An Assessment of the Pietermaritzburg Waste Minimisation Club and the Waste Minimisation Opportunities on a Coil Coating Plant

Submitted in fulfilment of the academic requirements for the degree of

Master of Science (Chemical Technology)

By

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Abstract

This study involved an assessment of the Pietermaritzburg Waste Minimisation Club (PWMC) during 2001, and a waste minimisation audit conducted at two coil coating lines. Waste minimisation is the reduction or elimination of waste at source[4]. It is often achieved through waste minimisation clubs which comprise a small number of companies, generally in the same geographical area, that are interested in reducing waste [1,7,11].

The success of the PMWC was evaluated in terms of the degree to which members implemented waste minimisation principles. Two questionnaires were used to assess the success of the club. These indicated that although the training material gave the members a good understanding of the basic principles of waste minimisation, the material has not given the members enough practical information to implement a waste minimisation programme in their companies. The main barriers to waste minimisation identified include production pressure, operational constraints, lack of human resources and a lack of management time. The drivers for waste minimisation were financial savings, improved plant utilisation and improved environmental performance.

Coil coating is a continuous process where a coiled sheet of aluminium is cleaned, pretreated and coated with paint. The flow rates, compositions and costs of all input and output streams to the cleaning and pretreatment sections were gathered from operators or measured. The data were collected over a three-month period to obtain a representative sample, and then analysed to determine waste minimisation opportunities using mass balances, monitoring and targeting, a scoping audit and a true cost of waste assessment. The scoping audit was found to be the

most useful technique because it accurately prioritised the waste minimisation opportunities but required a relatively small amount of data for its application. However, the scoping audit underestimated the savings that could be achieved at the coil coating department and therefore the ‘scope to save’ percentages, which were developed for United Kingdom industries, need modification to better reflect South African industry.

Opportunities for waste minimisation on Coil Coating Line 1 (CCL1) included reducing the water consumption, reducing the acid and chromium raw materials consumption, and finding a cheaper energy source for heating the process and rinse tanks. Potential financial savings of R116 000 and environmental savings of 18 200 kL of water or effluent per year were calculated for CCL1.

The chromium and acid effluent treatment and solid waste disposal are the main areas for waste minimisation on Coil Coating Line 2 (CCL2). Savings could be achieved in these areas by using roller application of the chromium pretreatment rather than spray application, and by preventing a leak of chromium pretreatment into the acid process and rinse tanks. Other savings can also be achieved by operating the chromium process tank as a fed-batch process, and operating the alkali and acid process tanks as continuous processes at the specified chemical concentrations and with recycle of the rinse water (dragout). The total financial savings that can be achieved on CCL2 are R5.3 million, and potential environmental savings are 31 600 kL of effluent per year.

Declaration

I hereby certify that this research is a result of my own investigation which has not already been accepted in substance for any degree and is not being submitted in candidature for any other degree.

Signed:...Dempster...............
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I hereby certify that this statement is correct.

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CHAPTER 1

Introduction

Every industrial process produces waste. Once created, waste cannot be destroyed although it can be concentrated, diluted or changed in its physical or chemical form in order to render it 'harmless'.[1] This is referred to as 'end-of-pipe technology'. Historically, end-of-pipe technology has been the most popular solution to waste.

In recent years, industries have realised that many conventional end-of-pipe systems are costly to operate and maintain.[2] Therefore emphasis has shifted to waste minimisation and pollution prevention. The waste management hierarchy shows how treatment of waste systems has been prioritised (see Figure 1.1).

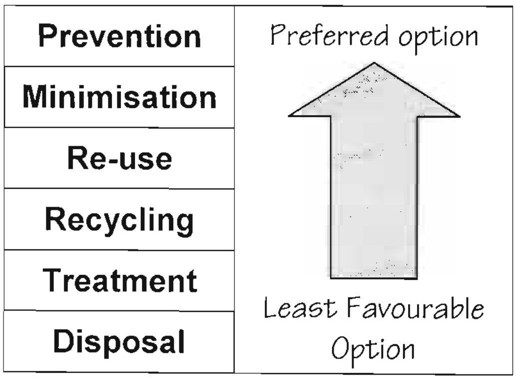


Figure 1.1: The waste management hierarchy [3]

Waste minimisation involves systematically reducing or eliminating waste at source.[4] In simple terms, it involves the design, purchase, manufacture or use of products and materials to reduce the amount of waste generated. Waste minimisation can be achieved in any process. Figure 1.2 illustrates a basic industrial process and how waste minimisation can be applied to it.

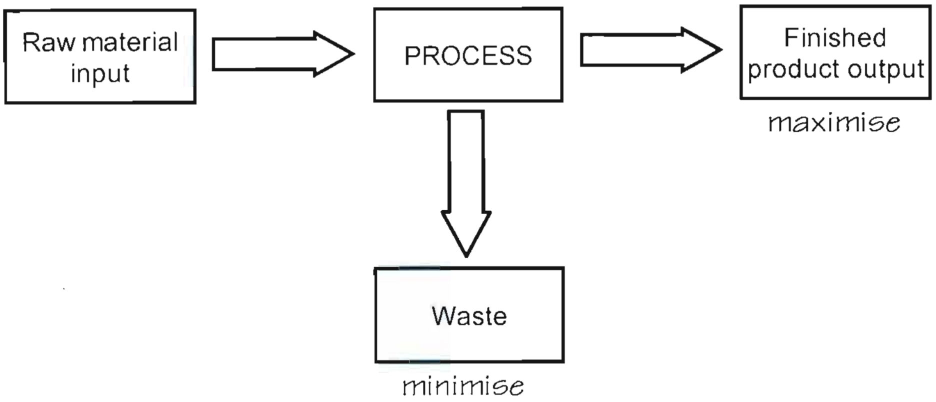


Figure 1.2: Flow diagram showing how waste minimisation can be achieved in a basic industrial process [5]

Waste minimisation results in benefits such as reduced raw material and utility consumption and costs; reduced waste treatment and disposal costs; compliance with regulations; improved process performance; and a competitive advantage.[6] Hence the greatest benefit of waste minimisation to industry is the financial savings. Waste minimisation also results in a decreased environmental impact through reducing emissions and the need for landfill.

During the last decade a new approach to waste minimisation has developed, namely waste minimisation clubs (WMCs).[7] A waste minimisation club comprises a small number of companies, generally in the same geographical area, that are interested in reducing waste. The club gives the companies an opportunity to exchange ideas, information and experiences on waste minimisation. In addition, the companies receive training in waste minimisation practices and are advised on new environmental legislation. Waste minimisation clubs can be sector-specific, where the club consists of companies of the same manufacturing sector. However, most clubs are general or cross-sectoral and therefore involve a wide range of businesses and sizes of companies.[4]

A waste minimisation club was started in Pietermaritzburg, South Africa, at the beginning of 2001. Pietermaritzburg is a city situated inland just north of Durban in the province of KwaZulu-Natal. It is currently the administrative capital of the province and the estimated population is 228 549 (in 1991). Pietermaritzburg has approximately 670 manufacturing industries, the majority of which are small and medium enterprises (SME's).[8] Manufactured products include fabricated aluminium, wattle bark extract, furniture, footwear, chocolate and cloth.[9]

This thesis presents an analysis of the first year of the Pietermaritzburg Waste Minimisation Club's existence. It details the progress of the club as well as a critical assessment of its success. This study also includes a waste minimisation audit that was conducted at an industry that is a member of the Pietermaritzburg Waste Minimisation Club. The audit was performed on the cleaning (wet) and chromium pretreatment sections of two coil coating lines at an aluminium company. Coil coating is the process whereby a coiled sheet of aluminium or steel is cleaned, pretreated and coated with paint or plastic laminate.[10]

The focus of the audit was to identify waste minimisation opportunities on the coil coating line and to evaluate the potential financial and environmental savings of these opportunities. The audit involved collecting composition, flow rate and cost data of all input and output streams to or from the wet and pretreatment sections of both coil coating lines. Assessment techniques such as mass balances, a scoping audit, monitoring and targeting, and a true cost of waste assessment were performed to identify waste minimisation opportunities, which were then presented to the company.

To introduce the concept of waste minimisation and waste minimisation clubs, the relevant literature is reviewed in Chapter 2. Examples are given of the financial and environmental savings achieved by waste minimisation clubs that have been completed. The chapter further describes the methods used to identify waste minimisation opportunities. In addition, a detailed description is presented of the two coil coating lines that were studied.

The data collection techniques for the assessment of the Pietermaritzburg Waste Minimisation Club and for the waste minimisation audit are presented in Chapter 3. For the waste minimisation audit, data were collected over a three-month period to obtain as representative a sample as possible. All the analytical tests performed are described in this chapter.

In Chapter 4, the progress of the Pietermaritzburg Waste Minimisation Club is assessed. The discussion includes the successes of the club as well as the financial and environmental savings achieved at the time of writing of this thesis. The training material used for club members is critically reviewed and the factors encountered by the members that motivate ('drivers') and hinder ('barriers') waste minimisation are described. It is important to determine the barriers and drivers to waste minimisation as it allows changes to be made to the training and to how the waste minimisation club is run as a whole. Understanding the barriers allows effective measures to be put in place to overcome them and achieve success through waste minimisation.

Chapter 5 describes the results of applying the assessment techniques to the audit data. The identified waste minimisation opportunities are described and the potential financial and environmental savings are presented. The assessment techniques are also compared, to find whether they identify the same waste minimisation opportunities and similar financial and environmental savings.

In Chapter 6, the conclusions drawn from this study are presented and recommendations are made regarding the running of a waste minimisation club and the continuation of waste minimisation practices at the two coil coating lines. Future work that can be performed to further increase the success of waste minimisation clubs is discussed.

CHAPTER 2

A Review of Waste Minimisation and the Coil Coating Process

A literature survey was conducted on waste minimisation and waste minimisation clubs, as well as the coil coating process. The literature is discussed in this chapter in five sections. The first section (Section 2.1) gives a brief discussion of the waste minimisation process, and Section 2.2 details the methods that can be used to generate waste minimisation opportunities. Section 2.3 describes the waste minimisation club approach, and gives examples of waste minimisation clubs in Europe and South Africa. There is also a discussion of the drivers and barriers experienced by industries to waste minimisation, including a review of the environmental legislation in South Africa. Section 2.4 discusses coil coating, including a general description of the coil coating process. The final section of this chapter (Section 2.5) gives a detailed description of the two coil coating lines that were studied in this work.

2.1 The Waste Minimisation Process

Waste minimisation is achieved through the implementation of a systematic waste minimisation programme. There are five basic changes that can be made to achieve success through waste minimisation: changes in the raw materials; a technology change; product change; improved housekeeping; and recycling and reuse.[7, 11]

Changing the raw materials might involve using non-toxic or renewable raw materials, or reducing the consumption of the same raw material.

Changing production technology includes alterations to equipment, operating conditions, and process control. It could also include automating various areas of the process. This does, however, often require significant capital expenditure.

Product change refers to changes in the properties of the product. This could mean changing the product characteristics so that it will have a longer lifetime or that it can be recycled more easily.

Improved housekeeping involves simple alterations that can result in financial savings. They include avoiding spillage, leaks and fugitive emissions by fixing leaking taps, ensuring that the right amount of chemicals is being used and reusing rinse water.

The last technique is to **reuse or recycle** waste materials for another process, or by recovering raw materials from the waste streams.[7]

The waste minimisation programme consists of implementing a number of steps (see Figure 2.1).

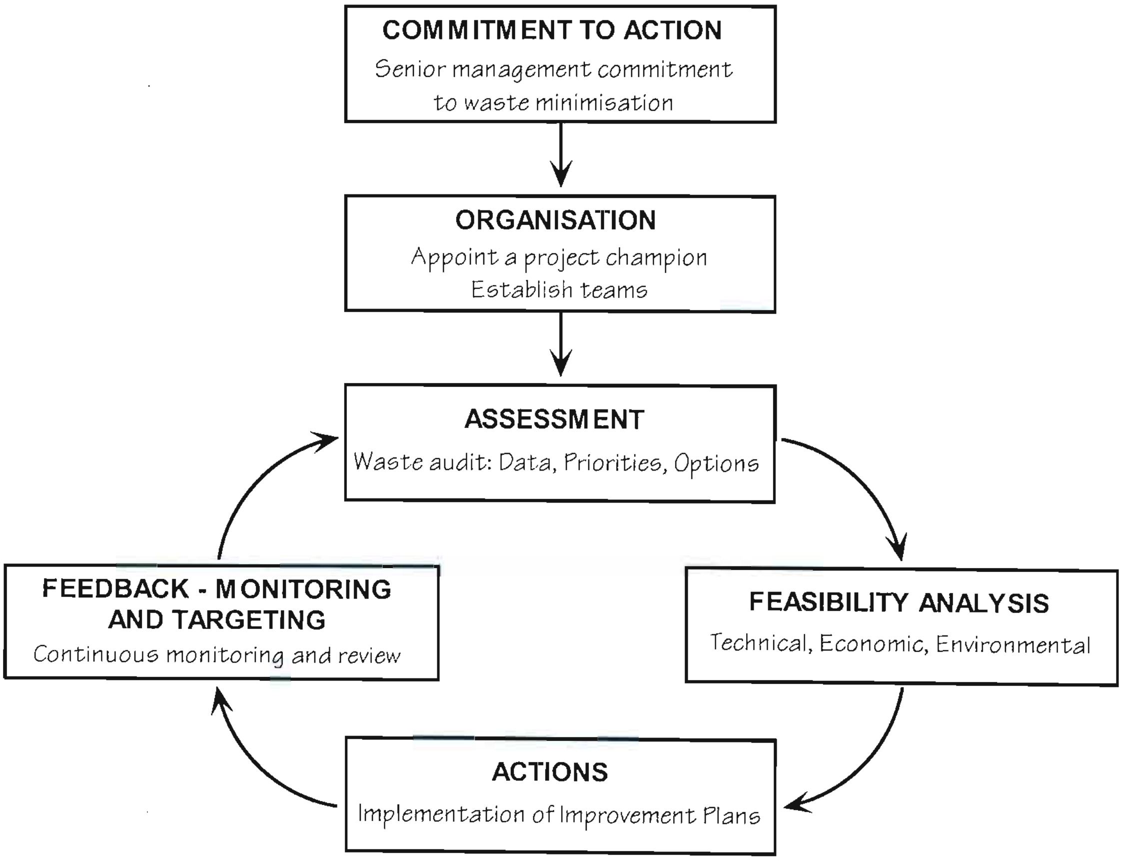


Figure 2.1: Overview of the procedure for establishing and running a waste minimisation programme [1, 11]

The first step involves gaining the commitment of senior management. This is essential, since the waste minimisation programme will not succeed without the involvement of management. The project champion must then be appointed. This individual is responsible for:

- co-ordinating and facilitating the waste minimisation programme within the company;
- publicising the programme within the company;
- training team members in waste minimisation practices;
- setting goals for the programme within the company; and
- reporting to management.[11, 12]

Once the project champion has been chosen, a project team is selected who assists the project champion with the waste minimisation programme. The project team is responsible for conducting the waste audit and ensuring that the waste minimisation opportunities are implemented. Hence the team should consist of a representative from each department in the company. It is also advisable to have team members representing each level in the management structure. This ensures that all employees are involved which increases the awareness of waste minimisation.[13]

The next step is to perform a waste minimisation audit, which involves collecting data on the composition, flow rates and costs of all process input and output streams. Much of this data is probably already available from a variety of existing sources. These sources could be:

- management reports;
- process flows;
- operating manuals;
- raw material specifications;
- treatment and disposal costs;
- raw material and production costs;
- storage and transport costs;
- customers and suppliers.[6]

If the available data is sufficient, then it is possible to proceed to the next stage of the waste minimisation process. However, it is likely that there will be missing data that will have to be measured. For example, flow, temperature or concentration measurements should be taken to obtain the information.[14] When gathering current data, it is essential to determine the best data gathering period to ensure that the data is representative of the process (and not during shutdowns or maintenance).[15]

This data is then analysed to identify waste minimisation opportunities (see Section 2.2). There are two main stages in the assessment phase: the pre-assessment phase to establish the focus areas (process flow diagram, scoping audit, mass balance and true cost of waste assessment) and the detailed assessment phase to identify waste minimisation opportunities in the areas identified in the pre-assessment phase (detailed mass balance, monitoring and targeting, statistical process control and option generation). Solutions to these opportunities are then investigated to determine which are the most technically, economically, and environmentally feasible.[11]

The last step in the waste minimisation programme is to implement the changes that have been identified as the most feasible. Once the changes have been made to the process, the process is monitored and the waste minimisation procedure can be repeated to further improve the process.[11]

The waste minimisation case study presented in this thesis is focused on the assessment (audit) phase of a waste minimisation programme on a coil coating plant. The waste minimisation audit is discussed in more detail in the following section.

2.2 The Waste Minimisation Audit: Generating Waste Minimisation Opportunities

2.2.1 Process Flow Diagrams

Before data is collected for the waste minimisation audit, it is important to understand the processes under investigation as well as to identify all the material flows into and out of the processes.[15] Process flow diagrams can be used for this since they indicate the flow of all input, output and recycle streams to or from a single process, a number of processes or an entire production line.[16] The inputs are purchased raw materials or any other materials needed to perform the process. Outputs are the products that are sold to the customers as well as losses to the environment. This is demonstrated in the generalised process flow diagram shown in Figure 2.2.[15] Process flow diagrams are useful for the scoping audit and mass balance analytical techniques, which are discussed in Sections 2.2.2 and 2.2.3 respectively.[16]

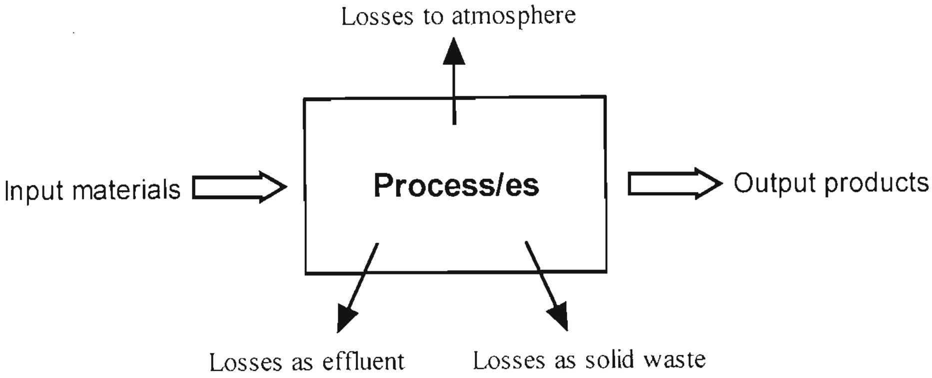


Figure 2.2: Generalised process model [15]

2.2.2 Scoping Audit

The purpose of a scoping audit is to estimate the financial savings that can be achieved through waste minimisation. It involves collecting basic consumption and cost data and then assessing the scope of savings. Hence areas are identified where the largest savings can be made.[6]

When performing a scoping audit, the first step is to map the process under investigation (a process flow diagram). It is then necessary to determine the amounts and costs of raw materials, utilities and wastes at each step. This information is used to fill in a 'waste minimisation cost assessment table' (see Table 2.1). In this table, each resource or service is allocated a 'scope to save' minimum and maximum percentage. These 'scope to save' percentages were recommended by Enviros in their training material.[6] They were developed for industries in the United Kingdom and therefore might not be entirely accurate for South African industries. Unfortunately as yet no percentages have been investigated for South African industries and therefore the UK percentages were used in this study. Multiplying the cost of each input or output stream by the respective 'scope to save' percentage determines the 'scope to save' value. 'Scope(min)' is the minimum savings that can be achieved and 'Scope(max)' is the maximum savings that can be achieved through waste minimisation. The 'scope to save' values can be ranked to identify the area where the largest savings can be achieved. Hence waste minimisation efforts can be focused on these streams.[6]

Table 2.1: Waste minimisation cost assessment table for a scoping audit [6]

Resources & Services	Quantity	Units	Cost/Year	Priority (1=Highest)	Scope to Save %	Scope (min)	Scope (max)
Materials:							
Raw materials					1 to 5		
Cleaning agents					5 to 20		
Packaging					10 to 90		
Utilities:							
Electricity					5 to 20		
Heat					10 to 30		
Water					20 to 80		
Waste:							
Effluent					20 to 80		
Solid waste					10 to 50		
Total:							

2.2.3 Mass Balance

A mass balance of a process or site involves tracking materials through the process and identifying their destination and efficiency of use.[15] This identifies and quantifies any unknown losses from the system. The general mass balance equation for each species in a process is:

$$\text{input} + \text{generation} - \text{output} - \text{consumption} = \text{accumulation}$$ [17]

Equation 2.1

In Equation 2.1, each of the terms refers to the number of moles. In specific situations, this equation can be simplified:

- If the balance is for total mass, the generation term and the consumption term are zero.
- If the balance is for a non-reactive species, generation and consumption are zero.
- If a system is operating at steady-state (no fluctuations in any variables with time), the accumulation is zero.[17]

If the mass balance does not balance then there is a loss from the system, which represents an inefficiency in the process.[18] The mass balance hence enables unmeasured waste streams to be estimated and areas missing from the process flow diagram to be identified. In this way waste minimisation opportunities can be identified.[6]

2.2.4 True Cost of Waste

Most companies think of waste costs as being only the cost of treatment and disposal. These are the easily visible direct costs. However, there are also indirect waste costs, which make up the largest portion of the total cost of waste. The true cost of waste is typically 4% of turnover and can be as much as 10%.[4, 19]

The true cost of waste can be calculated by adding the costs of raw materials and utilities that are not converted into product, and other waste-related costs. These other costs include rework costs, management time, monitoring costs as well as storage costs, to name a few (see Figure 2.3).[6] This analysis enables one to prioritise the waste streams that will benefit from a waste minimisation study.

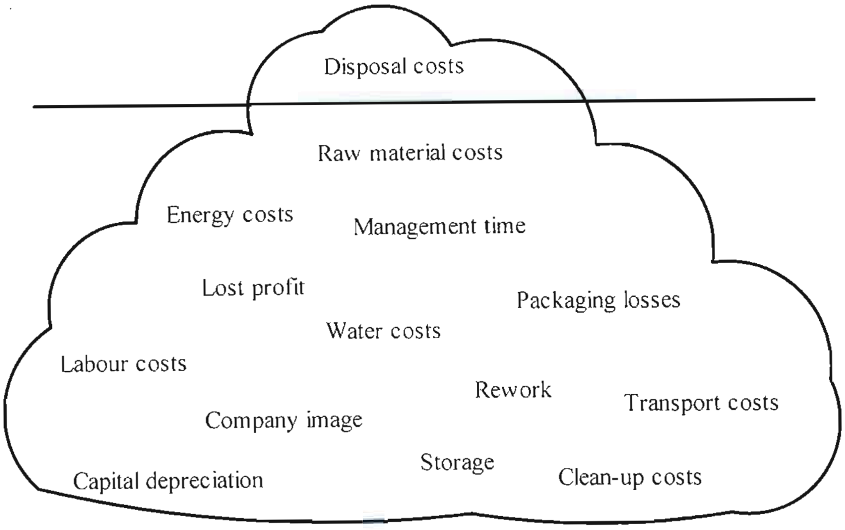


Figure 2.3: Waste cost 'Iceberg' [6]

2.2.5 Monitoring and Targeting

A key tool in waste minimisation is monitoring and targeting. This analytical tool involves monitoring the consumption of all raw materials and utilities to a process and then comparing them to a measure of activity such as production.[6] Monitoring and targeting consists of five main steps:

- monitoring the consumption of the material or resource;
- determining performance levels (targets);
- establishing regular reporting systems (metering);
- setting up teams to brainstorm ideas for improving performance; and
- establishing a feedback mechanism to create awareness.[6]

Since measurement of resource consumption is central to monitoring and targeting, meters should be installed to monitor the consumption or flow. These meters must be read at regular time intervals and compared to the amount of product manufactured in order to gain a better understanding of the process.[20]

A simple way of analysing the data is to represent it graphically. This will show visually when a process is out of control. Two examples of graphs that can be drawn are trend graphs and XY scatter graphs.[6] Trend graphs are a simple yet effective way of monitoring a process and identifying when the process goes out of control. A trend graph shows the material consumption over a certain time period (see Figure 2.4). This allows the comparison of various time periods and can show variations in performance. A target level can also be included on a trend graph (see Figure 2.4).[6] A disadvantage of trend graphs is that they do not show any dependence on production levels and therefore can only be used accurately for data that are independent of production.[15]

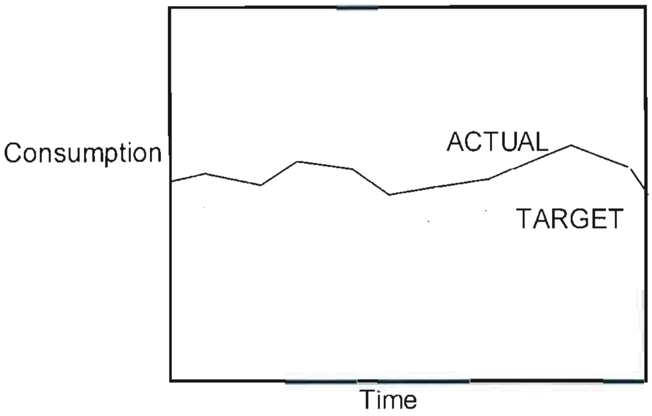


Figure 2.4: Example of a trend graph [6]

For data that are dependent on production, an XY scatter graph can be used. XY scatter graphs represent the process inputs as a function of the outputs, for example comparing raw material consumption and production (Figure 2.5). The data on both axes must be collected over the same time period. Once the data has been plotted, a linear regression line must be added which represents the average consumption for a given level of production (see Figure 2.5).[6, 15]

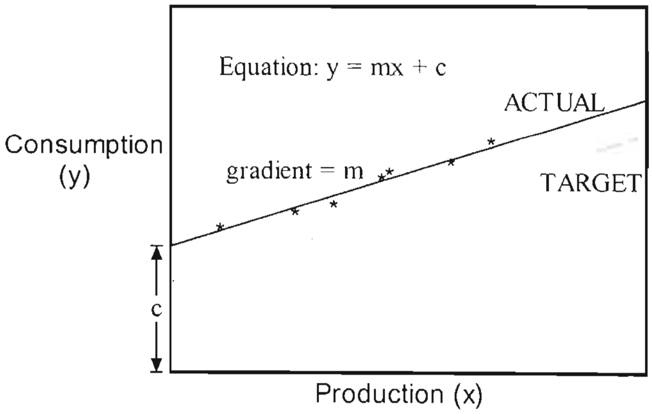


Figure 2.5: Example of an XY scatter graph [6]

The regression line can be used to highlight several features of the process such as:

- the y-intercept gives the **baseload** of the process (the amount consumed at zero production);
- the slope or gradient indicates the **process efficiency** of the plant (*i.e.* the smaller the slope, the higher the efficiency); and
- the spread of the points on either side of the line gives a measure of the **level of control** over the process.[6, 15, 20]

Determining the reasons for the poor running efficiency, process control and the baseload will lead to the identification of waste minimisation opportunities. Ideally the slope should be as small as possible and the intercept should be close to zero. The data points should lie close to the regression line.[20]

The regression line can also be used to set a realistic target, which is the desired consumption of the resource related to production. Once the regression line has been drawn, the target can be set below the actual consumption in order to reduce the consumption (see Figure 2.5).[6] The practicality of this target could be verified using a mass balance.

2.2.6 Statistical Process Control

Statistical process control applies statistical tests to measurements of the input and output streams of a process to determine whether the process is performing satisfactorily. Identifying the reasons for a process going out of control leads to improved control and reduced wastage.[21] Statistical process control is similar to monitoring and targeting but is more useful for monitoring process variation when it is related to a fixed target, such as quality. Hence statistical process control is often used in industry to prevent defects and to reduce costs by improving quality.[6]

Control charts are most often used in applying statistical process control (see Figure 2.6). The purpose of a control chart is to monitor the variability in a repetitive process. This helps identify specific changes in the way a process is set up or operated. Such changes can cause the process to become unstable, producing products that are out of specification and which will have to be scrapped or reworked. An important feature of the control chart is the inclusion of control or action limits. These are set as an upper and a lower limit and help to identify when the process is out of control. A value that is out of the control limits will show the operator that a change has occurred and that the process will have to be adjusted to ensure that it returns to the acceptable level.[15]

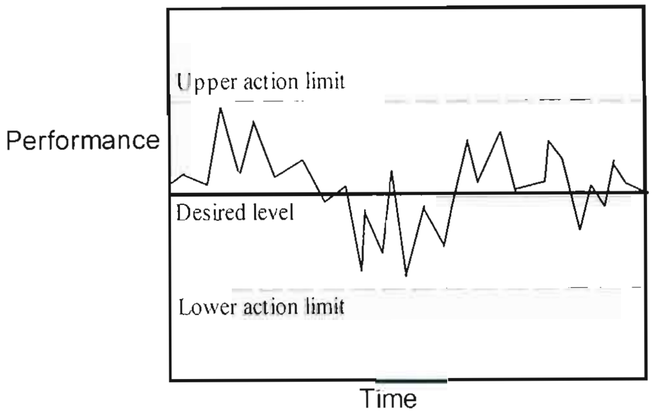


Figure 2.6: General example of a control chart [15]

2.3 *Waste Minimisation Clubs*

A waste minimisation club is a voluntary partnership created to promote the exchange of experience and information in the implementation of waste minimisation measures between geographically close manufacturers. The typical activities of a waste minimisation club are:

- meetings where waste minimisation experiences are shared (ranging from every month to every quarter depending on the club;
- workshops and training;
- individual audits to establish waste flows at every company;
- identifying waste minimisation opportunities;
- implementing selected opportunities;
- monitoring progress.[7]

Many waste minimisation clubs receive funding and facilitation for a predetermined period of time until the waste minimisation options have been implemented and progress monitored. This funding and facilitation usually last between one and a half to three years, after which the club may continue under new leadership and structure.[7]

The concept of waste minimisation clubs was first developed in the Netherlands in the early 1990's.[11] Waste minimisation clubs have been a great success; there are currently 76 active clubs, 45 inactive clubs and 15 planned clubs in the United Kingdom.[22] There are also similar initiatives in New Zealand and India.[11] The concept was introduced in South Africa in 1998 and there are 27 waste minimisation clubs running or planned in South Africa (as of July 2002).[23] One of the active clubs is the Pietermaritzburg Waste Minimisation Club which this study is focused on. Examples of successful waste minimisation clubs are discussed below.

2.3.1 The Netherlands

The first waste minimisation club was the PRISMA project in the Netherlands, which ran from 1988 to the end of 1990. It consisted of 10 companies from Rotterdam and Amsterdam. The club was a cross-sectoral club with members from the food, chemical, electroplating, metal processing and public transport sectors. The most important outcome of this club was the identification of the barriers that prevented industries from implementing a waste minimisation programme.[11]

2.3.2 The United Kingdom

Following the success of the PRISMA project, the Aire and Calder project was established in the United Kingdom in 1992. It consisted of eleven companies from the catchments of the Rivers Aire and Calder of West Yorkshire.[1] It was a cross-sectoral club, involving industries from the beverage, chemical, laundry, printing, transport and dye manufacturing sectors. The significant financial and environmental savings (see Table 2.2) achieved spurred on the development of other waste minimisation clubs in the United Kingdom.[11]

Table 2.2: Savings achieved in the Aire and Calder project by 1996 [1]

Number of waste minimisation opportunities identified:	671
Number of waste minimisation opportunities implemented:	399
Savings achieved:	£ 3 million / annum
Potential savings:	£ 4 million / annum
Reduction in amount of wastewater discharged:	659 000 kL / annum (27% decrease)

2.3.3 South Africa

Two waste minimisation club projects have already been officially completed in South Africa. The first club was formed in June 1998 in the Durban and Pinetown region for the metal finishing sector. The second club was situated in Hammarsdale and was initiated in November 1998. The Metal Finishing Waste Minimisation Club consisted of 29 members, most of which were electroplaters (three members were galvanisers and three were powder coaters).[13] The results achieved by March 2000 are summarised in Table 2.3.

Table 2.3: Savings achieved by the Metal Finishing Waste Minimisation Club [24]

Energy savings:	R 280 000 / annum
Financial savings:	R 2.1 million / annum
Environmental savings:	149 000 kL water and effluent

The Hammarsdale Waste Minimisation Club was originally established in the textile sector but it was decided to include other industries in the area: a chemical manufacturer, the Hammarsdale Wastewater Treatment Works and a chicken abattoir. There were ten members in total.[13] Table 2.4 reports the savings achieved by the Hammarsdale Club by March 2000.

Table 2.4: Savings achieved by the Hammarsdale Waste Minimisation Club [24]

Number of opportunities identified:	80
Energy savings:	R 400 000 / annum
Financial savings:	R 16.5 million / annum
Environmental savings:	2.7 million kL water and effluent

2.3.4 Forming a Waste Minimisation Club

A waste minimisation club is usually run by an individual or group of individuals who are interested in waste minimisation and are aware of the benefits of implementing a waste minimisation programme.[4] This individual or group of individuals (the club facilitators) have to approach companies in the area to promote the concept of waste minimisation to them. They are responsible for organising club meetings, which are usually held every two months. The club facilitators further organise guest speakers, training of the club members and facilitate discussion during the meetings on waste minimisation problems experienced and successes achieved. The duties of the club facilitators include disseminating the results of the club to other clubs and internationally.[4]

2.3.5 Barriers to Waste Minimisation

Waste minimisation is a new concept for many companies and therefore there are a number of barriers that have to be overcome before the waste minimisation programme can be implemented. Barriers are usually economic, technical, regulatory and cultural.[11]

a) Economic barriers

Economic barriers occur when the company does not have sufficient funds to implement a waste minimisation programme. In this case, management should investigate options that require low capital input such as improved housekeeping and better process control.[11]

b) Technical barriers

Technical barriers refer to the concerns about changes in product quality from process modifications resulting from a waste minimisation programme and the lack of information on waste minimisation techniques. These barriers can be overcome by carrying out pilot studies of the new process and then testing whether the new product will still satisfy the customers' specifications.[11]

c) Regulatory barriers

This is the easiest barrier to overcome since most regulatory bodies favour waste minimisation and its outcomes. Therefore there should be close co-operation between the company and the relevant authorities, and there ought to be few problems.[11]

d) Cultural barriers

Cultural barriers are caused by a lack of management commitment, poor communication, an inflexible organisational structure, and friction and resistance to change within the company. Improved management, employee training and the involvement of employees at all levels can overcome this barrier.[11]

The barriers that were identified through the Metal Finishing and Hammarsdale Waste Minimisation Clubs included a lack of time and a lack of resources.[24] A lack of time refers to the time to undertake audits, identify waste minimisation options and to implement and monitor the results. A lack of resources means that there is not a specific person dedicated to waste minimisation. Each employee has a number of responsibilities in a company and waste minimisation is usually low on the list of priorities. These barriers are often the result of many companies being strongly production-orientated and therefore not having the time and resources to implement a full waste minimisation programme.[24] They can be overcome by informing all employees of waste minimisation so that they understand the benefits that can be achieved and hopefully become more involved in the waste minimisation programme.

2.3.6 Drivers for Waste Minimisation

The main drivers for waste minimisation are:

- heightened awareness of pollution and environmental impact amongst society;
- the increasing numbers and scope of environmental regulations and laws;
- the rising cost of waste treatment and disposal; and
- increased awareness of the value of waste minimisation to a company's bottom line.[25]

The financial and environmental benefits of waste minimisation were presented in Sections 2.3.1 – 2.3.3. However, since 1996 environmental legislation in South Africa has been improved and contains sections on pollution prevention. The pollution liability of waste generating enterprises has increased considerably with increased fines, clean up orders, liability for environmental rehabilitation, and personal liability all being issues included in the new acts, policies, and guidelines.[26] Therefore the improved environmental legislation may be the greatest driver for many South African companies to consider implementing waste minimisation programmes, and is therefore discussed in detail below.

a) Environmental legislature and policy in South Africa

Legislation on environmental matters in South Africa has, in the past, been fragmented and ineffective and lacks clear identification of the responsibilities of the various governmental departments. Since 1996, a number of Acts, Policies and White Papers have been promulgated that deal with environmental management. The most important documents pertaining to waste management are:

- The Constitution of the Republic of South Africa (Act No. 108 of 1996),
- The National Water Act (No. 36 of 1998),
- The National Environmental Management Act (No. 107 of 1998), and
- The White Paper on Integrated Pollution and Waste Management for South Africa (2000).[11]

These documents are discussed in detail below, together with the Pietermaritzburg-Msunduzi Effluent Bylaws.

i) Constitution of the Republic of South Africa (Act No. 108 of 1996)

The New Constitution for South Africa was probably the greatest step towards improving environmental legislation. This is because the Constitution contains an 'Environmental Right' in The Bill of Rights (Chapter Two), which states:

"Everyone has the right –

a. to an environment that is not harmful to their health or well-being; and
b. to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –
    i. prevent pollution and ecological degradation;
    ii. promote conservation; and
    iii. secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development." [27]

The Constitution entrenches the right of every South African to an environment that is free of pollution and waste, which means that industries will have to consider their impact on the environment. This clause also states that the South African government will introduce legislation to ensure that the environment is protected. It therefore obligates the government to revise present legislation to ensure that this Right is upheld.

The Constitution further allows any member of public to enforce the Bill of Rights. This means that any South African can enforce the Environmental Right. The traditional stumbling block for a person wanting to take action on behalf of the environment has been that the person must have legal standing. This means that "a plaintiff must have a direct and personal interest in a matter over and above the ordinary member of the public to bring an action." [28] The constitution has overcome this obstacle with the 'Enforcement of Rights' clause, which states:

"Anyone listed in this section has the right to approach a competent court, alleging that a right in the Bill of Rights has been infringed or threatened, and the court may grant appropriate relief, including a declaration of rights. The persons who may approach a court are –

a. anyone acting in their own interest;
b. anyone acting on behalf of another person who cannot act in their own name;
c. anyone acting as a member of, or in the interest of, a group or class of persons;
d. anyone acting in the public interest; and
e. an association acting in the interest of its members." [28]

ii) The National Water Act (No. 36 of 1998)

The National Water Act has a section that deals with pollution prevention, and in particular, where the pollution impacts on a water resource. It states that "the person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken, the catchment management agency concerned may itself do whatever is necessary to prevent the pollution or to remedy its effects, and to recover all reasonable costs from the persons responsible for the pollution." [29] The catchment management agency is a body corporate responsible for managing water use in the area. The Department of Water Affairs and Forestry intends to delegate water resource management to the regional level and therefore involve local communities.[29]

iii) The National Environmental Management Act (No. 107 of 1998)

The National Environmental Management Act (NEMA) includes the three fields of environmental concern namely resource conservation and exploitation; pollution control and waste management; and land-use planning and development. The most important sections relating to waste are discussed below.

Principles:

The waste hierarchy is essentially referred to in this section. It states that waste must be avoided and where this is not altogether possible, it must be minimised, re-used or recycled, or otherwise disposed of in a responsible manner.[30]

The 'polluter pays' principle is also mentioned in this section. It states that the costs of remedying or controlling pollution and environmental degradation, as well as adverse health effects, must be paid for by those responsible for the pollution.[30] This means that any industry that causes damage to the environment will have to pay to have it remediated. This includes industries that are no longer at the polluted premises; they will still be responsible for the clean-up costs.

Protection of workers refusing to do environmentally hazardous work:

A worker is entitled to refuse any work if they believe that it would result in an imminent and serious threat to the environment. In this case, the employer may not take action against the worker, as long as the employer has been notified of the situation by the worker.[30]

Access to environmental information and protection of whistle-blowers:

This section allows for any person to have access to information held by the South African government that relates to threats to the environment.[11, 30] It also states that no person will be criminally liable, dismissed, disciplined or prejudiced for having disclosed any information of an environmental risk.[30]

Legal standing to enforce environmental laws:

This section is similar to the 'Enforcement of Rights' section of the Constitution, as it allows any person or group of persons to have legal standing if they allege that there is a breach of any law relating to the protection of the environment. In the event of the prosecution being successful, the accused may be required to pay the private prosecutor's legal costs.[11, 30]

Director liability:

If the director, or a person who was the director of a company at the time at which a company committed a breach of the environmental law, is found not to have taken all reasonable steps to prevent the pollution from occurring, they can be held legally accountable in a private capacity. There is therefore an obligation on the part of a director of a company to be aware of all aspects relating to the production of waste on site.[11, 30]

iv) The White Paper on Integrated Pollution and Waste Management for South Africa (2000)

The most important document relating to waste minimisation is the White Paper on Integrated Pollution and Waste Management for South Africa. It recognises that the existing legislation regarding pollution and waste is fragmented and uncoordinated and that there are insufficient resources to implement and monitor the legislation. This White Paper strives to eliminate the current problems and will result in a review of all existing legislation and the preparation of a single piece of legislation, which will deal with all waste and pollution matters.[31] A further important feature of the White Paper is that pollution is the responsibility of the polluter from the 'cradle to grave'. This covers the generation, collection, transportation, treatment and final disposal of the waste.[28]

The White Paper on Integrated Pollution and Waste Management focuses on a shift from pollution control to pollution prevention and waste minimisation. Pollution prevention is believed to be the most effective way of protecting South Africa's people and the environment. The government aims to eliminate the causes of pollution, rather than treating the symptoms. This White Paper also stresses the need to make pollution prevention a way of life for all sectors and individuals.[31]

National government is not responsible for monitoring and controlling industrial waste. This is the responsibility of local government, which in the case of Pietermaritzburg, is the Msunduzi Municipality. They have bylaws that control waste and pollution. However, the Pietermaritzburg industrial effluent treatment works (Darvill Waste Water Works) is managed by Umgeni Water who is the local water board. They are therefore primarily responsible for ensuring that industries obey the bylaws. The industrial effluent bylaws for Pietermaritzburg are discussed below.

v) Msunduzi Municipality Industrial Effluent Bylaws

The Msunduzi Municipality Industrial Effluent Bylaws state that any industry under the jurisdiction of the Msunduzi Municipality may not discharge any industrial effluent anywhere other than a sewer. Also, no person may discharge any industrial effluent into a sewer without having obtained written permission from the City Engineer, which is obtained through an application to the City Engineer. Accompanying the application, a notice of intent must be published in a newspaper designated by the City Engineer. Interested parties can inspect the application for a period of fourteen days after the publication of the notice. The permission that is granted is personal to the applicant, and terminates two years from the date of grant.[32]

If an industry does not obey the conditions stipulated in the permission, the City Engineer may, subject to giving fourteen days' notice to the applicant, withdraw the permission to discharge industrial effluent to the sewer. The City Engineer may then seal the drainage connection from the premises to the sewer and refuse to accept any further industrial effluent from the premises.[32]

The Bylaws also state that all industrial effluent that passes through the industrial effluent treatment works must be within the specifications set out in Table 2.5. Every industry must prevent the discharge of effluent that is prohibited by these specifications.[32]

If any industrial effluent that is discharged into the sewer damages any component of the industrial effluent treatment works, the responsible party shall be liable for the costs of the necessary repairs to the sewer and industrial effluent treatment works. If any person contravenes the Industrial Effluent Bylaws, they will be liable on conviction for a fine not exceeding R500 and/or imprisonment for a period not exceeding six months. If there is a second contravention, they will be liable on conviction for a fine not exceeding R1000 and/or imprisonment for a period not exceeding one year.[32]

As discussed, there are a number of regulations that Pietermaritzburg industries must abide by. However, if there is an infringement of the effluent specifications, the fine that is given is almost negligible. Therefore it does not pressurise industries into obeying the regulations.

2.3.7 Success of United Kingdom Waste Minimisation Clubs

There is no standard means of reporting the results of waste minimisation clubs, and therefore it is difficult to directly compare many of the more recent United Kingdom waste minimisation projects with the early demonstration projects, for example the Aire and Calder project (Section 2.3.2).[33] However, according to Read[33] the waste minimisation clubs in the United Kingdom have demonstrated that significant reductions in waste can be made, especially solid and liquid wastes, as well as improved resource efficiency, especially for water. However Read claims that not all clubs have met their objectives, and that cost savings rather than environmental improvement remain the key motivating influence for companies' waste minimisation activities.[33]

Table 2.5: Specifications for discharge of industrial effluent in Pietermaritzburg [34]

Description	Units	Limit
Temperature	°C	45
pH		> 6.5 & < 9.5
Electrical conductivity	mS/m	400
Total dissolved solids	mg/L	5000
Solids in suspension	mg/L	400
Mineral oils and grease	mg/L	50
Soap oil and grease	mg/L	250
Sulfates in solution (expressed as SO_4)	mg/L	250
Total sulfides (expressed as S)	mg/L	25
Soluble reactive phosphate (expressed as P)	mg/L	20
Free and saline ammonia (expressed as N)	mg/L	80
Total Kjeldahl nitrogen	mg/L	100
Chloride (expressed as Cl)	mg/L	not specified
Fluoride (expressed as F)	mg/L	5
Hydrocyanic acid and cyanides (expressed as HCN)	mg/L	10
Sodium (expressed as Na)	mg/L	not specified
Copper (expressed as Cu)	mg/L	5
Zinc (expressed as Zn)	mg/L	5
Lead (expressed as Pb)	mg/L	5
Cadmium (expressed as Cd)	mg/L	1
Total chromium (expressed as Cr(III))	mg/L	25
Chromium(VI) (expressed as Cr(VI))	mg/L	0
Mercury (expressed as Hg)	mg/L	1
Arsenic (expressed as As)	mg/L	1
Selenium (expressed as Se)	mg/L	1
Nickel (expressed as Ni)	mg/L	5
Boron (expressed as B)	mg/L	5
Cobalt (expressed as Co)	mg/L	5
Molybdenum (expressed as Mo)	mg/L	1

2.4 Coil Coating

2.4.1 What is Coil Coating?

Coil coating is a highly automated, continuous process where a coiled sheet of steel or aluminium is cleaned, pretreated and receives a coating of paint or plastic laminate. The coated metal can then be fabricated into the finished product by the end-user.[10] Coil coating was developed in the 1930's as part of the process to produce Venetian blinds. It has since become an integral part of the manufacture of many steel and aluminium products so that today approximately five million tons of steel and aluminium are coated annually.[35] In general, process line speeds vary between 30-160 m/min and output varies between 4.5 tons/hour and 24 tons/hour for aluminium substrate.[36]

2.4.2 Typical End Uses of Coated Coil

Aluminium coated coil is predominantly used for building products, *e.g.* door and window frames, building sheet, gutters and downspouts, roof decking, and patio covers and supports. The transportation industry currently ranks as the second largest users of aluminium coated coil. The aluminium is fabricated into bus and train ceilings, highway guard rails, and interior components.[35]

The fastest growing area where coated coil is used is the fabrication of coated metal into a variety of end-use applications. These include recreational equipment (boats, exercise equipment), residential and commercial furniture (cabinets, chairs, desks, lockers), farm and garden equipment (feed troughs, tools, mowers), packaging (bulk containers, beverage cans, drums and film canisters), and appliances (air conditioners, dishwashers, refrigerators and freezers, washing machines, hair driers, can openers, and vacuum cleaners).[35]

2.4.3 The Coil Coating Process

The coil coating process involves a number of operations. These are shown in Figure 2.7 and described below.

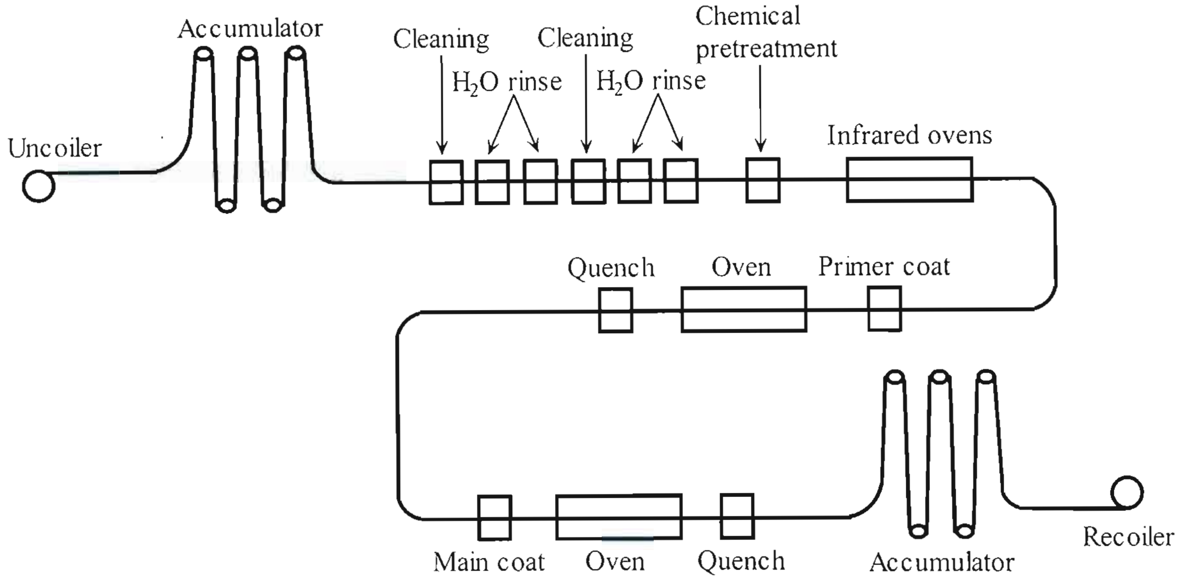


Figure 2.7: Simplified diagram of the coil coating process

a) Step 1: Coil entry

The coils that are used come from the mill where they have been rolled to a specified width and thickness. The mill finish coil is placed onto the decoiler that unwinds the coil for entry into the coating line. The head of the new coil is spliced (joined) onto the tail of the running coil to create a continuous strip. This is impossible to achieve when the line is running at full speed, as there is not enough time for the splice to be made. This problem is overcome by using an accumulation tower. When the splice has to be made, the accumulation tower carriage moves upwards which results in the tail of the running coil slowing down so that the new coil can be spliced onto it. The rest of the line can proceed at the same speed, which means that the line does not have to be slowed down each time a new coil is introduced. Therefore the accumulator facilitates continuous processing. Once the splice has been made, the carriage is lowered to its normal running position.[35]

b) Step 2: Cleaner / wet section

The strip moves from the entry accumulator to a series of cleaning and rinse tanks, usually referred to as the wet section. The cleaner tanks have a number of spray bars which spray the cleaning solution onto both sides of the strip. After cleaning, the metal passes through a few water rinses to ensure that all the residual cleaning solution has been removed. The rinse tanks are designed in the same way as the cleaner tanks, so that the rinsing water is sprayed onto both sides of the strip. Each tank exit has a set of squeegee rolls that prevent solution from transferring to the next tank. At the end of the wet section, the strip is air-dried by an air knife.

Cleaning of the metal is a vital step in the coil coating process since paint adhesion problems can occur if the metal is not cleaned properly.[35]

c) Step 3: Chemical pretreatment

The chemical pretreatment provides a protective layer to the metal substrate. It reacts with the metal surface to produce a surface with improved paint adhesion properties. It further protects the metal from corrosion.

The chemical pretreatment can be applied to the strip in two ways: the first method is to use a chemical roller coater and the second method is to pass the strip through a spray or dip tank. The chemical coater consists of a series of rollers that support the strip and apply a thin film of chemical to the strip. In this way, there is no waste produced from the chemical coater, making this the most environmentally safe method of applying the chemical pretreatment. If the chemical pretreatment is applied by using a spray or dip tank, the metal surface has to be rinsed after the application of the pretreatment to terminate the reaction and remove any unwanted reaction products from the substrate surface.[37]

Once the strip exits the chemical pretreatment, it proceeds directly into a drying oven where the chemical pretreatment is dried onto the metal surface. The oven also removes any moisture from the strip so that the paint can be applied.[35]

d) Step 4: Application of paint

The strip moves through the paint roller coater where it is coated on both sides simultaneously. The coater consists of a series of rollers that support the strip as well as a pick-up roller and a rubber applicator roller which apply the paint to the strip.[35] The coater can apply different coatings to each side of the strip simultaneously.[38]

e) Step 5: Curing the paint

After the paint has been applied, the strip is dried in the curing ovens. The oven temperature is set and monitored to achieve a peak metal temperature (PMT) which is specified by the coating supplier for a specific paint and line speed. The curing ovens can reach temperatures of 600 - 800°C.[35] The paint fumes which result from the curing process are incinerated to produce energy which can be used in other areas of the plant.

Steps 4 and 5 describe a process that consists of the application of a single coat finish. If the line is a tandem line (two coat coating line), then a primer is applied before the finish coat. The primer coat is applied in the same way as the finish coat in that it is roller-applied and then cured in an oven.

f) Step 6: Cooling the strip

The painted strip moves from the curing ovens to a cooling section so that it can be cooled before recoiling. The cooling section usually consists of a water quench and an air knife. The water quench sprays water onto both sides of the strip. It then passes through the air knife that dries the painted surface.[35]

g) Step 7: Recoiling the strip

When the coated strip exits the cooling section, it moves directly into the exit accumulation tower and to a recoiling unit. When the strip needs to be cut (for the end of a coil), the accumulator carriage moves upwards, providing enough time for the cut to be made. Once the cut has been made, the accumulator returns to its normal running position and the completed coil is removed from the recoiler. A sample is taken and the coil is sent for packaging.[35]

There are two types of coil coating operations:

- **Toll coater**

  This is a service coater that coats to the needs and specifications of its customers. The bare metal coils come from a supplier and the coated coils are delivered to the customer who forms the end products.

- **Captive coater**

  This coater is part of a manufacturing process. A company will mill the metal, coat the coils and then form the end products.[39]

2.4.4 The Benefits of Coated Coil

Coil coating is claimed to be the most environmentally safe, energy-efficient and cost-effective way to apply paint to metal.[38] It also results in a high-quality product. This is because prepainted metal is cleaned, treated, and painted while flat rather than after fabrication, resulting in a more uniform finished product.[38]

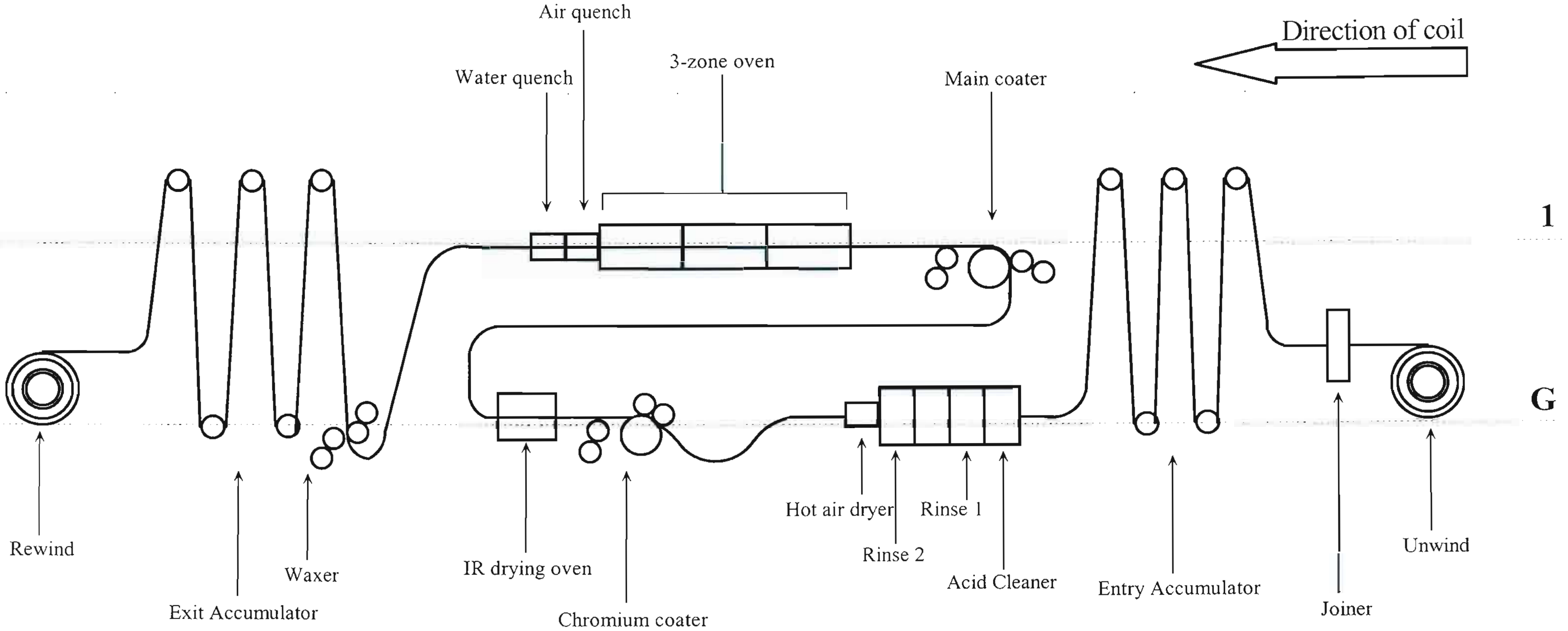
2.5 Case Study: Two Coil Coating Lines

The case study in this project was conducted at an aluminium coil coating department of a captive coating company situated in Pietermaritzburg. There are two coating lines in operation: an older one that runs at between 70 and 100 metres per minute (Line 1) and a new line running at 100 metres per minute (Line 2). The two lines coat aluminium coils for beverage can lids (approximately 70% of production), for household appliances, and for architectural uses (gutters and corrugated roofing). Both lines operate 24 hours a day and seven days a week. About 600 tons of coated coil is produced per week, of which half is exported.[40]

2.5.1 Coil Coating Line 1 (CCL1)

Coil coating line 1 is the older line of the two. It was imported from Kingston in Canada eleven years ago where it had already been used for 25 years. This line is approximately 1 200 metres of strip length. It is used mostly for coating aluminium for household appliances and architectural products.

Line 1 consists of a cleaner / wet section followed by chemical pretreatment, coating, curing and waxing sections. The salient features of these sections are discussed below and are shown in Figure 2.8.



Key:
1: First floor
G: Ground floor

Not drawn to scale

Figure 2.8: Diagram of Coil Coating Line 1 (CCL1)

a) Wet section

Figure 2.9 is a process flow diagram for the wet and pretreatment section of CCL1, showing all input and output streams. The volumes in parentheses are the volumes of the respective tanks.

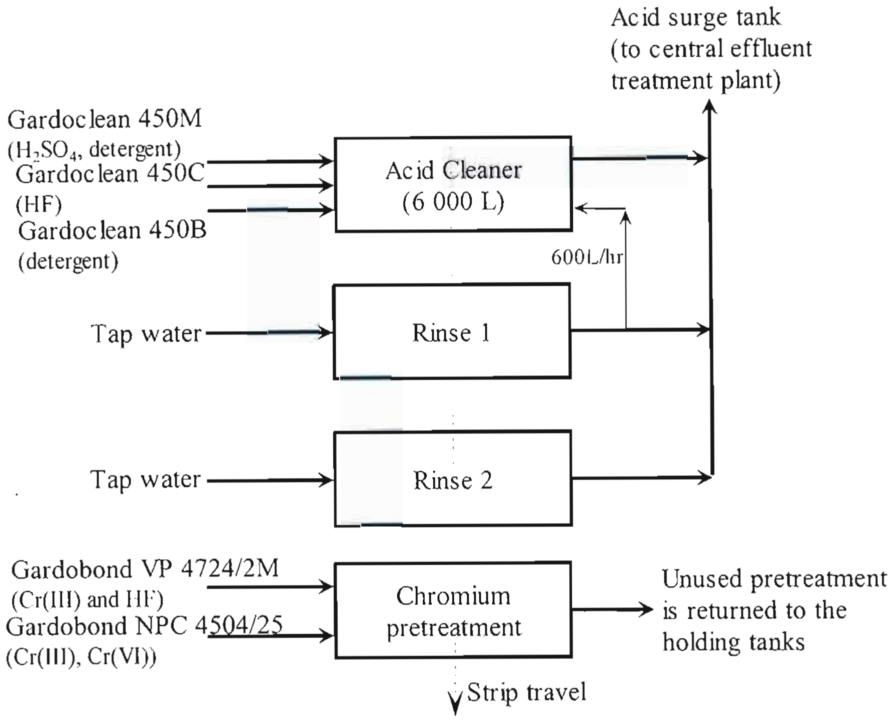


Figure 2.9: Diagram of the wet and pretreatment sections of Coil Coating Line 1 (CCL1)

The wet section consists of an Acid Cleaner and two tap water rinses. The chemicals used in the Acid Cleaner are sulfuric acid with a detergent (in Gardoclean 450M) and hydrofluoric acid (in Gardoclean 450C). If the coils are dirtier than usual, Gardoclean 450B is added to the Acid Cleaner tank. Gardoclean 450B contains strong detergents and is therefore a more effective cleaner than Gardoclean 450M.

Rinse water from the first rinse tank can be used to top up the Acid Cleaner tank if necessary (see Figure 2.9). Between these two rinse tanks is an empty tank that was previously used for the acid solution when the wet section included an alkaline degreasing process. Each tank is about five metres in length.

The strip passes through all these tanks horizontally with the liquid sprayed on the top and bottom of the strip. After each tank, excess liquid is removed from the strip by a pair of polyurethane rollers to minimise dragout of chemicals. All effluent from these tanks is sent to the company's central effluent plant. There, the effluent from the acid tank is treated with caustic soda and a flocculant to raise the pH and settle any heavy metals.

The strip next passes through a hot air dryer, where the air is heated by the energy produced from the incineration of the paint fumes.

b) Chemical pretreatment section

After being cleaned and dried, the aluminium is pretreated with a chromium solution, Gardobond VP 4724/2M (chromium(III) and hydrofluoric acid) or Gardobond NPC 4504/25 (chromium(III) and chromium(VI)). The chromium solution is pumped up from a holding tank and is fed onto a solid roller. It is then transferred onto a polyurethane roller that applies the chromium onto the aluminium strip. Chromium pretreatment can be applied simultaneously to both sides of the strip. The chromium is dried onto the aluminium in an infrared oven. Unused chromium is filtered and returned to the holding tank.

c) Coating section

The aluminium coil exits the infrared oven and passes up to the first floor where it is coated with paint (PVDF (polyvinylidene fluoride) or polyester) or lacquer (epoxy or organosol). The paint is applied by using two rollers and is applied onto both sides of the sheet.

For architectural products the bare aluminium first receives chromium pretreatment and a layer of primer. The primed coil is then passed through the line a second time to receive its main paint coat. On the second pass the strip passes through the water rinse tanks to clean any dirt off the coated aluminium surface.

d) Curing section

The coating is cured by passing it through a three-zone oven, which is 46 metres long and capable of temperatures up to 300°C. The sheet is suspended in the oven so the coating can dry on both sides. The strip is first cooled by an air quench (60°C) and then a spray-mist water quench (ambient temperature). The aluminium strip has to be cooled down slowly otherwise it will buckle.

e) Waxing section

The coiled sheet moves down to the ground floor where a layer of lanolin wax (60°C) can be applied to the surface of the beverage can aluminium. This acts as a lubricant in the fabrication process at the can maker and is only applied on request from the can maker. Thereafter, the sheet passes through an air dryer at ambient temperature followed by an exit accumulator. The coil is rewound and sent for packaging.

2.5.2 Coil Coating Line 2 (CCL2)

Coil coating line 2 was constructed by the coil coating company about two years ago. It is fully automated, utilising spray application chromium pretreatment. This process results in non-reacted chromium being rinsed off whereas in CCL1 the chromium pretreatment is dried onto the aluminium. Other differences are that CCL2 has an in-line tension leveller to alleviate metal tension in the strip, and it is a longer line (~ 1500 m strip length) therefore coating coil for larger orders. The automation has led to advances in material handling with robotics employed for placement of the coils and removal of damaged outer edges, whereas on CCL1 this operation is performed by lift trucks and human operators. CCL2 produces coated aluminium for the beverage can industry.

Figure 2.10 is a simplified diagram of CCL2. The cleaner / wet, chemical pretreatment, coating, curing and waxing sections are discussed below.

a) Wet section

Figure 2.11 is a process flow diagram for the wet and pretreatment section of CCL2, showing all input and output streams. The volumes in parentheses are the volumes of the respective tanks.

The wet section on CCL2 consists of an alkali degreaser tank, an acid cleaner tank and three water rinse tanks. The coil first passes into the alkali degreaser tank (Stage 1) that contains potassium hydroxide and detergent (in Gardoclean S5160), followed by a water rinse (Stage 2) and drying by an air knife (60°C). The strip then travels through the entry accumulator on to the tension leveler. The tension leveler increases the length of the strip by about 0.3 - 0.5%.

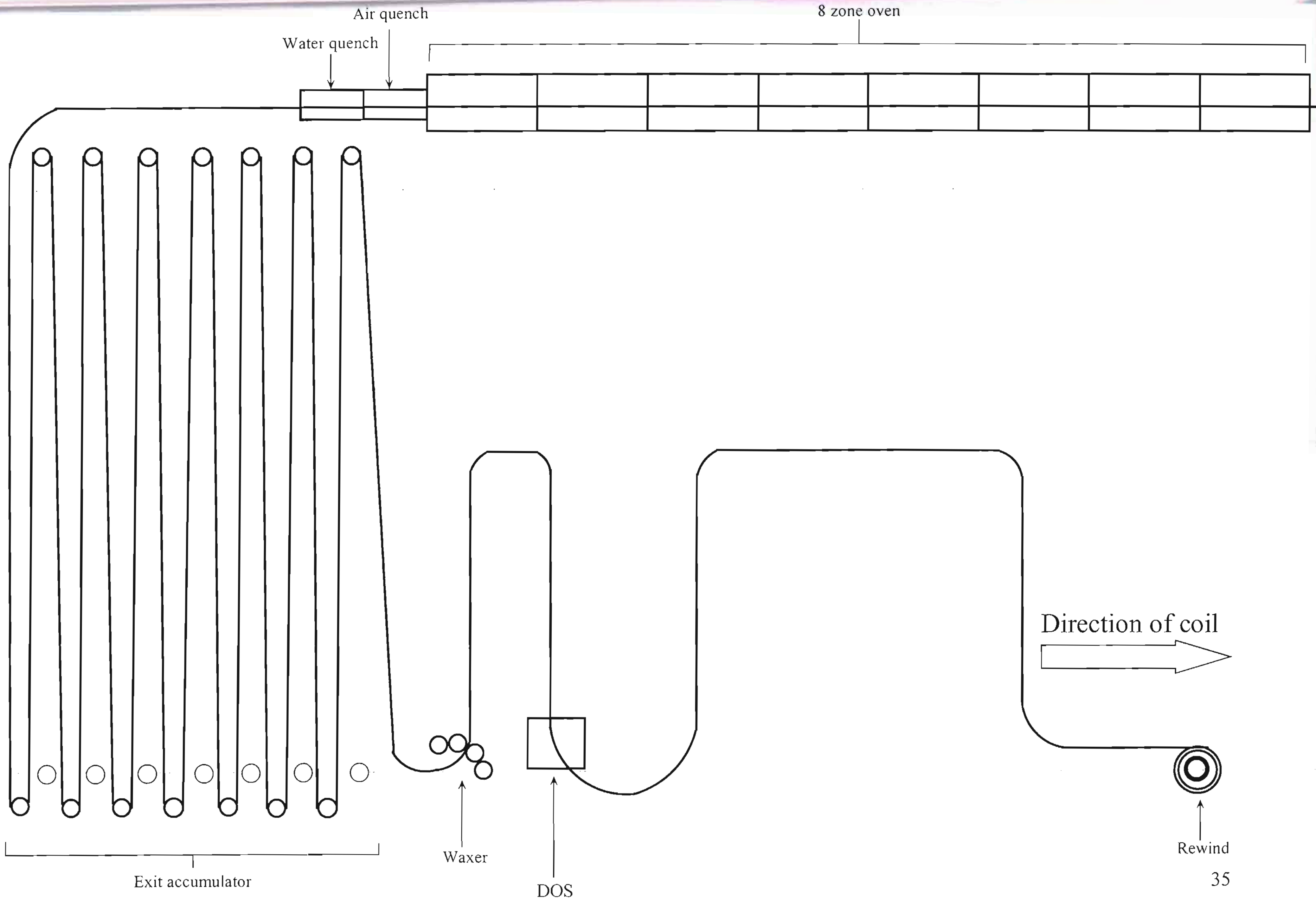
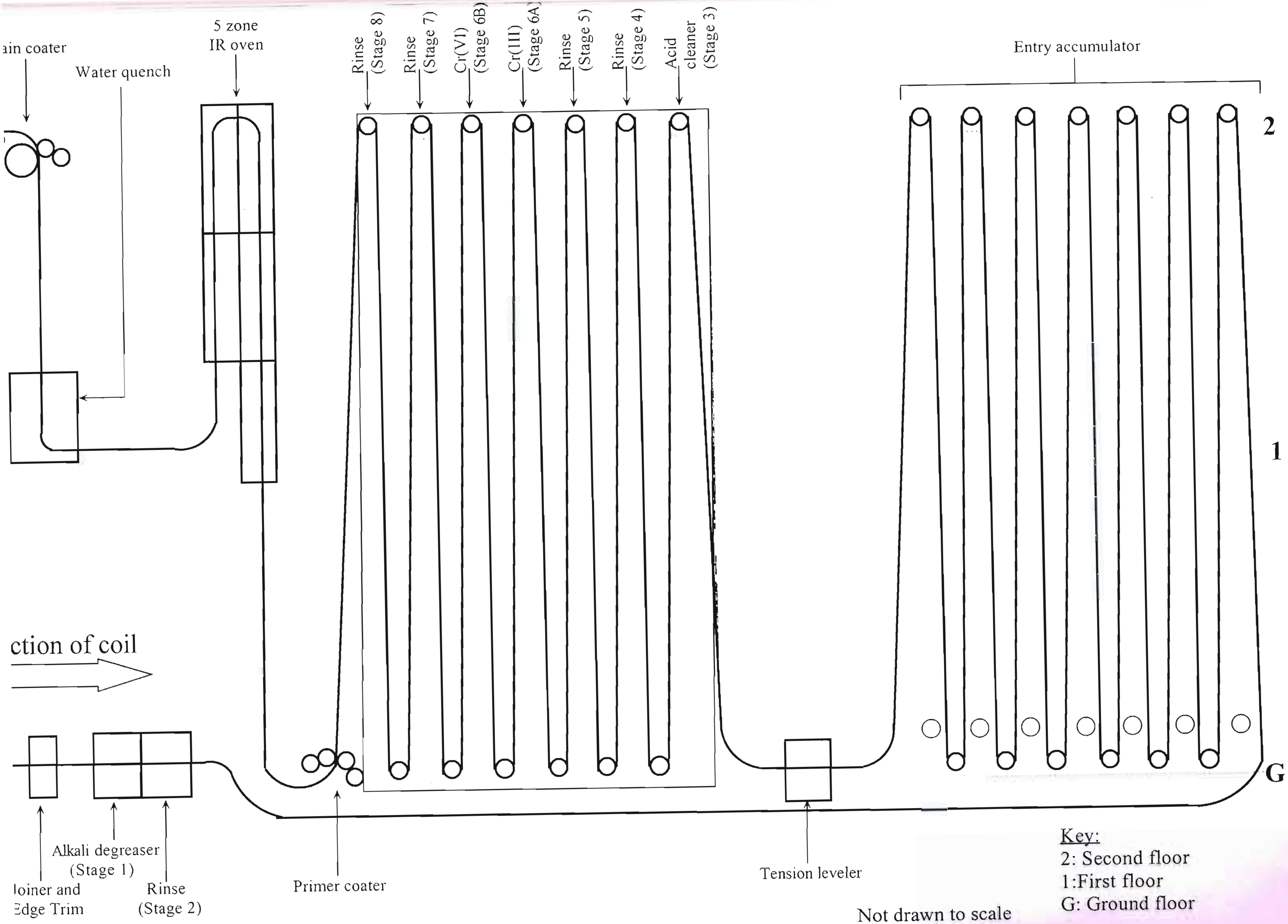


Figure 2.10: Diagram of Coil Coating Line 2 (CCL2)



Not drawn to scale

Key:
2: Second floor
1:First floor
G: Ground floor

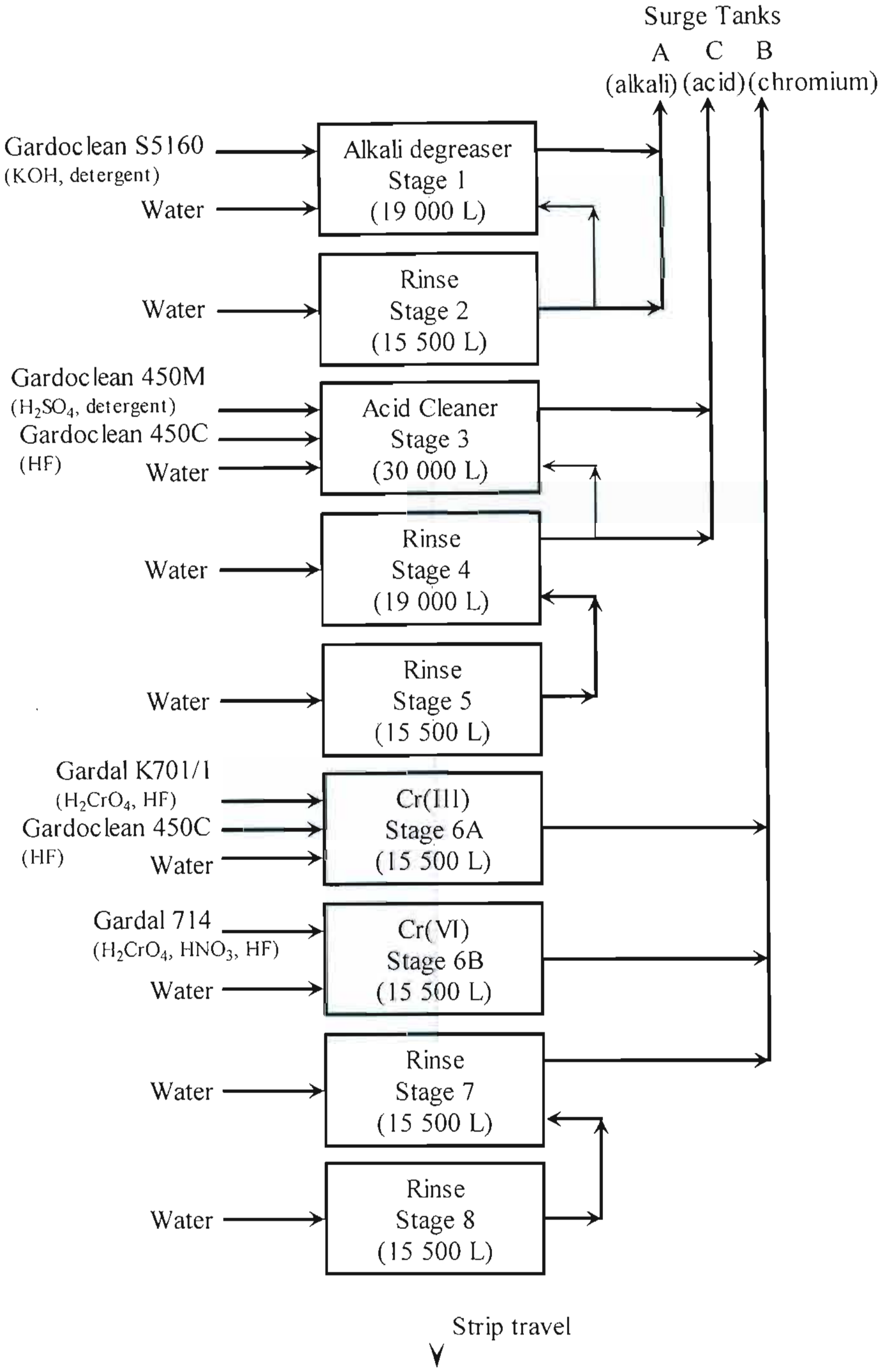


Figure 2.11: Diagram of the wet and pretreatment sections of Coil Coating Line 2 (CCL2)

The acid cleaning section is a vertical spray operation with spray bars located up the entire height of the strip. The spray configuration allows for the simultaneous treatment of both sides of the strip. The acid cleaner solution (Stage 3) is the same as that used in CCL1 (Gardoclean 450M and Gardoclean 450C). This is followed by two water rinses (Stages 4 and 5).

The water rinses in the wet section have overflows which flow into the preceding tank (counter-current rinse system). These overflows were designed to run continuously while the line was running. However, they are currently used infrequently and the process tanks and rinse tanks are topped up using tap water.

b) Chemical pretreatment section

The chromium pretreatment is also a vertical spray operation. Gardal 714 (chromic acid, nitric acid and hydrofluoric acid) is used in Stage 6B for architectural panels, which dries onto the aluminium as chromium(VI). Stage 6A contains Gardal K701/1 (chromic acid and hydrofluoric acid) which is used for beverage cans, and dries onto the aluminium as chromium(III). Chromium(VI) is a recognised carcinogen, and therefore cannot be used for food-grade aluminium.[41] CCL2 produces coated aluminium for beverage cans and therefore Stage 6A is used mostly. The chromium pretreatment is followed by another two water rinses (Stages 7 and 8) where any excess chromium is washed off. Each stage has a pair of squeegee rollers at either end of the tank to prevent dragout.

The effluent from the wet and chemical pretreatment sections of CCL2 flows to three surge tanks situated under the Stages 1 and 2 tanks. The three surge tanks are a chromium tank (30 000 L), an acid tank (50 000 L) and an alkaline tank (80 000 L). A private company is contracted to treat the chromium effluent. The chromium effluent is treated with sodium metabisulfite ($Na_2S_2O_5$) in the chromium surge tank at a pH of 2 – 2.5 to reduce the chromium(VI) to chromium(III) (see Equations 2.2 and 2.3).

$$S_2O_5^{2-} + H_2O \rightarrow 2HSO_3^- \qquad \text{\underline{Equation 2.2}}$$

$$3HSO_3^- + 2CrO_3 + 6H^+ \rightarrow 3HSO_4^- + 2Cr^{3+} + 3H_2O \qquad \text{\underline{Equation 2.3}}$$

This solution is then pumped outside the building to a clarifier, where caustic soda and a flocculant are added to increase the pH and to settle the chromium(III) and other heavy metals. A waste disposal company removes the sludge and the liquid is sent to the sewer.

The acid effluent was initially treated by the coil coating company's central effluent plant. However, chromium(VI) leaks from the chromium pretreatment tank (Stage 6A) into the acid process and rinse tanks (Stages 3 – 5). This leak occurs at the spray bars where the chromium pretreatment is sprayed onto the aluminium surface. The leaked chromium solution flows down onto the lids of the acid process and rinse tanks (Stages 3 – 5) where it slowly leaks into the tanks and contaminates the acid process and rinse tank solutions with chromium(VI). Due to this contamination of the acid effluent stream, the acid effluent is now treated by the private company along with the chromium effluent. The acid effluent is pumped from the acid surge tank into the chromium surge tank prior to treatment. All of the alkaline effluent is sent to the coil coating company's central effluent plant for treatment.

The chromium effluent plant was designed and built to treat 140 mg/L chromium(VI) but currently receives in excess of 1100 mg/L. In addition, it now treats both the chromium and acid effluent. The size of the original chromium clarifier is thus insufficient to cope with the resultant effluent load, and the time required to settle the chromium(III) is longer than practical. This causes a permanent backlog in effluent treatment. This problem has been partially addressed by connecting the two clarifiers in series.

c) Coating section

i) Architectural sheet

After the cleaning and pretreatment, the coil can be coated with a primer if desired. The primer is applied with a two-roller system and can be applied onto both sides of the aluminium. The coil then passes vertically through a five-zone infrared oven where the primer is cured. The strip passes upwards through three zones and then back downwards through two zones. When it leaves the oven at 230°C, it passes through a spray-mist water quench at ambient temperature. The quench water is then used to top-up the rinse tanks in the wet section. After passing through an air dryer, the strip is conveyed up to the first floor where it receives its main coat of paint or lacquer which can be applied to both sides of the strip.

ii) Lacquered sheet (beverage cans)

This sheet is similarly cleaned and pretreated, but no primer is applied. The lacquer is then applied with a two-roller system at the main coater.

d) Curing section

Once the main coat has been applied, it is cured in an eight-zone oven. In this oven each zone has a partition separating it from the adjacent zones. In this way, the temperature of each zone can be accurately controlled. Upon exiting the oven the strip is cooled with an air quench at

60□C followed by a water quench at ambient temperature. Rollers are positioned at the end of the water quench to minimise the water carried through to the next stage. The strip is then dried by air blown through an air knife.

e) Waxing section

The aluminium strip moves back down to the ground floor where it passes through the exit accumulator. While the strip is passing through the accumulator it is manually inspected for any flaws. A red tag is placed to indicate a section where a flaw exists so that it can later be removed. It then passes on to the waxer where a layer of wax (60□C) can be applied to both sides of the strip. The wax is applied using a two-roller system.

Alternatively there is a final unit operation before the cutting of the strip which is the application of dioctyl sebasate (DOS). This organic oil prevents the strip from being scratched when it is wound and unwound. DOS is only applied to aluminium that has received no coating. The aluminium is first cleaned of rolling oil, and is then covered with DOS. The DOS is sprayed on in a fine mist to produce a coating of 20 mg/m^2. The DOS can be washed off with mild soap and water (food packaging). The strip passes through a cold air knife before it is finally rewound into a coil.

2.6 Conclusions

Relevant literature was reviewed on waste minimisation, waste minimisation clubs, and the process of coil coating. Waste minimisation involves systematically reducing or eliminating industrial waste at source.[4] The literature revealed that waste minimisation is achieved through the implementation of a waste minimisation programme. This is a process of forming a project team, conducting a waste audit and implementing the opportunities identified.[11] This review identified a number of techniques that can be used when identifying opportunities for waste minimisation: process flow diagrams, performing a scoping audit, mass balances, determining the true cost of each effluent stream, monitoring and targeting, and statistical process control.[6]

The literature revealed that waste minimisation is often achieved through the creation of waste minimisation clubs. A number of clubs have been run in Europe and South Africa and all achieved good financial and environmental savings.[11]

For a waste minimisation programme to succeed in a company, the barriers must be identified. According to literature, the most frequent barriers encountered when implementing a waste minimisation programme in a company are economic, technical, regulatory and cultural.[11] Other barriers that were identified by the South African waste minimisation clubs were a lack of time and resources, which are a result of the companies being strongly production-driven.[24] These barriers can usually be overcome by educating the management and other employees about waste minimisation.

The drivers for waste minimisation are greater profitability and a decreased environmental impact. Another driver is the strict environmental legislation that is being developed in South Africa. This was reviewed in terms of the Constitution of South Africa (Act No. 108 of 1996), the National Water Act (No. 36 of 1998), the National Environmental Management Act (No. 107 of 1998) and the White Paper on Integrated Pollution and Waste Management for South Africa (2000). Local legislation, in terms of the effluent bylaws of the Msunduzi Municipality, was also reviewed.

This study includes a waste minimisation audit conducted at two aluminium coil coating lines in Pietermaritzburg. These continuous processes were described in terms of their cleaning, chemical pretreatment, coating, curing and waxing sections. This review also highlighted the effluent problems experienced on Coil Coating Line 2 (CCL2) of the company. Both the effluent chromium concentration and volume exceed the design specifications of the effluent treatment plant with the result that there is a permanent backlog in effluent treatment. The identification of waste minimisation opportunities on this plant could help solve this problem and achieve financial savings.

CHAPTER 3

Materials and Methods

In this chapter the materials and methods that were used to gather and analyse the data for this study are discussed. There are three main sections: firstly, the method for the data collection from the Pietermaritzburg Waste Minimisation Club is described in Section 3.1. Section 3.2 discusses the materials and methods used in the data collection at the two coil coating lines. The methods used to analyse the coil coating data are discussed in Section 3.3.

3.1 Data Collection from the Pietermaritzburg Waste Minimisation Club

The data collected from the Pietermaritzburg Waste Minimisation Club members were obtained through questionnaires, which the members completed. Two questionnaires were completed during the year: one in April 2001 (Appendix A.1) and the second in December 2001 (Appendix A.2). The questionnaires were designed based on the experiences of Barclay and Buckley[11] in the Durban Metal Finishing and the Hammarsdale Waste Minimisation Clubs. The first questionnaire was designed to gain an understanding of what the members would like to gain from implementing a waste minimisation programme in their companies and to identify the barriers and drivers to waste minimisation. The second questionnaire was compiled to gauge the views of the club members on the progress of the waste minimisation club and waste minimisation in general.

3.2 Data Collection at two Coil Coating Lines

Data needed for the waste minimisation audits at the coil coating lines included the flow rates, compositions and costs of all input and output streams to the respective wet and pretreatment sections. It was decided that data would be collected over a three-month period to obtain a representative sample.

Information about the coil coating lines was gathered through interviews and correspondence with employees at the coil coating department. From this information it was determined which data the operators were already collecting, and which data would have to be collected during the three-month period (July to September 2001). The data that were already being collected were gathered from the operators throughout the three-month period.

3.2.1 Data Collected through Measurement

a) Sampling

For data (composition, temperature, conductivity and pH) that needed to be collected through measurement, samples of the respective input and output streams were taken at 08h00 and 14h00 every weekday during the three-month period. For the process and rinse tanks, the samples were taken from the sample taps of the tanks. The effluent treatment plant operators collected the effluent samples at the same times by dropping a container into the surge tanks and sampling from the top of the respective tanks. Since the tanks were well mixed, it was assumed that the composition of the tanks was the same as their output streams.

b) Analytical tests

Table 3.1 shows the analytical tests conducted on the various streams (see Figures 2.9 and 2.11). The tests are described in more detail below.

i) Temperature, pH and conductivity

The temperature was recorded using the thermometers located in the process and rinse tanks. The coefficient of variance in the temperature measurements (in □C) was typically less than 20%. The pH was measured using Universal pH Indicator strips (Merck), and the conductivity was measured using a hand-held conductivity meter (Hanna Instruments, DiST WP 4). The coefficient of variance in the conductivity measurements (in mS) was typically less than 40%.

Table 3.1: Analytical tests carried out on the daily samples

Output stream from:	Tests
Coil Coating Line 1 (CCL1)	
Acid Cleaner	temperature
Rinse 1	temperature, fluoride
Rinse 2	temperature, fluoride
Acid surge tank	pH, conductivity, total acid, fluoride
Coil Coating Line 2 (CCL2)	
Acid Rinse (Stage 4)	fluoride
Chromium Rinse (Stage 7)	fluoride, chromium(VI)
Surge tank A (alkali)	pH, conductivity, total alkali
Surge tank B (chromium)	pH, conductivity, total acid, fluoride
Surge tank C (acid)	pH, conductivity, total acid, chromium(VI), fluoride

ii) Titrations

The total acid, total alkali and chromium(VI) concentrations were determined by titration. Each titration was repeated until two concordant results (within 0.10 mL of each other) were obtained. For some of the titrations where the sample concentrations were low, the test solutions were diluted to reduce the error associated with titrating small volumes. Titration volumes of between 10 mL and 100 mL were used. The titration methods used are described below and detailed analytical methods are included in Appendix B.

Total acid titration

The total acid is the total concentration of the H^+ ions, and hence it includes both strong and weak acids. To determine the concentration of total acid, the sample was titrated with a sodium hydroxide test solution (see part (c)), using phenolphthalein as the indicator. The reaction that occurs is as follows:

$$H^+ + NaOH \rightarrow Na^+ + H_2O \qquad \text{Equation 3.1}$$

Total alkali titration

The total alkali concentration is the concentration of both the strong and weak bases. It was determined by titrating the sample with a sulfuric acid test solution (see part (c)) with bromocresol green as the indicator. The hydroxyl ions react with sulfuric acid as follows:

$$2OH^- + H_2SO_4 \rightarrow SO_4^{2-} + 2H_2O \qquad \text{Equation 3.2}$$

Chromium(VI) titration

The chromium(VI) titration gives the concentration of chromium(VI) only. Sulfuric acid was added to acidify the sample as the reaction can only occur in an acidic medium (H^+ ions are required). Excess potassium iodide was then added. As a result of the conversion of iodide to iodine (I_2), a dark red-brown solution resulted:

$$2\,Cr^{6+} + 6\,I^{-} \rightarrow 2\,Cr^{3+} + 3\,I_2 \qquad \underline{\text{Equation 3.3}}$$

The resultant sample was then titrated with a sodium thiosulfate ($Na_2S_2O_3$) test solution (see part (c)) until the solution colour lightened to a pale yellow. A starch indicator, thyodene, was then added to give a blackish-blue colouration as a result of the presence of iodine. The starch indicator cannot be added until the endpoint is near since high concentrations of iodine can cause the decomposition of starch. The titration was continued until the dark colour disappeared:

$$3\,I_2 + 6\,S_2O_3^{\,2-} \rightarrow 3\,S_4O_6^{\,2-} + 6\,I^{-} \qquad \underline{\text{Equation 3.4}}$$

Hence by calculating the moles of iodine consumed in Equation 3.4 (and formed in Equation 3.3), the concentration of chromium(VI) could be determined.

iii) Free fluoride content

The free fluoride content is the concentration of fluoride ions in the sample. It was measured using a fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA). A total ionic strength adjustment buffer (TISAB) was added to the samples to adjust all solutions to the same ionic strength. This allows the concentration of the fluoride, rather than its activity, to be measured.[44] Each day a set of fluoride calibration standard solutions were also measured using the fluoride ion selective electrode so that the concentrations of the samples could be calculated (see Appendix B).

c) Test solutions

The test solutions used for the titrations were provided by the chemical suppliers. They were standardised before they were used, using the titration methods described below. These titrations were repeated until three concordant results were obtained.

i) Sodium hydroxide

The sodium hydroxide was standardised with a standard solution of potassium hydrogen phthalate ($KHC_8H_4O_4$) (about 2 g in 100.0 mL), using phenolphthalein as the indicator. A concentration of 0.09722 mol.dm^{-3} was obtained for the sodium hydroxide solution. The equation is shown below:

$$KHC_8H_4O_4 + NaOH \rightarrow KNaC_8H_4O_4 + H_2O$$ Equation 3.5

ii) Sulfuric acid

The sulfuric acid was standardised with borax ($Na_2B_4O_7$) (about 1 g in 100.0 mL), using methyl red as the indicator. The concentration of the sulfuric acid test solution was determined to be 0.04901 mol.dm^{-3}. The reaction is as follows:

$$Na_2B_4O_7 + H_2SO_4 + 5H_2O \rightarrow 4H_3BO_3 + Na_2SO_4$$ Equation 3.6

iii) Sodium thiosulfate

The sodium thiosulfate concentration was determined to be 0.1010 mol.dm^{-3} through standardisation with potassium iodate (about 1.3 – 1.4 g in 250.0 mL). Potassium iodide (20 mL of 10% solution) and sulfuric acid (5 mL of 1 mol.dm^{-3} solution) were added to the potassium iodate solution to yield iodine:

$$IO^{3-} + 5\,I^- + 6\,H^+ \rightarrow 3\,I_2 + 3\,H_2O$$ Equation 3.7

The iodine solution was titrated with sodium thiosulfate until the solution turned from brown to a pale yellow colour. Starch indicator was then added, and the titration was continued until the colour changed from blackish-blue to colourless:

$$3\,I_2 + 6\,S_2O_3{}^{2-} \rightarrow 3\,S_4O_6{}^{2-} + 6\,I^-$$ Equation 3.8

d) Chemical raw materials

The chemical raw materials (input streams to the process tanks) were analysed to determine their exact chemical concentrations (Table 3.2). The respective concentrations were determined by titration, using the same methods as outlined in Section 3.2.1 (b). The titrations were repeated until three concordant results (within 0.10 mL of each other) were obtained. Titration volumes of about 25 mL were used to reduce the error.

Table 3.2: Concentrations of the chemical raw materials

Chemical raw material	Input stream to:	Concentration (g/kl)
Gardoclean 450M	CCL1 Acid Cleaner CCL2 Acid cleaner (Stage 3)	7 354 (total acid)
Gardoclean 450C	CCL1 Acid Cleaner CCL2 Acid cleaner (Stage 3) CCL2 Chromium (Stage 6A, 6B)	11 790 (total acid)
Gardoclean S5160	CCL2 Alkali degreaser (Stage 1)	60 110 (total alkali)
Gardal K701/1	CCL2 Chromium (Stage 6A)	9 933 (total acid) 54 760 (chromium(VI))

e) Chromium(III) in surge tank B (chromium surge tank)

It was not possible to determine the chromium(VI) content in surge tank B on a daily basis since it is continuously reduced to chromium(III) in the surge tank. Three samples taken during September were analysed for total chromium by first oxidising the chromium(III) to chromium(VI) using silver nitrate ($AgNO_3$) as the catalyst and potassium persulfate ($K_2S_2O_8$) as the oxidising agent (Appendix B). The method detailed in Section 3.2.1 (b) for measuring chromium(VI) was not used as a result of the excess oxidising agent ($K_2S_2O_8$) present in solution. Hence a UV-visible spectrophotometer (Varian, Cary 50 Probe UV-visible spectrophotometer, USA) was used to determine the chromium(VI) concentrations at a wavelength of 440 nm. Potassium dichromate ($K_2Cr_2O_7$) was used as the calibration standard.

3.2.2 Data Collected from the Operators

The following production data was collected from the operators: the uptime percentage, the number of coils produced per day, the mass of aluminium processed and the area of aluminium processed per day. The volumes of the chemical raw materials added per day to the CCL2 process tanks were also obtained from operators. The volumes of effluent going to the sewer and solid waste were gathered from the respective effluent treatment plant operators.

The analytical tests performed by the wet section operators are shown in Table 3.3. All the tests shown in Table 3.3 for CCL2 were performed for each coil that was coated. Where there were a number of coils processed in one day, the readings that were closest to 08h00 were used in this study.

The temperatures and conductivities were recorded from thermometers and conductivity meters located in the process and rinse tanks. The coefficient of variance in the temperature measurements (in □C) was typically less than 12%, and in the conductivity measurements was typically less than 44% (in □S/cm).

Table 3.3: Analytical tests performed by the wet section operators

Output stream from:	**Tests**
Coil Coating Line 1 (CCL1)	
Acid Cleaner	free acid, total acid, fluoride
Rinse 1	total acid
Rinse 2	total acid
Coil Coating Line 2 (CCL2)	
Alkali degreaser (Stage 1)	temperature, conductivity, free alkali, total alkali
Alkali rinse (Stage 2)	temperature, free alkali
Acid cleaner (Stage 3)	temperature, conductivity, free acid, total acid, fluoride
1st Acid Rinse (Stage 4)	temperature, total acid
2nd Acid rinse (Stage 5)	temperature, conductivity, total acid
Chromium(VI) (Stage 6A)	temperature, conductivity, free acid, total acid, chromium(VI), fluoride
1st Chromium rinse (Stage 7)	temperature, total acid
2nd Chromium rinse (Stage 8)	temperature, conductivity, total acid

The wet section operators used the same methods as described in Section 3.2.1 (b) for the determination of the total acid, total alkali, chromium(VI) and fluoride concentrations. For the free alkali, the same method was used as for the total alkali, except that phenolphthalein was used as the indicator. The free alkali determination indicates the presence of the strong bases OH^- and CO_3^{2-} in solution, since phenolphthalein is an alkali-range indicator. The difference between the total and free alkali concentrations indicates the presence of weak bases, for example HCO_3^-.

The acid inputs to CCL1 and CCL2 are a mixture of the strong acid, sulfuric acid (H_2SO_4) in Gardoclean 450M, and the weak acid, hydrofluoric acid (HF) in Gardoclean 450C. The free acid titration was performed to determine the concentration of the strong acid (therefore excluding HF). To prevent the HF from dissociating, potassium fluoride (KF) was added before the titration was performed (see Equations 3.9 and 3.10). Hence Equation 3.10 is forced to the right (le Chatelier's principle). The remaining H^+ ions were then titrated with sodium hydroxide, using phenolphthalein as the indicator (see Equation 3.1).

$$KF \rightarrow K^+ + F^-$$ Equation 3.9

$$H^+ + F^-(\text{excess}) \leftrightarrow HF$$ Equation 3.10

3.3 Data Analysis to Identify Waste Minimisation Opportunities

The data collected over the three-month period were analysed to identify waste minimisation opportunities on both coil coating lines. The methods used were mass balances, a scoping audit, calculating the true cost of the effluent streams, and monitoring and targeting graphs (Section 2.2).

The standard deviations of some of the data were calculated to compare the sets of data. The sample standard deviation was used for data sets smaller than 30 data points, and the population standard deviation was used for data sets of 30 points or greater.[45]

CHAPTER 4

Results and Discussion: The Pietermaritzburg Waste Minimisation Club

This chapter discusses the progress of the Pietermaritzburg Waste Minimisation Club (PWMC). It details the proceedings of the club, the potential financial and environmental savings identified to date, and the barriers and drivers experienced by the members to waste minimisation. It also includes a critical assessment of the training material used and the waste minimisation structure.

4.1 Background

As a result of the success of the Metal Finishing and Hammarsdale Waste Minimisation Clubs[24], it was proposed to begin a general (cross-sectoral) waste minimisation club in Pietermaritzburg. The Pollution Research Group from the University of Natal, Durban, initiated the formation of these clubs in the latter part of 2000, as part of a project funded by the Water Research Commission. The Pietermaritzburg Waste Minimisation Club (PWMC) was officially launched in February 2001. By the end of 2001, the club consisted of 11 members (Table 4.1). Company 10 frequently attended the meetings but was not an official member of the club.

As can be seen from Table 4.1 many of the member companies of the Pietermaritzburg Waste Minimisation Club are small and medium enterprises (SME's). The definition of SME's varies from source to source.[7] However the National Small Business Act (No. 102 of 1996) defines a small business in the manufacturing sector as shown in Table 4.2.

Table 4.1: Members of the Pietermaritzburg Waste Minimisation Club

Company Name	Products	Number of Employees	Classification
Company 1	Air-conditioning and refrigeration	73	SME*
Company 2	Leather and textile auxiliaries	60	SME*
Company 3	Steel brackets	6	SME*
Company 4	Printing plates	200	SME*
Company 5	Semi-fabricated aluminium products	1500	Large
Company 6	Personal (retired)		Private
Company 7	Waste management		Regulator
Company 8	Automotive components, metal pressings and plastics	200	SME*
Company 9	Edible refined oil, candles, soap	250	SME*
Company 10	Sewage water management		Regulator
Company 11	Waste management	10	Service provider
Company 12	Springs, wire and sheet metal products	75	SME*

* SME: small and medium enterprise

Table 4.2: The definition of a small business in the manufacturing sector [44]

Size or class	Total full-time equivalent of paid employees	Total annual turnover	Total gross asset value (fixed property excluded)
Medium	< 200	< R40.00 m	< R15.00 m
Small	< 50	< R10.00 m	< R3.75 m
Very small	< 20	< R4.00 m	< R1.50 m
Micro	< 5	< R0.15 m	< R0.10 m

4.2 *The Pietermaritzburg Waste Minimisation Club Meetings*

Seven club meetings were held during 2001 and are summarised in Table 4.3. The minutes for the meetings can be found in Appendix C. The Chemical Technology Group of the University of Natal, Pietermaritzburg, is responsible for the administration of the PWMC. Their role is to organise the meetings and any guest speakers whom the club requests, and to provide training in waste minimisation principles.

Table 4.3: Summary of the meetings of the Pietermaritzburg Waste Minimisation Club

Date of meeting	Attendance	Guest speakers	Training module
7 February 2001	5	Chris Buckley: Introduction to Waste Minimisation	
14 March 2001	9	Phillip Symons: Incineration	Barriers and drivers, scoping audit
4 April 2001	8	Bill Armitage: How to Identify / Handle Waste Management: Some Clues from Industry	Process flow diagrams
6 June 2001	9	Frank Trump: A Method for Recycling Solvents	Data gathering, true cost of waste
12 September 2001	8	Chris Fennemore: Trade Effluent Bylaws in Pietermaritzburg	Mass and energy balances
31 October 2001	6		Monitoring and targeting, statistical process control
5 December 2001	3	John Danks: The Ups and Downs of Waste Minimisation	

The annual membership fee for attending the PWMC meetings was R400 per member for 2001. This covered all the administrative costs of running the club for the year and included a 10% fee for a central fund at the Pollution Research Group to set up a South African waste minimisation database.

4.3 The Success of the Club

The aims of the PWMC were to create awareness of waste minimisation amongst members and for all members to achieve financial and environmental benefits from waste minimisation in their respective companies. Therefore the success of the PWMC was evaluated by how well the Club was achieving its aims. Most of the information reported was gathered through the questionnaires completed by the PWMC members (excluding Company 7 and Company 10 since they are classified as regulators). The results of the questionnaires can be found in Appendix D.

4.3.1 Success of the Training Material

The material used for the waste minimisation training was seven modules developed by the March Consulting Group (now Enviros).[6] At the time of writing the first four modules had been covered. These dealt with data gathering and the processing of the data to identify waste minimisation opportunities.

a) Relevance of the training material

The training material appears to have been successful in introducing the concept of waste minimisation to the club members. Nine of the ten members agreed that the training material has been useful in giving them a broad idea of what a waste minimisation programme is, and what implementation of one involves. However, the training material did not seem to be as successful in showing members how practically to begin a waste minimisation programme: only half the members stated that it was useful for this purpose. The information delivered in the material appears to have broadened members ideas about waste minimisation but has not prompted them to take action in their own company.

Table 4.4 shows what the club members thought of the level at which the training material is pitched. It shows that three members of the PWMC found the training material too general, and did not recognise how it could be used in their own company. Three members found the material too technical and mathematical, and four members found it pitched at the correct level. This lends further support to the finding that some members did not feel equipped to initiate waste minimisation in their own company. Each category in Table 4.4 had at least one response from a member who had attended the majority of the meetings. This suggests that there is no correlation between the number of meetings that the member attended and how they found the training material.

Table 4.4: The pitch of the training material

Pitch of material	Number of responses	No of meetings attended
Too technical	1	6
Too mathematical	2	4; 6
Too general	3	5°; 4; 2
Just right	4	$3^{\times}$; 3°; 3; 6

Key: ∘ = Regulator or private member
× = Large company
No superscript = SME

b) Implementation of the training material

The usefulness of the training material in raising the club members' awareness of waste management is illustrated by nine of the ten members having made waste-related changes through casual observation or other informal means (rather than by applying the methods covered in the training material). In the questionnaire, members were asked to give examples of these changes. Most of these changes were not substantial and were more often waste management rather than waste minimisation solutions. For example, one company said that they had improved their solid waste collection and disposal system. Another company said that they dilute their acid before using it.

However, fewer members identified waste minimisation opportunities using techniques from the training material (Table 4.5). It can be seen that it is only the members that attended most of the seven meetings, and who were thus most committed to waste minimisation, that used any of the waste minimisation techniques. Table 4.5 also demonstrates that attendance at the club meetings is of great importance to the company if it wants to achieve savings through waste minimisation.

Table 4.5: The waste minimisation techniques used in the training material

Technique	Number of responses	No of meetings attended
Process flow diagram	3	5°; 6; 6
Data collection	0	
Scoping audit	0	
Mass/energy balance	1	6
Monitoring and targeting	4	3; 4; 5°; 6
Statistical process control	1	5°

Key: ○ = Regulator or private member
No superscript = SME

It can be seen from Table 4.5 that none of the members have attempted a scoping audit. This was unexpected as it is a simple procedure and is a useful start to a waste minimisation programme. It is also noted that no members have collected new data. This could mean that the relevant data are already being collected, as many companies have made use of mass and energy balances, monitoring and targeting and statistical process control.

The greatest disappointment of the PWMC has been the failure of most members to use the given techniques to identify waste minimisation opportunities. Most of the companies in the PWMC are SME's, and therefore do not have the manpower to focus on waste minimisation. This is confirmed by eight members remarking that they would prefer help from the Chemical Technology Group in the initial waste minimisation audit. This audit is the starting point for identifying waste minimisation.[6] It thus appears that success in initiating a structured waste minimisation programme can only be achieved if waste audits are done for the member companies.

This approach has produced excellent results in the United Kingdom where the governmental organisation, Envirowise, offers a limited free service to companies in performing waste minimisation audits.[22] This approach was also used successfully in the Metal Finishing and Hammarsdale Waste Minimisation Clubs where consultants, masters students and fourth year engineering students performed the audits.[24] Hence it can be concluded that the ultimate success of the PWMC is dependent on whether waste minimisation audits are conducted for the companies. These audits will be completed during 2002.

A further incentive for implementing a waste minimisation programme is the competition that will be run in 2002/2003 by the Msunduzi Municipality / UNP Chemical Technology Group for the company that achieves the most environmental and financial savings through waste minimisation. The Pietermaritzburg Chamber of Commerce and Industry have kindly donated a trophy for the competition. The winning company will further receive publicity through press coverage.

4.3.2 Success of the Guest Speakers

All the guest speakers were well received by the club members. The members always asked questions and showed interest in the topics. Three of the eight companies have introduced the mission-directed work team system spoken about by Bill Armitage of Webroy. None of the members have introduced incineration (Phillip Symons) or had their solvent recycled (Frank Trump). This was not due to a lack of interest but more because it was not relevant to the member companies. The address by Chris Fennemore of Umgeni Water was well received. Members appreciated information on how the effluent tariffs are calculated and how they can successfully reduce effluent discharge costs.

4.3.3 Success of the Waste Minimisation Club Structure

A waste minimisation club usually comprises a representative (project champion) from each of the member companies. As discussed in Section 2.1, it is the responsibility of the project champion to perform the following duties:

- co-ordinate the waste minimisation programme in the company;
- attend club meetings;
- publicise the programme within the company;
- develop action plans within the company;
- identify team members within the company;
- report to management; and
- establish the systems which will ensure the success of the programme.[12]

Five of the eleven members in the PWMC said that it is not realistic to appoint a project champion to oversee waste minimisation in their company. This may be because many of the member companies of the PWMC are small and therefore no one person has the time to take on this responsibility. Also, five members said that it is difficult for that person to involve other people in the company in the waste minimisation programme. Only two members found it easy to involve other people. Both these companies employ more than 70 people and have a flat organisational structure.

4.3.4 Barriers to Waste Minimisation

Each club member was asked to identify five barriers to waste minimisation that they encountered out of a list of sixteen possibilities (shown in Appendix A.2; question 16). The responses are summarised in Figure 4.1.

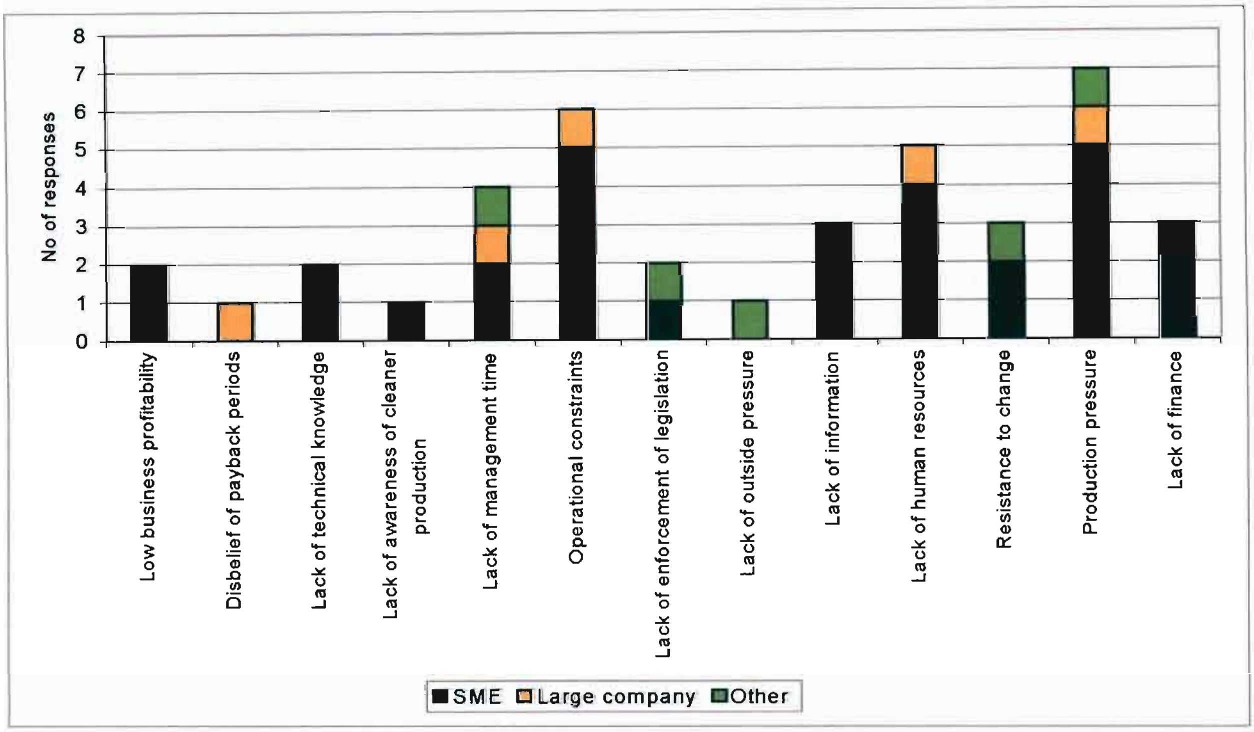


Figure 4.1: Barriers to waste minimisation identified by members of the PWMC

The greatest barriers to waste minimisation appear to have been production pressure, operational constraints, lack of human resources and a lack of management time. Most companies are under great pressure to increase production to operate at a profit. This makes it difficult for them to dedicate time and manpower to generating waste minimisation opportunities and consequently making changes to their process. 'Operational constraints' refer to difficulties in changing the way a process is operating, for example changing the plant layout or the order of the unit operations. This is different to the barrier 'resistance to change', as a resistance to change refers to the entire company's attitude to change. These barriers are often not so much a problem in terms of cost or ease of implementation but have more to do with a reluctance to change attitudes to longstanding work practices.

The third major barrier, a lack of human resources, can be attributed to most of the companies being SME's and therefore not having a dedicated environmental or health and safety officer who can manage the waste minimisation programme. In addition, some of the project champions are in managerial positions and therefore do not have the time to oversee personally a waste minimisation programme. Since environmental responsibility is relatively new in South Africa, most companies do not have someone assigned to deal with environmental issues. This, however, may change in the near future due to increased pressure from government for industries to reduce their environmental impact.[11] The final major barrier, a lack of management time, is closely linked to a lack of human resources and arises for the same reason.

Three of the barrier possibilities did not get any responses, suggesting that they are not perceived as barriers. They are low business confidence, that waste minimisation is perceived as high risk, and unclear legislation. Low business profitability, disbelief of payback periods, lack of technical knowledge, lack of awareness of cleaner production, lack of enforcement of legislation, lack of outside pressure, lack of information, resistance to change and lack of finance did not appear to be serious barriers to waste minimisation.

The main barriers identified by the Metal Finishing and the Hammarsdale Waste Minimisation Clubs were a lack of time, a lack of resources and a lack of finance. The former two were identified as major barriers by the PWMC, but a lack of finance was not.[24]

At the start of the PWMC, the members were asked if they were concerned whether waste minimisation would be a success in their company and half of them were slightly concerned. This opinion seems to have changed over the course of the year with most members beginning to generate waste minimisation opportunities through casual observation.

4.3.5 Drivers for Waste Minimisation

Each club member identified three drivers for waste minimisation out of a possible seven. The responses are summarised in Figure 4.2.

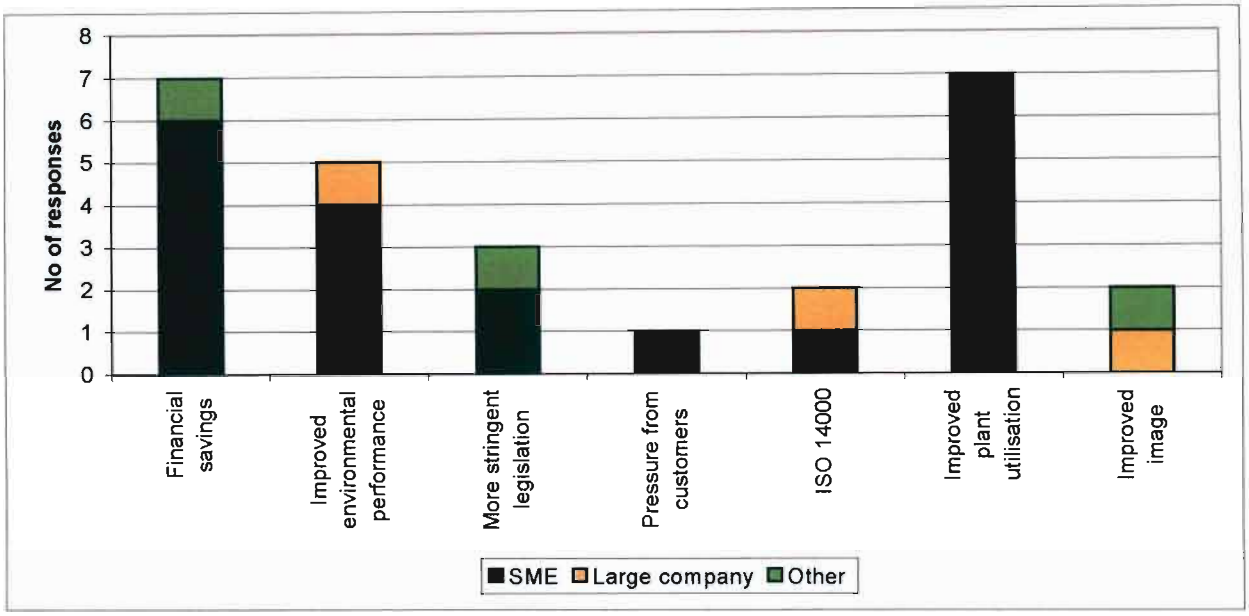


Figure 4.2: Drivers for waste minimisation identified by members of the PWMC

From Figure 4.2 it can be seen that the biggest drivers are financial savings, improved plant utilisation and improved environmental performance. This is consistent with the aims of waste minimisation *i.e.* to make a process more efficient and to yield environmental and financial savings.[6] The minor drivers are more stringent legislation, pressure from customers, ISO 14 000 (environmental management standards), and an improved image.

These drivers are similar to those obtained at the start of the PWMC. In April 2001, all members seemed to be most interested in decreasing their companies' environmental impact, as well as improving their process performance. The minor drivers were complying with environmental regulations and promoting a good image. The only difference was that financial savings were rated as the least important driver at the start of the club. Clearly members are beginning to appreciate the large financial savings that can be achieved through waste minimisation.

The Metal Finishing and Hammarsdale Waste Minimisation Clubs also identified financial savings and improved environmental performance as the main drivers. However, more stringent legislation was the third greatest driver identified by these two clubs.

The PWMC is a cross-sectoral club, which means that the member companies manufacture different products or provide different services. This seems to make members more open to discussing their company's waste minimisation efforts with other members probably because they do not feel as if they are divulging information to a competitor.

Another benefit of the club meetings, which could be classified as a driver for waste minimisation clubs, is social interaction between the PWMC members. Six of the ten club members have established useful or mutually beneficial relationships with companies or authorities as a result of the club. Most of the companies developed an improved relationship with the regulator, Umgeni Water. The companies have further developed a greater trust of the facilitators, the Chemical Technology Group: in February 2001 only 67% of the respondents wanted assistance with waste minimisation audits; in December 2001, 89% of the respondents requested assistance.

4.3.6 Environmental and Financial Savings Achieved

Two waste minimisation audits have been completed and a further four are currently being performed by Chemical Technology students (as of April 2002). Preliminary data collections were performed at companies 3 and 5 (remelt). However, the audit process will be completed by the respective companies. The companies where the audits were/are being performed and the potential financial and environmental savings identified are shown in Table 4.6.

Table 4.6: Summary of the audits performed in the PWMC to date

Company	Degree	Status of Audit
Company 1	Masters	Audit in progress
Company 2	Masters, Honours	Audit in progress
Company 3	Honours	Baseline measurements taken
Company 5 (coil coating)	Masters	Fin. savings = R5.3 million p.a. Env. savings = 31 600 kL p.a.
Company 5 (milling)	Honours	Fin. savings = R19 500 p.a. Env. savings = 1 600 kL p.a.
Company 5 (remelt)	Honours	Factors influencing waste production identified
Company 8	Honours	Baseline measurements taken, Audit in progress
Company 12	Honours	Audit in progress

4.4 Conclusions

The Pietermaritzburg Waste Minimisation Club, consisting of eleven members, was started in February 2001. Seven meetings were held in 2001, and training was provided by the Chemical Technology Group (UNP) using training modules developed by the March Consulting Group (now Enviros).[6] The training material used was found to have given members a good understanding of the basic principles of waste minimisation. However, it appears not to have given the members enough practical information to implement a waste minimisation programme in their companies. To assist members, waste audits will be conducted by the Chemical Techology Group in the respective companies.

At most club meetings there was a guest speaker who spoke on a topic of interest to the club members. Guest speakers were well received, especially Chris Fennemore from Umgeni Water. The speakers generated good discussion amongst club members.

Many of the members of the PWMC find it unrealistic to appoint someone as a project champion for waste minimisation. Half the members further stated that it is difficult to involve other employees in the waste minimisation programme. A reason for this could be that the companies are small and therefore do not have the manpower to have a full waste minimisation project team.

During 2001, the main barriers of member companies to waste minimisation were production pressure, operational constraints, lack of human resources and a lack of management time. The drivers for implementing waste minimisation were financial savings, improved plant utilisation and improved environmental performance. Another unforeseen and positive result of the waste minimisation club is that there has been good social interaction between members. This has resulted in many of the companies improving their relationship with Umgeni Water. The cross-sectoral nature of the club seems to have provided a safe environment in which members can share information about their waste minimisation efforts with each other. During the course of 2001, the club members developed a greater trust of the facilitators, becoming more open to the Chemical Technology Group performing audits in their companies.

CHAPTER 5

Results and Discussion: A Waste Minimisation Study at Two Coil Coating Lines

In this chapter the results obtained from a waste minimisation audit conducted at two coil coating lines are discussed. Data collected included the compositions, flow rates and costs of all input and output streams to the respective wet and pretreatment sections. These data can be found in Appendix E. In this chapter, the data are analysed to identify waste minimisation opportunities using mass balances, monitoring and targeting graphs, a scoping audit, and a true cost of waste assessment. The theory of these techniques is discussed in Section 2.2. From the opportunities identified, the environmental and financial savings were then calculated. The financial savings represent the amount that can be saved from the implementation of the recommendations, and do not include the capital costs of implementation.

Section 5.1 discusses the results obtained for Coil Coating Line 1, and Section 5.2 discusses Coil Coating Line 2. For some of these analyses, annual data were required. The data were collected over a three-month period, and therefore all volumes were quadrupled to represent annual figures. The three-month period was therefore assumed to be a representative sample for the whole year.

5.1 Coil Coating Line 1 (CCL1)

The wet section and chromium pretreatment section of Coil Coating Line 1 are described in Section 2.5.1, and are shown diagrammatically in Figure 5.1.

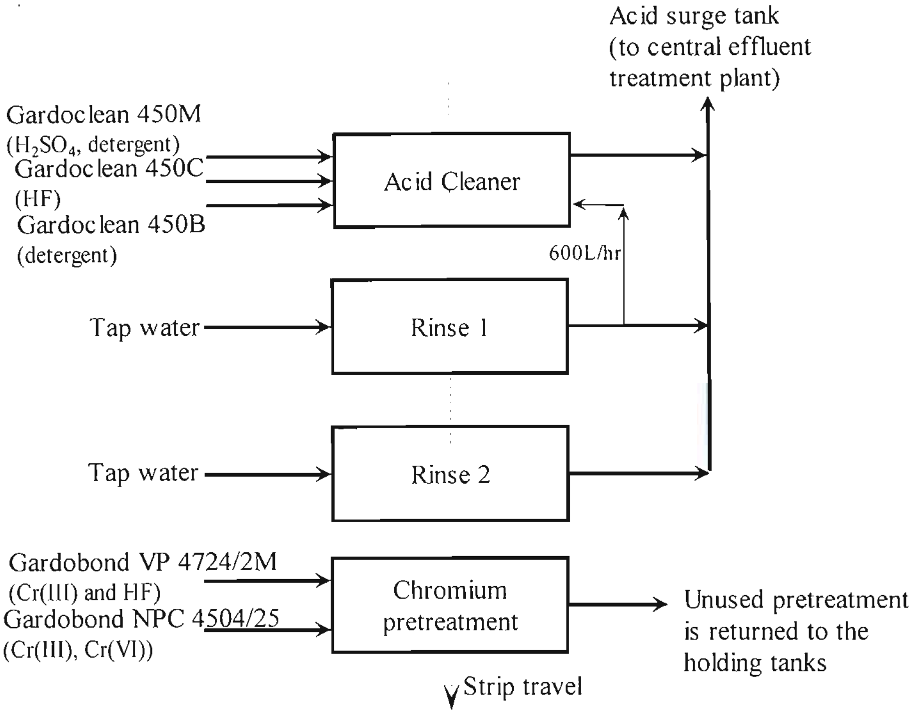


Figure 5.1: Diagram of the wet and pretreatment sections of Coil Coating Line 1 (CCL1)

The volumes of the chemical raw materials for CCL1 were calculated from the number of drums of raw material that were used per month, except for Gardoclean 450C, which was calculated from the delivery figures. Gardoclean 450C is used by both CCL1 and CCL2, and because it was not possible to divide the volume between the two lines, the total amount has been included in the respective calculations. The total volume of water used on CCL1 was determined from the mass balance:

$$\text{Volume of water} = \text{Volume of effluent} - \text{Volume of raw materials}$$

Equation 5.1

For CCL1, equation 5.1 becomes:

Volume of water (annual) = Volume of acid effluent – (Volume of Gardoclean 450M + Volume of Gardoclean 450C + Volume of Gardoclean 450B)

Volume of water (annual) = 28 900 000 L – (12 600 L + 4 000 L + 300 L)

= 28 883 100 L

5.1.1 Monitoring and Targeting Graphs

a) Trend graphs

Figure 5.2 is a trend graph of the temperature of the Acid Cleaner, Rinse 1 and Rinse 2. Table 5.1 shows the means, standard deviations[43] and the set points for the temperature data.

Table 5.1: The means, standard deviations and set points for the temperature data of the CCL1 wet section

		Mean (°C)	Std. Deviation (°C)	Set Point (°C)
Acid Cleaner	1/7 - 27/7	56	1	55
	28/7 - 18/9	61	1	60
	19/9 - 30/9	66	1	65
Rinse 1		70	16	70
Rinse 2		72	13	65

From Figure 5.2 it can be seen that the temperature of the rinse tanks is more variable than the Acid Cleaner. This is substantiated by a comparison of the standard deviations in Table 5.1, with large standard deviations for the rinse tanks (16°C and 13°C) and small standard deviations for the acid cleaner (1°C). This shows that there is poor control over the temperatures of the rinse tanks. As can be seen, the set point for the temperature of the Acid Cleaner was increased twice (from 55°C to 60°C, and then 60°C to 65°C) during the three months. This was because it was hoped that a higher temperature would make the cleaning process more efficient.[40]

Figure 5.3 is a plot of the concentrations of the major chemical species in the Acid Cleaner tank and the two rinse tanks. The total acid concentration is the concentration of all acids and the free acid concentration is the sulfuric acid only. Figure 5.3 shows that the acid and fluoride concentrations in the Acid cleaner bath are scattered. This is because the operators measure the concentrations infrequently, and therefore adjustments are only made every few days. Since the concentrations of fluoride in the rinse tanks were found to be low (< 3 g/kL), the measurements were discontinued. The fluoride concentrations are low because the rinse tanks are continually flushed with water. Low levels of chemicals are required in the rinse tanks to clean the primed aluminium that receives a topcoat.

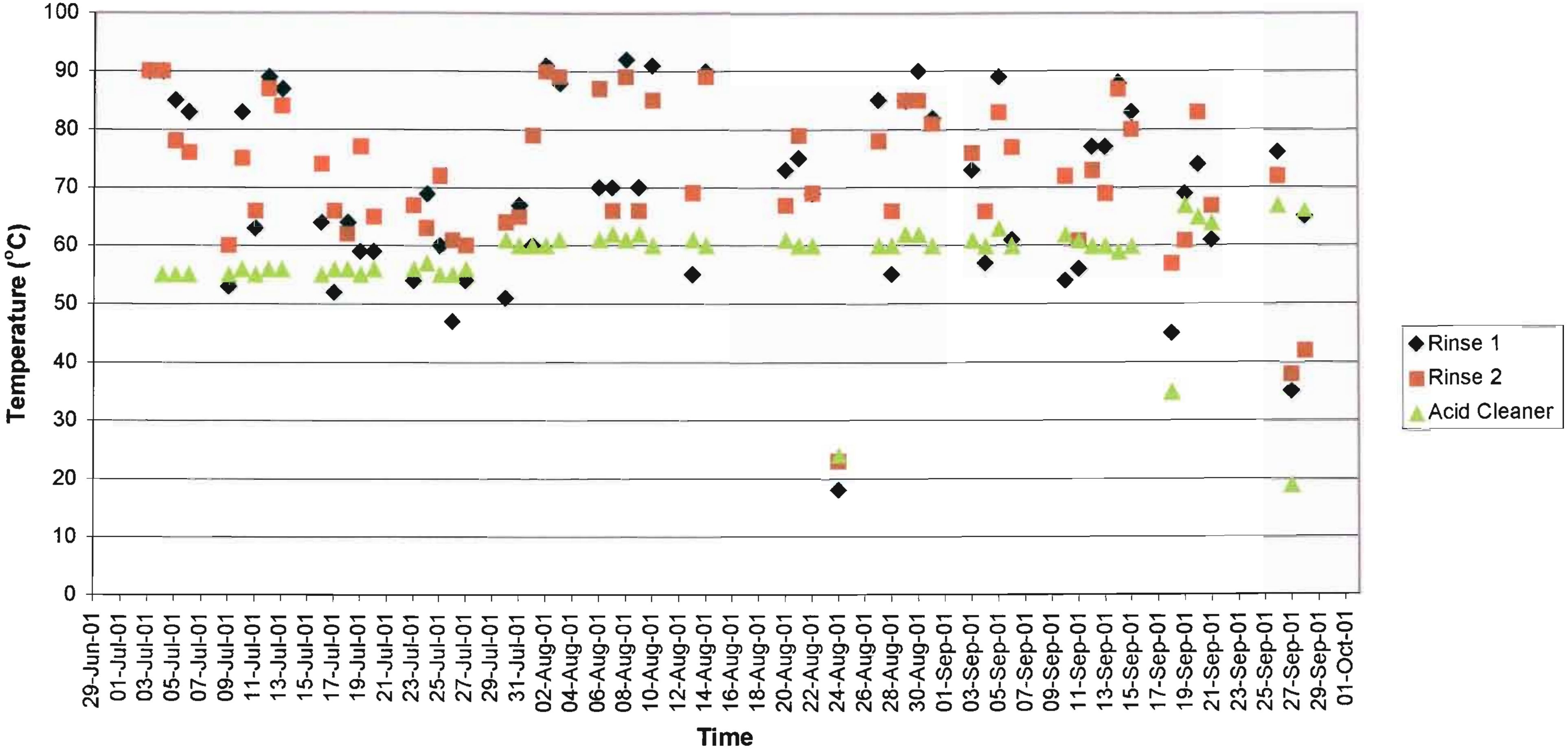


Figure 5.2: Temperature (°C) as a function of time for Rinse 1, Rinse 2 and Acid cleaner (CCL1)

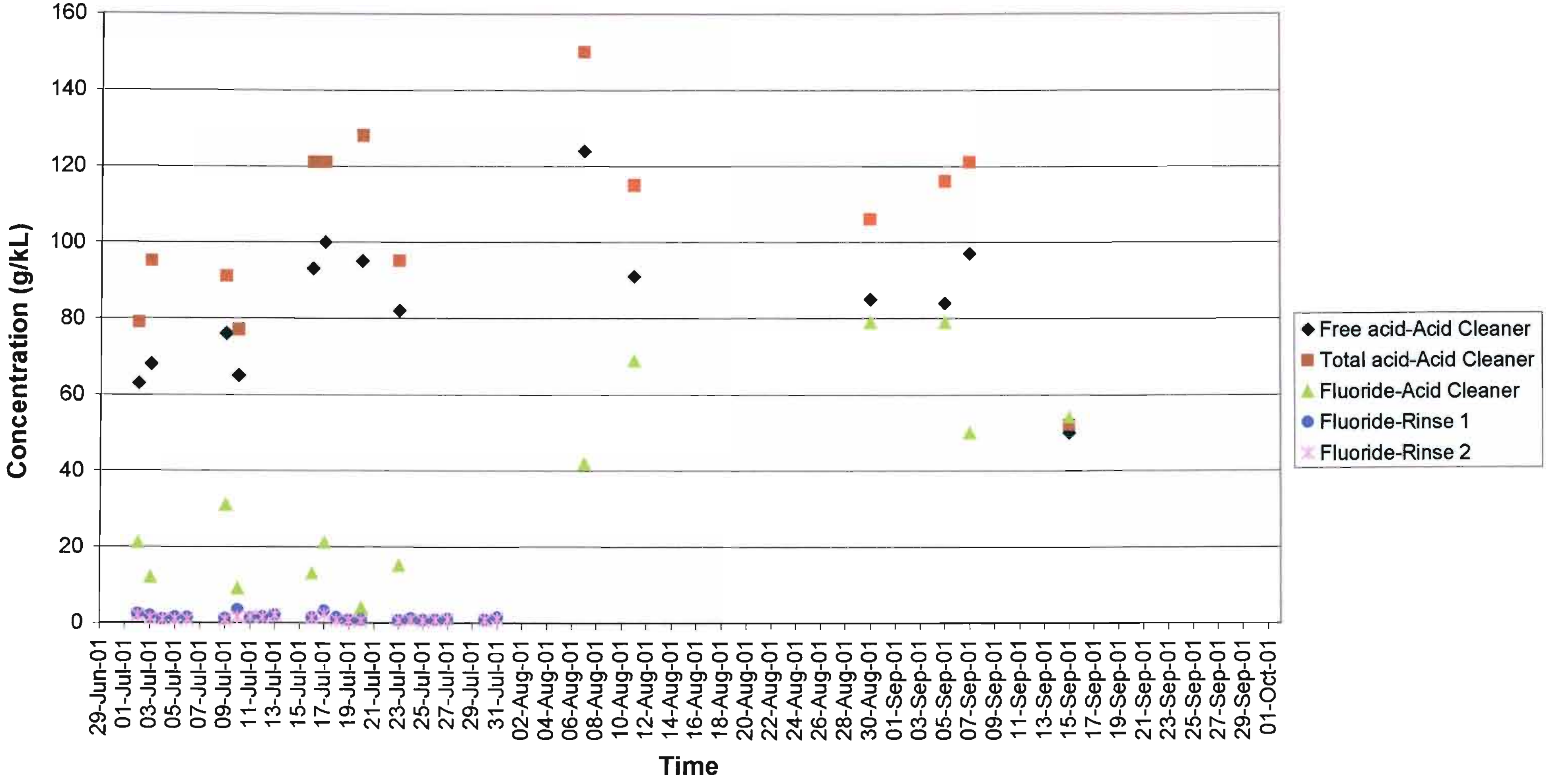


Figure 5.3: Concentration (g/kL) of various chemical species as a function of time for the Acid cleaner, Rinse 1 and Rinse 2 (CCL1)

b) XY scatter graphs

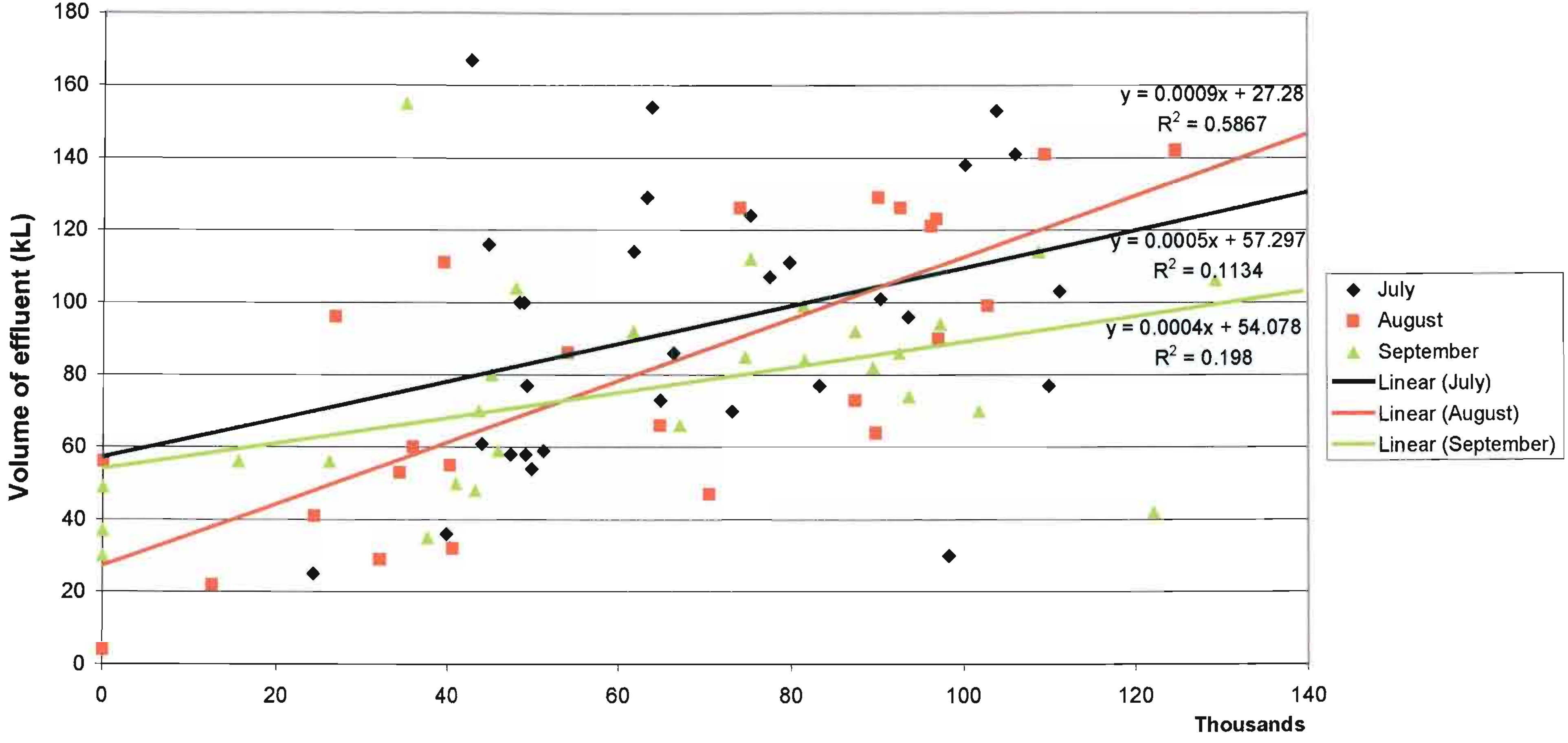
The volumes of acid effluent (Figure 5.1) were plotted against the mass of aluminium processed (Figure 5.4). Most of the effluent is water since the chemicals are an insignificant proportion of the total effluent volume. For example, in July the total effluent volume was 2 901 kL. Only 1 550 L was the volume of acid and the remaining 2 900 kL was water.

The correlation coefficients (R^2–values) for the scatter graphs are poor (between 0.1 and 0.6) and therefore it was difficult to draw accurate conclusions from the data. The XY scatter graph for the acid effluent (Figure 5.4) shows that the baseload, indicated by the y-intercept of the trendline, is high (ranging from 27 to 57 kL). This is due to the amount of water that is used to maintain the clean rinse water. A recommendation for this problem is given in Section 5.1.4. In addition, the data points are scattered which shows that there is little control over the water additions. The process efficiency, indicated by the slope of the graph, was poor in August but improved in September.

5.1.2 Scoping Audit

Table 5.2 shows the scoping audit assessment for CCL1 that was determined on an annual basis. The effluent treatment costs are not included as the acid effluent is treated by the company's central effluent plant, where other effluent from different areas of the company is added to it before treatment. Therefore it was not possible to calculate a treatment cost specifically for the coil coating department.

The scoping audit estimates that the area where the largest saving can be made is the water consumption, with a minimum saving of R25 700 and a maximum saving of R102 600 per year. The area giving the second and third largest savings is the chromium raw materials consumption. Suggestions on how these savings can be achieved are given in Section 5.1.4. The estimated total minimum saving for CCL1 from implementing waste minimisation principles is R31 300 per year, and the maximum saving is R131 100 per year. The validity of this estimation technique is discussed in Section 5.1.4.



Mass of aluminium processed (kg)

Figure 5.4: Volume of acid effluent from CCL1 (kL) as a function of the mass of aluminium processed (kg)

Table 5.2: Scoping audit for the wet and pretreatment sections of Coil Coating Line 1 (CCL1)

Resources & Services	**Quantity**	**Units**	**Cost/Unit**	**Cost/Year**	**Priority**	**Scope to Save**	**Scope**	**Scope**
			R	R		%	R(min)	R(max)
Raw Materials								
Gardoclean 450M	12 600	Litres	8.22	103 600		1 to 5	1 000	5 200
Gardoclean 450C	4 000	Litres	12.82	51 300		1 to 5	500	2 600
Gardoclean 450B	300	Litres	13.98	4 200		1 to 5	40	200
Gardobond VP4724/2M	20 200	Litres	5.30	107 100	3	1 to 5	1 100	5 400
Gardobond NPC4504/25	36 100	Litres	8.38	302 500	2	1 to 5	3 000	15 100
Water	28 900	Kilolitres	4.44	128 300	1	20 to 80	25 700	102 600
Effluent	28 900	Kilolitres	n.d.	n.d.		20 to 80	n.d.	n.d.
Total:							31 300	131 100

5.1.3 True Cost of Waste

Table 5.3 is the true cost of waste assessment for the waste stream from the CCL1 wet section. The only effluent stream is the acid effluent stream since the chromium coat is dried onto the aluminium strip. The true cost of waste has also been calculated on an annual basis.

Table 5.3: True cost of waste for the wet section of CCL1 (acid effluent stream)

	Volume	Units	Cost/Unit (R)	Cost/Year (R)	Priority
Acid	17 900	Litres	9.32	166 800	1
Water	28 900	Kilolitres	4.44	128 300	2
Effluent	28 900	Kilolitres	n.d.	n.d.	
Total Cost:				295 100	

The volume of acid in the waste stream that originates from the raw materials was calculated from the volume of effluent and the concentration of the acid in the effluent. The concentration and the purchase cost of the acid raw material was determined as a weighted cost so that it represents the mixture of acids. These calculations are shown below:

$$\text{Mass of acid in effluent} = \text{Volume of effluent x concentration of acid in effluent}$$

Equation 5.2

For CCL1, Equation 5.2 becomes;

Mass of acid in effluent (annual) = 28 900 kL x 5.2 g/kL

= 150 280 g

$$\text{Volume of acid in effluent} = \frac{\text{Mass of acid in effluent}}{\text{Weighted concentration of raw materials}}$$

Equation 5.3

Therefore, using a weighting of 76% Gardoclean 450M and 24 %Gardoclean 450C;

$$\text{Volume of acid in effluent (annual)} = \frac{150280\ \text{g}}{8419\ \text{g/kL}}$$

$$= 17\,900\ \text{L}$$

The volume of acid in the effluent was calculated to be 17 900 L, but only 16 900 L of acid raw materials enter. This discrepancy could be due to the volumes of acid raw materials added being the delivery volumes, and therefore are not accurate.

The true cost of waste assessment shows that the acid raw materials are the most expensive component of the waste stream, with the water being the second. The total cost of the acid effluent stream from CCL1 is R295 100 per year.

The scoping audit analysis (Table 5.2) estimates that approximately R110 600 can be saved in water and the acid raw materials through waste minimisation on CCL1. This represents 37% of the cost of the effluent stream.

5.1.4 Process Control and Design

The main recommendation for the process control and design of the CCL1 wet section concerns water consumption. If the tap water were not run continuously through the rinse tanks but rather added to flush the tanks just before rinsing the primed aluminium, water consumption could be reduced. Hence 18 200 kL (R80 800) per year could be saved. This value was calculated from the baseloads of the XY scatter graphs (Figure 5.4; *i.e.* the water consumption at zero production). The value of R80 800 per year compares well with the water savings range of R25 700 – R102 600 predicted in the scoping audit (Table 5.2).

Savings in water consumption for CCL1 might also be achieved if there was more control over water additions. The XY scatter graph for the acid effluent (Figure 5.4) shows a large amount of scatter, indicating the poor control over the water additions. Further savings in water consumption could also be achieved if the empty tank which was previously used for alkali cleaner (Figure 2.8) is used as another rinse tank. Therefore a counter-current rinse system could be used for all three rinse tanks, resulting in a decrease in the amount of tap water that would be required.

Another potential financial saving, identified by casual observation, was reducing the use of heavy fuel oil, which is burnt to produce steam for heating the process and rinse tanks. It would be preferable to use energy that is produced in another part of the plant, for example from the ovens or from the incineration of the paint fumes.

The acid raw materials were identified as contributing the most to the true cost of waste (Table 5.3) and a maximum saving of R8 000 per year for the acid raw materials was estimated by the scoping audit (Table 5.2). The acid concentration of the Acid Cleaner varies greatly, which presents an area for waste minimisation: savings could be achieved if the acid concentration were controlled better. The acid concentration of the Acid Cleaner is measured infrequently and greater control could be achieved by introducing a conductivity meter into the bath solution. The conductivity of the optimum acid concentration for the Acid Cleaner could be used as the set point. In this way the conductivity could be measured at various time intervals, and adjustments to the acid concentration could be made accordingly.

The consumption of the chromium raw materials was identified in the scoping audit (Table 5.2) as an area for savings on CCL1. Presently, about 400 L (estimated by the operators) of the chromium raw materials is lost per month through leaks in the holding tanks. If these leaks were fixed, a saving of R34 900 per year could be achieved (calculated using a weighted cost of R7.27/L). This saving is greater than the R20 500 in savings predicted by the scoping audit.

5.2 Coil Coating Line 2 (CCL2)

Figure 5.5 is a process flow diagram of the wet section and chromium pretreatment section of CCL2. All of the chemical raw material volumes for CCL2 are the volumes that were added on a daily basis (except for the volume of Gardoclean 450C which was determined from the number of drums delivered). The volume of water added to the tanks was determined from a mass balance. Sample calculations for determining the volume of water added to the alkali section (Stages 1 and 2) and the acid and chromium sections (Stages 3 – 8) are shown in Appendix F.1.

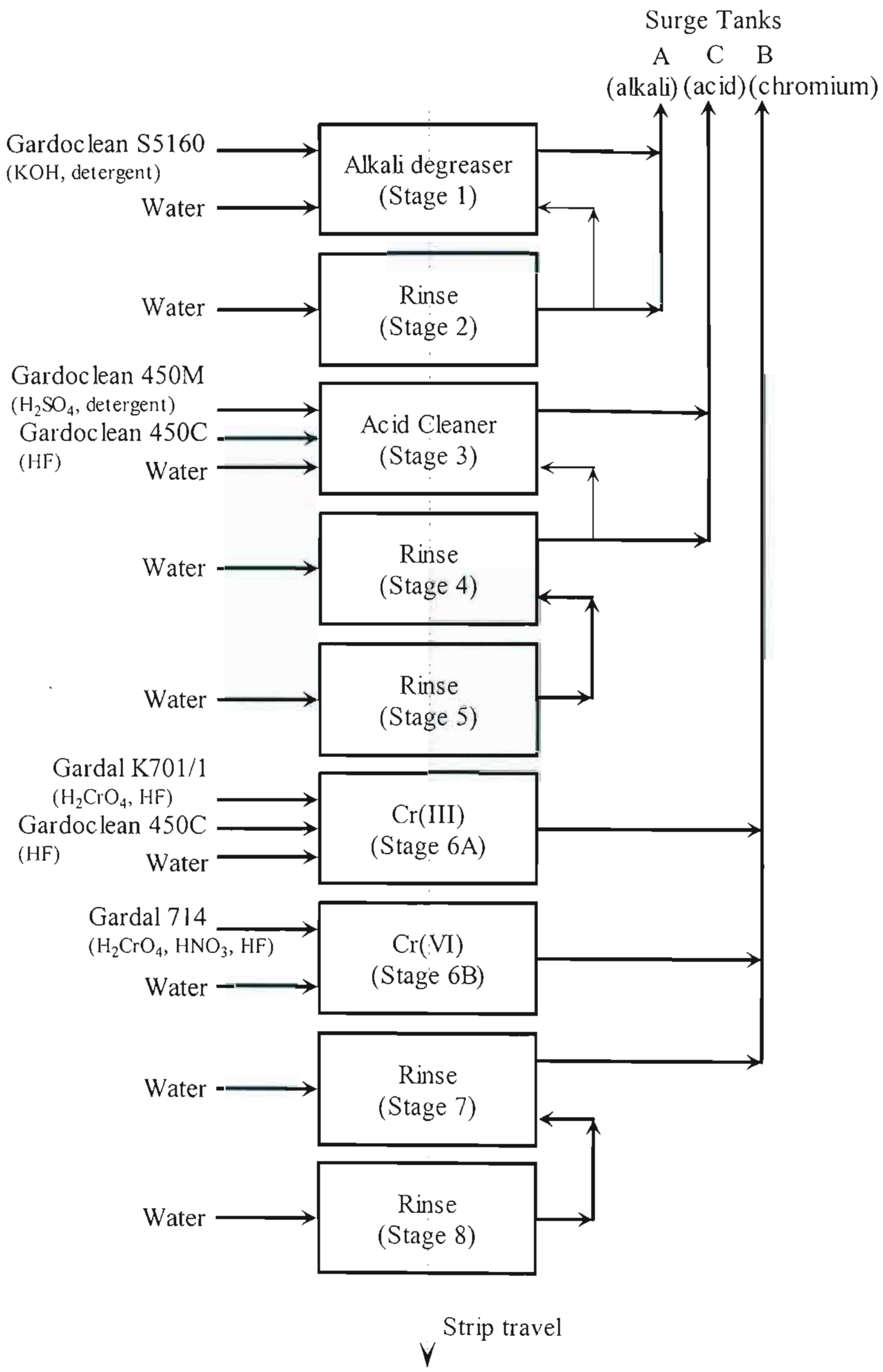


Figure 5.5: Diagram of the wet and pretreatment sections of Coil Coating Line 2 (CCL2)

5.2.1 Monitoring and Targeting Graphs

a) Trend graphs

i) Alkali

Figure 5.6 is the trend graph of the conductivity in Stage 1 and Figure 5.7 shows the alkali concentrations in Stages 1 and 2. Table 5.4 shows the means and standard deviations of the data and the design specifications that were advised by the chemical supplier. The total alkali concentration is the concentration of all alkali whereas the free alkali is the concentration of strong bases only (*i.e.* OH^- and CO_3^{2-}).

Table 5.4: The means, standard deviations (s.d.) and specified concentrations for Stages 1 and 2 of CCL2

		1 July– 6 September			**7– 30 September**		
		Mean	**s.d.**	**Spec.**	**Mean**	**s.d.**	**Spec.**
Stage 1	**Conductivity (μS/cm)**	3853	861		2461	99	
	Free alkali (g/kL)	350	79	85-102	240	20	425-510
	Total alkali (g/kL)	680	146	204	470	41	1020
Stage 2	**Free alkali (g/kL)**	323	118	51	243	38	102

Figures 5.6 and 5.7 show that the conductivity and the alkali concentrations were variable up to the 6 September, and from the 7 September they were significantly more constant. This is further shown by the standard deviations, since they are lower from the 7 September (Table 5.4). The change resulted from the introduction of an auto-dosing system, based on the conductivity of the tank solution, for the additions of Gardoclean S5160. Before the 7 September it was the responsibility of the wet section operators to perform a titration, and if the concentration was below the specifications, to add Gardoclean S5160 until the correct concentration was achieved. This resulted in large errors and a large variation in concentration. Since the introduction of the auto-dosing system, these errors have been minimised and the concentrations are more constant.

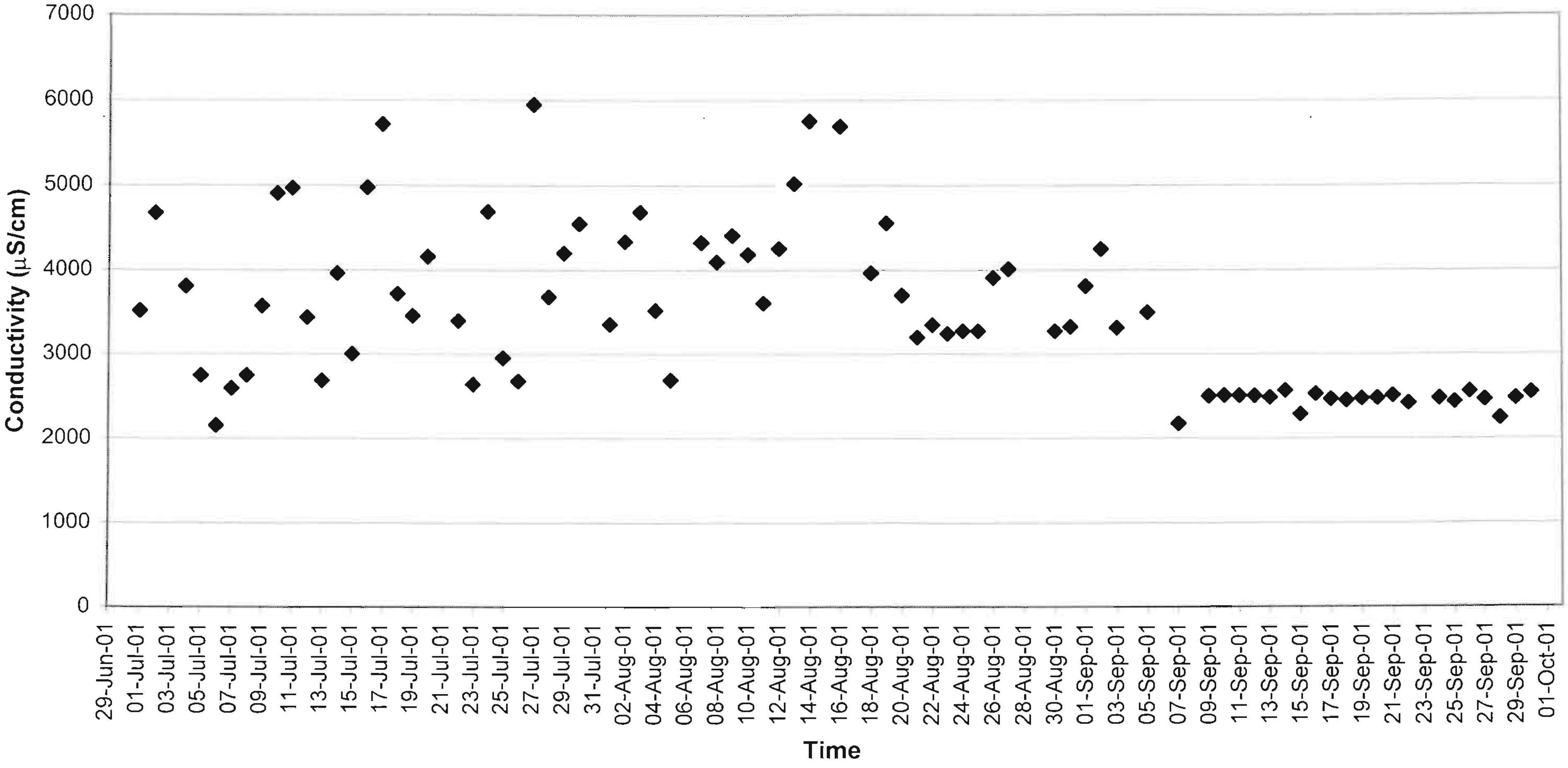


Figure 5.6: Conductivity (µS/cm) as a function of time for Stage 1 (CCL2)

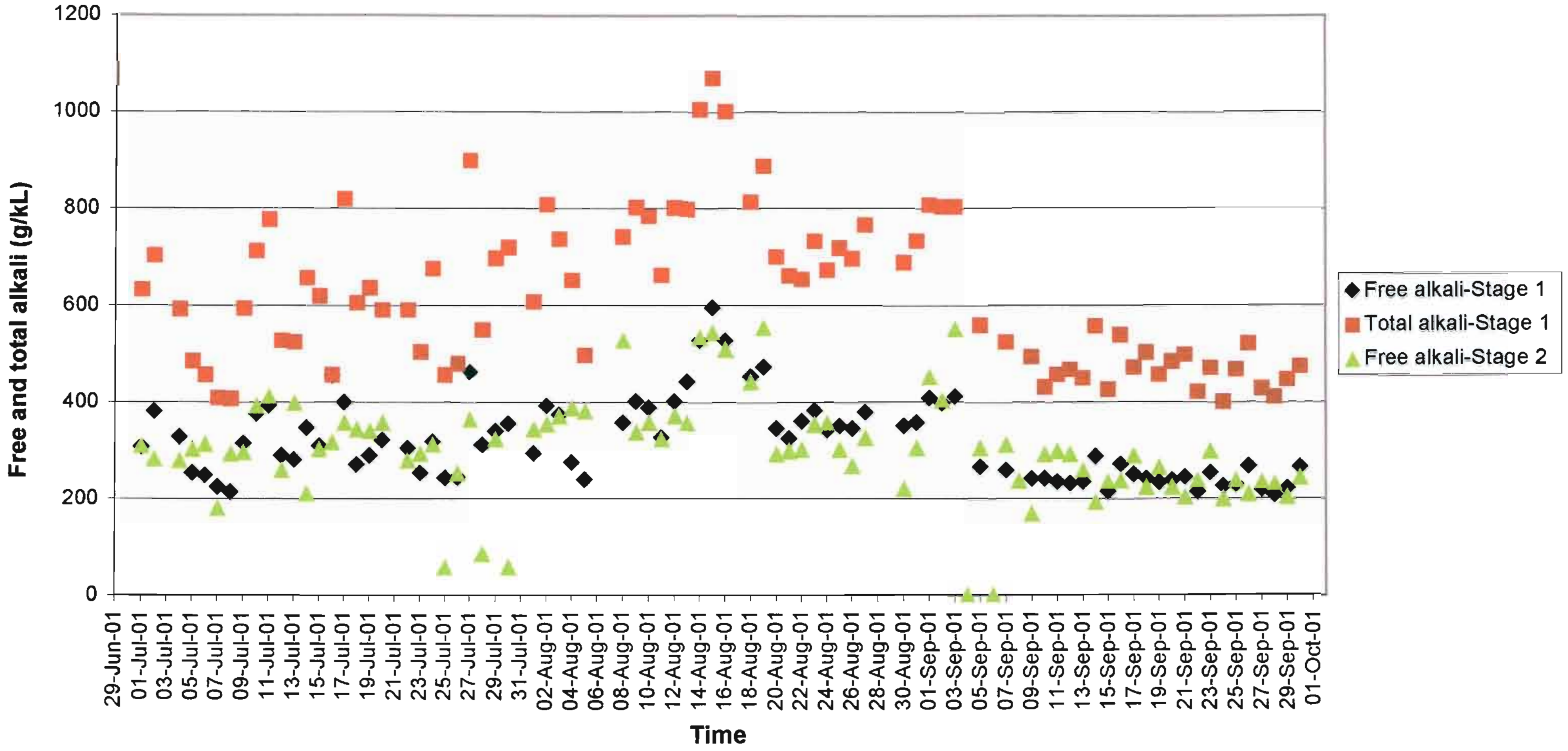


Figure 5.7: Concentrations of free and total alkali (g/kL) as a function of time for Stages 1 and 2 (CCL2)

It is interesting to note that most of the free and total alkali concentrations are well above the specifications up until the 6 September. This could have been caused by the operators increasing the concentrations when the process was not running efficiently and then never reducing the concentrations to their original values. This has resulted in the bath concentrations gradually increasing over time. The coil coating company then decided to increase many of the specifications from the 7 September so that the specifications were more realistic.[45] The financial and environmental savings that could be achieved by operating Stage 1 at the initial concentration specification have been calculated in Section 5.2.4.

ii) Acid

Figure 5.8 is a plot of the free and total acid concentrations and the fluoride concentration in Stage 3 as a function of time. Table 5.5 shows the means and standard deviations of the data as well as the specified acid concentrations.

Table 5.5: The means, standard deviations (s.d.) and specified concentrations for Stage 3 of CCL2

	July		**August**		**September**		
	Mean	**s.d.**	**Mean**	**s.d.**	**Mean**	**s.d.**	**Specification**
Free acid (g/kL)	86	49	92	62	61	51	40-50
Total acid (g/kL)	162	35	149	46	113	31	76-95
Fluoride (g/kL)	94	24	80	30	54	12	30-70

The acid concentrations for Stage 3 show a similar trend to the alkali concentrations of Stage 1. Up to the 7 September the concentrations are scattered, and then become stable after the 7 September. There is not an autodosing system for the addition of Gardoclean 450M as yet. However, one is being introduced. A possible explanation for the concentrations becoming more constant is that the wet section operators had more time to focus on Stage 3, as they did not have to control Stages 1 and 2. They could further have become more aware of the need to control the concentrations more closely.

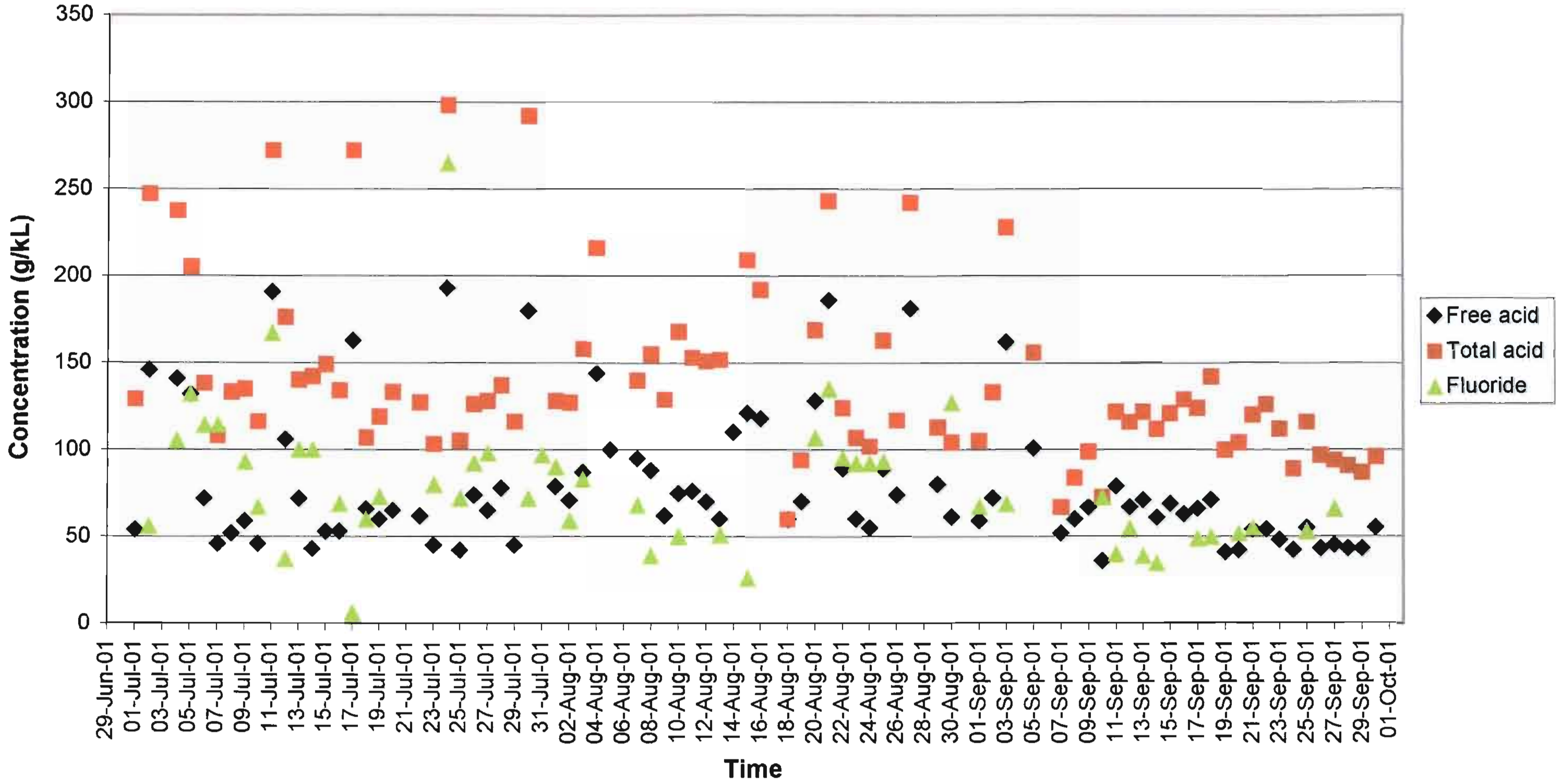


Figure 5.8: Concentrations (g/kL) of various chemical species as a function of time for Stage 3 (CCL2)

As with the alkali concentrations in Stages 1 and 2, these acid and fluoride concentrations are also above the specifications. However, in this case there is not such a great difference between the actual and the specified concentrations and therefore the specifications were not increased. The financial and environmental savings that could be achieved by operating Stage 3 within the specifications have been calculated in Section 5.2.4.

iii) Chromium

The trend graphs for the acid concentrations and the chromium(VI) concentrations for Stage 6A are shown in Figures 5.9 and 5.10 respectively. Figure 5.10 also includes the chromium concentrations of surge tank B that were measured spectrophotometrically. Table 5.6 shows the means and standard deviations of the data and the specified concentrations for Stage 6A.

Table 5.6:The means, standard deviations and specified concentrations for Stage 6A of CCL2

	July		**August**		**September**		
	Mean	**s.d.**	**Mean**	**s.d.**	**Mean**	**s.d.**	**Specification**
Free acid (g/kL)	744	244	676	162	734	98	
Total acid (g/kL)	1464	461	1302	337	1488	277	
Fluoride (g/kL)	2014	428	2292	579	2752	470	750-800
Chromium(VI) (g/kL)	6459	1324	6240	1877	7309	1147	2600-3467

The acid and chromium(VI) concentrations of Stage 6A are variable and do not show any trends over the three months of data. The chromium(VI) concentration is particularly varied, ranging from 2 000 to 9 500 g/kL. The chromium(VI) is the pretreatment layer on the aluminium strip and should always produce an even coating. The great variations in concentration measured in this study suggest varying thicknesses of the coating layer. However, some variation in the chromium(VI) concentration is expected since the company varies the concentration of the chromium according to the product requested by the customer. It is difficult to define which variations in Figure 5.10 are valid, and which are the result of poor control.

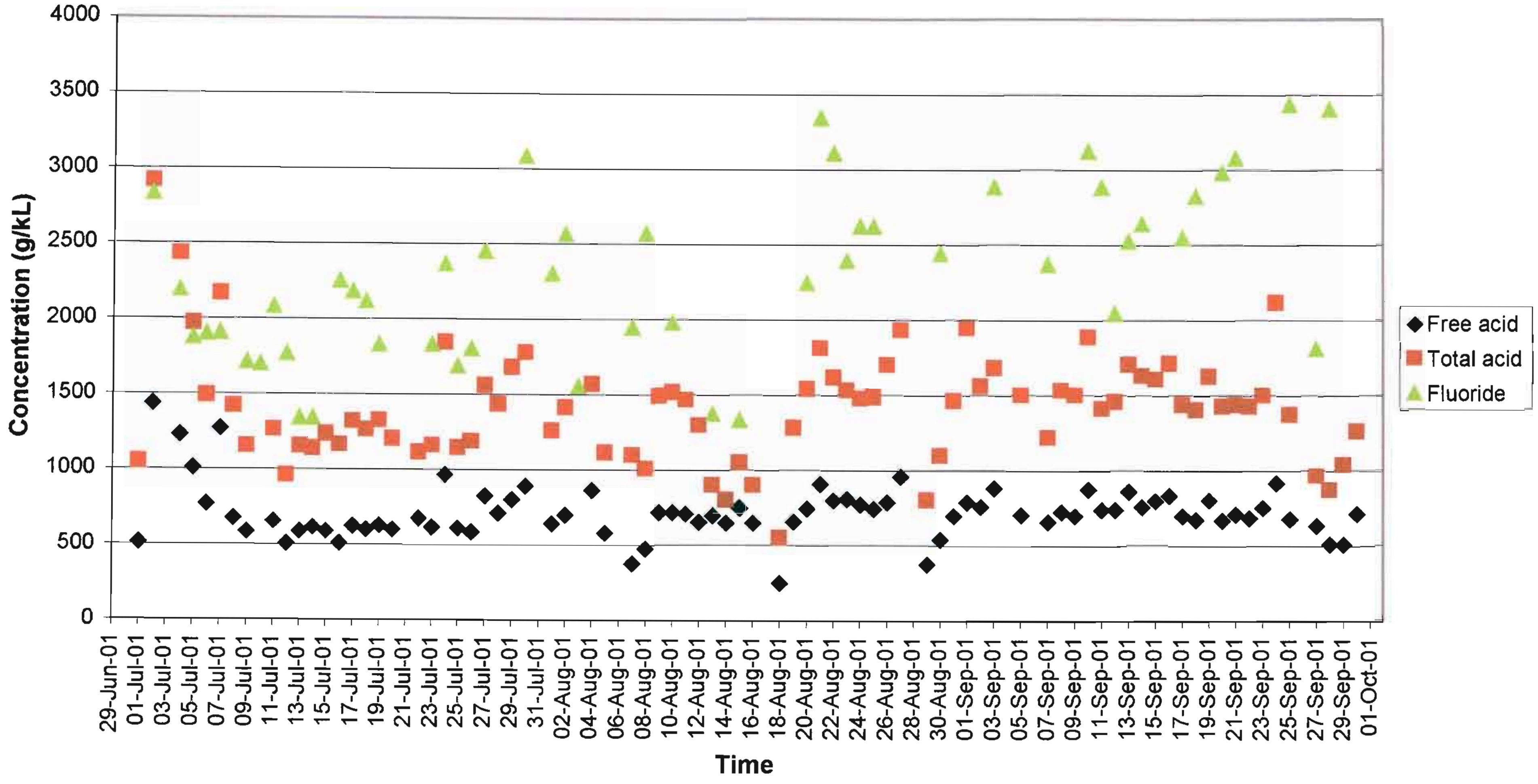
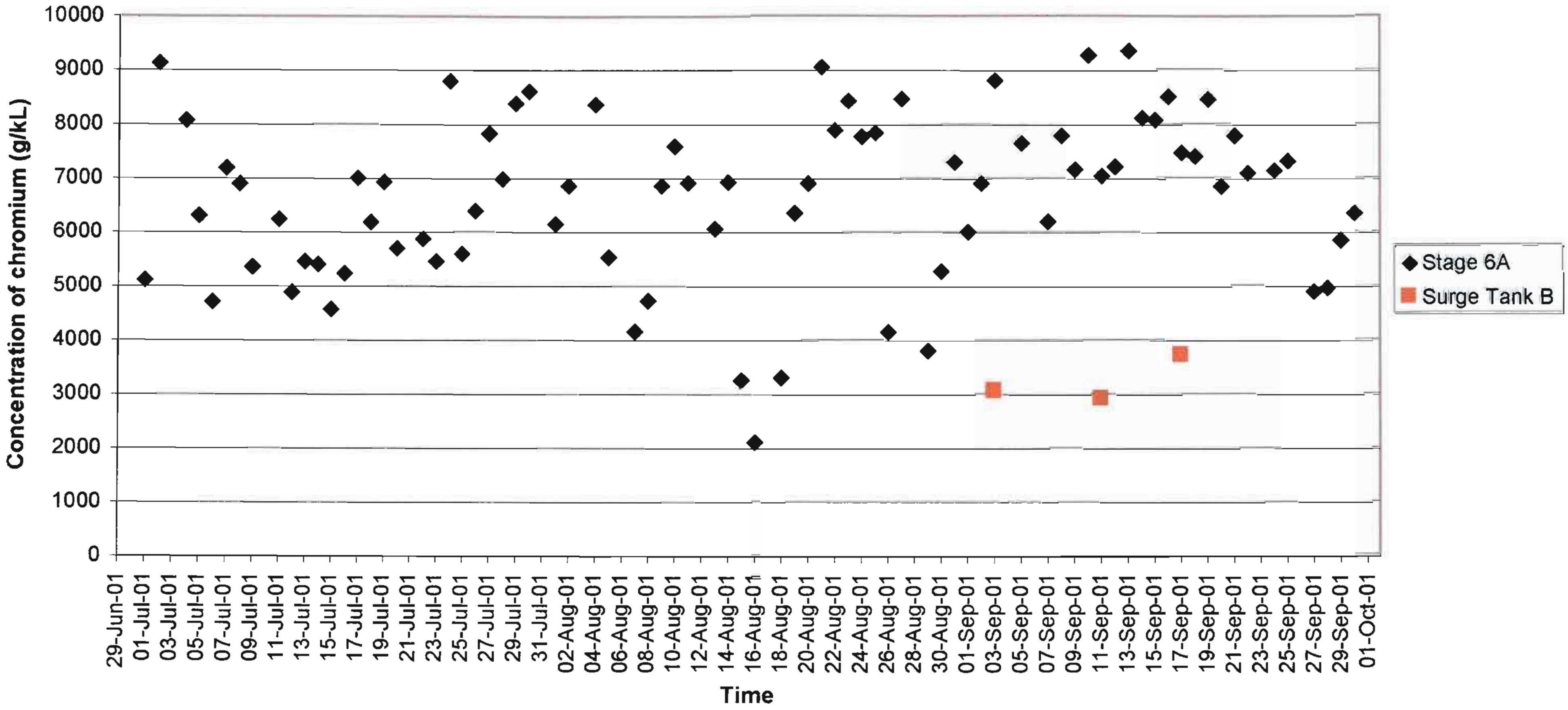


Figure 5.9: Concentrations (g/kL) of various chemical species as a function of time for Stage 6A (CCL2)



<u>**Figure 5.10: Concentration of chromium (g/kL) as a function of time for Stage 6A (chromium(VI)) and for Surge tank B (total chromium) (CCL2)**</u>

Yet again the concentrations of fluoride and chromium(VI) are above the design specifications. These specifications were not changed because they are the operating conditions for the chromium pretreatment. The financial and environmental savings have been calculated for operating Stage 6A within the specified chromium(VI) concentration in Section 5.2.4.

From Figure 5.10 it can be see that the concentrations of total chromium in surge tank B are lower than the concentrations of chromium(VI) in Stage 6A. This is because the effluent in surge tank C is continually added into surge tank B and will therefore dilute the chromium.

b) XY scatter graphs

i) Alkali

An XY scatter graph was plotted for the consumption of Gardoclean S5160 for Stage 1 (Figure 5.11). As with CCL1, the correlation coefficients (R^2–values) are poor (between 0.2 and 0.5) and therefore it was difficult to draw accurate conclusions from the data. Figure 5.11 does however illustrate the benefits of introducing the auto-dosing system in September 2001. From July through to September the baseload (indicated by the y-intercept) decreased from 89 L to 18 L. Furthermore, the process efficiency (indicated by the slope of the line) and the process control (indicated by the scatter of data) improved from July to September.

Unfortunately, an XY scatter graph for the water used in Stages 1 and 2 could not be plotted. This arose because of inaccuracies in the effluent volumes used to calculate the volumes of water. The alkali effluent volume readings were taken at the company's central effluent treatment plant. Because of a recurring chromium(VI) leak into the alkali surge tank during the three months, the alkali effluent was often treated by a waste disposal company and was not sent to the effluent treatment plant. Hence the effluent was recorded as being zero on those days.

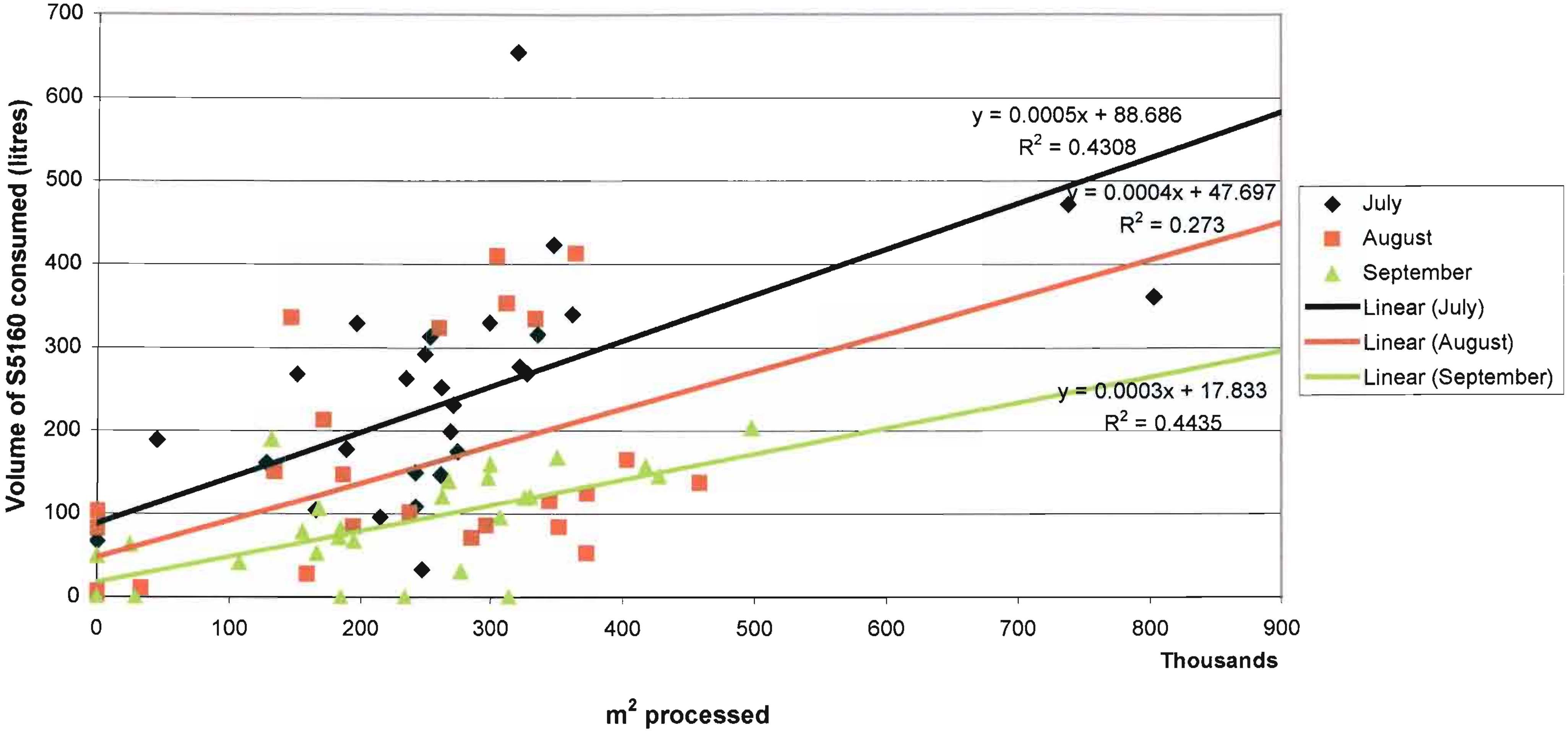


Figure 5.11: Volume of Gardoclean S5160 consumed (litres) as a function of m^2 of aluminium processed for Stage 1 (CCL2)

ii) Acid and Chromium

Figures 5.12 and 5.13 are the XY scatter graphs for the consumption of Gardoclean 450M (Stage 3) and Gardal K701/1 (Stage 6A) respectively. Separation of the volume data for the acid and chromium effluent was not possible since they are combined in the surge tanks before treatment by the coil coating effluent treatment plant. Hence the water usage for Stages 3 to 8 is included in one XY scatter graph (Figure 5.14). Once again, the correlation coefficients (R^2–values) are poor (between 0.02 and 0.2 for Figure 5.12 and 0.4 and 0.7 for Figure 5.13) and therefore it was difficult to draw accurate conclusions from the data.

For the Gardoclean 450M consumption (Figure 5.12), the best process efficiency was observed in September and the poorest efficiency in August. The process control is poor for all three months, with a large amount of scatter around the trendlines (confirmed by the poor correlation coefficients). However, if the September data is considered from the 7 September (which excludes four of the lowest points (at 0 L) and the highest point (614 L)) then the process control for September is better than the other two months. A reason for this improvement is given in Section 5.2.1(a). The baseloads for the three months range from 43 to 74 L, which equates to a large daily cost (R323 – R556). The baseload is the volume of Gardoclean 450M required to replace the acid that is lost in partial dumping of the tank. A solution on how to reduce this volume is discussed in Section 5.2.4.

Figure 5.13 illustrates how inefficient the chromium pretreatment process is. This is shown by the large slopes of all three trendlines. This could be improved by introducing an auto-dosing system similar to the one used for Stage 1 (see Section 5.2.1(a)). In addition, the process control is relatively poor. The baseloads range from 227 to 703 L, corresponding to a high daily cost of R1 941 – R6 011. The chromium process tank (Stage 6A) was designed to operate continuously but is operated currently in fed-batch mode. To prevent contamination of the tank by products / by-products, a fraction of the tank is dumped periodically and replaced with fresh chromium solution. The baseload in Figure 5.13 corresponds to chromium needed for this replacement in addition to chromium needed to replace material lost in a leak. This leak is from the spray bars (Section 2.5.2) and is the cause of the chromium contamination of the acid process and rinse tanks (Stages 3 – 5). The chromium(VI) concentrations in Stages 3, 4 and 5 were found to be 15 g/kL, 93 g/kL and 256 g/kL respectively (measured on the 24 August 2001). Possible savings that could be achieved by preventing these problems are discussed in Section 5.2.4.

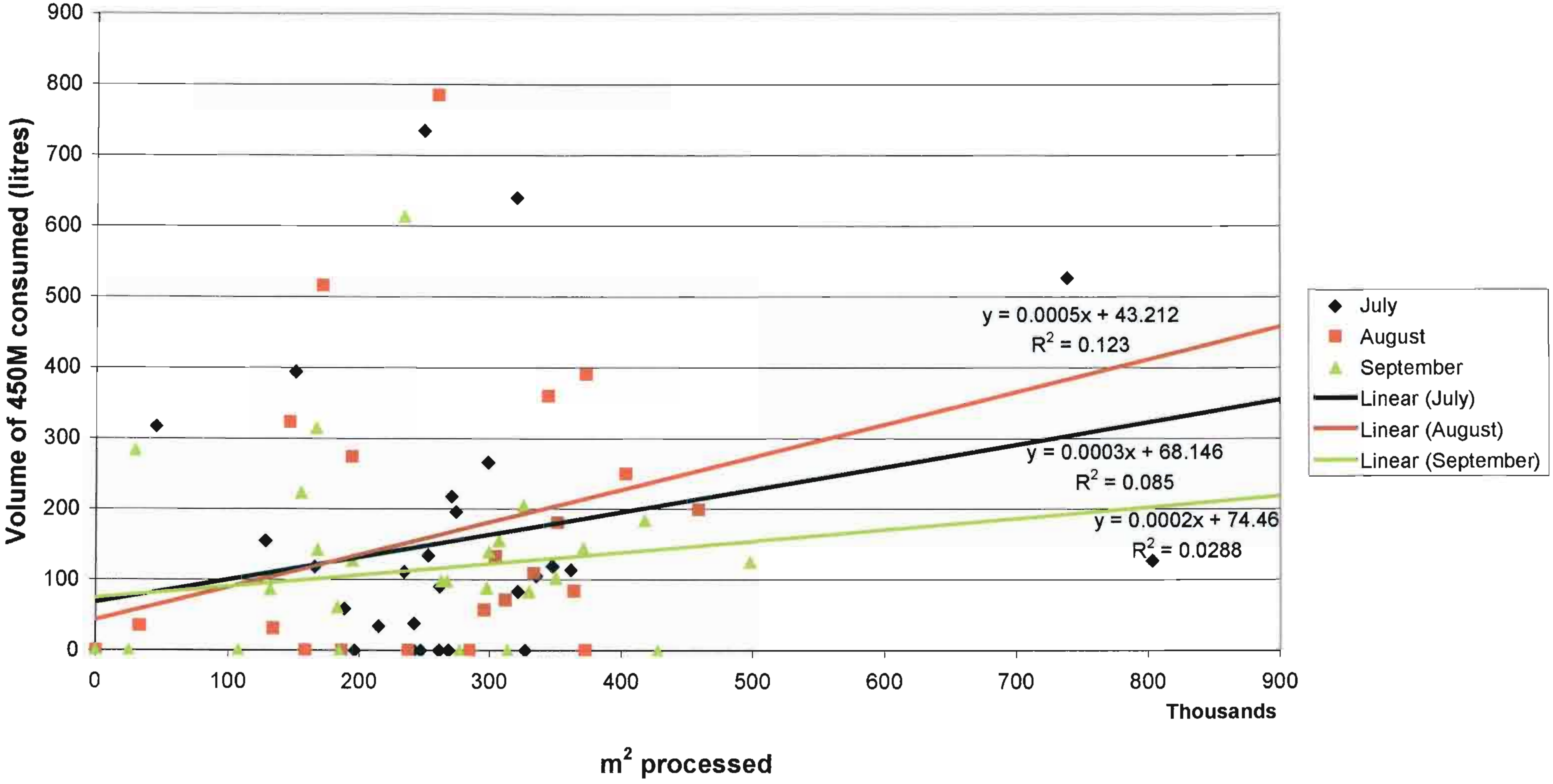


Figure 5.12: Volume of Gardoclean 450M consumed (litres) as a function of m^2 of aluminium processed for Stage 3 (CCL2)

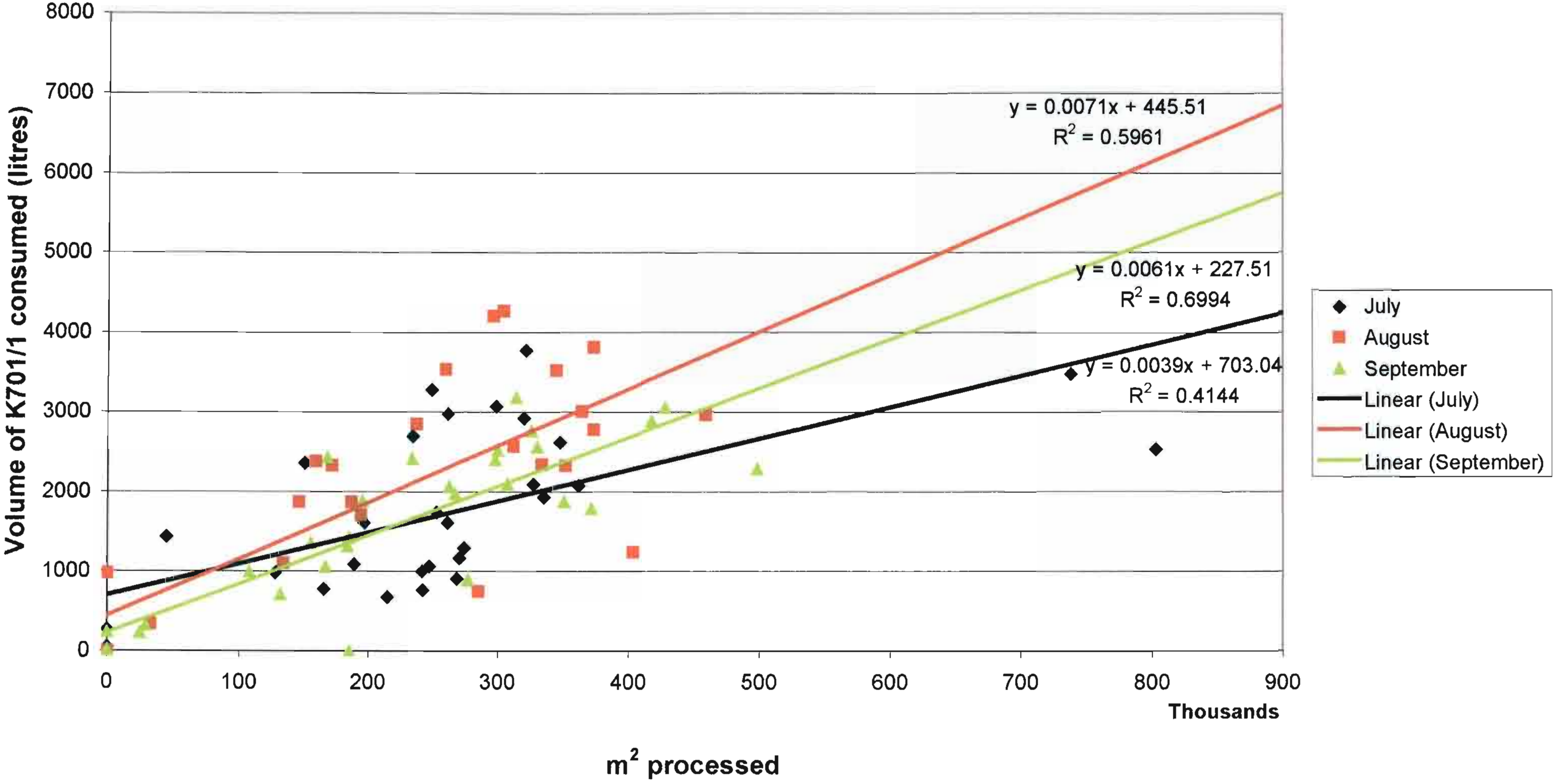


Figure 5.13: Volume of Gardal K701/1 consumed (litres) as a function of m^2 of aluminium processed for Stage 6A (CCL2)

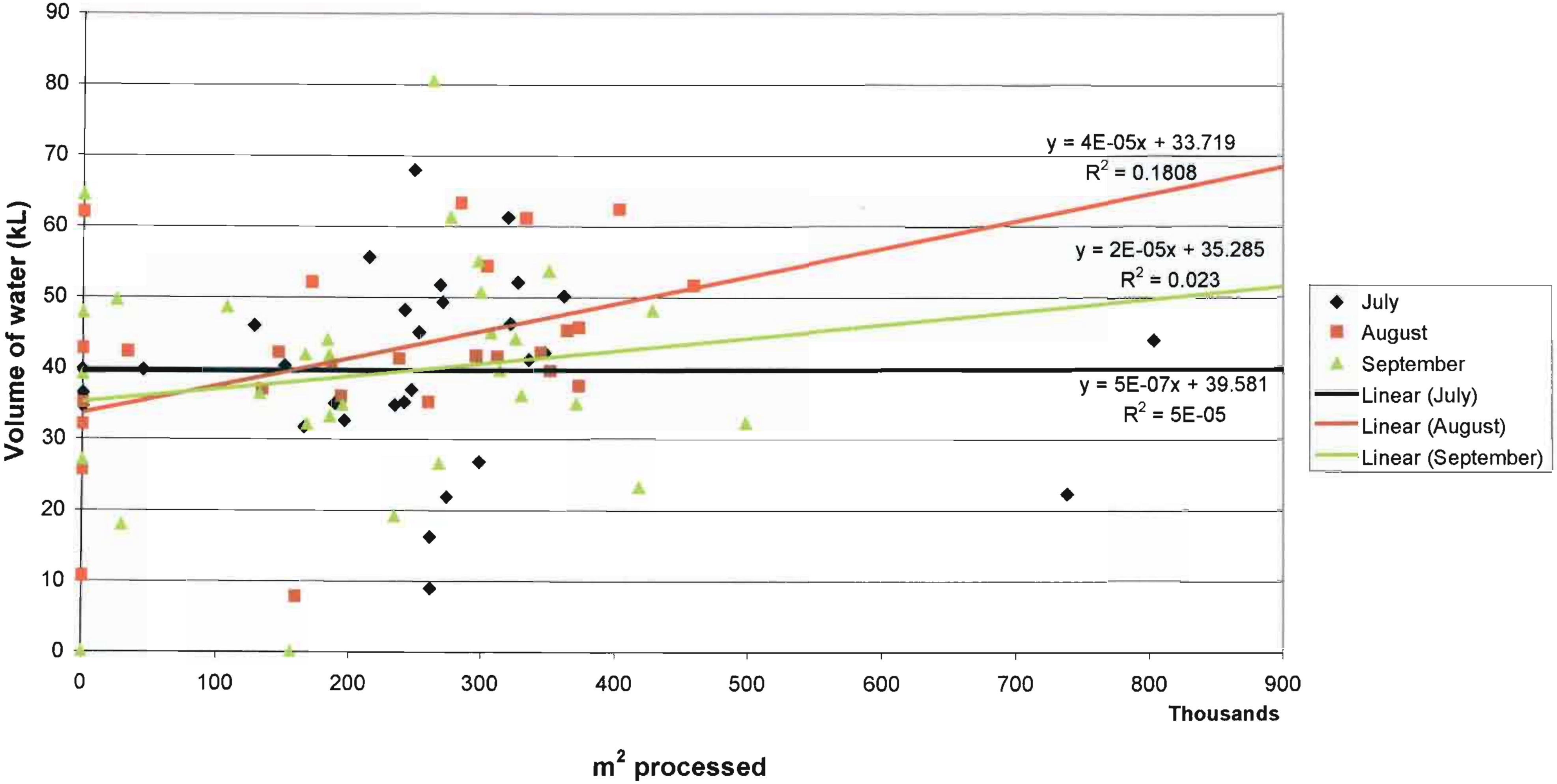


Figure 5.14: Volume of water added to Stages 3 to 8 (kL) as a function of m^2 of aluminium processed (CCL2)

Significant scatter in the XY scatter graph for the water consumption (Figure 5.14) can be observed indicating poor process control. Regression of the data with a trendline is thus difficult. The baseload is also high, ranging from 30 kL to 40 kL. The high baseload and poor control can be attributed to the fact that water additions are erratic: the operators add water manually and often taps are left running for prolonged periods of time. Potential savings and solutions are addressed in Section 5.2.4.

5.2.2 Scoping Audit

Table 5.7 shows the scoping audit for Coil Coating Line 2, which was calculated on an annual basis. In this assessment, the waste is considered as alkali effluent (which goes to the company's central effluent treatment plant), acid and chromium effluent (which goes to the private effluent treatment company) and solid waste (the sludge from the reduction of the chromium(VI) to chromium(III) and which is removed by a waste management company). The cost per unit of effluent and solid waste was then calculated from the total volume and total cost data.

From the 'scope to save' values, it can be seen that the effluent and solid waste are the areas where the greatest savings can be made. This is followed by consumption of the chromium raw material and then the water consumption. The total estimated minimum saving that can be achieved is R816 000, and the maximum saving is R3.6 million per year. The validity of these estimations is assessed in Section 5.2.4.

Table 5.7: Scoping audit for the wet and pretreatment sections of Coil Coating Line 2 (CCL2)

Resources & Services	**Quantity**	**Units**	**Cost/Unit**	**Cost/Year**	**Priority**	**Scope to Save**	**Scope**	**Scope**
			R	R		%	R(min)	R(max)
Raw Materials								
Gardoclean S5160	55 600	Litres	8.09	449 800	5	1 to 5	4 500	22 500
Gardoclean 450M	49 600	Litres	7.52	373 000		1 to 5	3 700	18 600
Gardoclean 450C	4 000	Litres	12.82	51 300		1 to 5	500	2 600
Gardal K701/1	620 000	Litres	8.55	5 301 000	3	1 to 5	53 000	265 000
Water	18 300	Kilolitres	4.44	81 300	4	20 to 80	16 300	65 000
Effluent								
Alkali	3900	Kilolitres	0	0		20 to 80	0	0
Acid and chromium	7700	Kilolitres	318.83	2 455 000	1	20 to 80	491 000	1 964 000
Solid waste	7 500	Kilolitres	331.63	2 487 000	2	10 to 50	248 700	1 243 000
Total:							**817 700**	**3 581 000**

5.2.3 True Cost of Waste

Table 5.8 shows the true cost of all waste streams from CCL2. The costs of the raw materials in the effluent stream were calculated from the volume of effluent, the concentrations of the chemical in the effluent and the raw material, and the purchase cost of the raw material. The volume of the raw materials in the effluent is the excess raw material that is discharged to the sewer.

Table 5.8: True cost of waste for the wet and pretreatments section of CCL2

Alkali stream (Stages 1 and 2):

	Volume	Units	Cost/Unit (R)	Cost/Year (R)	Priority
Gardoclean S5160	13 300	Litres	8.09	107 600	1
Water	3 800	Kilolitres	4.44	16 900	2
Effluent	3 800	Kilolitres	0	0	
Total Cost:				**124 500**	**3**

Acid stream (Stages 3, 4 and 5):

	Volume	Units	Cost/Unit (R)	Cost/Year (R)	Priority
Gardoclean 450M, 450C	82 800	Litres	7.92	655 800	2
Water	6 700	Kilolitres	4.44	29 700	3
Effluent	3 400	Kilolitres	318.83	1 084 000	1
Solid waste	3 400	Kilolitres	331.63	1 128 000	
Total Cost:				**2 897 000**	**2**

Chromium stream (Stages 6A, 7 and 8):

	Volume	Units	Cost/Unit (R)	Cost/Year (R)	Priority
Gardal K701/1	291 000	Litres	8.55	2 488 000	2
Water	7 800	Kilolitres	4.44	34 600	3
Effluent	4 300	Kilolitres	318.83	1 339 000	1
Solid waste	4 100	Kilolitres	331.63	1 371 000	
Total Cost:				**5 254 000**	**1**

The distribution of water between the acid and the chromium sections was estimated according to the ratio of the design water flowrates (20 L/min for Stages 4, 5 and 6 and 23 L/min for Stages 6A, 7 and 8). Sample calculations are shown in Appendix F.2. The effluent treatment cost for the alkali effluent was not included since the effluent is treated at the company's central effluent treatment plant, along with other effluent.

The most costly effluent stream from CCL2 is the chromium stream. This is due to the large cost of the effluent treatment and disposal in addition to the high expense of the chromium raw material. The latter results because of the high chromium(VI) concentration (Figure 5.10) in Stage 6A; hence a large amount of chromium(VI) is discharged with the effluent. The more chromium(VI) in the effluent, the greater the effluent treatment and disposal costs. Therefore in order to reduce the effluent costs it would be sensible to decrease the chromium(VI) concentration or to recycle part of the effluent stream. This is discussed further in Section 5.2.4.

The acid stream is the second most expensive waste stream from CCL2. The high cost arises primarily from the effluent treatment and disposal costs. The volume of the acid raw material in the waste stream was calculated to be larger than the amount of acid raw material added (Table 5.7). This is probably due to the assumption that the ratio of the acid and chromium effluent volumes is the same as the design flow rates of the water additions. Hence the calculated acid effluent volume is probably higher than in reality resulting in a larger volume of acid raw material than was added. However this was the most accurate data available, and was therefore used.

The least expensive waste stream is the alkali waste stream. This is largely because there are no effluent treatment and disposal costs included in this calculation. Furthermore, the concentration of the alkali raw material in the effluent stream is relatively low.

5.2.4 Process Control and Design

There are a number of recommendations for the process control and design of the CCL2 wet and pretreatment sections. Different modes of operating the alkali, acid and chromium process tanks were investigated to determine savings in raw material and water consumption. These options included a continuous mode of operation with recycling of the rinse water to the respective process tanks, operating each of the process tanks at the design concentration, and recycling 50% of the output streams from the process tanks. The choice of a 50% recycle was arbitrary; it was merely used to illustrate the financial and environmental savings that could be achieved. In determining the actual recycle ratio, the effect of contaminants on the aluminium strip would need to be determined. Operation of the chromium process tank in fed-batch mode at the current chemical concentrations with top-up from the rinse tank was also investigated.

Potential financial and environmental savings achievable using these different options are summarised in Table 5.9 (page 95). Sample calculations for the chromium process tank are shown below. The calculations for the alkali and acid process tanks are included in Appendix F.3 and F.4 respectively.

SAMPLE CALCULATIONS FOR THE CHROMIUM PROCESS TANK

To perform the calculations, it was necessary to estimate the average daily volume of the chromium raw material (Gardal K701/1) added to the process tank. Hence a graph of the volume of Gardal K701/1 added was plotted as a function of the % uptime (Figure 5.15). The following regression was obtained ($R^2 = 0.6418$):

$$\text{Volume Gardal K701/1/day (L)} = 31.283(\%\ \text{uptime}) + 199.64$$

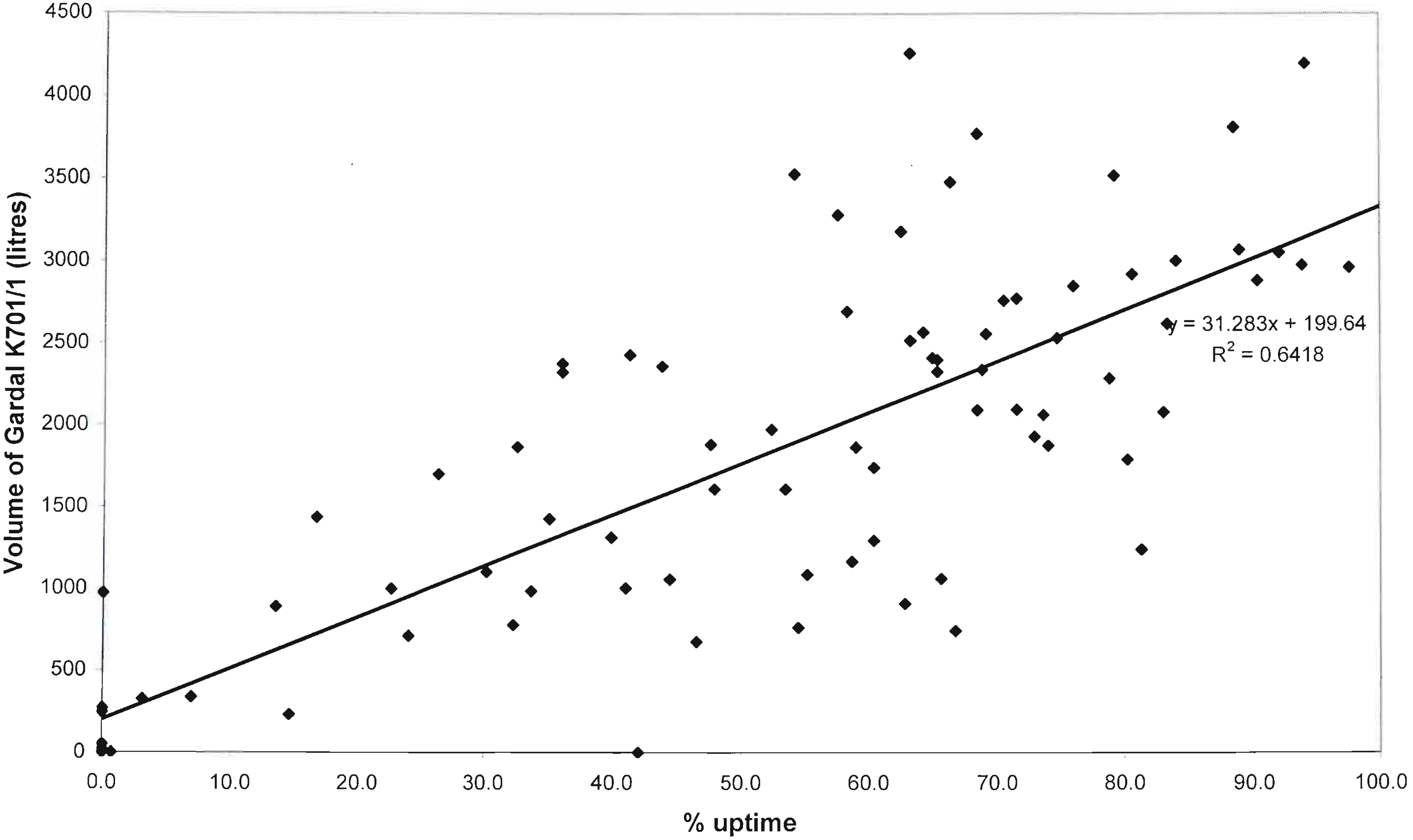
Equation 5.4

Since the average % uptime was 48.8% over the three month period, the average Gardal K701/1 volume added was determined as 1 726 litres per day. The first term in Equation 5.4 corresponds to the volume of Gardal K701/1 used in the reaction with the aluminium (1 527 L/day or 83 597 g/day). The second term in Equation 5.4 corresponds to the volume of Gardal K701/1 required to top up the tank (199.64 L/day or 10 932 g/day) as a result of the chromium pretreatment leak and dumping a fraction of the tank periodically.

If the process were run continuously at steady state, the mass balance for chromium(VI) would be:[17]

$$\text{Input} - \text{Output} - \text{Reacted} = 0$$

Equation 5.5



<u>**Figure 5.15: Volume of Gardal K701/1 (litres) added to Stage 6A as a function of % uptime (CCL2)**</u>

Figure 5.16 is a schematic representation of the continuous operation of Stages 6A – 8.

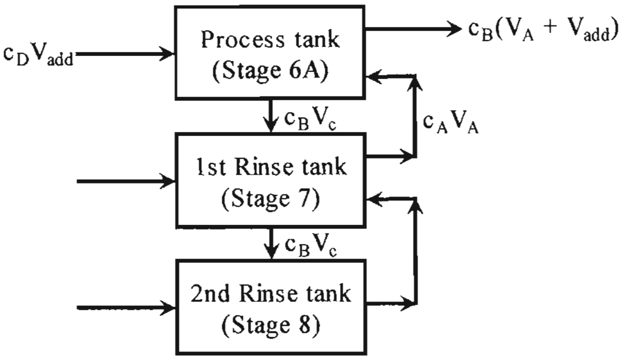


Figure 5.16: Diagram of Stages 6A – 8 showing recycle of the rinse water

Where: c_A = the average chromium(VI) concentration for the rinse tank (g/L)

c_D = the chromium(VI) concentration in the raw material, Gardal K701/1 (54.760 g/L)

V_{add} = the volume of Gardal K701/1 that needs to be added to ensure that there is enough chromium(VI) for the reaction per day (L)

c_B = the average chromium(VI) concentration for the process tank (g/L)

m_{react} = the mass of chromium(VI) that reacts per day (83 597 g; first term in equation 5.4)

V_A = the volume of the recycle (calculated from the flow rate) (L)

V_c = the volume of the dragout (L)

Since this is a liquid reaction, it is assumed that the volume of the output stream is the sum of the volumes of the two input streams.[46] Performing the mass balance over the chromium process tank, Equation 5.5 becomes:

$$[c_AV_A + c_DV_{add}] - [c_B(V_A + V_{add} - V_c) + c_BV_c] - m_{react} = 0 \qquad \text{Equation 5.6}$$

Simplifying. Equation 5.6 becomes:

$$[c_AV_A + c_DV_{add}] - [c_B(V_A + V_{add})] - m_{react} = 0 \qquad \text{Equation 5.7}$$

For each of the different options below, V_{add} was calculated. The volume savings (Table 5.9) were then determined by subtracting V_{add} from the current average volume of Gardal K701/1 added per day (calculated using Equation 5.4 with an average uptime of 48.8%).

1. Recycling the dragout (using the rinse water to top up the process tank)

Equation 5.7 was solved for V_{add} using the current average process tank chromium(VI) concentration of 6 667 g/kL, the current average rinse tank chromium(VI) concentration of 1 243 g/kL, and the original design recycle flow rate of 1.2 kL/hour. V_A was calculated by multiplying the recycle flow rate by the average uptime and by 24 hours to convert it to a volume (L) per day.

2. Recycling dragout to process tank and operating at the design specifications for the chromium(VI) concentrations

The specified process tank chromium(VI) concentration is 2 600 g/kL, and the specified rinse tank chromium(VI) concentration is 485 g/kL. In this calculation it was assumed that the mass of chromium(VI) that reacts is constant at different c_B values (*i.e.* it is always 83 597 grams).

3. Recycling dragout to process tank, operating at the specified chromium(VI) concentration and recycling 50% of the process output stream

A schematic representation of this option is shown in Figure 5.17. Equation 5.7 was used to solve for V_{add}.

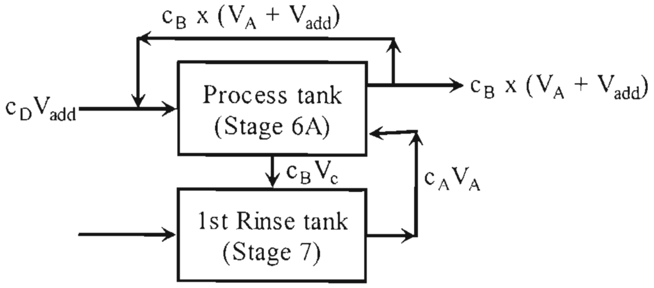


Figure 5.17: Diagram of Stages 6A and 7 showing recycle of the rinse water and process output stream

4. Running as a fed-batch operation (operating at current process tank chromium(VI) concentration)

In this mode, the chromium(VI) that reacts and which is lost through leaks and periodic dumping is replenished from the rinse tank (Stage 7) and the stock Gardal K701/1 solution. In this calculation, the current average process tank chromium(VI) concentration (6 667 g/kL) and the current average rinse tank chromium(VI) concentration (1 243 g/kL) are used. Equation 5.8 is the mass balance on the chromium process tank when operating in fed-batch mode. However, the volume of chromium(VI) that can be added is limited by the volume of chromium(VI) that is lost through reaction, leaks and partial dumping (Equation 5.9). Equations 5.8 and 5.9 were solved simultaneously to determine V_{add}.

$$m_{react} + m_{topup} = c_A V_{rinse} + c_D V_{add} \qquad \text{Equation 5.8}$$

$$V_{add} + V_{rinse} = \frac{m_{react} + m_{topup}}{c_B} \qquad \text{Equation 5.9}$$

Where:
m_{topup} = the mass of chromium(VI) required to top up the process tank every day (10 932 g/day; second term in Equation 5.4)
V_{rinse} = the volume of rinse water that can be used to top up the process tank (L)

Using fed-batch mode, V_{rinse} was calculated to be 12 742 L/day. This means that at a certain time each day 12.7 kL of rinse water is required to be pumped into the chromium process tank. In terms of the pumping requirements, this would not be practical. However, 12.7 kL is the optimum volume and therefore it would be possible to decrease the volume of rinse water and still achieve financial savings.

If the chromium pretreatment leak from the spraybars into the acid process and rinse tanks (Section 2.5.2) could be fixed then V_{rinse} will be further reduced, since m_{topup} will be decreased. This will result in further volume savings in Gardal K701/1.

The additional savings that are shown in Table 5.9 were calculated from the effluent treatment and disposal costs that could be saved by implementing the different modes of operation. If the input volume to the process and rinse tanks is decreased then the effluent (output) volume will also decrease, resulting in financial savings.

Table 5.9: Savings for the chemical raw materials and water from implementing simple process modifications

		Volume Savings (L/day)	Financial Savings (R/day)	Additional Savings	Total Savings (R/day)
Alkali	**1**	25	202		202
	2	26	210		210
	3	26	210		210
Acid	**1**	-12	-90		-90
	2	15	113		113
	3	15	113		113
Chromium	**1**	-1 596	-13 646		-13 646
	2	-446	-3 813		-3 813
	3	-446	-3 813		-3 813
	4	289	2471	cost of disposing 12 742 L rinse water = R4 135/day and less sludge generated	6 606

Key: 1 = Continuous mode; recycling rinse water (dragout) to process tank
2 = Continuous mode; recycling rinse water to process tank, and running at the design specifications for the chemical concentrations
3 = Continuous mode; recycling rinse water, running at the specified concentrations and recycling 50% of the process tank output stream
4 = Running in fed-batch mode, using current chromium(VI) concentrations

For some of the options in Table 5.9 a negative volume savings was obtained. This shows that the option is less feasible than the current operating conditions. However in some cases the additional savings give a resultant positive savings.

It can be seen from Table 5.9 that the introduction of a recycle to the process tank (option 3) gives the same savings as option 2. This arises because the recycled stream is the same composition as the output stream and because it was assumed in the calculation that the mass of chemical that reacts is constant with varying process chemical concentration. Hence the overall chromium(VI) mass balances for options 2 and 3 are identical.

When comparing options 2 and 4 for the chromium process tank (Table 5.9) it can be deduced that it is more economical to run the chromium process tank in fed-batch mode (option 4) rather than continuous mode (option 2). In fed-batch mode, a certain volume is dumped every 24 hours, and then the tank is re-filled using the rinse tank solution in addition to chromium raw material. Running in fed-batch mode will give total savings of R6 600 per day, compared to a loss of R3 800 per day when running in continuous mode. This is because of the high chromium(VI) concentration (currently an average of 6 667 g/kL; specification of 2 600 g/kL) of the process tank solution. When operating in continuous mode the output carries the same concentration of chromium(VI) as the process tank, and therefore a large amount of chromium raw material is lost in the effluent. Hence the effluent treatment and disposal costs are high.

From Table 5.9 it can be seen that it is most economical to run the alkali and acid process tanks as option 2, with total savings of R210 per day for the alkali and R113 per day for the acid.

Table 5.10 shows the annual financial and environmental savings that can be achieved through operating the process tanks in the different modes discussed above as well as other simple process modifications. The savings reported do not account for the capital costs of implementation of these solutions. However, many of the recommendations are merely improved housekeeping. In addition, piping and equipment already exist on CCL2 for implementation of options 1 and 2 in Table 5.9. It is assumed that the recommendations reported will not decrease the quality of the product.

Table 5.10: Potential savings for the wet and pretreatment sections of CCL2

		Resource for Savings	Volume Savings (per year)	Financial Savings (per year)	Priority
Alkali	1	Gardoclean S5160	9 100 L	R 73 700	
	2	Gardoclean S5160	9 500 L	R 76 600	5
	3	Gardoclean S5160	9 500 L	R 76 600	
Acid	1	Gardoclean 450M	- 4 400 L	- R 32 800	
	2	Gardoclean 450M	5 500 L	R 41 200	
	3	Gardoclean 450M	5 500 L	R 41 200	
Chromium	1	Gardal K701/1	- 583 000 L	- R 4 981 000	
	2	Gardal K701/1	- 162 800 L	- R 1 392 000	
	3	Gardal K701/1	- 162 800 L	- R 1 392 000	
	4	Gardal K701/1	105 500 L	R 2 411 000	2
Clean-up costs*		Effluent spills	600 kL	R 258 200	4
Water losses+		Water	15 000 kL	R 66 600	
Prevent leaks#		Acid effluent	0 kL	R 2 244 000	3
Roller applic.§		Chromium effluent	8 300 kL	R 2 694 000	1
		Water	7 700 kL	R 34 200	

Key: 1 = Continuous mode; recycling rinse water (dragout) to process tank
2 = Continuous mode; recycling rinse water to process tank, and running at the design specifications for the chemical concentrations
3 = Continuous mode; recycling rinse water, running at the specified concentrations and recycling 50% of the process tank output stream
4 = Running in fed-batch mode, using current chromium(VI) concentrations
* = Costs of treating the alkali effluent after chromium(VI) leaked into the alkali surge tank from the acid surge tank (only for 3 months)
+ = Water losses calculated from the baseload of the Monitoring and Targeting graph for water (Figure 5.14)
# = Stopping the leak from the chromium process tank (Stage 6A) into the acid tanks (Stages 3-5) – Effluent treatment saving
§ = Using roller application to apply the chromium pretreatment rather than spray application

From the priorities it can be seen that the largest financial and environmental saving can be achieved through the introduction of roller application of the chromium pretreatment rather than spray application, yielding an annual saving of about R2.7 million per year. Roller application results in no chromium effluent, which is expensive to treat since the chromium(VI) first has to be converted to chromium(III) and then precipitated out to remove the heavy metals completely.

Spray application is being phased out of many coil coating lines around the world because of the costly effluent generated.[37] There has been the development, principally in the USA, the UK and Germany, of chemicals that do not require rinsing after application [37] and so reduce the burden placed on the environment. Pretreatment processes based on such chemicals are therefore known as 'no-rinse' processes. The aqueous chemicals react on the aluminium surface after application. Their limited reactivity with the aluminium means that no reaction products are formed which will subsequently require removal. These pretreatment chemicals are superior to rinse processes and are also more economical. They can be used for both architectural and food-packaging end-use products.[37] The value in Table 5.10 compares well with the scoping audit estimate of between R739 700 and R3.2 million in savings in effluent and solid waste disposal.

As discussed, it is most economical to operate the chromium process tank (Stage 6A) as a fed-batch process if the average chromium(VI) concentration of 6 667 g/kL is used. This waste minimisation opportunity results in the second largest saving in Table 5.10 of R2.4 million per year. This saving cannot be compared to the estimation in the scoping audit since it was calculated from disposal costs in addition to raw material costs.

The third largest financial saving can be achieved by preventing the chromium pretreatment from leaking into the acid process and rinse tanks (Stages 3 – 5) at the spray bars (Section 2.5.2). This would mean that the acid effluent could be treated by the company's central effluent treatment plant rather than by the private effluent treatment company. If this leak could be prevented as well as introducing roller application of the chromium pretreatment, all the coil coating effluent could be treated at the company's central effluent treatment plant. The resultant savings (R5 million) exceed the scoping audit estimation (R3.2 million) by 56%.

The fourth priority in Table 5.10 involves preventing spillage of chromium(VI) into the alkali surge tank, which requires clean-up by a private waste disposal company. Clean-up operations are costly, and therefore spills must be prevented. This will save R258 200 per year for the Coil Coating department.

Table 5.10 shows the introduction of option 2 to the alkali process tank as the fifth priority on CCL2. This involves recycling the rinse water to the alkali process tank, and keeping the process and rinse tank concentrations at the design specifications. This option will also yield savings on the acid process tank, with total savings for both process tanks of R117 800 per year. The scoping audit underestimated the savings in alkali and acid raw materials with a predicted maximum saving of R43 700.

A further recommendation in Table 5.10, which is essentially improved housekeeping, is to prevent water wastage. A saving in water consumption, and therefore purchasing costs, usually leads to a saving in wastewater volumes and thus disposal costs. A reduction in water consumption may also reduce the environmental impact of any subsequent discharge to a river.[47] The savings that can be achieved by reducing the water consumption (R66 600) compare well with the maximum water saving estimated by the scoping audit of R65 000.

The maximum total savings that can be achieved in Table 5.10 are R5.3 million. The scoping audit was therefore an underestimate of the maximum savings since it estimated a maximum saving of R3.6 million. However the priorities identified by the two methods compare favourably. The first priority in the scoping audit and in Table 5.10 is the chromium effluent treatment. The consumption of the chromium raw material (Gardal K701/1) is also a high priority, with it being the second priority in Table 5.10 and the third in the scoping audit. Also, the alkali raw material consumption is the fifth priority in both the scoping audit and Table 5.10.

The true cost of waste assessment priorities also compare well with the scoping audit and Table 5.10. Once again, the effluent and solid waste are the first priority for savings as they are the greatest costs in the three waste streams. The second largest cost is Gardal K701/1, with the acid raw materials (Gardoclean 450M and 450C) being next. However, the water is a small proportion of the total cost of the waste streams (14% for the alkali waste stream, and

1% for both the acid and the chromium stream). This suggests that the reduction of water consumption is least important in minimising waste.

When comparing the waste minimisation techniques used, each of the pre-assessment techniques (scoping audit, rough mass balances and true cost of waste assessment) identified similar priorities in waste minimisation opportunities on the two coil coating lines. These priorities were further confirmed in the monitoring and targeting analysis. Since each of the techniques is able to identify and prioritise waste minimisation opportunities, the techniques were then compared in terms of their usefulness. The most useful technique for identifying waste minimisation opportunities was considered to be that which yielded the most information with the greatest ease of application.

The scoping audit was considered the most useful of the pre-assessment techniques because of the relatively small amount of data required for its application. The scoping audit did however underestimate the magnitude of the potential financial and environmental savings (from implementing waste minimisation solutions) on the coil coating lines: potential savings in solid waste and effluent disposal were underestimated by 56%, and potential savings in raw materials were underestimated by up to 170%. This may be attributed to the 'scope to save' percentages being developed for industries in the United Kingdom where environmental legislation enforcement and implementation appear to be more stringent than in South Africa. As a result, the 'scope to save' in raw materials and waste from implementing waste minimisation solutions is greater for South African industries. Thus the 'scope to save' percentages would need to be modified to describe local conditions better. Maximum 'scope to save' percentages of 13 and 100 were obtained in this study for raw materials, and effluent and solid waste disposal, respectively. These figures need to be verified by application to other industrial sectors within South Africa.

Monitoring and targeting was found to be the most useful of the detailed assessment techniques since information on the process control, efficiency and baseload can be obtained from a single plot. Several waste minimisation opportunities can thus be identified simultaneously through this technique. However, data with much scatter and hence a poor correlation coefficient (R^2-value) only indicates poor process control. The meaning of the gradient and y-intercept are less certain with such data.

5.3 Conclusion

Coil Coating Line 1 and 2 wet sections and pretreatment sections were analysed in this chapter to determine waste minimisation opportunities using mass balances, monitoring and targeting graphs, scoping audits, and true cost of waste assessments.

For CCL1, all the techniques identified water consumption as a major area where savings can be made. Financial savings of R80 800 and environmental savings of 18 200 kL can be achieved by decreasing the water consumption in the rinse tanks. This could be achieved by adding clean water to flush the rinse tanks only prior to their use, and by maintaining more control over the water additions. Further savings can be made by using energy from other areas of the plant (either the ovens or from the incineration of the paint fumes) instead of heavy fuel oil to heat the process and rinse tank solutions.

The true cost of the acid waste stream from CCL1 was calculated to be R295 100 per year, with the acid raw materials contributing the most of all the constituents (R166 800 per year). The acid raw materials consumption could be decreased by controlling the additions more effectively, for example by using a conductivity meter. The conductivity can be measured and can be related to the acid concentration. Adjustments could then be made accordingly to keep the acid concentration constant.

The scoping audit for CCL1 identified the consumption of the chromium raw materials as an area for savings. During the data collection period there was a leak in the holding tanks. If this leak is fixed, a saving of R34 900 per year could be achieved.

The scoping audit estimated total savings through waste minimisation of between R31 300 and R131 100 per year for CCL1. This compares favourably with the savings given above, and was therefore a reasonable estimation of the savings that could be achieved through waste minimisation for CCL1.

A number of waste minimisation opportunities were identified for CCL2. The greatest saving, which was identified by the scoping audit, the true cost of waste assessment and process design considerations is the effluent treatment and solid waste disposal. A total of

R2.7 million and 8 300 kL of chromium effluent per year could be saved if roller application of the chromium pretreatment was used instead of spray application. In addition, R2.2 million per year could be saved if the leak at the spraybars of chromium pretreatment solution into the acid process and rinse tanks could be prevented.

The next greatest saving for CCL2 can be achieved by running the chromium process tank as a fed-batch process, and the alkali and acid process tanks as continuous processes at the specified chemical concentrations and with recycling the rinse water. The financial and environmental savings that can be achieved are R2.4 million and 106 kL per year for the chromium, R 76 600 and 9.5 kL per year for the alkali, and R41 200 and 5.5 kL per year for the acid.

Another saving for CCL2 that was identified by the scoping audit is the water consumption. A saving of R66 600 and 15 000 kL of water per year can be achieved by controlling the water additions better and ensuring that taps are not left open.

An auto-dosing system for the alkali raw material, based on conductivity, was introduced into the alkali process tank at the beginning of September. This improved the control over the alkali concentration in the process tank significantly and also improved the process efficiency. It is therefore recommended that an auto-dosing system be used for the acid and chromium process tanks as well.

The total maximum financial and environmental savings that were calculated for CCL2 were R5.3 million and 31 600 kL per year respectively. The financial savings are greater than the value of R3.6 million per year predicted by the scoping audit. This shows that in this case the scoping audit was an underestimate of the savings that could be achieved, and therefore the 'scope to save' percentages require modification for application to South African industry. However, the priorities identified by the scoping audit are accurate since all five priorities are areas where savings can be made.

The savings that have been reported do not include the capital costs of implementing the waste minimisation changes. However, most of the recommendations are improved housekeeping, and those changes that are more complex mostly make use of piping and equipment that already exist on the plant.

CHAPTER 6

Conclusions and Recommendations

In recent years, waste minimisation and pollution prevention have become the preferred methods for dealing with industrial waste. With increased environmental pressure and the rising cost of waste treatment and disposal, it has become beneficial to reduce or eliminate waste at source.[2, 4] Waste minimisation has resulted in great successes in the United Kingdom and has now been introduced in South Africa.[11] This thesis has been concerned with an assessment of the Pietermaritzburg Waste Minimisation Club (PWMC). It also involves a waste minimisation audit that was conducted at two aluminium coil coating lines at a company which is a member of the PWMC. The major findings from this assessment are summarised in this chapter, as well as recommendations regarding running a waste minimisation club and conducting a waste minimisation audit. Areas where future research could be conducted to further assess the PWMC are discussed.

6.1 Conclusions

Waste minimisation is achieved through the implementation of a systematic waste minimisation programme, and involves a variety of changes to the way a process is carried out to decrease the amount of waste produced. The benefits include reduced raw material and utility costs; reduced waste treatment and disposal costs; compliance with regulations; improved process performance; and a competitive advantage.

A literature survey revealed that waste minimisation is achieved effectively through the forum of a waste minimisation club. These clubs consist of a group of industries in a geographical area that are interested in reducing their waste and hence reducing the impact on their environment. The Pietermaritzburg Waste Minimisation Club was started in February 2001 and consisted of 11 member companies during 2001. The club is cross-sectoral, meaning that the member companies manufacture different products or provide different services. The

PWMC is administered by the Chemical Technology Group of the University of Natal, Pietermaritzburg.

Information to assess the success of the PWMC was gathered through two questionnaires that were completed by the members. The training material used in the PWMC was waste minimisation modules developed by the March Consulting Group (now Enviros).[6] These modules were useful in giving the members a broad idea of what a waste minimisation programme is, and what implementation of one involves. However, the training material does not seem to have given the members enough practical information to implement a waste minimisation programme in their companies. Hence the members requested the Chemical Technology Group to assist with conducting the waste audits.

Part of this study was concerned with identifying the factors that hinder ('barriers') and motivate ('drivers') waste minimisation. The PWMC members were asked to identify the major barriers and drivers that they encountered to waste minimisation during 2001. The main barriers were production pressure, operational constraints, lack of human resources and a lack of management time. The main drivers identified were financial savings, improved plant utilisation and improved environmental performance. These drivers and barriers were found to be similar to those reported in the literature[11, 24, 25] except that environmental legislation was not a driver for the PWMC.

This study focused primarily on the waste audit stage of a waste minimisation programme since a waste audit was conducted on two coil coating lines at a company that is a member of the PWMC. A literature review identified six techniques that can be used to generate waste minimisation opportunities. They are process flow diagrams; a scoping audit; mass balances; true cost of waste; monitoring and targeting; and statistical process control.

Coil coating is a highly automated, continuous process where a coiled sheet of steel or aluminium (in this case aluminium) is cleaned, pretreated and receives a coating of paint or plastic laminate. Coil Coating Line 1 (CCL1) is the older line of the two processes audited and coats aluminium for architectural uses. Coil Coating Line 2 (CCL2) is fully automated and produces coated aluminium primarily for the beverage can industry. The waste minimisation audit was focused on the cleaning (wet) and pretreatment sections of the coil coating lines.

Data needed for the waste minimisation audits included the flow rates, compositions and costs of all input and output streams to the respective wet and pretreatment sections. The data were collected over a three-month period (July to September 2001) and were obtained from operators and, where not available, were measured.

The true cost of waste for CCL1 was calculated as R295 100 per year. The scoping audit for CCL1 estimated annual minimum savings of R31 300 and maximum savings of R131 100 from implementing waste minimisation principles. The greatest area for savings is the water consumption. Other areas in which savings could be achieved include greater control over the total acid, free acid and fluoride concentrations in the Acid Cleaner tank; fixing the leak in the chromium holding tanks; and finding an alternative energy source to heat the process and rinse tank solutions rather than burning heavy fuel oil.

Large amounts of water have been used in the rinse tanks on CCL1 to maintain the fluoride concentrations at low levels so that primed aluminium can be rinsed in the tanks. The large amounts of water used were also reflected in the high baseload (ranging from 27 to 57 kL) of the XY scatter graphs. This baseload equates to 18 200 kL of water (R80 800) which could be saved annually by flushing the rinse tanks with clean water only prior to use rather than adding water continuously. This savings compares well with the savings range of R25 700 – R102 600 predicted in the water scoping audit.

Potential financial savings of R116 000 and environmental savings of 18 200 kL of water or effluent per year were calculated for CCL1.

The conductivity and free and total alkali concentrations for the Alkali degreaser (Stage 1) on CCL2 are variable up to the 6 September, and become significantly more constant from the 7 September. This was due to the introduction of an auto-dosing system, based on the conductivity of the tank solution, for the additions of the alkali raw material (Gardoclean S5160). The XY scatter graph for the consumption of alkali further indicates the improvement that was achieved through the introduction of the auto-dosing system. The baseload, process efficiency and the process control all improved from July to September.

The scoping audit for CCL2 estimated total minimum savings of R816 000 and maximum savings of R3.6 million per year. The true cost of waste for the alkali waste stream was calculated to be R124 900 per year; the costs of the acid and chromium waste streams were R2.9 million, and R5.2 million respectively.

The greatest area for saving on CCL2, identified by both the scoping audit and the true cost of waste assessment, was the effluent treatment and solid waste disposal. A saving of R2.7 million per year could be achieved by using roller application of the chromium pretreatment rather than spray application. A further R2.2 million per year could be saved by preventing the leak of chromium(VI) into the acid process and rinse tanks. The total savings calculated (R5 million) exceed the scoping audit estimation of R3.2 million by 56%.

Other savings that can be achieved on CCL2 include operating the chromium process tank as a fed-batch process (R2.4 million per year) and operating the alkali and acid process tanks as continuous processes with the specified chemical concentrations and with a recycle of the rinse water. This would yield annual savings of R76 600 for the alkali and R41 200 for the acid.

Decreasing the water consumption on CCL2 could achieve savings of R66 600, which compares well with the maximum water savings estimated by the scoping audit (R65 000). Greater control over the water additions to the process and rinse tanks could decrease the water consumption.

Overall, the scoping audit was an underestimate of the financial savings that could be achieved on CCL2. The maximum savings were calculated as R5.3 million per year whereas the scoping audit estimated a total maximum saving of R3.6 million.

The three pre-assessment techniques (scoping audit, true cost of waste assessment, and rough mass balances) and the two techniques for a more detailed assessment (monitoring and targeting, detailed mass balances) were evaluated for their usefulness in identifying waste minimisation opportunities. All pre-assessment techniques identified similar waste minimisation opportunities, which were verified through a more detailed assessment. The scoping audit and the monitoring and targeting analysis were found to be the most useful of the techniques, although the 'scope to save' percentages require modification for application to South African industry.

6.2 Recommendations

From the assessment of the first year of the Pietermaritzburg Waste Minimisation Club, the following recommendations are made regarding the running of a waste minimisation club:

i. A definite focus of a waste minimisation club should be on the members taking ownership of the waste minimisation efforts in their companies, otherwise waste minimisation will not be as effective as it could be.

ii. The training material used in a waste minimisation club should be relevant to the companies that are members. It is then easier for them to identify with relevant examples.

iii. If possible, a preliminary audit should be conducted by the club facilitators for the member companies to get them started in the waste minimisation process.

iv. Incentives such as certificates of membership or a prize for the best savings achieved, should be used to increase the companies' interest in waste minimisation. With society becoming more aware of an industry's environmental impact, companies are eager to promote themselves as 'environmentally-friendly'.

From the waste minimisation audit conducted at the two coil coating lines, the following recommendations are made:

i. On CCL1, the water consumption could be reduced by only adding clean tap water when the line is running, by maintaining control over water additions, and by using the presently empty tank as another counter-current rinse tank.

ii. Roller application of the chromium pre-treatment for CCL2 could be used rather than spray application resulting in little or no effluent and sludge production.

iii. On CCL2, it is advised that an auto-dosing system is installed for the raw material additions of Stage 3 (acid cleaner) and Stage 6A (chromium pretreatment).

iv. The water consumption on CCL2 could also be reduced by maintaining greater control over water additions.

v. It is recommended to run the alkali and acid process tanks (CCL2) as continuous processes at the specified chemical concentrations and with recycling the rinse water.

6.3 Areas for Further Research

The following areas of research could yield a greater understanding of waste minimisation clubs:

i. Continue monitoring the progress of the waste minimisation programme of the member companies to determine whether their drivers and barriers change throughout the club's existence.
ii. Assess the success of having students performing the waste minimisation audits for the companies.
iii. Assess the success of having a prize for the company that achieves the greatest savings through waste minimisation.

The following areas of research could further improve the results of waste minimisation audits in South African industries:

i. Determine whether the scoping audit under predicts the potential savings in other industrial sectors in South Africa, and if so, to determine 'scope to save' percentages which are more relevant for South African industry.
ii. Assess whether the waste minimisation techniques used in this study yield the same opportunities when applied to other industrial sectors.

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Appendix A

In this Appendix, the questionnaires that were completed by the Pietermaritzburg Waste Minimisation Club members are shown. Appendix A.1 is the first questionnaire that was completed by six members in April 2001. The second questionnaire (Appendix A.2) was completed by all members in November 2001.

Appendix A.1: The First Questionnaire for Club Members (April 2001)

A sample of the first questionnaire sent to club members is shown below. The results from the questionnaire are summarised in Appendix D.1.

Waste Minimisation Questionnaire

A. Please can you answer the following by placing an "X" in the most appropriate box.

1. Is the management of your company committed to waste minimisation?

Very committed		Average		Not Committed	

2. Would the management of your company be open to appointing waste minimisation team members who would be involved in overseeing data collection, brainstorming, and implementing waste minimisation options?

Very open		Average		Not open	

3. How does your company feel about a person(s) spending time collecting data for the waste minimisation audit?

Very happy		Average		Not happy	

4. Would your company be open to allowing University of Natal, Pietermaritzburg (UNP) students to help you in the necessary data collection?

Very open		Average		Not open	

5. How do you feel about sharing information on your problems, solutions and successes in waste minimisation with other club members?

Very happy		Average		Not happy	

6. Do you think waste minimisation is useful for small and/or large companies?

Small only		Large only		Both	

7. Is your company already implementing waste minimisation measures?

Yes		No	

8. Do you believe there is much room for waste minimisation in your company?

Yes		No	

9. Are you concerned about whether waste minimisation will be a success in your company?

Yes		Slightly		No	

B. Please rate on a scale of 1– 5 (1 = not important; 5 = very important) how important the following benefits of waste minimisation are to your company. Do not use the same ranking more than once.

1. An improvement in emissions and their impact on the environment. ☐
2. Compliance with environmental regulations. ☐
3. Improved process performance. ☐
4. Promoting a company image of environmental awareness. ☐
5. Greater financial savings. ☐

C. Please comment on any other reasons that are motivating you to participate in this waste minimisation club.

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D. Please comment on any other difficulties (barriers) that your organization perceives in participating in this waste minimisation club.

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Appendix A.2: The Second Questionnaire for Club Members (December 2001)

A sample of the second questionnaire sent to club members is shown below. The results from the questionnaire are summarised in Appendix D.2.

The Pietermaritzburg Waste Minimisation Club

Waste Minimisation Clubs

Working together

1. Please classify your company:
- ☐ Small-to-medium sized enterprise
- ☐ Large company (greater than 500 employees)
- ☐ Regulator
- ☐ Other

2. How many meetings have you attended (this is the seventh meeting)?________

3. Has the training material been useful for giving you a broad idea of what a waste minimisation program is, and what implementation of one involves?

Yes	☐	No	☐

4. Has the training material been useful for actually implementing a program in waste minimisation in your company?

Yes	☐	No	☐

5. Did you find that the level at which the training material was pitched was:
- ☐ too technical
- ☐ too mathematical
- ☐ too general
- ☐ just right

6. Has the training material raised your awareness about waste minimisation in general?

Yes	☐	No	☐

7. Have you identified opportunities for waste minimisation in your company through casual observation or other informal means (rather than applying the methods covered in the training material)?

Yes	☐	No	☐

8. If so, what action did you take?

____

____

____

9. Have you used any of the following:

☐ Process flow diagram
☐ Collecting any data for a waste minimisation audit
☐ Scoping audit
☐ Mass/energy balance
☐ Monitoring and targeting
☐ Statistical process control

10. Have you identified any waste minimisation opportunities using the above techniques?

Yes		No	

11. To get the waste minimisation program underway:

- Is it realistic to have someone appointed as a project champion to oversee waste minimisation in your company?

Yes		No	

- How easy is it for this person to involve other people in the company in the waste minimisation process?

Easy		Average		Not easy	

- Would you prefer some help from us (Chemical Technology Group) in the initial waste minimisation audit?

Yes		No	

12. Have you introduced the Mission-directed work team system used by Webroy?

Yes		No	

13. Have you introduced incineration as spoken about by Phillip Symons?

Yes		No	

14. Have you given solvent to Frank Trump or purchased one of his units?

Yes		No	

15. Have you established useful environmental connections with companies or authorities as a result of the Club?

Yes		No	

If yes, please give details:

____

____

16. Please tick the 5 most significant barriers that you/your company has/have experienced to waste minimisation:

	Low business confidence
	Low business profitability
	Disbelief of payback periods
	Lack of technical knowledge
	Lack of awareness of cleaner production
	Perceived as high risk
	Lack of management time
	Operational constraints
	Lack of enforcement of legislation
	Unclear legislation
	Lack of outside pressure
	Lack of information
	Lack of human resources
	Resistance to change
	Production pressure
	Lack of finance

17. Please tick the 3 most significant drivers that you/your company has/have experienced to waste minimisation:

	Financial savings
	Improved environmental performance
	More stringent legislation
	Pressure from customers
	ISO 14000
	Improved plant utilisation
	Improved image

18. Are you inhibited by the presence of Umgeni Water at club meetings?

Yes		No	

19. Is there anything else that you would like included in the club activities?

____

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20. Any other comments?

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Appendix B

Details of the analytical methods used for the data collection at the two coil coating lines are presented in this Appendix. The analytical methods that are described are for the determination of fluoride, total acid, total alkali, chromium(VI) and chromium(III) concentrations of samples from Coil Coating Line 1 (CCL1) and Coil Coating Line 2 (CCL2).

Rinse 1: CCL1

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA).

Rinse 2: CCL1

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA).

Acid Surge Tank :CCL1

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA).

Total acid

Sample (ml)	10.00
Water (ml)	100
Indicator	5 drops phenolphthalein
Titration solution	0.09722 M sodium hydroxide
Colour change	clear to pink

Acid Rinse (Stage 4): CCL2

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA).

Chromium pretreatment Rinse (Stage 7): CCL2

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode.

Chromium(VI) - Chromic acid point

Sample (ml)	10.00
Water (ml)	50
Indicator	20 drops 50% sulfuric acid and 1g potassium iodide
Titration solution	0.1010 M sodium thiosulfate
Colour change	brown to yellow
Indicator	0.2 g thyodene
Colour change	black-blue to clear green

Surge Tank A (alkali): CCL2

Total alkali

Sample (ml)	100.00
Water (ml)	100
Indicator	5 drops bromocresol green
Titration solution	0.04901 M sulfuric acid
Colour change	blue to yellow

Surge Tank B (chromium): CCL2

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA).

Total acid

Sample (ml)	10.00
Water (ml)	100
Indicator	5 drops phenolphthalein
Titration solution	0.09722 M sodium hydroxide
Colour change	clear to pink

Chromium(III)

5.00 ml of sample, with 2.00 ml 0.05 M silver nitrate ($AgNO_3$), 5 g potassium persulfate ($K_2S_2O_8$). Boil for five minutes, and make up to 100.0 ml. Measure with a UV-visible spectrophotometer at 440 nm, using potassium dichromate ($K_2Cr_2O_7$) calibration standards (0.03392 mmol/L; 0.08480 mmol/L;
0.1696 mmol/L; 0.3392 mmol/L).

Surge Tank C (acid):CCL2

Fluoride

25 ml sample with 25 ml TISAB buffer.
Standards: 20.0 mg/L, 40.0 mg/L, 60.0 mg/L, 80.0 mg/L, 100.0 mg/L, 200.0 mg/L.
Measure with fluoride ion selective electrode (Orion, Fluoride Ionplus Sure-Flow® electrode Model 96-09, USA).

Total acid

Sample (ml)	10.00
Water (ml)	100
Indicator	5 drops phenolphthalein
Titration solution	0.09722 M sodium hydroxide
Colour change	clear to pink

Chromium(VI) - Chromic acid point

Sample (ml)	10.00
Water (ml)	50
Indicator	20 drops 50% sulfuric acid and 1g potassium iodide
Titration solution	0.1010 M sodium thiosulfate
Colour change	brown to yellow
Indicator	0.2 g thyodene
Colour change	black-blue to clear green

Appendix C

In this Appendix, the minutes of the seven Pietermaritzburg Waste Minimisation Club meetings held during 2001 are shown.

The Pietermaritzburg Waste Minimisation Club

MINUTES OF THE MEETING HELD WEDNESDAY 7 FEBRUARY 2001 AT 16:00 CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. WELCOME

Nicola Brown welcomed everyone to the Inaugural meeting of the Pietermaritzburg Waste Minimisation Club.

2. PRESENTATION BY PROFESSOR CHRIS BUCKLEY

Professor Chris Buckley of the Pollution Research Group at the University of Natal (Durban) gave a presentation on the large financial and environmental savings that can be achieved through waste minimisation clubs. He spoke with specific reference to the two very successful waste minimisation clubs that he and Susan Barclay have set up in Durban (Metal Finishing Club) and Hammarsdale (cross-sectoral club, mainly textile industry).

3. SHORT VIDEO ON WASTE MINIMISATION

A 25-minute video was shown on the Aire and Calder and Project Catalyst waste minimisation clubs that were run in the United Kingdom. The video further outlined the large financial savings that can be achieved through introduction of a waste minimisation programme in companies. It also illustrated that many of the changes that saved money in companies were simple house-keeping.

4. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

Agenda Item		Action
4.1	**Future Meetings:** Nicola Brown reported that the PMB Waste Minimisation Club will be run by the Chemical Technology Section of the University of Natal, Pietermaritzburg (UNP). The training in waste minimisation takes the form of a series of modules (developed by the March Consultancy Group in the U.K.). It was agreed that all future meetings will be held in the Chemistry Honours Seminar Room (UNP), the same venue used for the Inaugural Meeting. The next meeting will be held on Wednesday, 14 March 2001, at 4 pm. Thereafter, training modules will be held every two months to give companies an opportunity to implement the module tasks.	

Agenda Item		Action
4.2	**Club Costs:** Nicola Brown presented a budget for the running of the club. Those companies that wish to participate in the waste minimisation training need to send a R400 cheque to the University of Natal. Please address the envelopes to Dr N. Brown, School of Chemical and Physical Sciences, University of Natal, Private Bag X01, Scottsville, 3209. This fee will cover the club costs for the year.	
4.3	**Support by the Chemical Technology Section:** Sally Spankie discussed how the Chemical Technology Section would like to use the waste minimisation club as an educational opportunity for its Honours and Masters students. As part of their training, these students have a sound grounding in analytical techniques in addition to training in occupational hygiene and chemical engineering principles. The latter includes training in mass and energy balances. Students would be available to help companies with collecting the data and performing the material balances necessary for the waste minimisation audit. An additional fee of R200 plus petrol costs would be necessary for students to do this work at companies. This fee covers the University's expenses (eg. stationery, chemicals etc.)	
5	**General:** Bill Armitage (Webroy) inquired whether he could send other members of Webroy along to the training modules. Sally Spankie and Nicola Brown agreed that this was fine. Bill Armitage also questioned what the difference was between the PMB Waste Minimisation Club and the PMB Metal Finishing Club. The former is intended for all industry other than the Metal Finishing industry in Pietermaritzburg. The latter is intended only for the Metal Finishing Industry in Pietermaritzburg. Bill Armitage further expressed his disappointment that more industry had not attended the Inaugural meeting. Chris Fennemore (Umgeni Water) pointed out that waste minimisation benefits everyone: manufacturers in the financial savings that they make, Umgeni Water in that it is easier to treat the potable water in the Umgeni/Inanda Dam area, and consumers in that the potable water will consequently be cheaper. Sally Spankie thanked everyone for attending the Inaugural meeting and invited everyone to the Chemistry bar area for the braai and refreshments. The meeting closed at 17H20.	

The Pietermaritzburg Waste Minimisation Club

Waste Minimisation Clubs

Working together

MINUTES OF THE MEETING HELD ON WEDNESDAY 14 MARCH 2001 AT 16:00 CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. WELCOME

Nicola Brown welcomed everyone to the second meeting of the Pietermaritzburg Waste Minimisation Club.

2. PRESENTATION BY PHILLIP SYMONS

Phillip Symons gave a short presentation on the benefits of effective recycling and incineration. He brought the idea from Florida in the USA, where domestic waste is incinerated in specially designed furnaces. He ran an incineration plant in New Hanover for timber chips and it was found to be very efficient. The furnaces are smokeless and can incinerate glass, plastic, cardboard and cans. They are also very cost-effective to run. Skukuza camp in the Kruger National Park has incinerators that work very effectively to eradicate all the camp waste. Phillip Symons is presently looking for anyone who will be interested in running an incineration plant in Pietermaritzburg.

3. FIRST SEMINAR ON WASTE MINIMISATION

Sally Spankie and Nicola Brown gave the first seminar on Waste Minimisation. It introduced the concept of waste minimisation, as well as the many benefits. The methodology used for waste minimisation was discussed. The barriers and drivers were also highlighted.

4. WORKED EXAMPLE

To illustrate the idea of the scoping audit, an example was done for an imaginary company by the name of DriCoates Ltd.

5. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

5.1 Role of UNP

The role of UNP in the Pietermaritzburg Waste Minimisation Club is to train members, as well as to see to the administrative issues of the Club. UNP would organise guest speakers, or facilitate discussion on any problems that the club members may have. UNP will also provide students for data collection or for the audits, if companies need assistance in this regard.

5.2 Questionnaire and Information Sheets

All the companies that attended the meeting were asked to fill in information sheets on their company, and to answer a questionnaire about their company's attitude to waste minimisation.

5.3 Disposal of Fluorescent tubes and Mercury lamps

The club was informed that Ronnie Wilmans is able to dispose of fluorescent tubes and mercury lamps. His phone number is 083 555 0358.

5.4 Date and Time of Next Meeting

Nicola Brown proposed that the next meeting be held on Wednesday, 4 April 2001, at 4 PM. This was agreed to by all. The meeting will once again be held in the Chemistry Honours Seminar Room (UNP). Bill Armitage offered to talk on waste minimisation at Webroy (Pty) Ltd. Thereafter, the scoping audit example will be discussed and the second module will be presented.

6. CLOSURE OF MEETING

The meeting was closed at 17h40.

The Pietermaritzburg Waste Minimisation Club

Waste Minimisation Clubs

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MINUTES OF THE MEETING HELD ON WEDNESDAY 4 APRIL 2001 AT 16:00 CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. WELCOME

Nicola Brown welcomed everyone to the meeting of the Pietermaritzburg Waste Minimisation Club.

2. PRESENTATION BY BILL ARMITAGE

Bill Armitage is the Production Director at Webroy Pty Ltd. Webroy Pty Ltd has recently become involved in a new management plan (Mission-directed Work Teams) developed by Competitive Dynamics, a management consultancy in Johannesburg. This program involves creating mini-businesses out of the departments in the company. Each mini-business focuses on their quality, speed, cost, safety and morale. These five points are monitored daily and the progress of each is plotted on a graph. Team meetings are held for ten minutes every morning before work starts, where workers evaluate their progress in each of these areas. Here, they can also voice their complaints or suggestions. This management approach has worked exceptionally well at Webroy Pty Ltd as can be seen from the morale of all workers. There have been minimal disagreements between departments and the attendance is now up to 98%. Bill Armitage stated that Webroy Pty Ltd will never look back. The entire program takes five years to work through. This program was initiated by the Department of Trade and Industry who cover 75% of the costs. The training courses are run by Competitive Dynamics.

Waste minimisation will be incorporated into each mini-business in the cost category. The management style used at Webroy (Pty) Ltd complements very well the team approach advocated in waste minimisation. The management style thus facilitates the implementation of waste minimisation principles.

3. DISCUSSION OF SCOPING AUDIT EXAMPLE

The answer to the scoping audit based on the imaginary company DriCoates Ltd was discussed. Nicola Brown explained that this scoping audit was developed for a cross-sectoral waste minimisation club, and therefore the "Scope to Save" percentages can be used in any company. The value of the scoping audit is that it allows companies to identify (approximately) those areas with the greatest potential for environmental and financial savings on applying waste minimisation principles.

4. SECOND SEMINAR ON WASTE MINIMISATION

Nicola Brown began the first part of the second seminar on Waste Minimisation. It introduced the use of process flow diagrams, which was explained further by the use of a case study of DriCoates Ltd. Two groups of members were formed, and each group had to develop a process flow diagram for a certain department of the DriCoates Ltd plant.

Nicola Brown proposed that before the next meeting, all members perform a scoping audit and a process flow diagram on the area in their own company with the greatest potential savings. Andrew Turner requested UNP to remind the members a month before the meeting that they need to complete these tasks. Nicola Brown informed him that that would be possible.

5. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

5.1 Questionnaire

All the companies that attended the meeting were asked to fill in a questionnaire about their company's attitude to waste minimisation.

5.2 Disposal of Oil

Andrew Turner informed the club of a company (OILKOL), which is part of FFS Refineries. They pay companies to remove their oil and deduct a small fee for the container. They then reprocess the oil. They can remove machine and motor oil, but unfortunately cannot reprocess diesel and paraffin. Their telephone number is 0800 107 107.

5.3 Date and Time of Next Meeting

Nicola Brown proposed that the next meeting be held on Wednesday, 6 June 2001, at 4 PM. This was agreed to by all. The meeting will once again be held in the Chemistry Honours Seminar Room (UNP). Nicola Brown proposed a guest speaker, Frank Trump, to talk on the recycling of solvents. This was well received by all members. The second half of the second seminar on waste minimisation would also be completed at this meeting.

6. CLOSURE OF MEETING

The meeting was closed at 18h00.

The Pietermaritzburg Waste Minimisation Club

Waste Minimisation Clubs
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MINUTES OF THE MEETING HELD ON WEDNESDAY 6 JUNE 2001 AT 16:00 CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. WELCOME

Sally Spankie welcomed everyone to the meeting of the Pietermaritzburg Waste Minimisation Club. Nicola Brown introduced the guest speaker, Frank Trump.

2. PRESENTATION BY FRANK AND EDDIE TRUMP

The Trump family have produced and marketed two distillation machines for recycling various organic solvents including thinners and benzene, initially for the spray painting industry. The advantages of the two models over existing machines were discussed. Firstly they are fully enclosed which reduces the flammability risk and making it safer to use, and secondly the sludge remaining at the end of the distillation process can be easily drained off from the flask. The first model had the capacity to distil 100 litres over 24 hours and this was increased to 300 litres per 24 hours in the newer model. The newer model was fitted with a microprocessor to allow the oil and distillation temperatures and the pressure inside the flask to be monitored. It also has a fractionating column attached to the distillation flask to allow different solvents to be distilled off one at a time.

The financial and performance benefits of the machines were then outlined. 95% of the solvents from paints can be recovered. It costs R4.60 to buy a litre of new thinners but the Trumps sell thinners recycled on their machine for R3.00 with 50 cents off if the client returns their used thinners. Performance of recycled thinners was reported as being very satisfactory and a comparison of samples of recycled and new thinners seemed to bear this out. Mr Trump reported that it cost R275 to get a private waste disposal company to remove the 200 litres of sludge produced from recycling 4000 litres of thinners. The new model costs R40 000 compared to R37 000 for the less safety conscious machine produced by an established company in this field. Mr Trump can be contacted on 033 345 6503 for any further information.

3. DISCUSSION OF SCOPING AUDIT EXAMPLE

Some of the companies were having their scoping audits done by students and these were not ready for discussion. Participants preferred to move onto the next item on the agenda.

4. SECOND SEMINAR ON WASTE MINIMISATION

Sally Spankie began the latter part of the second seminar on Waste Minimisation. It covered the searching and using of existing data of different sorts available in a company to carry out the waste minimisation scoping audit. Data needed for the audit includes volumetric or mass flow rates of all the process input and output streams, and the concentrations of all major chemical species in these streams. The cost of each of these species is also required.

Nicola Brown discussed the gathering of new information and briefly outlined the analyses that can be performed on this data to identify waste minimisation opportunities. Calculation of the true cost of waste was then discussed. This was illustrated through a case study on the imaginary textile company, DriCoates. This exercise showed that the cost of waste is much more than the disposal costs: the raw material, processing costs and rework costs of the waste contribute significantly to this cost.

5. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

5.1 Duration of Meeting

Nicola Brown proposed that future meetings be of 2.5 hour duration so that more of the training module material can be covered. The members were in agreement with this, although some would still need to leave at 6 PM.

5.2 Date and Time of Next Meeting

Nicola Brown proposed that the next meeting be held on Wednesday, 8 August 2001, at 4 PM. This was agreed to by all. The meeting will once again be held in the Chemistry Honours Seminar Room (UNP). Chris Fennemore of Umgeni Water offered to talk on the treatment of municipal water at the Darvill Sewage Works. The third seminar on waste minimisation, which deals with the analysis of the audit data, will also be started at this meeting.

6. CLOSURE OF MEETING

The meeting was closed at 18h00.

The Pietermaritzburg Waste Minimisation Club

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MINUTES OF THE MEETING HELD ON WEDNESDAY 12 SEPTEMBER 2001 AT 16:00 CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. WELCOME

Sally Spankie welcomed everyone to the meeting of the Pietermaritzburg Waste Minimisation Club and introduced the guest speaker, Chris Fennemore from Umgeni Water.

2. PRESENTATION BY CHRIS FENNEMORE OF UMGENI WATER

Mr Fennemore introduced the need for safeguarding and managing water supplies at the global and local (national and municipal) levels. This focused on the legislative controls for protecting water supplies and the legal implications surrounding water pollution in this country. He also talked about how agencies like Umgeni Water apply an effluent discharge tariff for industries using and polluting water which is cleaned up in their sewage works. This is based on the following equation:-

$$C = (V \times X) + 0.256VY(COD - 350)$$

Where: C is the charge made to the company discharging effluent to the sewer
V is a the volume of effluent discharged
X is a cost adjustment factor based on the volume of effluent discharged
so when $V \leq 400k\ell$, $X = 220c/k\ell/month$
$400kl<V<1000k\ell$, $X = 204c/k\ell/month$
$V > 1001k\ell$, $X = 170c/k\ell/month$
Y is a time factor for phasing in the full trade effluent charge. Current/initial value is 0.33 and this is progressively increased to 1
COD is the averaged Chemical Oxygen Demand taken over 6 months in mg/ℓ
350 is the assumed normal Chemical Oxygen Demand for domestic sewage in mg/ℓ
0.256 is an aeration factor associated with the effluent treatment

This means that there is a discount if a large volume of water is going through the effluent treatment plant. There is also a maximum value of R8800 per month for the (V x X) element of the equation. The Y value is likely to be increased and the new value will be set in November this year. Mr Fennemore also mentioned that Umgeni Water were considering introducing tariffs based on for example chromium levels in water in addition to those using COD.

3. REVIEW OF THE WASTE MINIMISTATION PROCESS IN THE PMB CLUB

Sally Spankie summarised the steps of the waste minimisation process and discussed the completion of the audits early next year with assistance from the Chemical Technology Group of the University. She also announced that a trophy would be awarded at the end of 2002 for the company who had made the best achievements in waste minimisation. The PCCI were thanked for their kind donation of this trophy. Members were asked to complete a waste minimisation questionnaire designed to give feedback on the status of waste minimisation implementation in their company.

4. THIRD SEMINAR ON WASTE MINIMISATION

Nicola Brown discussed how to use mass balances to identify and quantify waste minimisation opportunities. This looked at how inputs to, outputs from and losses from a process are related to the stock levels. This was illustrated through a case study on the imaginary textile company, DriCoates. This exercise costed the loss to the manufacturer based on the percentage of (input) materials not being incorporated into the final product and also looked at opportunities for recycling water.

5. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

5.1 Date and Time of Next Meeting

It was agreed that there would be two more meetings this year, the next one being on Wednesday the 31st of October. The meeting will once again be held in the Chemistry Honours Seminar Room (UNP).

6. CLOSURE OF MEETING

The meeting was closed at 18h00.

The Pietermaritzburg Waste Minimisation Club

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MINUTES OF THE MEETING HELD ON WEDNESDAY 31 OCTOBER 2001 AT 16:00, CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. WELCOME

Nicola Brown welcomed everyone to the meeting of the Pietermaritzburg Waste Minimisation Club. She also informed the club that the University of Natal would like to perform waste audits for every company in the club, and this will hopefully be completed by June 2002. The club members can then report back on their actual savings, and the award will be made for the best achievements in waste minimisation.

Nicola Brown informed the club about a breakfast held by the Waste Minimisation Interest Group of KZN. The breakfast is on the 15 November 2001 at the Westville Hotel. Details are attached.

2. 3rd MODULE: USING MONITORING AND TARGETING TO IDENTIFY WASTE MINIMISATION OPPORTUNITIES

Nicola Brown discussed various methods used in monitoring and targeting. Monitoring and targeting involves monitoring the consumption of a material, and then comparing it to a measure of activity such as production. It uses graphical techniques to show visually when the process is out of control. These are the XY scatter plot, trend graph, variance graph, and a CUSUM plot. The XY scatter plot is simple, yet it gives a large amount of information. It is used to compare consumption to a relevant production variable. This information can then be used to set consumption targets. A workshop was completed using these methods to set targets for the electrical consumption of a Bottling department.

3. 3rd MODULE: USING STATISTICAL PROCESS CONTROL TO IDENTIFY WASTE MINIMISATION OPPORTUNITIES

Sally Spankie spoke on the use of statistical process control in waste minimisation. Statistical process control is most useful when monitoring process variation that is related to a fixed target, such as quality. Control charts are used which are plots of a certain variable with time, and which show the process stability. Sally Spankie also highlighted the importance of keeping records of all potential opportunities. This prevents the possibility of re-inventing opportunity or potential solutions.

In summary, the following methods were again highlighted as ways of identifying waste minimisation opportunities:

- Scoping audit (Module 1)

- Data analysis (Module 3: mass balance, monitoring and targeting, statistical process control)
- Observation of the process
- Involving people so they come up with good ideas.

4. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

4.1 Date and Time of Next Meeting

Nicola Brown proposed that the next meeting be held on Wednesday, 5 December 2001, at 4 PM. This was agreed to by all. The meeting will be held in the Chemistry Honours Seminar Room (UNP). John Danks of Saayman Danks in Durban will be asked to be the guest speaker, as he has achieved great savings through waste minimisation in his company. There will also be a report back of results from Chemical Technology Honours students who have performed audits in companies this year. There will be a questionnaire for club members at the next meeting so that the club administrators can gather information on the performance of the club this year.

4.2 Increase in the effluent discharge tariff

Nicola Brown drew the club members' attention to the fact that the effluent discharge tariff for industries sending effluent to the Darvill Wastewater Works has increased. The charge is based on the equation:

$$C = (V \times X) + [V \times 0.256\ (COD - 350)\ 0.33]$$

The equation is now:

$$C = (V \times X) + [V \times \mathbf{0.28}\ (COD - 350)\ \mathbf{0.66}]$$

5. CLOSURE OF MEETING

The meeting was closed at 17h30.

The Pietermaritzburg Waste Minimisation Club

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MINUTES OF THE MEETING HELD ON WEDNESDAY 5 DECEMBER 2001 AT 16:00, CHEMISTRY BUILDING, UNIVERSITY OF NATAL (PMB)

1. THE UPS AND DOWNS OF WASTE MINIMISATION

John Danks from Saayman Danks Electroplating spoke on the implementation of waste minimisation in his company. He said that it is sometimes difficult to convert the theory of waste minimisation learnt at the waste minimisation club into practise. From his experiences, the easiest way to begin is to start with the small things first. These are the problems that can be easily identified and quickly changed. For example, a good place to start is to consult the data sheets/methods/specifications on how the plant was originally meant to run, and then try get processes back to that stage. Therefore waste minimisation is not "rocket-scientist stuff", but is simply going back to the basics. He also said that you have to look to the future, and plan things that will save the most money in the long run. That can mean spending a large amount of money to fix or replace something that will save money later.

John Danks also discussed the difficulties in getting staff to help in the process of waste minimisation. He suggested that you explain to the workers what you are trying to achieve and get them to participate in the waste minimisation process. If you want to change a process, John suggested that you explain to the workers that if the change is not working they must speak to you first before changing back to the old method. One of the main points he stressed was taking time to know your process and plant very well in order to make the most of waste minimisation.

2. QUESTIONNAIRE

The three members that were present at the meeting were asked to complete a questionnaire on the success of the Pietermaritzburg Waste Minimisation Club this year.

3. SUCCESSES ACHIEVED IN THE PMB WASTE MINIMISATION CLUB DURING 2001

Nicola Brown spoke on 2 projects done by Chemical Technology Honours students at Hulett Aluminium. Paula Blomquist worked at the Hot Line Department, and she identified financial savings of R19500 per annum, as well as effluent and water savings of 1600 m^3 per annum. These savings could be achieved through simple waste minimisation measures. Kate Dyson worked at the Remelt Department, and dealt with the dross. This is their main form of waste and consists of metal oxides. Kate identified a number of factors that affect the formation of the dross. Future work will be done on this project to obtain a more detailed idea of the factors affecting dross formation.

Sally Spankie spoke on projects done by two other Chemical Technology Honours students, Andre van Daele and Mabu Mamabolo. They were involved with two electroplating companies, Ramsay Engineering and E.S. & L.C. Detailed chemical analyses have been performed on the process tanks of these two companies to give baseline data on chemical movements through the tank solution. These projects will be taken further next year to identify opportunities for waste minimisation.

4. ADMINISTRATIVE ARRANGEMENTS

The following administrative business was addressed:

4.1 Date and Time of Next Meeting

The next meeting was scheduled for the 13 February 2002 at 4 PM in the Chemistry Honours Seminar Room. Nicola Brown suggested inviting an environmental lawyer to speak on the present environmental legislation in South Africa.

5. CLOSURE OF MEETING

The meeting was closed at 18h15.

Appendix D

A summary of the responses of the Pietermaritzburg Waste Minimisation Club members' to the questionnaires is shown in this Appendix. Appendix D.1 shows the responses to the first questionnaire that was completed by six members in April 2001. Unfortunately part B of the questionnaire was over the page, and only four members turned the page. Also, two members used the same ranking more than once. The responses to the second questionnaire that was completed by all members (excluding the two regulators) in November 2001 are shown in Appendix D.2.

Appendix D.1: Summary of Club Members' Responses to the First Questionnaire (April 2001)

A.

1. Is the management of your company committed to waste minimisation?

Very committed	6	Average	0	Not Committed	0

2. Would the management of your company be open to appointing waste minimisation team members who would be involved in overseeing data collection, brainstorming, and implementing waste minimisation options?

Very open	4	Average	1	Not open	1

3. How does your company feel about a person(s) spending time collecting data for the waste minimisation audit?

Very happy	5	Average	1	Not happy	0

4. Would your company be open to allowing University of Natal, Pietermaritzburg (UNP) students to help you in the necessary data collection?

Very open	4	Average	2	Not open	0

5. How do you feel about sharing information on your problems, solutions and successes in waste minimisation with other club members?

Very happy	5	Average	1	Not happy	0

6. Do you think waste minimisation is useful for small and/or large companies?

Small only	0	Large only	0	Both	6

7. Is your company already implementing waste minimisation measures?

Yes	3	No	3

8. Do you believe there is much room for waste minimisation in your company?

Yes	6	No	0

9. Are you concerned about whether waste minimisation will be a success in your company?

Yes	3	Slightly	2	No	1

B.

1. An improvement in emissions and their impact on the environment.	1, 3, 4, 5
2. Compliance with environmental regulations.	2, 4, 5, 5
3. Improved process performance.	2, 3, 4, 4
4. Promoting a company image of environmental awareness.	3, 4, 4, 4
5. Greater financial savings.	1, 5, 5, 5

Appendix D.2: Summary of Club Members' Responses to the Second Questionnaire (December 2001)

Question	Total	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 8	Comp 9	Comp 11	Comp 12
1. Please classify your company:											
Small-to-medium sized enterprise	**7**	X	X	X	X			X	X		X
Large company	**1**					X					
Regulator	**0**										
Other	**2**						X			X	
2. How many meetings have you attended?											
2	**1**			X							
3	**3**				X	X				X	
4	**2**							X	X		
5	**2**	X					X				
6	**2**		X								X
7	**0**										
3. Has the training material been useful for giving you a broad idea of what a waste minimisation program is, and what implementation of one involves?											
Yes	**9**	X	X		X	X	X	X	X	X	X
No	**1**			X							
4. Has the training material been useful for actually implementaing a program in waste minimisation in your company?											
Yes	**5**	X	X		X			X	X		
No	**4**			X		X				X	X
5. Did you find that the level at which the training material was pitched was:											
too technical	**1**										X
too mathematical	**2**								X		X
too general	**3**			X			X	X			
just right	**4**		X		X	X				X	
6. Has the training material raised your awareness about waste minimisation in general?											
Yes	**10**	X	X	X	X	X	X	X	X	X	X
No	**0**										

Question	Total	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 8	Comp 9	Comp 11	Comp 12
7. Have you identified opportunities for waste minimisation in your company through casual observation or other informal means?											
Yes	**9**	X	X	X	X	X	X	X	X		X
No	**1**									X	
9. Have you used any of the following:											
Process flow diagram	**3**		X				X				X
Data collection	**0**										
Scoping audit	**0**										
Mass/energy balance	**1**		X								
Monitoring and targeting	**4**		X		X		X		X		
Statistical process control	**1**						X				
10. Have you identified any waste minimisation opportunities using the above?											
Yes	**4**		X		X		X		X		
No	**5**	X				X		X		X	X
11a. Is it realistic to have someone appointed as a project champion to oversee waste minimisation in your company?											
Yes	**5**	X		X		X	X	X			
No	**5**		X		X				X	X	X
11b. How easy is it for this person to involve other people in the company in the waste minimisation audit?											
Easy	**2**				X						X
Average	**1**							X			
Not easy	**5**	X		X		X	X		X		
11c. Would you prefer some help from us (Chemical Technology Group) in the initial waste minimisation audit?											
Yes	**8**	X	X	X	X	X	X	X			X
No	**1**								X		
12. Have you introduced the Mission-directed work team system used by Webroy?											
Yes	**3**	X	X								X
No	**7**			X	X	X	X	X	X	X	

Question	**Total**	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 8	Comp 9	Comp 11	Comp 12
13. Have you introduced incineration as spoken about by Phillip Symons?											
Yes	**0**										
No	**10**	X	X	X	X	X	X	X	X	X	X
14. Have you given solvent to Frank Trump or purchased one of his units?											
Yes	**0**										
No	**10**	X	X	X	X	X	X	X	X	X	X
15. Have you established useful environmental connections with companies or authorities as a result of the club?											
Yes	**6**			X	X		X	X	X	X	
No	**4**	X	X			X					X
16. Please mark the 5 most significant barriers that you/your company have/has experienced to waste minimisation?											
Low business confidence	**0**										
Low business profitability	**2**			X					X		
Disbelief of payback periods	**1**					X					
Lack of technical knowledge	**2**	X									X
Lack of awareness of cleaner production	**1**			X							
Perceived as high risk	**0**										
Lack of management time	**4**	X				X	X		X		
Operational constraints	**6**	X	X		X	X		X			X
Lack of enforcement of legislation	**2**			X			X				
Unclear legislation	**0**										
Lack of outside pressure	**1**						X				
Lack of information	**3**			X	X						X
Lack of human resources	**5**	X	X			X		X			X
Resistance to change	**3**	X					X	X			
Production pressure	**7**		X		X	X	X	X	X		X
Lack of finance	**3**		X	X				X			

Question	**Total**	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 8	Comp 9	Comp 11	Comp 12
17. Please mark the 3 most significant drivers that you/your company have/has experienced to waste minimisation?											
Financial savings	**7**	X	X	X	X		X		X		X
Improved environmental performance	**5**		X	X		X		X	X		
More stringent legislation	**3**				X		X				X
Pressure from customers	**1**	X									
ISO 14000	**2**					X		X			
Improved plant utilisation	**7**	X	X	X	X			X	X		X
Improved image	**2**					X	X				
18. Are you inhibited by the presence of Umgeni Water at club meetings?											
Yes	**0**										
No	**9**	X	X	X	X	X	X	X		X	X

Appendix E

In this Appendix, the data collected at Coil Coating Line 1 (CCL1) and Coil Coating Line 2 (CCL2) from July to September 2001 are shown. Table E.1 shows the volumes of the chemical raw materials used monthly on CCL1. Tables E.2 and E.3 give the costs of the chemical raw materials for CCL1 and CCL2 respectively. Table E.4 shows the daily data collected on CCL1, and Tables E.5 and E.6 show the daily data collected on CCL2.

Table E.1: The volumes of the chemical raw materials used on CCL1

	Gardoclean 450M	Gardoclean 450C*	Gardoclean 450B
July	1 050 L	500 L	0
August	1 050 L	375 L	0
September	1 050 L	125 L	75 L

* The volumes of Gardoclean 450C shown here were shared between CCL1 and CCL2

Table E.2: The costs of the chemical raw materials for CCL1

Chemical raw material	Cost	Drum size
Gardoclean 450M	R8.22/L	210 L
Gardoclean 450C	R12.82/L	25 L
Gardoclean 450B	R13.98/L	25 L
Gardobond NPC 4504/25	R8.38/L	210 L
Gardobond VP 4724/2M	R5.30/L	210 L

Table E.3: The costs of the chemical raw materials for CCL2

Chemical raw material	Cost	Drum size
Gardoclean S5160	R8.09/L	bulk
Gardoclean 450M	R7.52/L	bulk
Gardoclean 450C	R12.82/L	25 L
Gardal K701/1	R8.55/L	bulk

Table E.4: Data collected on Coil Coating Line 1 (CCL1)

						Rinse 1	Rinse 2	Acid Cleaner	
Date	Uptime (%)	No. of coils (topcoats)	No. of coils (priming)	No. of coils (other)	Mass (kg)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Free acid (g/kl)
01-Jul-01	26.0	12	0	0	83198				
02-Jul-01	53.1	5	20	0	93537				63
03-Jul-01	27.8	8	3	0	51143	90	90		68
04-Jul-01	7.3	5	5	0	39835	90	90	55	
05-Jul-01	39.2	22	1	0	49804	85	78	55	
06-Jul-01	38.9	3	7	0	49235	83	76	55	
07-Jul-01	48.6	1	10	0	66261				
08-Jul-01	44.2	15	0	0	77425				
09-Jul-01	49.0	15	5	0	111104	53	60	55	76
10-Jul-01	49.7	4	19	0	105978	83	75	56	65
11-Jul-01	47.1	20	0	0	90334	63	66	55	
12-Jul-01	49.2	10	10	0	109823	89	87	56	
13-Jul-01	46.3	9	0	0	61715	87	84	56	
14-Jul-01	52.1	3	5	0	49104				
15-Jul-01	45.8	0	8	5	75210				
16-Jul-01	32.6	2	4	1	44775	64	74	55	93
17-Jul-01	27.4	9	2	0	44004	52	66	56	100
18-Jul-01	53.8	1	22	2	103790	64	62	56	
19-Jul-01	45.1	15	0	0	73095	59	77	55	
20-Jul-01	19.2	5	0	2	24316	59	65	56	95
21-Jul-01	50.0	0	9	0	64782				
22-Jul-01	47.6	9	11	0	98266				
23-Jul-01	38.2	16	0	0	63201	54	67	56	82
24-Jul-01	29.5	8	0	1	48871	69	63	57	
25-Jul-01	55.2	0	0	11	79727	60	72	55	
26-Jul-01	43.8	0	7	6	63769	47	61	55	
27-Jul-01	37.9	6	3	3	47346	54	60	56	
28-Jul-01	37.5	0	7	0	48377				
29-Jul-01	53.1	14	11	0	100149				
30-Jul-01	20.5	5	8	0	42714	51	64	61	
31-Jul-01	64.6	11	3	1	108242	67	65	60	

Table E.4 contd.

	Acid Cleaner		Surge Tank			
Date	Total acid (g/kl)	Fluoride (g/kl)	Volume of effluent (kl)	pH	Total acid (g/kl)	Fluoride (g/kl)
01-Jul-01			77			
02-Jul-01	79	21	96			
03-Jul-01	95	12	59			
04-Jul-01			36	6	1.9	1.3
05-Jul-01			54	5	2.0	2.2
06-Jul-01			77	6	1.1	0.73
07-Jul-01			86			
08-Jul-01			107			
09-Jul-01	91	31	103			
10-Jul-01	77	9	141	6	1.5	1.3
11-Jul-01			101	6	1.3	1.5
12-Jul-01			77	6	1.8	1.9
13-Jul-01			114	5.5	1.8	3.6
14-Jul-01			58			
15-Jul-01			124			
16-Jul-01	121	13	116	6	12.7	61
17-Jul-01	121	21	61	6	9.2	37
18-Jul-01			153	4	1.6	2.0
19-Jul-01			70	3	5.8	3.0
20-Jul-01	128	4	25	6	1.3	0.61
21-Jul-01			73			
22-Jul-01			30			
23-Jul-01	95	15	129	6	0.7	0.76
24-Jul-01			100	6	1.3	0.80
25-Jul-01			111	6	1.3	0.55
26-Jul-01			154	6	1.2	1.3
27-Jul-01			58	6	1.2	0.76
28-Jul-01			100			
29-Jul-01			138			
30-Jul-01			167	6	2.4	1.9
31-Jul-01			106	5	1.8	4.3

Table E.4 contd.

						Rinse 1	Rinse 2	Acid Cleaner	
Date	Uptime (%)	No. of coils (topcoats)	No. of coils (priming)	No. of coils (other)	Mass (kg)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Free acid (g/kl)
01-Aug-01	36.8	3	3	5	35902	60	79	60	
02-Aug-01	9.0	4	0	0	26890	91	90	60	
03-Aug-01	47.6	6	20	0	102779	88	89	61	
04-Aug-01	11.1	2	0	0	12560				
05-Aug-01	24.0	12	0	0	40570				
06-Aug-01	21.5	7	3	0	40305	70	87	61	
07-Aug-01	51.7	15	0	1	97032	70	66	62	124
08-Aug-01	45.5	11	1	0	92681	92	89	61	
09-Aug-01	44.8	6	16	0	109419	70	66	62	
10-Aug-01	31.9	17	0	0	74030	91	85	60	
11-Aug-01	47.6	5	17	0	96206				91
12-Aug-01	50.7	7	17	0	124650				
13-Aug-01	STRIKE ACTION					55	69	61	
14-Aug-01	STRIKE ACTION					90	89	60	
15-Aug-01	STRIKE ACTION								
16-Aug-01	STRIKE ACTION								
17-Aug-01	43.1	6	0	0	21675				
18-Aug-01	46.5	5	0	0	39535				
19-Aug-01	46.9	13	6	0	90107				
20-Aug-01	42.7	5	6	2	64715	73	67	61	
21-Aug-01	34.7	14	3	1	70448	75	79	60	
22-Aug-01	0.0	0	0	0	0	69	69	60	
23-Aug-01	0.0	0	0	0	0				
24-Aug-01	14.6	0	1	3	24393	18	23	24	
25-Aug-01	31.9	4	0	0	32103				
26-Aug-01	31.9	8	8	0	89831				
27-Aug-01	32.6	7	0	3	54019	85	78	60	
28-Aug-01	76.0	0	0	16	96814	55	66	60	
29-Aug-01	13.9	4	4	3	34387	85	85	62	
30-Aug-01	44.4	3	20	0	87395	90	85	62	
31-Aug-01	26.4	12	0	0	50680	82	81	60	

Table E.4 contd.

	Acid Cleaner		Surge Tank				
Date	Total acid (g/kl)	Fluoride (g/kl)	Volume of effluent (kl)	Conductivity (mS/cm)	pH	Total acid (g/kl)	Fluoride (g/kl)
01-Aug-01			60		6	1.4	0.81
02-Aug-01			96	0.08	6	0.6	0.50
03-Aug-01			99	0.10	6	0.5	0.86
04-Aug-01			22				
05-Aug-01			32				
06-Aug-01			55	0.45	6	40	1.1
07-Aug-01	150	42	90	0.08	5.5	1.0	3.9
08-Aug-01			126	1.14	3	4.3	3.0
09-Aug-01			141	0.98	3	3.5	2.2
10-Aug-01			126	0.24	5.5	2.8	1.6
11-Aug-01	115	69	121				
12-Aug-01			142				
13-Aug-01			62	0.12	5.5	2.3	1.8
14-Aug-01			77	0.20	5	1.7	2.0
15-Aug-01							
16-Aug-01							
17-Aug-01				0.20	4	3.6	2.4
18-Aug-01			111				
19-Aug-01			129				
20-Aug-01			66	0.13	6	3.3	0.85
21-Aug-01			47	0.11	5.5	1.5	1.7
22-Aug-01			56	0.11	6	1.1	0.94
23-Aug-01			4	0.09	6	1.3	1.1
24-Aug-01			41	0.11	5	1.9	3.3
25-Aug-01			29				
26-Aug-01			64				
27-Aug-01			86	0.15	5	2.1	1.2
28-Aug-01			123	3.05	2.5	11	15
29-Aug-01			53	2.21	2.5	7.9	12
30-Aug-01			73	1.16	3	5.3	6.5
31-Aug-01			49	2.62	2	9.7	23

Table E.4 contd.

						Rinse 1	Rinse 2	Acid Cleaner	
Date	Uptime (%)	No. of coils (topcoats)	No. of coils (priming)	No. of coils (other)	Mass (kg)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Free acid (g/kl)
01-Sep-01	22.2	4	0	2	15585				
02-Sep-01	52.1	5	12	0	122081				
03-Sep-01	47.6	11	4	1	108656	73	76	61	
04-Sep-01	29.5	7	0	0	61646	57	66	60	
05-Sep-01	44.4	2	24	0	89517	89	83	63	84
06-Sep-01	29.2	13	0	2	45910	61	77	60	
07-Sep-01	59.0	13	5	0	129257				
08-Sep-01	43.1	0	6	0	43258				
09-Sep-01	33.3	3	4	3	75245				
10-Sep-01	39.2	4	10	2	87454	54	72	62	
11-Sep-01	35.8	18	4	0	92525	56	61	61	
12-Sep-01	23.6	7	2	0	45126	77	73	60	
13-Sep-01	32.3	8	10	0	74645	77	69	60	
14-Sep-01	10.4	4	0	0	26225	88	87	59	
15-Sep-01	28.5	1	8	0	43641	83	80	60	
16-Sep-01	41.0	13	4	0	81379				
17-Sep-01	45.8	13	0	0	97294				
18-Sep-01	30.6	6	8	0	47980	45	57	35	
19-Sep-01	17.4	11	1	6	67020	69	61	67	
20-Sep-01	35.8	7	6	0	81514	74	83	65	
21-Sep-01	20.8	10	0	2	35075	61	67	64	
22-Sep-01	0.0	0	0	0	0				
23-Sep-01	0.0	0	0	0	0				
24-Sep-01	65.3	0	4	10	101725				
25-Sep-01	44.8	8	8	0	93616				
26-Sep-01	18.4	4	2	0	37613	76	72	67	
27-Sep-01	0.0	0	0	0	0	35	38	19	
28-Sep-01	32.1	0	0	6	41012	65	42	66	
29-Sep-01									
30-Sep-01									

Table E.4 contd.

	Acid Cleaner		Surge Tank				
Date	Total acid (g/kl)	Fluoride (g/kl)	Volume of effluent (kl)	Conductivity (mS/cm)	pH	Total acid (g/kl)	Fluoride (g/kl)
01-Sep-01			56				
02-Sep-01			42				
03-Sep-01			114	0.12	5.5	1.9	1.2
04-Sep-01			92	1.72	3	6.0	10
05-Sep-01	116	79	82	1.62	3	7.5	6.7
06-Sep-01			59	0.87	3	4.2	3.5
07-Sep-01			106				
08-Sep-01			48				
09-Sep-01			112				
10-Sep-01			92	0.16	5.5	3.3	2.4
11-Sep-01			86		5	3.8	3.5
12-Sep-01			80	0.16	5	3.1	2.8
13-Sep-01			85	0.31	5	1.9	3.5
14-Sep-01			56	0.09	5.5	1.7	1.7
15-Sep-01			70				
16-Sep-01			99				
17-Sep-01			94	2.94	2	9.2	7.3
18-Sep-01			104	2.20	2.5	6.6	3.3
19-Sep-01			66	0.84	3	67	1.5
20-Sep-01			84		3	4.7	2.2
21-Sep-01			155	0.19	5	2.5	1.4
22-Sep-01			30				
23-Sep-01			37				
24-Sep-01			70				
25-Sep-01			74				
26-Sep-01			35		5.5	1.5	1.5
27-Sep-01			49		2	47	40
28-Sep-01			50		6	3.0	1.8
29-Sep-01			0				
30-Sep-01			15				

Table E.5: Data collected from the alkali section of Coil Coating Line 2 (CCL2)

					Stage 1			
Date	**Uptime (%)**	**No. of coils**	**Mass (kg)**	**m^2 processed**	**Vol. of S5160 consumed (l)**	**Temperature (^oC)**	**Conductivity ($\mu S/cm$)**	**Free alkali (g/kl)**
01-Jul-01	65.6	11	72643	246947.25	33	54	3517	308
02-Jul-01	93.8	11	85250	261346.74	252	50	4675	381
03-Jul-01	0.0	0	0	0	0			
04-Jul-01	0.0	0	0	0	67	52	3809	328
05-Jul-01	41.0	8	80033	241430.5	150	49	2748	253
06-Jul-01	72.9	12	111054	335009.57	834	46	2158	248
07-Jul-01	83.0	15	119803	361402.13		46	2600	224
08-Jul-01	55.2	8	61371	188355.31		46	2755	214
09-Jul-01	47.9	9	70241	196192.95	329	49	3575	315
10-Jul-01	57.6	10	84939	248688.15	292	42	4906	376
11-Jul-01	62.8	10	90994	268472.44	199	54	4967	393
12-Jul-01	68.4	15	117099	327073.9	269	49	3439	289
13-Jul-01	54.5	9	73995	241820.37	566	49	2691	281
14-Jul-01	46.5	9	62142	214578.73		43	3964	347
15-Jul-01	74.7	16	100353	802921.89		53	3009	309
16-Jul-01	80.6	12	93760	319707.58	655	43	4977	456
17-Jul-01	58.3	10	79893	234163.86	263	53	5720	400
18-Jul-01	68.4	11	95469	321422.78	277	44	3720	270
19-Jul-01	60.4	11	74093	252450.19	313	49	3459	289
20-Jul-01	0.0	0	0	0	147	46	4158	321
21-Jul-01	0.0	0	0	0				
22-Jul-01	53.5	10	93496	261147.42		49	3399	304
23-Jul-01	43.8	7	49424	150214.94	268	43	2645	253
24-Jul-01	16.7	2	14670	44973.1	189	39	4690	318
25-Jul-01	33.7	5	37912	127641.23	162	56	2958	243
26-Jul-01	83.3	12	103099	347111.3	423	44	2684	245
27-Jul-01	32.3	6	49844	165189.61	752	40	5950	462
28-Jul-01	60.4	11	98094	273990.28		51	3680	311
29-Jul-01	66.3	13	107063	738221.85		47	4197	340
30-Jul-01	88.9	14	98592	298585.28	330	45	4547	355
31-Jul-01	58.7	9	80338	270480.1	231			

Table E.5 contd.

	Stage 1	Stage 2			Surge Tank A (alkali)			
Date	Total alkali (g/kl)	Temperature (°C)	Conductivity (μS/cm)	Free alkali (g/kl)	Volume of effluent (kl)	Conductivity (mS/cm)	pH	Total alkali (g/kl)
01-Jul-01	632	49	1289	309	21			
02-Jul-01	702	44	1289	282	21			
03-Jul-01					6			972.4
04-Jul-01	592	51	1289	279	0		10	508.3
05-Jul-01	485	56	1289	303	16		10	455.6
06-Jul-01	456	45	1289	313	20		10	499.8
07-Jul-01	408	42	1289	180	29			
08-Jul-01	406	48	1289	292	29			
09-Jul-01	593	49	1289	296	10		10	442
10-Jul-01	712	43	1289	391	14		10	430.1
11-Jul-01	777	53	1289	411	6		10	511.7
12-Jul-01	527	44	1289	258	2		10	484.5
13-Jul-01	524	45	1270	398	1		9.5	477.7
14-Jul-01	656	36	1289	211	1			
15-Jul-01	619	44	1289	303	9			
16-Jul-01	456	40	1289	316	5		9	426.7
17-Jul-01	819	49	1289	357	1		9	506.6
18-Jul-01	605	44	1289	343	0		9	28.39
19-Jul-01	636	46	1289	340	7		9	377.4
20-Jul-01	590	44	1289	357	1		9.5	392.7
21-Jul-01			1289		6			
22-Jul-01	590	47	1289	279	2			
23-Jul-01	503	43	1289	292	13		9.5	47.09
24-Jul-01	675	42	1289	313	6		10	581.4
25-Jul-01	456	55	1289	58	2		9	200.6
26-Jul-01	479	48	1289	252	5		9	351.9
27-Jul-01	899	46	1289	364	4		9	479.4
28-Jul-01	549	54	1289	85	6			
29-Jul-01	697	45	1289	323	13			
30-Jul-01	719	56	1289	58	9		10	82.11
31-Jul-01			1289		0			

Table E.5 contd.

Date	Uptime (%)	No. of coils	Mass (kg)	m^2 processed	Stage 1			
					Vol. of S5160 consumed (l)	Temperature (^0C)	Conductivity ($\mu S/cm$)	Free alkali (g/kl)
01-Aug-01	68.8	11	98917	333031.44	335		3355	294
02-Aug-01	81.3	14	124070	403006.24	165	54	4333	393
03-Aug-01	59.0	8	54893	145759.43	336	54	4681	374
04-Aug-01	0.0	0	0	0		54	3522	275
05-Aug-01	0.7	0	0	0		63	2694	240
06-Aug-01	0.0	0	0	0	0			
07-Aug-01	32.6	7	54866	186009.57	147	60	4320	
08-Aug-01	66.7	11	82515	284927.48	71	58	4090	357
09-Aug-01	63.2	11	100821	304140.32	410	59	4405	401
10-Aug-01	84.0	13	128021	363695.45	917	58	4180	388
11-Aug-01	30.2	5	47831	133598.68		58	3607	326
12-Aug-01	64.2	14	97051	311668.71		58	4250	401
13-Aug-01	STRIKE ACTION				299	58	5019	442
14-Aug-01	STRIKE ACTION				391.2	54	5755	527
15-Aug-01	STRIKE ACTION					56		595
16-Aug-01	STRIKE ACTION					58	5692	527
17-Aug-01	0.0	0	0	0	537			
18-Aug-01	54.2	8	77103	259588.58		55	3962	452
19-Aug-01	36.1	7	53255	170800.69		55	4553	473
20-Aug-01	94.1	13	97416	296040.44	86	59	3698	345
21-Aug-01	76.0	11	78020	237128.71	102	59	3202	325
22-Aug-01	71.5	14	123426	372331.4	53	59	3350	360
23-Aug-01	65.3	13	116460	351317.5	84	59	3247	383
24-Aug-01	79.2	17	111608	344005.96	252	59	3278	342
25-Aug-01	6.9	1	9867	33219.99		59	3278	350
26-Aug-01	88.5	14	116987	372530.96		63	3905	345
27-Aug-01	0.0	0	0	0	0	64	4009	379
28-Aug-01	0.0	0	0	0	7			
29-Aug-01	36.1	5	45870	158390.88	28			
30-Aug-01	97.6	17	132814	458611.86	138	64	3278	350
31-Aug-01	26.4	12	50680	193539.36	270	64	3329	357
01-Sep-01				184571		64	3809	408
02-Sep-01				233593		63	4248	398

Table E.5 contd.

	Stage 1	Stage 2			Surge Tank A (alkali)			
Date	Total alkali (g/kl)	Temperature (^{0}C)	Conductivity (μS/cm)	Free alkali (g/kl)	Volume of effluent (kl)	Conductivity (mS/cm)	pH	Total alkali (g/kl)
01-Aug-01	607	58	1289	343	0		10	135
02-Aug-01	808	58	1289	354	4	2.59	9	135
03-Aug-01	736	64	1289	371	9	2.90	10	153
04-Aug-01	651	58	1289	388	0			
05-Aug-01	496	62	1289	381	0			
06-Aug-01			1289		0	3.10	9	115
07-Aug-01		65	1289		1	2.80	10	105
08-Aug-01	741	61	1289	527	8	2.65	10	110
09-Aug-01	802	63	1289	337	5	3.07	9	127
10-Aug-01	784	62	1289	357	1	2.74	10	143
11-Aug-01	661	55	1289	323	2			
12-Aug-01	801	49	1289	371	3			
13-Aug-01	799	49	1289	357	0	3.56	10	160
14-Aug-01	1006	57	1289	534	0	3.35	10	156
15-Aug-01	1071	56	1289	544	0			
16-Aug-01	1003	59	1289	510	0			
17-Aug-01			1289		2	3.26	10	155
18-Aug-01	814	58	1289	442	0			
19-Aug-01	889	59	1289	554	3			
20-Aug-01	700	53	1289	292	4	4.09	9.5	114
21-Aug-01	661	55	1289	299	0	3.16	10	113
22-Aug-01	655	50	1289	303	0	2.84	9	131
23-Aug-01	733	47	1289	354	0	3.01	9	125
24-Aug-01	673	49	1289	357	0	3.44	9	145
25-Aug-01	719	48	1289	303	0			
26-Aug-01	697	49	1289	269	0			
27-Aug-01	767	50	1289	326	0			
28-Aug-01			1289		0	2.66	9	86
29-Aug-01			1289		0	2.30	9	71
30-Aug-01	689	60	1289	221	0	1.84	9	62
31-Aug-01	733	56	1289	306	0	2.62	9	109
01-Sep-01	808	59	1289	452	0			
02-Sep-01	804	56	1289	405	0			

Table E.5 contd.

					Stage 1			
Date	Uptime (%)	No. of coils	Mass (kg)	m^2 processed	Vol. of S5160 consumed (l)	Temperature (^0C)	Conductivity (μS/cm)	Free alkali (g/kl)
01-Sep-01	42.0	6	54821	184571	0	64	3809	408
02-Sep-01	64.9	11	84895	233593	0	63	4248	398
03-Sep-01	22.6	4	31076	107307.2	42	58	3316	411
04-Sep-01	0.0	0	0	0	50			
05-Sep-01	0.0	0	0	0	1	54	3497	265
06-Sep-01	3.1	1	9722	29236	0			
07-Sep-01	80.2	13	122905	370759	52	54	2180	258
08-Sep-01	24.0	7	35005	131368.53	190			
09-Sep-01	62.5	9	93141	313586.44	0	59	2505	241
10-Sep-01	44.4	6	61224	165858.36	53	59	2513	241
11-Sep-01	69.1	12	109288	329682.3	121	60	2513	235
12-Sep-01	70.5	12	113404	325193.2	120	59	2510	231
13-Sep-01	35.1	6	62002	184220.1	82	60	2488	235
14-Sep-01	47.6	8	62303	194421.8	68	57	2570	287
15-Sep-01	65.3	13	86186	297603.85	144	59	2293	214
16-Sep-01	71.5	11	101609	307006.74	96	59	2531	270
17-Sep-01	90.3	13	127533	417429.71	157	58	2469	250
18-Sep-01	92.0	14	128579	427594.03	146	58	2455	241
19-Sep-01	14.6	1	7224	24944.75	63	59	2480	233
20-Sep-01	63.2	13	95488	299464.24	160	54	2481	238
21-Sep-01	74.0	17	117644	350008.69	168	54	2512	245
22-Sep-01	78.8	14	104571	497859.72	204	56	2425	214
23-Sep-01	13.5	2	13281	276747.23	31	34		253
24-Sep-01	52.4	11	83411	267134.62	140	59	2481	226
25-Sep-01	0.0	0	0	0	0	58	2439	230
26-Sep-01	41.3	7	67128	167290.36	107	59	2563	267
27-Sep-01	39.9	6	53928	182870.58	72	59	2466	219
28-Sep-01	73.6	15	106255	262479.61	121	45	2245	207
29-Sep-01	0.0	0	0	0	0	59	2481	221
30-Sep-01		5		154714.24	79	59	2552	265

Table E.5 contd.

	Stage 1	Stage 2			Surge Tank A (alkali)			
Date	Total alkali (g/kl)	Temperature (^{0}C)	Conductivity (μS/cm)	Free alkali (g/kl)	Volume of effluent (kl)	Conductivity (mS/cm)	pH	Total alkali (g/kl)
01-Sep-01	808	59	1289	452	0			
02-Sep-01	804	56	1289	405	0			
03-Sep-01	804	49	1289	551	0	3.15	9	84
04-Sep-01				0	0	3.12	9	117
05-Sep-01	559	63	1289	306	0	2.96	9	115
06-Sep-01				0	0	3.07	9	108
07-Sep-01	525	57	1289	313	3			
08-Sep-01				238	0			
09-Sep-01	495	58	1289	170	1			
10-Sep-01	432	56	1289	292	0	2.63	9	82
11-Sep-01	457	65	1289	299	1	2.86	9	93
12-Sep-01	468	59	1289	292	0	2.07	9	75
13-Sep-01	451	60	1289	258	5	2.16	8	45
14-Sep-01	558	56	1289	194	1	2.14	7	38
15-Sep-01	427	56	1289	235	4			
16-Sep-01	539	56	1289	238	0			
17-Sep-01	473	56	1289	289	2	2.28	9	69
18-Sep-01	503	56	1289	224	0	2.19	9	76
19-Sep-01	457	56	1289	265	2	2.58	9	85
20-Sep-01	485	56	1289	224	7	2.64	9	83
21-Sep-01	498	56	1289	204	2	2.02	9	75
22-Sep-01	422	58	1289	238	0			
23-Sep-01	471	52		299	0			
24-Sep-01	401	57	1289	201	26			
25-Sep-01	468	56	1289	238	9			
26-Sep-01	522	57	1289	211	4		9	75
27-Sep-01	428	57	1289	235	1	3.21	7	59
28-Sep-01	411	51	1289	231	4	3.25	7	55
29-Sep-01	447	53	1289	204	0			
30-Sep-01	474	57	1289	245	0			

Table E.6: Data collected from the acid and chromium sections of Coil Coating Line 2 (CCL2)

					Stage 3			
Date	Uptime (%)	No. of coils	Mass (kg)	m^2 processed	Volume of 450M (l)	Temperature (^oC)	Conductivity (μS/cm)	Free acid (g/kl)
01-Jul-01	65.6	11	72643	246947.25	0	52	11544	54
02-Jul-01	93.8	11	85250	261346.74	90	49	25844	146
03-Jul-01	0.0	0	0	0	0			
04-Jul-01	0.0	0	0	0	0	52	21293	141
05-Jul-01	41.0	8	80033	241430.5	0	45	-47	132
06-Jul-01	72.9	12	111054	335009.57	278	54	13228	72
07-Jul-01	83.0	15	119803	361402.13		54	-106	46
08-Jul-01	55.2	8	61371	188355.31		50	11006	52
09-Jul-01	47.9	9	70241	196192.95	0	54	-72	59
10-Jul-01	57.6	10	84939	248688.15	735	47	10425	46
11-Jul-01	62.8	10	90994	268472.44	0	57	29572	191
12-Jul-01	68.4	15	117099	327073.9	0	54	18691	106
13-Jul-01	54.5	9	73995	241820.37	199	63		72
14-Jul-01	46.5	9	62142	214578.73		54	11719	43
15-Jul-01	74.7	16	100353	802921.89		56	10581	53
16-Jul-01	80.6	12	93760	319707.58	640	54	10672	53
17-Jul-01	58.3	10	79893	234163.86	111	57	27147	163
18-Jul-01	68.4	11	95469	321422.78	83	54	12544	66
19-Jul-01	60.4	11	74093	252450.19	134	57	11697	60
20-Jul-01	0.0	0	0	0	0	54	13203	65
21-Jul-01	0.0	0	0	0				
22-Jul-01	53.5	10	93496	261147.42		54	11538	62
23-Jul-01	43.8	7	49424	150214.94	394	55	8708	45
24-Jul-01	16.7	2	14670	44973.1	317	54	31424	193
25-Jul-01	33.7	5	37912	127641.23	155	64	-22	42
26-Jul-01	83.3	12	103099	347111.3	119	55	13881	74
27-Jul-01	32.3	6	49844	165189.61	841	54	12269	65
28-Jul-01	60.4	11	98094	273990.28		55	13753	78
29-Jul-01	66.3	13	107063	738221.85		54	9463	45
30-Jul-01	88.9	14	98592	298585.28	266	55	30603	180
31-Jul-01	58.7	9	80338	270480.1	218			

Table E.6 contd.

	Stage 3		Stage 4		Stage 5		Stage 6	
Date	Total acid (g/kl)	Fluoride (g/kl)	Temperature (°C)	Total acid (g/kl)	Temperature (°C)	Total acid (g/kl)	Volume of K701/1 (l)	Temperature (°C)
01-Jul-01	129		55	28	54	67	1062	55
02-Jul-01	247	56	55	32	54	59	2975	56
03-Jul-01							49	
04-Jul-01	237	105	55	47	54	40	268.6	56
05-Jul-01	205	132	57	45	55	40	1002.4	68
06-Jul-01	138	114	55	39	55	36	5096	55
07-Jul-01	108	114	55	26	54	26		54
08-Jul-01	133		53	25	54	29		54
09-Jul-01	135	93	55	27	54	30	1609	54
10-Jul-01	116	67	54	19	53	28	3281.5	
11-Jul-01	272	167	53	19	52	27	908.5	54
12-Jul-01	176	37	55	26	54	49	2093	51
13-Jul-01	140	100	55	31	55	38	3969	57
14-Jul-01	142	100	55	27	53	36		54
15-Jul-01	149		55	23	54	25		54
16-Jul-01	134	69	54	21	54	24	2921	54
17-Jul-01	272	6	55	35	54	42	2694	56
18-Jul-01	107	60	55	38	54	76	3774	50
19-Jul-01	119	73	55	28	54	60	1741	54
20-Jul-01	133		55	31	54	59	1609	54
21-Jul-01								
22-Jul-01	127		55	34	54	44		54
23-Jul-01	103	80	55	29	54	44	2360	54
24-Jul-01	298	265	54	21	53	55	1437	54
25-Jul-01	105	72	56	21	55	82	984	59
26-Jul-01	126	92	55	20	54	63	2618	55
27-Jul-01	128	98	55	16	54	28	5553	55
28-Jul-01	137		55	20	54	26		54
29-Jul-01	116		55	15	55	14		54
30-Jul-01	292	72	55	16	54	18	3068	55
31-Jul-01		97					1164.9	

Table E.6 contd.

	Stage 6					Stage 7		
Date	Conductivity (μS/cm)	Free acid (g/kl)	Total acid (g/kl)	Cr(VI) (g/kl)	Fluoride (g/kl)	Temperature (°C)	Total acid (g/kl)	Cr(VI) (g/kl)
01-Jul-01	2390	515	1050	5113		59	312	
02-Jul-01	2760	1435	2915	9135	2837	58	330	2083
03-Jul-01								2258
04-Jul-01	2840	1230	2430	8077	2192	57	55	254
05-Jul-01	2860	1010	1970	6309	1877	65	50	294
06-Jul-01	10	770	1490	4715	1903	56	92	625
07-Jul-01	10	1270	2165	7193	1908	55	207	
08-Jul-01	10	675	1420	6899		55	247	
09-Jul-01	10	585	1155	5356	1715	56	288	1346
10-Jul-01					1701	51	270	1275
11-Jul-01	0	655	1265	6240	2082	56	280	1311
12-Jul-01	30	505	960	4888	1770	54	280	1378
13-Jul-01	10	590	1155	5460	1343	59	314	1273
14-Jul-01	10	615	1140	5408	1343	55	290	
15-Jul-01	10	590	1235	4576		56	308	
16-Jul-01	20	510	1165	5235	2255	52	318	1309
17-Jul-01	0	625	1320	7003	2184	56	279	1390
18-Jul-01	0	600	1265	6188	2118	53	318	1442
19-Jul-01	10	630	1325	6933	1832	53	315	1477
20-Jul-01	10	600	1205	5703		53	334	1604
21-Jul-01								
22-Jul-01	40	675	1115	5876		55	331	
23-Jul-01	20	615	1160	5460	1832	54	320	1406
24-Jul-01	0	965	1845	8805	2366	52	354	1770
25-Jul-01	0	610	1145	5599	1692	65	27	140
26-Jul-01	10	585	1190	6396	1804	53	43	290
27-Jul-01	-10	825	1560	7835	2450	55	122	669
28-Jul-01	10	710	1435	6985		53	146	
29-Jul-01	0	800	1680	8389		53	168	
30-Jul-01	0	890	1780	8615	3083	55	182	1231
31-Jul-01								1682

Table E.6 contd.

	Stage 7	Stage 8			Surge Tank B (chromium)			
Date	**Fluoride (g/kl)**	**Temperature (°C)**	**Conductivity (μS/cm)**	**Total acid (g/kl)**	**Conductivity (mS/cm)**	**pH**	**Total acid (g/kl)**	**Fluoride (g/kl)**
01-Jul-01		69	707	20				
02-Jul-01	384	65	793	36				
03-Jul-01	342						542	305
04-Jul-01	164	64	707	39		2	474	357
05-Jul-01	188	69	764	39		2	397	372
06-Jul-01	312	65	788	25		1	382	338
07-Jul-01		64	754	14				
08-Jul-01		60	732	16				
09-Jul-01	374	59	816	16				
10-Jul-01	459	52	625	16		2	351	457
11-Jul-01	472	60	686	16		2	401	516
12-Jul-01	435	61	824	21		2	384	409
13-Jul-01	342	68	822	21		2	377	316
14-Jul-01		66	842	23				
15-Jul-01		65	850	19				
16-Jul-01	392	61	887	19		2	347	326
17-Jul-01	299	69	852	18		1.5	393	258
18-Jul-01	312	61	891	14		2	353	334
19-Jul-01	406	62	866	18		2	394	347
20-Jul-01	329	59	899	20		1.5	424	299
21-Jul-01								
22-Jul-01		64	505	20				
23-Jul-01	429	60	749	24		2	473	196
24-Jul-01	501	58	787	13		2	476	399
25-Jul-01	68	71	709	14		2	385	376
26-Jul-01	158	66	795	12		2	371	393
27-Jul-01	246	66	801	9		2	398	374
28-Jul-01		65	635	10				
29-Jul-01		64	760	10				
30-Jul-01	357	63	624	12		2	520	389
31-Jul-01	511						464	444

Table E.6 contd.

Date	Surge Tank C (acid)					Surge Tank B & C		
	Conductivity (mS/cm)	**pH**	**Total acid (g/kl)**	**Cr(VI) (g/kl)**	**Fluoride (g/kl)**	**Effluent (kl)**	**Solid waste (kl)**	**Total Waste (kl)**
01-Jul-01						21	17	38
02-Jul-01						7	6	13
03-Jul-01			113		242	19	15	34
04-Jul-01		2	128		257	22	17	39
05-Jul-01		2	139		191	20	16	36
06-Jul-01		1	117		197	24	19	43
07-Jul-01						29	23	52
08-Jul-01						20	16	36
09-Jul-01		2	74		171	19	15	34
10-Jul-01		2	70	114	163	40	32	72
11-Jul-01		2	70	137	165	29	23	52
12-Jul-01		2	46	156	129	30	24	54
13-Jul-01		2	50	105	159	27	21	48
14-Jul-01						31	25	56
15-Jul-01						26	21	47
16-Jul-01		2	38	117	90	36	29	65
17-Jul-01		2	52	154	99	21	17	38
18-Jul-01		1	132	0	73	28	22	50
19-Jul-01		2	96	154	184	26	21	47
20-Jul-01		2	89	249	198	20	16	36
21-Jul-01						19	15	34
22-Jul-01						10	8	18
23-Jul-01		2	89	191	361	24	19	43
24-Jul-01		2	94	187	240	23	18	41
25-Jul-01		2	140	147	208	26	21	47
26-Jul-01		2	101	242	216	25	20	45
27-Jul-01		2	87	144	206	18	14	32
28-Jul-01						13	10	23
29-Jul-01						15	12	27
30-Jul-01		2	68	108	154	17	14	31
31-Jul-01			64	122	169	28	22	50

Table E.6 contd.

					Stage 3			
Date	Uptime (%)	No. of coils	Mass (kg)	m^2 processed	Volume of 450M (l)	Temperature (^oC)	Conductivity ($\mu S/cm$)	Free acid (g/kl)
01-Aug-01	68.8	11	98917	333031.44	109	54	16297	79
02-Aug-01	81.3	14	124070	403006.24	250	54	14759	71
03-Aug-01	59.0	8	54893	145759.43	323	60	16469	87
04-Aug-01	0.0	0	0	0		55	25178	144
05-Aug-01	0.7	0	0	0				100
06-Aug-01	0.0	0	0	0	0			
07-Aug-01	32.6	7	54866	186009.57	0	61	-19	95
08-Aug-01	66.7	11	82515	284927.48	0	54	14722	88
09-Aug-01	63.2	11	100821	304140.32	133	56	12201	62
10-Aug-01	84.0	13	128021	363695.45	186	55	12363	75
11-Aug-01	30.2	5	47831	133598.68		54	13209	76
12-Aug-01	64.2	14	97051	311668.71		54	12999	70
13-Aug-01	STRIKE ACTION				187	52	11378	60
14-Aug-01	STRIKE ACTION				554.2	47		110
15-Aug-01	STRIKE ACTION					44		121
16-Aug-01	STRIKE ACTION					55		118
17-Aug-01	0.0	0	0	0	1301			
18-Aug-01	54.2	8	77103	259588.58		55	18372	60
19-Aug-01	36.1	7	53255	170800.69		55	15616	70
20-Aug-01	94.1	13	97416	296040.44	57	57	24006	128
21-Aug-01	76.0	11	78020	237128.71	0	54	33893	186
22-Aug-01	71.5	14	123426	372331.4	0	53	16878	89
23-Aug-01	65.3	13	116460	351317.5	181	53	11097	60
24-Aug-01	79.2	17	111608	344005.96	785	53	9972	55
25-Aug-01	6.9	1	9867	33219.99		54	15866	89
26-Aug-01	88.5	14	116987	372530.96		54	13359	74
27-Aug-01	0.0	0	0	0	0	54	30196	181
28-Aug-01	0.0	0	0	0	0			
29-Aug-01	36.1	5	45870	158390.88	0	68	12186	80
30-Aug-01	97.6	17	132814	458611.86	199	54	10466	61
31-Aug-01	26.4	12	50680	193539.36	867	55	11122	
01-Sep-01				184571		57	13506	59
02-Sep-01				233593		53	13997	72

Table E.6 contd.

	Stage 3		Stage 4		Stage 5		Stage 6	
Date	Total acid (g/kl)	Fluoride (g/kl)	Temperature (°C)	Total acid (g/kl)	Temperature (°C)	Total acid (g/kl)	Volume of K701/1 (l)	Temperature (°C)
01-Aug-01	128	90	55	26.000	54	41.000	2340	54
02-Aug-01	127	59	55	24	54	26	1238	54
03-Aug-01	158	83	54	19	54	23	1865	
04-Aug-01	216		55	19	54	21		54
05-Aug-01			55	18	54	21		54
06-Aug-01							0	
07-Aug-01	140	68	55	18	55	21	1867	55
08-Aug-01	155	39	55	18	54	5	741	54
09-Aug-01	129		55	19	54	11	4261	55
10-Aug-01	168	50	55	21	55	45	6670	55
11-Aug-01	153		55	21	54	40		54
12-Aug-01	151		55	23	54	46		54
13-Aug-01	152	51	55	23	54	47	1589	50
14-Aug-01			55	25	54	48	1792.2	54
15-Aug-01	209	26	52	37	54	49		54
16-Aug-01	192		55	36	55	45		55
17-Aug-01							5851	
18-Aug-01	60		55	50	54	38		55
19-Aug-01	94		55	42	54	34		54
20-Aug-01	169	107	55	49	54	34	4198	54
21-Aug-01	243	135	55	32	54	35	2847	55
22-Aug-01	124	95	55	47	54	82	2773	55
23-Aug-01	107	92	55	53	54	90	2328	55
24-Aug-01	102	92	55	25	54	86	7669	55
25-Aug-01	163	93	54	25	51	37		55
26-Aug-01	117		55	27	54	39		55
27-Aug-01	242		55	30	54	61	0	55
28-Aug-01							971.5	
29-Aug-01	113		58	34	59	3	2375.9	56
30-Aug-01	104	127	56	22	59	13	2959.7	59
31-Aug-01			55	17	58	31	5385	59
01-Sep-01	105	67	56	20	59	33		60
02-Sep-01	133		55	27	58	37		59

Table E.6 contd.

Date	Stage 6					Stage 7		
	Conductivity (μS/cm)	Free acid (g/kl)	Total acid (g/kl)	Cr(VI) (g/kl)	Fluoride (g/kl)	Temperature (°C)	Total acid (g/kl)	Cr(VI) (g/kl)
01-Aug-01	20	640	1260	6153	2303	55	334	1717
02-Aug-01		700	1415	6864	2566	54	380	
03-Aug-01					1554	47	91	
04-Aug-01	0	865	1570	8372		56	108	
05-Aug-01	20	580	1115	5529		53	110	
06-Aug-01								728
07-Aug-01	30	375	1100	4160	1947	60	112	655
08-Aug-01	20	475	1010	4732	2570	51	16	150
09-Aug-01	0	720	1490	6864		51	46	501
10-Aug-01	0	720	1515	7592	1978	53	135	807
11-Aug-01	0	710	1465	6916		54	158	
12-Aug-01	10	655	1295			53	168	
13-Aug-01	20	700	900	6067	1372	52	170	1332
14-Aug-01	10	650	800	6933		50	170	
15-Aug-01		750	1050	3259	1333	53	211	
16-Aug-01	40	650	900	2115		53	200	
17-Aug-01								
18-Aug-01	40	250	550	3311		56	178	
19-Aug-01	20	660	1280	6361		54	154	
20-Aug-01	10	745	1540	6916	2243	54	150	986
21-Aug-01	-10	910	1810	9065	3341	55	247	1353
22-Aug-01	0	800	1615	7904	3104	55	327	1712
23-Aug-01	0	810	1530	8441	2390	54	364	1815
24-Aug-01	20	775	1475	7783	2618	59	442	1906
25-Aug-01	20	745	1485	7852	2618	55	420	
26-Aug-01	10	790	1700	4160		55	381	
27-Aug-01	0	960	1930	8476		54	425	1819
28-Aug-01								1870
29-Aug-01	20	375	800	3813		69	331	1789
30-Aug-01	10	540	1095	5287	2438	57	369	1423
31-Aug-01	0	700	1460	7315		55		1133
01-Sep-01	10	790	1945	6015		59	374	
02-Sep-01	0	760	1560	6916		54	408	

Table E.6 contd.

	Stage 7	Stage 8			Surge Tank B (chromium)			
Date	**Fluoride (g/kl)**	**Temperature (°C)**	**Conductivity (µS/cm)**	**Total acid (g/kl)**	**Conductivity (mS/cm)**	**pH**	**Total acid (g/kl)**	**Fluoride (g/kl)**
01-Aug-01	546	63	746	21		2	530	390
02-Aug-01		64	735	23	17.55	1.5	494	487
03-Aug-01		63	574	15	17.47	2	460	498
04-Aug-01		64	706	14				
05-Aug-01		65	597	12				
06-Aug-01	342				16.78	2	314	477
07-Aug-01	359	70	758	12	15.24	2	271	460
08-Aug-01	77	64	752	12	13.24	2	290	476
09-Aug-01	219	68	709	12	15.85	2	362	390
10-Aug-01	307	67	695	8	16.32	2	455	462
11-Aug-01		64	654	10				
12-Aug-01		61	715	11				
13-Aug-01	362	60	685	11	>20	1	608	359
14-Aug-01		66	670	11	19.04	1	585	341
15-Aug-01		60		33				
16-Aug-01		67	846	32				
17-Aug-01					10.78	2	424	445
18-Aug-01		64	169	30				
19-Aug-01		63	119	19				
20-Aug-01	512	62	107	24	19.97	2	365	619
21-Aug-01	509	63	407	20	>20	2	551	720
22-Aug-01	549	63	464	24	>20	1	619	535
23-Aug-01	669	57	619	28	>20	1.5	599	784
24-Aug-01	653	65	230	26	>20	2	544	783
25-Aug-01		67	327	32				
26-Aug-01		63	537	28				
27-Aug-01	192	60	436	30	>20	2	465	692
28-Aug-01	566				13.11	2.5	289	558
29-Aug-01	480	70		24	11.45	2	355	491
30-Aug-01	527	67	190	22	16.97	2	402	661
31-Aug-01	462	64	301	22	18.59	2	470	590
01-Sep-01		67	261	33				
02-Sep-01		62	520	25				

Table E.6 contd.

	Surge Tank C (acid)					Surge Tank B & C		
Date	**Conductivity (mS/cm)**	**pH**	**Total acid (g/kl)**	**Cr(VI) (g/kl)**	**Fluoride (g/kl)**	**Volume of effluent (kl)**	**Solid waste (kl)**	**Total Waste (kl)**
01-Aug-01		2	49	116	147	30	33	63
02-Aug-01	7.41	2	61	117	137	30	33	63
03-Aug-01	9.60	2	82	167	185	21	23	44
04-Aug-01						29	32	61
05-Aug-01						12	13	25
06-Aug-01	17.34	2	162	341	262	20	22	42
07-Aug-01	17.26	2	192	5	331	20	22	42
08-Aug-01	17.51	2	96	360	222	30	33	63
09-Aug-01	7.11	2	76	281	175	28	31	59
10-Aug-01	7.41	2	86	306	193	23	25	48
11-Aug-01						18	20	38
12-Aug-01						21	23	44
13-Aug-01	7.83	2	85	314	191	13	14	27
14-Aug-01	6.76	2	80	304	158	5	6	11
15-Aug-01						15	17	32
16-Aug-01						11	12	23
17-Aug-01	11.21	2	179	139	202	5	6	11
18-Aug-01						19	21	40
19-Aug-01						26	29	55
20-Aug-01	12.40	2	91	192	190	22	24	46
21-Aug-01	14.95	2	154	297	398	21	23	44
22-Aug-01	>20	1	148	77	227	23	25	48
23-Aug-01	8.69	2	87	226	236	20	22	42
24-Aug-01	5.11	2	53	217	161	22	24	46
25-Aug-01						20	22	42
26-Aug-01						20	22	42
27-Aug-01	10.45	2	89	79	598	15	17	32
28-Aug-01	14.54	1.5	114	0	223	17	19	36
29-Aug-01	4.42	3	44	179	187	5	6	11
30-Aug-01	9.24	4	61	0	283	26	29	55
31-Aug-01	8.14	2	59	62	146	18	20	38
01-Sep-01						16	18	
02-Sep-01						11	12	

Table E.6 contd.

					Stage 3			
Date	Uptime (%)	No. of coils	Mass (kg)	m^2 processed	Volume of 450M (l)	Temperature (°C)	Conductivity (µS/cm)	Free acid (g/kl)
01-Sep-01	42.0	6	54821	184571	0	57	13506	59
02-Sep-01	64.9	11	84895	233593	614	53	13997	72
03-Sep-01	22.6	4	31076	107307.2	0	56	27756	162
04-Sep-01	0.0	0	0	0	0			
05-Sep-01	0.0	0	0	0	0	48	19903	101
06-Sep-01	3.1	1	9722	29236	283			
07-Sep-01	80.2	13	122905	370759	144	47	31	52
08-Sep-01	24.0	7	35005	131368.53	86	52	34	60
09-Sep-01	62.5	9	93141	313586.44	0	62	22	67
10-Sep-01	44.4	6	61224	165858.36	315	54	34	36
11-Sep-01	69.1	12	109288	329682.3	83	59	25	79
12-Sep-01	70.5	12	113404	325193.2	205	53	-3	67
13-Sep-01	35.1	6	62002	184220.1	0	56	-9	71
14-Sep-01	47.6	8	62303	194421.8	127	56	10231	61
15-Sep-01	65.3	13	86186	297603.85	88	53	-6	69
16-Sep-01	71.5	11	101609	307006.74	155	53	13	63
17-Sep-01	90.3	13	127533	417429.71	184	54	19	66
18-Sep-01	92.0	14	128579	427594.03	0	54	13	71
19-Sep-01	14.6	1	7224	24944.75	0	54	25	41
20-Sep-01	63.2	13	95488	299464.24	139	54	-69	42
21-Sep-01	74.0	17	117644	350008.69	102	54	-84	54
22-Sep-01	78.8	14	104571	497859.72	125	61	-47	54
23-Sep-01	13.5	2	13281	276747.23	0	54	-19	48
24-Sep-01	52.4	11	83411	267134.62	98	52	8756	42
25-Sep-01	0.0	0	0	0	0	53	10069	55
26-Sep-01	41.3	7	67128	167290.36	142	58	8294	43
27-Sep-01	39.9	6	53928	182870.58	61	53	8872	45
28-Sep-01	73.6	15	106255	262479.61	98	52	8609	43
29-Sep-01	0.0	0	0	0	0	49	8556	43
30-Sep-01		5		154714.24	223	56	10094	55

Table E.6 contd.

	Stage 3		Stage 4		Stage 5		Stage 6	
Date	Total acid (g/kl)	Fluoride (g/kl)	Temperature (^{o}C)	Total acid (g/kl)	Temperature (^{o}C)	Total acid (g/kl)	Volume of K701/1 (l)	Temperature (^{o}C)
01-Sep-01	105	67	56	20	59	33	0	60
02-Sep-01	133		55	27	58	37	2411	59
03-Sep-01	228	69	55	24	59	49	999	60
04-Sep-01							243	
05-Sep-01	156		55	24	59	50	19.6	59
06-Sep-01							325	
07-Sep-01	67		55	23	58	54	1789	59
08-Sep-01	84		55	27	59	52	711	59
09-Sep-01	99		57	23	60	34	3181	67
10-Sep-01	73	73	55	16	59	53	1056	59
11-Sep-01	122	40	56	16	60	53	2558	61
12-Sep-01	116	55	55	34	60	52	2760	59
13-Sep-01	122	39	55	32	59	45	1426	60
14-Sep-01	112	35	54	40	58	71	1883	60
15-Sep-01	121		55	36	59	55	2400	59
16-Sep-01	129		52	46	54	73	2097	59
17-Sep-01	124	49	55	33	59	54	2882	58
18-Sep-01	142	50	55	35	59	52	3051	59
19-Sep-01	100		55	45	59	69	231	59
20-Sep-01	104	52	57	40	59	13	2517	65
21-Sep-01	120	55	56	27	59	30	1876	65
22-Sep-01	126		57	27	60	39	2286	82
23-Sep-01	112		58	33	60	45	890	70
24-Sep-01	89		56	33	59	42	1974	60
25-Sep-01	116	53	56	26	59	44	0	63
26-Sep-01	97		55	29	54	60	2429	Using 6B
27-Sep-01	94	66	55	38	59	61	1313	64
28-Sep-01	91		60	29	59	71	2064	66
29-Sep-01	87		60	6	59	66	0	64
30-Sep-01	96		59	21	59	50	1354	67

Table E.6 contd.

Date	Stage 6					Stage 7		
	Conductivity (μS/cm)	Free acid (g/kl)	Total acid (g/kl)	Cr(VI) (g/kl)	Fluoride (g/kl)	Temperature (°C)	Total acid (g/kl)	Cr(VI) (g/kl)
01-Sep-01	10	790	1945	6015.000		59	374	
02-Sep-01	0	760	1560	6916		54	408	
03-Sep-01	10	885	1680	8823	2884	61	402	1619
04-Sep-01								1689
05-Sep-01	10	705	1500	7661		63	287	1663
06-Sep-01								1402
07-Sep-01	20	660	1215	6205	2367	58	30	
08-Sep-01	10	725	1530	7800		57	125	
09-Sep-01	10	700	1500	7176		65	157	
10-Sep-01	0	875	1885	9291	3123	58	207	1236
11-Sep-01	0	740	1410	7055	2881	65	216	1346
12-Sep-01	10	740	1455	7228	2043	59	273	1633
13-Sep-01	10	865	1705	9377	2520	65	274	
14-Sep-01	0	760	1630	8129	2638	58	281	1665
15-Sep-01	10	800	1605	8095		57	300	
16-Sep-01	10	835	1710	8528		56	326	
17-Sep-01	10	700	1435	7488	2547	55	279	1534
18-Sep-01	10	675	1400	7419	2822	56	266	1553
19-Sep-01	10	805	1625	8476		56	319	
20-Sep-01	0	670	1425	6864	2979	58	77	366
21-Sep-01	10	710	1435	7800	3076	58	209	1232
22-Sep-01	-30	685	1425	7107		49	242	
23-Sep-01	10	755	1500			59	284	
24-Sep-01	20	920	2115	7159		58	301	
25-Sep-01	20	680	1370	7332	3431	58	292	
26-Sep-01		Using 6B		Using 6B		56	285	550
27-Sep-01	30	635	960	4905	1809	58	121	635
28-Sep-01	10	510	865	4975	3402	63	129	767
29-Sep-01	20	510	1035	5859		62	132	
30-Sep-01	20	715	1260	6361		56	147	

Table E.6 contd.

	Stage 7	Stage 8			Surge Tank B (chromium)			
Date	**Fluoride (g/kl)**	**Temperature (°C)**	**Conductivity (μS/cm)**	**Total acid (g/kl)**	**Conductivity (mS/cm)**	**pH**	**Total acid (g/kl)**	**Fluoride (g/kl)**
01-Sep-01		67	261	33				
02-Sep-01		62	520	25				
03-Sep-01	555	66	435	18	>20	2	538	745
04-Sep-01	465				17.56	2	394	519
05-Sep-01	449	69	249	19	17.28	2	471	442
06-Sep-01	71				15.45	2	315	382
07-Sep-01		67	571	21				
08-Sep-01		66	487	11				
09-Sep-01		70	411	9				
10-Sep-01	518	64	378	10	>20	2	523	681
11-Sep-01	521	71	315	10	>20	2	460	597
12-Sep-01	425	66	608	14	>20	2	496	599
13-Sep-01		70	535	16	>20	2	490	490
14-Sep-01	472	65	570	31	19.90	2	430	504
15-Sep-01		63	423	23				
16-Sep-01		63	374	22				
17-Sep-01	432	61	526	19	>20	2	549	573
18-Sep-01	412	63	292	21	>20	1.5	520	524
19-Sep-01		63	326	20	>20	2	556	488
20-Sep-01	161	63	302	24	16.90	2	334	491
21-Sep-01	407	64	343	20	17.21	2	404	
22-Sep-01		70	292	30				
23-Sep-01		70		17				
24-Sep-01		61	-53	19				
25-Sep-01		64	124	16				
26-Sep-01	324	64	375	18		2	483	1099
27-Sep-01	320	61	204	17	>20	2	448	839
28-Sep-01	309	67	427	13	>20	2	403	702
29-Sep-01		66	402	12				
30-Sep-01		66	106	14				

Table E.6 contd.

	Surge Tank C (acid)					Surge Tank B & C		
Date	Conductivity (mS/cm)	pH	Total acid (g/kl)	Cr(VI) (g/kl)	Fluoride (g/kl)	Volume of effluent (kl)	Solid waste (kl)	Total Waste (kl)
01-Sep-01						16	17	33
02-Sep-01						11	12	23
03-Sep-01	7.83	2	64	108	151	24	25	49
04-Sep-01	12.21	2	87	67	145	19	20	39
05-Sep-01	12.29	2	94	107	165	13	14	27
06-Sep-01	19.90	1.5	146	21	111	9	9	18
07-Sep-01						18	19	37
08-Sep-01						18	19	37
09-Sep-01						21	22	43
10-Sep-01	7.61	2	68	196	145	21	22	43
11-Sep-01	6.72	2	60	120	140	19	20	39
12-Sep-01	7.98	2	76	268	158	23	24	47
13-Sep-01	9.39	2	89	258	136	21	22	43
14-Sep-01	8.95	2	87	279	176	18	19	37
15-Sep-01						28	29	57
16-Sep-01						23	24	47
17-Sep-01	9.76	2	103	346	203	13	14	27
18-Sep-01	11.49	2	208	212	209	25	26	51
19-Sep-01	10.90	2	112	335	161	24	25	49
20-Sep-01	7.83	2	83	326	173	26	27	53
21-Sep-01	8.42	2	89	326	189	27	28	55
22-Sep-01						17	18	35
23-Sep-01						30	31	61
24-Sep-01						14	15	29
25-Sep-01						23	24	47
26-Sep-01		2	96	243	180	17	18	35
27-Sep-01	9.92	2	92	129	172	22	23	45
28-Sep-01	10.45	2	91	223	184	40	42	82
29-Sep-01						31	32	63
30-Sep-01								0

Appendix F

Calculations that were performed in this study are detailed in this Appendix. Appendix F.1 shows the calculations to determine the volume of water added to the alkali section and the combined acid and chromium sections of CCL2. Appendix F.2 shows the calculations to estimate the volume of water added to each of the acid and chromium sections of CCL2. Appendices F.3 and F.4 detail the calculations of simple process modifications to the alkali process tank (Stage 1) and the acid process tank (Stage 3) respectively.

Appendix F.1: Calculations to determine the total volume of water added to the alkali section and the combined acid and chromium sections of CCL2

The general mass balance used to calculate the volume of water is:

Volume of water = Volume of effluent – Volume of raw materials

Equation F.1

For the alkali section of CCL2:

Volume of water (annual) = Volume of alkali effluent – Volume of Gardoclean S5160

Volume of water (annual) = 3 900 000 L – 55 600 L

= 3 844 000 L

For the acid and chromium sections of CCL2:

Volume of water (annual) = Volume of acid and chromium effluent and solid waste – (Volume of Gardoclean 450M + Volume of Gardoclean 450C + Volume of Gardal K701/1)

Volume of water (annual) = 15 200 000 L – (49 600 L + 4 000 L +620 000 L)

= 14 526 000 L

Appendix F.2: Calculations to estimate the volume of water added to the acid section and chromium section of CCL2

Average total volume of water added to the acid and chromium sections = 14 500 kL per year

Flowrate to acid section (Stages 3, 4 and 5) = 20 L/min

Flowrate to chromium section (Stages 6A, 7 and 8) = 23 L/min

$$\text{Volume of water to acid section} = \frac{20\,\text{L/min}}{43\,\text{L/min}} \times 14500\,\text{kL}$$

= 6 700 kL per year

$$\text{Volume of water to chromium section} = \frac{23\,\text{L/min}}{43\,\text{L/min}} \times 14500\,\text{kL}$$
$$= 7\ 800\ \text{kL per year}$$

Appendix F.3: Calculations of simple process modifications to the alkali process tank

A graph of the volume of Gardoclean S5160 added to the alkali process tank as a function of the % uptime was plotted. The regression equation obtained ($R^2 = 0.3159$) was:

$$\text{Vol added} = 2.5468\ (\%\ \text{uptime}) + 26.696 \qquad \underline{\text{Equation F.2}}$$

The alkali process tank is currently operated in a combination of continuous and fed-batch mode. Figure F.1 is a schematic representation of the continuous operation of Stages 1 and 2.

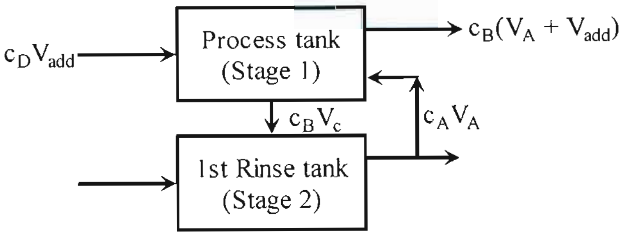

Figure F.1: Diagram of Stages 1 and 2 showing recycle of the rinse water

Where:
c_A = the average alkali concentration for the rinse tank (g/L)
c_D = the alkali concentration in the raw material, Gardoclean S5160 (60.110 g/L)
V_{add} = the volume of Gardoclean S5160 that needs to be added to ensure there is enough alkali for the reaction per day (L)
c_B = the average alkali concentration for the process tank (g/L)
m_{react} = the mass of alkali that reacts per day (7 454 g)
V_A = the volume of the recycle (calculated from the flow rate) (L)
V_c = the volume of the dragout (L)

$$[c_AV_A + c_DV_{add}] - [c_B(V_A + V_{add})] - m_{react} = 0 \qquad \underline{\text{Equation F.3}}$$

For each of the different options below, V_{add} was calculated. The volume savings were then determined by subtracting V_{add} from the current average volume of Gardoclean S5160 added per day.

1. Recycling the dragout (using the rinse water to top up the process tank)

Equation F.3 was solved for V_{add} using the current average process tank alkali concentration of 620 g/kL, the current average rinse tank alkali concentration of 600 g/kL, and the original design recycle flow rate of 0.3 kL/hour. V_A was calculated by multiplying the recycle flow rate by the average uptime and by 24 hours to convert it to a volume (L) per day.

2. Recycling dragout to process tank and operating at the design specifications for the alkali concentrations

The specified process tank alkali concentration is 204 g/kL, and the specified rinse tank alkali concentration is 197 g/kL. In this calculation it was assumed that the mass of alkali that reacts is constant at different c_B values (*i.e.* it is always 7 454 grams).

3. Recycling dragout to process tank, operating at the specified alkali concentration and recycling 50% of the process output stream

Equation F.3 was used to solve for V_{add}.

Appendix F.4: Calculations of simple process modifications to the acid process tank

A graph of the volume of Gardoclean 450M added to the acid process tank as a function of the % uptime was plotted. The regression equation obtained ($R^2 = 0.0904$) was:

$$\text{Vol added} = 1.7645\ (\%\ \text{uptime}) + 45.186 \qquad \text{Equation F.4}$$

The acid process tank is currently operated in a combination of continuous and fed-batch mode. Figure F.2 is a schematic representation of the continuous operation of Stages 3 – 5.

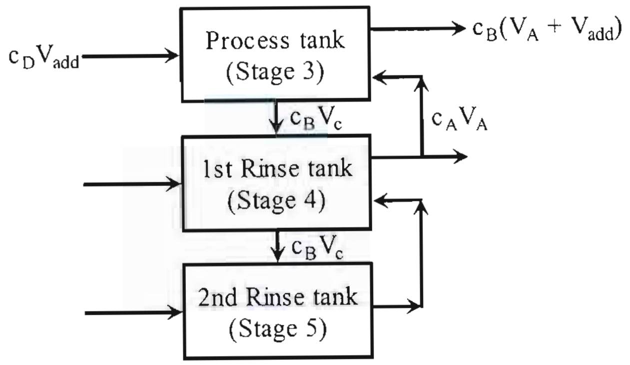

Figure F.2: Diagram of Stages 3 – 5 showing recycle of the rinse water

Where:
c_A = the average acid concentration for the rinse tank (g/L)
c_D = the acid concentration in the raw material, Gardoclean 450M (7.354 g/L)
V_{add} = the volume of Gardoclean 450M that needs to be added to ensure there is enough acid for the reaction per day (L)
c_B = the average acid concentration for the process tank (g/L)
m_{react} = the mass of acid that reacts per day (632 g)
V_A = the volume of the recycle (calculated from the flow rate) (L)
V_c = the volume of the dragout (L)

For each of the different options below, V_{add} was calculated using Equation F.3. The volume savings were then determined by subtracting V_{add} from the average volume of Gardoclean 450M added per day.

1. Recycling the dragout (using the rinse water to top up the process tank)

Equation F.3 was solved for V_{add} using the current average process tank acid concentration of 141 g/kL, the current average rinse tank acid concentration of 28 g/kL, and the original design recycle flow rate of 0.3 kL/hour. V_A was calculated by multiplying the recycle flow rate by the average uptime and by 24 hours to convert it to a volume (L) per day.

2. Recycling dragout to process tank and operating at the design specifications for the acid concentrations

The specified process tank acid concentration is 76 g/kL, and the specified rinse tank acid concentration is 15 g/kL. In this calculation it was assumed that the mass of acid that reacts is constant at different c_B values (*i.e.* it is always 632 grams).

3. Recycling dragout to process tank, operating at the specified acid concentration and recycling 50% of the process output stream

Equation F.3 was used to solve for V_{add}.