# DESIGN OF A CONVEYOR BELT WASHER

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2003

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# Abstract

The purpose of this project is to design a device to clean fish solids and plaque from plastic conveyor belts after they have been taken off fishing ships. This project involved a systematic design study along with an experimental investigation into the effectiveness of cleaning methods.

While fishing factory ships are at sea, the plastic conveyor belts that are used to transport fish become tainted with a biological plaque that some bacteria create to protect themselves, and fish residue. A brief was evolved that required the development of a land based cleaning device to reduce the non-productive cleaning time at sea.

A systematic design procedure was adopted for the design of the belt-cleaning device. Research showed that strongly alkaline solutions were the best method of cleaning protein-based biofilms. This research led to the most promising cleaning mechanism concepts being tested to quantitatively evaluate their cleaning effectiveness. The development of the final concept considered the requirements of New Zealand legislation and a professional code of ethics, materials issues due to the aggressive environment, structural design using finite element methods, and a heat and mass transfer analysis.

The final design solution consisted of two units. Firstly, a tank to receive the coiled belt, another insulated tank to store the sodium hydroxide cleaning solution, an overhead crane to load/unload the belt, and a transfer pump and control system to control the flow of fluids. The second unit was a separate rinser to perform the water blasting. This study resulted in the final manufacturing information for the belt washer. This includes detailed drawings and a costing for all parts and construction.

# 1.0 Introduction

## 1.1 Background

While fishing factory ships (also known as ‘freezer boats’) are at sea, they catch fish, process the catch in a factory that is installed on a mid-level deck, freeze it, and store it. Plastic conveyor belts transport the fish through the various stages of processing. During the voyage these belts become tainted with fish residue, and with a biological plaque (produced by bacteria). This occurs despite the belts being cleaned every 8 hours. The ships are not allowed to unload cargo at port until the plaque and residue is removed, and the rest of the factory cleaned.

Currently the plaque and residue must be removed either by hand (on the Aorere, Rehua, and the Kiwa) or in a chemical bath (on the Aoraki) while the ship is returning to port. Removing all of the belts and washing them by hand with a water-blaster, takes approximately 18 man-hours (the whole factory takes 20-36 hours for 30 staff). The chemical bath is effective and fast at cleaning the belts, but is undesirable due to the safety hazardsit presents. These include dangerous chemicals being improperly contained in a moving vessel, risks of having the concentrate handled and poured by crew, and size constraints in some of the vessels. Also it is ecologically unkind to discharge the chemical into the sea.

If the belts are washed by a device that reduces the non-productive time the ship must spend at sea cleaning, time will be saved. The value of time saved has been estimated at about $2,000 per hour the ship is at sea. Other benefits include an increase in revenue from more time being available for fishing each season. Also there may be peripheral savings in unexpected areas, for example a possible reduction in MAF (Ministry of Agriculture and Fisheries) inspections and their cost.

## 1.2 Problem Statement

The purpose of this project is to design a device to clean biofilms and biosolids off the plastic conveyor belts that are used on fishing factory ships. The device must be suitable to be installed and used outdoors on-site at the Nelson factory, using only resources that are already available. The device must be able to clean all the belts from a boat without increasing the time it must spend in port. The device will be operated by crew from the ship.

## 1.5 Literature Review and Research

A search of papers relating to the cleaning of proteins and plaques was conducted in many engineering and general databases, as well as using Internet search engines. The most useful source of relevant papers was the Internet search engine ‘Google’. The abstracts of many papers were reviewed, and a few were reviewed in their entirety. None of the papers related specifically to the cleaning of biofilms off plastic belts, but the principles found suggested that strongly alkaline solutions were the best method of cleaning protein-based biofilms, especially if followed by sanitizing. These findings reinforced the validity of the preferred cleaning principle at that time, which is at the core of the final design of the device.

In addition to searching for published papers and articles, a survey of the United States Patent Office and the European Patent Office was conducted-looking for any inventions in the field of cleaning proteins, plaques or other fish related contaminants from anything bearing a similarity to the plastic conveyor belts. Nothing relevant was found in either database. There were many devices for scraping contaminants off belts, but none of them appeared suitable for the type of belt in question, or the microbiological nature of the contamination.

Another fishing company, Vela Fishing, had a device on one of their fishing ships that they used to clean their conveyor belts. Visiting the ship, the Pacific Pride, and talking to the crewmembers revealed that the device was similar to that which is used aboard Aoraki, i.e. a tank that is loaded with coils of dirty belt, and filled with a caustic chemical, and left to soak, being agitated by the ships motion. Vela Fishing did not want to reveal details about the chemical, but they said that there was no mechanical action or pumps, only a tank.

## 1.6 Specification Table

| Specification description | ***D**emand or **W**ish* |
|---|---|
| Level of automation | ***W*** one-button operation with technician over-ride facility. |
| Empty weight of the device | ***D*** <2500kg ***W*** <1500kg |
| Wash time for all belts | ***D*** <18hrs ***W*** <12hrs |
| Width of belt to be washed | ***D*** Up to 0.9m |
| Thickness of belt and flutes | ***D*** Up to 0.1m |
| Belt coil diameter (no hollow core) | ***D*** Up to 0.95 m |
| Microbiological count | ***D*** Up to 250 cfu/cm$^2$ |
| Electrical energy requirements | ***D*** 240V single phase or 440V 3 phase |
| Oil pressure requirements | ***D*** Up to 100 bar |
| Air pressure requirements | ***D*** Up to 25 bar ***W*** Up to 7 bar |
| Air flow rate requirements | Ample, limited by pipe diameter |
| Fresh water pressure requirements | ***D*** Up to 7 bar |
| Fresh water flow rate requirements | Ample, limited by pipe diameter |
| Steam requirements | Ample of steam at 165$^o$C / 7 bar |
| Allowable materials | ***D*** Anything that will not corrode or otherwise taint fish. |
| Control System | ***D*** Isolated, simple, interrupt friendly. |
| Information output | ***D*** Cycle progress ***W*** … and fault indication |
| Emergency Stops | ***D*** At least one remote and one at device. |
| General Hazards | ***D*** To comply with the Health and Safety in Employment Act 1992. |
| Chemical hazards | ***D*** Drainable in event of an emergency. |
| | ***D*** Fully contained, no open hazards. |
| | Minimise risk during transport of chemicals. |
| Motion hazards | ***D*** Only user-controlled motions externally. |
| | ***D*** Overload detection. |
| Over-exertion hazards | ***W*** No operator to lift more than 32kg. |
| | ***D*** Able to be used by a weaker than average adult. |
| Electrical hazards | ***D*** Emergency stop/short circuit isolation. |
| Thermal hazards | ***D*** No easily accessible surface to exceed 45$^o$C |
| Warnings | ***D*** To comply with NZ/AS 1319-1994. |

| | | |
|---|---|---|
| Environmental hazards | ***D*** To comply with regulations; chemicals must be suitable for disposal via the sewerage system | |
| Noise | ***D*** Usable with ear protection. ***W*** Usable without ear protection. | |
| Design life | ***D*** 5years | ***W*** 15years |
| Manufacturing | ***W*** Non-specialised parts able to be made in Nelson. | |
| Purchasing | ***D*** Specialised parts to be sourced in design report. | |
| Assembly | ***D*** Able to be assembled in Nelson. | |
| Maintenance | ***D*** Easy access to pump, tanks removable. | |
| Concept design complete date | ***D*** 15/1/03 | ***W*** 1/1/03 |
| Design complete date | ***D*** 15/4/03 | ***W*** 15/3/03 |

# 2.0 Conceptual Design

## 2.1 The Crux of the Problem

The crux of the problem was abstracted from the demands and wishes list and problem statement following the procedure set out in Pahl and Beitz (1993). The crux of the problem was identified as:

‘**To clean fish solids and plaque off plastic conveyor belts after they have been taken off fishing ships**’.

## 2.2 Function Blocks

The following function blocks were made to represent the flow of materials involved in the cleaning process, and to show a breakdown of the necessary processes and their sub-processes.

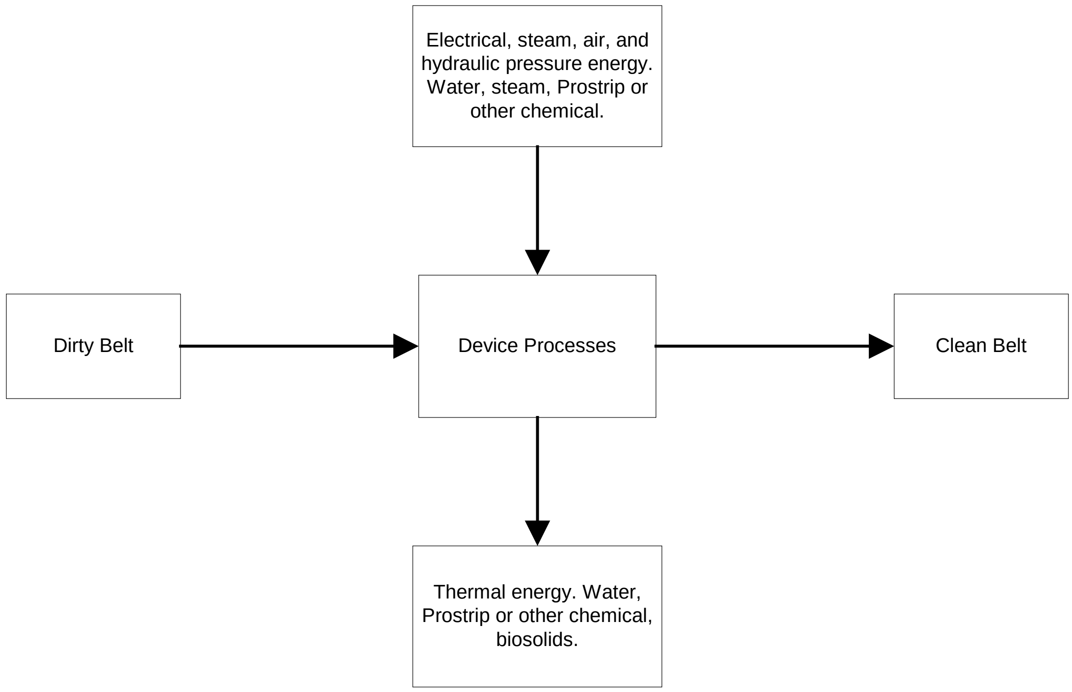



Fig. 1. The flow of materials.

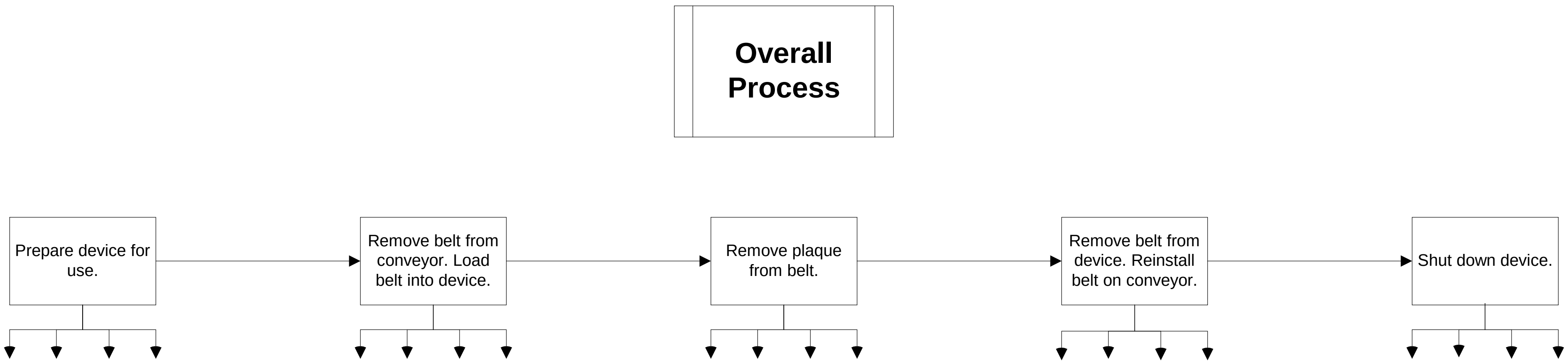



Fig. 2. Overall process diagram.

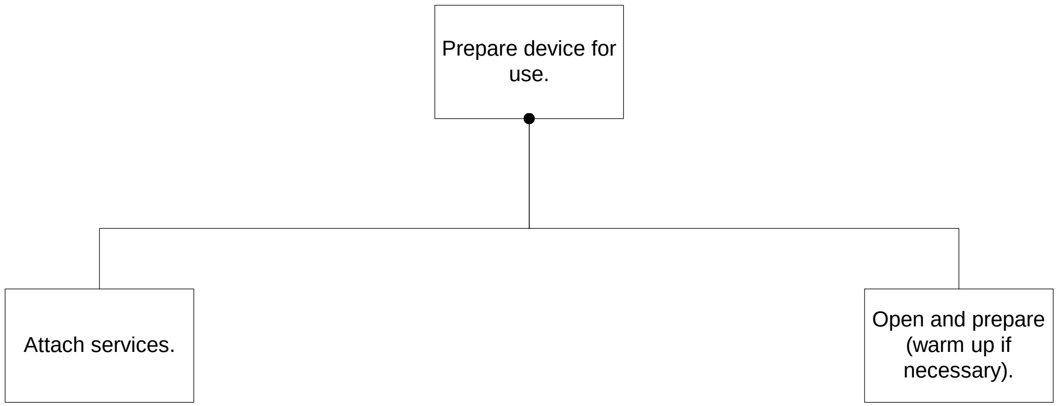



Fig. 3. ‘Prepare device for use’ sub-process diagram.

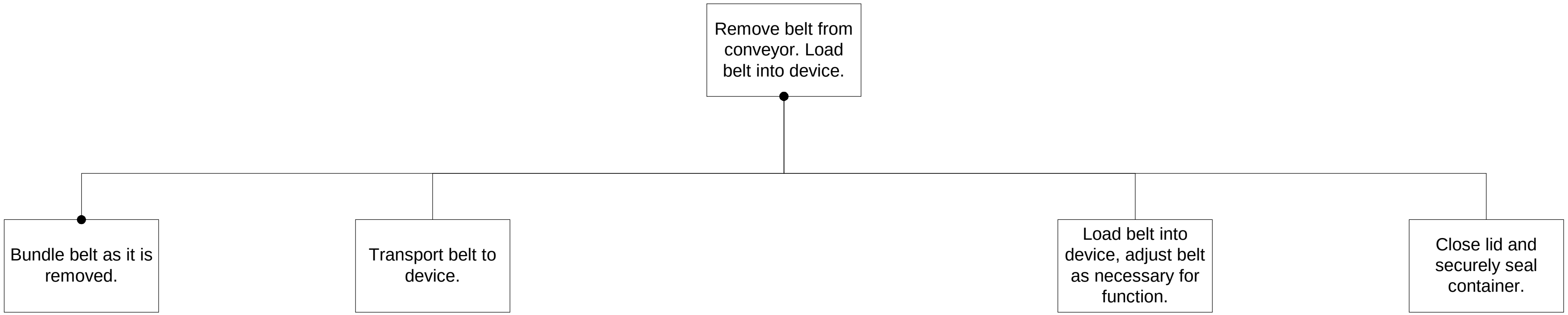



Fig. 4. ‘Remove belt from conveyor - Load belt into device.’ sub-process diagram.

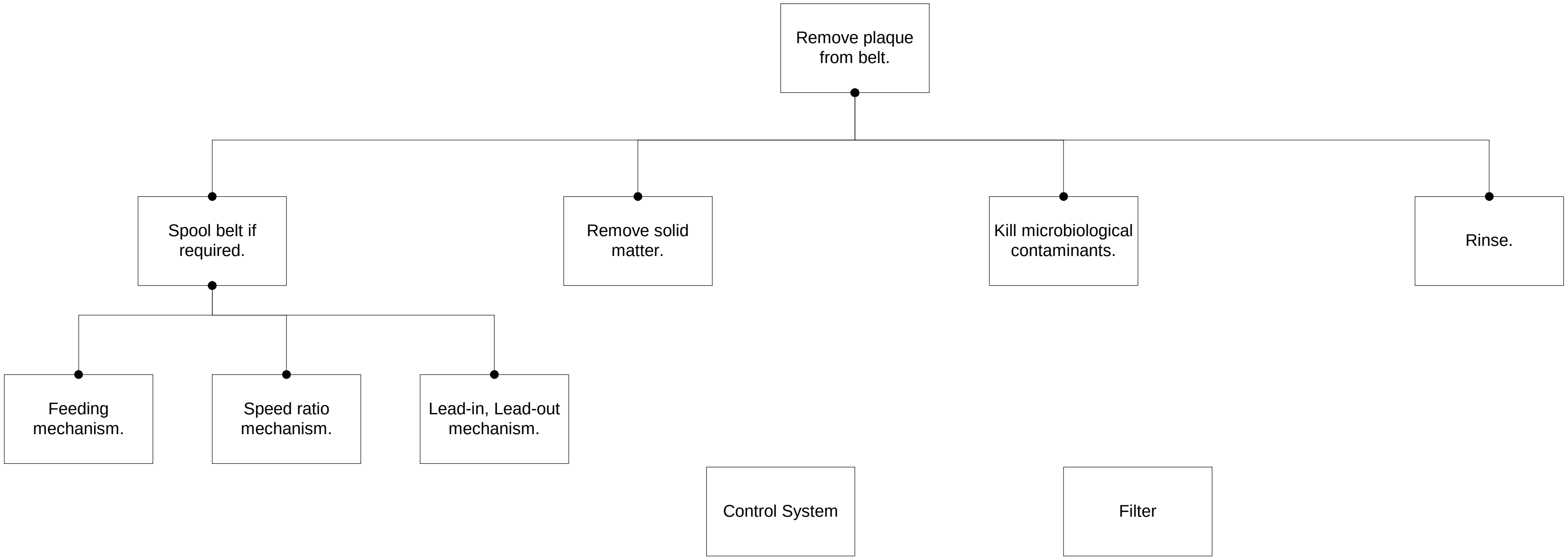



Fig. 5. ‘Remove plaque from belt.’ sub-process diagram, and associated functions.

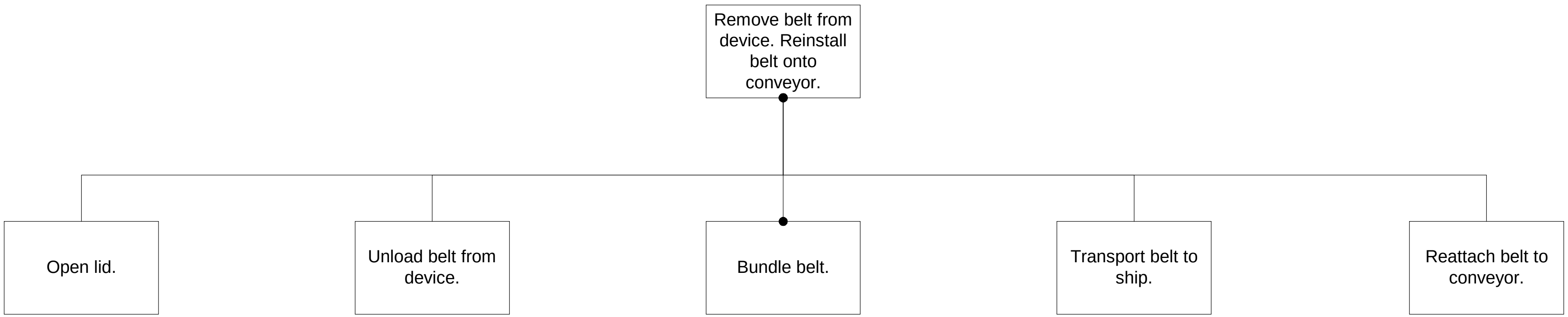


Fig. 6. ‘Remove belt from device - Reinstall belt onto conveyor.’ sub-process diagram.

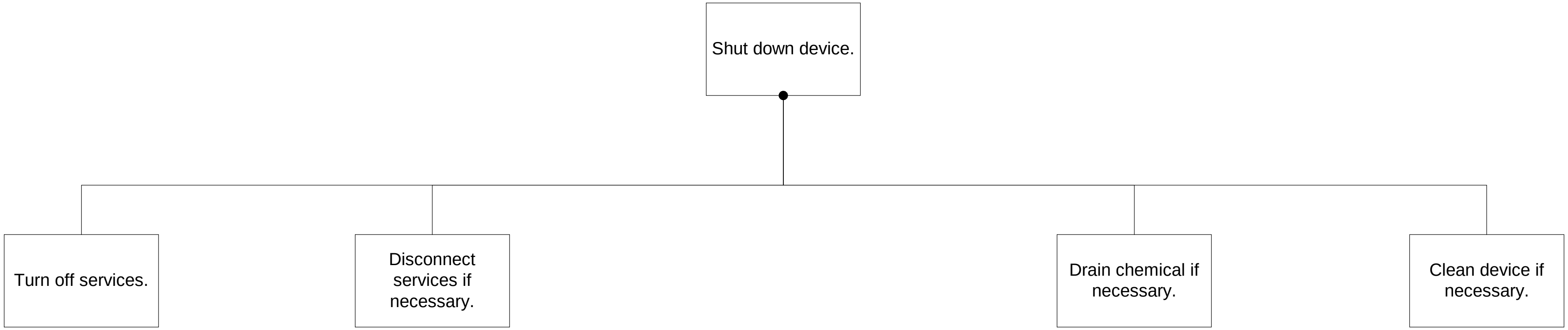



Fig. 7. ‘Shut down device.’ sub-process diagram.

## 2.3 Existing devices

As was mentioned in Section 1.2, there are currently two methods employed to clean the belts on the boats. In addition to these, there are other devices owned by Sealord that are of technical relevance. Box Washers are machines that are used to wash plastic boxes of approximately 800mm x 450mm x 200mm in size. They do this by passing the boxes along a conveyor, with water jet nozzles arranged around the path of the box spraying heated chemical and a water rinse. The Scaling Machine works on a similar principle, using an angled water jet array to blast the scales off the fish. The machines are filtered by what is known as a wedge-wire filter. This involves a grating of wedge shaped wires that the solids flow over, and the liquid flows through (see Figure 8 below).

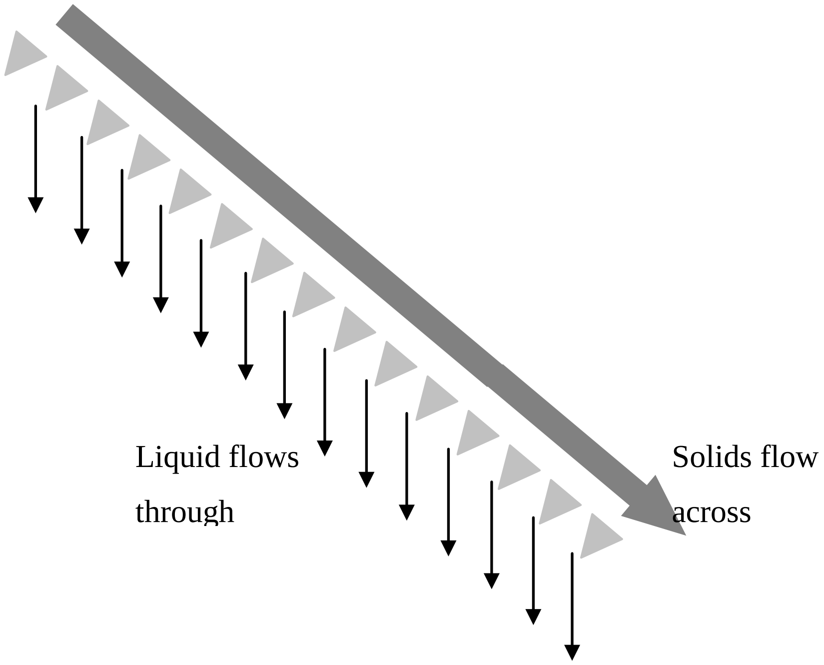


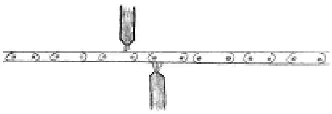

Fig. 8. Schematic diagram of a wedge wire filter.

## 2.4 Concept sketches

The following concept sketches were made to try and satisfy the crux of the problem.

### 2.4.1 Cleaning Mechanisms

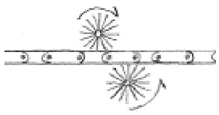
(Remove solid matter and kill microbiological contaminants subfunctions (Fig. 5)).



1) Water Jets

Pros: Proven method, what is currently used, resources available, simple to make, no solid parts contact the belt.

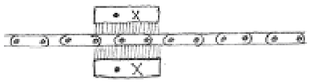
Cons: Does not kill any remaining bacteria, intensive water blasting is required. Ideas: Angled jets to clean the sides of the flutes



2) Rotating Brushes

Pros: Mechanical action abrades the biofilms, simple to make and run.

Cons: Difficult to design around flutes, bristles will not penetrate into crevices, no cleaning of cross-belt normal surfaces, does not kill any remaining bacteria.



3) Reciprocating Brushes

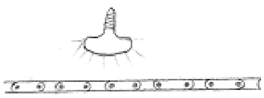
Pros: Mechanical action abrades the biofilms, provides cleaning of cross-belt normal surfaces.

Cons: Difficult to design around flutes, bristles will not penetrate into crevices, no cleaning of cross-belt normal surfaces, does not kill any remaining bacteria.

4) Ultrasonic Cleaning

Pros: Can remove biosolids from difficult to access surfaces, less simple to make.

Cons: Difficult to find appropriate harmonic frequencies, likely to be expensive to build, does not kill any remaining bacteria.

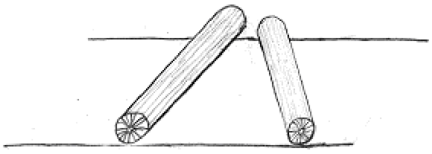


5) UV Light

Pros: Kills the bacteria contaminating the belts, easy to make.

Cons: Does not remove the biosolids that are contaminating the belt.

6) Angled Brushes



Pros: Mechanical action abrades the biofilms, accesses all sides of the belt.

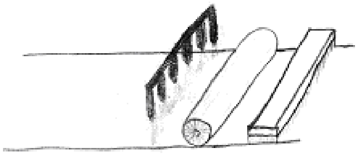
Cons: Bristles will not penetrate into crevices, does not kill any remaining bacteria.

7) Caustic Bath


Pros: Better solids removal and bacteria killing, belt can stay coiled.

Cons: No mechanical action, will not remove all solids, hazardous.
Ideas: Agitate belt with respect to the solution.

8) Combination



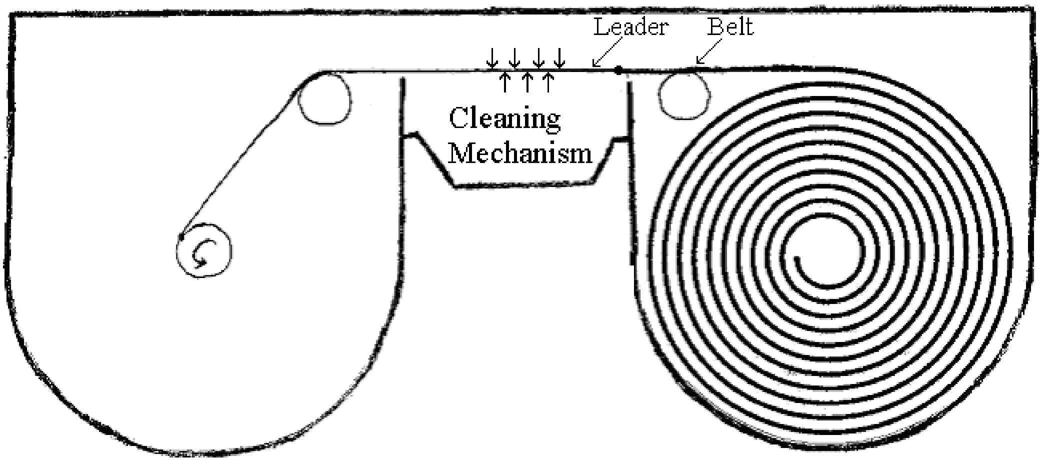
Pros: Can combine bacteria killing with effective biosolids removal by using multiple techniques.

Cons: Increased cost and complexity.

### 2.4.2 System Concepts

(Remove plaque from belt function (Fig. 5))

1) Tape Deck Spooling through Washing Tanks

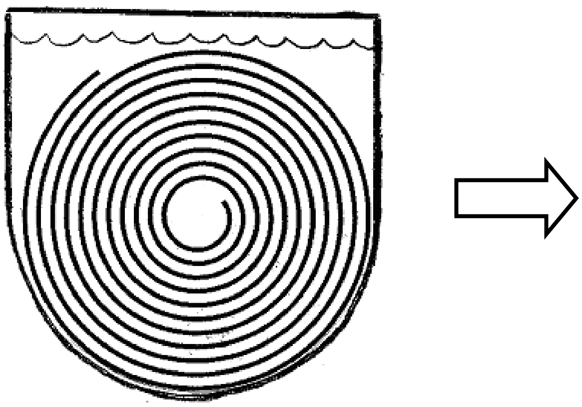



The belt is coiled up and placed in the wash tank, for chemical treatment. There is a leader so that the belt may be attached to the receiving drum, and still be able to be washed along its entire length.

Pros: Can combine bacteria killing with effective biosolids removal by using multiple cleaning methods, fully contained cleaning system, regular clean quality along belt.

Cons: Increased cost and complexity, increased size.

2) Separate Soak and Clean



Cleaning mechanism, like a tape deck spooling system with cleaning mechanism, but not enclosed in a tank.

Pros: Can combine bacteria killing with effective biosolids removal by using multiple cleaning methods, smaller size, simpler to make.

Cons: More manual processes, requires multiple units.

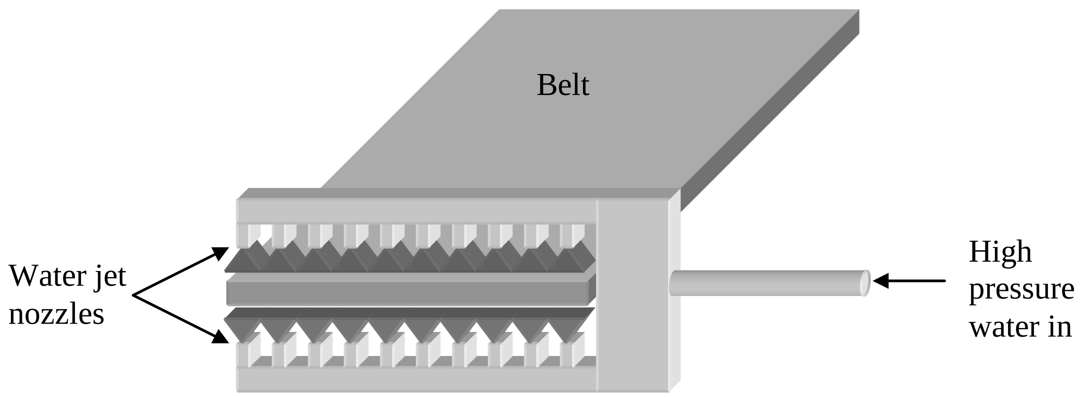
3) Agitation in Tank

This uses a tank similar to that in system 2 above, except that there is a method of agitating the fluid through the belt, or the belt through the fluid, incorporated in the design. Also there is no cleaning afterwards, the agitation is a cleaning mechanism in itself. This leads on to Section 2.3.3.

Pros: Can combine bacteria killing with effective biosolids removal by using multiple cleaning methods, improved effects of chemical, less chemical/time required to clean, smaller size. May be less heating required.

Cons: More manual processes, requires multiple units, more complex and expensive to make.

4) Clean In Place System



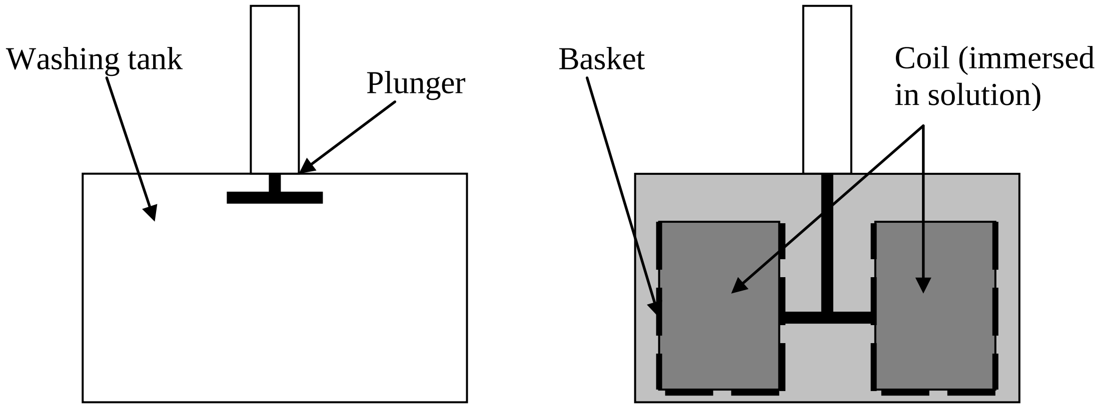

This option was discounted prior to a specification change. This concept involves cleaning the belts while they remain on the conveyor tracks. It would involve a series of water jets, and possibly also another cleaning mechanism.

Pros: Very small size, simple and cheap to make, easy to use.

Cons: Less effective cleaning, belts will have to be removed anyway, difficult to find suitable receptacle on each conveyor, not easily adjustable for different belts.

### 2.4.3 Agitation Concepts

1) Plunger System

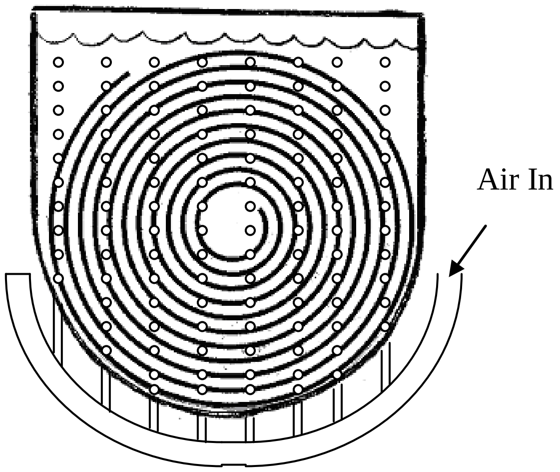



Two cross sections are shown above, ‘empty’, and ‘in use’. This method involves a cylindrical tank, with a plunger attached to a pneumatic or hydraulic ram fixed to the lid of the tank. The lid is removed, and the belt (enclosed in a metal basket) is inserted into the tank. The tank is filled with a chemical solution from a holding tank (not shown). The plunger cyclically moves up and down the empty core of the basket, forcing the liquid through the belt.

Pros: Simple, large volume movement, varying high flow areas.

Cons: Lid requires pneumatic attachment, ram makes system quite tall/long.

2) Air Bubble Agitation

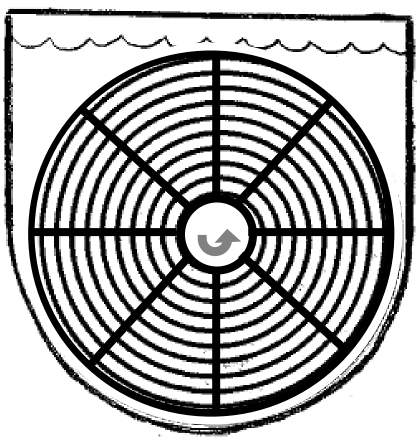



Air is fed into the bottom of a tank containing the chemical and the belt, the bubbles rise up through the belt, and in doing so disturb the solution as they pass, this will generate currents that will encourage the cleaning of the belt.

Pros: Simple, no moving parts, used successfully in other applications.

Cons: Possibility of trapping air, preventing wetting of areas of belt, 'weak' agitation, minimal mechanical cleaning action.

3) Rotating Basket

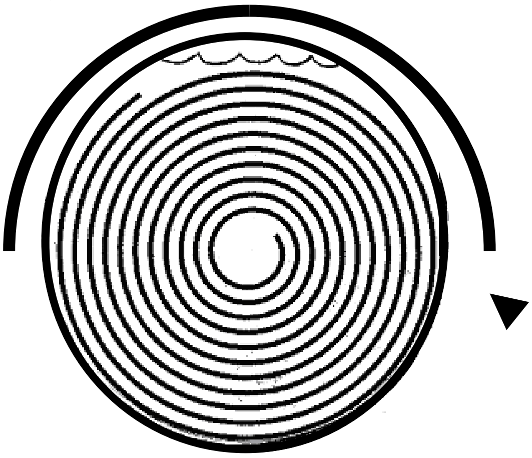


In this design, shown above, the coil of belt is held in a basket, and the basket and the belt inside it are rotated, either in one direction only, or back and forth in opposite directions.

Pros: Fairly simple, high flow rates, tank may not have to be full.

Cons: Difficult to achieve a secure temporary mounting of the basket on the shaft.

4) Entire Tank Rotates

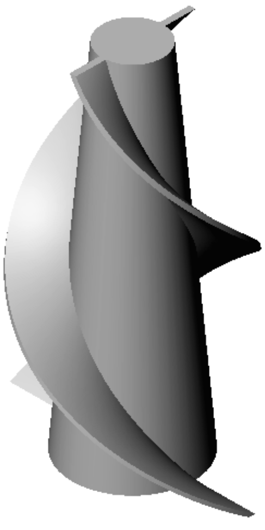


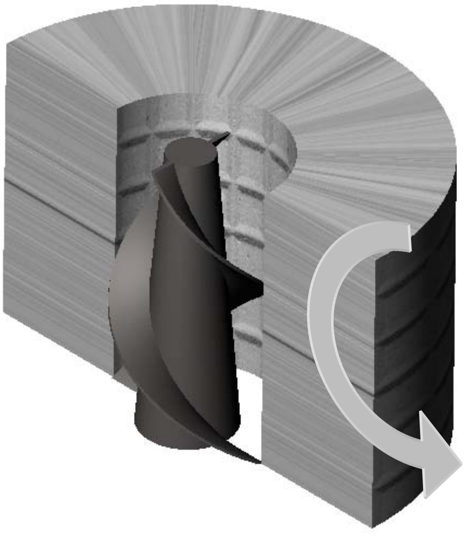
In the diagram above, the coil of belt is held in a basket as previously, but the entire tank and its contents are rotated.

Pros: Simple, large volume movement, varying high flow areas less sealing requirements, easier shaft design.

Cons: Large external moving parts, plumbing more difficult to design.

5) Solution Motion by Washing-Machine Style Agitation



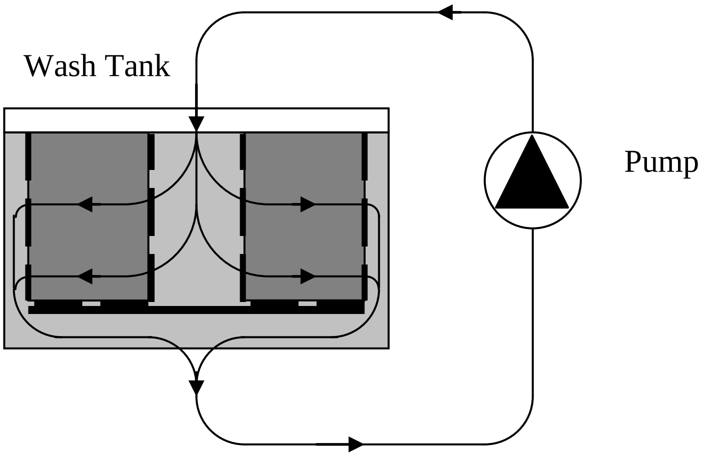


The above pictures show the core and how it would be arranged in a cross-section of the coil of belt. The motion of the core draws the solution through the top of the belt, down the centre, and out through the bottom of the belt (as shown by arrow).

Pros: Facilitates top loading which is easier than side loading, relatively simple mechanical action.

Cons: Difficult to make core, concept may not work so well for rigid contents (as opposed to flexible clothes).

6) Solution Recirculation



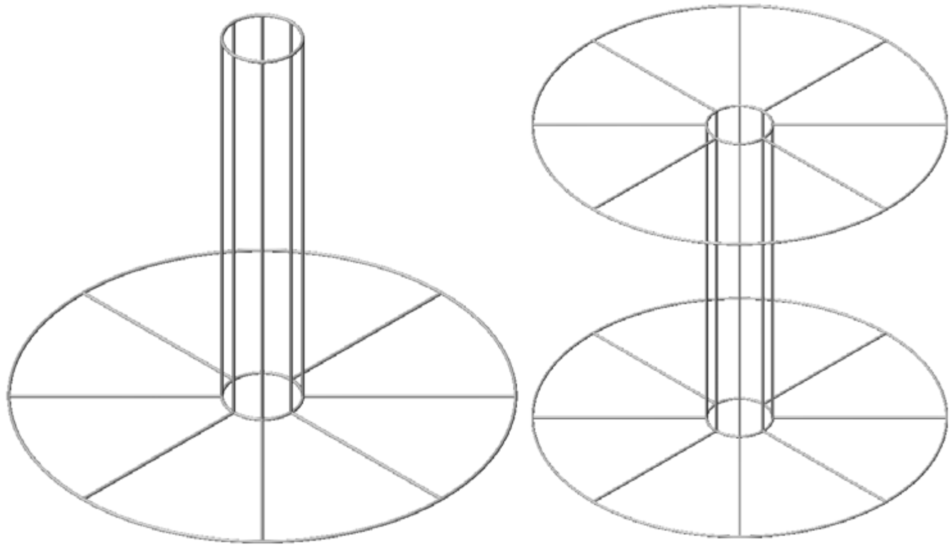

In this design concept the cleaning solution is recirculated through the tank, and forced to flow through the belt, by means of a pump.

Pros: Very simple, no moving parts in tank, even flow through belt, highly variable design.

Cons: Lesser flow rate through belt.

### 2.4.4 Basket Form Concepts

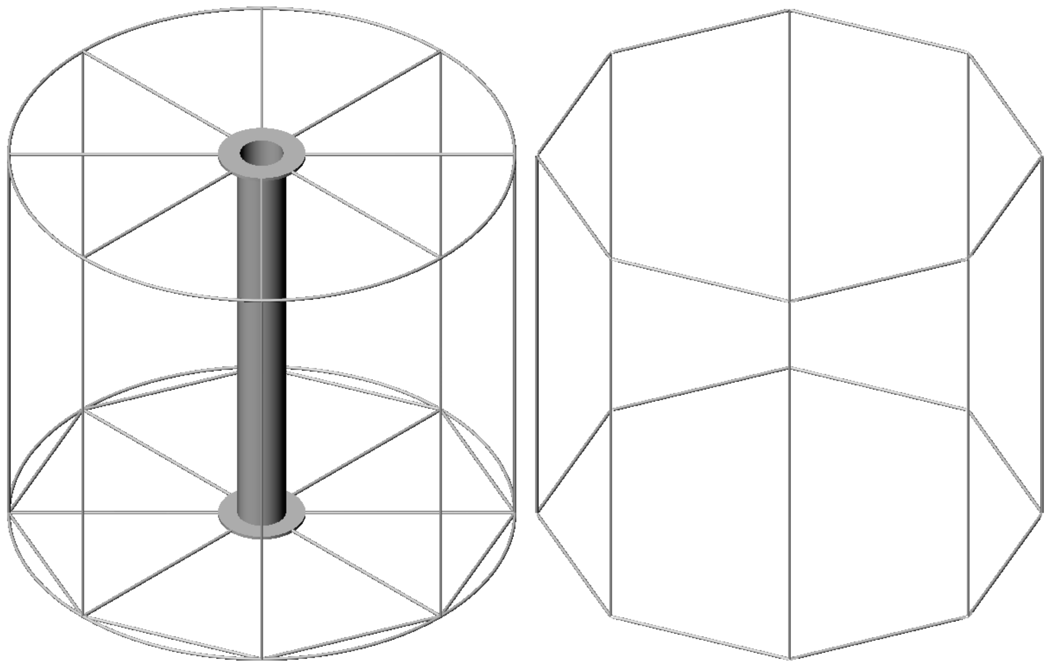
1a) Detachable outer wall



Depending upon the cleaning mechanism, a top end may not be required.

Pros: Lightweight, easy to spool-on / spool-off belt, easy to manually carry belt.

Cons: Fragile, many small welds to make it.



1b) Complete basket, and detachable outer wall.

This variant has a solid pipe core, and detachable walls to hold the belt in.

Pros: Easier to manufacture, easier to attach any locking pins.

Cons: Heavier, more expensive materials of manufacture.

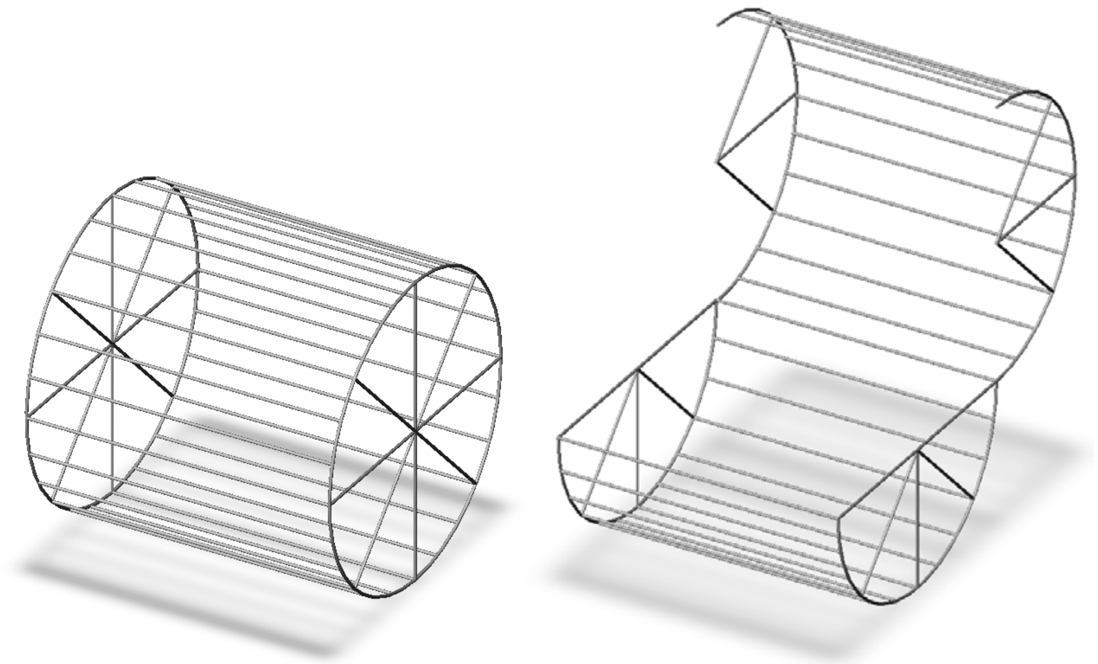
2) Plastic strap or similar external restraint

Plastic strapping or multiple cable ties joined together could be used to wrap around the coiled belt in order to hold the coil together.

Pros: Very simple, lightweight, quick to attach, easy to replace if damaged.

Cons: Less robust.

3) Horizontal frame basket with no core, side opening.

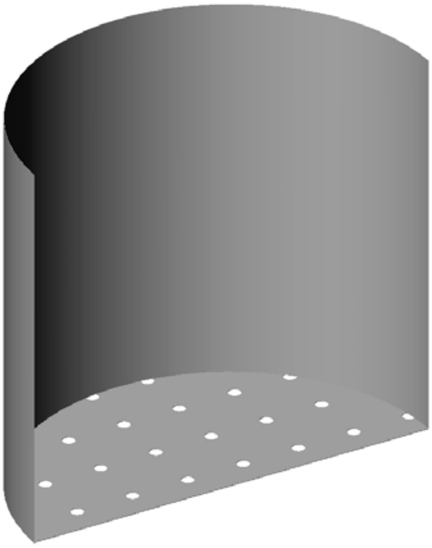


This option would be mounted as shown inside a tank, and be rotated from its ends.

Pros: Basket can remain in tank, wide mouthed opening for easy access.

Cons: Many welds in construction, belts may ‘bang around’ and get damaged.

4) Sheet basket with no core



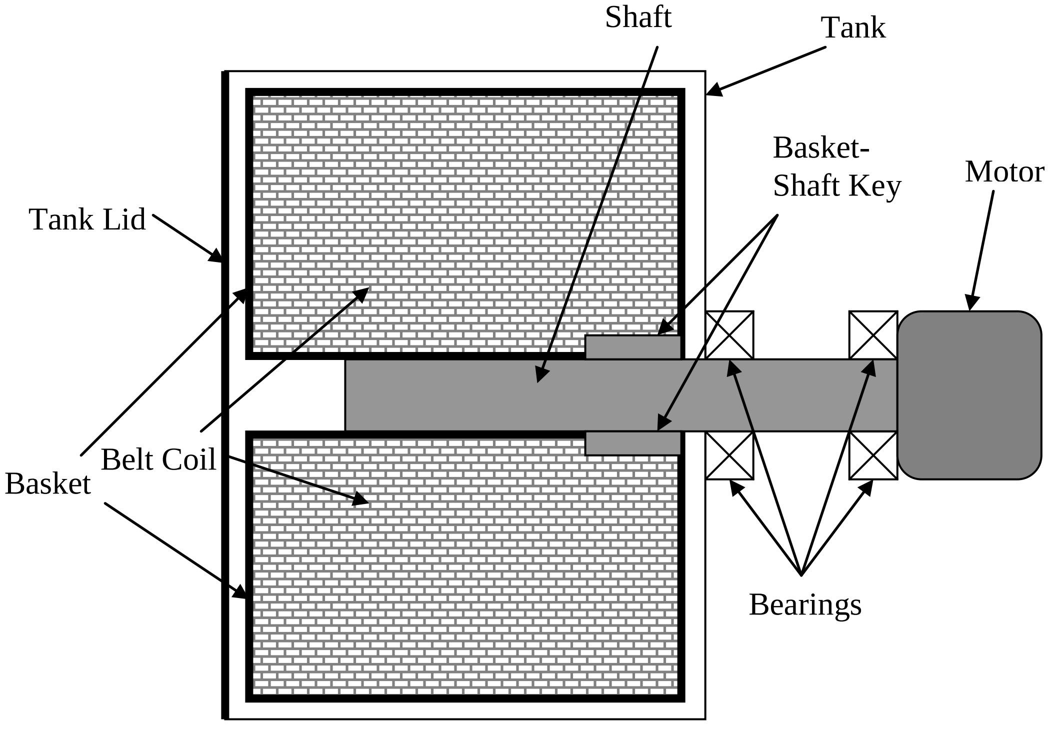
Section view of basket, note holes in bottom to let caustic solution to flow in and out.

Pros: Simpler construction, less chance of damage to the belt due to solid walls.

Cons: Heavier, less ability to force belt through solution due to minimal wall friction.

## 2.4.5 Basket Agitation Concepts

1) Cantilever shaft

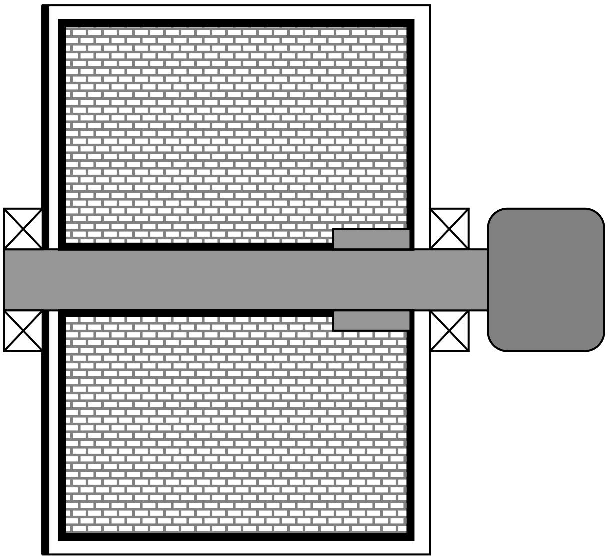



This is the most simple shaft arrangement.

Pros: Simplicity, easy to put basket onto, easy to design.

Cons: Potentially large cantilever bending moments in shaft.

2) Supported shaft

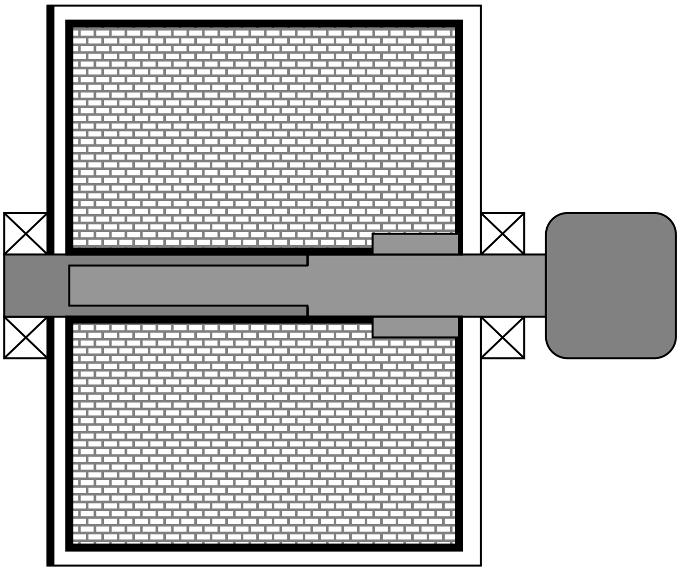


The shaft is supported at both ends by the addition of bearings attached to the lid. This requires that the shaft be slid out of the lid bearing every time that it is opened.

Pros: Better load bearing support locations.

Cons: Very difficult to get shaft into bearing every time the lid is removed. When lid is off all the bending moment will be supported by a single bearing, extra seal.

3) Two piece shaft

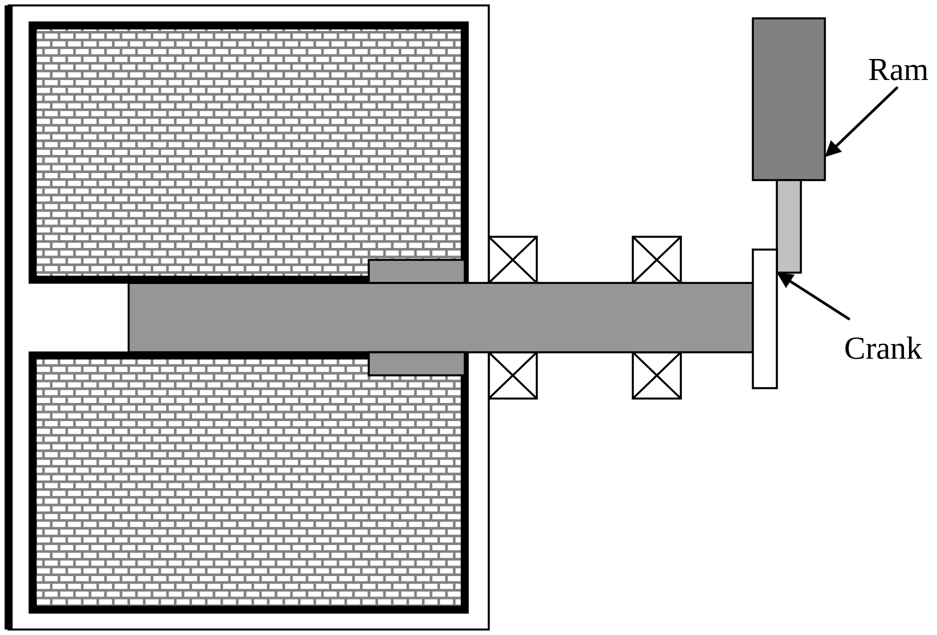


This arrangement prevents the necessity of removing the shaft from the bearing. Once the device is loaded with a belt coil, the shafts are put together as the lid is put on.

Pros: Good load bearing locations, no need to repeatedly fit shaft through bearing.

Cons: Has to fit two pieces of shaft together without line of sight, again all the bending moment will be supported by one bearing when lid is off.

4) Pneumatic ram with crank arm




This design has a pneumatic ram and a crank instead of a motor, the shaft options are as above. It allows for an alternating two-direction rotation motion, rather than a one direction rotation motion.

Pros: Better agitation as solution will not spin with belt, but will be forced through it.

Cons: Higher fatigue demands, higher torque forces.

### 2.4.6 Initial Selection of Concepts to Pursue

Of the ‘Cleaning Mechanisms’ concepts in Section 2.3.1, many were not investigated. This section outlines the decisions and reasons for pursuing or abandoning the ideas.

1) The water jets idea was deemed worthy of pursuing as it is the existing effective method.

2, 3, 7) All of the options using brushes were abandoned due to the fact that the bristles would not penetrate into the gaps around the teeth in the joins between adjacent belt sections (see below).

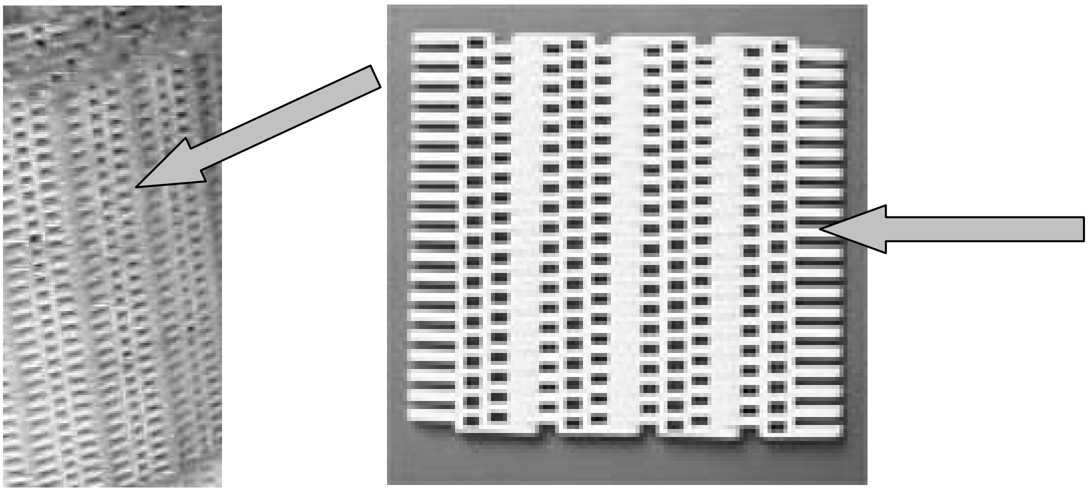


Fig. 9. The structure of the belt, showing difficult to reach crevices.

4) Ultrasonic cleaning was investigated briefly, but the results showed that to test its effectiveness would require finetuning of the cleaner to the harmonic frequencies of the biofilms. The difficulty of doing this, the expense of ultrasonic cleaners, and the variability in the biofilms between different sections of belt made this option less appealing, and so it was discontinued.

5) UV light is successfully used to kill bacteria in wastewater treatment, however for this application there may be problems penetrating both the biomass and the crevices of the belt. Also the belt would not be able to be treated while coiled. For these reasons and because UV light could potentially, over time, degrade the belts, the concept was abandoned.

7) Caustic chemical cleaning was the method recommended for cleaning plaques, in literature found on cleaning (see Section 1.5). The Prostrip chemical was recommended by Sealord, as they already use it. The manufacturer stated that the parameters affecting the quality of a clean are: the concentration of the solution; the temperature of the solution; the time the belt spends in solution; and the mechanical action against the plaque. This concept was deemed worthy of further investigation.

8) Combinations of several cleaning mechanisms provides an opportunity to incorporate the best aspects of multiple cleaning mechanisms into one system. The concept was deemed worthy, though restricted to combinations of those mechanisms above that are being pursued.

| key | | |
|---|---|---|
| | poor | - |
| | fair | + |
| | good | ++ |
| | very good | +++ |

| # | Concept | Effectiveness at removing Biosolids | Effectiveness at killing Bacteria | Cost to manufacture | Ease of design | Ease of maintenance | Other factors | Overall score | Continue concept development? |
|---|---|---|---|---|---|---|---|---|---|
| 1 | water jets | ++ | + | +++ | +++ | ++ | familiar technology | ++ | Y |
| 1b | angled | +++ | + | +++ | +++ | ++ | familiar technology | ++ | Y |
| 2 | rotat brushes | + | - | ++ | ++ | ++ | no penetration of belt | + | N |
| 3 | recip brushes | + | - | ++ | ++ | ++ | no penetration of belt | + | N |
| 4 | ultrasonic | unknown | - | - | - | - | unknown technology | - | N |
| 5 | UV light | - | +++ | ++ | ++ | ++ | | + | N |
| 6 | angl brushes | ++ | - | + | ++ | ++ | no penetration of belt | + | N |
| 7 | caustic bath | + | ++ | + | + | ++ | | ++ | Y |
| 7b | agitated bath | ++ | +++ | + | + | ++ | | ++ | Y |
| 8 | combination | ++ | ++ | + | + | + | varies with combination | ++ | Y |

Table 1 Concept selection table.

## 2.5 Discussion and Conclusions from Concept Designs

The conclusion from the concept generation stage was that there was insufficient knowledge of the effectiveness of the various cleaning mechanisms to decide upon one ‘best’ alternative. Thus it was decided to conduct a series of tests to determine more definitively the effectiveness of the various methods. The concepts showing promise, which were to be tested, were those involving water jets, and those involving a caustic bath (and a combination of the two). It should be noted that both of these methods were already being used to some extent by Sealord to clean belts.

This decision led to the development of the system concepts shown in Section 2.3.2, using the cleaning methods identified above. Note - all of the system concepts involved a tank for soaking the belt in chemicals and/or water jets. The selection of the system concepts was dependant upon the results of the experiments (see the following chapter).

# 3.0 Experimental

## 3.1 Introduction to experimental section

After discussions with Sealord staff and an expert (Morgan. H), a series of experiments was designed. The aim was **to quantitatively compare the effectiveness of various cleaning methods and parameters in killing bacteria, and to qualitatively compare the effectiveness of various cleaning methods and parameters in removing biosolids.**

In the previous section it was shown that the cleaning mechanisms that warranted testing were the use of water jets, the soaking of the belt in a caustic solution, and agitating the belt in a caustic solution.

## 3.2 Method

A test rig was designed to be able to hold a belt section in its foot, and provide consistent agitation of about 75 cycles per minute with a stroke length of 100mm (Fig. 10). This rig was also used to hold the belt sample for those tests that were not agitated. Some tests used a water-blaster. Each time the cleaning process was completed, five swab samples were taken from the join in the section of belt that had been washed (Figures 11, 12). These swabs were then used to do a microbiological count (Fig. 13). For a more in-depth description of the process see Appendix 1.

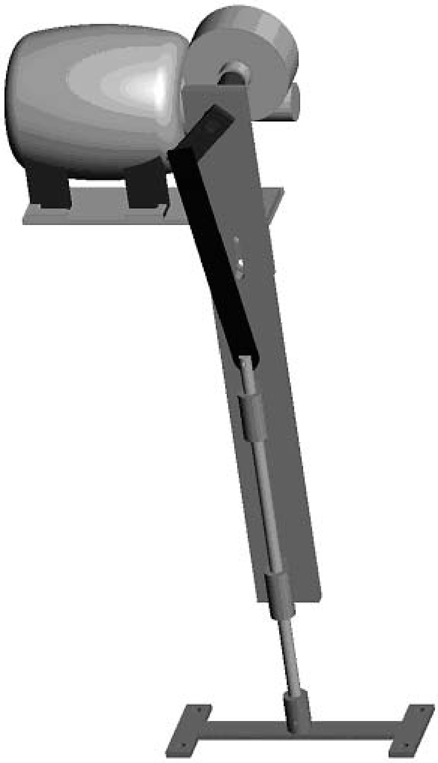


Fig 10. Test Rig.

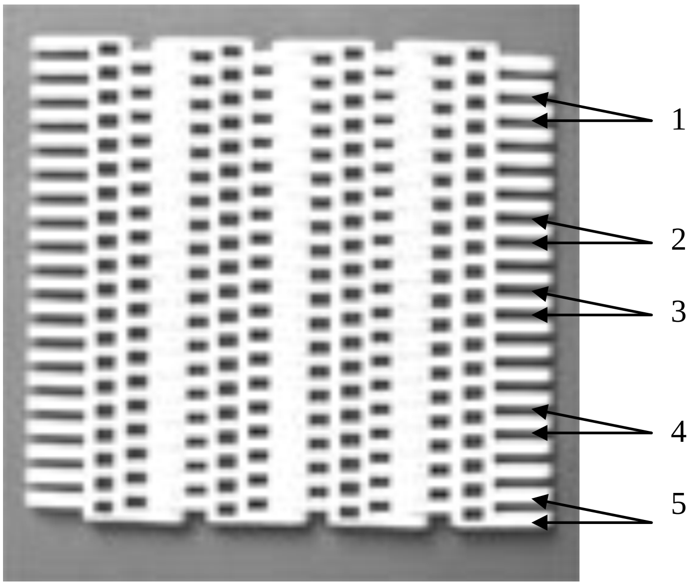


Fig. 11. swab locations.


Fig. 12. Swabbing the cleaned belt

Fig 13. Preparing the SPC plates

## 3.3 Results

The results of the first series of experiments showed that water-blasting had some positive effect on the microbiological cleanliness, but that the time spent in the solution was much more significant. It was noticed that the water-blasted sections appeared noticeably whiter than the non-water-blasted sections.

The second series of experiments varied the dilution of the ‘Prostrip’ chemical, the length of time spent in the chemical, the temperature of the solution, and the degree of agitation that was applied to the belt sample. The results of this showed that more concentrated solutions tend to clean better, 8% solutions (8% v/v Prostrip, 92% v/v hot water, or approximately 54g/L NaOH) and 4% solutions both tended to clean well over 5 or 10 minute tests, but 2% solutions proved less reliable. Keeping the belt in the solution longer resulted in a better clean; there was a significant difference between 10 minutes and 5 minutes in solution. Hot solutions cleaned significantly better than cold solutions. Agitating the belt through the solution caused a significant improvement in the cleanliness of the belt, with ‘shallow’ agitation (where the belt moves into and out of the water during the cycle) being better than ‘deep’ agitation (where the belt remains submerged for the full cycle).

| | |
|---|---|
| Test set # | cfu/sq cm 1 |
| time (min) | cfu/sq cm 2 |
| concentration % | cfu/sq cm 3 |
| agitation | cfu/sq cm 4 |
| average count | cfu/sq cm 5 |

| | |
|---|---|
| Test 1 | 14 |
| 10 minutes | 0 |
| conc = 8 % | 1 |
| soak | 6 |
| 10.4 | 31 |

| | |
|---|---|
| Test 2 | 17 |
| 10 minutes | 4 |
| conc = 8 % | 2 |
| soak & wb | 2 |
| 6.0 | 5 |

| | |
|---|---|
| Test 3 | 671 |
| 5 minutes | 517 |
| conc = 8 % | 3960 |
| soak & wb 10E-1 | 3740 |
| 2043.8 | 1331 |

| | |
|---|---|
| Test 4 | 11000 |
| 0 minutes | 8800 |
| conc = 0 % | 7150 |
| dirty 10E-1 | 7700 |
| 8250.0 | 6600 |

| | |
|---|---|
| Test 5 | 4 |
| 5 minutes | 3 |
| conc = 8 % | 1 |
| shallow | 1 |
| 1.8 | 0 |

| | |
|---|---|
| Test 6 | 10 |
| 5 minutes | 5 |
| conc = 4 % | 17 |
| shallow | 0 |
| 7.8 | 7 |

| | |
|---|---|
| Test 7 | 5000 |
| 5 minutes | 300 |
| conc = 2 % | 300 |
| shallow | 28 |
| 1325.6 | 1000 |

| | |
|---|---|
| Test 8 | 2 |
| 10 minutes | 0 |
| conc = 4 % | 41 |
| shallow | 8 |
| 10.8 | 3 |

| | |
|---|---|
| Test 9 | n/a |
| 10 minutes | 7 |
| conc = 2 % | 55 |
| shallow | n/a |
| 22.7 | 6 |

| | |
|---|---|
| Test 10 | 200 |
| 10 minutes | 450 |
| conc = 4 % | 90 |
| soak | 32 |
| 166.4 | 60 |

| | |
|---|---|
| Test 11 | 200 |
| 10 minutes | 60 |
| conc = 2 % | 70 |
| soak | 15 |
| 69.6 | 3 |

| | |
|---|---|
| Test 12 | 4 |
| 10 minutes | 0 |
| conc = 8 % | 1 |
| soak | 1 |
| 2.6 | 7 |

| | |
|---|---|
| Test 13 | 120 |
| 7.5 minutes | 21 |
| conc = 8 % | 21 |
| soak | 4 |
| 33.2 | 0 |

| | |
|---|---|
| Test 14 | 1 |
| 10 minutes | 120 |
| conc = 8 % | 20 |
| soak | 1 |
| 29.2 | 4 |

| | |
|---|---|
| Test 15 | 82 |
| 10 minutes | 110 |
| conc = 8 % | 160 |
| cold soak | 340 |
| 173.0 | n/a |

| | |
|---|---|
| Test 16 | 3 |
| 5 minutes | 12 |
| conc = 8 % | 31 |
| deep | n/a |
| 12.0 | 2 |

| | |
|---|---|
| Test 17 | 18 |
| 5 minutes | 30 |
| conc = 4 % | 14 |
| deep | 0 |
| 13.2 | 4 |

| | |
|---|---|
| Test 18 | 5000 |
| 0 minutes | 5000 |
| conc = 0 % | 3500 |
| dirty 10E-1 | 2500 |
| 3500.0 | 1500 |

| | |
|---|---|
| Test 18b | 50000 |
| 0 minutes | 25000 |
| conc = 0 % | 20000 |
| dirty 10E-2 | 15000 |
| 27500.0 | n/a |

Table 2. Results of microbiological tests.

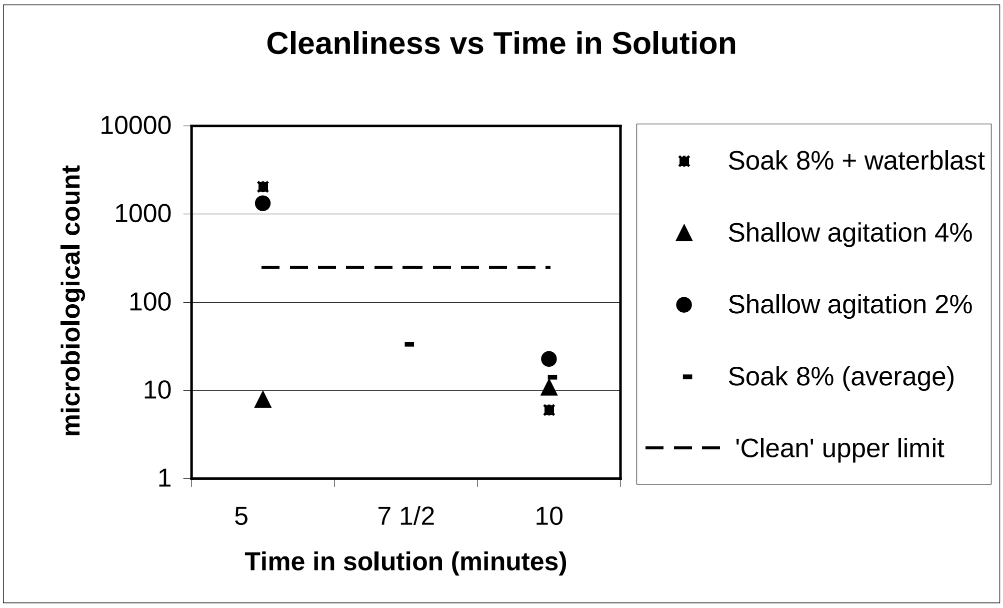



Figure 14. Influence of wash duration on cleanliness.

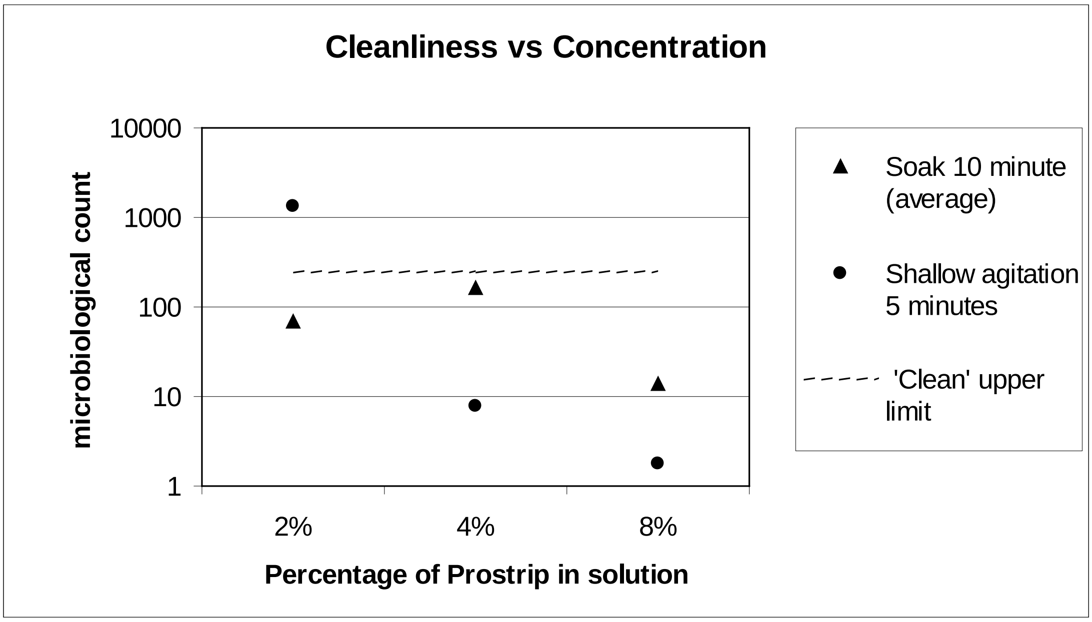



Figure 15. Influence of solution concentration on cleanliness.

## 3.4 Discussion

Sections of the belt that were water-blasted appeared significantly whiter to the naked eye. This is likely to indicate that these sections had less biosolid than the non-water-blasted sections. Although less biosolid does not necessarily correlate with fewer living bacteria, it does reduce the amount of ‘food’ remaining on the belt for subsequent contamination.

This theory was based on discussions with Morgan H, a microbiological expert. He stated: “*You might have spore formers present which would easily survive a 60$^{o}$C exposure. The importance of this is that they would germinate when normal conditions are regained and* ***quickly grow on any soil remaining in the biofilm***.” This theory supports the original requirement to remove biosolids as well as killing any existing bacteria.

Temperature was optimised at 60$^{o}$C (limited by the softening temperature of the belt). The microbiological expert did not feel that the elevated temperatures would 'cook' the plaque and make it any more difficult to remove.

Therefore the design variables were:

- Whether or not to agitate
- Minimising concentration
- Adjusting the above to suit time constraints

Figures 14 and 15 demonstrate that the agitation of the system significantly improved cleaning effectiveness. Tests indicated that a solution concentration of about 4% Prostrip at 60$^{o}$C, being soaked for about 10 minutes, or agitated for 5-10 minutes would provide good cleaning, when followed by water blasting.

Note that all results were disguised by statistical variations, which masked trends and may cast doubt on the validity of the conclusions.

## 3.5 Conclusions

Because water-blasting the belt sections resulted in significantly less biosolid being left on the belt, it was decided that water-blasting was to be included in the design.

Agitating the system significantly improved the effectiveness of the clean. However, after considering the increased complexity and cost of this, it was difficult to ascertain whether agitation would improve the cleaning to the extent that it should be designed into the system. It was therefore decided to develop an initial embodiment for soaking with and without agitation. Each option would have a separate water-blasting unit to use afterwards.

# 4.0 Embodiment of Ship Based Design

## 4.1 Situation

At the time that the initial embodiment took place the specification was for a device to be installed on the factory deck of each of the fishing boats. Two design embodiments were done to fulfil this situation. The most influential constraint on the embodiment of the design was size. The Sealord vessel 'Kiwa' was inspected as this was represented as being one of the most tight-for-space vessels. The space that was available and recommended is shown in Figures 16, 17, and 18. The space is located under a conveyor that is used to move fish in front of some trimming or filleting crew.

The conveyor, a waste race and other miscellaneous machinery parts cover most of the area. At the 'front' it is bordered by a raised walkway that the crew stand on when they are working at that job, there is 610mm clearance between the grating and the deck. The race that can be seen in Figure 16 is removable during the time that the device being designed would be used. The device should not overly impede the access to a piece of machinery that has an opening that is visible but obscured in the middle right of Figure 16. Hydraulic, 3-phase power, and water sources were all available within a few metres, also available within 20 metres was an air supply, a steam supply, and bilge drains (to discharge overboard).

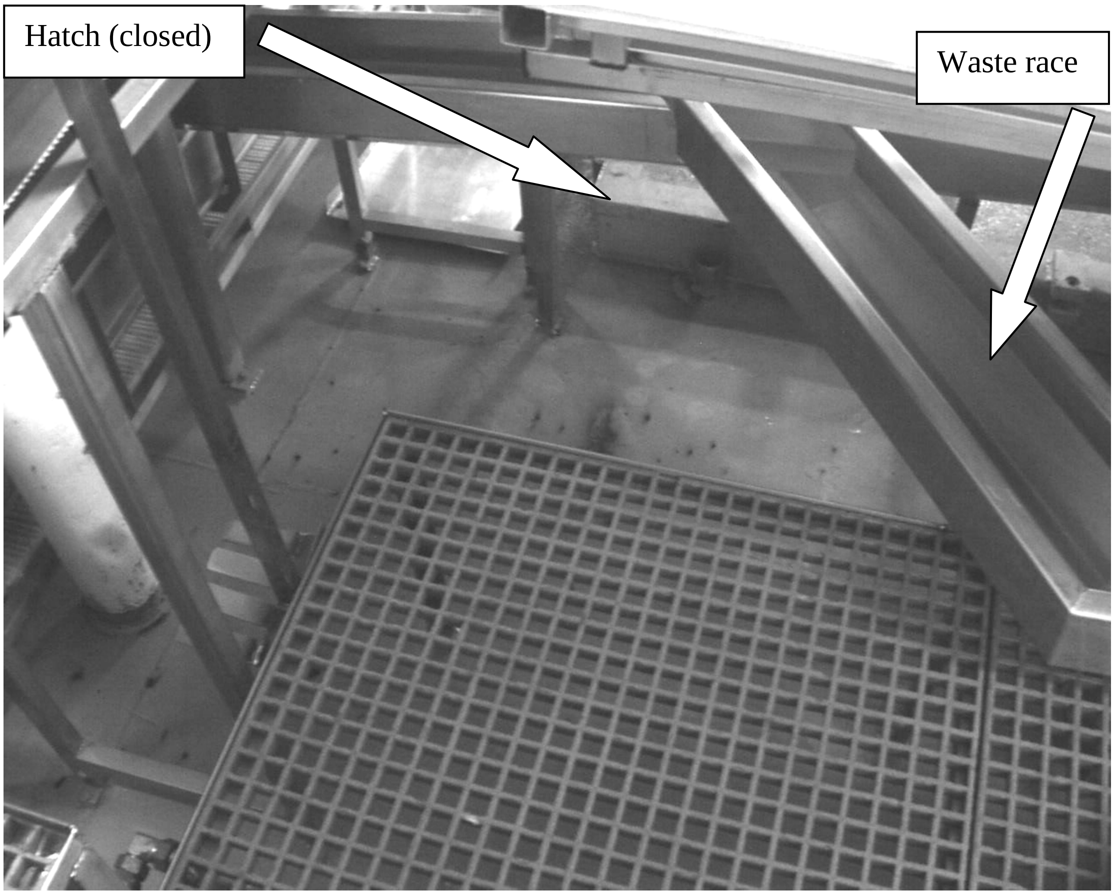



Fig. 16. The space in the Kiwa with the waste race in place, and the hatch closed.

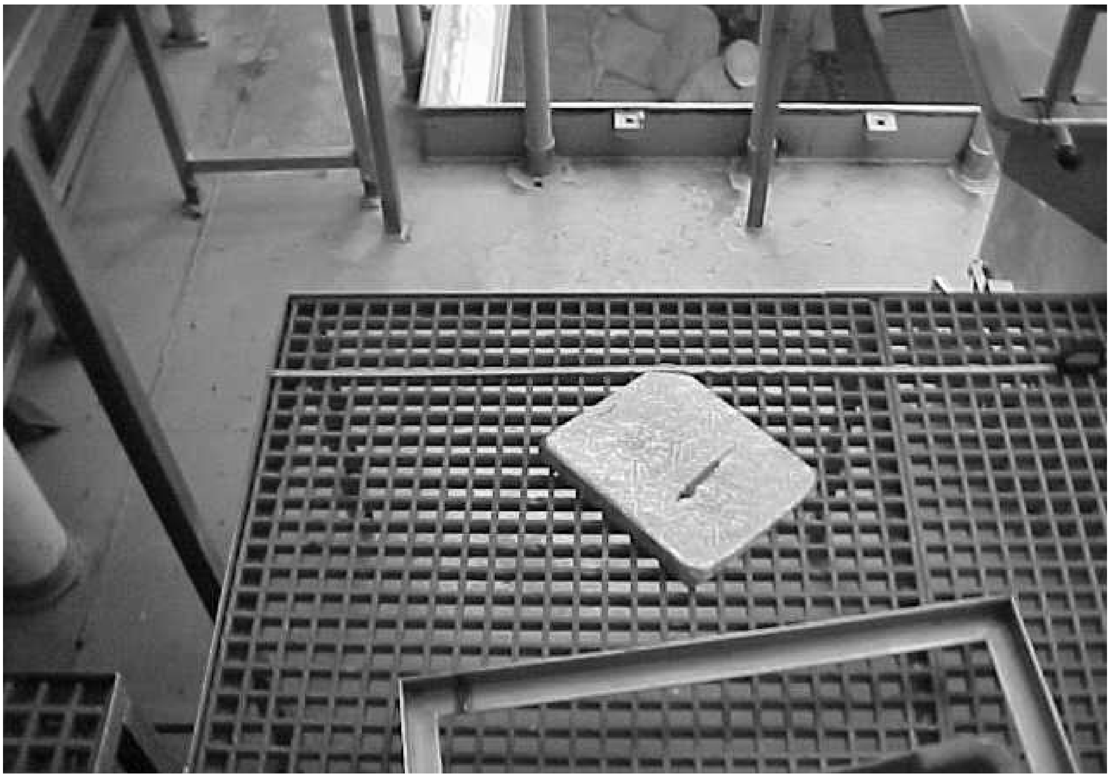


Fig. 17. The space in the Kiwa without the waste race in place, and the hatch open.

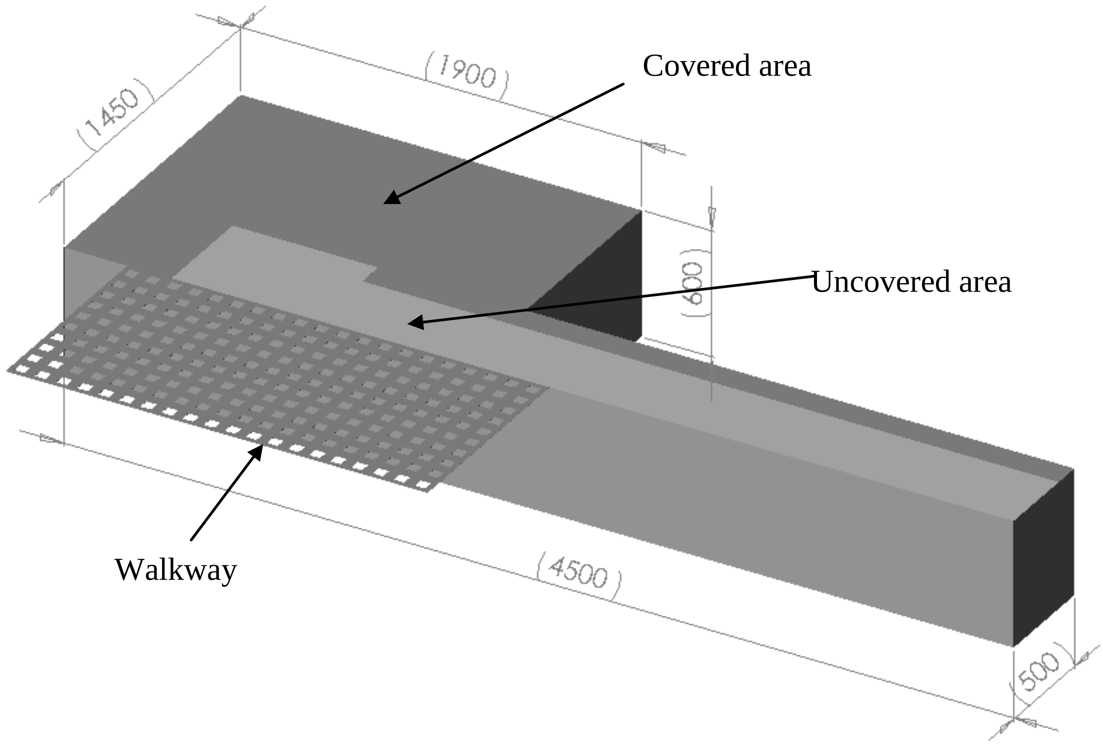



Fig. 18. Schematic diagram showing space constraints for the ship based design, in the vessel 'Kiwa', with major dimensions shown.

## 4.2 Legislative influences

The initial specifications stated that chemical solutions must not be required to be unloaded at the dock. This meant that it was necessary to discharge any cleaning solution overboard at sea. The safety of the crew must also be protected considering that the device being designed could pose serious chemical, heat, and/or motion hazards.

### 4.2.1 Resource Management Act

After some research it was found that the acts governing the ecological and cultural ramifications of any discharge into the sea were the Resource Management Acts (1991-present).

This set of acts and amendments started with the resource management act 1991. It was designed to "restate and reform the law relating to the use of land, air, and water" (RMA 1991). A through investigation of the Act revealed that the relevant section is Section 15B.

Part of this section is stated (having been adjusted as detailed by amendments up to and including 1997) below. Note that this excerpt does not include all relevant clauses, nor is it guaranteed to be accurate and up to date, it is only intended to be indicative of the general intention of the act.

*15B.*

*(1) No person may, in the coastal marine area, discharge a harmful substance or contaminant, from a ship or offshore installation into water, onto or into land, or into air, unless---*

*(a) The discharge is permitted or controlled by regulations made under this Act, a rule in a regional coastal plan, proposed regional coastal plan, regional plan, proposed regional plan, or a resource consent; or*

*(b) After reasonable mixing, the harmful substance or contaminant discharged (either by itself or in combination with any other discharge) is not likely to give rise to all or any of the following effects in the receiving waters:*

*(i) The production of any conspicuous oil or grease films, scums or foams, or floatable or suspended materials:*

*(ii) Any conspicuous change of colour or visual clarity:*

*(iii) Any emission of objectionable odour:*

***(iv) Any significant adverse effects on aquatic life; or***

*(c) The harmful substance or contaminant, when discharged into air, is not likely to be noxious, dangerous, offensive, or objectionable to such an extent that it has or is likely to have a significant adverse effect on the environment.*

The readers attention is drawn to the line in bold, as this clause was the most concerning considering the caustic nature of the discharge and the relatively shallow waters that the discharge would often be discharged into. Summarised this means that if the discharge may potentially result in significant adverse effects on aquatic life then the discharge is prohibited, unless it is permitted under a regional coastal plan.

Because of this an investigation into the likely effects of such a discharge was initiated. This is documented in Section 4.3 below.

### 4.2.2 MARPOL and The London Convention

The international agreements of the London Convention, and the MARPOL agreement were examined. The London Convention was first held in 1972, and resulted from a UN resolution, and oil tanker disasters. This agreement's intention was the "prevention of marine pollution by dumping of wastes and other matter" (London Convention 1972). This however allowed discharges that were part of 'normal operations' of a ship. In addition to this agreement, in 1973 and 1978 a larger and more influential agreement was drafted, known as the MARPOL agreement, which was hosted by the International Maritime Organisation (IMO). The IMO made many additions and amendments to the agreements. In late 1998 New Zealand signed its acceptance of all of the agreement except Annex IV (relating to sewage). This was preceded by a major change in the RMA being drafted (in order to comply) in 1998. This was known as "Resource Management (Marine Pollution) Regulations 1998". The relevant parts of those regulations are reproduced below.

*15.Discharges made as part of normal operations of ship or offshore installation*
*Any person may discharge, in the coastal marine area, a contaminant that is incidental to, or derived from, or generated during, the operations listed in Schedule 4 as the normal operations of a ship or offshore installation.*

Schedule 4 includes:
5. The cleaning of the ship or offshore installation, except for the exterior of the hull below the load line or parts of the ship used for carrying cargo.

This would appear to expressly allow the discharge of contaminants used for cleaning of the ships conveyor belts. However at the time that this information was relevant it was not clear whether these regulations were still a draft or had been made into legislation.

### 4.2.3 Health and Safety in Employment Act

The Health and Safety in Employment Act 1992 sets out regulations for the employer's responsibilities regarding hazards to employees. Sections 7 through 10 give the employer the responsibility to systematically identify and classify hazards (potential to do harm), and significant hazards (potential to do serious harm (such as that which should lead to hospital or specialist treatment)). The employer must also deal with significant hazards by:

1) Eliminating them if practical,
2) If not then isolate them if practical,
3) If not then minimise the likelihood of harm, protect the employees from it (protective clothing and equipment), and monitor both the employees' exposure to the hazard, and (with the employees' consent) their health.

This influences the design of the device in that the device should not pose any significant hazard, or if this is practically unavoidable, then such hazards should be isolated by design, and if this is unavoidable then recommended safety policies must be well documented and emphasised.

### 4.2.4 Institution of Professional Engineers New Zealand

The esteem that IPENZ is held in gives weight to its code of ethics which are summarised as:

Protection of Life and Safeguarding People
Professionalism and Integrity
Society and Community Well-being
Sustainable Management and Care of the Environment
Promotion of Engineering Knowledge

## 4.3 Environmental influences

Due to the unknown condition of the draft regulations inspired by New Zealand's acceptance of the MARPOL agreement, an investigation into whether "*Any significant adverse effects on aquatic life*" would result from the dumping at sea of the cleaning solution was conducted. An Associate Professor with an interest in marine ecology gave an opinion on the matter but did not want to be named. He thought that although the discharge would most likely cause no significant adverse effects on aquatic life, he would strongly recommend against the discharge because of public and political objection (despite the minimal consequences) if it became a media issue. Essentially he warned that discharging several hundred litres of high-pH sodium hydroxide solution into the sea could give very bad publicity to the company and anyone associated with the activity. The several hundred litres was an approximate figure based on the most favourable design options at that time (see below).

## 4.4 Design development

The careful consideration during the concept development phase led to the two options that were carried through to the embodiment stage, being fairly similar. They both consisted of two tanks, one that the belt was put into, called the wash tank, and one to hold the chemical solution when it wasn't in the wash tank, called the holding tank. They both had heating elements in the holding tank, and a transfer pump to move the solution into and out of the wash tank. The designs consisted of a cylindrical tank, with a lid on the end of the cylinder, the lid was designed as is shown in Figure 19. This was housed in a frame that could be inclined to facilitate loading and unloading as is shown in Figure 20. The inclination was to be achieved using two pneumatic rams mounted on pivots on the deck and tank frame. With both options the wash cycle was followed by a separate rinse cycle to be carried out in a separate portable unit.

The agitation design option had a hydraulic motor driving a shaft with a basket on it, similar to what is shown in Section 2.3.5 Concept 1. It was designed to be filled to just over halfway with solution, and have the belt and basket spun through it. This was because the shallow agitation was shown to be superior, and because this would allow half the holding tank size, and less demand for heaters in that tank (although the solution would cool further each time, so the reduction would be less than half the original requirements). The basic form of the design is similar to that of the no agitation option, except that there is a motor on the end of the wash tank opposite the lid, and an internal shaft.

The special constraints forced a layout as is shown in Figures 21 and 22. Because of the location of the walkway, and the weight of the belt, it was decided to have the wash tank inclinable when it was being loaded and unloaded.

Preliminary costings were developed for each option, this included materials costs, expected labour, and a multiplier for the price of labour (a wage rate). The price arrived at was $23,000 for the agitation option and $21,000 for the no-agitation option. With more recent experience it is believed that these were significant underestimates, more likely costs would be $46,000 and $41,000 respectively. The major contributors to these discrepancies were significant underestimations of the cost of the control system, the cost of labour, and the cost of valves, however a cheaper than expected pump was found.

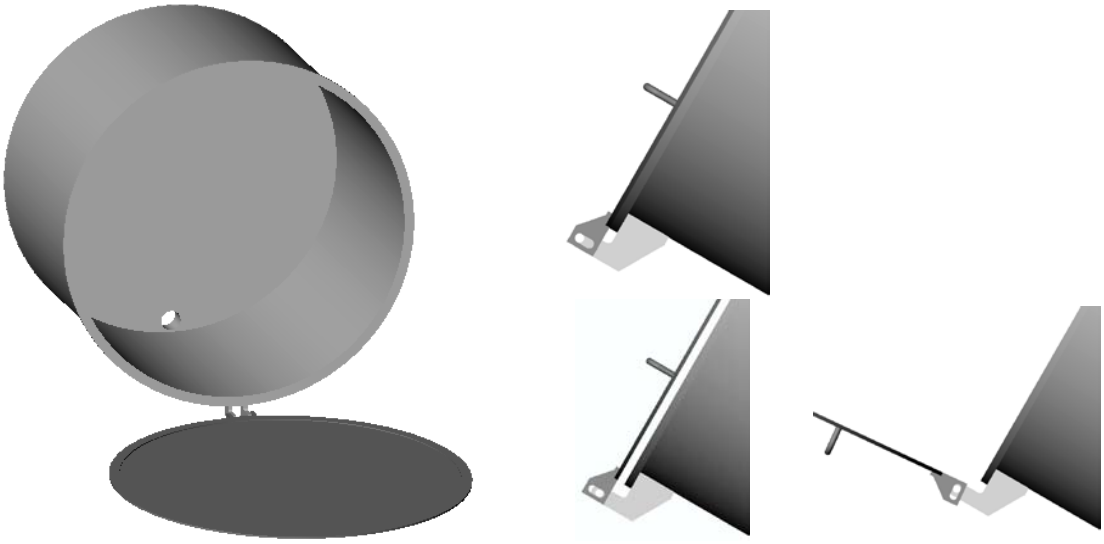


Fig 19. Drawing of the wash tank when opened (no agitation option), and lid mechanism.

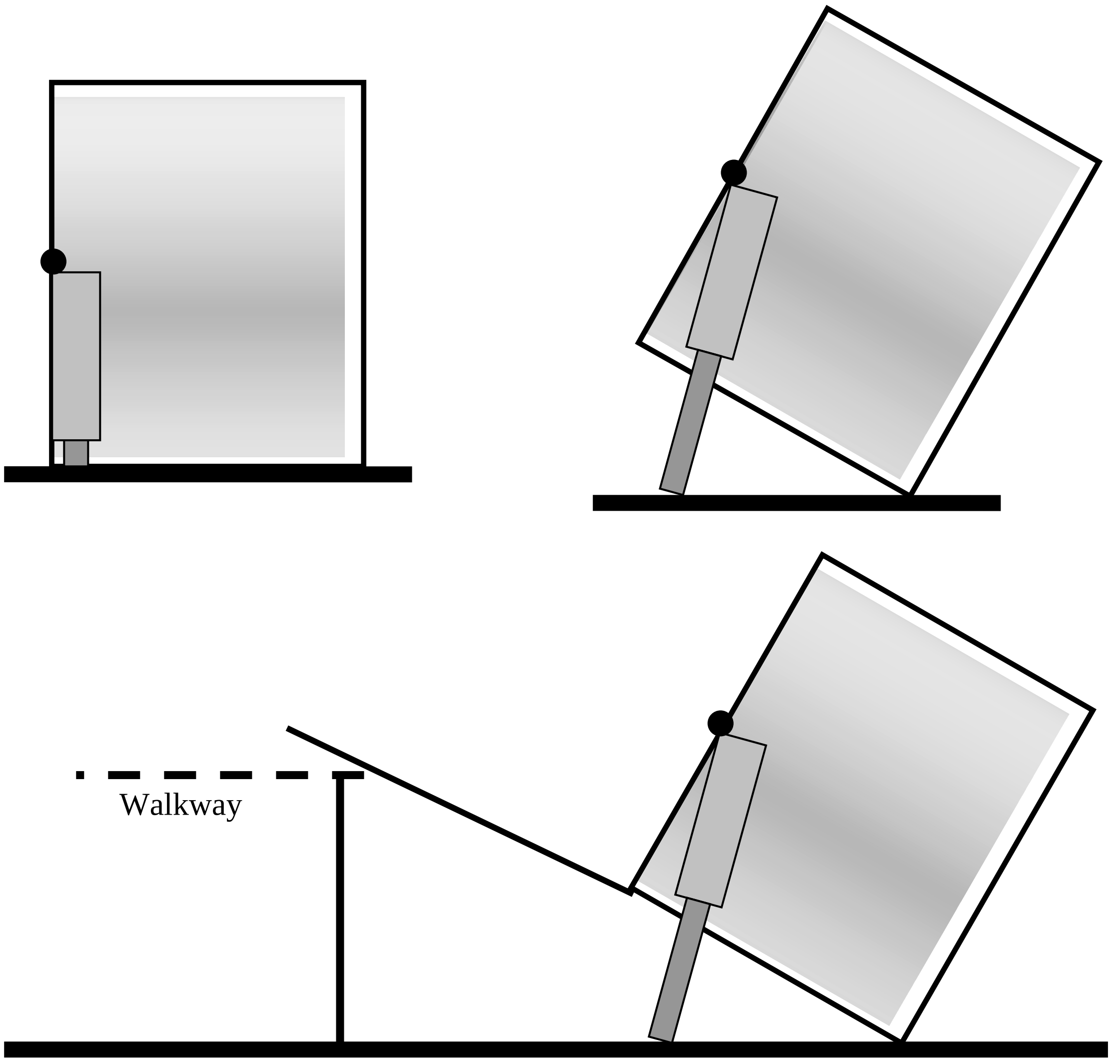



Fig 20. Diagram of the wash tank flat on the deck, tilting up, and opening to be loaded and unloaded.

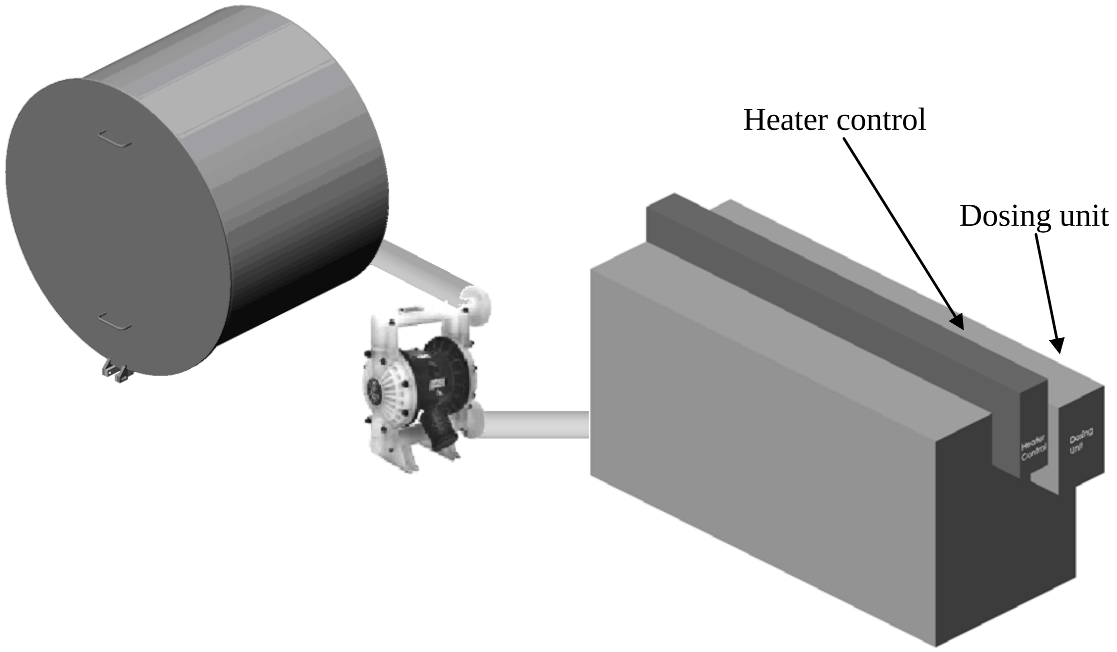



Fig 21 – Pictorial view of layout

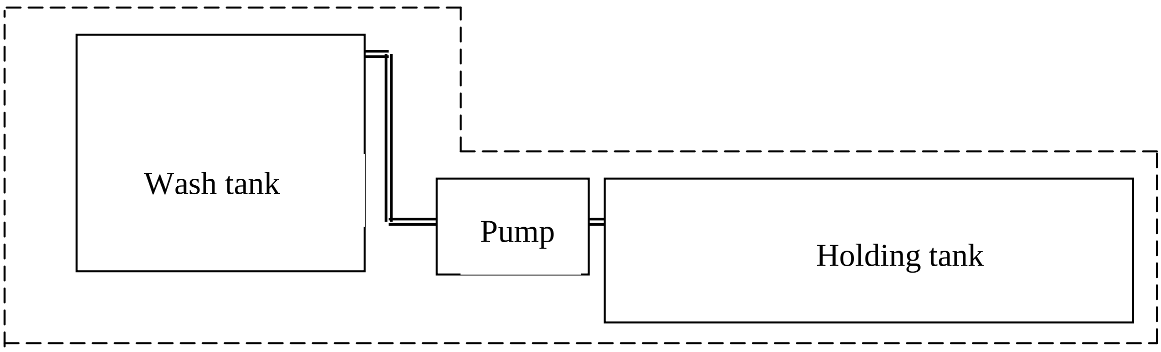



Fig 22 – Plan schematic of layout

## 4.5 Change of specification

In late November 2002 a progress meeting was held with Sealord. The intention of this meeting was to decide which of the two designs to develop into a detail design. However during the meeting the decision was made to abandon the ship-based concept and instead pursue a land-based design. There were several reasons for this. Firstly the concept of unloading the dirty belt after the ships arrival in port was understood to be not an option, prior to the meeting. Secondly the weight of the proposed basket and belt would be heavier than was desirable, bordering upon being unacceptable. Thirdly there were concerns about the sturdiness of the design when considering the rough treatment the crew were likely to give it ("if it is made fisherman-proof, then you won't be able to lift it"). There would be time savings if the job did not have to be done out at sea, delaying the arrival of the ship, and instead could be done during time when the ship was in port. Finally and most importantly, it was decided that rather than pay for four units (one on each freezer boat) that would be used approximately once every six weeks, a single unit on land that would be used four times in six weeks, and possibly more (for cleaning land based factory belts and other items) would be much more cost-effective.

Thus a decision was made to instead develop a land-based device. Because of the drastic nature of the change, and therefore the disruption to the schedule, a concept was agreed upon on the day of the meeting. The design was to be similar to the no-agitation option of the ship-based design, but larger (specifically 1m diameter, 1 m high), with a vertical wash tank, and a holding tank, all enclosed in a forklift-resistant fence. Also the design was to be fairly open to facilitate modification if at a later date it was decided to add an agitation feature. This last criterion was due to the frequency of occurrences where forklifts were accidentally driven into doors and other obstacles. The time spent in port meant that the belts should be washed in a 12-18 hour window at the most.

Initially there was a desire to make the unit easily portable so that it could be put on the back of an articulated truck and transported to Picton in order to clean the belts off the 'fresher' boats on the wharf there. This specification was dropped due to the objections of the Picton Wharf authorities, and the limited resources available there. It was later decided to only insulate the holding tank, due to the reduced touch risk provided by the fence, combined with the fact that most of the heat loss occurred due to the heat capacity of the cold tank and belt, and that the solution temperature of $60^{o}$C was a small burning risk. The specification shown in Section 1.5 is as modified after these changes.

# 5.0 Embodiment of land based machine

## 5.1 Fundamental Parts

After the visit to Nelson, a new specification and concept were developed. The design was to consist of a wash tank and a chemical holding tank, mounted on a single chassis that provided protection for the tanks and other equipment from forklifts. Early in the embodiment stage it was decided in consultation with Sealord that the level of environmental protection required for the electronic products and enclosures was IP65. This means that the parts will be totally protected against dust, and protected from low-pressure water jets from all directions.

To transfer the caustic solution between the tanks a pump was needed, initially an air operated double diaphragm pump was the preferred choice, as air lines are safer than electrical wires in this environment, and because it was less likely to suffer damage when the tank ran dry. However the capacity to cost ratio for such pumps was considerably worse than for a conventional electrically powered centrifugal pump (several thousand dollars compared to just under one thousand dollars for comparable performance). Bi-directional pumps were considered but discounted as they were too expensive and not suited to high flows, instead valves will be used to control the flow direction (see Figure 23 below) (white valves, and light grey valves operate as pairs, mid grey and dark grey operate independently).

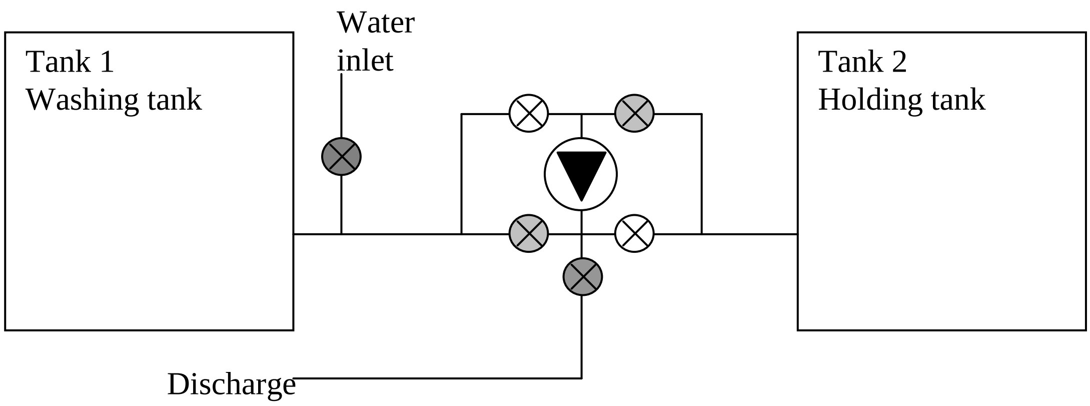



Fig. 23. Pump and flow control.

A heat source was required to heat the sodium hydroxide solution. Electrical heater elements, steam injection, and steam heat exchangers were investigated to fulfil this need. Steam injection is the method most commonly used by Sealord to heat liquids, however it was not favoured in this application because of its violent and poorly controlled nature. It would have added volume to the solution, which when combined with topping up from a chemical dosing unit, may be sufficient to overflow the holding tank. A cost and thermal comparison was done between using a steam heat exchanger, and electrical elements, and they came out with approximately the same cost. Using electrical elements was selected, as it was easier to design, easier to control accurately, and did not have the problem of disposing of cooled steam (there was no return-to-boiler facility available). This is discussed more fully in Appendix 3.

The device was desired to be fairly automatic, and so automatic control of the valves was decided upon, for ease of use and for safety reasons (so tanks of caustic soda were not allowed to overflow). Electrically operated and pneumatically operated valves were investigated. Pneumatically operated valves were decided upon because they were cheaper at the required sizes, and safer in this environment.

## 5.2 Control System

To control the pump and valves a control mechanism was needed. Two options were investigated, a PLC and a PCB with a CPU. They came to a similar cost, but the PLC offered greater ease of design, installation, programming, and program modification so it was selected. As inputs to the control device, several signals were needed. These were: when the tanks were full, to prevent overflows; when the pump was dry to prevent it continuing running when the wash tank had been emptied; when there was insufficient air pressure to activate the valves; when the lid was not in place, for safety reasons; when the solution was up to temperature, to control the heater elements; and when the start button was pressed. The emergency stop was not an input into the control system, but rather a switch that would cut all power, including to the control system. To indicate when the tanks were full, various level switches were investigated, combined float/proximity switches, separate floats and proximity switches, and conductivity switches (see Figure 24 for diagrams). Optical switches, and vibration-based switches were not seriously considered because they were unnecessarily complex for this situation. Combined float/proximity switches were selected, because they were simple, reliable, easy to install, and cheap.

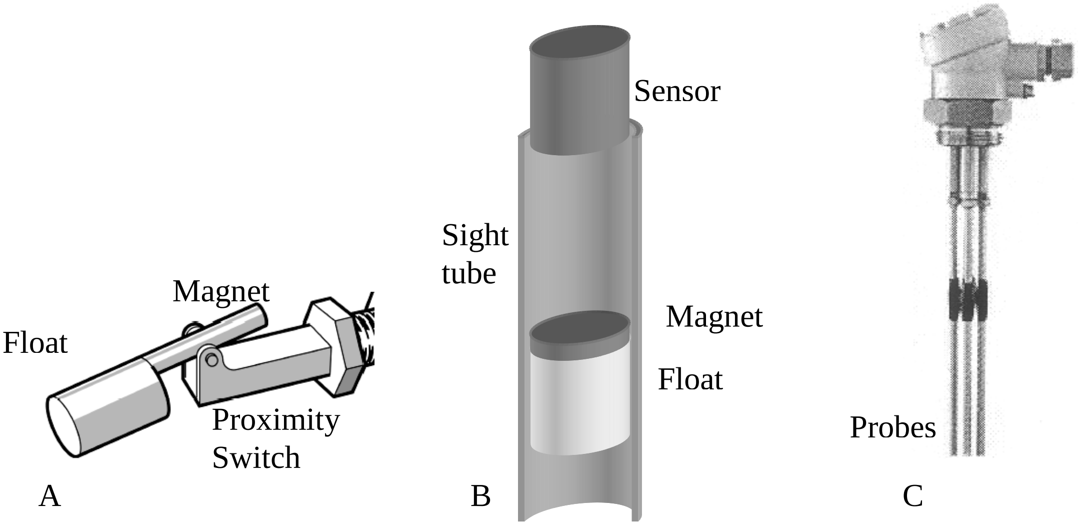



Fig 24. level switches A combined; B separate; C conductivity.

To check to see whether the pump was running dry or not, initially a flow switch was intended to be used, these were one of the cheapest types at $600 each, but caused some impedance to the flow. An alternative to using a flow switch was suggested, that was to use a pressure switch to check to see whether the pump was developing any significant head. If all it was moving was air, then the pressure built up would be much less. This option cost only $150 for a pressure switch that could handle the pressure and caustic solution, and would result in much less flow disturbance. It was therefore selected as the switch to use. The emergency stop switch and start switch were selected from those that had an IP 65 or better rating, and then in view of price and availability. The pneumatic pressure switch was selected on price and availability.

A chemical dosing unit was required to keep the cleaning potential at a constant level. On the advice of the chemical manufacturer a $600 dosing unit was selected. The unit selected consisted of a conductivity probe to measure the concentration of unused sodium hydroxide in the solution (conductivity is approximately linear with concentration, whereas pH is logarithmic, which is why a pH meter was not used), a control box, and a pump to dispense the concentrate into the solution.

The cables were selected by their ability to carry the current, whether they allowed fewer cables to be used (for example several single core cables were considered, but a multiple core cable was found that filled the requirements and used fewer cable glands and was easier to install), and price. The cable glands were not specified, but it is recommended that ones that grip the cable so as to take any tension (as opposed to the terminals in the enclosures) be used. The enclosures were chosen by price, but polycarbonate ones were not preferred because they are incompatible with sodium hydroxide.

## 5.3 Display

The display was desired to indicate the cycle progress (i.e. not ready to start, ready to start, washing, and rinsing), and fault indication (lid insecure, low air pressure, process timed out, and unexpected input). To minimise the number of outputs from the PLC needed, it was decided to try and use three outputs, which between them could have eight different open/closed combinations, to light up one of eight different LEDs (one associated with each state (progress or fault)).

Initially, after a difficult investigation a chip was found, designed to achieve this. It was called a 3 to 8 demultiplexer (also known as a ‘demux’). An alternative to a demultiplexer was suggested, This was a BCD (Binary Coded Decimal) to decimal decoder. A BCD to decimal decoder is effectively a 4 to 16 decoder, where the last 6 combinations are invalid, allowing 4 binary signals to define a decimal (0-9) value. This chip can also be used as a 3 to 8 decoder by earthing one of the inputs and ignoring two of the outputs. The advantages are that they have fewer ‘enable’ pins to worry about, and they are generally slightly cheaper and more tolerant in their operating conditions, and so this (type 4028 integrated circuit) was decided upon.

As these chips are not able to put out sufficient current to drive an LED, a series of transistors was necessary to convert the low current output to a level where it could drive an LED. For the LEDs, it was decided that a 5mm high intensity LED would provide sufficient indication, as an operator would have to actively look at the display (close up) to read the writing, so the LEDs were not intended to attract attention from a distance.

## 5.4 Structural Issues

A chassis was necessary to support all the parts of the device, so that it would be unitary and portable. The necessity of having the tanks close to horizontal, both in themselves and in relation to each other (for drainage purposes), meant that a strong frame was needed to lift them off the ground. Large beams of stainless steel would have been very expensive, so it was decided to make the chassis out of mild steel. Due to the marine environment the chassis would be going into, it would need to be galvanised. In order to be able to be picked up by a forklift, the chassis needed to have two 200 by 100 RHS sections in its side, with their centres 800mm apart, and needed to weigh 2000kg or less when empty. Incorporated into the chassis was an overhead trolley crane, to be used to load and unload the belt from the wash tank (it was too heavy and awkward to do manually).

Because the device was now going to contain both stainless steel and galvanised mild steel parts, there emerged a risk that the two materials would react and that the zinc galvanising would be eroded through galvanic corrosion. Hot dipped steel has an anodic index of 1.2V, stainless steel has an anodic index of 0.6V, resulting in a difference in the anodic index of 0.6V, where for the environment that the device would be going into, “typically there should be not more than 0.15V difference in the anodic index” (all information is from the Engineers Edge website). To prevent galvanic corrosion, plastic spacers were designed to isolate the two components, so that metal ions could not travel between the dissimilar materials.

## 5.5 The Lid Mechanism

Several different lid mechanisms (for the wash tank) were developed and compared. The first option was a hinged lid (see Figure 25a). The second was a sliding lid (see Figure 25b). The third was a dropping lid (see Figure 25c).

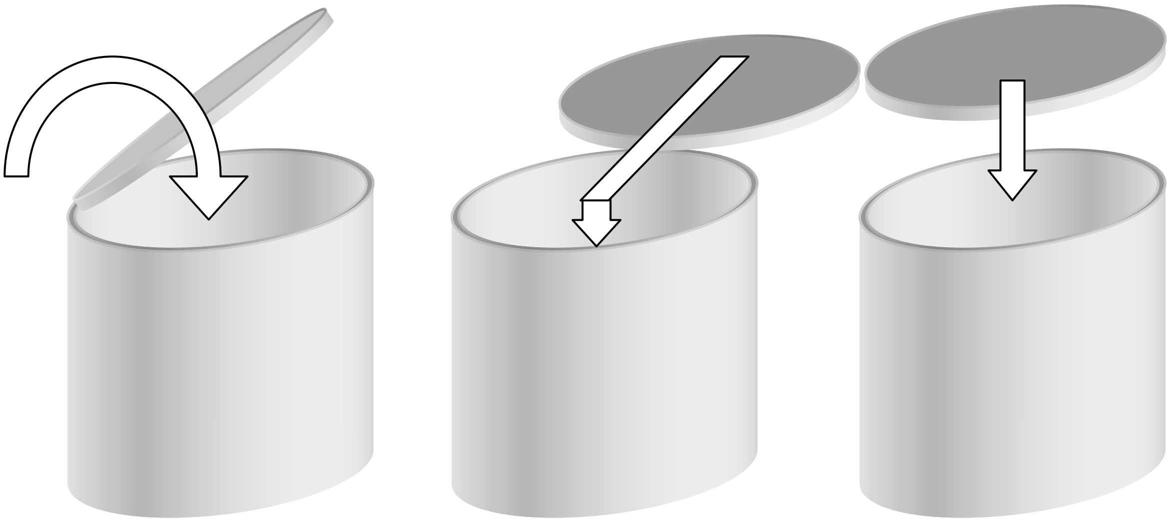


Fig. 25. Lid types: a) Hinged; b) Sliding; c) Dropping

A variant of option c was chosen. Since an overhead crane was needed to load the belt into the tank, the variant incorporated the lid being semi-permanently attached to the hook end of the crane (see Figure W). Instead of hooking the basket full of belt to the crane, it was attached to the lid using carabiners (quick to take on and off, more secure than a hook especially when there is slack in the line). It was then lifted up, moved over to the wash tank, and lowered in. This removed the otherwise necessary steps of removing the crane from the basket and putting the lid in place, and the opposite when unloading. An additional benefit of the lid being lowered by a chain block, is that it will move relatively slowly, and in a controlled fashion. Hinged lids especially, and to a lesser extent sliding lids have the significant hazard of slamming on fingers and hands.

Fig. 26. Lid mechanism

The basket needed to be strong enough to lift up to 60kg of belts, and also be permeable to water (so that when the tank was filled, the solution got into the belts). The design developed for this was a flat bar frame, with sheet sides, and a perforated sheet base (to let the water in). Other options investigated and discarded included using wire netting/mesh, using rods to make a grill/frame, and attaching the belts to the lid with rope or a net.

## 5.6 Safety Issues

The existence of the overhead crane gives rise to the opportunity of installing the tanks using the crane, instead of doing it manually or with a forklift, both options being cumbersome and difficult by comparison. Having holes or some other mounting facility conveniently located near the top of the sides of each tank was considered. It was decided not to go ahead with this as it was thought that the job would be easy enough with the existing mounting options (having a strop passing underneath or attaching to the feet). The advantage of having a mounting facility near the top of the sides is that the tanks will hang in a stable fashion, whereas if they are suspended by the feet, they could topple over if they are not properly restrained. However this risk was small, and judged not great enough to justify putting in the mounting facility.

A safety fence was required to help to protect the device from damage suffered from being hit by forklifts, as this is a relatively high risk in this situation. Various options were considered as solutions for this problem including; wire netting, sheet steel, wood, and steel extrusions or pipe. Wire netting was chosen as it is light, cheap, and see through (so that any failures may be easily spotted by operators). It will not be impenetrable, but the level of protection is satisfactory to Sealord. It will provide a collision that the driver will notice, and will stretch to absorb energy if the forklift strikes it.

A hazard was identified (see the Health and Safety in Employment Act 1992, Section 4.2.3 of this report) that if the plumbing began to leak, then when it was subjected to high pressure by the pump, the leak could spray caustic solution out, potentially getting in the eyes of an operator. This could cause injuries that would constitute serious harm as defined by the act. In order to reduce the danger if a leak occurs a safety guard was designed. The intention of the guard was to act as a shield against any sprays aimed toward the front of the unit, where any injury would most likely occur. A mounting location for the control box was incorporated into this guard.

A self-draining spill tray was designed, large enough to hold the entire contents of the larger tank (in the event of a rapid failure, emptying its contents). The tray has a permanently open drain leading to the channel where all discharges will go, to let out rainwater and any spilt chemicals. The tray is to be made from galvanised steel, which would be attacked by sodium hydroxide if it came into contact, but the tray is only expected to come into contact with the sodium hydroxide in the event of an emergency, and can be re-galvanised if necessary.

## 5.7 The Rinser

The experiments showed that water blasting the belts after soaking in sodium hydroxide solution helped to remove more biomass from the belts. This was desirable because although the soak killed most of the bacteria, the biomass would provide food and shelter for recontamination. On these grounds it was decided that a brief water blasting would be done after the soak.

To do this, the chosen method was to feed the belt through a set of spraying nozzles. Two options for the nozzle arrangement were immediately obvious. Firstly to have the nozzles stationary, with fan shaped nozzles aiming down onto the belt (see Figure X below), angled so that they would impact upon the front and the back of any flights that were on the belt, and up from below to clean the under surface (not shown in Figure X). The second option was to have some fan nozzles mounted on T shaped rotors, angled so that the reaction force from spraying water would cause the rotor to spin (see Figure Y below). This allows fewer nozzles to cover a larger area, and means that as the belt moves under the rotor, each time a particular piece of belt is hit by spray, the spray has a different angle of incidence. Note that in Figure Y the rotating union is not in the centre of the rotor, this means that the nozzles create an unbalanced reaction torque, which spins the rotor. There are many other variations of nozzle arrangements which all result in an unbalanced torque spinning a rotor.

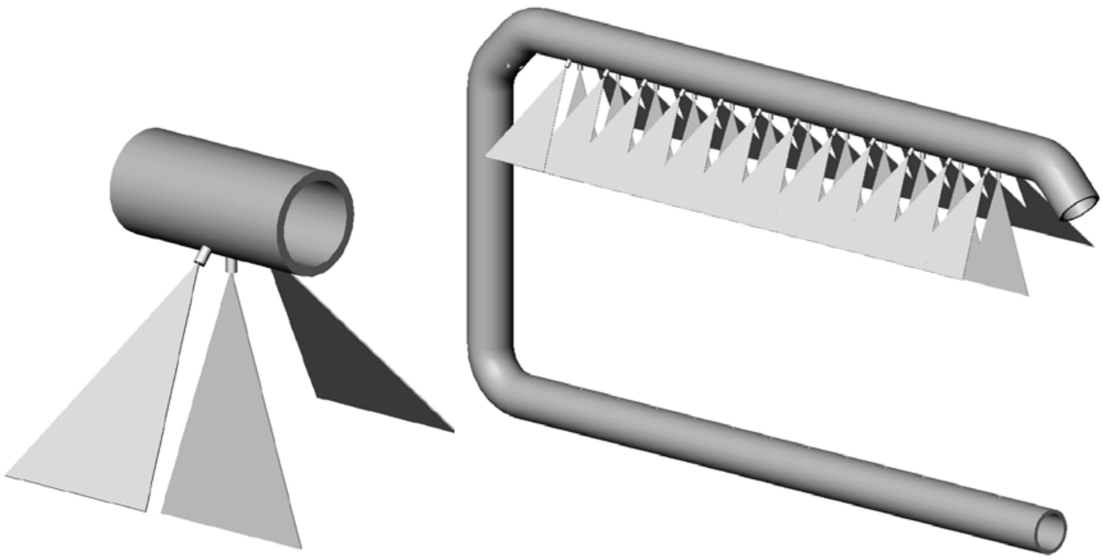


Fig. 27. Stationary nozzle segment; Full pipe with top nozzles shown only.

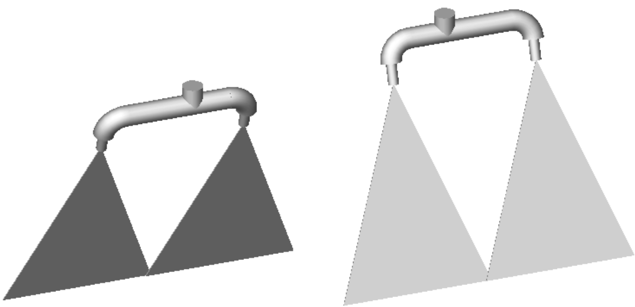


Fig. 28. Spinning rotor design (feed pipe not shown)

It was decided that the significant benefits of having a lower water consumption rate due to fewer nozzles in the rotating boom option, and also the reduction in the cost of the fewer nozzles, was sufficient to offset the significant expense of the rotating unions. Therefore the option of having a spinning rotor was decided upon. It was decided that the design and building of this was to be contracted out to Spray Pump, who have much experience in this field.

## 5.8 Heat and Mass Transfer

Early on in the project, as part of a heat and mass transfer assignment, an analysis was done on what were at that time thought to be the most likely operating conditions and design parameters. This is reproduced as Appendix 2. The results showed that an insulated tank would suffer negligibly from the effects of heat loss to the environment, and that by far the greater component of cooling was due to reaching equilibrium between the cool belt and tank, and the hot solution. The limiting factor was not ensuring that the solution did not cool down too fast, but rather that the outside of the tank did not get too hot and burn people.

The size of the tank model used in the analysis was considerably smaller than that of the final design. Fortunately the ratios of heat capacities of the hot and cold components in each case are similar (comparing 250kg of cold steel, 60kg of cold belt, and 900 litres of hot solution in the final design, with the parameters used in the analysis), and hence the degree of cooling should be similar. As was mentioned at the end of section 4, it was decided not to insulate the wash tank. This makes the heat transfer analysis less valid, but it can be seen from the calculations associated with figure 12 on page 15 of Appendix 2, that under normal operating conditions the resistance from the convection of the air was larger than that from the insulation, and thus the lack of insulation in the final design, would not make the analysis' conclusions irrelevant. In short, although the wash tank is not insulated the solution temperature is not expected to drop intolerably due to heat loss to the environment. The fence and the moderate temperature are relied upon to prevent burns. The heating section of the analysis was useful in sizing heater elements for the design, however the prevention of boiling section was not useful. As for the holding tank, the fact that the insulation is considerably thicker than the tank in the analysis outweighs the slight increase in the thermal conductivity of the material, and means that the holding tank will lose heat at an even slower rate than the tank in the analysis.

## 5.9 Filtration and Plumbing

Due to the caustic nature of the solution used to clean the belts, and the detrimental effects that it could have when discharged into the sea, it was deemed desirable to recycle the solution as much as was practical. An additional benefit of this would be that reducing the amount of chemical used would reduce the operating costs of the device. In order for the recycled solution to be of any use, it would have to retain its caustic nature. The presence in the solution of undissolved proteins and other solids removed from the belt, would cause the solution to dissolve such solids over time, and in doing so reduce the solution's potential to clean belts in the future. Therefore it was desirable to filter out any such undissolved solids prior to the solution being stored in the holding tank. Because of the very dirty nature of the belts, a filter that could be cleaned as part of the devices normal automatic cycle was required. T or Y filters fulfil this requirement by allowing the solution to pass through the filter, and in a different part of the cycle, the flow through the filter is stopped, and water is allowed to flush across the filter cleaning out any trapped solids through a side branch (see Figure 29 below).

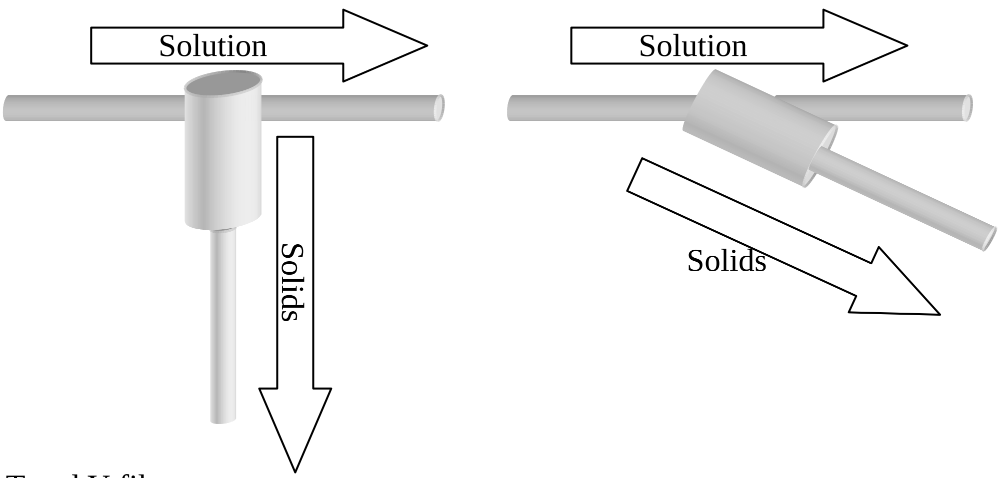



Fig. 29. T and Y filters.

Other options available were larger external filters, similar to what are already in use in Sealord, these were not chosen because of their size, and the fact that they open to the environment rather than contained.

The need to control the delivery of water and solution around the device required a relatively complex plumbing system, considering its size. 304 and 316 stainless steel was used to ensure chemical resistance to the solution as well as to the marine environment. To achieve all the necessary liquid transfers, deliveries, and discharges, a plumbing system was designed. In addition to the main part shown in Figure 23, an automatically controlled water inlet to the holding tank was required (for the initial filling, and to top it up), as was a method of draining the holding tank without power, and a manual isolation valve to control all water delivery to the device. To accomplish this three more valves were used, 2 50mm manual valves, shown in light grey, and one 25mm actuated valve shown in dark grey (see Figure 30 below).

The filter mentioned in the previous paragraph is represented by the light grey rectangle. As can be seen from all the joins, many tee junctions were needed. In order to isolate vibration from the pump, short sections of hose were designed into the system near the inlet and outlet.

To accommodate variability in the exact mounting position, hose was designed into the links near the tank inlet / outlets. Also for delivery from the installed water system, and discharge into the outflow system, hose was to be used. All these hose segments are represented by thicker lines in Figure 30. It can be seen that many hose-tails would be needed to connect these parts. Also in order to facilitate assembly and disassembly, flanges were designed into the main plumbing piece, these are represented by the dashed lines. The exact dimensions of the assembled plumbing were impossible to ascertain accurately, so it is recommended that the main part is assembled and measured prior to manufacture of the chassis, so that any modifications (eg to the placement of the pump mount) can be made.

The rinser is designed to use 5MPa high-pressure water, its plumbing system is very simple however, consisting of a manual valve on the installed supply, a hose to the rinser, and a pipe to which the rotors and nozzles are to be installed (as mentioned in an earlier paragraph).

There was some concern and uncertainty about the flow capacity of the mains supply at the site, and the effects that large demand on it by the device might have on supply to other devices and processes in the factory. To mitigate this problem the option of using a header tank was suggested by Sealord. Due to the uncertainty in the supply however it was decided to try operating the device without a header tank, and only install one if needed. The header tank if built would be situated after the manual water inlet valve, but before the hose to the device. It was recommended that the tank be installed on the roof of the existing building near the supply, rather than on the top of the crane for safety reasons (the danger of making top heavy, the danger of it falling off, and the fact that the structure would need to be redesigned to take such a weight).

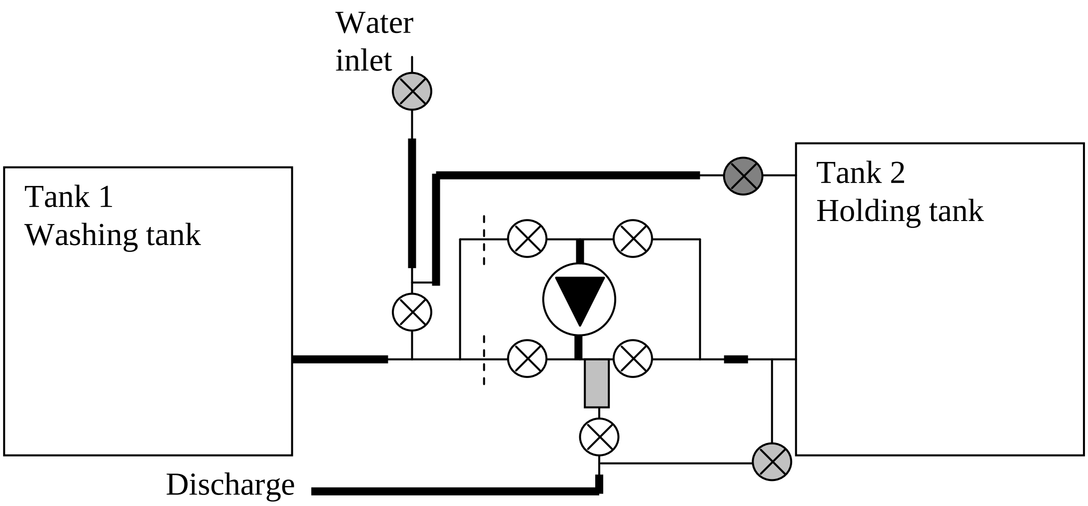



Fig 29. Additional plumbing requirements.

# 6.0 Detail design

One of the technical details that was investigated in the design of this device was the possibility of stress-corrosion-cracking. This can occur in stainless steels when they are subjected to stresses in a corrosive enviromnent(particularly when halides, in this case chlorides, are present).

*"Austenitic stainless steels may be susceptible to chloride stress corrosion cracking (CSCC). The standard 304/304L and 316/316L grades are most susceptible. Increasing nickel content above 18 to 20% or the use of duplex, or ferritic stainless steels improves resistance to CSCC. High residual or applied stresses, temperatures above 65-71C (150-160F) and chlorides increase the likelihood of CSCC. Crevices and wet/dry locations such as liquid vapor interfaces and wet insulation are particularly likely to initiate CSCC in susceptible alloys."* This quote is from the Hendrix Group website.

It was decided to initially specify that 304 or 316 stainless steel be used, as this was recommended by staff from Wilsons Chemical Limited. If further investigation finds that the specified materials are not suitable, then either upgrading the material to 2205 or increasing the thickness is recommended. 304 has the lowest resistance to CSCC, followed by 316, followed by 2205 (from personal contact with staff from Nalder and Biddle).

The compatibility of plastics and rubbers with sodium hydroxide was sourced from several compatibility charts, including a Cole Parmer chemical compatibility chart, an Efunda O-ring chemical compatibility chart, and a Goodyear industrial hose chemical resistance chart.

The definition of welds has largely been omitted from drawings. This is because the joining of the parts is obvious in most cases (and where it is not, weld details have been included). Also to include weld information on all of them would overly crowd them, and require many more drawings to be made. Contracting companies should be able to manufacture the parts without such details.

## 6.1 Chassis and Crane

The primary function of the chassis was to support the load of the two tanks, and to provide a horizontal frame for their mounting. A stress analysis of the main lengthwise beams of the chassis was done to find an appropriate size. The weight of the holding tank when full was calculated as being approximately 1250kg, or 6250kg per beam, modelled as 6376.5N, 935mm from end one of the beam. The weight of the wash tank when full was calculated as 1180kg, or a 393kg load for one beam, and 787kg for the other; this was modelled as a 7717N load 3161mm from end one of the beam. The weight of the plumbing and other parts was calculated as about 50kg , modelled as a central load of 491N. The self-weight of the chassis was calculated as 590kg, which was modelled as a uniform distributed load of 1447N per metre. The loading condition is shown in figure 30 below.

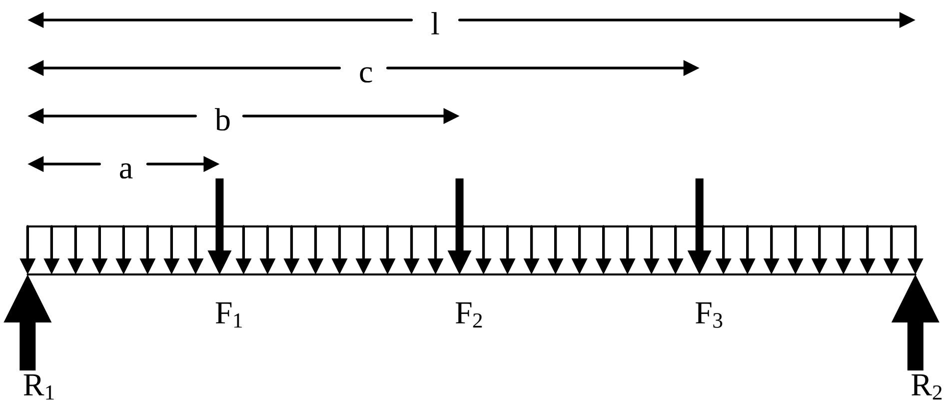



Fig. 30. Model of the loading condition.

This was analysed as the sum of two intermediate loads, one central load, and one uniform load; all simply supported. The beam has two cut outs in its web where the RHS section passes through. These cause a decrease in the beams I value. A 150 x 14 (mm height x mass per metre) universal beam was analysed. The resulting stress distribution, which reaches a maximum at 119 MPa, can be seen in figure 31. This stress level was deemed to result in a satisfactory (considering the lack of shock loading) factor of safety of greater than 2. A similar but simpler analysis was conducted of the stresses experienced by the equal angle that runs parallel to these beams in the chassis.

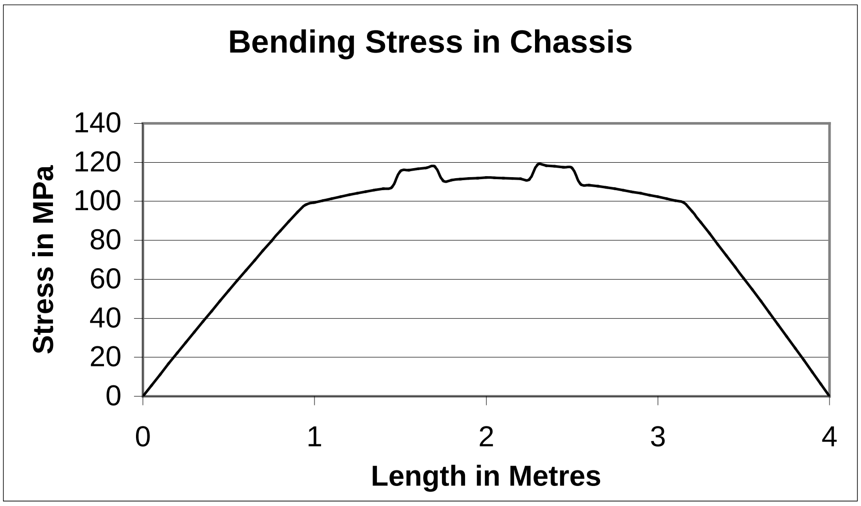



Fig. 31. Bending stress in chassis beam.

The spill tray was designed to have holes in it for bolts to pass through. The issue of sealing it was considered, so that in the event of a failure large amounts of solution would not escape through the holes. It was decided that the plastic galvanic isolation parts used to secure the feet and mounts to the chassis would, when compressed by the bolts, provide sufficient sealing, and that a very small amount of leakage was acceptable.

The design of the legs involved several concepts being developed, including having swivelling feet on their bases, and having threaded rod sitting directly on the asphalt. Although these options were feasible, they either provided insufficient safety factors in bending or compression of the asphalt, or were unnecessarily expensive. The option chosen was to have RHS with a plate welded on one end. The leg extension would be adjusted so that the chassis was almost horizontal (with a gentle slope to allow the spill tray to drain rainwater) despite the uneven nature of the ground in the area where the device will be built. The holes to pass a M24 bolt through would be drilled on site, upon assembly of the chassis.

A stress analysis of the rail of the crane was done, similar to that which was done for the chassis beams. The worst case loading condition was when the crane was at the end of the beam, in the overhang section. The mass of the trolley, chain block, chain and basket was thought to be about 150kg, or 1471N. The uniform distributed load was modelled by a uniform load of 132.4 N/m between the supports and a moment at the second support, equal to the moment afforded at the base of a cantilever beam subjected to a full length uniform distributed load (87.54 Nm). This is shown in figure 32.

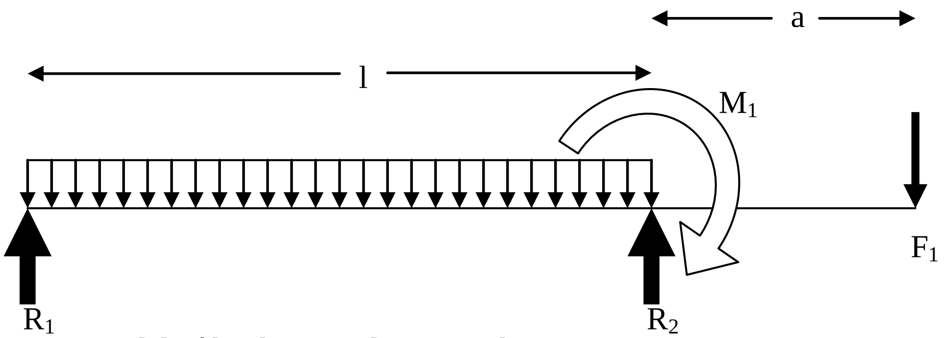



Fig. 32. Model of loading conditions in the crane.

The analysis of the stress in the beam was done only between the members, which is acceptable as the maximum stress occurs at the second support. The results can be seen in figure 33. It can be seen that the maximum stress magnitude is negative 73Mpa.

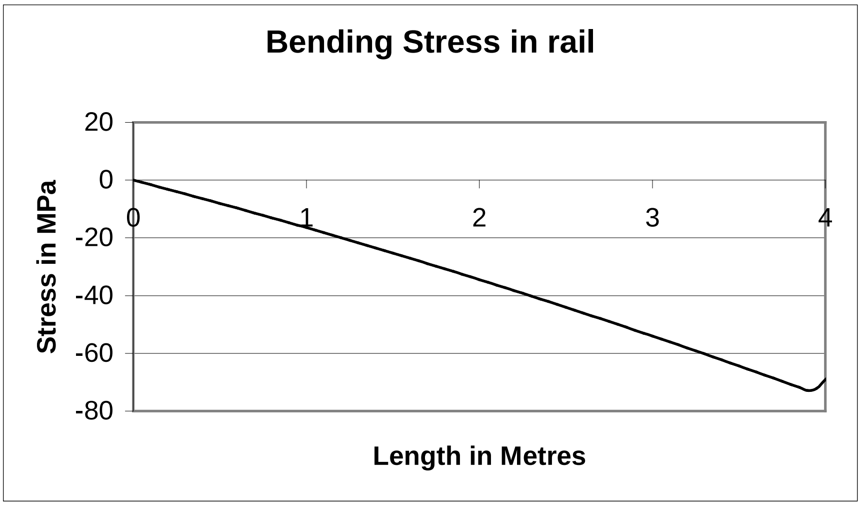



Fig. 33. Bending stress in the crane rail.

## 6.2 Wash Tank

The dimensions of the wash tank, about which the rest of the device was designed, were driven by the decision by Sealord staff that the basket should be 1 metre diameter, and 1 metre high.

The conical bottom is to allow the tank to empty liquids and small particles of fish solids easily. The ring at the base is to help distribute the load between the legs and the bottom, and to reinforce the stress concentration that is found at the intersection of the walls and the bottom. The rim is designed thickly to provide additional rigidity, and to protect the walls from impacts from the basket. The cross-sectional shape of the rim is designed to allow the rim to sit comfortably in its seat, and is chamfered to guide the basket in if it is slightly off-centre. The piece of pipe protruding from the side is to house the level switch, safely out of the way of the basket.

To find the wall thicknesses necessary to keep the stress levels to an appropriately low level, a finite element analysis was done using the COSMOS program. The tank shape was made in Solidworks, and thin shells defined for each of the significant surfaces. The thicknesses of the shells were altered until a satisfactory solution was achieved.

The results showed that having a bottom thickness of 3mm with a lower rim of 40 x 40 x 5 equal angle and a wall thickness of 2mm, resulted in a maximum stress, when full of solution, of about 32 MPa. The maximum stress is found in the immediate vicinity of the restraints, which represent the welds to the legs. This gives a factor of safety of greater than 8 when compared to a yield stress of 260 MPa. However the lower stress is desirable for avoiding stress corrosion cracking. Figure 34 shows the stress intensities in the design. The variation in intensity around the circumference is due to the point reactions of the legs.

The displacement distribution in figure 35 shows that the greatest displacement occurs around the rim, but is less than a millimetre (the view is scaled up by a factor of 80).

Note that in this analysis all of the load was deemed to be restrained by single lines in the lower support, when in reality two lines of weld for each leg would join the lower support, and also the legs would be joined to the rim, and some of the load would be borne through there. The black lines at the extreme bottom of the image are discontinuities and are believed to be caused by the orientation of the triangular mesh sides to the principle stresses in those areas. From examining the other areas of the bottom it is thought that the discontinuities do not give rise to excessive inaccuracy. The pressures applied were slightly greater than would be experienced if the tank was filled with water, this is because the sodium hydroxide solution has a slightly higher density (about 102% of water).

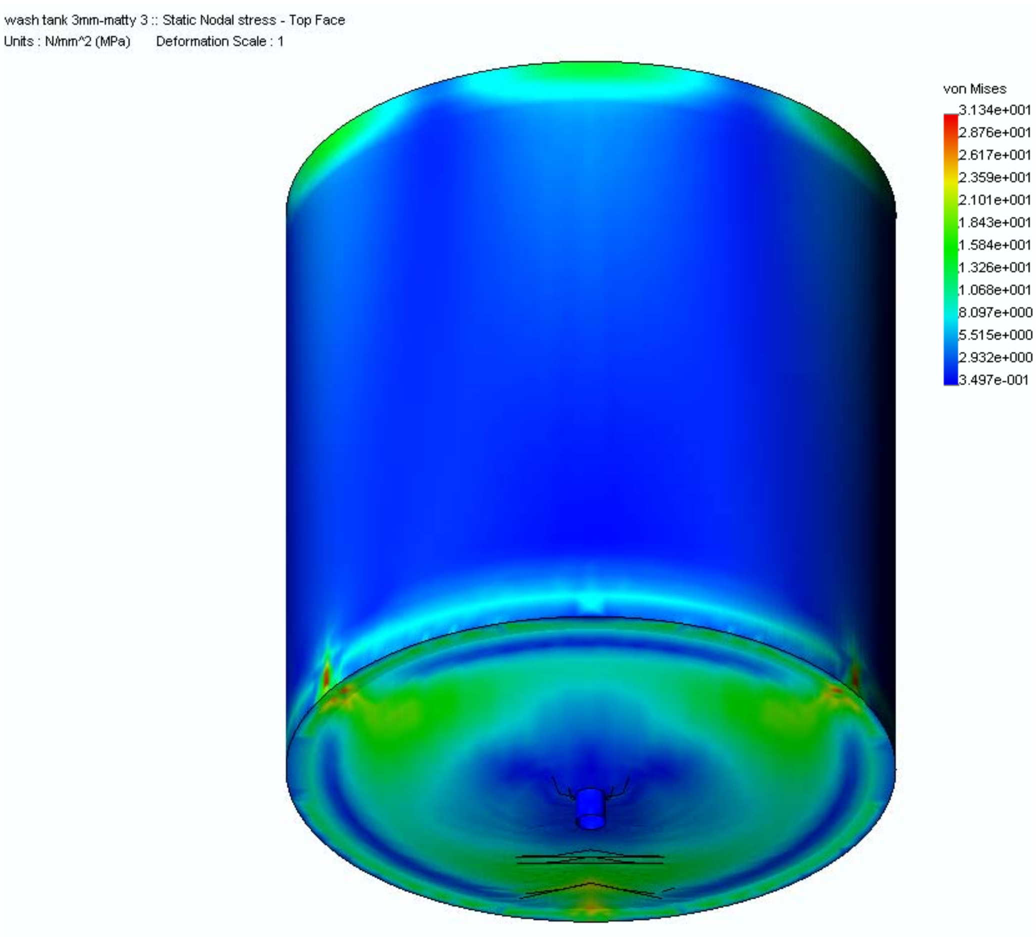



Fig. 34. Stress distribution in the wash tank when full.

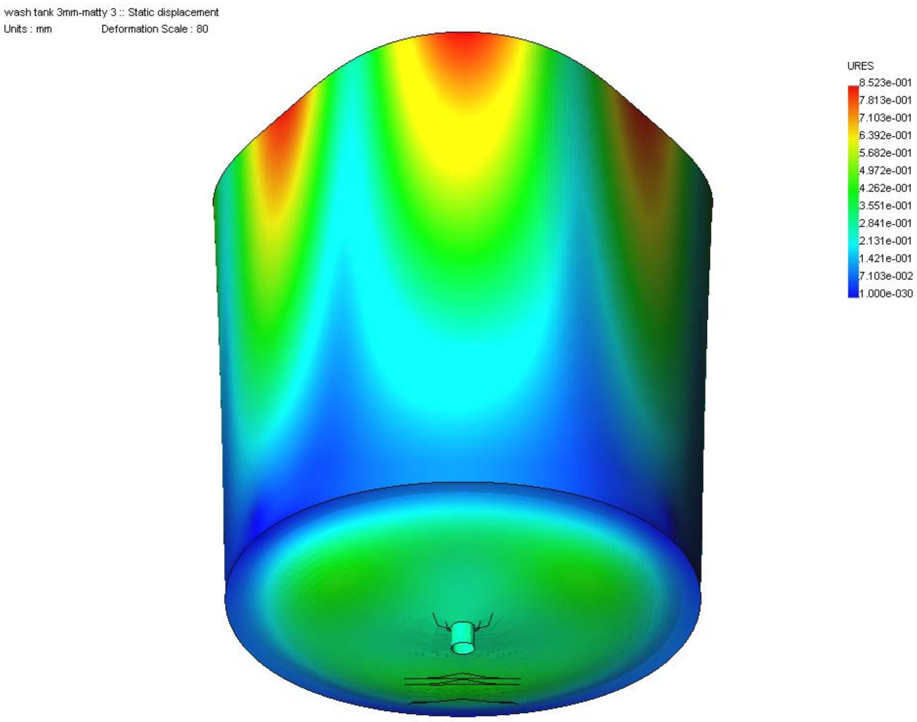



Fig. 35. Displacement distribution in the wash tank when full.

## 6.3 Holding Tank

The wash tank when empty (little or no belt in the basket) could hold up to 950 litres of solution, therefore the holding tank needed to be able to hold at least 960 litres (to allow for solution in the pipes, with a small margin so the tank did not run dry).

Initially the tank was intended to have a rectangular plan, but after analysing the part with COSMOS it was modified to a square plan, because a square plan minimises the maximum stress for any given capacity. The shape meant that the stresses experienced were higher than for a cylindrical tank of the same capacity and wall thickness. The option of using a cylindrical shape was seriously considered, but the requirements of the heating elements and other components, and increased fabrication costs for a cylinder outweighed the costs of increasing the wall thickness. The result of some COSMOS analyses was that a tank with 5mm walls and bottom was designed. In the COSMOS analyses of this part, the bottom corners were restrained from translating, which is not an accurate portrayal of the situation, and stresses at the corners were very high. Figure 36 shows that when elements closer than 3 nodes from the restraints were ignored, the maximum stress in the part was about 90MPa, occurring in the middle of the edge between the bottom and the side. An accurate maximum deflection value could not be found, but would be less than 6mm. The exaggerated displacement is shown in figure 37. Figure 38 shows an analysis in which the bottom plane was restrained in the vertical direction, which resulted in a maximum stress of 65MPa in the same vicinity as the previous analysis.

It was decided on the basis of a heat and mass transfer analysis to insulate the holding tank. It was found that the best insulation for this situation was expanded polystyrene types of insulation. Polyfoam, which is marketed by James Hardie, was selected, and the mechanical properties were examined. There was a desire to be able to support the holding tank directly on the insulation, but a concern that the weight would crush the holding tank. Some simple calculations showed that if the weight of 1.25 tonne is evenly distributed over 902500 sq mm, then the stress in the polystyrene would be 13.6kPa. This is acceptable as the compressive stress to cause minimal strain is between 25kPa and 50kPa depending upon the grade.

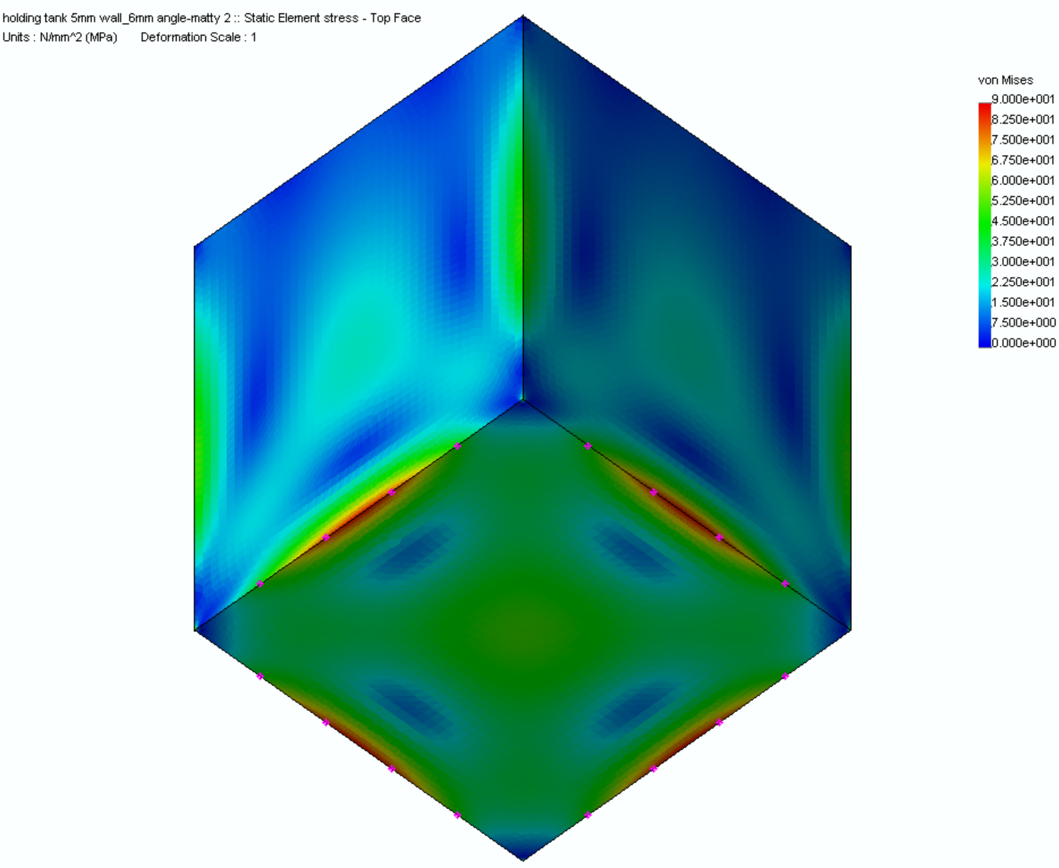
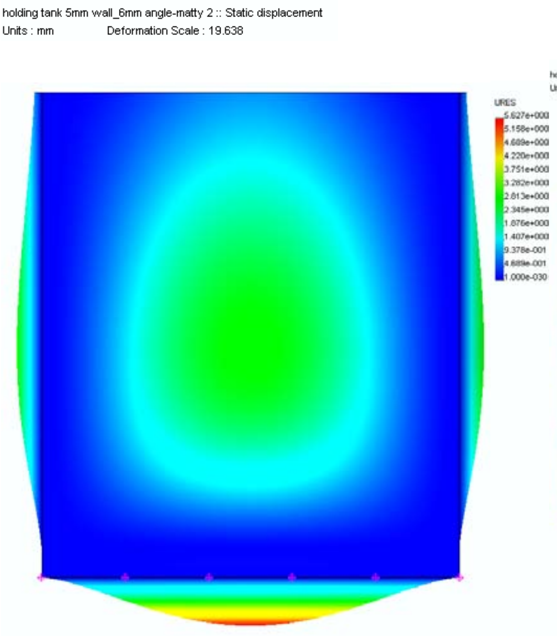



Fig. 36. Stress distribution in the wash tank when full.



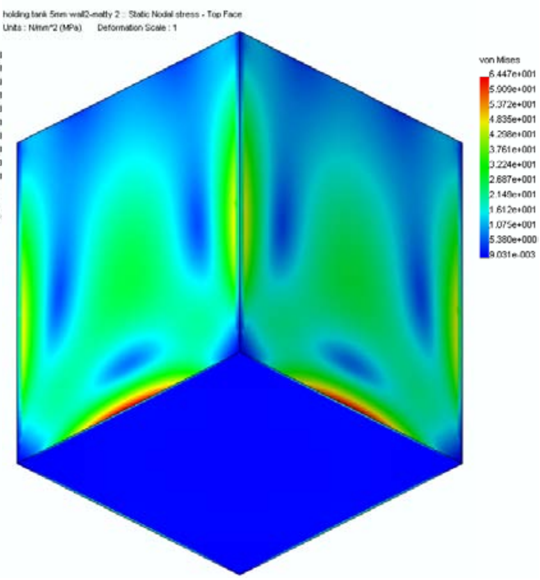




Fig. 37. Displacement distribution in the full holding tank.

Fig. 38. Stress distribution in the full holding tank with a restrained surface.

## 6.4 Plumbing

The option of using PVC piping was investigated, but it was decided to use stainless steel piping because of issues with relative thermal expansion between the stainless steel valves and the PVC piping. The greatest difficulty with the detail deign of the plumbing was that it was impossible to know the overall dimensions of the assembled parts. This is due to the fact that the dimensions of individual parts are not easily obtainable without already having a part to measure, and because parts that screw together can screw up to different lengths. Therefore the placement of the mounts is indicative only, and should be modified to suit the dimensional requirements of the assembled main plumbing piece. Some care must be taken to ensure that the thread tape used is compatible with sodium hydroxide, but as there are many suitable plastics, this is not expected to pose any difficulty.

## 6.5 Rinser

It is recommended that Spray Pump be contracted to do the design of the rinser rotors and nozzles. Until it has been finalised the detail design of the rinser frame and skin cannot be completed. A layout for the unit has been suggested, and once the required space has been determined, completion of the design will be straightforward.

## 6.6 Electrical Design

The control box design has been reviewed by an electrician contracted to Sealord, who felt it was sufficiently complete to use for manufacture, and suitable for the task. The display was developed with the assistance of an electrical engineering student. Although no testing has been done, great care has been taken in the design, and the system is expected to function correctly without modification. It is recommended that the LEDs be mounted so that they insert through a dark material such as black Perspex, this means non-lit LEDs are less likely to appear lit when in sunlight. The display will be mounted in a protected enclosure with a clear lid, alongside the emergency stop and the start button. It is suggested that the pneumatics and pump pressure switch be mounted in an enclosure separate from the rest of the control system, so that it can have some protection but not provide any threat to the rest of the electronics.

## 6.7 Assembly Details and Planning Advice

It is recommended that the plumbing be built prior to the chassis, as the dimensional requirements of the plumbing may make it desirable to modify the location of the control and pump mount, so that the pump is more in line with the associated hosetails on the main plumbing piece.

The chassis must be assembled to ensure the spill tray is angled so that the outlet is about 50mm lower than the opposite corner. The wash tank should be adjusted so it is very near to horizontal, this is to facilitate the lowering of the basket into the tank. The holding tank should be angled slightly down so that the outlet is about 10mm lower than the opposite corner.

There exists opportunities at the time of writing, that may not be available for a long period. It is recommended that if Sealord intends to build this device; the chain block should be purchased as soon as possible, as it is currently on sale. Also, the display should be contracted out to an electrical engineering student, as this would cost significantly less than contracting out to a company.

Prior to commissioning Spray Pump to design and build the rotors and nozzles assembly, it is recommended that some further experimentation be conducted to get some raw data on the impacts required to remove the contaminants from the belt. This will be cheaper than having Spray Pump do the tests.

This device should never be moved unless it is completely empty of water and sodium hydroxide.

# 7.0 Conclusion

This project was successful in achieving its objective of designing a device to clean fish solids and plaque from plastic conveyor belts after they have been taken off fishing ships. The systematic nature of the study brought about a clear pattern of problem definition, research, concept generation, evaluation, embodiment, and detail design.

The design study involved research into work already done in the area. This study led to the development of several promising design concepts. The best of these, which involved soaking and agitating in a caustic bath, and water blasting evaluated in a series of experiments, which expanded the knowledge in the field. The results of the experiments showed that the chosen methods were indeed effective at cleaning the belt. The concept chosen to develop consisted of a washing tank, a chemical holding tank, and a transfer pump. Factors that influenced the embodiment of this concept were control options, safety and legislation, materials compatibility, thermal control, cost, and structural issues.

The final design solution consisted of two units. Firstly, a tank to receive the coiled belt, another insulated electrically heated tank to store the sodium hydroxide cleaning solution, an overhead crane to load/unload the belt, and a transfer pump and control system to control the flow of fluids. The second unit was a separate rinser utilising nozzles on rotating booms to perform the water blasting. This study resulted in the final manufacturing information for the belt washer. This includes detailed drawings and advice, and a costing for all parts and construction.

# 8.0 Acknowledgements

The Author would like to thank the following people for their assistance in the undertaking of this project.

Alan Gare
Craig Galilee
Cliff Brunning
Gill Wright
Graham Wright
Hugh Morgan
Iain McMIllian
Jacob Mattingley
John Hawkins
Ken Brown
Marina Gosnell
Paul Wells
Ruth Mattingley
Scott Aimes
Shayne Gooch
Tania
Tony Jones
Vela Fishing
Vince Williams

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Professor Hugh Morgan, University of Waikato, personal communications with Matthew Wright. 5/6/2002

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The Hendrix Group website: http://www.hghouston.com/ss_scc.html

Tony Jones, Nalder and Biddle, personal communication with Matthew Wright 3/4/03

Efunda O-ring chemical compatibility chart:
http://www.efunda.com/designstandards/oring/oring_chemical.cfm?SM=none&SC=Sodium%20Hydroxide#mat

Industrial hose products; Goodyear chemical resistance chart

Cole Parmer chemical compatibility chart:
http://www.coleparmer.com/techinfo/ChemCompResults.asp (search for all materials with 20% sodium hydroxide)

# Appendix 1

## Introduction

Two sets of tests were conducted. The first set(1-4) on 22/08/02 - 24/08/02 compared the cleaning results of dirty belt versus just soaking versus soaking and water blasting. The second set (5-18) on 11/10/02 - 13/10/02 compared the cleaning results of variations in agitation, concentration, time in solution; and also tried a cold soak.

## Preparation

After visiting the microbiological department at Sealord, it was decided to use Standard Plate Count (SPC) tests to measure the success of the cleaning mechanisms, as this was the more appropriate of the two main tests they already conduct. The SPC test is a common hygiene test, used across the microbiology field and involves growing the bacteria swabbed from a surface, and counting the visible colonies that develop. The procedure that was recommended to me by Sealord was from 'Compendium of Methods for Micro. Examination of food, by Marvin Speck, Section 3.4'.

The following preparations were made for the microbiological tests:

- 3 1L 'Schott' bottles were filled with 700ml of SPC agar (Standard methods agar).
- 111 swabs were dry autoclaved in sealed tubes.
- 90 bottles were filled with 10 ml of peptone water and wet autoclaved.

## Belt sourcing

A section of dirty conveyor belt that had been out on a voyage was requested from Sealord. It was intended to be kept cold from the time it left the ship in Port Nelson, until it reached the University of Canterbury, where it was to be tested. Unfortunately this was not the case, instead it traveled in a plastic bag in the boot of a car for the first series of tests, and in an overnight courier from Dunedin for the second series. This may have increased the bacteria numbers, or encouraged the growth of bacteria that would not normally thrive in colder environments.

## Procedure

The procedure involved cleaning a section of the belt according to a specific set of test parameters, then separating the section of belt into two pieces and swabbing a $10cm^2$ area in the join between the two pieces. Swabbing was done by moistening the head of a sterile swab in a bottle containing 10ml of peptone water, and rubbing it across the test area. The head of the swab was then broken off into the peptone bottle, and the bottle labeled with a sticker to identify it with a particular test. The peptone bottle and swab head were then vortexed to transfer all of the bacteria from the head into the solution. A sample of the solution was then pipetted out of the bottle and put into a petri dish (some having been diluted by a factor of 10). Agar was then poured into the dish, so that the bottom of the dish was covered when the dish was gently swirled. The dish had its lid put on, was sealed with plastic wrap, and was labeled (the same as the bottle from which the sample came (or given a new code if it was a dilution)). The dishes were incubated for 48hrs at $37^oC$. All visible colonies were then counted, and comments made on any unusual characteristics of the colonies.

Fig. 1. Swabbing a belt section after cleaning.

Fig. 2. Plating samples in the microbiology laboratory.

## Results

On the following page there is a summary of the numerical results of the tests; each block contains the details of the test and the colony counts. Each colony count is extrapolated from the most appropriate dilution, except for test 18. For test 18, two dilutions are shown to emphasize the problems with inaccuracies from having overcrowded petri dishes. At the $10^{-1}$ dilution the dishes are so overcrowded that no more colonies can live in the space available due to competition (for food and using toxins against each other), this is also true for the $10^{-2}$ dilution for some dishes, and to a lesser extent in the others. An accurate value is unknown, but the $10^{-2}$ dilution is closer to being accurate because the colony density is closer to the recommended acceptable range.

The details of the varying appearance of the colonies have not been transferred from the original records because no useful data can be gleaned from it (it is impossible to tell what type of bacteria the colonies are from the macroscopic appearance of the colonies). The recommended range of number of colonies per petri dish is 25-250. If there are fewer than 25, then the sample's accuracy suffers from excessive random variation compared to the population mean. If there are greater than 250 colonies, then the accuracy suffers because of competition between colonies resulting in an artificially low number of colonies surviving (as is illustrated by the case mentioned involving test 18).

| | |
|---|---|
| Test set # | cfu/sq cm 1 |
| time (min) | cfu/sq cm 2 |
| concentration % | cfu/sq cm 3 |
| agitation | cfu/sq cm 4 |
| average count | cfu/sq cm 5 |

| | |
|---|---|
| Test 1 | 14 |
| 10 minutes | 0 |
| conc = 8 % | 1 |
| soak | 6 |
| 10.4 | 31 |

| | |
|---|---|
| Test 2 | 17 |
| 10 minutes | 4 |
| conc = 8 % | 2 |
| soak & wb | 2 |
| 6.0 | 5 |

| | |
|---|---|
| Test 3 | 671 |
| 5 minutes | 517 |
| conc = 8 % | 3960 |
| soak & wb 10E-1 | 3740 |
| 2043.8 | 1331 |

| | |
|---|---|
| Test 4 | 11000 |
| 0 minutes | 8800 |
| conc = 0 % | 7150 |
| dirty 10E-1 | 7700 |
| 8250.0 | 6600 |

| | |
|---|---|
| Test 5 | 4 |
| 5 minutes | 3 |
| conc = 8 % | 1 |
| shallow | 1 |
| 1.8 | 0 |

| | |
|---|---|
| Test 6 | 10 |
| 5 minutes | 5 |
| conc = 4 % | 17 |
| shallow | 0 |
| 7.8 | 7 |

| | |
|---|---|
| Test 7 | 5000 |
| 5 minutes | 300 |
| conc = 2 % | 300 |
| shallow | 28 |
| 1325.6 | 1000 |

| | |
|---|---|
| Test 8 | 2 |
| 10 minutes | 0 |
| conc = 4 % | 41 |
| shallow | 8 |
| 10.8 | 3 |

| | |
|---|---|
| Test 9 | n/a |
| 10 minutes | 7 |
| conc = 2 % | 55 |
| shallow | n/a |
| 22.7 | 6 |

| | |
|---|---|
| Test 10 | 200 |
| 10 minutes | 450 |
| conc = 4 % | 90 |
| soak | 32 |
| 166.4 | 60 |

| | |
|---|---|
| Test 11 | 200 |
| 10 minutes | 60 |
| conc = 2 % | 70 |
| soak | 15 |
| 69.6 | 3 |

| | |
|---|---|
| Test 12 | 4 |
| 10 minutes | 0 |
| conc = 8 % | 1 |
| soak | 1 |
| 2.6 | 7 |

| | |
|---|---|
| Test 13 | 120 |
| 7.5 minutes | 21 |
| conc = 8 % | 21 |
| soak | 4 |
| 33.2 | 0 |

| | |
|---|---|
| Test 14 | 1 |
| 10 minutes | 120 |
| conc = 8 % | 20 |
| soak | 1 |
| 29.2 | 4 |

| | |
|---|---|
| Test 15 | 82 |
| 10 minutes | 110 |
| conc = 8 % | 160 |
| cold soak | 340 |
| 173.0 | n/a |

| | |
|---|---|
| Test 16 | 3 |
| 5 minutes | 12 |
| conc = 8 % | 31 |
| deep | n/a |
| 12.0 | 2 |

| | |
|---|---|
| Test 17 | 18 |
| 5 minutes | 30 |
| conc = 4 % | 14 |
| deep | 0 |
| 13.2 | 4 |

| | |
|---|---|
| Test 18 | 5000 |
| 0 minutes | 5000 |
| conc = 0 % | 3500 |
| dirty 10E-1 | 2500 |
| 3500.0 | 1500 |

| | |
|---|---|
| Test 18b | 50000 |
| 0 minutes | 25000 |
| conc = 0 % | 20000 |
| dirty 10E-2 | 15000 |
| 27500.0 | n/a |

# Heat transfer design of a washing device for plastic seafood conveyor belts.

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**Abstract**

This report investigates the heat transfer of various insulation options available for a device designed to automatically clean plastic conveyor belts on fishing factory ships while at sea. A model was developed based on the most promising concept design available at the time of the writing of the report. The design in question for the washing device requires a large volume of hot sodium hydroxide based solution to be pumped between a holding/heating tank and a washing tank. The solution has to be maintained within a certain temperature range throughout the operation. There were three primary areas of investigation; measures needed to ensure the outside surfaces do not reach temperatures that could burn crew; measures needed to ensure that the solution does not cool excessively while it is in the washing tank; finally the heating unit was investigated to find the required power and what flow rate would be required to ensure that the solution did not boil during heating.

**Introduction**

In fishing factory ships the fish caught are processed on board into fillets and other fish products (e.g.: fish fingers, fertiliser). On the factory deck of the vessel there are many (typically 20 to 25) polyethylene and polypropylene conveyor belts. During the course of a voyage, bacteria adhere and grow on these belts. The bacteria create a plaque biofilm over themselves in order to protect them. This plaque needs to be removed, and currently this is done in a highly labour intensive fashion with a water blaster that typically takes around 18 hours to complete all the belts. The ship cannot dock and unload cargo until the factory is properly clean. Plaques are particularly difficult to remove with standard cleaning agents, the best solutions for this task are strongly alkaline, and heated as high as possible.

The design in question consists of two tanks, a holding tank where the caustic solution is stored and heated by being passed through an attached heating unit when it is not washing the belt, and a washing tank into which the coiled belt, held in a stainless steel basket, is inserted (see fig 1). The wash cycle consists of immersing the coil in the pH 12 caustic solution, agitating it by a plunger that travels down the core of the coil, pumping the solution back into the holding tank to be recycled for future coils, and rinsing the belt with cold seawater to make it safe to handle.

**Summary of Problems**

The polyethylene belts have a maximum temperature of 66$^{o}$C before they can be damaged. In order to prevent this the design maximum temperature of the solution has been set at 60$^{o}$C. This temperature poses a hazard to the crew from burning, thus it is desired to expose them to a temperature of no more than 45$^{o}$C. This means that the outside surfaces should be designed not to exceed 45$^{o}$C whilst still allowing the solution temperature to be as high as 60$^{o}$C.

The hotter the solution, the better it functions as a cleaner. Thus it is desired to keep the temperature above 50$^{o}$C while it is in the washing tank. As there is no heating facility in this tank the thermal energy supplied to the solution in the holding tank, must be kept in the fluid as much as is practicable. The tank, piping and belt will all be cold when the solution is first pumped in due to being cooled by the seawater rinse of the previous belt. The aforementioned parts will reach a thermal quasi-equilibrium (assumed to be a perfect equilibrium), which will initially cool the solution, after that the solution will cool due to heat escaping the tank through the sides, top and bottom (other methods of energy loss are neglected). It is assumed that the washing cycle will take 15 minutes to complete. The design of the tank needed to be such that excessive cooling did not occur.

While the clean coil is being rinsed and unloaded, and a new dirty one loaded, there is an opportunity to reheat the solution to get it up to the optimal temperature for the process (60$^{o}$C). The heater will be required to give a significant amount of energy to the solution in a short time window. The small physical size of the heater unit could cause the solution to boil if the flow rate through the unit was not great enough to dissipate the heat into the bulk of the solution at a fast enough rate to avoid this. Thus calculating the minimum flow rate through the heater needed to be calculated to avoid boiling of the solution.

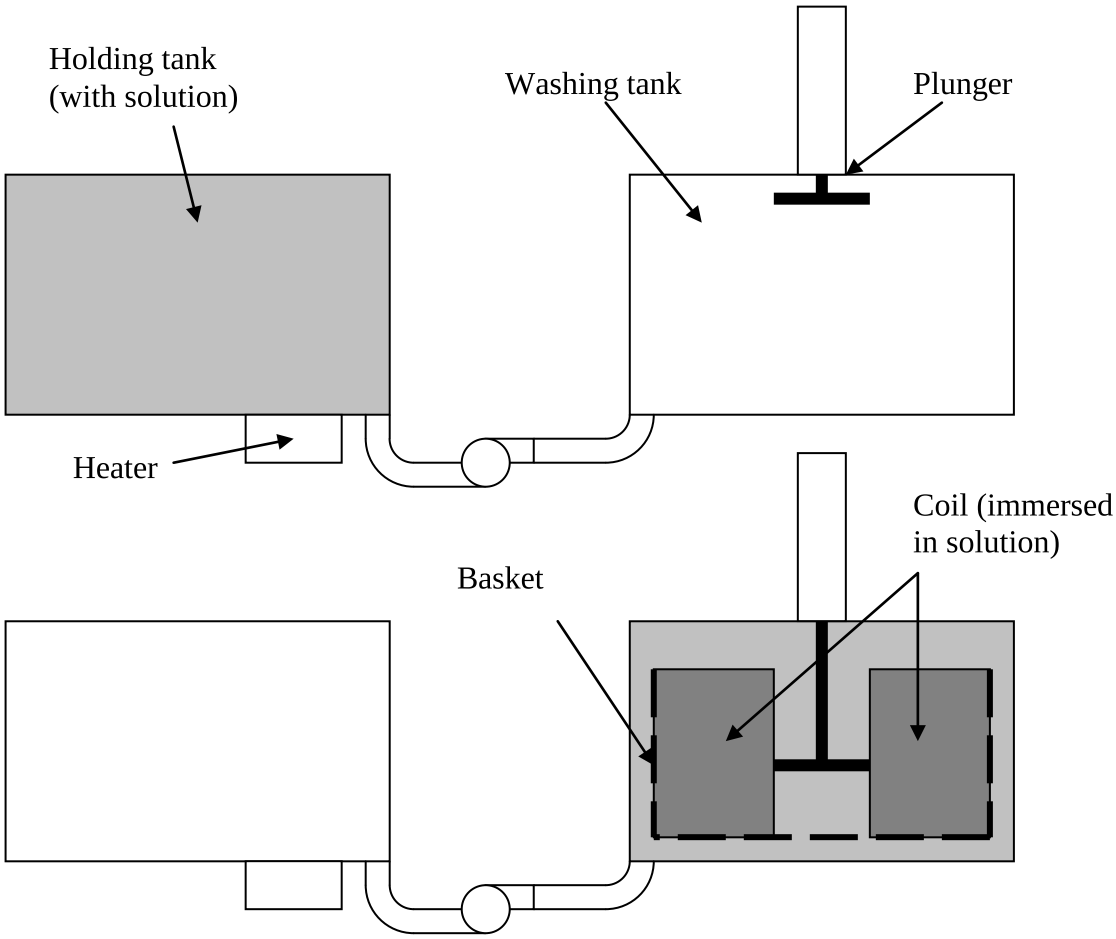


Figure 1. Functional schematic of the design.

**Heat Transfer Analysis**

In the course of the analysis the properties of the solution will be assumed to be the same as that of water, partly due to the fact the vast majority of the solution was comprised of water, and partly due to a lack of knowledge of the effects of the additives. Also where data for properties of materials at particular temperatures was not available, the values used in the calculations were approximated using linear interpolation from surrounding values, or assuming the property values given for a similar temperature were true for the actual temperature. The analysis of the three problems was done in each case at the worst-case environments, which were not necessarily the same for all three (e.g.: the surrounding ambient temperature could vary between 5$^{o}$C and 20$^{o}$C). The outer surfaces of the tanks were assumed to be in still air (i.e.: on the outside of the walls free convection applied rather than forced convection). The conduction of heat from the tanks through the mountings into the deck was ignored. Also the outer surfaces were assumed to be dry, which is a less than ideal assumption as they may well be occasionally splashed as the factory is cleaned. The dry assumption was made, as there is no way to gauge the likelihood of being splashed, and the volume of water on, and evaporating from, any surface at any given time. Where Nusselt numbers and convection coefficients are given they refer to the average over a surface rather than a local value.

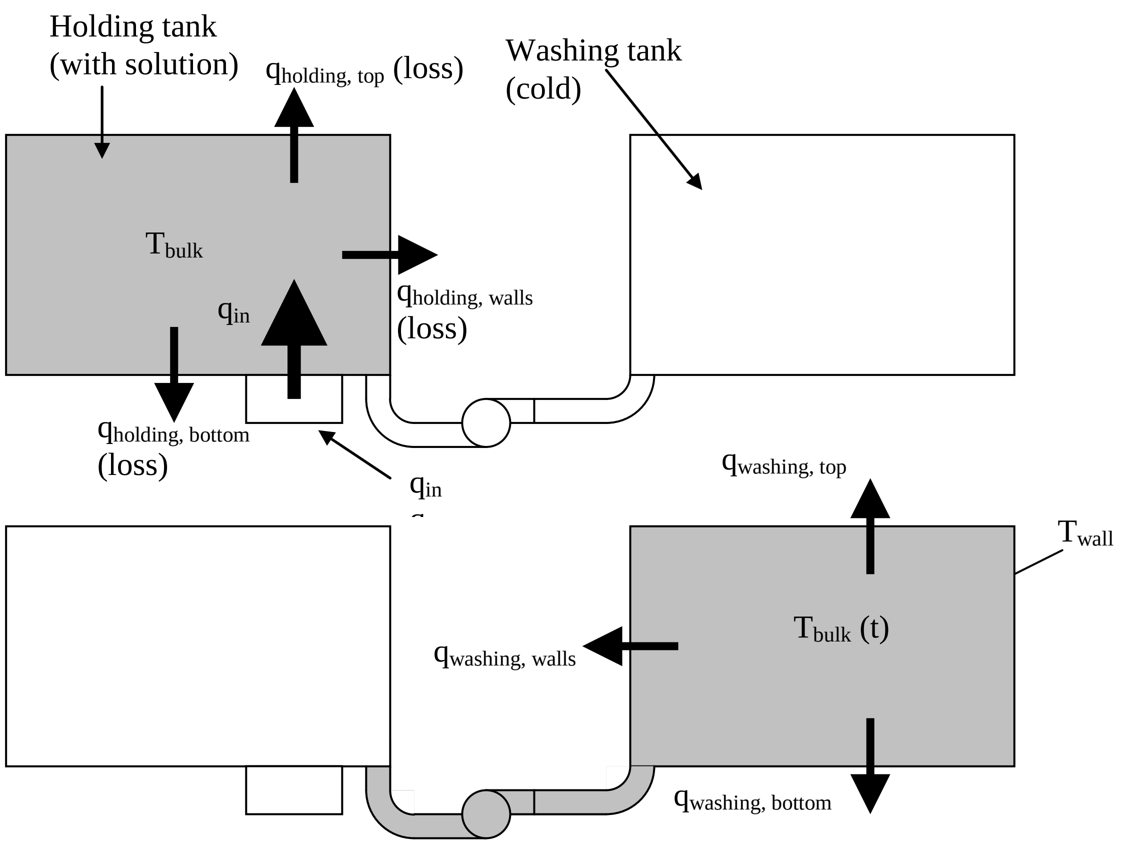


Figure 2. Heat transfer schematic of the design.

**Critical parameters.**

| Description | Label | Limit type | Value |
|---|---|---|---|
| Outer surface temperature | $T_{wall}$ | Less or equal | 45$^{o}$C |
| Temperature of solution | $T_{bulk}$ | Less or equal | 60$^{o}$C |
| Solution temperature during washing cycle | $T_{bulk}$ | Greater than | 50$^{o}$C |
| Washing cycle duration | $t_{wash}$ | At least | 15 minutes |
| Time taken to reheat solution between washes | $t_{reheat}$ | Less or equal | 5 minutes |
| Solution temperature during heating | $T_{max}$ | Less than | 99$^{o}$C |

**Analysis Part 1: Maximum outer surface temperature.**

The hot solution tends to heat up the tank, if the outside of the tank gets too hot it could burn crew. The dimensions of the washing tank (before the addition of any insulation) are assumed to be 950mm x 950mm x 700mm high. For this section the worst case is on the sides of the washing tank, where the bulk liquid temperature is 60$^{o}$C, the ambient temperature is 20$^{o}$C, and the convection in the liquid-wall boundary is forced (by the plunger's motion). This is when the resistance up until the outer surface is minimum, and the resistance off that surface is maximum. Below is a schematic (fig 3) showing the physical situation and the resistances to heat flow from the solution to the surroundings. Note that the model is of a flat vertical plate.

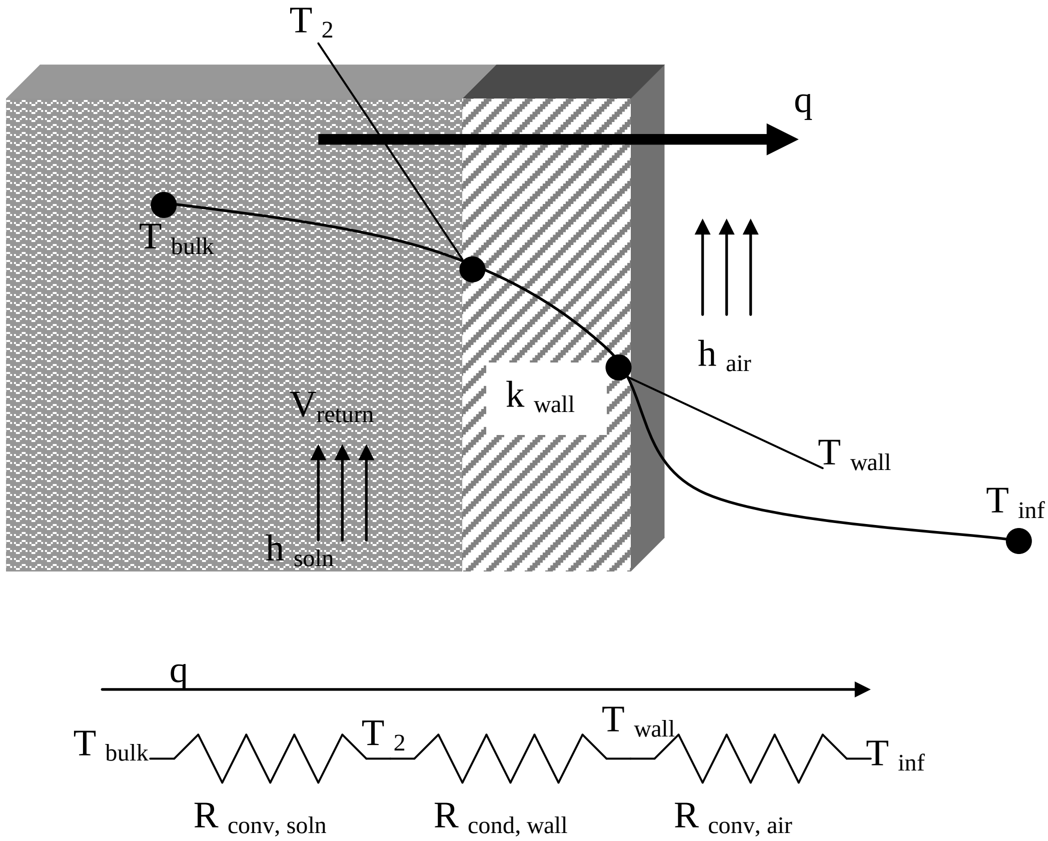


Figure 3. The physical situation and the resistance network for part 1.

Forced convection in the solution.

In order to calculate the resistance to heat flow, the convection coefficient for the flow of the solution past the wall must be calculated. The flow regime on the inside of the tank wall is a forced convection situation. The fluid is forced by the motion of the plunger. The velocity of the liquid past the wall is required so that Reynolds number can be calculated. As the plunger moves in the centre of the device, it forces solution to flow through the belt and return in the opposite direction between the coil and the tank. A schematic of this and the plan section view of the washing tank is shown below.

d=300mm D=910mm W=950mm

L = 0.7

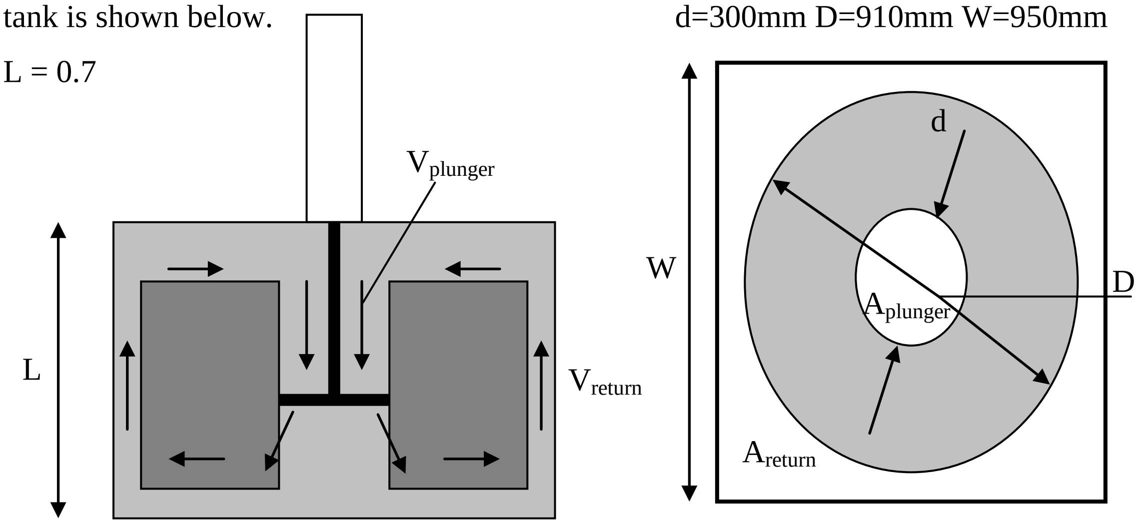


Figure 4. Flow pattern and plan section view through the washing tank.

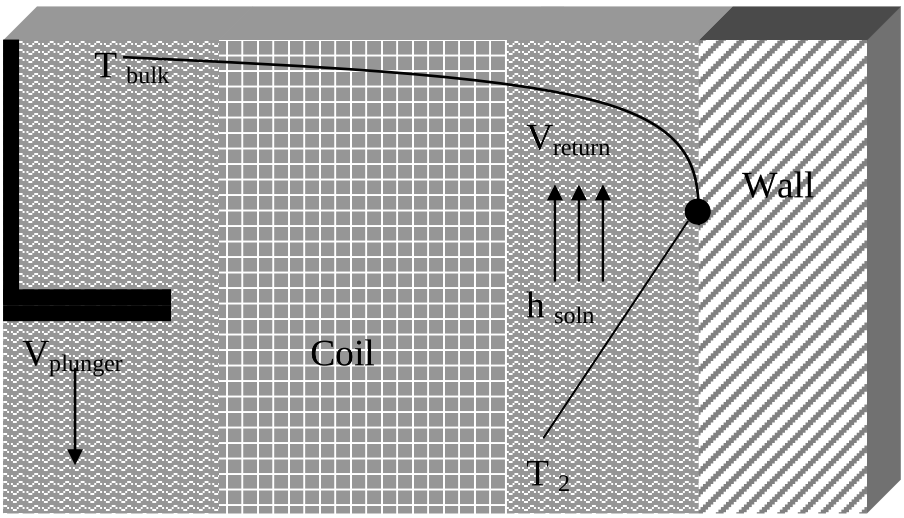


Figure 5. Forced convection model in the solution.

From F. Incropera, D. DeWitt; Properties of water at 60°C:

| Property | Symbol | Units | Value |
|---|---|---|---|
| Viscosity | $\mu$ | $N*s / m^2$ | $466 \times 10^{-6}$ |
| Specific volume | $\nu$ | $m^3 / kg$ | $1.017 \times 10^{-3}$ |
| Prandtl number | Pr | | 2.98 |
| Conduction coefficient | k | W / (m*K) | $654 \times 10^{-3}$ |

Firstly it is necessary to calculate $V_{return}$ the velocity of the solution past the wall of the tank so that it may be possible to to calculate the Reynolds number. Let stroke length of the plunger = 700mm, with a full cycle time = 14 seconds, this leads to a plunger velocity = 0.1m/s. If it is assumed that there is no vertical flow through belt coil.

Area moving upwards = $A_{return} = W^2-(\pi/4)D^2 = 0.252m^2$

Plunger area = $A_{plunger} = (\pi/4)d^2 = 0.071m^2$

$V_{return} = V_{plunger} (A_{plunger} / A_{return}) = 0.028m/s$

Kinematic viscosity $\nu = \mu/\rho = 4.74 \times 10^{-7}$

Reynolds number Re = velocity x characteristic length / kinematic velocity

$= VL/\nu = 4.1 \times 10^4$

Critical Reynolds number $Re_{cr} = 5 \times 10^5$ Hence flow is assumed to be laminar.

Now that we have the Reynolds number we can calculate the Nusselt number using the following equation from F. Incropera, D. DeWitt, eqn 7.31; since Pr>0.6, average Nusselt number:

$Nu = 0.664\, Re^{1/2}\, Pr^{1/3} = 194$

Convection coefficient $h_{soln}$ = Nu x k / L = <u>182 W/m$^2$ K</u>

Free convection in air on the outside of the tank wall:

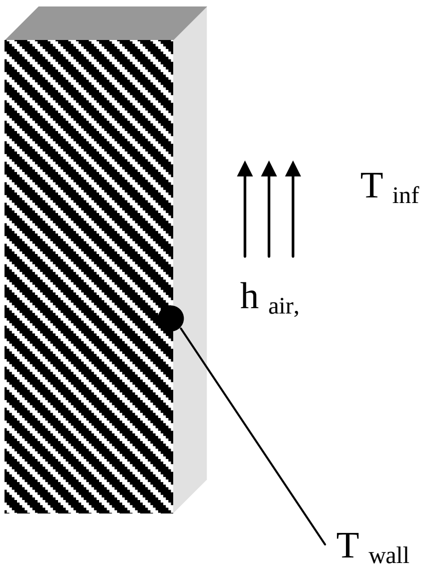


Figure 6. Free convection model from the side walls into air.

From F. Incropera, D. DeWitt; Properties of air:

| Property | Symbol | Units | Value |
|---|---|---|---|
| Density of air at 250K | $\rho_{250}$ | $kg / m^3$ | 1.3947 |
| Density of air at 350K | $\rho_{350}$ | $kg / m^3$ | 0.9950 |
| Viscosity | $\mu$ | $N*s / m^2$ | $184.6 \times 10^{-7}$ |
| Conduction coefficient | k | W / (m*K) | $26.3 \times 10^{-3}$ |
| Density | $\rho$ | $kg / m^3$ | 1.1614 |
| Prandtl number @ 300K | Pr | | 0.707 |

It is desired to calculate the Grashof number. For this we need the coefficient of thermal expansion ($\beta$), which accounts for the buoyancy of the heated fluid. In order to set up the equation, the temperatures over which the convection occurs are assumed to be; $T_{inf} = 20^oC$, $T_{wall} = 45^oC$

From F. Incropera, D. DeWitt , if it assumed that air behaves as an ideal gas then the thermal expansion coefficient is given by eqn 9.9;

$\beta = 1/T = 0.00327$ (at 306K)

Alternatively, also from F. Incropera, D. DeWitt, eqn 9.4, if it is assumed that the value is approximated instead by:

$\beta = 1/\rho_s((\rho_{inf}-\rho_s)/(T_{inf}-T_s))$ if $T_{inf} = 350K$, and $T_s = 250K$

$=0.00287$

Henceforth it is assumed that for air at the operating temperature, $\beta = 0.003$

Also required for finding the Grashof number are the;

Characteristic length $L = 0.7m$

Kinematic viscosity $\nu = \mu/\rho = 15.9 \times 10^{-6}$

From F. Incropera, D. DeWitt;

eqn 9.12, Grashof number, $Gr = (g \times \beta \times (T_s - T_{inf}) \times L^3)/\nu^2 = 9.98 \times 10^8$

Also required to find the Nusselt number is the Rayleigh number, given by;

eqn 9.23, Rayleigh number $Ra = Gr \times Pr = 7.06 \times 10^8$

Compared to the critical value of $10^9$ the flow is borderline laminar.

figure 9.6 and eqn 9.24, Nusselt number $Nu = 0.59Ra^{1/4} = 96.2$

$h_{air} = Nu \times k / L =$ <u>$3.61 W/m^2K$</u>

The objective of this sub-section is to determine what insulation will satisfy the specifications. To do this it is necessary to calculate the conductive resistance required for the insulation. Now that the convection coefficients for the solution and the air are known, it is possible to, by setting the operating temperatures, determine what the conductive resistance must be to satisfy the temperature constraints. This is done by finding the heat that passes through the three resistances, and the temperature difference across the resistance in question. The general equations for convective and conductive resistances are:

$R_{conv} = 1/hA$, $R_{cond} = L/kA$

For a per unit area case (A=1):

$R''_{conv, soln} = 1/h_{soln}$, $R''_{conv, air} = 1/h_{air}$, $R''_{cond, wall} = L/kA$ (refer to fig 3)

Finding the heat flux:

$R''_{conv, air} = 1/h_{air} = 1 / 3.61 = 0.277$

$q''_{air} = (T_{wall} - T_{inf})/R''_{conv, air} = 25 / 0.277 = 90.3 \text{ W/m}^2$

All heat must pass through all resistances, hence;

$q''_{soln} = 90.3 \text{ W/m}^2 = (T_{bulk} - T_2)/R''_{conv, soln}$

$R_{conv, soln} = 1/h_{soln} = 1 / 182 = 0.00551$

$T_2 = T_{bulk} - q_{soln} \times R_{conv, soln} = 60 - 90.3 \times 0.00551 = 59.5^oC$

Now that the heat flux and temperature difference are known, the resistance can be calculated.

$q''_{cond} = (T_2 - T_{wall})/R_{cond, wall} = 90.3 \text{ W/m}^2$

By setting the wall temperature to $45^oC$ we can solve for $R''_{cond, wall}$;

$R''_{cond, wall} = (T_2 - T_{wall}) / q''_{cond} = (59.5 - 45) / 90.3 = 0.161$ = wall thickness / conductivity

$R''_{cond} = L/k = 0.161$, hence $L = k \times 0.161$

Trial various materials, from F. Incropera, D. DeWitt, appendix A:

| Material | Conductivity (W / (m*K) | Wall thickness |
|---|---|---|
| 316 stainless steel @300K | 13.4 | 2.15 m |
| Extruded polystyrene @310K | 0.029 | 0.00466 m = 4.7mm |
| Foamed rubber @310K | 0.033 | 0.00531 m = 5.3mm |

<u>Extruded Polystyrene is selected as the insulation, with a thickness of at least 4.7mm.</u>

**Analysis Part 2: Heat loss during washing.**

It is desired to keep the bulk temperature between 50$^{o}$C and 60$^{o}$C for at least 15 minutes (the estimated time required for washing). During the washing of the belt there is a reduction in the bulk temperature of the solution. This is initially caused by the thermal equalisation with the cold tank, and thereafter by heat loss through the walls, top and bottom. Thus the analysis of this section deals with the two causes for cooling separately.

Initial Cooling

Prior to the hot solution being pumped in, the washing tank is cold due to having been rinsed with salt water at the end of the previous wash cycle. The rinse is necessary to make the belts safe to handle and to carry food. The hot solution is pumped into a cold washing tank, and the two interact to reach an approximate thermal equilibrium. The equilibrium temperature is calculated by calculating the heat capacities of the two masses, and knowing their initial temperatures.

From F. Incropera, D. DeWitt; Properties of materials:

| Property | Symbol | Value |
|---|---|---|
| Specific heat capacity of stainless steel | $c_{p\ 316\ stainless\ steel}$ | 468 J/kg K |
| Specific heat capacity of water | $c_{p\ water}$ | 4186 J/kg K |

From http://www.matweb.com/search/SpecificMaterial.asp?bassnum=O4000

| | | |
|---|---|---|
| Specific heat capacity of polyethylene | $c_{p\ polyethylene}$ | 2200 J/kg K |

From http://www.pbaindustrial.com/html/material_description2.html

| | | |
|---|---|---|
| Density of belt | $\rho_{belt}$ | 920 kg/m$^3$ |

Approximate mass values were obtained from Solidworks based on a tank wall of 3mm thick stainless steel.

Mass of tank: 106kg

Mass of pipes and pump and basket: 10kg

Total mass of cold stainless steel: 116kg

Heat capacity: $C_{p\ tank} = m \ x\ c_p = 54$ kJ/K

Mass of belt (estimated maximum): 40kg

Heat capacity: $C_{p\ belt} = m\ \ x\ c_p = 88$ kJ/K

Total cold heat capacity: $\Sigma(m\ \ x\ c_p)_{cold\ parts} = 142$ kJ/K

Volume of belt = 0.043 $m^3$

Volume of full tank = 0.95 x 0.95 x 0.65 = 0.587 $m^3$ (tank is not filled to brim)

Mass of water = $(V_{full\ tank} - V_{belt})\ x\ \rho_{water} = 535$ kg

Heat capacity: $C_{p\ water} = 2238$ kJ/K

'Cold' components initial temperature $T_c = 5^oC$

Solution initial temperature $T_h= 60^oC$

From the first law of thermodynamics (conservation of energy):

$\Sigma(m\ \ x\ c_p)_{cold\ parts}\ x\ (T_e - T_c) = (m\ \ x\ c_p)_{solution}\ x\ (T_h - T_c)$,

Hence the equilibrium temperature:

$T_e = T_h - (\Sigma(m\ \ x\ c_p)_{cold\ parts} / (m\ \ x\ c_p)_{solution} + \Sigma(m\ \ x\ c_p)_{cold\ parts})\ x\ (T_h - T_c\ )$

$= \underline{56.7^oC}$

Note: total heat capacity = $\Sigma(m\ x\ _{cp}) = 2.38\ x\ 10^6$ J / K

Cooling During Use

The cooling of the solution due to heat loss through the walls and top and bottom can be calculated by finding the resistance to heat flow through each path, assuming lumped capacitance. The assumption of lumped capacitance appears to be the best assumption that can be made because the other options such as calculating the centreline temperature do not make much sense in this application.

Lumped Capacitance Assumption:

The assumption of lumped capacitance is normally only applied to solid bodies with internal conduction and subject to convection from the surface. The model in this analysis is not solid, so a traditional lumped capacitance approach is not possible. Instead the approach will be modified to allow for the difference. In traditional lumped capacitance the measure of whether it is a good assumption or not is the Biot number. This is a ratio given by hL/k, this is the thermal resistance up to the surface of the 'lump', divided by the thermal resistance beyond the surface of the 'lump' (assumed to be just convection). If this ratio is less than 0.1 then the assumption is considered 'good' (see ENME 602 lecture notes). In the lumping method undertaken here, the surface of the lump was defined as the inner surface of the tank wall. Therefore the thermal resistance up to the surface of the lump is comprised of the convection resistance at the solution-tank wall boundary. The thermal resistance beyond the surface of the 'lump', becomes the conduction resistance through the wall, and the convection resistance off the wall. Instead of a traditional Biot number a new effective-Biot number was used.

efective-Biot number = $(1/h_{solution}) / ((1/h_{air}) + (L/k_{wall})) = 0.0125$

Which is less than 0.1 and so this assumption is considered 'good'.

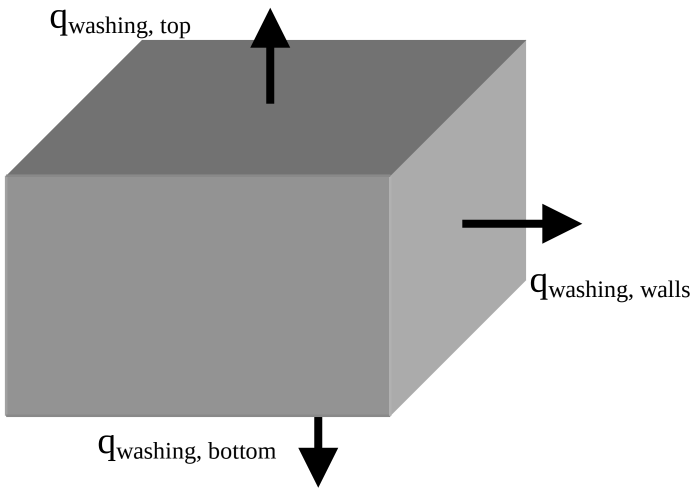


Figure 7. Schematic showing heat loss paths from the washing tank.

Top Surface of Tank

The top of the tank is a distinct path for heat loss. The mechanism by which this occurs is free convection. It is assumed that the splashing of the solution will provide sufficiently low resistance to maintain the validity of the lumped capacitance assumption, and also that the assumption that the outer surface temperature is 45$^{o}$C.

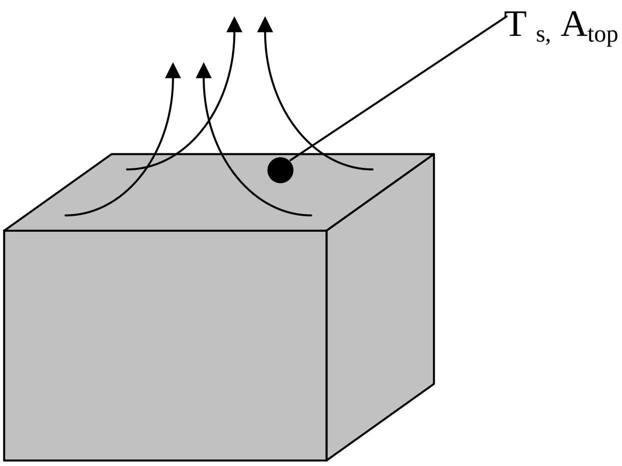


Figure 8. Convection from the top surface of the washing tank.

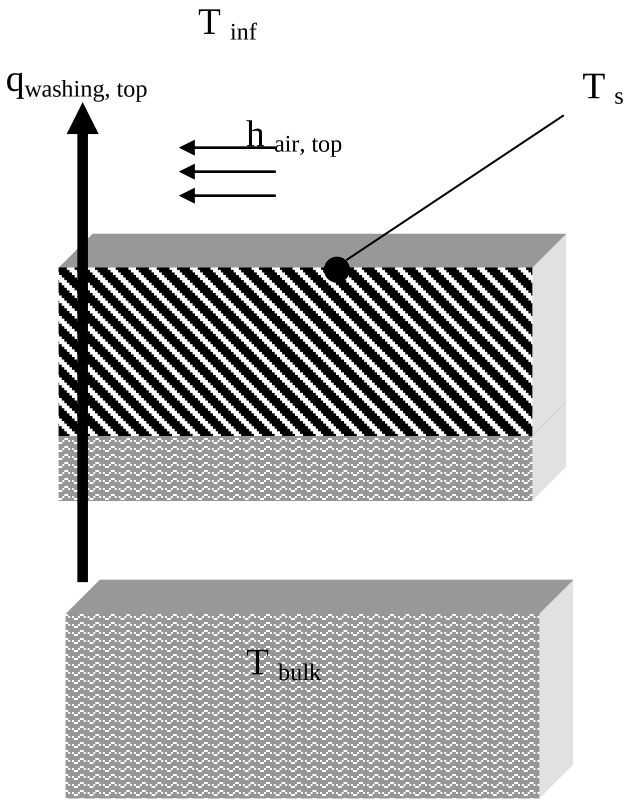


Figure 9. Convection from the top surface of the washing tank.

Firstly the Grashof number (using the properties of air from the previous example using free convection in air), and then the Rayleigh number need to be found. This leads on to the Nusselt number from which the convection coefficient can be derived.

From F. Incropera, D. DeWitt, equation 9.29;

The characteristic length is given by; L = Area / perimeter = $A_{top}$ / p

Area = $0.95^2$, perimeter = 4 x 0.95

Hence, L = 0.2375m

$Gr = g \times \beta \times (T_s - T_{inf}) \times L^3 / \nu^2$

$= 3.90 \times 10^7$

Pr = 0.707

$Ra = Gr \times Pr = 2.76 \times 10^7$

For this situation, from F. Incropera, D. DeWitt, equation 9.31;

$Nu = 0.15 \times Ra^{1/3} = 45.3$

$h_{air, top}$ = (k / L) x Nu = <u>5.02 W/m$^2$K</u>

Bottom Surface of Tank

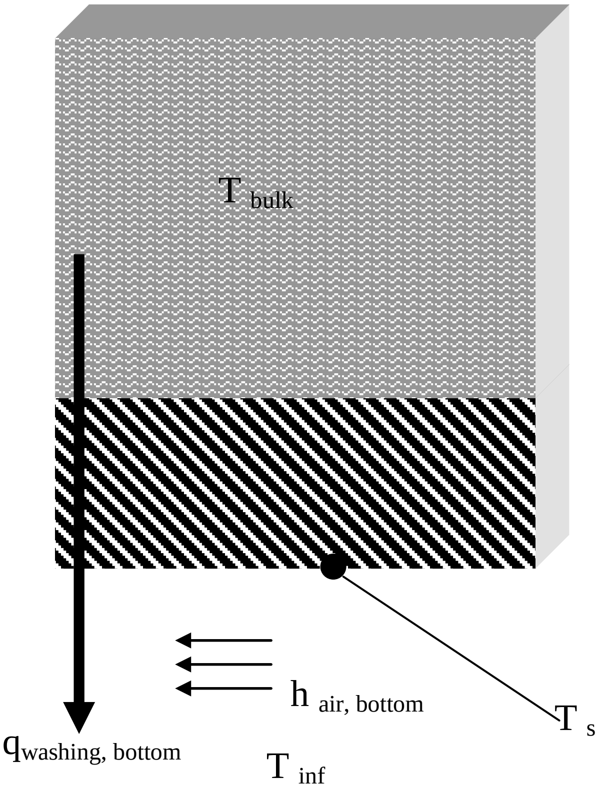


Figure 10. Convection from the bottom surface of the washing tank.

The situation on the bottom is geometrically similar to the situation on the top. Hence: $A_{bottom} = A_{top}$ , $L_{bottom} = L_{top}$, which means that it will have the same Rayleigh number as the case above; Ra = $2.76 \times 10^7$

For this situation, from F. Incropera, D. DeWitt, equation 9.32;

$Nu = 0.27\ Ra^{1/4} = 19.6$

$h = (k / L) \times Nu = 2.17\ W/m^2K$

Resistance Network

$A_{sides} = 0.7 \times 0.95 \times 4 = 2.66 m^2$

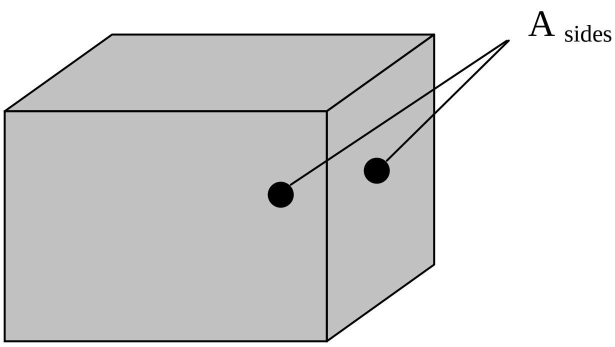


Figure 11. general form of the washing tank.

The three paths by which the heat can leave the tank (see figure 7) are represented by the three arms of the resistance network below.

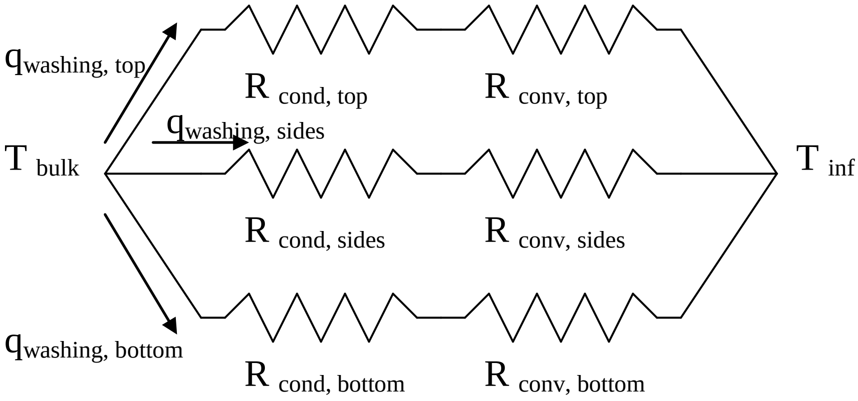


Figure 12. Resistance network assuming lumped capacitance.

Assume $R''_{cond} = 0.106$ as determined in part 1.

$R_{bottom,\ conduction} = R_{top,\ conduction} = 0.161/A_{bottom} = 0.178$

$R_{sides,\ conduction} = 0.161/A_{sides} = 0.061$

$R_{top,\ convection} = 1/hA = 1/(5.02 \text{ x } 0.9025) = 0.221$

$R_{bottom,\ convection} = 1/hA = 1/(2.17 \text{ x } 0.9025) = 0.511$

$R_{sides,\ convection} = 1/hA = 1/(3.61 \text{ x } 2.66) = 0.104$

$R_{total} = 1 / (1 / (R_{top,\ conduction} + R_{top,\ convection}) + 1 / (R_{bottom,\ conduction} + R_{bottom,\ convection}) + 1 / (R_{sides,\ conduction} + R_{sides,\ convection}))$

$R_{total} = 0.100$ (K x s) /J

Energy balance:

$-Q = \Delta E_{thermal,\ tank}$

$-(T_{bulk} - T_{inf}) / R_{total} = \rho Vc\ \delta T/\delta t$ Where t refers to time. Let $\theta = T_{bulk} - T_{inf}$

$-\theta = \rho VcR_{total}\ \delta\theta/\delta t$

$$\rho VcR_{total} \int_{\theta_i}^{\theta} \frac{\delta\theta}{\theta} = -\int_0^t \delta t$$

Where $\theta_i$ is the initial temperature difference.

$t = \rho VcR_{total} \ln(\theta_i / \theta)$

$$\frac{\theta}{\theta_i} = \exp\left[-\left(\frac{1}{\rho VcR_{total}}\right)t\right]$$

$\rho V c R_{total} = RC = \tau = 2.38 \times 10^5$

$\theta_i = (56.7 - 5) = 51.7^oC$

How long until the bulk solution temperature drops to $50^oC$?

$\theta = (50 - 5) = 45^oC$

t = 24180s = 6 hrs 43 min

What will the bulk solution temperature be after 15 minutes?

t = 900s

$\theta_i / \theta = 0.9945$ hence $\underline{T_f = 56.4^oC}$

**Analysis Part 3: Heater design: Prevention of boiling in the heater.**

The heater unit will need to be able to heat the solution by $6^oC$ over 5 minutes (300 seconds). The 5 minutes was estimated as the minimum time it would take to rinse and unload the clean belt, and load a dirty belt. The $6^oC$ was derived from several causes; the $3.6^oC$ drop during cleaning; a further drop from returning through cooled pipes into a slightly cooled holding tank; having cold water and sodium hydroxide concentrate mixed in to replenish the solutions volume and pH; and the heat lost from the holding tank while the solution is being reheated. From these specifications the specifications for the heater unit will need to be derived. In order to prevent local boiling in the heater, there must be an adequate solution flow rate to keep the temperature below $100^oC$. The flow rate should be such that the temperature does not exceed $90^oC$ to provide a safety margin.

The volume of the holding tank must be sufficient to fill the washing tank to 650mm with no belt present. Hence the volume is:

$V = 0.587m^3$

From F. Incropera, D. DeWitt; Properties of water at various temperatures:

| Property | Symbol | Value |
|---|---|---|
| Specific volume at $60^oC$ | $\nu$ | $1.017 \times 10^{-3}$ |
| Specific heat capacity of water at $60^oC$ | $c_{p\ water\ 60}$ | 4186 J/kg K |
| Specific heat capacity of water at $75^oC$ | $c_{p\ water\ 75}$ | 4191 J/kg K |

$\rho = 1/\nu = 983.3$

Mass: $M = V \times \rho = 577$

$Q_{required} = \Delta T \times m \times c_{p\ water\ 60} = 14.5 \times 10^6$ J

It is desired to have a non-variable heat output (power) hence the power rate is

q = Q / t = <u>48.3 kW</u>

A heater was selected on this basis, it is an electric tankless water heater, the water is heated by passing it through heated tubes. An image of the heater is shown below.


Figure 13. Water heater example.

The critical time of the heating process is at the end when the solution entering the heater is 60°C.

$T_1 = 60^oC$

$T_2 = 90^oC$

$\Delta T = 30^oC$

Average over 60°C to 90°C; $c_{p\ water\ 75}$ = 4191 J/kg K

$q = m \times c_p \times \Delta T$ where q and m are flow rates

$m = q / (c_p \times \Delta T) = 0.384$ kg/s

0.384 kg/s x 1000 l/ $m^3$ x 60 s/min / 983.3 kg/$m^3$= <u>23.4 litres/minute</u>

**Analysis Part 4: Sensitivity analysis: Cooling during use when in wet conditions.**

The analysis in part 2 assumed that the device would be used with dry outer surfaces. The device will be needed at the end of the voyage when there is a ship-wide clean-up in progress, as was mentioned in the introduction. This clean-up involves washing down every piece of machinery on board, including those around the device. Therefore there will be a period where the device will have water being sprayed on it. It is not known how much water will be sprayed on, or what the possible potential for evaporation will be. Therefore a range of conditions will be analysed, corresponding to a range of conditions. The addition of sprayed water will have the effect of reducing the resistance to heat flow out of the tank, whether this reduction is from the water being heated and flowing off, or whether it is due to the water evaporating the resistance to heat transfer is decreased. The resistance to heat transfer can vary between the likely value given in the analysis above, and a much lower value where the resistance through the convection (or other surface heat flow mechanisms) is negligible. A sensitivity analysis was conducted comparing the cooling that occurs during a wash cycle with various resistances. There are 2 graphs shown, the first (see figure 14) shows the bulk temperature of the solution after 15 minutes of washing time has passed, compared to the total resistance. This gives a worst-case result of over 56.17$^{o}$C. The washing time of 15 minutes is an assumption; therefore the second graph (see figure 15) shows the bulk temperature of the solution over a range of washing times (10-60 minutes), and total resistances. This gives a worst-case result of over 54.5$^{o}$C (after 60 minutes). The plots assume an ambient temperature of 5$^{o}$C. The right-hand end/edge of the graphs represents the case as modelled above, where the surface is dry (see figure 16). This corresponds to a resistance value of 0.073. The left-hand end/edge represents the case where there is no convection resistance, only a conduction resistance (see figure 17), which is the limiting case for very wet operating conditions (where the outer surface is cooled to 5$^{o}$C). This corresponds to a resistance value of 0.036.

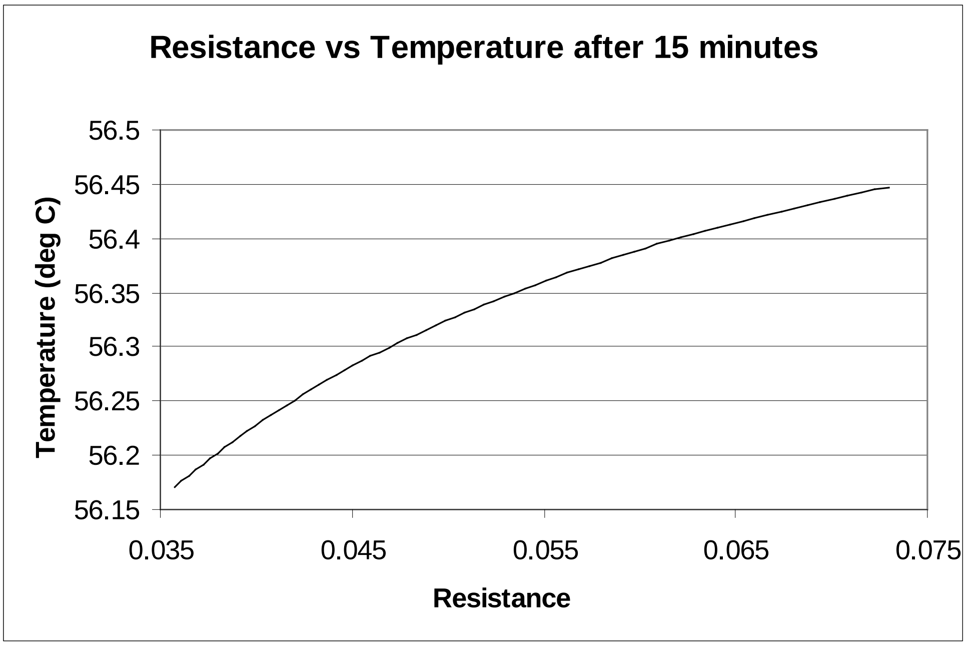


Figure 14: Graph of final bulk temperature vs the resistance to heat flow.

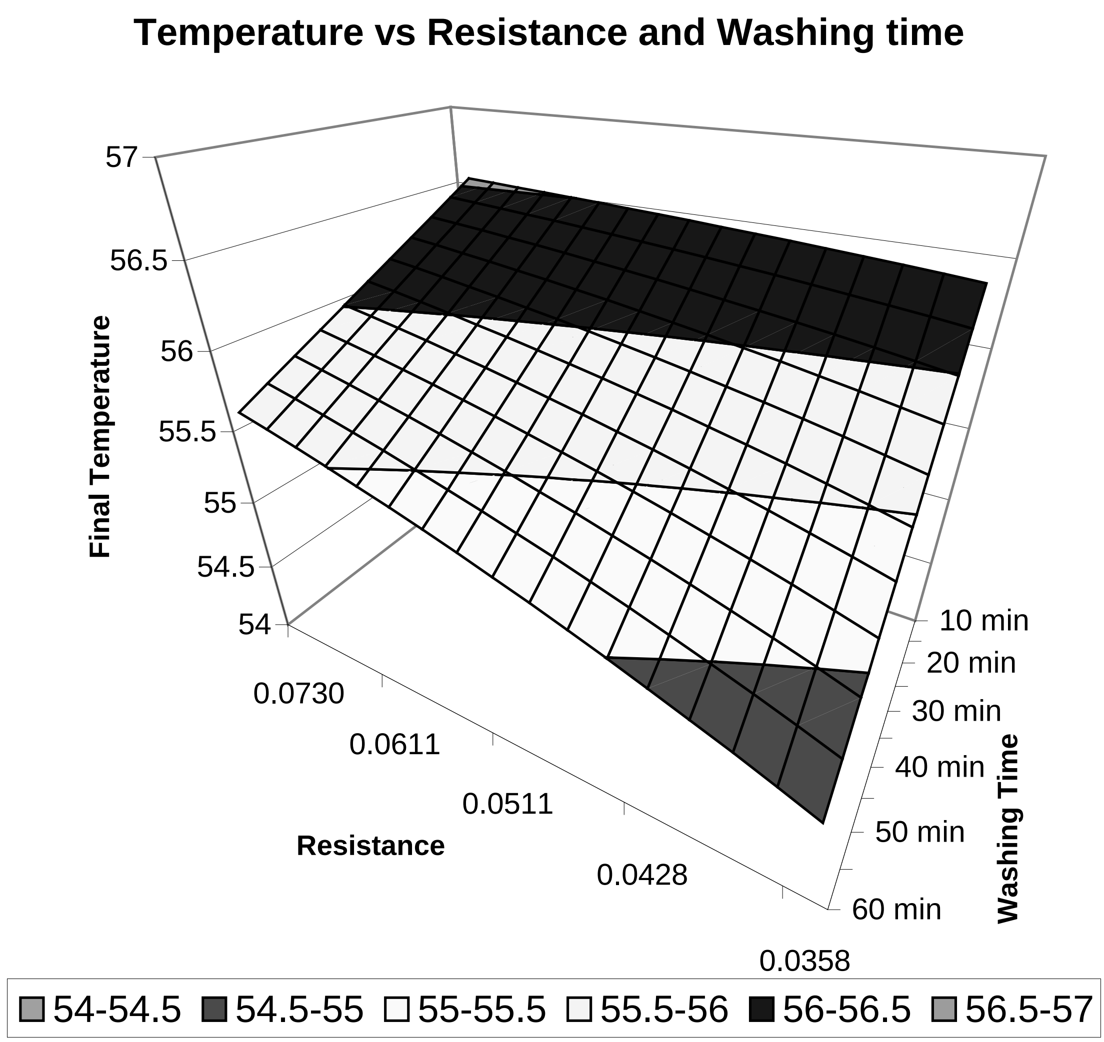


Figure 15: Graph of final temperature vs the resistance and washing time.

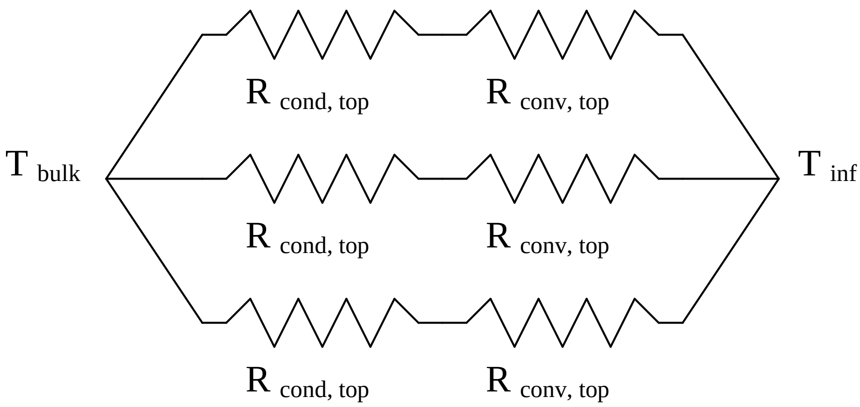


Figure 16: Resistance network for dry environment case.

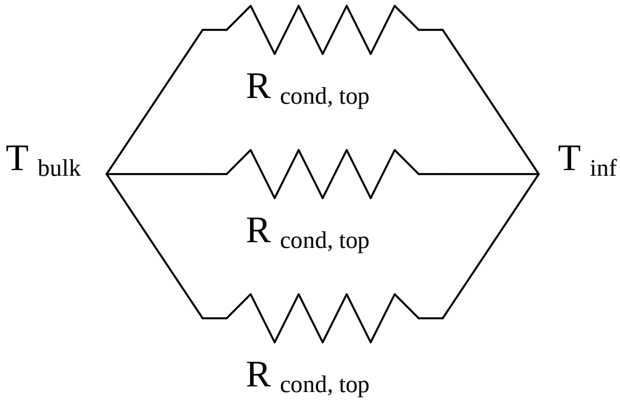


Figure 17: Resistance network for very wet environment case.

The justification for the approximation of no resistance to heat transfer in very wet conditions, is demonstrated by comparing the similar case in part 1. There it was shown that under forced convection conditions, a heat transfer coefficient of 182 $W/m^2 K$ was present on the sides. This would give a resistance per unit area of 0.055 ($m^2$ x s x K) / J, compared to a resistance per unit area of 0.161 ($m^2$ x s x K) / J for conduction. So the resistance due to the insulation under these conditions is 29 times larger, and hence the effect of the additional resistance is neglected. The total resistance is therefore:

$R_{total} = 1 / (1 / R_{top, conduction} + 1 / R_{bottom, conduction} + 1 / R_{sides, conduction})$

$R_{total} = 0.036$ (K x s) /J

**Conclusions.**

The heat transfer design for this concept had three objectives. Firstly, preventing the outer surface temperature from exceeding 45$^o$C. Secondly, ensuring that the bulk temperature of the liquid did not fall below 50$^o$C during the washing phase. And thirdly, ensuring that during re-heating of the solution, the heater unit did not cause local boiling. The heat and mass transfer analysis of the proposed design for the belt washer has shown that the design is feasible in its current form. A 4.7mm thick sheet of expanded polystyrene, or a 5.3mm thick sheet of foamed rubber would meet the insulation requirements on the tanks. With this insulation, excessive cooling of the liquid during the washing cycle should not be a problem. In order to heat the liquid to the desired temperature in 5 minutes, a 48.3 kW heater would be required, with a flow rate through the heating unit of at least 23.4 litres per minute. It is assumed that the dry tank will cool to about 56.4$^o$C in a 15 minute wash cycle. Further analysis showed that even if the tank is kept wet, the temperature will not drop below 56.1$^o$C, and the wash cycle takes up to an hour, the temperature will not drop below 54.5$^o$C.

**References.**

[1] F. Incropera, D. DeWitt, Fundamentals of Heat and Mass Transfer, John Wiley & Sons, 5th ed. 2002.

[2] http://www.matweb.com/search/SpecificMaterial.asp?bassnum=O4000

[3] http://www.pbaindustrial.com/html/material_description2.html

[4] ENME 602 lecture notes.

# Steam versus Electrical Heating Analysis

The optimal cleaning abilities of the solution are obtained when the solution is heated. The maximum temperature that the polyethylene belt can tolerate without softening is 65$^{o}$C, for this reason an operating temperature of 60$^{o}$C was selected. To obtain this temperature a source of heat was required. The two most practical options were electrical heating and steam heating, because both of these resources were already available, and suitable for the task. A costing for the necessary components for each option was conducted.

Firstly the heating requirements were identified through a heat transfer investigation that was done on earlier assumed conditions, and altered for changed conditions. The amount of energy required to reheat the solution after being used in cleaning was calculated as 19.8 MJ. The estimated time taken for the device to conduct a single rinse cycle is 10 minutes. To open and change the belts would take about 5 minutes. To provide this in 15 minutes would require 22kW. The maximum watt density allowable for this solution is 25-30 watts per square centimetre. Some electrical heating elements were sourced to satisfy the requirements, and could be found for $240 for each 4kW element (after the decision to use electrical heating, it was found that 8kW elements could be made for around $250, making this option even more desirable). In addition adequate contactors were sourced. For both solutions the resource needs to have a supply put out to the location of the device in the factory (wiring or piping), and a controller made to monitor the temperature and activate the heating.

For the steam option 10m of 1-inch diameter pipe would be required to satisfy the watt density constraint. An approximate cost analysis is shown below. It can be seen that there is not a significant difference in the expected costs of the two options. It is difficult to predict exactly how much heat will be delivered through a heat exchanger, particularly when the solution is subject to only natural convection. The two systems have similar safety risks, steam has a higher probability of injury, but a lower magnitude than electrical heaters. It is not suitable at Sealord to return the cooled steam or condensate to the boiler, instead the condensate must be bled off into the sewerage system. Direct injection of steam is also possible, but this was discounted, as there is a potential to add water to the tank, causing it to overflow.

| **Steam** | **units** | **unit price** | **cost** |
|---|---|---|---|
| tube | 15 | 6.3 | 94.5 |
| valve | 1 | 400 | 400 |
| welding | 20 | 60 | 1200 |
| steam piping | 1 | 500 | 500 |
| regulator | 1 | 100 | 100 |
| controller | 1 | 700 | 700 |
| **Total** | | | **2994.5** |

| **Electric** | **units** | **unit price** | **cost** |
|---|---|---|---|
| heater elements | 6 | 240 | 1440 |
| contactors | 3 | 100 | 300 |
| wiring | 1 | 500 | 500 |
| controller | 1 | 700 | 700 |
| **Total** | | | **2940** |

| **Advantages of electrical heaters** | **Advantages of steam heat exchangers** |
|---|---|
| Fine control of solution temperature | Lower running costs |
| Easier maintenance | Cannot ‘burn out’ |
| Easier design | |
| Less potential for corrosion problems | |
| No bled condensate requiring disposal | |
| Less hot piping | |
| More certain long term availability | |
| Cheaper set up costs | |
| More even watt density | |

| **Sheets and extrusions are stainless steel unless otherwise stated** | **Units** | **Quantity** | **Cost** | **Total Cost** | **Supplier** |
|---|---|---|---|---|---|
| warning signs (hot, o/h crane, caustic, electric shock, hands hurt (rinser) | each | 5 | 20 | 100 | NZ Safety LTD |
| **Wash Tank** | | | | | |
| 2mm sheet | 1220x2440 | 1.5 | 193 | 289.5 | NZF |
| 3mm sheet | 1220x2440 | 1 | 280 | 280 | NZF |
| 40x40x5 equal angle bent to OD 1080 type 2 | /m | 3.4 | 14.88 | 50.592 | NZF |
| 50x19 flat bar bent to OD 1108 type 12 | /m | 3.5 | 35.02 | 122.57 | NZF |
| 12mm round bar | /m | 2.2 | 4.17 | 9.174 | NZF |
| 50x50x6 equal angle | /m | 3.6 | 23.97 | 86.292 | NZF |
| hose tail 2" | each | 1 | 16.8 | 16.8 | NZF |
| elbow 2" | each | 1 | 14.04 | 14.04 | NZF |
| 50x5 flat bar (3 feet + switch mount) | /m | 0.2 | 9.53 | 1.906 | NZF |
| pipe 2" | /m | 0.2 | 22.25 | 4.45 | NZF |
| 50x10 flat bar (feet) | /m | 0.33 | 19.64 | 6.4812 | NZF |
| 12mm round bar (feet) | /m | 0.3 | 4.17 | 1.251 | NZF |
| **Basket** | | | | | |
| 2mm sheet | 1220x2440 | 1.5 | 193 | 289.5 | NZF |
| perforated sheet | 1220x1220 | 1 | 300 | 300 | NZF |
| 25x12 flat bar | /m | 4.5 | 27.2 | 122.4 | NZF |
| 25x5 flat bar, bent to OD 660 type 12 | /m | 2.1 | 5.1 | 10.71 | NZF |
| 65x6 flat bar, bent to OD 998 type 12 | /m | 3.2 | 16.15 | 51.68 | NZF |
| **Lid** | | | | | |
| flat section 40x5 bent to OD 1078 type 11 | /m | 3.4 | 8.5 | 28.9 | NZF |
| 25x12 flat bar | /m | 1.9 | 27.2 | 51.68 | NZF |
| 5mm chain | /m | 1.8 | 35 | 63 | NZF |
| 12mm round bar | /m | 0.1 | 4.17 | 0.417 | NZF |
| 2mm sheet | 1220x2440 | 1 | 193 | 193 | NZF |
| carabiners | each | 3 | 30 | 90 | |
| shackles (SWL >240kg) | each | 4 | 10 | 40 | |

| | Units | Quantity | Cost | Total Cost | Supplier |
|---|---|---|---|---|---|
| **Pipes and Fittings** | | | | | |
| straight pipe 2" | /m | 2 | 22.25 | 44.5 | NZF |
| elbow 2" | each | 4 | 14.04 | 56.16 | NZF |
| tee 2" | each | 7 | 19.8 | 138.6 | NZF |
| tee 2" 1" branch | each | 1 | 19.8 | 19.8 | NZF |
| valve 2" with actuator (DE 77-10-50) | each | 6 | 479.2 | 2875.2 | Mac |
| valve 1" with actuator (DE 77-10-25) | each | 1 | 357 | 357 | Mac |
| valve 2" with handle (DE 77-10-50) | each | 2 | 186 | 372 | Mac |
| slip on flanges | each | 4 | 72.08 | 288.32 | NZF |
| 2" to 1 1/4" reducer | each | 1 | 9.9 | 9.9 | NZF |
| 2" to 1 1/2" reducer | each | 1 | 10.8 | 10.8 | NZF |
| weld-thread 2" | each | | 7 | 0 | NZF |
| weld-thread 1 1/2" | each | | 6.09 | 0 | NZF |
| weld-thread 1 1/4" | each | | 4.9 | 0 | NZF |
| hose tail 1" | each | 2 | 14.91 | 29.82 | NZF |
| hose tail 2" | each | 11 | 16.8 | 184.8 | NZF |
| filter (Amiad 2" T Super Filter (disc) (Cat#:01-22) / Amiad 2" Manual Steel Filter (perf cylinder) (Cat#: 38-2) ) | each | 1 | 800 | 800 | Pumps & Filters Ltd |
| Hose 2" water suction and delivery (33.GWS051) | /m | 16 | 34.18 | 546.88 | Paykels |
| Hose 2" water delivery (33.GWd051) | /m | 5 | 22.57 | 112.85 | Paykels |
| Hose 1" to suit water (standard water hose) | /m | 4 | 15 | 60 | Paykels |
| Hose to suit high pressure water (fire reel hose) | /m | 3 | 50 | 150 | Paykels |
| **Miscellaneous** | | | | | |
| 5mm PVC plate (Plasticraft) | m^2 | 1 | 96.4 | 96.4 | |
| 50mm PVC round bar (Plasticraft) | m | 1 | 59.2 | 59.2 | |
| **Control** | | | | | |
| solenoid pnumatics valve (35A-OCB-DDA-A1-BA) | each | 5 | 51.8 | 259 | Mac |
| 5 port manifold (EBM35A-001C05) | each | 1 | 27 | 27 | Mac |
| PLC (Rockwell MicroLogix 1000 Controller (20 I / 12 O) 24Vdc or 240Vac) | each | 1 | 700 | 700 | Rockwell CHCH |

| | Units | Quantity | Cost | Total Cost | Supplier |
|---|---|---|---|---|---|
| control relays | each | 12 | 12 | 144 | |
| 24V power supply | each | 1 | 350 | 350 | |
| E-Stop | each | 1 | 60.9 | 60.9 | corys |
| E-Stop safety contactor (DIL 1M and Z1-24 ) | each | 1 | 165 | 165 | bremca (moeller) |
| 5mm LED (7 high intensity red diffused, 1 high intensity green diffused) | each | 8 | 0.4 | 3.2 | South Island Components |
| resistors 9 x 820ohm, 6 x 270k ohm | each | 15 | 0.2 | 3 | Dick Smith Electronics |
| Transistors (BC547 in a TO92 package) | each | 8 | 0.7 | 5.6 | Dick Smith Electronics |
| resistor network 47k ohm, 8 resistors | each | 1 | 0.6 | 0.6 | South Island Components |
| 15V 200mA zener diode | each | 1 | 0.25 | 0.25 | South Island Components |
| BCD to Decimal decoder (IC #4028) | total | 1 | 2 | 2 | South Island Components |
| 2 capacitors (0.1 microFarad (0.1mF) and 0.3 microFarad (0.3mF)) | each | 2 | 0.7 | 1.4 | Dick Smith Electronics |
| stripboard | each | 1 | 8 | 8 | Dick Smith Electronics |
| 3 phase plug and 5m 5 core cable (PDL 56P535) | each | 1 | 240 | 240 | corys |
| 3 phase socket (5 pole) (PDL 56CV535) | each | 1 | 235 | 235 | corys |
| 5 core cable, 7m long 6.0mm^2 (Ca07092 6.0mm^2) | 7m | 1 | 18.25 | 18.25 | corys |
| control cabling | /m | 10 | 1.45 | 14.5 | Dick Smith Electronics |
| contactor for heaters (DIL 1M) | each | 1 | 100 | 100 | bremca (moeller) |
| contactor for pump (DIL EM4-G and ZE-4 ) | each | 1 | 83 | 83 | bremca (moeller) |
| level switch (MFS9-N1-2) | each | 2 | 75 | 150 | hamer |
| Pressure switch - air (PEV-W_KL-LED-GH) | each | 1 | 89.06 | 89.06 | festo |
| Pressure switch - pump (Saginomiya Ammonia Model SNS-C106XN) | each | 1 | 150 | 150 | hamer |
| Start push button (56PB1/G, incl lid) | each | 1 | 29 | 29 | corys |
| Lid switches (V4-IP67 fully sealed microswitch cat # 320-528) | each | 2 | 16 | 32 | RS components |
| temp probe (Pt100 probe code: RL-PVC) | each | 1 | 58 | 58 | intech |
| temp probe collar (0.25 inch BSP 316 SS process fitting) | each | 1 | 22.5 | 22.5 | intech |
| temp switch (Shimaden SR34) | each | 1 | 162 | 162 | intech |
| pneumatic filter regulator with gauge | each | 1 | 92.31 | 92.31 | festo |
| pneumatic fittings | each | 15 | 8 | 120 | |
| air hose | total | 1 | 100 | 100 | |

| | Units | Quantity | Cost | Total Cost | Supplier |
|---|---|---|---|---|---|
| Control cabinet (Moeller CI45E-200 (500mm x 375mm x 225 (185 usable))) | each | 1 | 200 | 200 | bremca (moeller) |
| Cable Glands, various sizes (All IP 65 or better, providing strain relief) | each | 22 | 8 | 176 | |
| pH controller (Knight UP-1100-L) | each | 1 | 600 | 600 | Wilsons chemicals |
| Enclosure for buttons / display, base (`56E3) | each | 1 | 45 | 45 | corys |
| Enclosure for buttons / display, grey lid (56L1/G (only 1 as 1 is included in start button price)) | each | 1 | 10 | 10 | corys |
| Enclosure for buttons / display, clear lid (56L1/CL) | each | 1 | 15 | 15 | corys |
| **Chassis** | | | | | |
| 200x100x5 RHS for chassis and legs m/s (only 75% used, included in fabrication costing) | 8m | 1 | 315.67 | 0 | Fletcher Easysteel |
| 150 x 75 universal beam for primary frame m/s (included in fabrication costing) | 12m | 3 | 202.54 | 0 | Fletcher Easysteel |
| Plastic coated netting for fences | /m | 13 | 10 | 130 | Advanced Engineering |
| bund 3mm sheet m/s (included in fabrication costing) | 1220x2440 | 4 | 80.68 | 0 | Fletcher Easysteel |
| pump (Lowara CEA 370/1 or 370/2) | each | 1 | 950 | 950 | A W Harper Ltd |
| 40 x 40 x 5 equal angle m/s (included in fabrication costing) | 9m | 1 | 43.2 | 0 | Fletcher Easysteel |
| 2mm sheet m/s (only 50% used, included in fabrication costing) | 1220x2440 | 1 | 62.64 | 0 | Fletcher Easysteel |
| 50 x 50 x 6 equal angle s/s | /m | 3.2 | 23.97 | 76.704 | NZF |
| 5mm plate m/s (only 50% used, included in fabrication costing) | 1220x1200 | 1 | 120.6 | 0 | Fletcher Easysteel |
| 12mm round bar s/s | /m | 0.21 | 4.17 | 0.8757 | NZF |
| 1" pipe s/s | /m | 1 | 6.3 | 6.3 | NZF |
| 0.9mm sheet s/s (off cut from holding tank) | 1220x2440 | 0 | 0 | 0 | NZF |
| 5mm plate s/s (off cut from holding tank) | 1220x2440 | 0 | 0 | 0 | NZF |
| push trolley/girder trolley for chain block 500kg (both about $215) | each | 1 | 215 | 215 | Steel and tube/paykels |
| chain block 500kg (on special, regular price ~$200) | each | 1 | 100 | 100 | Steel and tube |

| | Units | Quantity | Cost | Total Cost | Supplier |
|---|---|---|---|---|---|
| **Rinser** | | | | | |
| nozzles and rotors | total | 1 | 300 | 300 | Spraying Systems |
| rotating unions | total | 1 | 2000 | 2000 | Spraying Systems |
| 40x40x5 equal angle | /m | 13.5 | 14.88 | 200.88 | NZF |
| 0.9mm sheet for waterblaster | 1220x2440 | 1 | 93 | 93 | NZF |
| | | | | | |
| **Holding Tank** | | | | | |
| insulation - polyfoam 10mm thick | 4800x1200 | 1 | 6.5 | 6.5 | James Hardie |
| heater elements 8kW (8kW tank elements, | | | | | |
| 2"bsp boss (Star wiring)) | each | 3 | 250 | 750 | Brian at Argus Heating |
| 12mm round bar (off cut from other pieces) | /m | 0.03 | 4.17 | 0 | NZF |
| 5mm plate | 1220x2440 | 3 | 459 | 1377 | NZF |
| 0.9mm sheet | 1220x2440 | 3 | 93 | 279 | NZF |
| straight pipe 2" | /m | 0.15 | 22.25 | 3.3375 | NZF |
| straight pipe 1" | /m | 0.05 | 12.24 | 0.612 | NZF |
| 50x5 flat bar | /m | 0.2 | 9.53 | 1.906 | NZF |
| 50x10 flat bar (feet) | /m | 0.4 | 19.64 | 7.856 | NZF |
| 12mm round bar (feet) | /m | 0.45 | 4.17 | 1.8765 | NZF |
| 2" BSP socket | each | 3 | 10 | 30 | NZF |
| | | | | | |
| **Fasteners** | | | | | |
| M24 x 130mm bolt and nut, m/s grade 4.6 galv'd | each | 4 | 12 | 48 | Fletcher Easysteel |
| M10 x 60mm bolt and nut, m/s grade 4.6 galv'd | each | 10 | 0.73 | 7.3 | Fletcher Easysteel |
| M10 x 30mm bolt and nut, m/s grade 4.6 galv'd | each | 50 | 0.45 | 22.5 | Fletcher Easysteel |
| M24 standard washer, m/s | each | 8 | 0.65 | 5.2 | Fletcher Easysteel |
| M10 standard washer, m/s | each | 106 | 0.2 | 21.2 | Fletcher Easysteel |
| M10 50mm square washer | each | 10 | 0.8 | 8 | Blacks Fasteners |
| | | | | | |
| **Miscellaneous parts** | | 100 | 10 | 1000 | |

| | Units | Quantity | Cost | Total Cost | Supplier |
|---|---|---|---|---|---|
| **Contracting** | | | | | |
| Hot Dip Galvanising | /kg | 984.2 | 1.1 | 1082.62 | CSP Galvanising |
| Mild Steel Fabrication | total | | | 4090 | Three way |
| Wash tank fabrication | | | | 4190 | Nalder and Biddle |
| Holding tank fabrication | | | | 4982 | Nalder and Biddle |
| Other stainless fabrication | | | | 3600 | Nalder and Biddle |
| Labour to build panel and install pneumatics | hrs | 24 | 40 | 960 | Smart Electronics |
| Labour to program PLC and commission program | hrs | 4 | 40 | 160 | Smart Electronics |
| Spray nozzles and rotors | hrs | 16 | 120 | 1920 | Spray Pump |
| labour to build display circuit | hrs | 16 | 20 | 320 | elec student |
| | | | | | |
| Assembly | hrs | 36 | 40 | 1440 | |
| On Land Commissioning | hrs | 24 | 40 | 960 | |
| Installation | hrs | 24 | 40 | 960 | |
| Miscellaneous( incl pneumatics and 3 phase adjustment) | hrs | 24 | 40 | 960 | |
| | | | | | |
| **Total** | | | | **$46,175.81** | |