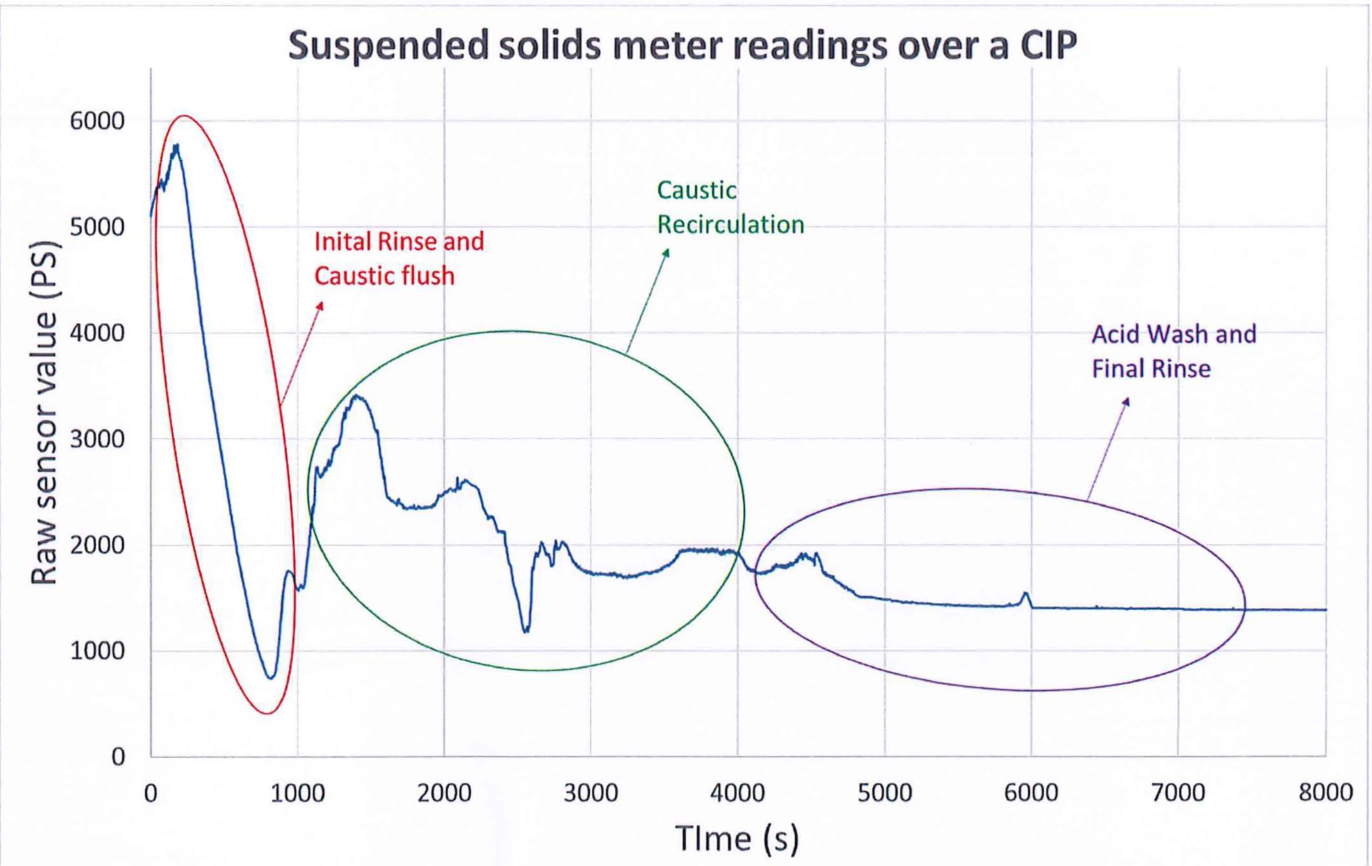


Figure 25: A profile of sensor readings over a CIP. This trend is an average of 10 measurements from the "Black Box" measuring device.

minimal suspended solids within it, it is reasonable to assume that the step has completed it goal of removing fouling from the system. To get an idea of what the sensor reads during a CIP a suspended solids meter was tested using Synlaits "Black Box" test rig (**Figure 25**), which allows for sensors to be tested without them having to be installed within the main line.

The figure shows the solids dropping as the low concentration *Caustic Flush removes* the milk film and other weakly bonded milk desposits from the system. High levels of suspended solids initally then dropping away as the steps effectiveness decreases. The higher concentration *Caustic Recirculation* removes the remaining milk fouling that is strongly bonded to the internal walls of the system, this boosts the solids within the solution. The levels don't drop off as they do in the *Caustic Flush* as the solution is being recirculated back through the system. Finally during the *Acid Wash* and *Final Rinse* most of the fouling has been removed from the system and the solution is clear through out these steps. A problem with this sensor is that it is possible that the concentration of caustic is not strong enough to remove the hardest to remove fouling from the system and the solution would come back clear as the fouling has remained on the walls and will not be present in the solution. This may provide a false positive to the CIP software running the CIP, allowing the process to proceed when the cleaning has not been completed. A solution to this may be a multi-sensor approach using direct measurement. Such as a conductivity watch dog that monitors the concentration of caustic throughout this step.

Direct Measurement

Ultrasonic sensor

Ultrasonic sensors have been tested within a CIP system and were able to detect the thickness of fouling upon the walls down to micro-metres[23].

The sensors use a time of flight and acoustic method to calculate this fouling thickness and had ±1µm in accuracy (see appendix 7.2). For these sensors to function in Synlait's CIP they would need to be place in strategic places throughout the system where the cleaning will take the longest. The system will need to be evaluated with respect to risk, flowrates and temperature to provide a sensor system that will be an accurate representation of the system. The idea is that if the sensors are placed in areas within the system that are the hardest to clean, it is reasonable to assume the entire system is clean when the ultrasonic sensors detect these areas to be clear. Such places occur towards the end of the system as the caustic becomes saturated with fouling earlier in the system and it loses it cleaning

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[23] "A multi-sensor approach for fouling level assessment in clean-in-place processes" – Alessando Simeone, Nicolas Watson, Ian Sterritt, Elliot Woolley. **Found on R drive**: *R:\SYNLAIT MILK\TECHNICAL PROCESS\6- MEM Students\CIP Optimisation - Hugh Paterson\Literature*

properties until fresh caustic is circulated through. Other places include area where the mechanical cleaning force is the weakest, such as in long straight pipes or in specific places in U-bends.

This sensor does not suffer some the same issue as the turbidity measurement as if the fouling is present it will be measured. The problem this type of measurement faces is the distribution of the fouling at the later stages of cleaning. At the start there is a film that covers the interior wall of the pipe, but by the end of the caustic wash the fouling becomes patchy as only the most strongly adhered fouling remains on the walls. Due to the narrow band of measurement of these sensors it is possible for the reading to be clear when there is still fouling within the system, see **Figure 26**. The way to counteract this is having multiple ultrasonic sensors throughout the system to increase the chances of catching one of these patches or using this system in tandem with the turbidity meter that can judge the fouling overall based on the solutions composition.

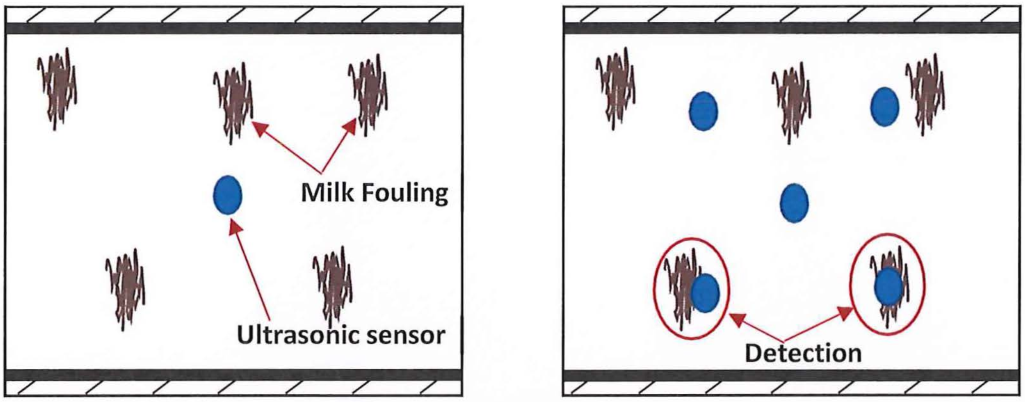

Figure 26: Cross section of a pipe showing milk fouling towards the end of the caustic cycle as it becomes patchy and harder to detect (left), chances of detection are improved with more sensors or diverse measurement options (right).

9.2 Intermediate Rinse

Goal: To clear the caustic solution from the system before the acid solution is introduced, to avoid neutralisation.

Conductivity Measurement

Conductivity sensor

This step is already being completed within the CIP process, though it still does include a timer. The caustic wash has a conductivity due to it being a basic solution. At the end of the caustic recirculation timer the system purges the caustic within the system by flushing water through the system. **Figure 27** shows the dropping conductivity of the solution exiting the system. The caustic must be expunged from the system by the time the *Intermediate Rinse* is complete. If the system was to run without timers, then an additional back-end conductivity sensor will be required to compare values with, in case of a sensor malfunction which could prematurely transition steps.

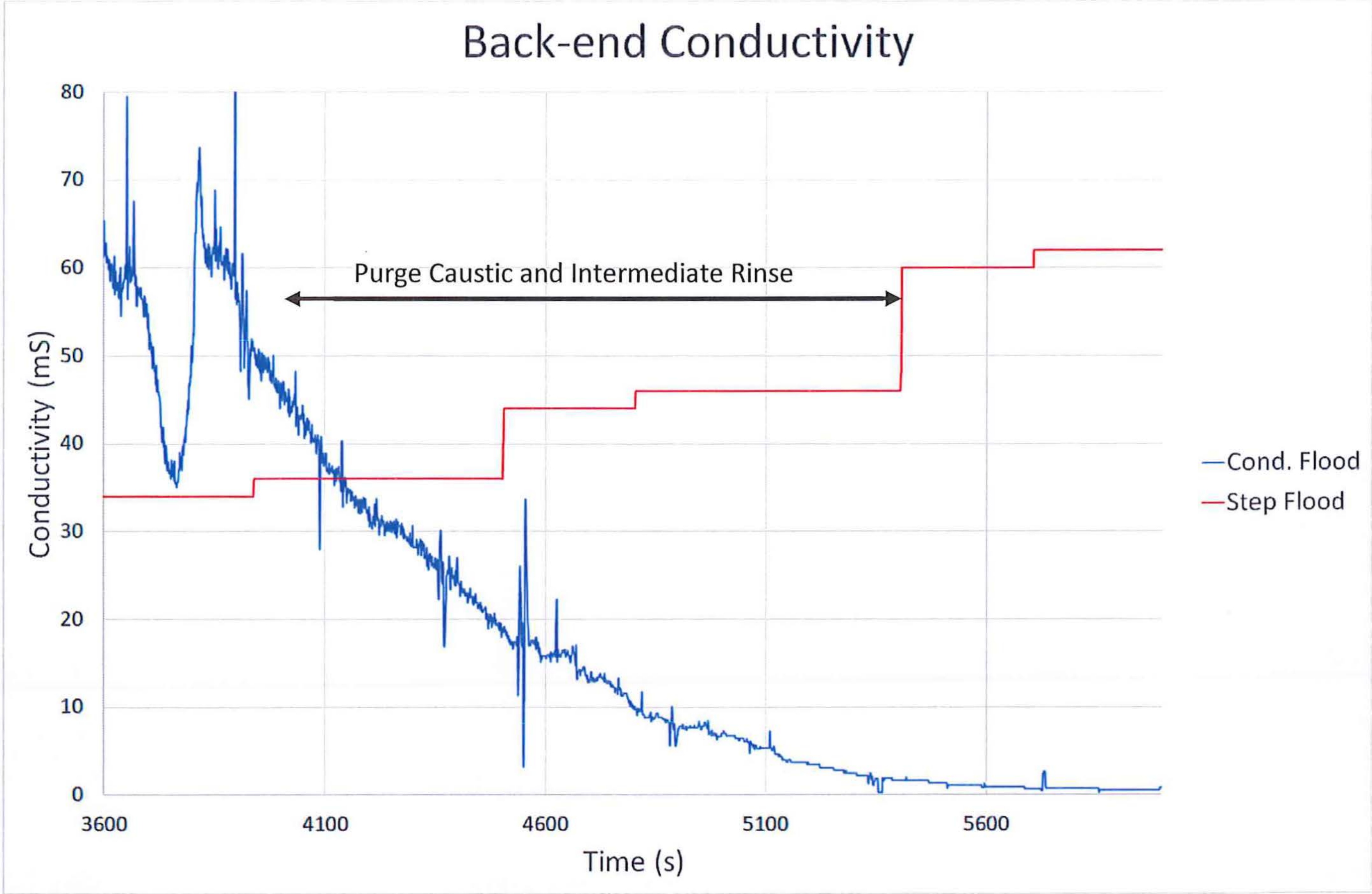

Figure 27: Conductivity taken from a sensor position at the end of the circuit, so an appropriate representation of the system's conductivity can be measured.

9.3 Acid Wash

Goal: To clear the mineral deposits left in the system from the milk and water hardness.

Dissolved Mineral Content Measurement

Total dissolved solids meter (conductivity meter setting)

The mineral deposits within the system react with the acid and become an aqueous solution that is taken away within the CIP solution. The level of minerals within in the solution can be measured. The most accurate measurement is done in a lab where the solution is evaporated, and the remaining solids are tested for minerals. This is not viable for real time monitoring of the system, so a less accurate TDS meter method could be used to measure mineral levels. The reason it is less accurate is because it calculates ALL the total solids not just the solids that are of interest, such as calcium and phosphorous. But with some calibration is should be possible to find a trend that works as an indicator to end the acid wash process.

Figure 28 shows IXOM results when testing for one of the main minerals present in milk, Calcium. This graph shows an acid wash step and its levels of calcium throughout. The acid wash is recirculated through the system which causes the shape in the trend. As the acid passes the sample point on the for the first time the levels are dropping as most of the minerals are cleaned out by the initial doses of acid. So, there is less minerals for the later doses to remove, this causes the sharp decline in calcium levels. The second spike is the original acid with the high levels of calcium returning and being sampled a second time. The spike is lower as the solution is recirculated through the system and is mixed together and the solution within the system trends toward an equilibrium state with the dissolved calcium dispersed through the circuits solution. As the calcium levels do not increase after this peak it shows that there is no remain mineral fouling left in the system. During this project other tests were done before the IXOM results, they can be found in appendix 7.3. The IXOM results helps to validate these results acquired by Synlait.

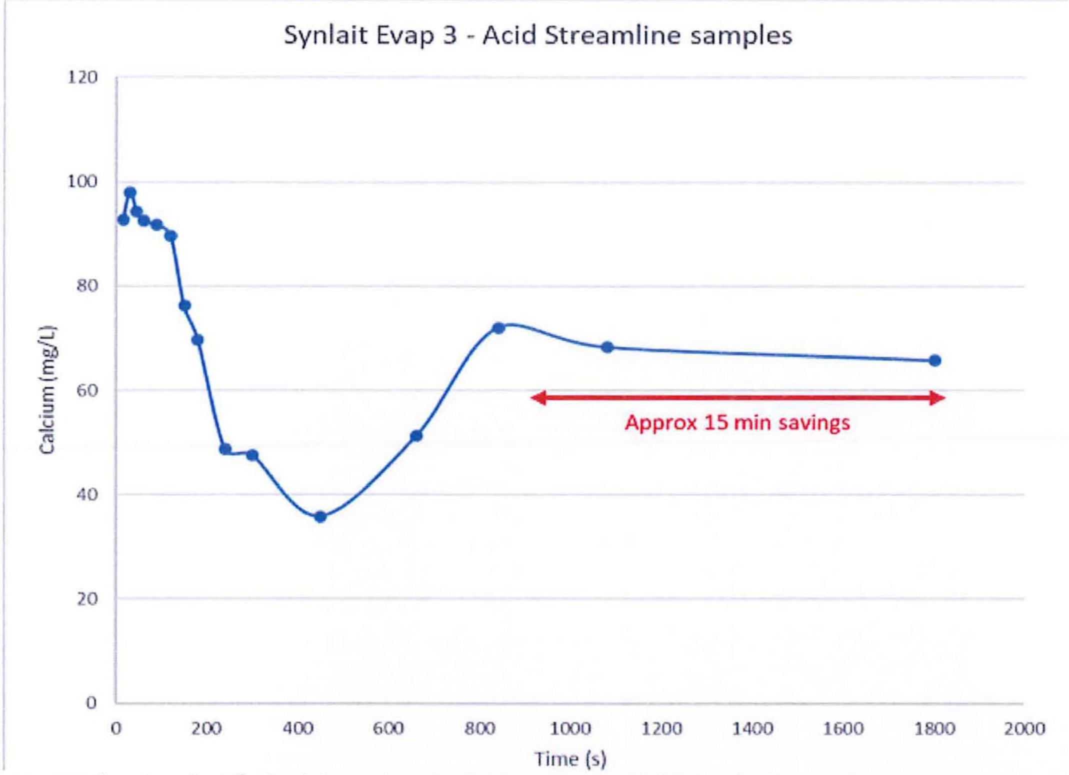

Figure 28: IXOM's mineral analysis of the acid wash of EV03. This also highlights the potential time savings that could be achieved.

The good thing about this method is that the standard conductivity probe could be used. Instrumatics states that conductivity measurements are able detect 'Total Dissolved Solids (ppm), conductivity (µS/cm) or Resistivity (MΩ/cm) and can indicate the total impurities present.'[24] So being able to use existing assets would decrease the price for implementing this control method.

The problem with this sensor is that it is untested using this setting, and it is unknown what kind of results the inline TDS reading will bring, and some intensive calibration and testing will be required to get this to work. This sensor has the potential for the most savings across the entire CIP as the acid wash in the process that has the buffer time within it, and so the TDS meter is worth the investment of time and money to get it up and running.

9.4 Final Rinse

Goal: To clear out the acidic residues and any other contaminants within the system before the product is reintroduced.

Nitrates measurement

Nitrate sensor

The nitric acid from the acid wash leaves harmful residues such as nitrates and nitrites within the system. The final rinse must remove them from the system. This is a critically important step as an ineffective process at this stage would lead to direct contamination of the final product. This could lead to an entire batch being out of spec and dumped. Or if the plant is on an infant formula run the contaminants could cause harm to a baby. A nitrate sensor can directly measure the nitrate levels within the system and combined with conductivity reading to ensure there is no traces of acid remaining in the system, this gives two methods of measuring this steps effectiveness.

A nitrate sensor has been tested over the course of this project. The sensor was developed by Hydrometrics and called the Nitrate GW50 Groundwater Optical Nitrate Sensor. This sensor has been validated by several lab tests, comparing the measured value with the more accurate lab tested value that were taken from samples of the same solution the nitrate sensor was testing. The results of a test can be seen in **Figure 29**, showing that the sensor seems to be working, see appendix 7.4 for additional validation. Safe nitrite levels in drinking water are considered below 0.2mg/L by the Ministry of Health[25] and during testing nitrites were present at 0.007mg/L at its highest measured value across two tests, so were considered negligible. When the conductivity has dropped to under 1mS and nitrates drop to safe level, then the final rinse is complete. This 'safe level' is described as

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[24] https://instrumatics.co.nz/category/category-analytical-1/sub-category-conductivity

[25] Drinking water standards for New Zealand- Ministry of Health, 2008.
https://www.health.govt.nz/system/files/documents/publications/drinking-water-standards-2008-jun14.pdf

50mg/L by Ministry of Health and 50mg/L in DPC1 from the Ministry of Primary Industries[26] specifically regarding dairy processing.

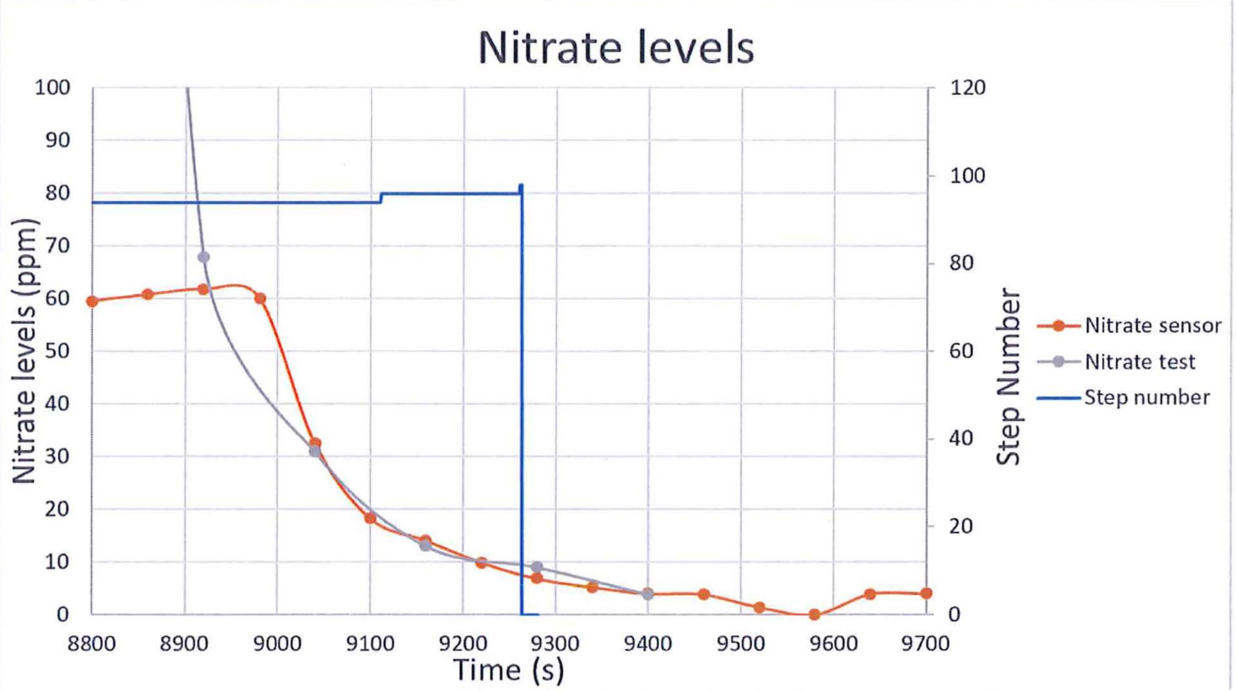

Figure 29: The nitrate levels within the final rinse solution, this shows that the nitrate sensor is reading accurately, the first few readings are when the sensor had not been connected to the main circuit.

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[26] Animal Products (Dairy): Approved Criteria for General Dairy Processing – MAF, 2011. https://www.mpi.govt.nz/dmsdocument/10145/send - Also states 5mg/L for nitrite.

Appendix 10: Gap Analysis

Step	Current State	Target State	Difference	Action Plan	Priority
3 – Initial -Rinse	Run's for 180 seconds and transitions when the step time is done.	Not run at all. A pre-rinse is done before the CIP starts so this step is doesn't achieve any additional cleaning	180 seconds difference. Put this time into increasing the caustic flush, as it could use this extra three minutes to help deal with flooding.	1. Change timer value **CIPASP301** to 1 second. Leave the step in the code, so operators can access set point in case the rinse is needed in the future. 2. Can be done on HMI – no work required from automation team.	**Medium**
18 – Caustic Flush	Run's for 900 seconds and transitions when the step time is done.	Run until suspended solids meter and ultrasonic sensors detect an appropriate reduction in the level of fouling within the system.	The difference is that the caustic flush will likely run longer depending on the set point, but it will clean the system better. Some of the length increase of this flush can be absorbed by the removal of the initial rinse. The system will also be much cleaner for the caustic recirculation, reducing the length of this step.	1. Test turbidity sensors and ultrasonic sensors purchased and installed. 2. Calibrate the sensors by testing on the current CIP system. 3. Analyse the trends the sensors are outputting over the course of a timer-based CIP. Find the 'zero' value of the SS meter by taken readings from the acid recirculation step as the solution is clear as this stage of the process.	High

Step	Current State	Target State	Difference	Action Plan	Priority
				4. Determine viable set points for this test based on the trends from both IF and WMP. And determine whether any additional signal processing is required to get robust readings with minimal noise from the sensor. 5. Automation to implement the new set points for the step to transition with. 6. Determine the impact of the rest of the CIP especially the caustic recirculation. And validate the change.	🟥
20 - Caustic Circuit Fill	Runs for 300s seconds and transitions when the step time is done.	Runs until the conductivity sensor **E3CT012323** at the back end of the circuit reaches the target conductivity required for the caustic recirculation step, 50mS. This	This will the increase the time of this step as the circuit is around 600 – 660 seconds long. However, it will result in the next two steps being only a couple of seconds long. And no cond. alarms	1. Analyse the trend of several past CIP's and the backend conductivity readings during this step. 2. Determine viable set points for this step based on caustic recirculation set points, around 50mS. And determine whether any additional signal processing is required to get robust	Low

Step	Current State	Target State	Difference	Action Plan	Priority
		shows that the circuit is full of correctly concentrated chemical.	will occur, as currently they trigger on most CIP's	readings with minimal noise from the sensor. Perhaps investigate re-positioning the back-end conductivity sensor to a place that doesn't get condensate running through it, as it plays havoc with the sensor readings. 3. Automation to implement the new set points. 4. Determine if the step works, this change does not require validation.	
22 – Caustic Circuit Fill - Monitor Control	Runs for around 300s seconds and transitions when the step time is done **OR** when the back-end conductivity sensor **E3CT012323** reads under a set point **E3CT012323HSP103**	The step already transitions on a sensor value. Some signal processing needs to be done on the signal, or a newly positioned back end conductivity sensor.	The issue with the step is that noise spikes and condensate readings on the sensor cause the 60s timer to restart, resulting in lost time. Signal processing such as a moving average or a digital filter that attenuates high values	1. Analyse previous CIP data that encompasses both IF and WMP to final the frequency and magnitude of noise and condensate spikes respectively 2. Moving average will slow response time and slightly slow the step but could fix this issue is the magnitudes are not too high.	Low

Step	Current State	Target State	Difference	Action Plan	Priority
	for 60 seconds (40mS).		caused by noise and condensate will reduce lost time.	3. If the magnitude is too high, then attenuating these values during this step may have to be considered. Or a installed conductivity in a different position. 4. No validation required.	🟩
24 - Caustic Circuit Cond. Check Alarm	Runs for 2 seconds and sets of alarm if certain conditions are not met.	No change.	N/A	N/A	**None**
26 - Caustic Recirc Temp/ Cond hold	Run on average 60s per run, transitions when the temperature and conductivity match the requirements for caustic recirculation, 60 C° and 50mS.	No change, transitions purely based on sensor readings.	N/A	N/A	**None**
28 – Caustic Recirculation	Runs on average 1500s, this step transitions when the	Runs with a minimum time of recirculation (i.e.	Due to a much more effective caustic flush the recirculation only cleans	1. Purchase and install turbidity sensors and ultrasonic sensors.	High

Step	Current State	Target State	Difference	Action Plan	Priority
	step timer is done, if the spray pulses are finished and no diverts tests are being run. Additionally, the timer only counts down when the right conditions of temp and cond. this results in a longer step time.	600s, time of one full recirculation) after that the step will transition when the ultrasonic sensors measure no levels of fouling remaining within the system. Combined with no increase in the suspended solids within the system.	the hardest to remove fouling from the system, so the solution does not become immediately saturated with fouling. This would keep ideal temp. and cond. conditions more reliably. The sensors would reduce CIP times of short production runs as there will be less fouling to remove from the system.	2. Calibrate the sensors using the current CIP system. 3. Analyse the trends the sensors are outputting over the course of a timer-based CIP. For WMP and IF. Will need to work out the standard variation of the suspended solids meter on recirculation. 4. Determine viable set points for this test based on the trends from both IF and WMP. Signal processing will be required on the suspended solids data as the system will need to look at the gradient of the suspended solids trendline. And when the gradient is approaching zero then the system can transition, (provided the ultrasonic sensors detect no more fouling). And a form of averaging will likely be required to smooth the noise from the data.	🟥

Step	Current State	Target State	Difference	Action Plan	Priority
				5. New transition set points will need to be added for the suspended solids meter and potentially the ultrasonic. 6. Validate the effectiveness of the change.	🟥
32 - Empty Feed tank	Runs for around 100 seconds and transitions when the step time is done **and** the level sensor in the tank is reading less than the empty tank set point. However, the step timer is set at 2s, so this steps transition is sensor controlled.	None	N/A	N/A	**None**
34 – Purge Caustic	Runs for around 550s, transitions when the step timer is complete.	Run until the backend conductivity sensor **E3CT012323** reads below a	This reading confirms to the system that no caustic solution remains in the system. Much like	1. Take the same conductivity set point from the next step and use it as a transition to progress.	**Medium**

Step	Current State	Target State	Difference	Action Plan	Priority
		specific set point. Before transitioning to the next step.	the *caustic circuit fill* this will increase the length of this step but decrease the following steps.	2. Analyse past trends to see how noisy this sensor is at this stage of the process to see whether the signal needs to be smoothed. 3. Implement changes, set point needs to be added to the this transition, no validation required.	
36 – Purge Caustic – Monitor Cond.	Runs for an average of 450 seconds and transitions when the step timer is complete, and the conductivity is below a certain set point **E3CT012323HSP101** for 60s[27]. The step timer is set at 10s, so the step is held up by the conductivity	This step needs a logic change, from **AND** logic to –> "Step time done **OR** the conductivity has been below the setpoint for more than 60s."	This logic change allows for the process to pass through this step if the conductivity is already low enough to progress. This step acts as the backstop from the previous step, making sure the conductivity is low with its 60s buffer, rather than just a short drop in cond.	1. And automation change to swap the logic from AND to OR. 2. No validation required as this won't affect operation, it just reduces the chance of issue in the future as if step timer was increased for some reason it would slow the process. As the timer would need to expire for the process could transition, even if the cond. is low enough to suggest the caustic solution has been purged from the system.	**Medium**

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[27] The FD states this set point, but this seems incorrect as it is 50mS. So the step should transition almost immediately. Yet it runs for 450s, so the PLC may be different.

Step	Current State	Target State	Difference	Action Plan	Priority
	being too high to progress. Or the conductivity is too noisy and keeps resetting the 60s.		If the change in the previous step is made this step time will be significantly reduced.		
40 - Purge Caustic – Cond. Chk Alarm	Runs for 2 seconds and sets of alarm if certain conditions are not met.	No change.	N/A	N/A	**None**
44 – Int Rinse	Runs for an average of 300s and transitions when the step timer is done. The intermediate rinse is like the purge caustic step; however, the spray balls are pulsed during this step to remove caustic residues from all the systems surfaces.	This step is irrelevant if the conductivity is reduced by the time this step starts. This step can be removed if the spray ball pulses are added to the purge caustic step.	Removes this time of running water through the system. This water doesn't do any cleaning as all that remains within the system at this stage is mineral deposits. So, no additional cleaning is being completed. This should reduce CIP time by 300s.	1. Once the purge caustic step is validated then either the step timer **CIPASP303** needs to be changed to a few seconds long, or another conductivity set point could be added as a transition condition with **OR** logic, so the timer can be bypassed if the system is functioning correctly. 2. If the step timer is reduced this would require no automation changes and could be implemented and validated immediately.	**Medium**

Step	Current State	Target State	Difference	Action Plan	Priority
46 - Int Rinse – Monitor Cond.	Runs for an average of 600s and transitions when the step timer is done, OR the back-end conductivity **E3CT012323L** drops below a 1000 micro Siemens (mS). Currently this step transitions due to the timer expiring, as the conductivity doesn't decrease enough before the timer expires due to the flooding.	Increase the mS setpoint and use the high sensor **E3CT012323H,** instead of the low sensor. It doesn't work and the step times out every time it runs because the conductivity never gets low enough. If the setpoint increased to 2mS instead of 1mS the system would transition faster, and the concentration of NaOH in the system would be minimal, around 0.1%.	This will make this transition more reliable. And acts as a watchdog step for the rest of the system, confirming that there is little or no NaOH present in the system before the acid is introduced.	1. The sensors that determines the transition will need to be an automation change. From **E3CT012323L** to **E3CT012323H**. 2. The set points can then be changed by the operators. **E3CT012323LSP107** will need to be changed from 1mS to 2mS. 3. The change won't need to be validated as the only change is a 0.05% increase in concentration of NaOH before acid is introduced. The worst risk is some acid could be slightly neutralised by remaining basic residue. But the system will dose more if the conductivity reading is not correct.	**Medium**

Step	Current State	Target State	Difference	Action Plan	Priority
48 - Int Rinse – Cond. Chk Alarm	Runs for 2 seconds and sets of alarm if certain conditions are not met.	No change.	N/A	N/A	**None**
60 – Acid Circuit fill – Conc Chem	Runs for an average of 300 seconds and transitions when the step timer is complete.	This step should transition when a set point conductivity of around 30mS is being read at the back-end conductivity sensor **E3CT012323**.	This reading confirms that the acid has filled the system as is of the desired concentration. Currently 300s isn't enough to fill half the system, so the following steps must compensate for this step not working correctly. This step length will increase with the changes, but the following steps will decrease.	1. The new set point in the transition needs to be implemented by the automation team. 2. No validation required as the current watchdog step will continue to function.	Low
62 - Acid Circuit fill – Monitor Cond.	Runs for an average of 300s and transitions when the step timer is	No change.	If the previous change is made this step should transition due to the	1. This step should be included to be checked in the previous step's implementation. To check its behaviour when the process is changed.	Low

Step	Current State	Target State	Difference	Action Plan	Priority
	complete, OR the conductivity reaches a set point **E3CT012323H_SP113** = 30mS. The transition is always the step timer event, as the acid has not enough time to completely travel through the system before the timer ends.		correct conductivity is being present.		🟩
64 - Acid Circuit fill – Cond. Chk Alarm	Runs for 2 seconds and sets of alarm if certain conditions are not met.	No change.	N/A	N/A	**None**
66 – Acid Recirc Temp/Cond. Hold	Runs for an average of 200s and is a completely sensor driven step. It transitions when the	No change.	If the previous steps are changed then we a likely to see a reduction in time on this step, as the temperature has time to	N/A	**None**

Step	Current State	Target State	Difference	Action Plan	Priority
	back-end temperature sensor **E3TT066123** reads over a setpoint **E3TT066123SP111** 60 C° and the back-end conductivity sensor is over a setpoint **E3CT012323HSP111** 40mS.		rise and acid has had time to reach the backend sensor.		
68 – Acid Recirculation	Runs for an average of 1600s and transitions when the step timer is complete, and the spray balls pulse sequence is complete. Additionally, the timer only counts down when the right	To have a total dissolved solids meters installed that can read the levels of minerals dissolved in the solution. The system would transition when the total dissolved solids stop increasing and the trend starts to	Instead of running the same length recirculation, the step would run until the system is clean. This would decrease the length of this step overall, but significantly reduce this step when the system is lightly fouled due to a short production run or cleaning for	1. Identifying sensors specs. 2. Identifying whether the current conductivity sensors within the system can output data on multiple channels as they can read TDS as a function of conductivity. 3. Testing a current conductivity sensor to determine whether this will be viable. Or purchasing a sensor that can	High

Step	Current State	Target State	Difference	Action Plan	Priority
	conditions of temp and cond. are being met, resulting in a longer step time. Another thing that increases the step time is the diverts being tested in this step. This holds the step for an additional 5-8 minutes until testing is complete.	plateau. This would indicate that there are no more minerals to remove from the system.	maintenance purposes. This also give the system an idea of when the system is clean and can respond to the level of fouling within the system, making it more adaptable.	measure TDS. Issues with the data may include, resolution, unstable, difficult sensor calibration. 4. Gain basic functionality in one sensor. 5. Take and analyse readings from a standard CIP to discover trends of the meter. The results of these will impact the control method used with these sensors. Some examples may be; - A TDS meter at each end of the circuit. The first TDS measures the fresh acid solution's TDS metric at the beginning to set a baseline. And then the front and back sensors compare readings until both readings are close to same value. This means that the TDS is consistent throughout the system and is approaching equilibrium, suggesting that no new minerals	🟥

Step	Current State	Target State	Difference	Action Plan	Priority
				are being dissolved into the solution. • If the trends are similar between the CIP's tests a sensor can be installed into the back end of the system and the system can look at the gradient of the trendline, transitioning when the readings plateau. Like the suspended solids meter logic. 6. Decide on and implement control system. 7. Validate the changes, verifying the changes with samples sent to the lab testing for calcium levels and phosphorous levels.	🟥
86 – Empty Feed tank	Runs for around 120 seconds and transitions when the step time is done	None	N/A	N/A	**None**

Step	Current State	Target State	Difference	Action Plan	Priority
	and the level sensor in the tank is less that the empty tank set point.				
88 - Purge Acid	Runs for an average of 530 seconds and transitions when the step timer is complete. The condensate runs past the sensor which gives extremely high readings that stop the timer from counting down as the system is not acting within its parameters. This results in the step running longer than its timer of 450s.	Transition the system on the back-end conductivity sensor reading **E3CT012323** is below a certain set point. The set point can come from the next step. **E3CT012323HSP114** 10mS.	This will make the system independent of the timer and this step will transition when the acid has been purged from the system. The condensate will not affect this control method as it causes the sensor to read very high, around 200mS and the control variable will be required to go under the set point to transition.	1. Implement this transition and set point change through automation team. 2. Confirm changes to check they function as expected.	**Medium**

Step	Current State	Target State	Difference	Action Plan	Priority
90 – Purge Acid – Monitor Cond.	Runs for an average of 250 seconds and transitions on the step timer completing and when conductivity is below the set point for 60s **E3CT012323HSP114** 10mS. The timer is set to 10 seconds, so conductivity usually triggers the transition.	Change the logic to **OR** instead of **AND**.	Prevents future trouble if the timer value is changed then lots of time may be wasted as the system waits for that to complete when it could progress.	1. Implement changes, no validation required as it will not affect how the system works.	Low
92 Purge Acid – Cond. Chk Alarm	Runs for 2 seconds and sets of alarm if certain conditions are not met.	No change.	N/A	N/A	**None**
94 – Final Rinse	Currently runs for 450s and transitions when the step timer is complete.	Transition this step when the nitrate sensors read below a set point that	From preliminary testing this will reduce this step length by 4 minutes. As the nitrate levels drop	1. Purchase and install nitrate sensor in the line. 2. Analyse trend over several CIP sets.	High

Step	Current State	Target State	Difference	Action Plan	Priority
		corresponds to the safe levels specified by MPI of 50ppm.	very fast, when the level reach safe ppm at the backend and the CIP finishes there is still 11 minutes of water to come through the circuit from the front end before the system goes back on product.	3. Confirm the 50ppM set point. Verify with nitrate samples being sent to the lab. 4. Implement new set point for the nitrate sensor through automation. 5. Validate.	🟥
96 – Final Rinse – Monitor Cond.	Runs on average for 200s and transitions when the step timer is complete, and the back-end conductivity **E3CT012323** is below 0.5mS **E3CT012323LSP108**.	Add another set point and parameter for the nitrate level being under a certain limit.	This helps guarantee the success of the final rinse as the system knows when it is achieving its goal of having a clean system that is ready for product. As an additional sensor check is being added.	1. If the nitrate sensor is already implemented, then the automation change is required to add another condition to this steps transition. This will require no validation as there is no change to how the system functions.	Low
98 – Final Rinse Cond. Chk Alarm	Runs for 2 seconds and sets of alarm.	No change.	N/A	N/A	**None**

Step Summary

No change	HMI set point change	Automation change	Physical, automation change and validation
24, 26, 32, 48, 62, 64, 66, 86, 92	3	20, 22, 34, 36, 44 ,46, 60, 88, 90	18, 28, 68,94

A Gap Analysis is a tool that involves a comparison of actual performance with desired performance. The analysis quantifies the difference between states and then identifies at a high level the steps that are required to move a system or process from its current state to its desired state. Priority is assigned to assist with determining the urgency of the change, this is affected by the steps with the largest difference, as the most gain is to be had from improving these steps. See **Figure 30** for a visual representation. This Gap Analysis looked at moving Synlait's EV03 timer-based CIP process to a sensor-based CIP process with the aim of increasing efficiency and reducing turnaround time for Dryer 3. This Gap Analysis will outline the steps that could be changed within a standard EV03 CIP.

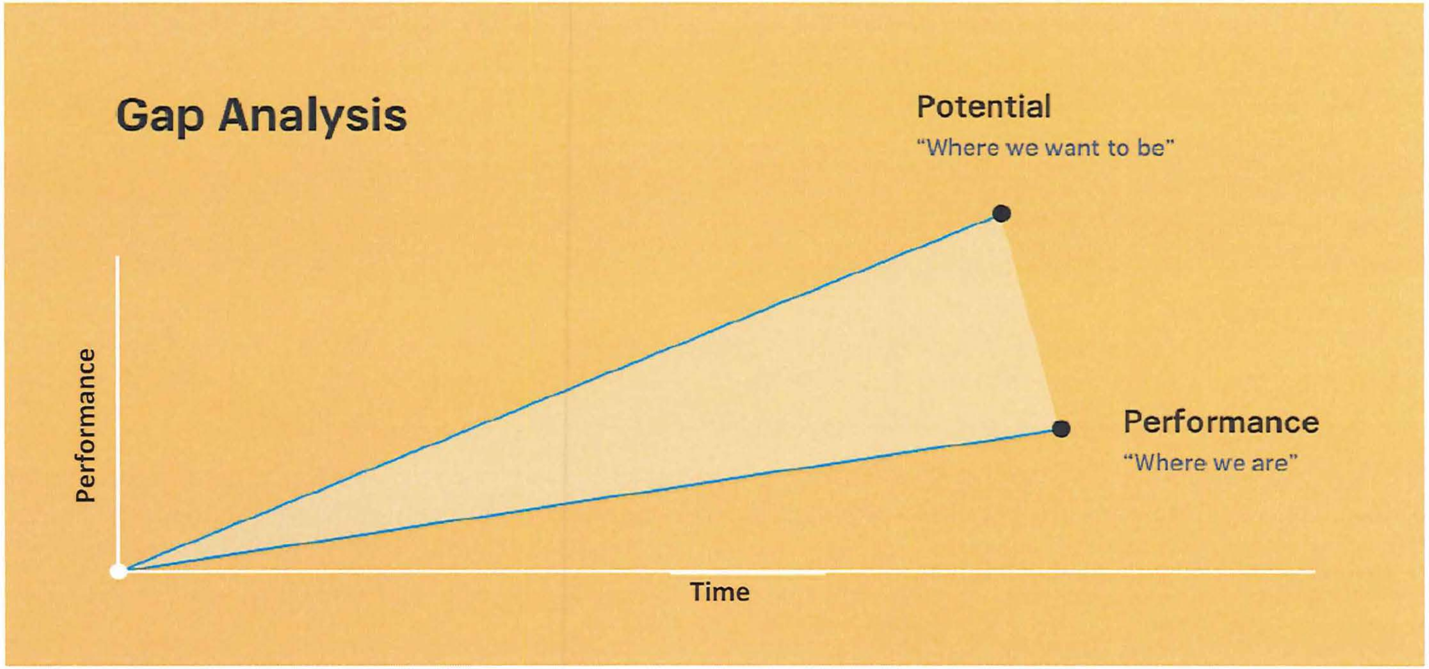
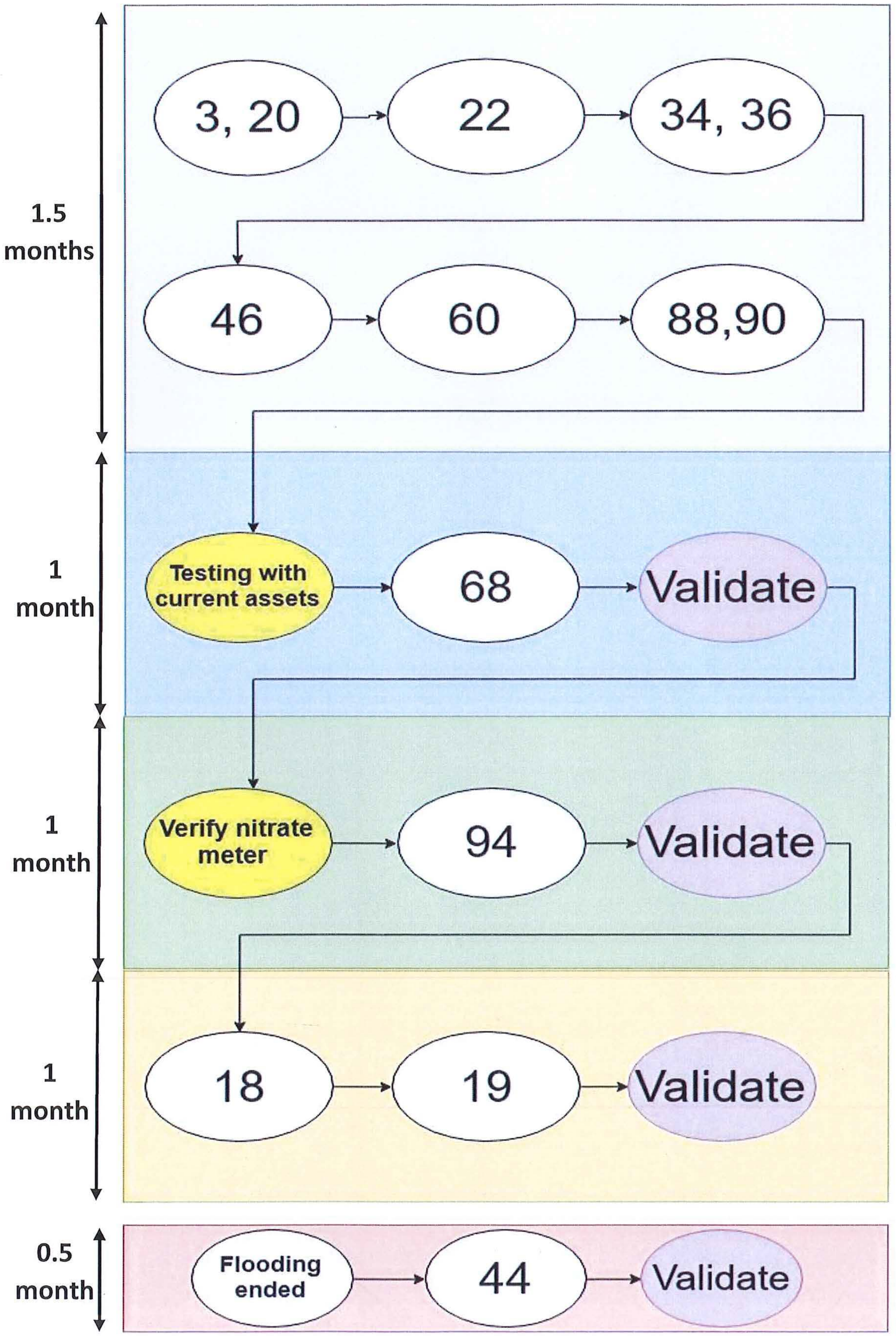


Figure 30: Graphic representation of a Gap Analysis that helps to visualise the goal of this method.

Appendix 11: PDCA Implementation Guide



Low Hanging Fruit

Resources Required:
Automation, Process engineer.

Acid wash

Resources Required:
Automation, Process engineer, Maintenance, Laboratory and Dryer Management.

Nitrate

Resources Required:
Automation, Process engineer, Maintenance, Laboratory and Dryer Management.

Caustic

Intermediate Rinse

Resources Required:
Laboratory and Process engineer.

What each step means:

Implement change from Gap Analysis using PDCA method.

Commission to see if the change works as expected. If yes, continue to the next change.

Notes

Low hanging fruit

1. Complete the task highlighted in the circles, then commission. If two tasks are in one circle, both can be completed before commissioning and testing on the plant.
2. The 'low hanging fruit' are tasks that require only software changes to the current CIP system. No additional hardware is required to implement changes to these steps.
3. These tasks should be easy to implement. However, they will not have major impacts on the speed of the system. They are good "warm up" objectives for the start of a project.

Acid wash

1. The acid wash change will likely to have the biggest effect on the time of the CIP as the most 'buffer' time is present in this step. Getting the biggest time savings early in the project will mean that more time is saved overall.
2. The current conductivity sensors could be used to output TDS, so the cost of capital will be lower. Although redundancy sensors may be required to be installed once the system is confirmed to be viable.
3. In this phase it would be recommended to investigate installing a conductivity sensor close to the back end of the system that avoids the condensate. Depending on results, switching all the current back-end cond. logic from the old sensor to this new one for a more stable CIP.

Nitrate

1. This phase has the most risk. The key thing to consider is to validate that the nitrate sensor is reading the correct nitrate levels with lab tests. And analyzing the sensor readings over several CIPs including WMP and IF, to make sure the sensor is behaving correctly.

Caustic

2. Saving the hardest phase till last, the key would be implementing the suspended solids sensor initially and seeing how it behaves. If it doesn't behave consistently enough then the ultrasonic sensors should be tested and implemented so minimal assumptions need to be made.

Intermediate Rinse

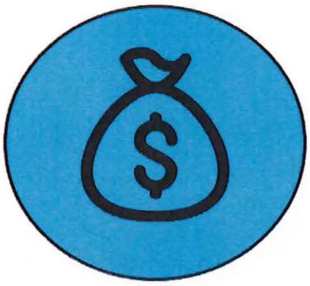
3. This step can be worked on anytime if the flooding is fixed. The idea is that if the conductivity is low enough at the back end from the purge, then this step can be skipped as there already is a 11-minute water gap between the caustic and acid due to the system being ~11minutes long. This will only be a software change through automation, as the spray balls need to be sprayed earlier in the purge caustic cycle, and some transitions need to be changed.

Appendix 12: Implementation Methodology

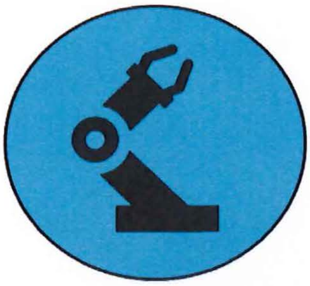
The CIP process is complex, with many different phases, states and controllable variables. Changing one thing in the process can have a big impact on many other parts of the process. It is important to consider that there are many changes suggested in this report and making all the changes at once would not be advisable. If there was an error in commissioning or one of the changes didn't work as intended it could take lots of time to pin point the exact change that is causing issues, creating a potential time sink. And due to this complete change of context the risks are highest during implementation of the system, so a careful approach must be used.

The best method for testing this process is a modified AB testing method alongside the implementation PDCA methodology. This means that one change in implemented and checked to see if it works, this will then be validated and compared with the previous system. The next change is implemented on the new system and is compared with the previous iteration. Normally an AB test all the changes are tested separately and are all compared to the current version of the system[28]. If all the changes are trialled separately there is potential for the system to not work at the end when it is all put together because some of the changes do not interact well with each other, and again a time sink will be created trying to pin point the issues. However, it is important during Synlait's testing to keep building upon the system and comparing with the previous iteration of the system due to the holistic affect changes may have upon the system. It is much easier to discover issues if one change is implemented to the system at a time, slowly building up to the finished product that is a sensor-based CIP system.

Appendix 13: Main Project Outcomes



~30 minutes less dryer downtime. With potentially another 30 minutes if the system is implemented.



Better understanding of the dryer's CIP and its potential control methods.

Learnings that can be transferred other CIP systems.

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[28] https://vwo.com/ab-testing/

Appendix 14: Personal Reflection

The following section outlines some key learnings, challenges and observations I made throughout this project.

Alumni

During the year Piet frequently mentioned the usefulness and power of the MEM alumni network, this included getting us all to join the MEM alumni group on LinkedIn. Synlait is a company that has taken MEM projects for several years. This has resulted in a good number of MEM students being employed by Synlait after their project (now also including the CEO, Leon Clement). I found having these connections very useful during the project as the alumni were always willing to assist with my project, whether it be by providing me with a contact, relevant information, or offering to have a look at my final MEM presentations to provide feedback. This highlighted to me the value of having this shared connection with hundreds of alumni and that this could benefit me in the future.

Buy-In

Getting stakeholder 'buy in' was a critical aspect of the project. When we first arrived the manager from D3, the dryer I was to work on, was re-assigned to Pokeno with no replacement. This resulted in the assistant manager of D3 taking on the responsibility of both manager and assistant manager. As he was extremely busy during this phase he had little time to dedicate to additional projects, I initially struggled to communicate the projects aims and outcomes during introductions and informal meetings. However, after I pushed for a meeting and explained that my project would benefit the dryer I achieved 'buy in'. Having critical stakeholders that want to see your project succeed was essential due to them helping me with;

- My own inexperience with the complex system - it was valuable to have knowledgeable people explain system specifics, with direct relevance to the project.
- Providing me with the resources that I required to complete changes and tests.
- Explaining the business processes that I would need to complete before implementing changes.

Communication

Communication was key in managing all parties in this project, the weekly meetings with my supervisor and sponsor were essential for ideas to be sense checked, and to ensure I was allocated the resources that I needed. I also noticed that everyone has different communication styles, for example some people like to communicate via emails, whereas some people take a long time to reply, if they even reply at all. For these people a different approach was required and interestingly the coffee machine was an asset in achieving this. Some people have a high workload and are fully booked up with meetings but are happy to discuss or answer a question informally while making a coffee or passing through the workspace. These informal discussions helped me keep up to date with the dryer and how it was running, if there were any issues that I should be aware of. Unfortunately, it probably resulted in me drinking twice as much coffee as I normally would throughout the course of the project.

Challenges

Outlined below are the several main challenges in completing this project;

- My supervisor was not present for the first two weeks of the project, this left me a little directionless at the beginning of the project. However, it allowed me to work on my project with little to no pre-conceived ideas which allows for a fresh look at the system. A paper[29] looking at this phenomenon states that issues are more likely to be raised by an external party versus an internal party.
- We presented five separate presentations during our project at Synlait, most of them were monthly updates to our sponsors, stakeholders, and department. These were a good form of communication to people external to the project and they provided their own external input and knowledge. All the stakeholders to the project knew what progress was being made already so no value was really added to people critical to the project. The presentations also took time to prepare for and the project was short enough as it is, so I think overall, they were a net loss in terms of value to the project.
- The complexity of an unfamiliar system was a large initial challenge. I undertook a very steep CIP learning curve. However, I found this to be made easier with the structured approach we outlined in our project proposals. Completing a literature review on critical CIP parameters, best practise, and a performance summary on the system I was optimising was essential with my initial understanding. And it was good to get this done before I got into looking at Synlait's system in detail as it gave me a solid base of knowledge to draw upon.

This project was a good experience that drew upon a wide range of knowledge that I have acquired from the MEM year. From systems thinking, to optimise a complex industrial system. To finance, to calculate the contribution of dryer time savings to the bottom line. This project gave me a practical opportunity to apply the skills I have learned over the year and has given me context as to why some of the topics covered were essential to the development of my career.

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[29] https://www.researchgate.net/publication/327746812_Is_a_fresh_pair_of_eyes_always_better_The_effect_of_consultant_type_and_assigned_task_purpose_on_communicating_project_escalation_concerns

Appendix 15: Change Control Structure

The process to submit a change to be documented is highlighted below.

1. A change control form is completed and submitted to change control.
2. The applicant attends a change control meeting that is held every Friday.
3. The change is explained by the applicant. The change is then discussed by a committee comprised of people from all areas of the business. The diversity of the committee helps catch any unforeseen effects the change could have upon other areas of the business.
4. Any actions that must be taken before implementing the change are decided upon.
5. The change is implemented, and the success is measured. Validation would also happen at this step in the process.
6. The outcome of the change is relayed back to a future change control meeting to confirm a permanent change or to close off an unsuccessful change.