University Of Southern Queensland

Faculty of Engineering and Surveying

# LOCOMOTIVE COOLING SYSTEM STRATEGY OPTIMISATION

A Dissertation submitted by

Mr Mark Windebank

In fulfilment of the requirements of

**Bachelor of Engineering (Mechanical)** 

November 2014

## Abstract

This report analyses the coolant management practices and procedures implemented at rail maintenance facilities to maintain the quality of coolants used in the GE Evolution and Dash 9 Series locomotives. Key motivations for the work conducted in this analysis include the identification of sediment observed in locomotive coolant samples and investigation into radiator core failure. In the conduct of the analysis experimental data validated the implementation of a method to determine the nitrite based corrosion inhibitor concentration through measurement of the electrical conductivity. Further experimentation confirmed that research identifying a minimum concentration of nitrite corrosion inhibitor of 500 ppm as adequate for effective inhibition could be applied as a reference minimum concentration for the corrosion inhibitor package to inhibit corrosion over the variety of metals that comprise the locomotive cooling system. Investigation into conclusions previously made as to the cause of radiator core failure in the locomotive have been determined to be unfounded and more probable causes for the material degradation have been identified. Recommendations have been made to implement a number of changes for the purpose of optimising the coolant management processes.

### Disclaimer

University of Southern Queensland Faculty of Health, Engineering and Sciences

### ENG4111 Research Project Part 1 ENG4112 Research Project Part 2

#### **Limitations of Use**

The Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences, and the staff of the University of Southern Queensland, do not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with this dissertation.

Persons using all or any part of this material do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course pair entitled "Research Project" is to contribute to the overall education within the student's chosen degree program. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user

# **Certification of Dissertation**

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Mark Windebank

Student Number 0061012351

Signature

Date

## Acknowledgments

Assistance in the completion of this project is thankfully acknowledged.

Mr John McArthur of Rio Tinto for identifying the initial project requirement and providing the benefit of experience and material support.

Dr Ray Malpress of the USQ Engineering Faculty for guidance in throughout the conduct of this project

# **Table of Contents**

Abstract	i
Disclaimer	ii
Certification of Dissertation	iii
Acknowledgments	iv
List of Figures	ix
List of Tables	X
Nomenclature	xi
Glossary of Terms	xiii
Chapter 1 Introduction	1
1. 3 Expected Outcomes	2
1. 4 Safety	3
Chapter 2 Literature Review	4
2. 1 RTIO Locomotive Fleet	4
2. 2 Closed Cooling Systems	4
2. 3 Corrosion	6
2. 3. 1 The Corrosion Reaction	6
2. 3. 2 Galvanic Corrosion	8
2. 3. 3 Pitting	10
2. 3. 4 Cavitation	11
2. 3. 5 Particle Erosion and Erosion Corrosion	12
2. 3. 6 Crevice Corrosion	13
2. 3. 7 Stress Corrosion Cracking	14
2. 3. 8 Microbial Influenced Corrosion	15
2. 3. 9 Dealloying	16
2. 4 Corrosion Inhibitors	17
2. 4. 1 Nitrites	18
2. 4. 2 Azoles	18
2. 5 Debris	19
2. 5. 1 Spectrochemical Analysis	19
2. 5. 2 Particle Quantifier (PQ) Index	20
2. 6 Coolant	20
2. 6. 1 Water	20
2. 6. 2 Monitoring	21
	$\mathbf{V}$

Chapter 3 Radiator Core Failure		
3. 1 Background Information	23	
3. 2 Analysis	24	
3. 2. 1 pH	25	
3. 2. 2 Nitrite	25	
3. 2. 3 Ammonia	26	
3. 2. 4 Azoles	26	
3. 2. 5 Material Degradation	26	
3. 3 Conclusions	27	
Chapter 4 Bulk coolant mixing	29	
4. 1 Current Process	29	
4. 2 Coolant Mixing Procedure	30	
Chapter 5 Coolant Monitoring	31	
5. 1 Inhibitor Concentration Testing	31	
5. 2 Coolant Condition Monitoring	32	
5. 2. 1 Spectrochemical analysis	32	
5. 2. 2 PQ Index	33	
5. 2. 3 pH	33	
5. 2. 4 Colour	33	
5. 2. 5 Odour	34	
5. 2. 6 Nitrite	34	
5. 2. 7 Conductivity	35	
5. 2. 8 Visual Debris	36	
5. 3 Coolant Contaminants	37	
5. 3. 1 Potential Sources of Contaminant	37	
5. 3. 2 Monitoring Frequency	39	
Chapter 6 Effect of Inhibitor Concentrations	40	
6. 1 Experimental Method	40	
6. 1. 1 Metal test Specimens	40	
6. 1. 2 Corrosion Inhibitor Concentrations	41	
6. 1. 3 Experiment Results	41	
6. 1. 4 Conclusions	42	
<b>Chapter 7 Inhibitor Concentration Testing</b>	44	
7.1 Current Inhibitor Concentration Test Method	44	
7.1.1 Limitations	45	

7. 1. 2 Key Concerns	46
7. 1. 3 Suitability	46
7. 2 Alternative Coolant Sampling Methods	47
7. 2. 1 Electrical Conductivity	47
7. 2. 2 Electrical Conductivity Test Units	49
7. 2. 3 Visual Colour Comparison	50
7. 3 Experiment	50
7. 3. 1 Results	50
7. 4 Conclusions	51
Chapter 8 Coolant Reclamation	53
8. 1 Analysis	53
8. 2 Improvements	54
Chapter 9 Contaminant Removal	55
9.1 Locomotive Located Filtration	55
9. 2 Reclamation Tank Located Filtration	56
9. 3 Filtration Type	56
9. 3. 1 Solid Medium Filtration	56
9. 3. 2 Magnetic Filtration	58
9. 3. 3 Pore Size	58
Chapter 10 Recommendations	59
10. 1 Radiator Core Failure	59
10. 2 Coolant Management	59
Chapter 11 References	62
Appendix A Project Specification	66
<b>Appendix B Locomotive 8125 Report Extract</b>	68
Appendix C Experiment for Effect of Corrosion Inhibitor Concentration on Corrosion Rates	70
C.1 Experiment to Determine Levels of Corrosion Relative to	<b>7</b> 0
Coolant Concentration	70
C.2 Procedure	77
C.3 Results	78
Appendix D Nitrite Concentration Relationship Graphs	79
Appendix E Experiment for Methods of Determining Coolant Concentration	83
E.1 Experiment Method	83
E.2 Results	91
	vii
	1 1 1

Appendix F Recommended Corrosion Inhibitor Concentration Procedure	on Testing 97
Appendix G Experiment for Comparison of Coolants Corros Inhibition	sion 104
Appendix H Material Compositions	105
H.1 Compositions	105
Appendix I Accuracy and Equipment Error	110
I.1 Class A, 50 mL Burette	110
I.2 Thermometer	111
I.3 Scales	111
Appendix J Risk Assessment	112
Appendix K Hazardous Chemical List	114

# List of Figures

Figure 2-1 Galvanic corrosion of steel pipe in a brass fitting	9
Figure 2-2 Pitting corrosion in a metal	10
Figure 2-3 Cavitation on a cylinder liner	11
Figure 2-4 Particle erosion in pipe bend	12
Figure 2-5 Particle erosion in tube inserts	13
Figure 2-6 Typical result of Microbial Corrosion	16
Figure 3-1 Radiator core removed from locomotive 8125	24
Figure 3-2 Enlarged section of the radiator cores	24
Figure 3-3 Longitudinal Stress Corrosion Cracking	27
Figure 3-4 Circumferential Stress Corrosion Cracking	27
Figure 4-1 ALS Generated Trend Analysis of Bulk Coolant Nitrite	
Concentration	30
Figure 5-1 Coolant Samples	33
Figure 5-2 Evolution series sampling point	36
Figure 7-1 Locomotive Coolant Sampling Locations	44
Figure 7-2 Nitrite Concentration vs Electrical Conductivity	48
Figure 7-3 Nitrite Concentration Testing Results	52
Figure 8-1 Reclamation Tank	53
Figure 8-2 Reclamation Tank Coolant Sample	54
Figure 9-1 Coolant Tank Sight Glass	55
Figure 9-2 Cape Lambert Coolant Filtration System	57
Figure 9-3 Magnetic Trap Section	57
Figure B- 1 Coolant Analysis for 8125 supplied to Rio Tinto	68
Figure B- 2 Coolant Analysis for 8125 Conducted by Rio Tinto	69
Figure C- 1 Equipment Configuration	73
Figure C- 2 Test and Support Coupon Dimensions	75
Figure C- 3 Metal Specimen Arrangement	75
Figure D- 1 Nitrite Concentration vs Conductivity	79
Figure D- 2 TDS Concentration vs Conductivity	80
Figure D- 3 Nitrite Concentration vs TDS Concentration	81
Figure E-1 Graphical Comparison of Concentration Estimation Methods	92
Figure E- 2 Enhanced Extract of Figure E-1 (1000 to 2000 ppm)	93
Figure E- 3 Comparison of Locomotive Sample Results	94

# List of Tables

Table 1 Selected Elemental Symbols by Alphabetical Order	xii
Table 2 Cooling System Component Materials	5
Table 3 Galvanic Series	9
Table 4 Spectrochemical Data Elemets (ALS 2010)	19
Table 5: Maximum Contaminant Levels in Raw Water	21
Table 6 Molar Masses	22
Table 7 Acceptable Range	32
Table 8 Nalco Recommended Contaminant Levels	38
Table 9 Sources of Elements in Cooling Systems	38
Table 10 Relationship of Elements to Components	38
Table 11 Allowable Material Weight Loss	41
Table 12 Coupon Weight Losses	42
Table 13 Coefficients of Determination	51
Table C- 1 Allowable Coupon Weight Losses	77
Table C- 2 Recorded Coupon Weight Losses	78
Table D- 1 Representative Sample Data	82
Table E-1 Mixing Volumes for Coolant Samples	87
Table E- 2 Nitrite Concentration Values	91
Table E- 3 Total Square of Residuals	95
Table E- 4 Total Spread of Data	95
Table E- 5 Coefficients of Determination	96
Table E- 6 Coefficients of Determination (1000 to 2000 ppm)	96
Table I- 1 Potential Variation Error in Volumes	110

# Nomenclature

Where appropriate SI units have been used within this dissertation.

Term	Definition
cm	Centimetre
mg/L	Milligrams per litre
ppm	Parts per million
μ	Mu – micro [x 10 <sup>6</sup> ]
S	Siemens
wt %	Percentage by weight.

Symbol	Element	Symbol Element	
Ag	Silver	Kr	Krypton
Al	Aluminium	Li	Lithium
Ar	Argon	Mg	Magnesium
As	Arsenic	Mn	Manganese
Au	Gold	Мо	Molybdenum
В	Boron	Ν	Nitrogen
Ba	Barium	Na	Sodium
Be	Berylium	Ne	Neon
Bi	Bismuth	Ni	Nickel
Br	Bromine	0	Oxygen
С	Carbon	Р	Phosphorus
Ca	Calcium	Pb	Lead
Cd	Calcium	Pd	Palladium
Ce	Cerium	Pt	Platinum
Cl	Chlorine	Rh	Rhodium
Со	Cobalt	S	Sulfur
Cr	Chromium	Sb	Antimony
Cu	Copper	Si	Silicon
F	Fluorine	Sn	Tin
Fe	Iron	Sr	Strontium
Ge	Germanium	Ti	Titanium
Н	Hydrogen	V	Vanadium
He	Helium	W	Tungsten
Ι	Iodine	Xe	Xenon
Ir	Iridium	Zn	Zinc
Κ	Potassium	Zr	Zirconium

Table 1 Selected Elemental Symbols by Alphabetical Order

# **Glossary of Terms**

Term	Definition
AC	Alternating Current
DC	Direct Current
EC	Electrical Conductivity
GE	General Electrics
Nitrate	The negative ion consisting of one nitrogen atom and three oxygen atoms. $NO_3^-$ .
Nitrite	The negative ion consisting of one nitrogen atom and two oxygen atoms. $NO_2^-$ .
OEM	Original Equipment Manufacturer
рН	Power of Hydrogen: The measure of the acidity or basicity of a solution.
PQ Index	Particle Quantifier Index: The total amount of magnetisable iron.
RTIO	Rio Tinto Iron Ore.
Sodium Nitrite	The ionic compound. $NaNO_2$ .
SI	Systeme International
TDS	Total Dissolved Solids

## **Chapter 1 Introduction**

The purpose of this project is to investigate aspects of the engine coolant used in Rio Tinto Iron Ore (RTIO) diesel electric locomotives and processes managing that coolant. The locomotives operated by RTIO are the General Electric (GE) Evolution and Dash 9 series diesel electric locomotives which run exclusively on their Pilbara rail network.

There have been concerns raised relative to the cooling systems of these locomotives and the coolant used in them. The broad aim of the project is to analyse these concerns and, where appropriate, identify and recommend actions to address those concerns.

#### 1.1 Initial Concerns

The initial concerns raised relative to the locomotive cooling system and the coolant used are detailed below:

- RTIO have identified issues in ensuring the coolant that is to be used in the locomotives is consistently mixed to the correct concentrations. No clear methodology exists for the mixing process.
- The routine coolant samples taken from the RTIO locomotive fleet contain an unknown debris which has a magnetic characteristic.
- The OEM (Original Equipment Manufacturer) has recommended RTIO change coolants to variety with a higher "azole" content. Azole is the family name given to a group of compounds that have a use in corrosion protection for copper and materials containing copper.
- The current process of sampling coolants includes an analysis carried out by an independent laboratory. There is currently no procedure that references or responds to the reports and alarms raised through the results of the laboratory testing.
- The alarm limits defined for use by the independent laboratory appear inconsistent with the OEM requirements for concentration levels of the coolant mix.
- A radiator core has shown evidence of erosion, information and anecdotal advice indicates this may be caused by a design fault or an excessive level of ammonia in the coolant. The belief is that the ammonia may be due to organic decomposition or excessive heat sources in the cooling system.
- There is no disposal method for coolant deemed unfit for further use.

### 1.2 Research Objectives

The project plans to address the initial concerns through experimentation, research, independent testing and consultation with external agencies. The objectives, summarised below, are detailed Project Specification, supplied in Annex A.

- Carry out a literature review for relative information on coolants and cooling systems pertaining to the initial concerns listed above in respect to their use.
- Review RTIO's current coolant sampling process.
- Determine the suitability of RTIO's current sampling process.
- Determine suitable coolant testing alarm limits for the RTIO locomotive fleet.
- Develop and implement a coolant sampling procedure.
- Review the coolant reclamation process and determine its suitability.
- Identify and recommend any improvements to the coolant reclamation process and/or equipment.
- Identify any contaminants in the coolant
- Identify the source of any contaminants in the coolant.
- Determine the acceptable levels of contamination allowable in the coolant.
- Identify and recommend a method to remove contamination from the coolant.
- Examine radiator cores and assess any erosion evident.
- Determine the cause of any erosion detected.
- Conduct a comparison of coolants available for use and recommend changes as appropriate.

### **1.3 Expected Outcomes**

The outcomes of this research project are expected to assist Rio Tinto Iron Ore in managing and maintaining their locomotives. The particular objectives addressed will provide guidance on the optimal coolant variety for use, preparation of coolant for use, sampling methods and management of the coolant whilst in use, and disposal of coolant on the conclusion of its useful life.

Furthermore, this research project will provide insight to the potential for reductions in service life of cooling system components that have been subjected to less than optimal conditions.

#### 1.4 Safety

Through the conduct of this research project, occupational hazards have been encountered and risk control measures were implemented to mitigate the risk of these hazards.

The nature of the rail transport industry presents a number of hazards in and around the maintenance workshop facility and further hazards have been introduced due to the environment and location of the workshop facility. The risks associated with these hazards have been addressed by Rio Tinto Iron Ore personnel and appropriate control measures have been implemented and identified in their general and site specific safety inductions. Completion of, and compliance with, these inductions is deemed the minimum level of safety required for tasks in this project that have been carried out in the workshop location. For reference, these inductions are held by Rio Tinto and are delivered as required.

In the conduct of the research and experiments described in this report, there has been a requirement to handle hazardous chemicals. In the interests of health and safety a risk assessment has been conducted and has been supplied in Appendix J This risk assessment identifies the hazards associated with the materials described in Appendix K and describes the control measures applied. The control measures applied are in compliance with the section 8, Exposure Controls/Personal Protection, of the respective MSDS's, the Occupational Safety and Health Act 1984 (WA) and its subsequent legislation, and the code of practice Managing Risks of Hazardous Chemicals in the Workplace (Safe Work Australia 2012).

Disposal of hazardous materials has been conducted in accordance with the requirements listed in with the legislation listed above and section 13, Disposal Considerations, of the respective MSDS. The applicable MSDS for the hazardous materials listed may be obtained from the materials supplier.

### **Chapter 2 Literature Review**

This chapter will review literature to further understand the use, application, and management of coolants in diesel engines and determine possibilities for improvements in the practices and procedures conducted by RTIO.

#### 2.1 RTIO Locomotive Fleet

Rio Tinto Iron Ore (RTIO) primarily utilise two types of GE locomotives, the 9-44CW locomotive (referred to colloquially as the Dash 9) and the ES44DCi locomotive (referred to as the Evo). A third type, an AC version of the Evo, is now being introduced into the fleet. At the time of writing, the RTIO fleet consists of 72 Dash 9's and 106 Evo's.

All three types of locomotives utilise a diesel engine as a generator to produce electrical energy which is then supplied to the electric traction motors mounted to the locomotive's axles. These diesel engines rely on closed cooling systems to transfer excess heat energy from the motor to the surrounding environment to maintain the optimal operating temperature for the engine.

#### 2. 2 Closed Cooling Systems

In analysing the modes of heat dissipation to the environment, Mollenhauer and Tschoeke (2010) and Avallone, Baumeister and Sadegh (2007) agree that approximately 30 % of heat energy created is transferred directly to the environment in exhaust gases. The remaining heat energy is dissipated through the engine components, with the predominate portion via some form of cooling system. It is noted that a small portion of heat is transferred from the engine components through conduction and radiation, however, the combined rate of heat transfer by these modes is negligible in comparison to the rate of heat transfer by convection within the cooling system. Thus the cooling system plays a significant role in maintaining optimal engine temperatures.

There are a variety of types of cooling systems in use for an even larger variety of applications. This dissertation only refers to the liquid cooled,

closed circuit type of cooling system as used in the locomotives operated by Rio Tinto. All of the OEM recommended coolants (Curtin 2013; GE Transportation 2012) for these locomotive models use a water based coolant. Curtin (2013) details the component materials and their respective surface contact areas with the water based coolant, shown in **Error! Reference source not found.** (chemical compositions for these materials are listed in Appendix F ).

As identified by Lazroff (2009) and Mollenhauer and Tschoke (2010), and Gershun and Woyciesjes (2003), water is the typical base component of the fluid used in the cooling systems. Whilst the use of water is convenient in supply and has very good characteristics for transferring heat, its electrolytic capacity increases the concern of corrosion in the metal cooling system components.

Component	Material	Coolant Velocity (m/s)	Surface Area (m <sup>2</sup> )
All coolant pipes in radiator cabinet, tanks, intercoolers	Steel (ASTM A53, A513, AISI 1020 B4A9B2)	<6	14.3
Plate Oil Cooler	SS (AISI 316, 304) Copper (CDA 122)	<3	43.6
Shell & Tube Oil Cooler	B50E183A (C12200)	<2.4	52
Engine	*	0 - 3	30
Other Intercoolers	Cu/Ni 90/10 (C70600)	<2.4	4.7
Radiator Cores	Red brass (C23000) Yellow Brass (UNS C26000, C26800, C85200)	<1.8	72
Flexible Hoses	Silicone	<6	0.4

Table 2	Cooling	System	Component	Materials
I able 2	Coomig	System	Component	wrateriais

\* Engine components may contain one or more of the following:

• Ductile or grey cast, compacted graphite, or vermicular iron

- ASTM 1030 carbon steel
- PTFE hose (Sae 100R14A)

#### 2.3 Corrosion

Callister (2007) defines corrosion as a destructive and unintentional attack on a metal. It may be noted that in some applications such as electroplating, the corrosive process may have desirable effects however, in respect to cooling systems occurrences of corrosion are typically considered to be detrimental. Particular to their cooling systems, GE (2014) describe corrosion as the destruction of a metal by chemical or electrochemical reaction with its environment, being the coolant and other metals. Marcus (2003) defines aqueous corrosion as an environment in which metal is exposed to a liquid electrolyte, being an accurate description of the typical cooling system.

Whilst the process of corrosion can be detailed by a series of common reactions, Gellings (1985) divides corrosion types as either a uniform, predictable corrosion over an entire surface or a localised attack. This localised attack is of more concern, of which Gershun and Woyciesjes (2003) identify galvanic, crevice, erosion, pitting and cavitation among the various forms that may occur in cooling systems.

#### 2.3.1 The Corrosion Reaction

Callister (2007) and Askeland and Phule (2008) both describe a generalised corrosion equation for metals, Equation 1 called oxidation which occurs at the anode. In the oxidation process the anode metal gives up electrons and becomes a positive ion of the original anodic metal, with a charge magnitude equal to the number of electrons given up by the metal atom.

This oxidation process is balanced with an equivalent reduction reaction, Equation 2, in which the opposing process occurs with the cathode material taking up electrons to become a negative ion of the original cathode material. This negative ion's charge is also of a magnitude equal to the number of electrons taken up by the metal ion. The balancing factor between these reactions is the number of electrons given must equal the number taken in.

Askeland and Phule (2008) state that the positive ions created through the oxidation reaction leave the anode and enter the solution, resulting in the corrosion of the anode material. The negative ions at the cathode draw these positive ions out of the solution which form a deposit on the cathode.

Protopopoff and Marcus (2005) shows the neutral metal atom as a solid state and the positively charged ion in an aqueous solution, being in solution the ion has the ability to be drawn toward a negative charge.

In cases where corrosion may be unavoidable, an ideal system would have oxidation and reduction occurring uniformly throughout the metal providing the longest, and most predictable, service life for the component. In practical systems, localised factors will encourage corrosion at particular locations within the systems.

In Equations 1 and 2, the reactions only involve the metals and transfer of electrons and their ions. In this instance the electrolyte is simply a means for the transportation of the positive ions, however, under certain conditions water may also undergo the reduction process, shown in Equation 3. When this reduction of water occurs, the positive ion created through the oxidation process combines with the negative hydroxide ion to form an insoluble compound which precipitates to from a sediment in the coolant. An example of this process (Callister 2007) is detailed in Equations 4 through 7, note that the term brackets indicates the state of the element or compound.

**Equation 1 Oxidation reaction for metal** 

$$M \rightarrow M^{n+} + ne^{-}$$

**Equation 2 Reduction reaction for metal** 

$$M^{n+} + ne^- \rightarrow M$$

Equation 3: Cathodic reduction of deaerated water

 $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ 

**Equation 4 Oxidation of Iron** 

$$Fe_{(s)} \rightarrow Fe_{(aq)}^{2+} + 2e^{-}$$

Equation 5 Formation of Ferrous Hydroxide  
(in deaerated water)  
$$Fe_{(s)}^{2+} + 2OH^- \rightarrow Fe(OH)_{(aq)}$$

Equation 6 Formation of Magnetite (black oxide)  $3Fe(OH)_{2(aq)} \rightarrow Fe_3O_{4(s)} + H_2 + 2H_2O$ 

Equation 7 Formation Ferric Oxide (red oxide / rust)  $2Fe_3O_{4(s)} + O_2 \rightarrow 3Fe_2O_{3(s)}$ 

Equations 4 to 6 detail the procession of chemical reactions within the cooling system from the iron element in the material of the cooling system component through to a magnetite sediment in the coolant. The formation of magnetite (black oxide) occurs due to the closed cooling system providing a deaerated, or low oxygen, environment. An important factor of magnetite is that it has strong magnetic properties.

Equation 7 details the final chemical reaction in which magnetite, exposed to oxygen, forms ferric oxide. Ferric oxide is the red iron oxide commonly known as rust, is non-magnetic.

#### 2.3.2 Galvanic Corrosion

Baboian (2003) and Callister (2007) both state galvanic corrosion occurs when two metals of different compositions are electrically coupled and exposed to the same electrolyte. In this process the electrons move through the metal and with the electrolyte providing the transport path for ion transfer. The potential difference, the willingness to give up electrons, between the dissimilar metals is the driving force for this form of corrosion and also the deciding factor on with of the two materials will become the anode and cathode. The galvanic series for the materials identified by Curtin (2012) are shown in Table 3. The cathode material will be protected in galvanic corrosion with the most anodic in the galvanic series being consumed. In the absence of dissimilar metals, non-metallic conductors, such as carbon filled polymers, may act as a cathode in a galvanic couple (Baboian 2003).

Galvanic Series of Cooling System Materials		
Anode	Low Carbon Steel	
(Corroding End)	Cast Iron	
	Stainless Steel (active)	
	Lead	
	Tin	
	Red Brass	
	Yellow Brass	
	Copper	
(Protected End)	Copper Nickel Alloys	
Cathode	Stainless Steel (passive)	

**Table 3 Galvanic Series** 

The rate of galvanic corrosion is influenced by factors such as surface areas and separation distance. Where the surface area ratio of the anode material is large in comparison to the surface area of the cathode, the potential to produce an electrical current is reduced and galvanic corrosion is minimised. Similarly this form of corrosion is minimised as the distance between the anode and cathode increases.

Figure 2-1, extracted from Baboian (2003), illustrates galvanic corrosion occurring at a steel and brass coupling. This photo shows material of the steel pipe, being more active on the galvanic series than the brass fitting, has been consumed while the brass remains intact. This is an easily identifiable trait distinctive to galvanic corrosion.



Figure 2-1 Galvanic corrosion of steel pipe in a brass fitting (Baboian 2003)

Cathodic protection is a widely recognised technique to prevent a specific metal corroding. By electrically connecting a more anodic sacrificial material to a particular component the galvanic couple is arranged to preserve the cathode metal whilst the sacrificial anode is consumed.

#### 2.3.3 Pitting

In Table 3, stainless steel has been listed separately as an active and a passive variant with very different galvanic properties. Kruger (2003) provides the distinction between the two variants in that a passive metal is one that has developed a thin corrosion resistant film over its surface where an active metal has not. Callister (2007) postulates this corrosion resistant film is produced through the active surface of the material forming a very thin, highly adherent oxide barrier. The normally active nature of the metal is reduced as this oxide barrier is far more reluctant to form positive ions. As this film is very thin, surface damage to the material will likely penetrate this passive layer to expose the active material underneath, in effect exposing two dissimilar, electrically connected metals to the electrolyte. Frankel (2003) defines this form of localised corrosive attack on the damaged surface of a passive filmed material as pitting, illustrated in Figure 2-2.

Classical pitting will only occur in the presence of highly active metals, typically in the presence of chloride ions, the severity of the pitting tend to vary with the concentration of these ions (Frankel 2003). Frankel also lists temperature as a critical factor in the formation of pitting as many materials will not form pits under a certain temperature.



Figure 2-2 Pitting corrosion in a metal (Frankel 2003)

In contrast to pit initiation through the presence of chloride ions and increased temperatures, Debaun and Alverson (2008) and Askeland and Phule (2008) describe pitting as corrosion initiating from erosion to the surface protection, exposing underlying material, caused through localised cavitation. Gellings (1985) suggests that pitting may be initiated through either mechanical damage or environmental conditions, categorising pitting by the formation, and continued growth, of an active-passive-element in the surface of a metal.

It is a consensus amongst these authors that once pitting has commenced, local conditions are altered in a manner that promotes pit growth through further corrosion highlighting the importance in preventing pitting from initiating.

#### 2.3.4 Cavitation

Whilst cavitation has been suggested as a precursor to pitting corrosion, Glaser and Wright (2003) and Gellings (2003) also describe the mechanical erosion impact of its occurrence. Cavitation is defined as the formation, and rapid collapse, of vapour bubbles in a fluid. The pressures created through the repeated collapse of these vapour bubbles cause localized deformation and cratering of the metal surface. Continued creation of these pits from ongoing cavitation eventually causes particle removal from the material, as shown in Figure 2-3. This process may be facilitated through removal of the corrosion resistant surface film.



Figure 2-3 Cavitation on a cylinder liner (Gellings 2003)

The cavitation that occurs in a cooling system is caused by localised low pressure regions created through rapid surface vibrations (Debaun and Alverson 2008). Gershun and Woyciesjes (2003) state that cavitation may also occur by formation of vapour bubbles at high temperature points which rapidly collapse when the temperature decreases. It would be logical to assume that cavitation in cooling systems would likely occur as a result of a combination of these two conditions. Glaeser and Wright (2003) highlight the engine cylinder liners, heat-exchanger inlet tubes, and pumps as likely areas in which cavitation may occur in a cooling system.

#### 2. 3. 5 Particle Erosion and Erosion Corrosion

Erosion in a cooling system may defined as the removal of surface material by the action of numerous solid or liquid particle impacts (Glaeser and Wright 2003). Although similar to cavitation in effect on the material, where cavitation produces microcraters, Figure 2-4, particle erosion produces imprints of the impacting particles (Glaeser and Wright 2003). Callister (2007) indicates that this form of corrosion may be identified by surface grooves, or waves, characteristic of the fluid flow as illustrated in Figure 2-4.

Conditions that may encourage particle erosion typically involve large amounts of entrained solid particles with high velocities and/or abrupt changes in the direction of fluid flow. In particular, abrupt changes in fluid flow may lead to the concentration of eroding particles and the subsequent focused particle erosion as shown in Figure 2-5.



Figure 2-4 Particle erosion in pipe bend (Gellings 1985)



Figure 2-5 Particle erosion in tube inserts (Glaeser and Wright 2003)

Debaun and Alverson (2008) and Callister (2007) that erosion corrosion is more prevalent in softer metals where fluid motion shear forces, abrasive contaminants, and cavitation may cause the metals protective coating to break away exposing the underlying material to corrosion. This agrees with Boffardi (2003), who states that erosion corrosion is normally restricted to copper base alloys. Boffardi also describes the phenomenon of inlet-end erosion corrosion as a result of the higher turbulence at the pipe entrance. As shown in Figure 2-5, inlet-end erosion corrosion produces a horseshoe shaped pattern extending away from the inlet, typically a short distance for the pipe entrance.

#### 2.3.6 Crevice Corrosion

Crevice corrosion, as described by Gershun and Woyciesjes (2003) and Kelly (2003), is localised in areas of stagnated fluid flow. The mechanism initiating the corrosive attack is the change in ion concentration in the electrolyte solution between two regions of the same material (Callister 2007). This potential difference creates a concentration cell, through transfer of electrons, which results in the formation of an anodic region in the location having the lower concentration. Callister (2007) qualifies the distinction of crevice corrosion from other forms of corrosion by the electrical potential for the cell being created by the local difference in the electrolyte rather than between a potential difference between the anode and the cathode. Kelly (2003) and Sheedy (1998) agree that the stagnant electrolyte, and the associated concentration of ions, in the crevice creates an anode within the crevice with the flowing electrolyte creating a cathode with the remaining metal surface. Due to the location of the anode, the corrosion occurs with the crevice subsequently increasing the size of the crevice and the concentration of ions within that crevice. Similar to the self-propagating nature of pitting, both of these effects encourage further corrosion. Another important aspect of crevice corrosion highlighted by Sheedy (1998) is the relative size of the corrosion product. Where the volume of this product is larger in size than the volume of material consumed in its creation, pressure is created on the crevice walls which may accelerate the growth of the crevice.

An important observation by Kelly (2003) and Bartholomew and Shifler (2007), notes that copper based alloys are the exception to this rule regarding the location of the anode. The concentration of ions in the crevice of these alloys renders the crevice area cathodic. The anode becomes the surrounding surface area and thus corrosion occurs outside the crevice. Cohen (2005) supports this, stating that the location of attack from crevice corrosion will be outside but immediately adjacent to the crevice.

Cohen (2005) lists high water temperatures or water flow on the outside of the crevice as conditions that will increase crevice corrosion. Cohen further states that the probability and severity of crevice corrosion increases if the area within the crevice is small in comparison to the area outside the crevice.

#### 2. 3. 7 Stress Corrosion Cracking

Jones (2003), Bartholomew and Shifler (2007), Callister (2007) and Watkins Borenstein (1994) agree that stress corrosion cracking occurs as a combined result of stress applied to, or residual stress within, a material and a corrosive environment. Copper alloys such as red and yellow brass, are susceptible to stress corrosion cracking in the presence of ammonia.

Ammonia is a common waste product of microorganisms however, in terms of its attack on copper, the source of the ammonia is immaterial. Stott (2003) suggests that cases of failure due to sulphides produced by sulphate reducing bacteria have been observed in copper-nickel heat exchanger tubes. Dexter (2003) agrees that occasionally ammonia induced stress corrosion cracking in copper materials has been attributed to microbial ammonia production. In contrast to the organic origin of ammonia, Warke (2003) also presents several case studies with a variety of ammonia sources including a case that identified the ammonia source as "the reduction of nitrates by hydrogen evolved during the corrosion of the steel shell and/or tubes". Boffardi (2003) agrees with Warke, stating that ammonia may be formed through thermal degradation of nitrogen containing compounds, such as sodium nitrite, added to the cooling water to reduce ferrous corrosion. The effect of ammonia on copper based alloys remains consistent, irrespective of the source.

Both Jones (2003) and Warke (2002) state that tensile stresses are required for stress corrosion cracking to occur and that cracking will occur perpendicular to the application of these stresses. The crack paths in copper based alloys may be intergranular, following grain boundaries, or transgranular, crossing grain boundaries. Warke (2003) defines the pH of the electrolyte as the determining factor for which type of cracking occurs with intergranular cracking only occurring within the 6 to 8 pH range. With the coolant in the cooling system maintained above a pH of 8, only transgranular cracking would occur. The appearance of transgranular cracking would display crack arrest marks with a cleavagelike appearance, consistent with discontinuous crack propagation (Warke 2003). Stress corrosion cracking is best identified under microscopic inspection where multiple crack branch lines would be observed, typically propagating perpendicular to applied stress, initiating in areas with the highest stress.

#### 2. 3. 8 Microbial Influenced Corrosion

Askeland and Phule (2008) and GE (2014) agree that the presence of microorganisms, such as fungi and bacteria, coating metal surfaces produce corrosive by-products. These by-products form anodic areas under the "biofilm", the surface of the microorganism colony, and the unaffected areas of the metal surface are cathodic. As the anodic area, and the subsequent corrosion, occurs under the biofilm, a distinct feature of this type of corrosion is the circular pattern of growth irrespective of coolant flow, illustrated in Figure 2-6.

Dexter (2003) states that whilst microorganisms can survive in pH ranges from ~0 to 10.5, most bacteria that have identified with corrosion grow best in the 6 to 8 pH range. Dexter also lists a select number of organisms that have been repeatedly reported as the cause of corrosion in environments in which there would be no corrosion in their absence. Of these, only *Desulfovbrio* (also known as *D. desulfuricans*) and *Acidithibacillus thiooxidans* affect copper based alloys. These bacteria prefer pH ranges from 4 to 8 and 0.5 to 8 respectively and Dexter (2003) describes *Acidithibacillus thiooxidans* as having an aerobic oxygen requirement. A closed cooling system is considered an anaerobic environment with a pH typically in the range of 8 to 10. Under this conditions a closed cooling system would be considered an inhospitable environment for growth of these microbes, and development of microbial corrosion.



Figure 2-6 Typical result of Microbial Corrosion (GE Power and Water 2014)

#### 2.3.9 Dealloying

Davis (2001) describes dealloying, also known as selective leeching, as a corrosion process in which a particular metal is selectively removed from an alloy. Cohen (2005) and Davis (2001) agree that copper zinc alloys with a zinc composition greater than 15% are susceptible to leeching in the form of dezincification. The remaining material is described as a relatively porous, weak layer of copper and copper oxide. Cohen (2005) also highlights that susceptibility to stress corrosion cracking reduces as the zinc content of the copper alloy decreases from 15 -0%

Cohen (2005) describes an investigation into dezincification in copper based alloys and states that it can be identified by viewing a cross section of the material. Here Davis (2001), Callister (2007) and Cohen (2005) describe the affected area in copper based alloys as a dark red in comparison to the surrounding yellow brass. The mode of dezincification may also be identified as either plug type or a uniform layer. In plug type dezincification, de-alloying only occurs in localised areas with the surrounding areas unaffected (Davis 2001). Davis (2001) and Cohen (2005) agree that plug type dezincification is typical in areas of high temperature and a pH of 7 or above. Davis (2001) states that dezincification is more severe in brasses with two phase structures, with the beta phase affected first due to its higher zinc content.

#### 2.4 Corrosion Inhibitors

With water being the most common fluid used in heat transfer systems and having very effective electrolytic qualities, corrosion has long been a significant issue in cooling systems. Through extensive and ongoing research across many industries, chemicals have been identified that have specific qualities of inhibiting corrosion when added to the cooling water. Whilst these chemicals generally have beneficial corrosion inhibition qualities, many have significant characteristics which have been identified as hazardous to health and the environment. Of the chemicals in use today, the most significant for the purpose of this research are nitrites, in the form of sodium nitrite, and azoles, in the form of sodium mercaptobenzothiazole, both of which are passivation inhibitors.

Passivation inhibitors are consumed in the formation of these protective layers, reducing the concentration of inhibitor remaining in the coolant. Therefore, in order to retain the required minimum concentration for corrosion inhibitor, it is general practice to develop a recommended minimum concentration that accounts for this attrition in creating the initial passivation layers on cooling system components and further depletion over the intended life of the coolant. These passivation layers are typically created on new components by inhibitors within 24 to 48 hours of their introduction. Given this time frame, the fastest rate of inhibitor depletion would be expected to occur when new components have been installed in the cooling system.

#### 2.4.1 Nitrites

Gershun and Woyciesjes (2003) identify nitrite, as a sodium salt in the form NaNO<sub>2</sub>, as an effective corrosion inhibitor for ferrous materials. Nitrite is the typical corrosion inhibitor used for the prevention of pitting in cast iron cylinder liners.

The effect of nitrite ion concentration on corrosion inhibition investigated by Karem et al. (2010) shows that effective corrosion inhibition is achieved at a concentration of 500 ppm of NaNO<sub>2</sub> for pH levels greater than 6. Boffardi (2003) also states that corrosion inhibition is achieved at nitrite concentration above the range of 500 to 750 ppm of NaNO<sub>2</sub> at a pH greater than 7.5. Research indicates that an increase in nitrite concentration above 500 ppm does not provide any significant beneficial or detrimental effect to inhibiting corrosion in the test environment.

In practical applications it becomes important to understand that nitrites are a passivation inhibitor, forming a protective layer on the surface (GE Power and Water 2014). Therefore, whilst the minimum concentration for corrosion inhibition is 500 ppm of NaNO<sub>2</sub>, the recommended minimum concentration advised by GE is 950 ppm of NaNO<sub>2</sub>.

#### 2.4.2 Azoles

Gershun and Woyciesjes (2003) state that mercaptobenzothiazole serves as an effective corrosion inhibitor for copper and brass components, both by itself and in conjunction with other azoles.

Azoles work in similar manner to nitrites in that they form a passivation layer to inhibit corrosion. Research conducted by the Ministry of Defence (2009), shows that azoles may effectively inhibit corrosion in copper and copper based alloys at concentrations as low as 2 ppm. This is due to the affinity of copper drawing the azole from the cooling solution. Therefore it may be considered that where any concentration of azole exists in solution, any copper based components in the system have a sufficient passivation layer.

Given this affinity for copper drawing azoles from solution, Curtin (2013) advises a recommended minimum concentration for azoles of 60ppm.

#### 2.5 Debris

Anderson, Lukas & Lynch (1998) define coolant analysis as a dual aspect process consisting of debris monitoring for the presence of contaminants and condition monitoring of the coolant itself. The processes involved in monitoring the coolant for contaminants are designed to evaluate the concentration of elements in the coolant that may indicate wearing of the cooling system components.

The particular wear elements are determined by the compositions of the materials from which the cooling system components are composed. A generalised list of the mater for OEM lists the material compositions

#### 2. 5. 1 Spectrochemical Analysis

Spectrochemical analysis is a method of measuring the concentration of specific trace elements in a sample through comparison of the intensity of radiation in specific wavelengths emitted when that sample is vaporised by an electric discharge (Spectro Scientific 2014). An increase in the concentration of an element specified as a wear metal above a predetermined level indicates excessive corrosion may have occurred within the cooling system. Likewise, a rate of increase in the wear metal concentration between routine sampling periods at a rate greater than a predetermined level indicates that excessive corrosion may be occurring within the cooling system. A generally accepted limitation of this type of analysis is that it is restricted to detection of wear particles smaller than 8-10 microns. Particles larger than 10 microns are not accurately detected by this method. ALS Tribology (2010) categorise the elements detected through spectrochemical analysis as additive, wear or water elements, as shown in Table 4. Of these wear elements, the reports supplied to RTIO include the concentration of chromium (Cr) however they omit silver (Ag) and zinc (Zn).

										`			,		
Coolant Spectrochemical Data	Aluminum (Al)	Boron (B)	Calcium (Ca)	Capper (Cu)	lron (Fe)	Lead (Pb)	Magnesium (Mg)	Molybdenum (Mo)	Phosphorus (P)	Potassium (IX)	silkon (Si)	Sodium (Na)	Silver (Ag)	Tin (Sn)	zinc (zn)
Additive Elements		•						•	•	•	•	•			
Wear Elements	•			•	•	•							•	•	•
Water Elements			•				•								

Table 4 Spectrochemical Data Elements (ALS 2010)

#### 2. 5. 2 Particle Quantifier (PQ) Index

Particle quantification is the relative measurement of a material content in a given sample The PQ Index provided by ALS is a relative measurement of the amount of ferrous particles in the coolant sample, independent of size shape or count of those particles (ALS). This method of detection is not limited by size and is recommended as complimentary test to spectrochemical analysis. Comparison against the PQ Index will indicate whether the content detected is predominately larger or smaller than the 10 micron limitation of the spectrometer.

As with the Spectrochemical Analysis, excessive or rapidly increasing levels may be indicative of problematic corrosion occurring within the cooling system.

#### 2.6 Coolant

The coolant used in the closed cooling systems of the locomotives is a mixture of demineralised water and a concentrated corrosion inhibitor solution. These are supplied separately and mixed on site in accordance with the concentrations advised by the supplier of the concentrate.

The concentrate supplied to Rio Tinto is the corrosion inhibitor package Alfloc 9518, supplied by Nalco as a replacement for the superseded Nalco 2100. Alfloc 9518 retains the concentration of the corrosion inhibitors supplied in Nalco 2100, with the addition of an inhibitor for preventing corrosion in aluminium. As the GE locomotives do not contain aluminium cooling system components, this additional inhibitor is not of interest.

#### 2. 6. 1 Water

GE Transport (2012) indicate that the raw water to be used for mixing the coolant should be tested to ensure contaminants do not exceed the maximum levels listed in Table 5 Maximum Contaminant Levels in Raw Water. This document also cautions "Distilled, demineralized or deionized water is corrosive since the water is mildly acidic, and must NOT be used in a cooling system without further treatment". The treatment applied to the water is the addition of the corrosion inhibitor concentrate which contains a borate based buffer to raise the pH of the water to a range from 9 to 11.

In contrast to the GE, Mollenhauer and Tschoke (2010) state the pH value in cooling systems, being a measure of hydrogen ion concentration, should be maintained between 6.5 and 8.5. Gershun and Woyciesjes (2003) state that some inhibitors may prefer an initially higher pH around 10, and pH between 7 and 9 whilst in use. This statement supports the higher range specified by GE as the initial requirement for the corrosion inhibitor and also Mollenhauer and Tschoke in advising a lower ongoing pH. Whilst not diminishing the validity of the work by the aforementioned authors, it is the opinion of the author of this report that GE, as the original equipment manufacturer, is the overriding subject matter expert for their locomotives and as such their standards should be adhered to as the requirements for warranty purposes.

Contaminant	Maximum Parts Per Million (ppm)
Chlorides	40
Sulfates	100
Total Dissolved Solids	340
Total Hardness	170
Suspended Solids	17

Table 5 Maximum Contaminant Levels in Raw Water(Extract from GE Transportation 2012)

#### 2. 6. 2 Monitoring

The current practice at Rio Tinto does not apply a life to a particular batch of coolant in the locomotive, instead the coolant is monitored at scheduled intervals and the concentration of the corrosion inhibitor is maintained to specifications through the addition of the inhibitor concentrate.

The concentration of the corrosion inhibitor in the coolant is determined by drawing a sample from the locomotive cooling system. The sample is tested with a Nitrite Test Kit which uses the titration method to estimate the concentration nitrite in the sample by the number of drops of reagent solution added to facilitate a colour change in the sample. The test kit method indicates that each drop of the reagent required to facilitate this colour change is equivalent to a concentration of 150 ppm of Nitrite as Sodium Nitrite. For example, a sample requiring 6 drops of reagent to change colour would have an estimated concentration of 900 ppm of N as NaNO<sub>2</sub>.

The concentration of the nitrite in the coolant sample is deemed indicative of the concentration of the corrosion inhibitor package in the coolant and thus dictates the required volume of inhibitor concentrate to be added to the locomotive coolant. No test method has been identified to test for azole concentration at the workshop level of operations.

It has been observed that nitrite concentrations may be reported as units in ppm of N as N, ppm of N as  $NO_2$  or ppm of N as  $NaNO_2$  depending on the practices of the testing agency or test method standard. These units are relative but not equivalent due to the molar masses of and may calculated by multiplication with the respective ratio of molar masses as shown in Table 6, noting 1 mg/L is approximately equivalent to 1 ppm.

Substance	Molar Mass (g/mol)	Mass relative to NaNO <sub>2</sub>		
Na	22.990			
0	15.999			
Ν	14.007	0.2		
NO <sub>2</sub>	46.005	0.67		
NaNO <sub>2</sub>	68.995	1		

**Table 6 Molar Masses** 

Note that all test methods mentioned in this report determine the concentration of sodium nitrite through measurement of either the nitrite ion or the nitrogen element. Applying the ratios from the table above, a sample concentration reported as 1500 ppm of N as NaNO<sub>2</sub> would be approximately 1000 ppm of N as NO<sub>2</sub>, or 300 ppm of N as N.
# **Chapter 3 Radiator Core Failure**

## 3.1 Background Information

As part of routine scheduled maintenance the radiator core is removed and overhauled on a ten yearly cycle. During this overhaul process, the external contractor identified material degradation, shown in Figure 3-1, of the radiator core removed from locomotive 8125. On discovery of the degradation, the coolant in locomotive 8125 was sampled and sent for further analysis, this sample was taken after the radiator banks had been replaced.

The report supplied to Rio Tinto RSM identified the following three anomalies in the coolant sample:

- A low pH value indicating a lack of proper coolant additive maintenance. [pH of 9.65]
- A high ammonia level indicating there is microbial activity in the system. [2.24 mg/L of Ammonia as N]
- A low nitrite level. [203 mg/L of Nitrite as N]

The conclusions drawn from the report were that microbial activity was occurring in the locomotive cooling system and the ammonia level was highly undesirable in respect to stress corrosion cracking in the radiator tubes. The concluding recommendation was that RSM should monitor for ammonia in their normal testing program to identify the origin of the ammonia.

After the completion of this report, the radiator core was scrapped in line with normal processes. This destruction of the radiator core has unfortunately prevented any further detailed investigation. Figure 3-1, and its enlarged section shown in Figure 3-2, is the only visual reference available for the material degradation.



Figure 3-1 Radiator core removed from locomotive 8125



Figure 3-2 Enlarged section of the radiator cores

# 3.2 Analysis

In response to the external analysis, further investigation was conducted into the anomalies noted in the report and the subsequent conclusion. It should be noted at this time that the radiator core is a significant component in the cooling system and its replacement involves the draining, storing, and replenishing the coolant in the system. Characteristics of the coolant samples recorded before after the change suggest that the cooling system has been replenished with the original coolant, however, there is a reasonable likelihood of contamination via residual coolant in the storage tanks or by introduction of the new components. Therefore any sample taken after this procedure may not be strictly representative of the environment to which the original radiator core was exposed. As it can not be confirmed if any contamination had occurred, the report was analysed on the assumption that it had not.

#### 3.2.1 pH

The report identified the pH of 9.5 in the coolant sample as low and signalled this as an indicator of poor coolant management. In contrast to this statement, documentation provided by GE Transport (2012), as the OEM, and Nalco representatives, as the supplier of the corrosion inhibitor, indicate safe operating ranges of pH from 9 to 11 and 8.2 to 10.1 respectively. Historical data for the locomotive 8125 indicates the pH has been maintained between 9.33 and 9.74. It is clear from this information that the pH was within the recommended ranges and would therefore not be indicative of poor coolant management.

#### 3. 2. 2 Nitrite

The report has also identified the nitrite, recorded as 203 mg/L of Nitrite as N, as low. As described in section 2. 4. 1, an inhibitor concentration reported as a value of Nitrite as N will be five times less than that same concentration reported as a value of Nitrite as NaNO<sub>2</sub>, therefore the equivalent concentration of this sample is 1015 mg/L of Nitrite as NaNO<sub>2</sub>. A value given in mg/L is approximately equal to ppm and may be considered interchangeable, ergo 1015 mg/L is equivalent 1015 ppm.

As stated by Karem et al (2010), and substantiated through experimentation in Chapter 4 of this report, effective corrosion inhibition is achieved at concentrations of NaNO<sub>2</sub> greater than 500 ppm. Concentrations greater than 500 ppm are recommended in coolants as the nitrite is depleted over time, a significantly higher concentration ensures that sufficient nitrite remains to inhibit corrosion throughout the coolant maintenance cycle.

In respect to original equipment manufacturer's recommendations, GE Transportation (2012) state the minimum concentration required for Nalco 2100 is 950 ppm as NaNO<sub>2</sub>. Nalco representatives have advised that Alfloc 9158 is the derivative of Nalco 2100, with the addition of an aluminium corrosion inhibitor, and the concentrations of inhibitors in Alfloc 9158 remain consistent with that of Nalco 2100.

#### 3.2.3 Ammonia

The report also concludes that the high ammonia level indicates microbial activity in the cooling system. As described by Boffardi (2003) and Warke (2003), ammonia may be produced through inorganic methods in the cooling system, for example, through the reduction of nitrite by hydrogen. Without any evidence of microbial influenced corrosion or build up consistent of microbial activity, the strongest likelihood is that the ammonia is non-organic in origin.

No specific concentration of ammonia has been found as a minimum requirement for stress corrosion cracking to occur therefore it would be reasonable to agree that any concentration of ammonia is undesirable. It has been highlighted that, in the presence of ammonia, a tensile stress is also required for stress corrosion cracking to occur.

#### 3. 2. 4 Azoles

Further commentary in respect to the report indicated that the azole concentration levels in the sample were low. It should be noted that the azole contained for copper based alloy protection in the corrosion inhibitor Alfloc 9158 is Sodium Mercaptobenzonthiazole and that the testing conducted in the analysis did not include this specific azole. Therefore the conclusions made in reference to the azole levels were inaccurate by omission of a test for the relevant azole.

#### 3.2.5 Material Degradation

As previously mentioned, stress corrosion cracking in copper based alloys requires the presence of ammonia and an applied tensile stress. The cracking propagates perpendicular to the applied stress which, in the case of residual hoop stress in tubing, would be circumferential resulting in longitudinal cracking. Where longitudinal stress is applied to the tube, cracking will occur circumferentially, however the location of fractures at the end of the cores is unlikely to be where any applied longitudinal stresses would be greatest. Examples of longitudinal and circumferential stress corrosion cracking are shown in Figure 3-3 and Figure 3-4 respectively (Engineering.com n.d.).



Figure 3-3 Longitudinal Stress Corrosion Cracking



Figure 3-4 Circumferential Stress Corrosion Cracking

# 3.3 Conclusions

From the information identified in the analysis, it has been concluded that the coolants pH and corrosion inhibitor concentration are within the ranges recommended for the coolant in the given application. The observations made in the report provided to Rio Tinto stating these two factors were indicative of poor coolant additive maintenance have no discernable merit. Further to this, the presence of ammonia alone is not definitive evidence of microbial activity in the cooling system. In the absence of other indicators consistent with such activity, and given the possibility of inorganic production in nitrite based coolants, an organic origin for the ammonia found in the system is not the most probable conclusion. The presence of ammonia is of concern in the cooling system in respect to promoting stress corrosion cracking in the brass components. The assertion 2.24 ppm of Ammonia as N is a high concentration remains unconfirmed in respect to the causation of stress cracking corrosion. In consideration of research, it may be concluded that any concentration of ammonia is undesirable in the coolant and rectification actions would be recommended. Investigations into the source of the ammonia should first consider non organic origins.

Although the corrosion inhibitor concentration was above the minimum concentration specified it was below the minimum concentrations set by Rio Tinto as an alarm limit. Investigations should be carried out to determine the root cause for this concentration being below that alarm limit and what, if any, effect that concentration would have on the locomotives cooling system. These investigations have been carried out later in this report.

The disposal of the radiator core prior to the completion of investigations has prohibited a conclusive analysis of the material degradation. In the absence of definitive test data, visual inspection suggests the cause of the material degradation is unlikely to be either stress corrosion cracking or microbially influenced. The red outer layer evident on the upper right side of the central tube of Figure 3-2 is consistent with the dezincification process of brass and its residual porous copper metal. This residual metal is far more brittle than the original brass and the subsequent fracture like degradation would be consistent with the exposure of the brittle material to the conditions found in the radiator core. Any observations, regardless of probability, can not be definitively confirmed without proper analysis and it would be prudent of Rio Tinto to stipulate that any further failures be quarantined and preserved to allow such analysis.

It has been identified that the coolant in locomotive 7081 has registered a concentration of 2.66 mg/L of Ammonia as N. Inspection of the radiator cores on this unit would be beneficial in evaluating the most likely cause of the material degradation in the radiator cores. The radiator cores on locomotive 7081 should be inspected at the earliest practicable opportunity. There is a very low failure rate of radiator cores, therefore it would be unlikely that a radiator core failed in service prior to the next scheduled service interval of the radiator core. However, in the interest of reducing exposure to risk, it would be prudent to inspect the core as early as an opportunity should arise.

# **Chapter 4 Bulk coolant mixing**

Having identified that the corrosion inhibitor concentration in locomotive 8125's coolant was below Rio Tinto target levels, a root cause analysis highlighted the corrosion inhibitor concentration of the bulk coolant concentrate for investigation.

## 4.1 Current Process

The current mixing process at Rio Tinto draws a volume of demineralised water from a local supplier and adds a corrosion inhibitor package to a specific volumetric ratio. The mixing process is carried out manually onsite and stored for later use in a 55,000 L storage tank.

Anecdotal evidence indicated there was an element of confusion as to which corrosion inhibitor package was to be used in the mixing process. Through historical purchasing data and physical evidence onsite it was determined that the replacement of the Nalco product with its Alfloc successor had resulted in the supply of Alfloc 9003 and Alfloc 9518 to Rio Tinto.

Alfloc 9518 is the corrosion inhibitor concentrate package recommended to be mixed at a ratio of 1 part in 32 parts of water, producing a corrosion inhibitor concentration between 1200 and 1500 ppm of N as NaNO<sub>2</sub>. The coolant mixed in this ratio, without subsequent addition of inhibitor, is intended for a service life of 1 year. Alfloc 9003 is a premixed coolant supplied by Nalco, with a corrosion inhibitor concentration of approximately 2850 ppm of N as NaNO<sub>2</sub>. The higher concentration of inhibitor is intended to increase the recommended service life out to 2 years.

Given that both products had been supplied to site, it is likely that incorrect mixing of the bulk coolant had occurred. A brief investigation on discovery of the two variations of the Alfloc product revealed that the Alfloc 9003 was only intended for service at Rio Tinto mine sites and the ability for it to be ordered was removed from the locomotive maintenance facilities. The ongoing supply to the Rio Tinto locomotive maintenance facility is of one consistent concentration of the corrosion inhibitor package, removing the possibility for further confusion.

## 4. 2 Coolant Mixing Procedure

Historical test results carried out on the concentration of the bulk coolant supply over a period of 6 months indicate the current coolant mixing process has previously been inadequate in consistently maintaining the correct inhibitor concentration in the coolant. It is likely that locomotive 8125 may have had a replenishment of the cooling system prior to the radiator core failure at one of the lower concentrations indicated in Figure 4-1 below.



Figure 4-1 ALS Generated Trend Analysis of Bulk Coolant Nitrite Concentration

A procedural change had been implemented prior to this investigation to improve the consistency of the concentration in the bulk supply through the implementation of a strict volumetric ratio for mixing the corrosion inhibitor concentrate. The reduction in variation of the inhibitor concentration over the last eight readings indicates the success of this change and it is expected that ongoing tests will show a continued improvement in delivering consistent coolant concentrations. Therefore it would be counterproductive to implement a change unless results show that it is no longer effective or conditions, such as end user requirements or inhibitor supply, are changed.

# **Chapter 5 Coolant Monitoring**

The corrosion inhibitor package, Alfloc 9518, as advised by the manufacturer, is added to demineralised or distilled water at a ratio of 1 part of concentrate to 32 parts of water. This produces an engine coolant designed for use in the locomotive with an intended service life of one year, at this point the coolant is to be discarded and the cooling system be replenished with a fresh batch of coolant.

Rio Tinto mix the corrosion inhibitor in accordance with the advised ratio however, the standard practice at the locomotive maintenance facicilities is to maintain the coolant in the locomotive indefinitely, reducing the cost of coolant replacement. In order to maintain the effectiveness of the coolant beyond the intended service life, Rio Tinto have implemented a coolant monitoring process. This coolant monitoring process is conducted in two separate procedures, the first of these is a corrosion inhibitor concentration test carried out within the maintenance facility by the locomotive technicians. The second procedure is the off-site testing in a laboratory facility which analyses the coolant for a range of parameters.

## 5.1 Inhibitor Concentration Testing

The onsite testing to determine the inhibitor concentration uses a nitrite test kit designed for use with Alfloc 9518. This kit specifies that, if the sample is visually dirty, cloudy rusty in colour or in any way contaminated, the coolant in the locomotive should be replaced with fresh coolant. If the sample is clean, the maintainer fills a test tube with 1 mL of the coolant sample to which they add two drops of an indicating solution containing 1,10-Phenanthroline which acts as a colorimetric indicator, initially turning the solution orange. Cerium Sulphate is then added by individual drops until the Cerium Sulphate reacts with the Phenanthroline to change the sample colour to blue. Each drop of cerium sulphate required to facilitate the colour change is equivalent to 150 ppm of NaNO<sub>2</sub> in the sample.

The accuracy of this test in determining the concentration of the corrosion inhibitor is limited by the 150 ppm increment in measurement, the ability of the maintainer to accurately apply the volumes and the level of care and attention they apply to the task. Given that the maintainers work a 12 hour shift in the hot climates typical of Northern Australia, the level of attention applied to the task is likely to be reduced by fatigue. The off-site tests carried out in the laboratory use the same principles and chemicals however the process and control of volumes is much more precise through the use of calibrated apparatus and the handling and storage of the reagent chemicals. These methods are discussed further in subsequent chapters.

## 5. 2 Coolant Condition Monitoring

Beyond the corrosion inhibitor concentrations, the laboratory analysis also determines the concentrations of a number of elements and other physical parameters. These values are compared against an acceptable range provided to the laboratory, shown in Table 7, and advice is provided to Rio Tinto on actions to be carried when these values fall outside predetermined alarm limits.

Wear Elements (ppm)		Contaminants (ppm)		Physical / Chemical	
Al	≤ 5	Zn	< 0.1	< 0.1 pH	
Cu	$\leq 10$	Si	210	Conductivity (uS/cm)	7930
Cr	$\leq 3$	Na	2200	Glycol Content (%) 3	
Fe	$\leq 10$	В	515	Nitrite (ppm)	1200
Pb	$\leq 5$	Мо	< 0.1	TDS (ppm)	5690
Sn	$\leq 5$	Р	20	Colour Neon	
		Ca	1	Clarity	Clear
		K	< 5	Visual Debris	None
		Mg	< 1	Odour	Bland
				PQ index	$\leq$ 59

**Table 7 Acceptable Range** 

#### 5. 2. 1 Spectrochemical analysis

When corrosion occurs within the cooling system, metal ions move from the material into the coolant and the presence of these metal elements can indicate wear of components in the cooling system. The concentrations of the specific elements, identified as either wear elements or contaminants listed in Table 7, are determined through spectrochemical analysis. This method is very effective in identifying an accurate concentration of each particular element however it is limited in that the apparatus is not capable of measuring particles larger than 10 microns. The impact of this limitation is that any particle larger than this size is excluded from this analysis.

## 5. 2. 2 PQ Index

This test is designed to provide an indication of the total iron content in a sample which can be used to determine the size of iron particles. A high PQ index combined with a low Fe concentration detected through spectrochemical analysis indicates that the majority of iron particles present in the sample are larger than 10 microns. Similarly, a low PQ index with a high Fe concentration indicates the majority of those particles would be smaller than 10 microns.

## 5. 2. 3 pH

The acceptable range given for the sample pH is 12.13, with an alert provided to Rio Tinto if the pH of the coolant was less than 7 or trending down rapidly. In reference to the pH range of 9 to 11 advised by GE and Nalco's range of 8.2 to 10.1, these alarm limits would be inadequate in maintaining the pH within these ranges.

### 5. 2. 4 Colour

The acceptable range for colour is listed as "Neon Pink". The pink colour of the coolant is due to the dye added to the corrosion inhibitor package by the supplier in accordance with Australian standards, which in concentrate form is a deep red. A common belief is that the concentration of the corrosion inhibitor in the coolant may be determined by the strength of the coolant colour. For the purposes of this analysis the colour is used as a general indicator of the quality of the coolant.

A review of the recent results supplied to Rio Tinto indicate that all of the samples shown Figure 5-1 were classified as "Neon Pink" suggesting this is simply being entered as a default value.



**Figure 5-1 Coolant Samples** 

#### 5.2.5 Odour

There has been a common practice to smell the coolant to identify any contaminants with a distinctive odour are present. The validity of this method is questionable considering ammonia has a very distinctive odour and was not detected by in the coolant of locomotive 8125. Alternative tests carried out as a result of the radiator core failure indicated that ammonia was actually present in the coolant samples, albeit in a low concentration of 2.24 ppm. Given that any presence of ammonia has been identified as detrimental to copper alloys suggests that this test method is inadequate as a tool for determining coolant quality.

Other than the adequacy of the method, of serious concern are the adverse effects on health that may arise from inhaling the chemicals. These effects include acute, or short term exposure, hazards such as irritation of the mucous membrane and chronic, or long term, hazards such as low blood pressure, withering of the testicles and the formation of carcinogenic nitrosamines. Whilst these effects are considered unlikely to occur through inhalation of the corrosion inhibitor, the questionable benefit of the practice does not warrant risk of exposure to the hazard. Internet searches indicate that artificial odour test units are available in the marketplace, the use of such equipment would remove any health implications associated with inhalation.

#### 5.2.6 Nitrite

The acceptable range of nitrite concentration has been listed as 1200 ppm of Nitrite as NO<sub>2</sub> with alerts to be issued when the concentration falls outside the range of 950 – 1200 ppm of NO<sub>2</sub>. The disparity of units used in reporting the nitrite concentration has caused confusion when comparing the results. In accordance with Table 6, the values of 1200 and 950 ppm of NO<sub>2</sub> (Nitrite) is relative to the values of 1800 and 1400 ppm of NaNO<sub>2</sub> (Sodium Nitrite). In contrast, GE Transport (2012) list their recommended nitrite level for Nalco 2100 as 950 ppm of NaNO<sub>2</sub>. The Nalco supplied test method for the Alfloc 9518 corrosion inhibitor package, which is the equivalent to Nalco 2100, lists 1350 ppm of NaNO<sub>2</sub> as the minimum recommended concentration. Through correspondence with Nalco representatives it was advised that the design range was 1250 to 2000 ppm of NaNO<sub>2</sub> however, where the OEM makes recommendations contrary to those made by Nalco, the OEM recommendations take precedence.

Given that the recommended concentration from GE, as the OEM, is a minimum concentration of 950 ppm of NaNO<sub>2</sub>, the acceptable range of 1200 ppm of NO<sub>2</sub> and the associated alarm level of 950 ppm of NO<sub>2</sub> appear to have been incorrectly determined through omission of clarification on the reporting units. Such confusion could be avoided if all concentrations were converted to ppm of NaNO<sub>2</sub> to standardise measurements.

Historical reporting data has shown the corrosion inhibitor concentration in the Rio Tinto locomotives has varied between extreme values of 626 and 2084 ppm of NaNO<sub>2</sub>. These values fall outside the predetermined ranges and show that concentrations have fallen below the minimum recommended by GE however research has indicated that a concentration of 500 ppm of NaNO<sub>2</sub> is sufficient to prevent corrosion. Given that Sodium Nitrite is a passive type corrosion inhibitor, when added to a cooling system, a portion of the Sodium Nitrite is drawn from the solution to form the protective passivation layer on the metal surfaces. The resultant concentration corrosion inhibitor remaining in the coolant will be lower than the initial concentration applied and will continue to deplete over the coolants service life. In reference to this depletion, the value of 950 ppm of NaNO<sub>2</sub> recommended by GE (2012) is referenced for new or newly overhauled engines, where creation of the passivation layer will occur. As this is the recommended initial concentrations, the ongoing concentrations are expected to fall below this however the effect of lower concentrations on the inhibition of corrosion have not be defined at Rio Tinto. Procedures for coolant management specify that coolants with a low inhibitor concentration are to have concentrate added to increase the concentration to a level within the acceptable range. Whilst it would be prudent of Rio Tinto to continue this practice, it would be of interest in the maintenance of the locomotive cooling systems to confirm that the lower concentrations detected have maintained effective corrosion inhibition. An experiment investigating the effect of corrosion inhibitor concentration on corrosion rates has been conducted and is detailed in Chapter 6.

#### 5.2.7 Conductivity

The conductivity of the coolant is a measurement of the solutions ability to pass electrons, or conduct an electrical current, also referred to as the solutions specific conductance. In common terms, conductivity is the inverse of electrical resistance. The higher the conductivity of the solution the more readily the ions in the solution will dissociate to allow the flow of electrical current. This flow of ions through the solution is required for the corrosion process, thus a high conductivity would appear to be detrimental to corrosion inhibition. It should be noted however that all ions contribute to the conductivity including the nitrite ions in the corrosion inhibitor package.

Comparing the nitrite concentrations to conductivity over the historical analysis results, indicates a proportional relationship exists these values. Further investigation into this relationship is discussed in 0 of this report.

## 5. 2. 8 Visual Debris

This test procedure simply involves identifying the presence visual debris and, to limited capacity, some physical characteristics with no quantitative measurement. Historically, the observations have been recorded as none, dirt, or black magnetic. The distinction between dirt and black magnetic has been identified by the response of the debris to a magnetic field.

A concern raised regarding the GE Evolution series locomotives is that the location of the sampling point in relation to the surrounding structure, illustrated in Figure 5-2, requires the fitment of hose to facilitate retrieval of a coolant sample. The concern is that this hose will collect contaminates which will then be collected in the sample and identified as debris from the cooling system.



Figure 5-2 Evolution series sampling point

Debris described as black magnetic would be consistent with the corrosion of iron in a low oxygen, high temperature environment such as a closed cooling system. In these environments the iron oxidation process typically results in the formation of magnetite, Fe<sub>3</sub>O<sub>4</sub>, rather than the ferric oxide, Fe<sub>2</sub>O<sub>3</sub>, produced from the complete oxidation of iron. In comparison to the more familiar ferric oxide, which is red in colour, magnetite is black and has relatively strong magnetic properties. However, magnetite is also a naturally occurring iron oxide and considering Rio Tinto use these locomotives for the transport of iron ore from mine sites, the presence of magnetite, and it's collection in the coolant sampling hose, is possible. Identification of debris in the coolant as dirt reinforces the probability of introducing external contaminates by this sampling method. The possibility of such contamination must be removed to be certain that the debris identified has originated from within the cooling system.

## 5. 3 Coolant Contaminants

The maximum parameters for the contaminants, as advised by Nalco's, the corrosion inhibitor supplier, product specialists are presented in Table 8. Of the wear elements, Nalco recommend lower tolerances for both copper (Cu) and iron (Fe) than are currently observed in the coolant analysis. Notably, Nalco also include a total wear elements limit of less than 15 ppm.

#### 5. 3. 1 Potential Sources of Contaminant

Information sourced from Anderson, Lukas and Lynch (1998), presented in Table 9, shows some typical sources of wear elements in the cooling system. Through comparison of the component materials listed in Table 2 and the material compositions given in Appendix H , the wear elements detected through analysis can be associated to a group of components with in the cooling system as shown in Table 10.

Given the commonality of most elements across multiple component groups, attempting to identify a wearing component by the presence of iron or copper in the coolant would be impractical. However, chromium (Cr), nickel (Ni) and zinc (Zn) are distinct to individual locations and their presence may isolate a particular location for further investigation. Silicon (Si), although located in only one location in cooling system, could provide a false indication due to its use in corrosion inhibitor packages.

Wear Elements (ppm)		Contaminants (ppm)		Physical / Chemical		
Al	< 5	Ca	< 5	pН	9.5 - 10.5	
Cu	< 5			Nitrite (ppm of NaNO <sub>2</sub> )	1200 - 2000	
Fe	< 5			Clarity	Clear	
Ni	< 5			Colour	Pink	
Zn	< 5					
Total	< 15					

Table 8 Nalco Recommended Contaminant Levels

\_

## Table 9 Sources of Elements in Cooling Systems

Wear Metals				
Fe	Liners, water pumps, cylinder blocks, cylinder heads			
Zn	Brass components			
Pb	Solder in radiators, oil cooler, after coolers, heater cores			
Cu	Radiator, oil cooler, after cooler, heater cores			
Al	Radiator tanks, coolant elbows, piping, spacer plates, thermostat housings			
Mg	Cast alloys			
Contaminants				
Si	Dirt			
Mg	Hard water scaling			
Ca	Hard water scaling			
<u>Additives</u>				
Κ	Buffer			
Si	Anti-foaming agent, aluminium corrosion inhibitor			
В	pH buffer, ferrous corrosion inhibitor			
Мо	Anti-cavitation agent, silicates			
Р	pH buffer, ferrous corrosion inhibitor			

## Table 10 Relationship of Elements to Components

Components	Materials	Significant Elements
All coolant pipes in radiator cabinets Tanks Intercoolers	Steel (ASTM A53, A513, AISI 1020, B4A9B2)	Fe
Plate Oil Cooler	Stainless Steel (AISI 316,304)	Fe, Cr
	Copper (CDA 122)	Cu
Shell & Tube Oil Cooler	Copper (C12200)	Cu
Engine	Cast Iron	Fe, C, Si
	Steel (ASTM 1030)	Fe
Other Intercoolers	Cu/Ni (C70600)	Cu, Ni
Radiator Cores	Brass (C23000, C26000, C26800, C85200)	Cu, Zn

Through experimentation it may be possible to build a profile relating the ratio of the wear element concentrations to specific types of corrosive attack on specific metals. To develop such a profile into a practical application for Rio Tinto would require resources for which the failure rates do not warrant the expenditure. With the information currently available, it would be reasonable to identify the presence of chromium, nickel and zinc as indicators for wear to their respective component groups. These indicators could only be interpreted as indication that wear is occurring in the respective components. No indication of the presence of the elements in the analysis would not indicate that wear is not occurring in those components, nor would their presence indicate wear is only occurring in those components.

#### 5. 3. 2 Monitoring Frequency

During the analysis of the monitoring process it was observed that the locomotives where sampled during a high frequency, short duration maintenance cycle. By conducting the sampling at this maintenance interval the locomotive has typically left the maintenance facility prior to the completion of the coolant analysis. Any recommended actions for these results are then required to be recorded on the system to be carried out during the four monthly maintenance cycle.

It was observed that actions on the reports appeared inconsistent with the results of analysis given in those reports. For example, of three reports observing a black magnetic debris in the sample, only one of those reports identified that debris as black oxide and recommended a complete check of the cooling system. Of the two reports stating no actions were required, one of these reported a higher PQ Index than that of the report requiring action. Given that the PQ Index is the test method capable of quantifying visual magnetic material, it would be logical to assume that the higher PQ Index would initiate actions for inspection as well.

The inconsistencies and omissions of actions suggest further investigation into the quality control procedures in reporting the coolant analysis results may be beneficial. A reduction in the frequency in sampling to the four monthly cycle would better facilitate the monitoring of the actions recommended in the reports. Given that the locomotive remains in the facility for a longer period during this cycle, the locomotive is more likely to be in the facility when the results are returned facilitating a more timely response to actions recommended.

# **Chapter 6 Effect of Inhibitor Concentrations**

Investigations into the recommended corrosion inhibitor concentrations has revealed that concentrations in the Rio Tinto locomotives have been recorded as low as 636 ppm of NaNO<sub>2</sub>. Research conducted by Karem et al. (2010) has shown that effective corrosion inhibition for mild steel has been achieved in simulated cooling water with a concentration of 500 ppm of NaNO<sub>2</sub>. The results of this research may not be directly applied to the GE locomotives as the surfaces exposed to cooling water in cooling systems are comprised of metals other than mild steel. Some of these materials, in particular the brass components, rely on other chemicals, such as Mercaptobenzothiazole, which are present in the corrosion inhibitor package for corrosion protection. The following experiment has been developed to determine whether the corrosion inhibitor package will provide a similar level of corrosion inhibition across a range of concentrations, measured in ppm of NaNO<sub>2</sub>, for the all the metals exposed to coolant in the GE locomotives.

## 6.1 Experimental Method

This experiment, detailed in Appendix C has been carried in accordance with the Standard Test Method for Corrosion Test for Engine Coolants in Glassware, ASTM D1384-05 (ASTM International 2012c) with respect to the two exceptions identified below.

#### 6. 1. 1 Metal test Specimens

GE (Curtin 2013) list the metal coupons to be used in ASTM D1384-05 are to be comprised of the materials listed in Table 11, with their respective allowable weight loss. These weights vary slightly from the allowable material weight losses presented in ASTM D1384-05.

	Material	Weight Loss (mg)
Red Brass	(C23000)	< 10
Copper	(UNS C11000 or C11300)	< 10
Cast Iron	(UNS F10007)	< 5
Steel	(G10200)	< 5
Solder	(Alloy Grade 30A)	< 10

#### **Table 11 Allowable Material Weight Loss**

## 6.1.2 Corrosion Inhibitor Concentrations

Typically the corrosion inhibitor concentration is to be mixed in accordance with the ratio advised by the supplier for use in the locomotive. The aim of this experiment to determine if the corrosion inhibitor concentrations recorded for the locomotives have impacted the corrosion inhibition ability of the coolant. Therefore the corrosion inhibitor concentrations have been mixed in ratios to provide the specific concentrations identified as relevant through research. These concentrations are:

- 500 ppm of NaNO<sub>2</sub>, identified by Karem et al. (2010) as sufficient to provide effective corrosion inhibition.
- 1200 ppm of NaNO<sub>2</sub>, the minimum operational concentration identified by Nalco and the lower alarm limit adopted by Rio Tinto.
- 1500 ppm of NaNO<sub>2</sub>, the upper alarm limit concentration adopted by Rio Tinto.
- 2000 ppm of NaNO<sub>2</sub>, the maximum operational concentration identified by Nalco.

## 6. 1. 3 Experiment Results

The coupon weights are measured immediately before commencing, and after completion, of the experiment. The weight change of the coupons is calculated by subtracting the final weight of the coupon from its initial weight. Therefore a weight loss is identified by a positive weight difference and a weight gain by a negative difference. A weight gain is not considered an unusual result due to the deposition of ions onto the cathodic material in the galvanic corrosion process. The Standard Guide for Laboratory Immersion Corrosion Testing of Metals (ASTM International 2012a) provides guidance in calculated corrosion rates from these weight changes. The acceptable corrosion rates defined by the OEM form the allowable weight loss for the coupons as described in Table 11. The results of this experiment have been detailed in Table 12 and can be compared to these weight losses. During the conduct of the experiment, a contaminant was identified in the sample containing the 2000 ppm of NaNO<sub>2</sub>. Therefore the results for this sample should be considered corrupted. As the corruption is believed to have only had a minor impact, the results have been included however they may be referenced as indicative of potential weight changes only.

Inhibitor Concentration (ppm of NaNO <sub>2</sub> )	500	1200	1500	2000	
Material	Weight Loss (mg)				
Copper	-0.003	-0.007	-0.002	0.005	
Solder	0.005	0.008	0.005	0.003	
Red Brass	0.001	0.003	0.001	0.003	
Steel	0.001	0.001	0.001	0.008	
Cast Iron	-0.002	-0.003	0.000	-0.002	

**Table 12 Coupon Weight Losses** 

#### 6.1.4 Conclusions

The aim of the experiment was to determine if the corrosion inhibitor concentrations recorded from the locomotive samples maintained effective corrosion inhibition.

Considering the valid results from the experiment, it was observed that the corrosion inhibitor concentrations of 500, 1200 and 1500 ppm of NaNO<sub>2</sub> all met the weight loss requirements for the experiment. The corrosion inhibitor concentration of 2000 ppm of NaNO<sub>2</sub> met all requirements excepting that it exceeded the steel weight loss. This weight loss may be contributable to contamination of the sample however this may not be confirmed without supporting data. Research has not indicated a significant concern that high concentrations of corrosion inhibitor in this range would impact the corrosion inhibition ability of the coolant. GE Transportation (2012) states

that an inhibitor concentration of five to ten times the concentration recommended by the supplier may negatively affect bonding between silicone sheet and brass ferrules. As concentrations of this magnitude, approximately 5000 ppm of NaNO<sub>2</sub>, have not been observed in these cooling systems this is not of concern to Rio Tinto.

In comparison, the results indicate that there is no reduction in the ability to inhibit corrosion in the corrosion inhibitor concentration range from 500 to 1500 ppm of NaNO<sub>2</sub>. These results support the hypothesis that the low concentrations of corrosion inhibitor observed in the locomotives would have maintained effective corrosion inhibition and no remedial actions would be required by Rio Tinto in response to observations of inhibitor concentrations above 500 ppm of NaNO<sub>2</sub> in service beyond the addition of concentrate to the coolant as described in the current procedures.

It should be noted that the low concentrations observed were recorded in cooling systems in which passivation layers have had time to form and that consumption of inhibitor to form these layers would have been completed. It would not be advisable on the basis of these results to lower the inhibitor concentration required for initial application to the cooling system as natural depletion in the system may reduce the concentration below 500 ppm of NaNO<sub>2</sub>.

# **Chapter 7 Inhibitor Concentration Testing**

A concern identified at the on-site level was the risk of exposure to hazardous chemicals when using the Nitrite Test Kits, the risk mitigation measures in place consisted of administrative and PPE controls which are recognised as the lowest forms in the hierarchy of controls. Rio Tinto practice is to, where possible, implement the highest form of control measures, starting with elimination of the hazard. Implementing an alternative method of testing the corrosion inhibitor concentration would eliminate the need to use these hazardous chemicals and thus eliminate the hazard.

# 7.1 Current Inhibitor Concentration Test Method

The corrosion inhibitor concentration in the locomotive coolant is tested by maintainers during the scheduled maintenance activities on the locomotive. The procedure requires the maintainer to draw a sample from the tap located at the bottom of the sight glass, shown for both locomotive types in Figure 7-1. Concerns with the tap location and the requirement for the fitted hose have been discussed previously in this report.



a) Dash 9 series

b) Evolution series

**Figure 7-1 Locomotive Coolant Sampling Locations** 

The sample drawn from the locomotive is tested with the nitrite test kit specific for Alfloc 9518. The test procedure detailed in the test kit can be summarised in the following process:

- Fill the test tube supplied with 1 mL of the coolant sample and 2 drops of the N1 indicator.
- Add drops of N2 titrant, mixing after each drop, until the solution in the test tube changes from orange to blue.
- Refer to the table for actions respective to the number of drops of N2 titrant required to change the colour of the sample.
- The maintainer then counts the number of drops of a Cerous Sulphate / Sulphuric Acid solution is required to change the colour of this solution to blue.

The number of drops required to facilitate this change is multiplied by 150 to determine the concentration of nitrite in ppm of NaNO<sub>2</sub>. The calculated concentration of sodium nitrite (NaNO<sub>2</sub>) is considered to be representative of the entire corrosion inhibitor package.

The concentration calculated from this method is used to determine what volume of corrosion inhibitor concentrate is required to be added to the coolant to return the inhibitor concentration to the required level.

## 7.1.1 Limitations

A flaw in this consideration is that the replacement of a radiator core in the cooling system would deplete the azole concentration, as the copper corrosion inhibitor, in the formation of a passivation layer but not the concentration of sodium nitrite. Subsequent tests may present the corrosion inhibitor package as sufficient based on this sodium nitrite concentration when the copper may not be adequately protected. This complication is difficult to address at the maintenance level as the concentration of the azole, sodium mercaptobenzothiazole, is determined through high performance liquid chromatography (HPLC). The equipment required for HPLC analysis is impractical to maintain in a workshop environment. Given the impracticality of testing azole concentration, the practice of taking the nitrite concentration as the representative of the total corrosion inhibitor package remains the standard practice.

### 7.1.2 Key Concerns

The risk of exposure to the hazardous chemicals, 1,10-Phenanthroline and the Cerous Sulphate / Sulphuric Acid solution, requires the safe storage of these solutions and the use of personal protective equipment (PPE) during handling of the chemicals. Whilst the exposure controls listed in the MSDS for these products are not unusually restrictive and Rio Tinto supply and require the use of the PPE described, it is a sound policy to eliminate hazards where possible. Further to safety concerns raised with the chemicals, it was observed that the reagents stored on site had passed their expiry date and had evidence of chemical residue.

When using the nitrite test kit it was observed that the solution would sometimes change initially from orange to blue when mixed then return to orange. No defined time frame for the colour change is given leaving this phenomenon open to the operator's interpretation. The increment in estimations with the nitrite test kit is 150 ppm and subsequently any error through miscounting drops of N2 titrant added or misinterpretation of the colour change will be incorrect by factors of 150 ppm of NaNO<sub>2</sub>.

This process is also dependant on the accuracy of the chemical composition of the solutions supplied with the test kit. There is no procedure provided to calibrate or confirm the accuracy of these compositions excepting comparison of results against a known concentration of sodium nitrite. Although the laboratory test result may be used for comparison no such procedure exists for RTIO personnel to do so. It was observed that the reagents in use on site had exceeded their expiry date.

#### 7.1.3 Suitability

To determining the suitability of estimating the sodium nitrite concentration in the coolant sample with the Alfloc 2000 Test Kit, any possible alternate methods must first be identified. The titration method would then be compared against any practicable alternative methods.

The parameters for comparison should include the range and accuracy of the concentration estimation, any associated safety hazards and financial costs, the ease of use and the practicality of the particular method.

## 7. 2 Alternative Coolant Sampling Methods

Research and discussion of alternative methods for estimating the sodium nitrite concentration in a coolant sample revealed a variety of methods claimed to be effective in providing estimations with a sufficient accuracy.

One of the methods raised in discussion suggested a maintainer could estimate the coolant concentration of a sample by smell. This method was dismissed summarily as the practice of smelling the coolant requires inhalation of the vapour by the person testing, in the opinion of the author this should not be recommended and would not constitute best practice for health and safety.

The two further alternate methods chosen to be investigated are detailed in the following sections. Both of these methods indicate a potential for relatively accurate estimations of the sodium nitrite concentration and do not introduce further hazards.

### 7.2.1 Electrical Conductivity

A review of historical analysis results indicated a potential method of sampling coolant using the relationship of a coolant samples electrical conductivity to the presence of nitrite to estimate the nitrite concentration. Research conducted by Carr (1999) has indicated that corrosion inhibitor concentration may not be viably determined through the electrical conductivity of the coolant. Carr's conclusion to the research identify that the glycol content of the coolant greatly affects the conductivity resulting an electrical conductivity that appears independent to the inhibitor concentration. Given the climate of the operating environment, a glycol additive is not required to prevent the coolant from freezing, therefore the legitimacy of the estimating corrosion inhibitor concentration through measurement of the electrical conductivity is unknown.

The relationship determined from the historical data shows that electrical conductivity is proportional to the total dissolved solids (TDS) in the solution. As the nitrite ions form a fixed portion of the TDS concentration, the concentration of nitrite in the solution is proportional to the TDS value. The assumption is the nitrite concentration may be estimated with reasonable accuracy through a measurement of the electrical conductivity of a sample.

Using the data provided by the ALS tribology department, the relationships between the nitrite concentration, TDS and electrical conductivity readings for a sample the RTIO locomotive fleet are displayed in Figure 7-2, further graphs detailing the relationship and the supporting data are supplied in 0



Figure 7-2 Nitrite Concentration vs Electrical Conductivity

This plot indicates a relationship does exist between the electrical conductivity of the coolant and the concentration of nitrite for the ALS data relating to the samples taken from the RTIO locomotive fleet. However the strongest relationship is between the concentration of total dissolved solids and electrical conductivity.

Given that TDS is the sum of all combined solids and the nitrite concentration has been determined using titration methods it may be assumed that contaminants have been introduced to the coolant sample through its use in service and human error or interpretation may affect the titration process. Consideration should be given here to the suspected presence of organic compounds and their effect on both electrical conductivity and nitrite titration methods.

To determine the accuracy of the relationship, and assess the effectiveness of estimating nitrite concentration through electrical conductivity, an

experiment should be conducted using samples of clean coolant with known concentrations of nitrite. The samples should also be measured using the existing methods of titration to define the relative accuracy of the estimation methods.

#### 7. 2. 2 Electrical Conductivity Test Units

The experiment described in Appendix E is conducted using two types of hand held conductivity testers, both supplied by Hanna Instruments.

The DiST 4 unit is a handheld test unit for testing electrical conductivity and total dissolved solids with temperature adjustment. Measurement with this unit is carried out by removing the protective cap, turning the unit on and immersing the unit into the sample to the immersion level. When the reading has settled the value indicates the electrical conductivity of the sample in mS/cm. Calibration of this device is carried out by measuring a sample of the specified calibrated solution, HI 7030L. The unit is manually adjusted by a trimmer until the electrical conductivity reading matches the known conductivity of the calibration solution. Calibration is to be carried out monthly or any time the calibration is suspected to incorrect. The range of the DiST 4 unit is 0.01 to 19.99 mS/cm with an accuracy of  $\pm 2\%$  f.s.

The DiST 6 unit is also a handheld test unit for testing electrical conductivity, total dissolved solids and solution temperature. Measurement is carried out in the same method as that described for the DiST 4 unit except that EC or TDS must be selected on the DiST 6. When the reading has settled the value indicates the temperature of the sample and either the electrical conductivity in mS/cm or the concentration of TDS in ppm as selected. Calibration is carried out in similar process to the DiSTt 4 however the unit is automatically adjusted by selecting the calibration function and following the procedure until the electrical conductivity reading matches the known conductivity of the calibration solution. Calibration for the DiST 6 is also to be carried out monthly or any time the calibration is suspected to incorrect. The range of the DiST 6 is 0.00 to 20.00 mS/cm with an accuracy of  $\pm 2\%$  f.s for electrical conductivity, 0 to 2000 ppm with an accuracy of  $\pm 2\%$  f.s. for TDS and 0.0 to 60 °C with an accuracy of  $\pm 0.5$  °C for temperature.

The HI 7030L calibration solution is an aqueous solution of a known electrical conductivity used to calibrate the DiST 4 & 6 hand held units. The MSDS indicates the solution is not hazardous in nature and will not contribute any risk towards the sampling process. The MSDS data for this solution is registered and is available on ChemAlert and has been approved for use in Rio Tinto sites.

#### 7.2.3 Visual Colour Comparison

The experiment will also present the opportunity to trial a suggested method of estimating nitrite concentration by colour. The premise of this suggestion is the coolant colouration is proportional to the concentration of the coolant and thus the concentration of nitrite. It is uncertain whether the colour of the coolant will change significantly, so that a variation will be discernable by observation with the naked eye, to make an estimation of nitrite concentration with reasonable accuracy. It is also uncertain that the colour of the coolant will remain relative the nitrite concentration through its service life.

### 7.3 Experiment

The experiment has been carried out in accordance with the method described in Appendix E During the conduct of this experiment, it was identified that the corrosion inhibitor concentrate supplied was actually the a pre-mixed corrosion inhibitor coolant package. The incorrect supply of the Alfloc 9003 pre-mix instead of the Alfloc 9518 concentrate was confirmed by Nalco representatives and this revelation lead to the discovery of a concern in the Rio Tinto procurement system. It is likely that the Alfloc 9003 pre-mix had been supplied to the maintenance facility and misinterpreted to be the concentrate form. The misuse of this product in mixing the bulk coolant on site may have been a contributing factor to variations in the bulk coolants corrosion inhibitor concentration.

#### 7. 3. 1 Results

Graphical representation of the resultant estimations by each method, detailed in Appendix E and displayed in Figure 7-3, displays the consistency

in accuracy in determining the actual nitrite concentration for the respective methods.

From the numerical results, the coefficient of determinations, also none as the R-squared value, have been calculated and displayed in Table 13. The coefficient of determinations has been interpreted here to show the relative measurement of a methods accuracy in estimating the actual concentration of sodium nitrite.

Coefficient of Determination						
Method	Nitrite Test Kit	Laboratory Titration	Conductivity (DiST 4)	Conductivity (Dist 6)	Visual Colour Chart	
r <sup>2</sup> -value	0.9770	0.9735	0.9979	0.9980	0.8754	

**Table 13 Coefficients of Determination** 

## 7.4 Conclusions

Both the graphical results and the coefficients of determination indicate that nitrite concentration estimation through measurement of the samples electrical conductivity is the most accurate and consistent method of estimation in this experiment.

The use of the hand held electrical conductivity testers in estimating the nitrite concentration provides a significant benefit in the simplicity of the process of testing the sample. The ability to calibrate the unit and the ease of the calibration method increases confidence in the reliability of testing results. Of the two test units, the Dist 4, besides providing the most basic function, is adequate to carry out the task required, is the least expensive and requires the least effort to calibrate. The simplicity of the test method and the associated calibration procedure for DiST 4 has been well received by the maintainers at the rail maintenance facility.

A significant benefit associated with the DiST 4 is that it does not rely on hazardous chemicals. The risk associated with the task of testing coolant concentration may be reduced by eliminating daily exposure to the hazardous chemicals, 1,10-Phenanthroline and the Cerous Sulphate / Sulphuric Acid solution. The monthly calibration procedure requires exposure to the calibration solution which is recognised in the MSDS as being non-toxic and having no adverse health effects.



Figure 7-3 Nitrite Concentration Testing Results

# **Chapter 8 Coolant Reclamation**

A number of maintenance activities on the locomotive cooling system components, particularly component replacements and addition of corrosion inhibitor concentrate, require the coolant to be drained from the locomotive. When such an activity is required, the coolant is stored in a reclamation tank and, on completion of the activity, is pumped back into the locomotive. It is not unusual for the reclamation tank, shown in Figure 8-1, to contain some residual coolant after replenishing the locomotive.



Figure 8-1 Reclamation Tank

## 8.1 Analysis

The locomotive has no capacity for corrosion inhibitor concentrate to be added directly to the cooling system. To facilitate the addition, a partial dump of the coolant into the reclamation tank is carried out, the required volume of concentrate is added to the tank and this mix is then pumped back into the tank. Due to the addition of the concentrate, there is more coolant in the reclamation tank than is required to completely replenish the cooling system.

Due to the time period between draining and replenishing activities, any sediment in the coolant has the opportunity to settle in the reclamation tank. This draining, settling and replenishment effects a crude from of decanting, leaving a sediment "rich" portion of the coolant. When the next locomotive in the maintenance program has its coolant drained in to the reclamation tank the sediment is mixed with this coolant, allowing cross contamination of the sediment through the locomotive fleet. In effect this corrupts the ability of coolant monitoring analysis to confidently identify any given locomotive as a source of the sediment.

There has not been a process to maintain the reclamation tanks previously however, a process has been implemented recently. Prior to the introduction of this process, samples drawn from the reclamation tanks highlighted the need for such a change, Figure 8-2. It is evident from the sample illustrated that it would not be desirable to allow this contamination to return to the cooling system.



Figure 8-2 Reclamation Tank Coolant Sample

Despite the remnant coolant and the potential for cross contamination, the reclamation tanks provide the most practicable solution for short term storage of locomotive coolant for maintenance requirements. With a systematic procedure for removing the coolant remnant and cleaning the tanks in place, the potential for cross contamination has been greatly reduced.

## 8.2 Improvements

The only other practical alternative to the use of reclamation tanks when requiring the cooling system to be drained is to dispose of the used coolant and replenish the cooling system with fresh coolant. The costs associated with the increased volume of fresh coolant required and the disposal of the used coolant significantly reduces the viability of this option.

Identifying that visible contaminates may be present in the coolant and that these contaminants are transported to the reclamation tanks, highlights an opportunity to remove this contaminant from the coolant exists. The removal of sediment would reduce the possibility of erosion corrosion and prevent sediment build-up from negatively affecting the heat transfer process.

# **Chapter 9 Contaminant Removal**

The sediment that has been identified in the coolant is a potential cause of corrosion erosion in the cooling system. Sediment build up in areas of the cooling system may also affect the coolant flow rates and in areas of significant reduction stagnant pockets of coolant may exist. In areas containing stagnant and free flowing coolant, the potential difference between these coolant flows provides an environment conducive to crevice corrosion. Sediment layers also act as an insulator in the heat exchangers to the detriment of heat transfer rates. Given that the removal of sediment is required, several suggestions were considered for to determine an optimal method to effect that removal.

## 9.1 Locomotive Located Filtration

It was suggested that, as the contaminating sediment had been identified as being magnetic, the installation of a magnetic filter in the locomotives may be successful in removing the sediment. A sight glass that had been designated for removal, shown in Figure 9-1, was identified as a potential location for fitting a magnetic trap inside the coolant tank. Considering the locomotive fleet size, fitting a magnetic trap would require the installation and monitoring of around 180 units. Whilst this method would provide the significant benefit of in service removal of sediment, that benefit would be measured against the costs for installation and management and the potential to introduce leaks in scheduled maintenance.



Figure 9-1 Coolant Tank Sight Glass

## 9. 2 Reclamation Tank Located Filtration

As the cooling system maintenance practices require routine dumping of the locomotive coolant, the use of filtration at the entry to the reclamation tanks would only require several filters. This would also assist in the prevention of sediment build up in the reclamation tanks and reduce the possibility of cross contamination. A considerable benefit for placing any filters on service equipment is that any scheduled maintenance of those filters would not require intrusion into the coolant tank on the locomotive. Scheduled filter maintenance could be carried out by general maintenance personnel and would not require any specialist locomotive trained technicians. The duration of scheduled maintenance activities. Given that a filter located on the reclamation tank would provide less impact in cost and management, and the cooling system components have a considerably low failure rate, location of filters on the reclamation tanks would be the most economic option.

### 9.3 Filtration Type

Having determined that, based on the considerations of cost and impact, the reclamation tank is the optimal location, the size and method of filtration will not be limited by concerns with integration to the locomotive. Therefore, aspects such as the effect on coolant flow rates, orientation, and size should be considered in respect to the environment and procedures associated with the reclamation tanks, previously illustrated in Figure 8-1.

#### 9.3.1 Solid Medium Filtration

The more common filtration method contains a solid media barrier retain particles larger than the pore size of the filter medium. The fluid is passed through this filter medium producing a filtrate clear of the particles that remain in the filter. To the detriment of a filter units flow rate, particulate remaining in the filter typically blocks the pores within the medium reducing the effective filtration area. A backwash process may remove the particulate blocking the pores, recovering a measure of the effective filtration area and subsequently the flow rate. A common example of this procedure is the backwash action of the typical household pool pump however particular types of filters, such as spun filter media, are not compatible with backwashing. The other significant factor in determining the flow rate through the filter is the differential between the input and output pressures. With a pump fitted to the existing piping to facilitate return of the coolant to the locomotive, rerouting of the piping and the inclusion of a flow direction tap would enable the pump to supply pressure to the filter.

A significant benefit with this solid media filtration is that the particle retained is determined by the pore size of the filter medium, this pore size can be readily changed with minimal cost and effort through replacement of this filter medium. A 20 micron filter is being considered for use in the reclamation system at the 7 Mile rail maintenance facility, the Cape Lambert maintenance facility has an automatic coolant reclamation system in place, shown in Figure 9-2. This unit has the capacity to receive the used coolant from the locomotive via a 5 micron filtration section, store the coolant until required and then add the required dosing of concentrate to the coolant as it is returned to the locomotive. Although the capability of this unit would meet the needs identified at the 7 Mile facility, the cost of unit is prohibitive against the facilities budget available for coolant maintenance.



Figure 9-2 Cape Lambert Coolant Filtration System



Figure 9-3 Magnetic Trap Section

## 9.3.2 Magnetic Filtration

An alternative relying on the magnetic response of the sediment was considered for installation at the 7 Mile facility on the reclamation tank inlet, shown in Figure 9-3. The aim of this unit was to retain the sediment attracted to the magnet prior to entry to either the filter or the reclamation tank.

Although the removal of a measure of sediment prior to the filter would be beneficial, the volume of the sediment retained may not be beneficial in comparison to the requirement to inspect and maintain a second filtration unit and the effect this unit would have on flow rate. Considering the presence of non-magnetic debris, such as the dirt identified in some sample, a magnetic trap alone would not be effective. With the requirement remaining for a solid media filter, any particle larger than the pore size would be removed regardless of physical characteristics. Therefore the fitment of a magnetic trap in this system would not provide a benefit to a degree warranting its inclusion.

### 9.3.3 Pore Size

The pore size of the solid filtration media will affect the flow rate of fluid through the filter, the pressure differential required to force fluid through the media and the throughput of the filter. The throughput of the filter is the volume of the fluid that can pass through the filter prior to the retained sediment clogging the solid medium. This factor is determines the effective service of the filter for a specific solution from which filter replacement intervals can be calculated.

At the time of writing this report, ongoing testing is being carried out to determine the typical volume and retention weight of sediment for 5 micron and 20 micron filter mediums. The data from these tests will be used to determine the required filter option, the required pressure differential and a recommended service interval.
## **Chapter 10 Recommendations**

### 10.1 Radiator Core Failure

On the strength of evidence contrary to the conclusions made in the report supplied from the external contractor it would be reasonable for Rio Tinto to dismiss the majority of findings in the report as unsubstantiated.

Therefore, in response to the report presented to Rio Tinto, it is recommended that Rio Tinto:

- Dispute the findings presented from the external investigation into the failed radiator core from locomotive 8125 on the basis the evidence is contrary to the conclusions drawn.
- Issue instruction to the external contractor indicating any further failure investigations carried out on RTIO equipment must include a RTIO representative.
- Inspect the radiator cores on locomotive 7081 at the earliest practicable opportunity for evidence of stress corrosion cracking as samples have shown ammonia present in the coolant.
- Investigate the likelihood of non-organic production of ammonia in the locomotive cooling systems.
- Investigate the use of alternative corrosion inhibitor packages that do not contain nitrites, eliminating the possibility of ammonia production through reduction by hydrogen.

#### 10. 2 Coolant Management

Given the review of the Rio Tinto's coolant monitoring procedures, it is apparent that there are a number of concerns with the current processes. A significant concern is Rio Tinto's response in respect to actions advised from the results of the coolant analysis conducted. It is also apparent that a number of tests and alarm limits are inappropriate, misinterpreted or should not be conducted. Results from experiments conducted, described in this report, have provided information beneficial to the understanding of corrosion inhibition and the ongoing management of the coolant. Therefore, in the interest of improving Rio Tinto's ongoing locomotive coolant management procedures, it is recommended that Rio Tinto:

- Enforce the standardisation of units when reporting measured concentrations within itself and between contracted organisations and suppliers to avoid misinterpretation of results.
- Cease any practice of personnel sniffing coolant as any benefit of this practice is outweighed by the risk of exposure to adverse health effects.
- Advise the contracted laboratory conducting coolant analysis that the colour should be reported correctly in lab results or omitted to avoid any misinterpretation of the default response.
- Change the alarm limits for the pH of the coolant to a minimum of 9 and a maximum of 11. These limits more accurately reflect the pH range of advised by the OEM.
- Change the alarm limits for the concentration of corrosion inhibitor to a minimum of 950 ppm of NaNO<sub>2</sub> and a maximum value of 2000 ppm of NaNO<sub>2</sub>. The coolant production and maintenance processes should be designed to produce an inhibitor concentration of 1200 ppm of NaNO<sub>2</sub>.
- Instruct personnel sampling the coolant from the GE Evolution series to flush the hose attached to the sample point so that any external contaminant is not collected when retrieving the sample.
- Align the scheduled sample collections for external analysis to the 4 monthly maintenance period and the collection of the sample prioritised to be completed as early as possible in this period due to the lead time of the analysis. This change should be monitored to ensure that analysis results are received in a timely manner so that any actions recommended may be carried out and that the number of reports received are appropriate to the manpower available to action them.
- Cease the use of titration type nitrite test kits to determine coolant concentration in the workshop, and remove all associated hazardous chemicals from the RSM facility.
- Implement the procedure detailed in Appendix F to use the Hanna Instruments DiST 4 Conductivity Tester to determine the corrosion inhibitor concentration within the maintenance facility.

- Continue routine monitoring of the inhibitor concentration of the bulk mixed coolant to ensure the mixing procedures provide coolant with a corrosion inhibitor concentration within the specified alarm limits.
- Identify excessive concentrations of the wear elements, chromium (Cr), nickel (Ni) and zinc (Zn), in coolant sample analysis as indicators that wear is likely to be occurring in the plate oil cooler, intercoolers, or radiator cores respectively. Follow up actions to prioritise inspections of these components should be carried out.

## **Chapter 11 References**

ALS Tribology 2010, *Engine Coolant Reference Guide*, ALS Tribology, viewed 20<sup>th</sup> April 2014,

http://esource.alstribology.com/WB033\_Nov\_2010/Coolant\_Reference\_Gui de-Eckert.pdf.

ALS n.d., *Technical Bulletin 1: What is the meaning of the PQ index*, ALS Global viewed 20<sup>th</sup> April 2014,

file:///C:/Users/Mark/Downloads/Technical\_Bulletin\_1\_What%20is%20the %20Meaning%20of%20the%20PQ%20Index w backer%20(3).pdf.

Anderson, DP, Lukas M & Lynch BK 1998, *Diesel Engine Coolant Analysis, New Application for Established Instrumentation,* Spectro Incorporated, Littleton.

Askeland, DR & Phule PP 2008, *the science and engineering of materials*, 5<sup>th</sup> edn., Cengage Learning, Stamford.

ASTM International 2008, *Standard specification for solder metal* (ASTM B 32 – 08), ASTM International, West Conshohocken.

ASTM International 2012, *Standard Specification for pipe, steel, black and hot-dipped, zinc coated, welded and seamless* (A53/A53M-12), ASTM International, West Conshohocken.

ASTM International 2012a, *Standard guide for laboratory immersion corrosion testing of metals* (ASTM G31 – 12a), ASTM International, West Conshohocken.

ASTM International 2012b, *Standard specification for Laboratory glass graduated burettes* (ASTM E287 – 02), ASTM International, West Conshohocken.

ASTM International 2012c, *Standard test method for corrosion test for engine coolants in glassware* (ASTM D 1384 – 05), ASTM International, West Conshohocken.

ASTM International 2013, *Standard specification for ASTM Liquid-in-Glass Thermometers* (ASTM E1 – 13), ASTM International, West Conshohocken.

ASTM International 2014, *Standard Specification for electric-resistancewelded carbon and alloy steel mechanical tubing* (A513/A513M-14), ASTM International, West Conshohocken.

ASM International Handbook Committee 1993, *ASM Handbook*, ASM International, viewed 20<sup>th</sup> Feb 2014, http://products.asminternational.org.ezproxy.usq.edu.au/hbk/index.jsp

Avallone, EA, Baumeister III, T & Sadegh, AM (ed.) 2007, *Marks'* standard handbook for mechanical engineers, 11<sup>th</sup> edn, McGraw Hill, New York.

Baboian, R 2003, 'Galvanic Corrosion' *ASM Handbook*, vol. 13A, pp. 210-213, ASM International.

Bartholomew, RD & Shifler, DA 2007, 'Corrosion' *Marks' standard handbook for mechanical engineers*, 11 edn, pp. 6.92-6.110, McGraw Hill, New York.

Boffardi, BP 2003, 'Corrosion inhibitors in the water treatment industry', *ASM Handbook*, vol 13A, pp. 891-906, ASM International.

Callister, W D 2007, *Materials science and engineering: an introduction*, John Wiley & Sons Inc, New York.

Carr, RP 1999, "Assessment of the validity of conductivity as an estimate of total dissolved solids in heavy-duty coolants" *Engine Coolant Testing*, vol. 4, pp. 199-209, American Society for Testing and Materials.

Cohen A, 2005, 'Corrosion of Copper and Copper Based Alloys', *ASM Handbook*, vol 13B, pp. 125-163, ASM International.

Curtin, J 2013, *GE Transportation Systems Engineering Specification:* Locomotive Coolant, GET Engineering.

Curtin, J 2013, Locomotive coolant: Rev B, GE Transport Engineering.

Davis, JR (ed.) 1993, *Aluminium and Aluminium Alloys*, ASM International, Materials Park

Davis, JR (ed) 2001, 'Corrosion Behaviour', *ASM Specialty Handbook: Copper and Copper Alloys*, pp. 385-418, ASTM International.

Davis, ML & Cornwell, DA 2008, *Introduction to environmental engineering*, 4th ed., McGraw Hill, New York.

DeBaun, HJ & Alverson, FC 2008, 'Heavy duty diesel engine coolant technology: past, present, and future', *Engine coolant technologies*, vol. 5, pp. 8 – 16, ASTM International, West Conshohocken.

Dexter, SC 2003, 'Microbiologically influenced corrosion' *ASM Handbook*, vol. 13A, pp. 398-416, ASM International.

Engineering.com n.d., *Stress Corrosion Cracking*, viewed 14<sup>th</sup> May 2014, <u>http://files.engineering.com/getfile.aspx?folder=263e0ac4-cf97-4aa3-96ed-fb285050bec8&file=Microsoft PowerPoint - SCC engtips.pdf</u>

Frankel, GS 2003, 'Pitting corrosion', *ASM Handbook*, vol. 13A, pp. 236-241, ASM International.

GE Australia 2014, *GE Australia transportation*, viewed 6<sup>th</sup> March 2014, <u>http://www.ge.com/au/b2b/transportation</u>.

GE Power and Water 2014, *Handbook of industrial water treatment*, viewed 31<sup>st</sup> March 2014, <u>http://www.gewater.com/handbook/index.jsp</u>.

GE Transportation 2012, *Cooling Water Maintenance: Rev. G*, GE Transport Technical Publications Department, Erie.

Gershun, AV & Woyciesjes, PM 2003, 'Engine coolant base components and inhibitors' *ASM Handbook*, vol. 13C, pp. 531-537, ASM International.

Glaser, W & Wright, IG 2003, 'Cavitation erosion and water drop impingment' *ASM Handbook*, vol. 13A, pp. 322-330, ASM International.

Karim S, Mustafa CM, Assaduzzaman Md & Islam M 2010, 'Effect of nitrite ion on corrosion inhibition of mild steel in simulated cooling water' *Chemical Engineering Research Bulletin*, vol 14, pp. 87-91, ASM International.

Kelly, RG 2003, 'Crevice corrosion' *ASM Handbook*, vol. 13A, pp. 242-247, ASM International.

Kreith, F, Manglick, RM & Bohn, MS 2011, *Principles of heat transfer: SI edition*, 7 edn, Cengage Learning, Stamford.

Kruger, J (2003), 'Passivity', *ASM Handbook*, vol. 13A, pp. 61-67, ASM International.

Kumar S, Narayanan S, Suresh Kumar M, & Manimaran A 2006, 'Dezincification of brass in sulphide polluted sodium chloride medium: evaluation of the effectiveness of 2-mercaptobenzothiazole', *International Journal of Electrochemical Science*, pp. 456-469, ESG.

Lazroff, J 2009, *Recent changes in coolant technology and testing*, ALS Tribology, viewed 5<sup>th</sup> April 2014,

http://esource.alstribology.com/WB022\_Jul\_09/Coolant\_Article\_Lazroff.ht ml

Marcus, P 2003, 'Introduction to the fundamentals of corrosion' *ASM handbook*, vol. 13A, pp. 3-4, ASM International.

Ministry of Defence 2009, *Defence Standard 02-781: Protection of seawater system pipework and heat exchanger tubes in HM surface ships and submarines*, Issue 2, UK Ministry of Defence Standards, London.

Mollenhauer, K & Tschoeke, H 2010, *Handbook of diesel engines*, Springer, Berlin.

Nalco 2012, *Safety Data Sheet: Alfloc 2000 N-2 titrant*, Nalco New Zealand, Te Rapa.

Nalco Australia 2012, *Safety Data Sheet: Nalco N-1 reagent*, Nalco Australia, Macquarie Park.

Nalco Australia 2013, Safety Data Sheet: Nalco 2100,

National Climate Centre 2012, *New temperature record set for Western Australia: special climate statement 37*, Bureau of Meteorology, Docklands.

Pellet, RJ, Bartley Jr., LS, & Fritz, PO 2008, 'Field test for carboxylate inhibitor levels in OAT coolants', *Engine coolant technologies*, vol. 5, pp. 17 – 25, ASTM International, West Conshohocken.

Protopopoff, E & Marcus P 2005, 'Electrode reactions' *ASM Handbook*, ASM International.

Safe Work Australia 2012, *Managing risks of hazardous chemicals in the workplace*, Code of Practice, Safe Work Australia, viewed 13<sup>th</sup> March 2014, <u>http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Docum</u>ents/697/Managing%20Risks%20of%20Hazardous%20Chemicals.pdf

Sheedy, PA 1988, *Materials: their properties testing and selection*, 2 edn, Ligare Pty Ltd, Riverwood.

Spectro Scientific 2014, Overview of rotating disc electrode (RDE) Optical emission spectroscopy for in-service oil analysis, Spectro Scientific, Chelmsford.

Standards Australia International 2004, *Australian Standard: Engine coolants type A and type B for engine cooling systems* (AS 2108-2004), Standards Australia International, Sydney.

Stott, JFD 2003, 'Evaluating microbiologically influenced corrosion' *ASM Handbook*, vol. 13A, pp. 664-649, ASM International.

Watkins Borenstien, S 1994, *Microbiologically Influenced Corrosion Handbook*, Woodhead Publishing, Cambridge.

Warke, WR 2002, 'Stress-corrosion cracking' *ASM Handbook*, vol. 11, ASM International.

Worden, J & Khan, S 2011, *ENG2102 Engineering Problem Solving*, Cengage Learning, South Melbourne.

## Appendix A Project Specification

## University of Southern Queensland FACULTY OF ENGINEERING AND SURVEYING

## **ENG 4111/4112 Research Project PROJECT SPECIFICATION**

- For:Mark WindebankTOPIC:LOCOMOTIVE COOLING SYSTEM STRATEGY<br/>OPTIMISATION
- SUPERVISORS: Dr Ray Malpress John McArthur (Locomotive Reliability Specialist, Rio Tinto Iron Ore)
- ENROLMENT: ENG 4111 S1, 2014 ENG 4112 – S2, 2014
- PROJECT AIM: This project aims to determine an optimum coolant strategy for the Rio Tinto Iron Ore (RTIO) locomotive fleet dependent on factors including life cycle costs, product suitability, engine and radiator protection, and health and environmental impacts.

SPONSORSHIP: Rio Tinto Iron Ore

#### **PROGRAM:**

- 1. Carry out a literature review on previous studies related to applications of coolants, their composition and testing methods, locomotive engine characteristics, local environmental conditions, and relevant standards, legislation or other literature regarding the composition, use and management of coolants.
- 2. Review the current, and determine the suitability of, RTIO's coolant sampling regime and sample alarm limits for the RTIO locomotives and, where relevant, recommend any process improvements to be implemented.
- 3. Review and determine the suitability of RTIO's locomotive coolant reclamation process in maintaining coolant quality.
- 4. Identify the contaminants, and their levels, occurring in the coolant of the RTIO locomotive fleet and the potential contaminant sources.
- 5. Validate the hypothesis of the potential source(s) through comparison of contaminants with samples.
- 6. Determine the normally expected level of ferrous material contamination occurring in the RTIO locomotive cooling systems.
- 7. Investigate a suitable removal method of ferrous contamination from the coolant.
- 8. Perform physical examinations of radiator cores and assess the extent of any erosion to determine if that erosion is consistent with modelling of the locomotive radiator designs and/or configurations.
- 9. Conduct a comparative analysis of the current coolant against a proposed alternative with respect to the cost of supply and change over, effects on service life of components, environmental impact and disposal requirements.

And as time permits:

- 10. Analyse the ability of the current coolant mixing process to consistently deliver a concentration in line with the required parameters.
- 11. Determine and recommend any improvements that may be made to the reclamation process and develop an implementation plan.
- 12. Recommend and develop a training plan for maintainers to maintain coolant concentration.
- 13. Validate the performance of the removal method through controlled experimental trials.

## Appendix B Locomotive 8125 Report Extract

Feedback from GE e	ngineering							
	0							
	a	ient sampli	ng date / time	29-MAY-2013 15:00				
Compound	CAS Number	LOR	Unit	EP1304064-001				
EA005P: pH by PC Titrator				pH v	alue is low indicating	lack of proper cool	ant additive mainta	inance
pH Value		0.01	pH Unit	9.65				
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	473				
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	844				
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	<1				
Total Alkalinity as CaCO3		1	mg/L	1320				
EG020F: Dissolved Metals by ICP-M	5							
Copper	7440-50-8	0.001	mg/L	0.592				
Iron	7439-89-6	0.05	mg/L	0.20				
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001				
EK010-1: Chlorine								
Total Residual Chlorine		0.02	mg/L	0.06				
Free Chlorine		0.02	mg/L	<0.02				
Monochloramine	10599-90-3	0.02	mg/L	0.05				
Dichloroamine	3400-09-7	0.02	mg/L	<0.02				
EK055G: Ammonia as N by Discrete	Anabicar				and the second second			
Ammonia as N	7664-41-7	0.01	mg/L	2.24 Amm	onia level is high ind	icating that there is	microbial activity in	the system. This i
EK057G: Nitrito as N by Discrete An	abrear			undes	irable from a stress	corrosion cracking	of radiator tube per	spective
Nitrite as N		0.01	ma/L	203	Investo and Investor	O and Trained Aller	to the state when we have	
P224E: Constale and Aminopurimi	dina Europiaidas			Nitrite	levels are low at 20	3 ppm. Typical Nith	te levels shoudi de	> 1400 ppm to ma
Cyproconazole	94361-06-5	0.02	ug/L	<0.02	late corrosion resist	ance.		
Difenoconazole	119446-68-3	0.02	ug/L	<0.02				
Flusilazole	85509-19-9	0.02	µg/L	<0.02				
Hexaconazole	79983-71-4	0.02	ug/L	<0.02		Diance refer r	into post	
Paciobutrazole	76738-62-0	0.05	ug/L	<0.05		riease reler r		
Penconazole	66246-88-6	0.01	ug/L	<0.01		page	,	
Propiconazole	60207-90-1	0.05	ug/l	<0.05				
Tebuconazole	107534-96-3	0.01	ug/	<0.01				
Cyprodinil	121552,61.2	0.01	uo/	<0.01				
	121002-01-2	0.01	P3-C	-0.01				

Figure B-1 Coolant Analysis for 8125 supplied to Rio Tinto

		PILBAR		- 7 MILE WO	ORKSHOP			
UNIT NO.	8125 GE	DA	TE SAMPLED	UIN UUAZFA0				
UNIT MODEL	ES44DCI	DA	TE REPORTED	28-Jun-13 COM	PARTMENT MODEL			Cooling System
SYSTEM CAPACITY	1550.0	Ltrs		MACH	HINE LOCATION	Dampier		DIAGNOSIS
		Acceptable Range						Current Sample :
DATE SAMPLED		01-Sep-12	18-Jun-13	06-May-13	21-Apr-13	15-Feb-13	15-Feb-13	All metals (AL Fe, Cu & Ph) are within normal
SERVICE TYPE		31241027	31033300	31302030	31341303	31410441	31440303	limits. Contamination elements (Ca, Mg)
WORK ORDER NO.								appear normal. The Nitrite [Inhibitor] level is
COMPONENT	Hrs							lower than normal for this coolant type. pH
OIL	Hrs							
OIL MAKE		Nalco	Nalco	Nalco	Nalco	Nalco	Nalco	Action: Recommend adding SCA-{Coolant
OIL TYPE		Nalco 2100	Nalco 2100	Nalco 2100	Coolant	Nalco 2100	Coolant	concentrate) as per manufactures
OIL ADDED	Ltrs	ooolan	ooonant	ooonan	oodan	obolant	ocousin	sample at normal recommended interval.
FILTER OIL CHANGED	Hrs	Not Applicable Not Changed	Not Applicable Not Changed	Not Changed	Not Changed	Not Changed	Not Changed	
Metals (ppm)						0		
Aluminium (AI)		s5	<1	<1	<1	<1	<1	
Copper (Cu)		≤10 50	1	<1	1	<1	1	
Chromium (Cr)		\$3	<1	<1	<1	<1	<1	
Lead (Pb)		≤5	<1	<1	<1	<1	<1	Last Sample :
Tin (Sn)		≤5	<1	<1	<1	<1	<1	
Contaminants (pp	om)							limits Contamination elements (Ca. Mo)
Zinc (Zn)		<0.1	<1	<1	<1	<1	<1	appear normal. The Nitrite [Inhibitor] level is
Sodium (Na)		2200	968	1051	1107	1094	1080	lower than normal for this coolant type. pH
Boron (B)		515	220	223	263	263	260	level is normal.
Molybdenum (Me	0)	<0.1	<1	<1	<1	<1	<1	Action: Recommend adding SCA-/Coolant
Phosphorus (P)		20	1	<1	<1	1	1	concentrate) as per manufactures
Calcium (Ca)		-5	2	=1	3	-1	-1	recommendations to raise inhibitor level. Re-
Magnesium (Mg	)	<1	<1	<1	<1	<1	<1	sample at normal recommended interval.
Physical / Chemic	al					12. 1720		
pH Constructivity (v.C.	(am)	12.13	9.33	9.74	9.69	9.54	9.53	
Glycol Content (	%)	7930	3615	3905	4033	4337	4292	
Nitrite (mg/L)	/0)	1200	788	653	734	680	680	
Total Dissolved	Solids	5690	2339	2797	2831	2723	2698	
Colour Clarity Carlant		Neon Pink	Neon Pink	Neon Pink	Neon Pink	Neon Pink	Neon Pink	LEGEND
Visual Debris - C	Coolant	None	None	Black-Mag	Dirt	Black-Mag	Black-Mag	
Odour	Joolan	Bland	Bland	Bland	Bland	Bland	Bland	
PQ Index		≤59	28	28	12	80	94	
WC 10103314233								Abnormal
Samantha.SmithPerth matthewj.lownsend			<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	
					•	•		Caution
								Caution

Figure B- 2 Coolant Analysis for 8125 Conducted by Rio Tinto

## Appendix C Experiment for Effect of Corrosion Inhibitor Concentration on Corrosion Rates

# C.1 Experiment to Determine Levels of Corrosion Relative to Coolant Concentration

The following experiment is to be conducted to determine the likely volume and composition of corrosion by-product expected in the GE Evolution and Dash 9 series locomotives under a specified range of coolant concentrations.

ASTM D1384 indicates a level of error may exist in the measurement of the coupon weights. To reduce any significance in measurement errors the test is to be carried out in triplicate, concurrently, and the final results are to be averaged.

#### C.1.1 Scope

This experiment determines the level of corrosion of the specified materials exposed to the coolant in the GE Evolution and Dash 9 series locomotives. The experiment is an adaptation of the Standard Test method for Corrosion Test for Engine Coolants in Glassware. The coolant used in this experiment is Alfloc 9518 coolant concentrate mixed in a range of concentrations with demineralised water taken from the bulk supply used in the Rio Tinto Iron Ore locomotive fleet.

#### C.1.2 Summary of the Experiment

The experiment creates a range of coolant concentrations reflective of the historical coolant concentration range as recorded from the locomotive coolant samples and the current and recommended concentration levels. The four coolant concentrations are mixed and used to conduct the Standard Test Method for Corrosion Test for Engine Coolants in Glassware (ASTM D1384 – 05). The coupons used are weighed before and after the test to determine the level of corrosion.

#### C.1.3 Significance and Use

The results of this experiment will assess the performance of the Alfloc 9518 coolant at a concentration within the current alarm limits against a concentration within the recommended limits by comparison of the ability to inhibit corrosion. By comparison, these results will validate the adjustment of the desired concentration of the coolant mixed for the Rio Tinto locomotive fleet and the nitrite concentration alarm limits for samples taken from those locomotives.

The experiment will also indicate the levels of corrosion for the materials included that is likely to occur within the cooling system under the average higher and lower concentrations recorded from the samples. From these levels an expected composition of corrosion by-product can be determined and comparison with the contaminant will verify if its origin is likely from corrosion within the cooling system.

Comparing the level of corrosion occurring on the test coupons against the guidelines provided by GE may indicate that corrosion in the cooling systems is than is acceptable. This would indicate that components consisting of those materials identified with excessive corrosion would be susceptible to corrosion in the system and subsequently, a decrease in service life.

#### C.1.4 Equipment

*Container* – Four 1000 mL, tall-form, spoutless beakers made of heat resistant glass.

*Condenser* – Four reflux, glass tube water condenser with a 400 mL cooling jacket.

Aerator Tube – Four gas dispersion tubes of porosity size 12-C.

*Thermometer* – Four thermometers with range from -20 °C to 150 °C and conforming to the requirements for Thermometer 1 C as prescribed in the Specification for ASTM Liquid-in-Glass Thermometers.

*Sealing Method* – Four rubber stoppers to fit the 1000 mL beakers, with holes drilled to accommodate the Condenser, Aerator Tube and Thermometer.

*Heater* – A constant temperature heat bath containing a high boiling point liquid capable of maintaining a constant temperature of  $88 \pm 2$  °C for a two week period (336 hours).

*Temperature Data Logging Device* [Optional] – A temperature sensing and recording device capable of recording a temperature range from 20 °C to 100 °C for a period of two weeks (336 hours)

Scales – An analytical scale with an accuracy of 1mg or better.

Brush – Brass bristle brush.

Air Supply – An air pump with the capacity to provide a constant air supply greater than 400 ml/min of air.

Water Pump – Adequate to supply a sufficient quantity of water to condense any vaporising liquids.

Tubing – As required to transport water and air. Sizes as required by the dimensions of the fittings to ensure no leakage.



Figure C-1 Equipment Configuration

#### C.1.5 Consumables

The following consumables list is the requirement for each iteration of the experiment.

*Water* - 5 L of demineralised water typical of the bulk supply used for mixing coolant for the RTIO locomotive fleet.

Coolant Concentrate - 200 mL of Alfloc 9518 coolant concentrate.

Material Coupons - Four of each of the following material coupons:

Dimensions are to be as specified in Error! Reference source not found., material compositions are detailed in 0.

- Steel, SAE 1020 (UNS G10200), cut from 1.59 mm thickness, cold rolled sheet stock.
- Copper, SAE CA110 (UNS C11000), cut from 1.59 mm thickness, cold rolled sheet stock.
- Brass, SAE CA 260 (UNS C26000), cut from 1.59 mm thickness, half hard sheet stock.
- Solder, SAE 3A (Alloy Grade 30A), cut from 1.59 mm sheet stock.
- *Cast Aluminium*, SAE 329 (Alloy UNS A23190), specimen size, 50.8 mm by 25.4 mm by 3.18 mm.
- *Cast Iron,* SAE G3500 (Alloy UNS F1007), specimen size, 50.8 mm by 25.4 mm by 3.18 mm.

*Specimen Support* – To support the specimens in the coolant the following items are required (these items are single use only):

- Four 50.8 mm 10 24 (M5) brass machine screws.
- Four 10 24 (M5) brass hex nuts.
- Four 42 mm lengths of tetrafluoroethylene (TFE) tubing having a minimum internal diameter of 5 mm and a maximum outside diameter of 6.3 mm.
- Eight half hard brass legs cut, dimensioned as specified in Figure C- 2, composition is not specified.
- Eight 4.76 mm thick brass spacers having a 6.75 mm internal diameter and an 11.11 mm outside diameter.
- Eight 4.76 mm thick steel spacers having a 6.75 mm internal diameter and an 11.11 mm outside diameter.
- Twenty 1.59 mm thick insulating tetrafluoroethylene spacers having a 6.75 mm internal diameter and an 11.11 mm outside diameter.

The material coupons and the supports may be sourced as a pre-assembled test bundle however, to ensure an accurate measurement of the weight change, any supplied weight measurements should be confirmed by the scales to be used for the final measurements.

*Emery Cloth* – "Coarse" grade (No. 1) emery cloth as required for surface finishing.

Acetone – 5 L of Acetone as required for rinsing specimens.

Acid Cleaning Solution - Mixed in an aqueous solution with distilled water

- 1 L of concentrated hydrochloric acid mixed at a 1 to 1 ratio water.
- 1 L of concentrated nitric acid mixed at a 1 to 4 ratio with water.
- 1 L of 1 % glacial acetic acid solution.



Figure C- 2 Test and Support Coupon Dimensions



Figure C- 3 Metal Specimen Arrangement

#### C.1.6 Testing Environment

The test environment must be a clean, contaminant free environment with a reliable constant power source. Due to the temperature sensitive nature of the experiment, care must be taken to ensure fluctuating ambient temperatures will not have an effect.

#### C.1.7 Calculations

As per the standard glassware corrosion test method (ASTM International 2012c), the weight loss is to be calculated by subtracting the final weight from the initial weight. A weight gain will be recorded as a negative weight loss.

The results of planned interval tests may be used to determine the average corrosion rate using the equations and values listed below, taken from the Standard Guide for Laboratory Immersion Corrosion Testing of Materials (ASTM International 2012a).

$$Corrosion \ rate = \frac{\left(K \times W\right)}{\left(A \times T \times D\right)}$$

Where:

- K = the corrosion rate constant,
- T = time of exposure (hours), to the nearest 0.01 h,
- $A = area (cm^2)$ , to the nearest 0.01 cm<sup>2</sup>,
- W = weight loss (g), to the nearest mg,
- $D = density (g/cm^2)$ .

The test in this form is planned for comparative purposes, therefore the relative weight losses will be sufficient to establish if any significant variations exist.

### C.1.8 Interpretation of the Results

Where a coupon has recorded a weight loss, a portion of the material has left the coupon as ions into solution through a corrosion process. Where a negative weight loss has been recorded for a coupon, ions have deposited onto the coupon from the solution. Very small weight changes may also be attributed to the formation of the passivation layer on the surface of the coupon through the intended reaction with the corrosion inhibitor.

The minimum requirements determined by the OEM are listed below in Table C- 1, extracted from Curtin (2013). These values represent the maximum weight loss allowable for each metal species.

Glassware corrosion test per ASTM D1384 on C23000	< 10 mg weight loss @88°C
red brass test coupon in locomotive coolant mix B**	@336 hours AND No pitting
Glassware corrosion test per ASTM D1384 on copper	< 10 mg weight loss @88°C
test coupon in locomotive coolant mix B**	@336 hours AND No pitting
Glassware corrosion test per ASTM D1384 on cast iron	< 5 mg weight loss @88°C
test coupon in locomotive coolant mix B**	@336 hours AND No pitting
Glassware corrosion test per ASTM D1384 on steel	< 5 mg weight loss @88°C
test coupon in locomotive coolant mix B**	@336 hours AND No pitting
Glassware corrosion test per ASTM D1384 on Solder	< 10 mg weight loss @88°C
(70% lead) in locomotive coolant mix B**	@336 hours AND No pitting

Table C-1 Allowable Coupon Weight Losses

### C.2 Procedure

This experiment is based upon ASTM D1384-05 Standard Test method for Corrosion Test for engine Coolants in Glassware (ASTM International 2012c). Except where directed otherwise, the procedure given in this standard is to be used as guidance for the method to conduct this experiment.

#### C.3 Results

The results of the experiment have been listed below in Table C- 2. In comparison to the maximum weight losses, it can be seen that only the steel coupon in the inhibitor concentration of 2193.1 ppm of Nitrite as  $NaNO_2$  has exceeded the limits applied. It is believed that this abnormal result is due to corruption of this particular sample during the conduct of the test. Any interferences may affect the integrity of the test and these results should be considered invalid. The similarity of these results in reference to the other samples indicate that it is likely a valid sample may have fallen within the maximum limits and would encourage a rerun of the sample had time permitted.

Of the lower three concentration samples, the results show weight losses within the maximums advised by the OEM.

Inhibitor Concentration (ppm of NaNO <sub>2</sub> )	500				1200			1500		2000		
Material (weights in mg)	Initial	Final	Change									
Copper	17.213	17.216	-0.003	17.212	17.219	-0.007	17.145	17.147	-0.002	17.108	17.103	0.005
Solder	18.646	18.641	0.005	19.286	19.278	0.008	19.203	19.198	0.005	19.292	19.289	0.003
Red Brass	13.103	13.102	0.001	13.050	13.047	0.003	13.098	13.097	0.001	12.814	12.811	0.003
Steel	15.069	15.068	0.001	14.958	14.957	0.001	15.067	15.066	0.001	15.006	14.998	0.008
Cast Iron	28.331	28.333	-0.002	28.262	28.265	-0.003	28.125	28.125	0.000	25.654	25.656	-0.002

Table C- 2 Recorded Coupon Weight Losses



## Appendix D Nitrite Concentration Relationship Graphs

Figure D-1 Nitrite Concentration vs Conductivity



Figure D- 2 TDS Concentration vs Conductivity



Figure D- 3 Nitrite Concentration vs TDS Concentration

Table D- 1 is representative of the data collated in an excel spreadsheet exported from the sample reports supplied by ALS Tribology.

This division of ALS is the contracted external laboratory for testing RTIO locomotive coolant samples. The test results are uploaded to a secure website and may be exported as a .csv for collation in Excel.

The total collated data is represented graphically in Figure D- 1, Figure D- 2 and Figure D- 3.

	Individual Sample Concentration Values																			
Al	В	Ca	Cr	Cu	Fe	K	Mg	Мо	Na	Р	Pb	Si	Sn	Zn	PQ Index	pН	TDS	Elec Cond	Nitrite	Glycol
1	184	2	<0.1	30	10	<5	1	<1	755	<5	<0.2	19	<1	9	40	9.91	1961	2877	1652	3
<1	177	2	<1	<1	2	6	<1	<1	1129	1	<1	186	<1	<1	475	9.81	1427	2190	1166	<9
1	280	3	<1	7	6	77	<1	1	1375	2	<1	85	<1	1	19	10.07	1519	2337	1166	<9
<1	319	4	<1	2	2	25	<1	3	1707	7	<1	215	<1	<1	<10	10.18	1924	2957	1382	<9
< 0.1	389	1	<0.1	2	2	<5	<1	<0.1	1550	<5	<0.2	33	<1	<1	<10	10.35	1712	2324	1220	3
<1	308	2	<1	<1	1	10	<1	2	1406	<1	<1	73	<1	<1	51	9.41	1608	2405	1112	3
< 0.1	302	<1	<0.1	<1	1	<5	<1	<0.1	1510	57	<0.2	182	<1	<1	57	9.92	1775	2512	1220	3
< 0.1	476	3	<0.1	<1	<0.1	<5	<1	<0.1	2240	50	1	214	<1	<1	22	10.72	2416	3388	1652	3
< 0.1	218	4	<0.1	6	6	22	<1	<1	961	<5	<0.2	75	<1	1	283	9.64	1074	1547	734	0
<1	386	4	<0.1	4	1	5	<1	<0.1	1960	76	<1	246	<1	4	59	9.69	2268	3352	1544	0
<1	302	4	<1	1	2	<1	<1	<1	1768	<1	<1	262	<1	<1	46	9.78	1866	2871	1270	<9
1	160	4	<0.1	3	3	<5	1	<0.1	747	<5	<0.2	52	<1	3	179	10.01	1966	3026	1328	3
<1	651	3	<0.1	3	4	17	<1	<1	2790	7	<0.2	143	<1	1	41	10.2	3205	4720	2138	3
1	474	2	<1	17	4	2	<1	<1	2021	14	<1	133	<1	5	39	9.96	2275	3413	1490	3
1	353	5	<0.1	7	5	<5	2	<0.1	1430	<5	<1	97	<1	7	51	11.3	1640	2123	1058	3
1	353	5	<0.1	7	5	<5	2	<0.1	1430	<5	<1	97	<1	7	51	11.3	1640	2123	1058	3
1	178	3	<1	12	5	2	1	<1	715	1	<1	35	<1	4	<10	9.53	2099	3048	1328	3
< 0.1	600	1	<0.1	1	<1	<5	<1	<0.1	2480	16	<0.2	188	<1	<1	13	10.19	2730	3512	1706	3
< 0.1	235	2	<0.1	1	1	<5	2	<0.1	1020	15	<1	82	<1	1	432	9.82	1090	1532	680	0
<1	678	3	<1	1	<1	9	<1	<1	2770	<1	<1	173	<1	1	59	9.82	2749	3958	1706	0
< 0.1	219	1	<0.1	3	3	<5	<1	<1	981	<5	<0.2	46	<1	1	68	10.29	1275	1980	788	3
<1	379	4	<1	1	1	<1	<1	<1	1643	<1	<1	94	<1	<1	<10	10.1	3830	5890	2327	0
< 0.1	358	1	<0.1	1	1	<5	<1	1	1720	30	<1	176	<1	1	14	10.12	2008	6020	1220	0
<0.1	488	2	3	1	14	<5	<1	1	2110	7	<0.2	52	<1	<0.1	<10	10.38	2291	3325	1382	0
<1	248	4	<1	6	6	18	1	<1	1174	<1	<1	111	1	3	31	9.8	1221	1874	734	<9
< 0.1	420	1	<0.1	<1	<1	<5	<1	<0.1	1710	<5	<0.2	136	<1	<0.1	28	9.85	1941	2824	1166	0
< 0.1	532	2	<1	<1	1	<5	<1	<1	2340	21	<1	188	<1	6	26	11.2	2398	3187	1436	3
<1	673	2	<0.1	1	< 0.1	8	<1	1	2750	<5	<0.2	150	<1	<1	474	10.06	3054	4086	1814	3
1	335	4	<0.1	4	3	8	<1	<1	1420	<5	<1	83	<1	2	75	9.87	1975	2769	1166	0
< 0.1	84	8	<0.1	2	1	8	<1	1	502	18	<0.2	54	1	<1	<10	9.54	1337	2058	788	3
2	251	<1	<0.1	25	7	<5	<1	<1	963	<5	<0.2	76	<1	14	45	10.24	971	1288	572	3
< 0.1	504	3	< 0.1	<1	<1	<5	<1	<1	2200	5	< 0.2	121	<1	< 0.1	<10	11.51	2576	3600	1490	3

 Table D- 1 Representative Sample Data

## Appendix E Experiment for Methods of Determining Coolant Concentration

#### **E.1 Experiment Method**

This experiment is to determine the validity of alternative sodium nitrite concentration estimation methods for samples of the Alfloc 9518 coolant mix taken from the RTIO locomotive fleet.

#### E.1.1 **Scope**

This experiment evaluates the accuracy of methods estimating the sodium nitrite concentration in an Alfloc 9518 coolant mix by measuring the electrical conductivity and by visual colour comparison against the two titration methods in current use. The nitrite titration methods in current use include a specific nitrite test kit provided by Nalco, the distributor of Alfloc 9518, and a precise titration method carried out by an independent testing laboratory. The coolant concentration range for the experiment is between 0 and 2500 ppm.

It should be noted that these methods measure the concentration of either sodium nitrite or nitrite in either ppm or mg/L. It is assumed that 1 mg/L is equivalent to 1 ppm. Due to the mass relationship of nitrite to sodium nitrite, a concentration 1000 ppm of nitrite is equivalent to 1500 ppm sodium nitrite. To ease the comparison of the results, all measurements are presented as the concentration of sodium nitrite in ppm. The experiment uses samples of a fresh coolant mix of Alfloc 9518 and demineralised water with known nitrite concentrations and test samples of used Alfloc 9518 mixed coolant as used in the GE Evolution and Dash 9 series locomotives. It should be noted that the concentration of sodium nitrite in Alfloc 9518 concentrate, as advised by the distributor, is 47,000 ppm. The coolant concentrate supplied for in this experiment has a sodium nitrite concentration of 2,850 ppm and adjustments have been made accordingly.

#### E.1.2 Summary of the Experiment

The experiment creates a range of coolant samples with known sodium nitrite concentrations. The demineralised water and the coolant concentrate are tested for sodium nitrite concentration and electrical conductivity to provide a reference level value. The samples are then tested using a standard nitrite titration test kit, a precise titration test method, an electrical conductivity test unit and a visual colour comparison method. The results of each test are compared graphically and compared for accuracy using the dimensionless coefficient of determination. Samples of used coolant taken from a locomotive fleet, of unknown sodium nitrite concentration, are then tested using all four methods and the results are compared to determine accuracy of the methods when applied to coolant samples contaminated through use.

#### E.1.3 Significance and Use

This experiment will assess the validity of the two hypotheses that, a relationship exists between the concentration of sodium nitrite in a coolant sample and the electrical conductivity of that sample, and a relationship exists between the concentration of sodium nitrite in a coolant sample and the colour of that sample.

Analysis of the methods will determine the accuracy of estimating the sodium nitrite concentration of a coolant sample through comparison of that samples colour and electrical conductivity against the titration methods in current use.

Validation that either method estimates the sodium nitrite with sufficient accuracy will provide an alternative to the use of a nitrite test kit within the workshop environment. Where a method is deemed to be sufficiently accurate, a subsequent comparison of this method against the nitrite test kit based on cost, ease of use and hazards associated with the method may be carried out. A determination may then be made of the total benefit, if any exists, in substituting the nitrite test kit with the new method for estimating sodium nitrite concentration in coolants within the workshop environment.

#### E.1.4 Equipment

*Electrical Conductivity Tester* – A portable electrical conductivity test unit capable of measuring electrical conductivity in solutions from 0 to 14,000  $\mu$ S/cm.

Nitrite Test Kit – A standard portable nitrite titration test kit with solutions.

Mixed Coolant Containers - Eleven 1000 mL glass beakers.

*Sample Transit Containers* – Eleven sample bottles appropriate for transporting a 100 mL sample.

Colour Sample Containers – Ten optically clear, 50 mL containers with lids.

Burette – A 50 mL glass burette with 0.1 mL graduations and stand.

*PPE* – Chemical splash goggles, nitrile gloves, long sleeved clothing and safety boots are to be worn.

### E.1.5 Consumables

Water - 10 L of demineralised water typical of any requirements specified by the coolant concentrate or equipment manufacturers.

Coolant Concentrate - 500 mL of Alfloc 9518 coolant concentrate.

*Titration Solutions* – All solutions required as specified in the Nitrate Test Kit.

#### E.1.6 External Resources

The precise titration test is to be carried out in a laboratory environment by personnel adequately trained in the task. This process is outsourced to the external laboratory that currently analyses the scheduled coolant samples to preserve the normal conditions and expertise for this test. This laboratory and personnel are equipped for, and experienced with, the techniques and handling of the hazardous materials required for the precise titration method.

#### E.1.7 Testing Environment

The test is to be carried out in conditions expected within a workshop environment, excepting the precise titration method. Ambient temperature and workspace cleanliness as expected by general OHS standards are deemed sufficient. The experiment is to be conducted in a well-ventilated area with adequate chemical spill containment.

#### E.1.8 Calculations

The calculations for this experiment have been performed using an excel spreadsheet based on the following equations.

The concentration of nitrites in the demineralised water to be used has been determined as negligible and is considered as zero for the purpose of this experiment.

The concentration of nitrites is determined using the concentration equation, Equation 8. Note that in assuming the water contains no mass of nitrites the equation is simplified to considering only the coolant concentrate and the final mixed solution. The volume of water required in the final solution is the difference in volume between the concentrate and final solutions.

**Equation 8: Concentration in Solution** 

The volumes of coolant concentrate and demineralised water required to mix the coolant concentrate samples are given in Table E- 1.

Concentrations for Nitrite Sampling Experiment							
Batch volume	500						
Concentration of Nitrite Coolant Concentra	2850						
	Volume						
Concentration (ppm)	Nalco Concentrate (mL)	Water (mL)					
0	0	500.0					
500	87.7	412.3					
750	131.6	368.4					
1000	175.4	324.6					
1200	210.5	289.5					
1300	228.1	271.9					
1400	245.6	254.4					
1500	263.2	236.8					
1800	315.8	184.2					
2150	377.2	122.8					
2500	438.6	61.4					
Total Volume Required	2500	4000					

**Table E-1 Mixing Volumes for Coolant Samples** 

The model for electrical conductivity is calculated through measuring the conductivities of the demineralised water and the coolant concentrate. The conductivity value for the water is assumed as the level respective to 0 ppm of sodium nitrite. The conductivity of the concentrate is set to the predetermined sodium nitrite concentration of 2600 ppm. As the concentration of sodium nitrite in the mixed solution increases linearly through the increase in the ratio of coolant concentrate to water, linear interpolation, Equation 9, of the two reference values is used to define a model for estimating the sodium nitrite concentration in mixed coolant solutions.

#### **Equation 9: Linear Interpolation**

`

$$C_{mix} = C_{conc} \left( \frac{\kappa_{mix} - \kappa_{H_2O}}{\kappa_{conc} - \kappa_{H_2O}} \right)$$

To compare the accuracy of the linear interpolation model for electrical conductivity against other concentration estimation methods available the dimensionless coefficient of determination is calculated. This coefficient, referred to as the r<sup>2</sup>-value, is calculated using the formula Where  $f(x_i)$  is the calculated concentration,  $y_i$  is the respective recorded estimation of concentration and  $\bar{y}$  is the arithmetic mean of the total calculated concentration values.

**Equation 10: Coefficient of Determination** 

$r^2 - 1_{-}$	$\left[f(x_i)-y_i\right]^2$
/ _1-	$\left[y_i - \overline{y}\right]^2$

#### E.1.9 Interpretation of the Results

The experiment results indicate the accuracy of estimating the nitrite concentration by measurement of the electrical conductivity or visual colour. The relevance of this accuracy is determined by a factor of the acceptable concentration range and the expected reduction in the nitrite concentration between sampling.

The Coefficient of Determination is the  $r^2$ - value and is used in statistical modelling to determine the quality of fit of model against a set of data points. This coefficient value varies between 0 and 1 where a coefficient value of 1 indicates the model perfectly predicts the data set and 0 indicates the data is completely random in comparison to the model.

For the purpose of this experiment an exact desired coefficient is not initially specified. The value of the coefficient for each method of estimation will instead be compared against the laboratory titration coefficient to determine a relative accuracy.

To be considered a satisfactory replacement for the Nitrite Test Kit in current use, the method of estimation must have a similar or greater coefficient of determination. A judgement may be made that a coefficient of determination lower than that of the Nitrite Test Kit is satisfactory where a safety benefit exists through implantation of the new method of estimation reducing or removing some element of hazard.

### E.1.10 Procedure

#### I. Preparation:

- a. Label the glass containers required with randomised batch codes.
- b. In the 1000 mL tall form glass beakers, mix the coolant concentrate and demineralised water in the volumes specified in Table E- 2 to obtain the required concentrations for the mixed coolant samples.

Note: For safety reasons, solutions are to be mixed by adding the concentrate to the water volume.

c. Record the batch codes for the applicable concentrations on the Concentration Experiment Record Sheet, Table D-3.

#### II. Laboratory Titration Test:

- a. Draw a 100 mL sample from each batch into a fresh sample bottle, label the sample bottle with the batch code.
- b. Forward the sample bottles to ALS for laboratory testing.
- c. Record the laboratory results relative to the batch code on the Concentration Experiment Record Sheet.

#### III. Visual Colour Chart Test:

- a. Fill a clean 100 mL clear glass bottle from each coolant concentrate batch and record the nitrite concentration on the bottle.
- b. Graphically record the colour of each mixed coolant batch and create a colour reference chart labelled with the calculated nitrite concentrations.
- c. Conduct a blind trial using a test subject to determine the nitrite concentration of randomly selected of batch samples by comparison with the colour chart.
- d. Record the test subjects estimated nitrite concentrations against the relevant batch code on the Concentration Experiment Record Sheet.

#### *IV. Conductivity Test:*

- a. Measure and record the electrical conductivity of the batches and record the values on the Concentration Experiment Record Sheet.
- b. Plot the recorded conductivity against the known nitrite concentration and use linear regression to model the relationship.

#### V. Nitrite Titration Kit Test:

- a. From a sample of coolant from each coolant batch, determine the nitrite concentration through titration using the Nitrite Test Kit.
- b. Record the nitrite concentration determined against the batch code.
- c. Plot the determined nitrite concentration against the known nitrite concentration and perform a linear regression to model the relationship.

#### VI. Analysis of Results:

- a. From the recorded experiment results calculate the r<sup>2</sup>-value for the model from each test method.
- b. Compare the calculated  $r^2$ -values to determine the relative suitability of each test method. The expected minimum value for engineering purposes is an  $r^2$ -value greater than 0.8.

#### VII. Application Testing:

- a. Repeat steps 3 6 using coolant samples drawn from the RTIO locomotive fleet.
- b. Using the laboratory titration tests, estimate the nitrite concentration range for each sample and determine the expected methods used in steps 3 6.
- c. Compare the expected nitrate concentrations against the nitrite concentrations determined by the conductivity and the visual colour comparison.
- d. Assess the accuracy of these methods for use in estimating nitrite concentrations of the coolants used in the RTIO locomotive fleet.

#### **E.2** Results

#### **Nitrite Concentration Experiment** Calculated Nitrite Volume (mL) Nitrite concentration Values Concentration Batch Code Alfloc 9158 Coolant Demin Laboratory Lab results Conductivity Conductivity Visual Colour mg/L Water Nitrite Test Titration adjusted (DiST 4) (Dist 6) Comparison concentrate Kit 0.0 500.0 С 0 0 0 0 0 0 0 87.7 412.3 Ι 500 600 437 655.5 541.08 525.08 667 368.4 131.6 750 785.08 749.08 983 В 750 506 759 175.4 324.6 F 1000 690 1035 1029.08 1233 1050 1053.08 K 210.5 289.5 805 1207.5 1249.08 1317 1200 1050 1229.08 228.1 271.9 1300 1200 874 1311 1333.08 1337.08 1667 А 245.6 254.4 G 1400 874 1441.08 1583 1350 1311 1433.08 263.2 236.8 1500 1545.08 2100 D 1350 1058 1587 1517.08 315.8 184.2 J 1800 1650 1081 1621.5 1821.08 1829.08 2017 377.2 Η 122.8 2150 2100 1311 1966.5 2141.08 2157.08 2383 438.6 61.4 Е 2500 2400 1771 2656.5 2457.08 2485.08 2500

#### Table E- 2 Nitrite Concentration Values



Figure E-1 Graphical Comparison of Concentration Estimation Methods



Figure E- 2 Enhanced Extract of Figure E-1 (1000 to 2000 ppm)



Figure E- 3 Comparison of Locomotive Sample Results
		$[f(x_i)-y_i]^2$			
Nitrite Test Kit	Laboratory Titration	Conductivity (DiST 4)	Conductivity (Dist 6)	Visual Colour Chart	
0.0	0.0	0.0	0.0	0.0	
10000.0	24180.3	1687.6	629.0	27777.8	
0.0	81.0	1230.6	0.8	54444.4	
2500.0	1225.0	2817.5	845.6	54444.4	
22500.0	56.3	845.6	2408.8	13611.1	
10000.0	121.0	1094.3	1374.9	134444.4	
2500.0	7921.0	1094.3	1687.6	33611.1	
22500.0	7569.0	291.7	2032.2	360000.0	
22500.0	31862.3	444.4	845.6	46944.4	
2500.0	33672.3	79.6	50.1	54444.4	
10000.0	24492.3	1842.1	222.6	0.0	
105000.0	131180.3	11427.7	10097.4	779722.2	$\Sigma[f(x_i)$

Table E- 3 Total Square of Residuals

Table E- 4 Total Spread of Data

		$[\mathcal{Y}_i - \bar{y}]^2$			
Nitrite Test Kit	Laboratory Titration	Conductivity (DiST 4)	Conductivity (Dist 6)	Visual Colour Chart	
1643058	1643058	1643058	1643058	1643058	
464876	392274	548693	572653	378411	
282831	273339	246749	283810	89093	
53740	60919	52321	63877	2351	
53740	5523	2781	1072	1214	
6694	852	2628	3054	148108	
4649	852	22880	25364	90911	
4649	93136	55348	69307	669421	
135558	115384	290803	299495	540002	
669421	468789	738331	766083	1213336	
1250331	1889750	1889750	1447839	1483967	
4569545	4943876	5493343	5175612	6259874	$\Sigma[y_i-\bar{y}]^2$

		Coefficien	nt of Determinati	on	
Method	Nitrite Test Kit	Laboratory Titration	Conductivity (DiST 4)	Conductivity (Dist 6)	Visual Colour Chart
r <sup>2</sup> -value	0.9770	0.9735	0.9979	0.9980	0.8754

Table E- 5 Coefficients of Determination

 Table E- 6 Coefficients of Determination (1000 to 2000 ppm)

Г

Coe	efficient of l	Determination	(ranged betweer	1000 and 2000	ppm)
Method	Nitrite Test Kit	Laboratory Titration	Conductivity (DiST 4)	Conductivity (Dist 6)	Visual Colour Chart
$\Sigma[f(x_i)-y_i]^2$	82500.0	48754.5	6587.8	9194.8	643055.6
$\Sigma[y_i\text{-}\bar{y}]^2$	259029	276665	426762	462169	1452009
r <sup>2</sup> -value	0.6815	0.8238	0.9846	0.9801	0.5571

# Appendix F Recommended Corrosion Inhibitor Concentration Testing Procedure



Copyright Statement © 2008 Rio Tinto Internal Use Only

	Rin Tinte Railways Division - Testing Inhibitor Concentration of Locomotive Engine Coolant	Page 3 of 14
R	no milo rainaya birison – resurg miliono concentratori o coonicure Ligine coorain	rageoorie
ō	Purpose	
<b>Tinto</b>	This document is made to guide a technician in the processes involved in determining the corrosion inhibitor concentrations in locomotive en using a conductivity tester.	gine coolants
	Application	
	This procedure defines the processes for using a hand help conductivity tester to determine the concentration of corrosion inhibitor present in coolant taken from a locomotive engine and maintaining that concentration within defined limits through addition of Alfloc 9518 concentrate.	n a sample of
	HSE	
	This document must be used in conjunction with a "Take 5" to identify any hazards associated with the job. If not satisfied that you have an understanding of the hazards involved then a JHA can be written to identify those hazards. Suitable gloves to be worn when handling coolant and components to avoid burns, cuts or grazes. Hearing protection to be used as directed in maintenance facility practices. Watch for pinch points and line of fire. Use good posture and lifting techniques for manual handling. Refer to MSDS sheets ALFLOC 9518 for information regarding this chemical.	
	Scope	
	This procedure applies only to the locomotive maintenance facilities at the 7-mile and Cape Lambert workshops. This document covers the management of Alfloc 9518 concentrate mixed coolant for GE dash 9, Evolution series locomotives.	
	Environmental	
	Use precautions to avoid any spills All spills must be cleaned up and reported	
	PRC-RP-X-XXX Printed documents are uncontrolled. See document management system for the current document	Version 1.0

Copyright Statement © 2008 Rio Tinto Internal Use Only

Pre Ta	sk Preparation
HSEQ Significant Risks: Rolling stock, Hot coolant, Chemical Contact, Spills and Slippery floors, Vehicle movements, Scaffolding and working at heights.	Additional PPE Requirements: Gloves, Hearing protection, Safety glasses.
	Permits & Isolation Requirements: The area to be worked in must fin be isolated by a competent isolation officer with master lock and tag placed. Personal locks must then be placed on Isolation blocks to creat a safe working area and provide protection from rolling stock. The person placing his locks must have a good understanding of the limits o his safe working area.
Special Tools & Equipment: Handheld EC/TDS test unit (Hanna Instruments DiST 4 Conductivity Tester, sample container, coolant bulk storage bin system.	Materials: ALFLOC 9518 corrosion inhibitor concentrate.
Resource (people/skills): Experienced person to guide new workers through job.	Special Qualifications/Licences Required: Lock holders, HSE and area induction





Corrosio	n Inhibitor C	oncentrati	ion Chart:	Evo Locomo	tive			
Cooling Syst	em Capacity:		1550 L					
Conductivity Reading	Nitrite Concentration	Required Concentrate	Conductivity Reading	Nitrite Concentration	Required Concentrate	Conductivity Reading	Nitrite Concentration	Required Concentrate
(mS/cm)	(NaNO <sub>3</sub> ppm)	(litres)	(mS/cm)	(NaNO <sub>3</sub> ppm)	(litres)	(mS/cm)	(NaNO <sub>3</sub> ppm)	(litres)
0.3	281.88	40	2	708.75	26	3.7	1135.62	12
0.4	306.99	40	2.1	733.86	26	3.8	1160.73	11
0.5	332.1	39	2.2	758.97	25	3.9	1185.84	11
0.6	357.21	38	2.3	784.08	24	4	1210.95	10
0.7	382.32	37	2.4	809.19	23	4.1	1236.06	9
0.8	407.43	36	2.5	834.3	22	4.2	1261.17	8
0.9	432.54	36	2.6	859.41	22	4.3	1286.28	7
1	457.65	35	2.7	884.52	21	4.4	1311.39	6
1.1	482.76	34	2.8	909.63	20	4.5	1336.5	6
1.2	507.87	33	2.9	934.74	19	4.6	1361.61	5
1.3	532.98	32	3	959.85	18	4.7	1386.72	4
1.4	558.09	31	3.1	984.96	17	4.8	1411.85	3
1.5	583.2	31	3.2	1010.07	17	4.9	1436.94	2
1.0	608.31	30	3.5	1055.18	16	2	1462.05	1
1.7	659.52	25	3.4	1080.25	15	5.1	1407.10	0
1.0	692.64	20	3.5	1110 51	12	>101	> 2850	
**	A nitrite conce	ntration abov	e 2850ppm is con	sidered excess	ve. To dilute the	e concentration	refer to table b	elow.
	Conductivit	y Reading	Nitrite Concentration	N Volume t	be dropped and r	replaced with Pren	nix Coolant	
	(mS/	cm)	(NaNO <sub>3</sub> ppm)		(lit	res)		
	11		2970		1	30	15	
	12		3220		3	40		
	13	•	3470		4	50		
	14	•	3720	1	6	10		
RP-X-XXX			Print	ted documents are und	ontrolled.			Version 1.0



	roccure m	lie. Tes	Locomotive Engine	Coolant	Jicenu	ation of
		Work	Step 1 – Isolations and set u	р	STEP TIME	[00:20:00]
	Sub-Step (What)	Symbol	Highlight/Key Point (How) (including relevant PPE)	Reason (Why)	Vis	ual Support
.1	Isolations	HSE	<ul> <li>The area to be worked in must first be isolated by a competent isolation officer with a master lock and tag placed.</li> </ul>	To provide protection from rolling stock and other work which could cause you harm.	100	M
		$\odot$	<ul> <li>Your personal lock must then be placed on the Isolation block to create a safe working area and provide protection from rolling stock.</li> </ul>			(8
			<ul> <li>The person placing their lock must have a good understanding of the limits of his safe working area.</li> </ul>			
.2	HSE	HSE	<ul> <li>Asses the job and your work area look for hazards then complete the take 5 book noting all the hazards and placing controls to prevent injury or damage.</li> </ul>	To identify and rectify any unsafe conditions that could harm you or someone else or cause damage to equipment.		
		$\odot$	<ul> <li>Use hearing protection when noise is present</li> </ul>			

ſ

Daily pre start checks	<ul> <li>Make sure you remove as many hazards as you can before you start so that you start with a clean and safe work area. Keep reassessing the hazards throughout the job.</li> <li>Assemble the equipment and tools needed for the job.</li> <li>Check the calibration of the handheld test unit is current.</li> <li>Turn on unit and ensure battery level is adequate for task. The unit will</li> </ul>	To avoid delays or incorrect readings.	
Daily pre start checks	Assemble the equipment and tools needed for the job.     Check the calibration of the handheld test unit is current.     Turn on unit and ensure battery level is adequate for task. The unit will	To avoid delays or incorrect readings.	
Daily pre start checks	<ul> <li>Check the calibration of the handheld test unit is current.</li> <li>Turn on unit and ensure battery level is adequate for task. The unit will</li> </ul>	To avoid delays or incorrect readings.	
	<ul> <li>Turn on unit and ensure battery level is adequate for task. The unit will</li> </ul>		
	tum off if battery level is inadequate.		
	<ul> <li>Inspect the probes of the hand held test unit for any damage or dirt as this may affect the reading. Clean unit as required.</li> </ul>		
	<ul> <li>Organise the unit to be calibrated if calibration is out of date, the unit does not urn on or stay on, or the accuracy of the unit is suspect for any reason (ie probe is damaged).</li> </ul>		
1.3 Preparation	<ul> <li>Ensure all equipment required is available and functional.</li> </ul>	To ensure everything is ready to go.	

101

Procedure In	e: res	Locomotive Engine	Coolant	oncentra	
	Wo	rk Step 2 – Testing Sample	of Coolant	STEP	[00:10:00
Sub-Step (What)	Symbol	Highlight/Key Point (How) (including relevant PPE)	Reason (Why)	Visu	al Support
Prepare coolant sample		<ul> <li>Remove covers to access the cooling system drain point.</li> </ul>	To allow testing of coolant.		1 1
1	HSE	Caution: Coolant and cooling system components may be hot.			
		<ul> <li>Fill coolant sample container form drain point to fill level mark.</li> </ul>		THE	
		<ul> <li>Note: Clear the sampling hose on the Evo Series of any contamination.</li> </ul>		Dash 9	Evo Serie
Test coolant sample	0	<ul> <li>Ensure coolant sample temperature is within the 0 - 50°C range.</li> </ul>	To determine the concentration of corrosion		
		<ul> <li>Turn on handheld test unit.</li> </ul>	inhibitor in the coolant.		•
2		<ul> <li>Immerse the hand held test unit into the coolant sample without exceeding the maximum immersion level marked on the handheld unit.</li> </ul>			#24.089A704
	Q	<ul> <li>Allow the value displayed on the tester to stabilise.</li> </ul>			111004
		<ul> <li>Record the date, tester reading and locomotive number on the Coolant Concentration Record Sheet.</li> </ul>			
C-RP-X-XXX		Printed documents are uncontroll See document management system for the cu	ed. Irrent document	V	ersion 1.0

o Tinto Railways Division – Testing Inhibitor	concentration of Locomotive Engine Coolant	Page 12 of 14
Determine corrosion inhibitor concentration	Compare the reading recorded against the respective Corrosion Inhibitor Concentration Chart to find the concentration of corrosion inhibitor in the coolant and required volume of ALFLOC 9518 concentrate.	
	<ul> <li>No action is required for an inhibitor concentration between 1500 and 2850 ppm.</li> </ul>	Data a
23	<ul> <li>If the concentration of corrosion inhibitor exceeds 2850 ppm, the coolant must be diluted in accordance with the Corrosion Inhibitor Concentration Chart.</li> </ul>	
	<ul> <li>Turn off the hand held test unit.</li> </ul>	
	<ul> <li>Dispose of any excess coolant as per requirements in the relevant MSDS.</li> </ul>	
	<ul> <li>Refit any covers to locomotive as required.</li> </ul>	
References		
SDS: ALFLOC 9518	Concentrate	
RC-RP-X-XXX	Printed documents are uncontrolled. See document management system for the current document	Version 1.0
	Copyright Statement © 2008 Rio Tinto	

F	Procedure Titl	e : Tes	sting and Maintaining Co	rosion Inhibitor C	oncentration of
			Locomotive Engine	Coolant	
		1	Work Step 4– Pack up and c	leisolate	STEP TIME [00:10:00
	Sub-Step (What)	Symbol	Highlight/Key Point (How) (including relevant PPE)	Reason (Why)	Visual Support
3.1	Pack up	0	<ul> <li>Dispose of any unused coolant as per MSDS requirements.</li> <li>Pack away any hoses, tools or equipment used</li> <li>Rinse and wipe dry the probe end of the hand held test unit with clean water. Be careful not to splash water above the maximum immersion level mark. Reft probe cover and retum the hand held unit to storage.</li> </ul>	Clean up.	
3.2	Remove isolations	HSE	<ul> <li>Check that all paperwork is completed and totals for day filled in.</li> <li>If necessary forward totals to supervisor.</li> <li>Remove your personal lock and count your locks to make sure they are all accounted for.</li> </ul>	Ensuring that paperwork is complete and your personal isolation lock is removed.	
C-R	P-X-XXX		Printed documents are uncontroll See document management system for the cu	ed. rrent document	Version 1.0

# Appendix G Experiment for Comparison of Coolants Corrosion Inhibition

This experiment will be run as per the Experiment for Corrosion Levels Relative to Coolant Concentration in Appendix B. The exception is that the variable between the coolant samples will be the variety of coolant concentrate added as opposed to the volume of coolant concentration added.

## Appendix H Material Compositions

#### **H.1 Compositions**

The following component elements of the materials listed are given as a percentage of weight (wt %).

Unless indicated otherwise, single values indicate the maximum percentage.

Steel, ASTM A53: [concentrations vary dependant on grade]

_	Iron	97.4	(minimum)
_	Carbon	0.25 to 0.30	
—	Manganese	0.95 to 1.20	
_	Phosphorus	0.05	
_	Sulphur	0.045	
_	Copper	0.40*	
_	Nickel	0.40*	
_	Chromium	0.40*	
_	Molybdenum	0.15*	
_	Vanadium	0.08*	

\* The total composition of these five elements is not to exceed 1.00%

#### ASTM A513: [concentrations vary dependent on grade]

—	Iron	94.45	(minimum)
_	Carbon	0.08 to 0.65	
—	Manganese	0.30 to 1.65	
—	Phosphorus	0.40	
—	Sulphur	0.050	
—	Silicon	0.15 to 0.35*	
—	Nickel	0.40 to 0.70*	
_	Chromium	0.40 to 1.10*	
_	Molybdenum	0.08 to 0.25*	

\* Of these four elements:

- Silicon is only present in grades 1340, and 4118 through 8630.
- Nickel is only present in grades 8620 and 8630.
- Chromium is only present in grades 4118 through 8630.

 Molybdenum is only present in grades 4118 through 8630, excepting 5130.

#### SAE 1020 (UNS G10200):

—	Iron	99.1	(minimum)
_	Carbon	0.18 to 0.23	
_	Manganese	0.30 to 0.60	
_	Phosphorus	0.035	
_	Sulphur	0.035	

### SAE 1030 (UNS G10300):

Iron	99.1	(minimum)
Carbon	0.28 to 0.34	
Manganese	0.60 to 0.90	
Phosphorus	0.040	
Sulphur	0.050	
	Iron Carbon Manganese Phosphorus Sulphur	Iron         99.1           Carbon         0.28 to 0.34           Manganese         0.60 to 0.90           Phosphorus         0.040           Sulphur         0.050

#### Stainless Steel, AISI 304:

_	Iron	66.33	(minimum)
_	Chromium	18.0 to 20.0	
_	Nickel	8.0 to 10.5	
_	Manganese	2.0	
_	Silicon	1.0	
_	Phosphorus	0.045	
_	Carbon	0.04 to 0.10	
_	Sulphur	0.03	

#### AISI 316:

_	Iron	61.75	(minimum)
_	Chromium	16.0 to 18.0	
_	Nickel	10.0 to 14.0	
_	Molybdenum	2.0 to 3.0	
_	Manganese	2.0	
_	Silicon	1.0	
_	Carbon	0.08	
_	Phosphorus	0.045	

—	Carbon	0.04 to 0.10
_	Sulphur	0.03

#### Copper, UNS C12200:

_	Copper	99.96	(minimum)
_	Phosphorus	0.015 to 0.040	1

#### UNS C70600:

_	Copper	88.6	(minimum)
_	Nickel	10	
—	Iron	1.4	

#### CDA 122 (AWS A5.8, Class BCu-1):

_	Copper	99	(minimum)
_	Phosphorus	0.075	
_	Lead	0.02	

#### Red Brass, UNS C23000:

—	Copper	84.0 to 86.0	
_	Lead	0.05	
_	Iron	0.05	
_	Zinc	remainder	(13.9 to 15.9 %)

#### Yellow Brass, UNS C26000:

_	Copper	68.5 to 71.5	
_	Lead	0.07	
_	Iron	0.05	
_	Zinc	remainder	(28.4 to 31.4 %)
			(

#### UNS C26800:

_	Copper	64.0 to 68.5	
_	Lead	0.15	
_	Iron	0.05	
_	Zinc	remainder	(31.3 to 35.8 %)
			107

#### UNS C85200:

_	Copper	72	
_	Zinc	24	(minimum)
_	Lead	3	
_	Tin	1	

## Solder, SAE 3A (Alloy Grade 30A):

_	Lead	67.6	(minimum)
_	Tin	29.5 to 31.5	
_	Antimony	0.50	
_	Bismuth	0.25	
_	Copper	0.08	
—	Arsenic	0.02	
_	Iron	0.02	
_	Silver	0.015	
_	Aluminium	0.005	
—	Zinc	0.005	
-	Cadmium	0.001	

#### Cast Iron, SAE G3500 (Alloy UNS F1007):

_	Iron	94
_	Carbon	3.0 to 3.3
_	Silicon	1.8 to 2.2
_	Manganese	0.60 to 0.90
_	Phosphorus	0.080
_	Sulfur	0.15

## Grey Cast:

-	Iron	91	(minimum)
_	Carbon	2.5 to 4.2	
_	Silicon	1.0 to 3.0	
_	Manganese	0.15 to 1.0	
_	Phosphorus	0.02 to 1.0	
_	Sulfur	0.02 to 0.25	

#### **Ductile Cast:**

_	Iron	89	(minimum)
_	Carbon	3.0 to 4.0	
_	Silicon	1.8 to 4.5	
_	Manganese	0.1 to 1.0	
_	Phosphorus	0.01 to 1.0	
_	Sulfur	0.01 to 0.03	

#### **Compacted Graphite (Vermicular):**

_	Iron	91	(minimum)
_	Carbon	2.5 to 4.0	
_	Silicon	1.5 to 3.0	
_	Manganese	0.2 to 1.0	
_	Phosphorus	0.01 to 1.0	
—	Sulfur	0.01 to 0.03	

These compositions have been sourced from the following standards:

ASM International Handbook Committee 1993, ASM Handbook, ASM International, viewed 20<sup>th</sup> Feb 2014,

http://products.asminternational.org.ezproxy.usq.edu.au/hbk/index.jsp

ASTM International 2014, *Standard Specification for electric-resistancewelded carbon and alloy steel mechanical tubing* (A513/A513M-14), ASTM International, West Conshohocken.

ASTM International 2012, *Standard Specification for pipe, steel, black and hot-dipped, zinc coated, welded and seamless* (A53/A53M-12), ASTM International, West Conshohocken.

## Appendix I Accuracy and Equipment Error

#### I.1 Class A, 50 mL Burette

Volumetric fluid measurements have been conducted using a 50 mL burette designated as "Class A" in accordance with the specifications stated in ASTM E287-02 (2012b). This burette has 0.1 mL measurement subdivisions with a volumetric tolerance of  $\pm$  0.05 mL.

In this application each volume measured can then have an expected accuracy of  $\pm 0.05$  for each measurement required to make that volume. For example a 240 mL volume would require five 50 mL units, and thus five measured volumes, which would indicate a limit for the total volume of  $\pm 0.25$  mL.

The percentage of variation for the range of nitrite concentrations are shown in Table I-1**Error! Reference source not found.** below, noting the maximum variation from the intended concentration is  $\pm 0.13$  %.

Potential Sample Concentration Ranges and Percentage of Variation								
Inten	ded Values				Extre	emes		
Concentratio	Concentrat e (mL)	Wate r (mL)	Concentrat e		Concentratio n		Variation (%)	
n (ppm)			Max	Min	Max	Min	Ma x	Mi n
500	87.7	412.3	87.8	87.6	500.6	499.4	0.13	0.13
750	131.6	368.4	131.7	131.4	750.9	749.1	0.12	0.12
1000	175.4	324.6	175.6	175.2	1001.1	998.9	0.11	0.11
1200	210.5	289.5	210.8	210.3	1201.3	1198.7	0.11	0.11
1300	228.1	271.9	228.3	227.8	1301.4	1298.6	0.11	0.11
1400	245.6	254.4	245.9	245.3	1401.5	1398.5	0.11	0.11
1500	263.2	236.8	263.4	262.9	1501.6	1498.4	0.11	0.11
1800	315.8	184.2	316.1	315.4	1801.9	1798.1	0.11	0.11
2150	377.2	122.8	377.6	376.8	2152.3	2147.7	0.11	0.11
2500	438.6	61.4	439.1	438.1	2502.6	2497.4	0.11	0.11

**Table I-1 Potential Variation Error in Volumes** 

#### I.2 Thermometer

The thermometer specified for use in the Corrosion Test for Engine Coolants in Glassware (ASTM 2012c) is to conform with the requirements for a Thermometer 1C (1F) as specified in ASTM Liquid-in-Glass Thermometers (ASTM 2013). The specifications for the 1C class thermometer detail a graduated scale of 1 °C and a subsequent maximum scale error of 0.5 °C.

As the temperature is only used for reference and has no further calculations or measurements dependent upon it, the magnitude of the error will not impact any experimentation further than a variation of  $\pm 0.5$  °C for all temperature readings.

#### I.3 Scales

The Corrosion Test for Engine Coolants in Glassware (ASTM 2012c) states that weight changes of specimens are to be reported to the nearest 1 mg. This indicates the scales to be used will require a maximum graduation in scale of 1 mg and subsequently a maximum error of 0.5 mg.

# Appendix J Risk Assessment

	Consequence						
	15	10	6	3	1	Almost Certain	expected in most circumstances (weekly)
	19	14	9	5	2	Likely	probably occur in most circumstances (monthly)
ikelihood	22	18	13	8	4	Possible	occur at some time (once a year)
	24	21	17	12	7	Unlikely	remotely possible, but not expected
	25	23	20	16	11	Rare	occur only in exceptional circumstances
	Insignificant	Minor	Significant	Major	Catastrophic		
Person	first aid treatment only	medically treated injury	impeding injury	restrictive injury	permanent disability or death		
Machine	cosmetic damage	minor damage	reduced operation	halted operation	destruction of property		

Extreme Risk	ACTION TO REDUCE THE LEVEL OF RISK IS MANDATORY: Cease work and discuss with supervisor/Manager. Action must be taken to lower the risk
High Risk	ACTION TO REDUCE THE LEVEL OF RISK IS MANDATORY: Consideration should be given to cease work. Action must be taken or controls implemented to diminish the risk.
Moderate Risk	ACTION TO DIMINISH THE RISK SHOULD BE TAKEN: Short-term action can be administrative controls to protective equipment.
Low Risk	ADMINISTRATIVE PROCEDURES OR PPE MAY CONTROL THE RISK: Controls may be applied as identified, no specific action is required.

Hazard No.	Hazards Identified	Risk Score
1	Chemical burn from skin or eye contact with hazardous chemicals	4
2	Inhalation of chemical vapours or products of chemical reaction	3
3	Chemical Spill or leak	9
4	Trips and falls	12

Hazard No	Control Measure Applied
1	Long sleeved shirts and pants must be worn at all times.
1	Chemical resistant gloves and splash proof safety glasses or goggles are to be worn when handling, or working near, hazardous chemicals.
1	When mixing solutions, the required volume water is to be poured first and the hazardous chemical is to be added to the volume of water.
1	Ensure an emergency eyewash/shower facility is operational and located near to the chemical handling area.
2	A respirator, fitted with a gas vapour filter, (compliant with AS/NZS 1715) is to be worn when handling hazardous chemicals and/or in the vicinity of chemical vapour sources.
2	Ensure chemicals are handled only in open or well ventilated areas.
3	Contain chemicals in a bunded area and replace lids immediately after use
3	Ensure a supply of neutralizing agent is readily available and chemical spill kit is located in the area
4	Apply housekeeping rules to the work environment ensuring working areas, walkways and exits are clear of obstructions

# Appendix K Hazardous Chemical List

#### Alflcoc 9518:

Sodium Metasilicate	1-5 %
Sodium Tetraborate	1-5 %
Sodium Nitrite	1-5 %
Sodium Hydroxide	0.1 – 1 %
Sodium Mecratobenzothiazole	1 – 5 %
	1

### Nalco N – 1 Reagent:

Raw, 10 – Phenanthroline	< 1 %

#### Nalco N2 Titrant:

Raw, cerium sulphate 99.5 ceric solution	10-30 %
Sulphuric acid	1-10 %

#### Fleetguard TR81160:

Sodium Metasilicate	5-9%
Sodium Borate, anhydrous	7-14 %
Sodium Nitrite	10 - 20 %
Sodium Nitrate	5 - 10 %