RECOVERY BOILER SUPERHEATER CORROSION – SOLUBILITY OF METAL OXIDES IN MOLTEN SALT

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RECOVERY BOILER SUPERHEATER CORROSION – SOLUBILITY OF METAL OXIDES IN MOLTEN SALT

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS…………………………………………………………………………………………………iii

LIST OF TABLES……………………………………………………………………………………………………vi

LIST OF FIGURES…………………………………………………………………………………………………xii

LIST OF SYMBOLS AND ABBREVIATIONS……………………………………………………………………xii

SUMMARY………………………………………………………………………………………………………...xiii

CHAPTER 1 INTRODUCTION…………………………………………………………………………………...1

CHAPTER 2 BACKGROUND……………………………………………………………………………………..4

2.1 History of Molten Salt Corrosion and Initial Theories…………………………………4

2.2 Electrochemistry in Molten Salts……………………………………………………………..5

2.3 Measuring Basicity…………………………………………………………………………………..9

2.4 Synergistic Dissolution ……………………………………………………………………….11

2.5 Diffusion Effects in Molten Salts……………………………………………………………11

2.6 Effects of Strong Acidic Oxides……………………………………………………………15

2.7 Hot Corrosion in the Paper Industry………………………………………………………18

CHAPTER 3 EXPERIMENTAL APPROACH…………………………………………………………………25

3.1 Solubility Testing of Metal Oxides in Molten Salt…………………………………….25

3.2 ICP Measurements for Metal Oxide Solubility…………………………………………29

3.3 Exposure Testing……………………………………………………………………………………30

CHAPTER 4 RESULTS……………………………………………………………………………………………..35

4.1 Solubility Results……………………………………………………………………………………35

4.2 Errors in Measuring Solubility…………………………………………………………………..39

4.3 Exposure Test Results……………………………………………………………………………….40

4.3.1 Before and After Images………………………………………………………………..40

4.3.2 Exposure Tests at 750^{o}C……………………………………………………………….44

4.3.3 Exposure Tests at 550^{o}C……………………………………………………………….59

4.4 Chemical Characterization of the Oxide Films…………………………………………61

4.4.1 XRD Results……………………………………………………………………………………..61

4.4.2 EDS Results……………………………………………………………………………………..64

4.5 Conclusions………………………………………………………………………………………………68

CHAPTER 5 OVERVIEW AND FUTURE WORK RECOMMENDATIONS……………………………..71

APPENDIX A ICP DATA…………………………………………………………………………………………..73

REFERENCES…….118

LIST OF TABLES

TABLE 1 Conditions that Occur in the Salt Film and What Type of Solubility Gradients Can Occur………………………………………………………… 12

TABLE 2 Alloys Used During Exposure Testing and Their Respective Compositions……………………………………………………………………………………..32

LIST OF FIGURES

FIGURE 1 Solubility of Alumina in fused Na_2SO_4 at 1200K and P_{O2} = 1atm……………..7

FIGURE 2 Solubility Curve of Fe_2O_3 in Fused Na_2SO_4 at 1200K and P_{O2} = 1 atm……….8

FIGURE 3 Compilation of Solubilities of Multiple Oxides in Fused Na_2SO_4 at 1200K..9

FIGURE 4 Schematic of the Precipitation of a MO Oxide Sustained by a Negative Solubility Gradient……………………………………………………………………………13

FIGURE 5 Changes in Local Basicity of a Nickel Coupon Exposed to Na_2SO_4 at 1173K the Dashed Line Indicates the Minimum NiO Solubility and Numbers Designate Hours Unless Otherwise Indicated……………………………………..15

FIGURE 6 Solubility of CeO_2 in Na_2SO_4 With and Without $NaVO_3$ Showing the Change in Solubility on the Acidic Reaction…………………………………………..17

FIGURE 7 NaCl-KCl Phase Diagram Showing a Minimum Melting Mixture……………21

FIGURE 8 NaCl-Na_2SO_4 Phase Diagram Showing a Eutectic Mixture……………………23

FIGURE 9 Top: Picture of Furnace Setup, Bottom: Schematic of Solubility Experiment Setup……………………………………………………………………………….26

FIGURE 10 Image of a Received Tube Sample Showing How the Samples Were Curved…………………………………………………………………………………………..31

FIGURE 11 Schematic of a Metal Sample in Salt with Concave Curve Facing the Bottom of the Crucible……………………………………………………………………….33

FIGURE 12 Solubility of SiO_2, Cr_2O_3, Al_2O_3, Fe_2O_3 and NiO in a Recovery Boiler Salt at 750^{o}C for 8 Hours……………………………………………………………………………….36

FIGURE 13 Solubility of Fe_2O_3, Cr_2O_3 NiO and Al_2O_3 in NaOH Over 4 day………………..36

FIGURE 14 Average Solubility of Al_2O_3 with the Addition of Other Oxides in 8 hours at 750^{o}C………………………………………………………………………………………………….38

FIGURE 15 Average Solubility of Al_2O_3 with the Addition of Other Oxides in 8 hours at 550^{o}C………………………………………………………………………………………………….39

FIGURE 16 Metal Samples Before Exposure Testing……………………………………………..41

FIGURE 17 Top Down Images of the Exposure Test Samples (1) and (2) after 24 hours at 750^{o}C……………………………………………………………………………………………..42

FIGURE 18 Bottom Images of the Exposure Test Samples (1) and (2) After 24 hours at 750^{o}C………………………………………………………………………………………………….43

FIGURE 19 Micrograph of Pure Cr Exposed to Recovery Boiler Ash for 24 Hours at 750^{o}C………………………………………………………………………………………………….44

FIGURE 20 Micrograph of Pure Iron Sample Exposed to a Recovery Boiler Ash at 750^{o}C for 24 hours……………………………………………………………………………..45

FIGURE 21 Micrograph of a Pure Nickel Sample Exposed to a Recovery Boiler Ash at 750^{o}C for 24 hours……………………………………………………………………………..46

FIGURE 22 Micrograph of Pure Manganese Exposed to a Recovery Boiler Ash at 750^oC for 24 hours……..47

FIGURE 23 Micrograph of Sanicro 28 Exposed for 24 hours at 750^oC……..49

FIGURE 24 Micrograph of 310H Exposed in a Recovery Boiler Ash for 24hours at 750^oC……..50

FIGURE 25 Micrographs of 347H Exposed in a Recovery Boiler Ash for 24 hours at 750^oC……..51

FIGURE 26 Micrograph of Esshite 1250 After Exposure to a Recovery Boiler Ash for 24 hours at 750^oC……..52

FIGURE 27 Micrograph of HR120 Exposed to a Recovery Boiler Ash for 24 hours at 750^oC……..53

FIGURE 28 Micrograph of 690 Exposed to a Recovery Boiler Ash for A) 24 hours at 750^oC……..55

FIGURE 29 Micrograph of 602CA Exposed to a Recovery Boiler Ash for A) 24 hours at 750^oC……..56

FIGURE 30 Micrograph of HR160 Exposed to a Recovery Boiler Ash for 24 hours at 750^oC……..57

FIGURE 31 Micrograph of Pre-oxidized Haynes 214 Exposed to a Recovery Boiler Ash for 24 Hours at 750^oC……..58

FIGURE 32 Optical Micrographs of (A) Sanciro28 (B) 310H (C) 347H (D) Esshite 1250 (E) HR120 (F) 690 (G) 602CA (H) HR160 and (I) Haynes 214 Exposed to a Recovery Boiler Ash for 1 Week at 550^{o}C……………………………………………61

FIGURE 33 XRD Spectrum of 310H……………………………………………………………62

FIGURE 34 XRD Spectrum of 347H……………………………………………………………62

FIGURE 35 XRD Spectrum of HR120…………………………………………………………..63

FIGURE 36 XRD Spectrum of Sanicro28……………………………………………………..63

FIGURE 37 SEM Micrograph of Esshite 1250 and EDS spectrum of the Base Metal, Oxide, and Salt……………………………………………………………………………65

FIGURE 38 SEM Micrograph of Haynes 214 and EDS spectrum of the Base Metal and Oxide…………………………………………………………………………………………65

FIGURE 39 SEM Micrograph of HR160 and EDS Spectrum of the Base Metal, Oxide, and Salt…………………………………………………………………………………66

LIST OF SYMBOLS AND ABBREVIATIONS

Fe - Iron

Cr - Chromium

Ni - Nickel

Si - Silicon

Al – Aluminum

Mn – Manganese

Na_2O – Sodium Oxide

K_2O – Potassium Oxide

NaCl - Sodium Chloride

KCl - Potassium Chloride

Na_2CO_3 - Sodium Carbonate

Na_2SO_4 - Sodium Sulphate

K_2SO_4 - Potassium Sulphate

g - Gram

µg – Microgram

mm - Millimeter

ICP-OES - Inductively Coupled Plasma Optical Emission Spectroscopy

XRD – X-Ray Diffraction

SEM - Scanning Electron Microscope

EDS – Energy Dispersive Spectroscopy

Summary

The recovery boiler in the pulp in paper industry is used to consume waste black liquor and convert it into steam and recoverable chemicals. The steam is used for drying, chemical processes, and can be used to generate electricity. Increasing the steam temperature will increase the efficiency of the boiler and allows the boiler to produce more energy. However, compared to similar coal fired plants or turbine engines, the recovery boiler or any biomass reactor is inefficient. The limit to the current steam temperature is limited due to molten salt corrosion on the superheater tubes.

The solubility of the protective metal oxide the alloy creates determines the alloy's resistance to molten salt corrosion. By finding a metal oxide with a low solubility alloys can be created to have superior corrosion resistance. Changes in solubility within the salt are very important because it can create a positive or negative solubility gradient. A negative solubility gradient should be avoided because it creates an out of control reaction with a very high corrosion rate.

This work looks at a salt composition from the Covington Virginia recovery boiler and determines the solubility of five metal oxides at 750^{p}C. NiO was found to be the least soluble followed by Fe_2O_3, Cr_2O_3, Al_2O_3, and SiO_2 where Cr_2O_3 and Al_2O_3 had similar solubility. Exposure tests were performed to verify the performance of pure elements and commercial alloys. Of the pure elements tested, manganese and iron were the most

corroded while chromium and nickel were the least corroded. The high corrosion rate of pure iron indicated that a negative solubility gradient is present in iron.

The commercial alloys were a mixture of nickel based alloys and stainless steels. The nickel alloys performed better than the stainless steels likely due to the formation of protective NiO, Cr_2O_3, or Al_2O_3. The stainless steels were heavily corroded and many samples were lost even after one day of testing. The stainless steels performed poorer than pure iron indicating synergistic reactions between iron and another element. Esshite 1250 was the best performing steel because it had the least amount of alloying elements. All of the stainless steels had negative solubility gradients but less alloying in Esshite 1250 reduced the effects of synergistic reactions. Overall, the best alloys were high nickel, high chromium, low iron alloys where nickel provides molten salt resistance and chromium reduces sulphidation.

CHAPTER 1

INTRODUCTION

1.1 Motivation for Research

A major concern for any modern country is generating enough energy to meet the needs of society and industry. Currently, a major portion of the energy produced in the United States is derived from fossil fuels. Fossil fuels are used because they are relatively cheap and provide considerable energy density. However, fossil fuels are non-renewable and they will eventually run out. Another issue with fossil fuels particularly oil is that oil imports for the United States can come from unstable regions like the Middle East. By converting from fossil fuels to renewable biomass like wood, energy can be supplied and simultaneously the complications of fossil fuels like uncertain supply can be avoided.

The disadvantage of biologically derived fuel is two-fold. Biomass contains lower energy density than similar fossil fuels meaning more material needs to be burned to generate the same amount of energy. At the same time, the ash that evolves from burning biomass tends to be much more corrosive than fossil fuels. In particular, the melting point of the ash from biofuels is much lower than for fossil fuels due to higher concentrations of chlorine. Additionally, biofuels can contain significant amounts of sulphur which can further increase corrosion. Other types of boilers are industrial boilers in the chemical process industry which makes energy out of waste by-products. As a result, biomass reactors such as the recovery boiler in the pulp and paper industry are run at a much lower temperature and therefore a lower inherent efficiency than a similar coal fired power plant. Finding resilient protective oxides and alloys that can withstand these more corrosive environments are a step towards increasing the firing temperature of biomass reactors and improving their inherent efficiency.

1.2 Research Objectives and Technical Approach

The goal of this work is to determine the corrosion mechanisms that are at work in a molten hardwood derived recovery boiler ash and to determine the metal oxides that are most protective in this environment. Specifically the following were studied:

1) The solubility of Fe_2O_3, NiO, Cr_2O_3, Al_2O_3, and SiO_2 in the given recovery boiler salt. Solubility tests were done because it gives a measure of thermodynamic stability in molten salt conditions where less soluble is more protective.
2) Perform pure metal and alloy exposure tests to verify solubility test results and to determine the corrosion kinetic mechanisms of the metal oxides. The kinetics are important because they show any changes in solubility of metal oxide in the molten salt system.
3) The corrosion products were characterized using EDS and XRD to verify what metal oxides are present in the scale.

From this work, the behavior of metal oxides can be evaluated and the most protective oxide or alloy can be determined.

CHAPTER 2

BACKGROUND

2.1 History of Molten Salt Corrosion and Initial Theories

Molten salt corrosion of metals is a relatively recent phenomenon that was first discovered in the 1940's. The initial instances of molten salt corrosion were observed on boiler vessels and were attributed to a slag of sodium or potassium sulphate [1]. It was not until the 1960's that molten salt corrosion was experienced in the gas turbine industry. The evidence was an unexplained, rapid increase in corrosion. It was initially believed to be a sulfidation reaction due to observed sulphides during microscopic examination. The theory was that the metal was sulphidized first and became more easily oxidized. This was a popular theory until it was shown that a pre-sulphidized metal was not more corrosion prone when left in an oxidizing environment [2]. The increased corrosion rate was also reproduced in $NaNO_3$ and Na_2CO_3 melts, [3] which are independent of sulfidation effects, and thereby proved that any reactions were with the oxide film and metal underneath it. It was later demonstrated that a thin film of molten sodium sulphate had formed on the metal and exacerbated the corrosion rate [4]. The sodium sulphate had formed by a combination of sulphur impurities in the jet fuel and aerosolized sodium salts from the air. The need for sodium explained the prevalence of salt corrosion around marine environments [5]. An important note is that the increased corrosion rate only appeared in the presence of condensed sodium sulphate rather than in a gaseous phase [3].

2.2 Electrochemistry in Molten Salts

One of the major results from the initial studies on molten salt corrosion is the effect of Na_2O. Oxyanion melts of common alkali salts can exhibit acid/base behavior similar to water [6]. Na_2SO_4 can then be described as an equilibrium between an acid (SO_3) and a base (Na_2O) with some equilibrium constant K at a given temperature. The activity of Na_2O is dependent on the partial pressure of the conjugate acid and the given equilibrium constant at the known temperature.

$$Na_2SO_4 = Na_2O + SO_{3(g)}$$

$$\log a_{Na2O} + \log P_{SO3} = K_{\text{equilibrium at given T}}$$

The result is that any corrosion reactions in the molten salt are electrochemical in nature and are controlled by Na_2O activity and the partial pressure of the conjugate acid.

Most oxides are amphoteric and can have either a basic or acidic reaction depending on the Na_2O activity. Increasing or decreasing the Na_2O activity will change the equilibrium conditions and more or less of the oxide will react. The solubility or amount of oxide that will dissolve in the salt is dependent on the Na_2O activity and the oxides acid/base reaction. Figure 1 shows a typical plot of a simple amphoteric metal oxide. A solubility minimum will occur when the acidic and basic curves meet. Nonamphoteric oxides will not exhibit acid/base reactions but can still react with the salt and dissolve. For oxides that are multivalent (e.g. Fe, Cr) the valence of the metal ion can change with basicity [7]. Higher valence states are more stable in basic salts while lower valence states are more stable in acidic salts. For iron in a molten salt, Fe^{3+} is stable in a basic salt while Fe^{2+} is stable in an acidic melt. A change in valence will be shown as a change in the solubility slope and will not necessarily occur at the minimum solubility point. Figure 2 shows the solubility graph of Fe_2O_3 which has a change in oxidation state. An acidic reaction is typically given as:

$M_xO_Y = X\ M^{Y+} + YO^{2-}$ where M = metal, O= oxygen

A basic reaction can be written as:

$M_xO_y + Z\ O^{2-} = X\ MO_A^{p-}$

An acidic reaction for NiO in Na_2SO_4 can then be written as: [8]

$NiO + Na_2SO_4 = NiSO_4 + Na_2O$

While the basic reaction is given as:

$2NiO + Na_2O + \frac{1}{2} O_2 = 2NaNiO_2$

The solubilities of multiple oxides in a given salt can be graphed together to get a graph as in Figure 3. Figure 3 shows the solubility curves of multiple metal oxides in Na_2SO_4. Every oxide will have a different reaction to a particular salt both in location of the minimum solubility limit and the slopes of the acid/base reactions. One oxide may be more protective than another due to the system's basicity and therefore an oxide like Cr_2O_3 can be less protective than an oxide that is typically considered inferior like Fe_2O_3.

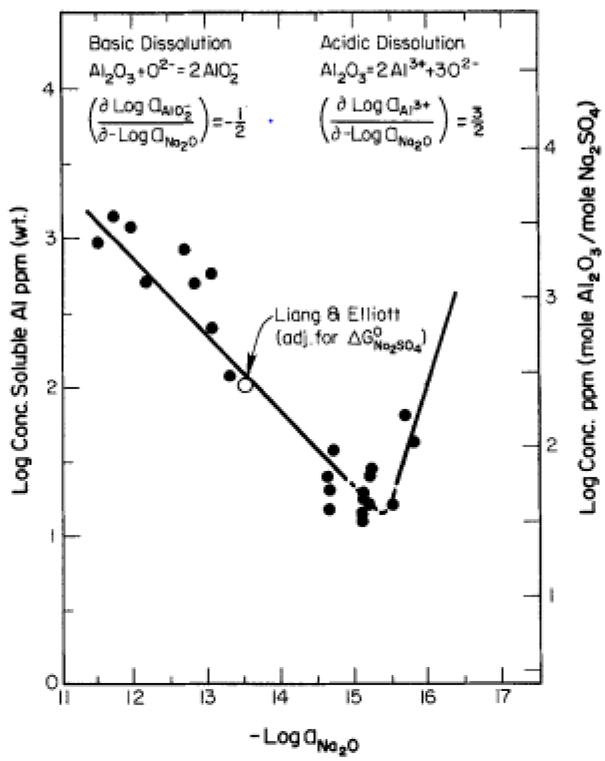


Figure 1 Solubility of Alumina in fused Na_2SO_4 at 1200K and P_{O2} = 1atm [9]

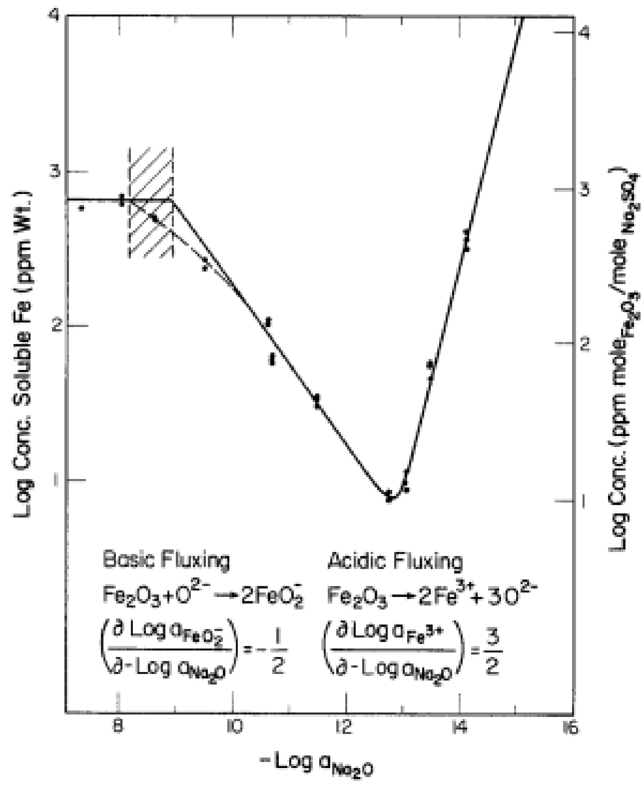


Figure 2 Solubility Curve of Fe_2O_3 in Fused Na_2SO_4 at 1200K and P_{O2} = 1 atm [10]

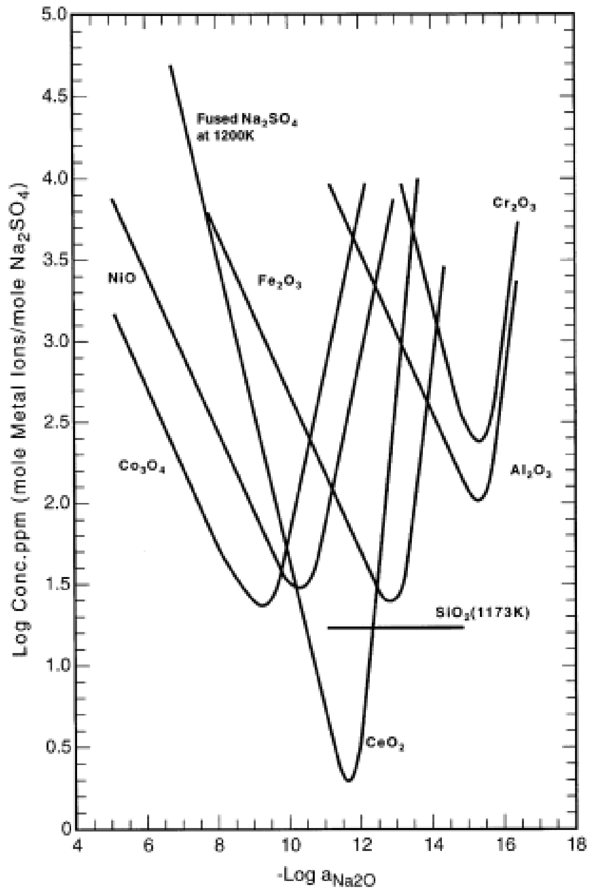


Figure 3 Compilation of Solubilities of Multiple Oxides in Fused Na_2SO_4 at 1200K [8]

2.3 Measuring Basicity

Basicity is a measure of Na_2O concentration in a given sodium based salt. Na_2O concentration can be evaluated electrochemically using oxygen and sodium electrodes. A typical oxygen electrode is an yttrium stabilized zirconium tube connected to a metal wire. A sodium electrode can be made of any number of materials. Mullite or doped β-alumina tubes can be used. A concentration gradient is used to generate a potential for these electrodes. The oxygen electrode is exposed to the atmosphere and the sodium electrode contains an amount of encapsulated sodium metal. The overall electrode reaction is given as:

Na | β-alumia | Na based salt | ZrO_2-Y_2O_2 | O_2(air)

The relationship between concentration and potential is described by the Nernst equation:

$$\varepsilon = \varepsilon^{o} - \frac{RT}{zF} lna$$

Where ε is the potential, ε^{o} is the potential under standard state of the reaction, R is the gas constant, T is temperature, z is moles of participating electrons, F is Faraday's constant, and a is the reaction coefficient. ln a = $\frac{\ln reactants}{\ln products}$. Substituting in the Na_2O reaction into the Nernst equation gives:

$$\varepsilon = \varepsilon^{o} - \frac{RT}{2F} lna_{(Na_2O)} + \frac{RT}{F} lna_{(Na)} + \frac{RT}{4F} lnp_{(O_2)} [11]$$

Because sodium is a pure element, $a_{(Na)} = 1$, the equation can be simplified further to:

$$\varepsilon = \varepsilon^{o} - \frac{RT}{2F} lna_{(Na_2O)} + \frac{RT}{4F} lnp_{(O_2)}$$

The potential at standard state ε^{o} is known experimentally by measuring potential in the electrodes with increasing concentration of Na_2O. By plotting the relationship between concentration and potential, the relationship can be extrapolated to a concentration of 0, giving the value of ε^{o}.

2.4 Synergistic Dissolution

The solubility of an oxide can be dependent on the influence of other oxides in the system. A synergistic dissolution can occur when two oxides are present and the basicity lies between the two oxide solubility curves [12]. One oxide will undergo acidic dissolution while the other will undergo a basic dissolution. From the reactions given above, one reaction will consume Na_2O while the other will create it. Since a rate limiting reagent is supplied or consumed by the reactions, the reaction can take place quicker than if only one oxide was present.

2.5 Diffusion Effects in Molten Salts

The conditions for molten salt corrosion are not just limited to the oxide salt interface but can be controlled by conditions within salt. The basicity can vary between the metal surface and the outside of the salt film depending on the concentrations of the conjugate acid/base. It is unlikely that solubility remains the same in the salt film and the oxide solubility can either increase (positive) or decrease (negative). [13]

A positive solubility gradient will have an increase of solubility away from the oxide surface. If the solubility increases as the ions diffuse, the ions will remain in solution. Then after some time, the ions will completely saturate the salt film and the dissolution reaction will reach equilibrium. Unless the metal is removed from solution, the reaction rate is reduced and the corrosion rate becomes limited. From a corrosion prevention standpoint, a positive solubility gradient is desirable. This effect affects more so if the salt film is undisturbed.

A negative solubility gradient has a decrease in solubility away from the oxide surface. As ions diffuse away from the oxide surface, the solubility will drop and the ions will precipitate out of solution. Any precipitated oxide is diffuse or porous and will give no protection against corrosion. Unlike a positive solubility gradient, a negative solubility gradient will not reach equilibrium and will increase the corrosion rate. Figure 4 shows a schematic of a negative solubility gradient. A negative solubility gradient then is an explanation of catastrophic corrosion even when the solubility of an oxide is limited.

The type of solubility gradient is dependent on the type of dissolution reaction and the change in basicity across the salt film. Table 1 gives the different combinations of conditions and what type of solubility gradient develops.

Table 1 Conditions that Occur in the Salt Film and What Type of Solubility Gradients can Occur [8]

Dissolution	Oxide/salt interface	Salt/gas interface	Gradient
Basic	High O^{2-}	Low O^{2-}	Negative
Basic	Low O^{2-}	High O^{2-}	Positive
Acidic	High O^{2-}	Low O^{2-}	Positive
Acidic	Low O^{2-}	High O^{2-}	Negative

From Table 1 there are two conditions that create a negative solubility gradient. The first is a basic reaction where the basicity decreases across the film and the second is an acidic reaction where the basicity increases across the film. Otherwise, the solubility gradient is positive.

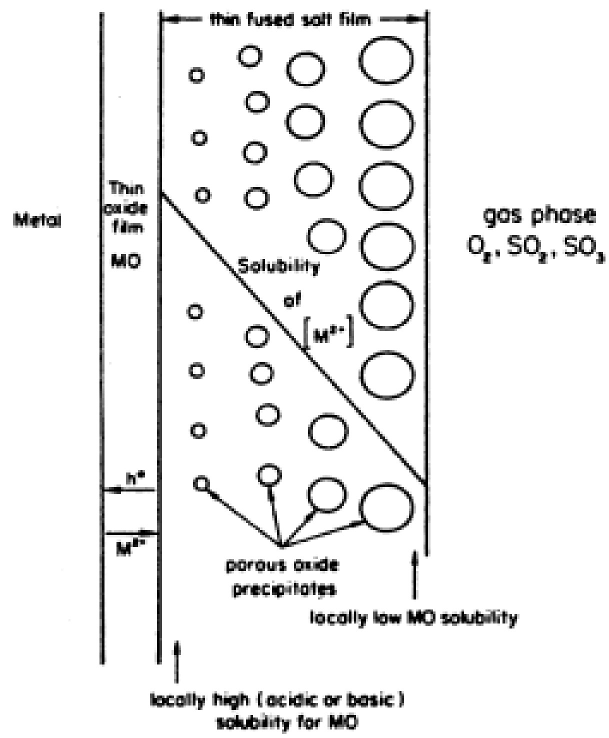


Figure 4 Schematic of the Precipitation of a MO Oxide Sustained by a Negative Solubility Gradient [13]

The conditions for a positive or negative solubility gradient are more controlled by the conditions in the salt rather than the conditions determined by the atmosphere. Otsuka and Rapp demonstrated that NiO can create a negative solubility gradient in conditions that promote a positive gradient.[14] Figure 5 shows the change in basicity with time for NiO as it switches from a positive to a negative solubility gradient. The reasoning for this is that in an acidic reaction for NiO will release Na_2O, change the basicity and make the system more basic. If the SO_3 from the environment cannot counterbalance the basicity change, then the conditions at the oxide/salt interface will be for a negative solubility gradient.

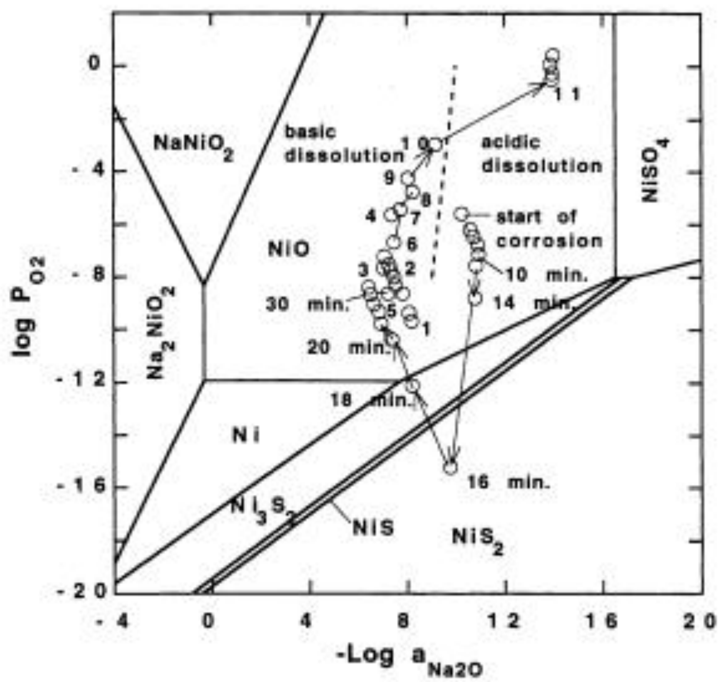


Figure 5 Changes in Local Basicity of a Nickel Coupon Exposed to Na_2SO_4 at 1173K the Dashed Line Indicates the Minimum NiO Solubility and Numbers Designate Hours Unless Otherwise Indicated [14]

2.6 Effects of Strong Acidic Oxides

Once chromium forms a film of oxide it is not necessarily finished oxidizing. Trivalent chromium can oxidize further into hexavalent chromium and form chromates. Similarly, other metals like vanadium, molybdenum, and titanium can form complex oxide ions such as vanadate or chromate. These complex oxide ions can react in the salt and affect solubility. Several of these elements are protective like chromium while others are detrimental like vanadium. The difference between them is how their respective complex ions react. Zhang and Rapp performed a solubility experiment where

CeO_2 was reacted in pure Na_2SO_4 and Na_2SO_4 + $NaVO_3$. The addition of the $NaVO_3$ increased the solubility of the oxide and made the solubility minimum become more basic. [15] Figure 6 shows the differences in solubility between the two conditions. The reason for the change in solubility is that the $NaVO_3$ was undergoing an acidic reaction with the CeO_2 to form orthovanadate and produce Na_2O. The reaction was determined to be the following:

$$3\ CeO_2 + NaVO_3 = Na_2O + Ce_3(VO_4)_4$$

This reaction was found to be general for all complex ion reactions and only occurs in acidic conditions.[16-18] Because the basic conditions do not support this reaction, only the acidic solubility curve increases solubility and the intersection between the two reactions becomes more basic.

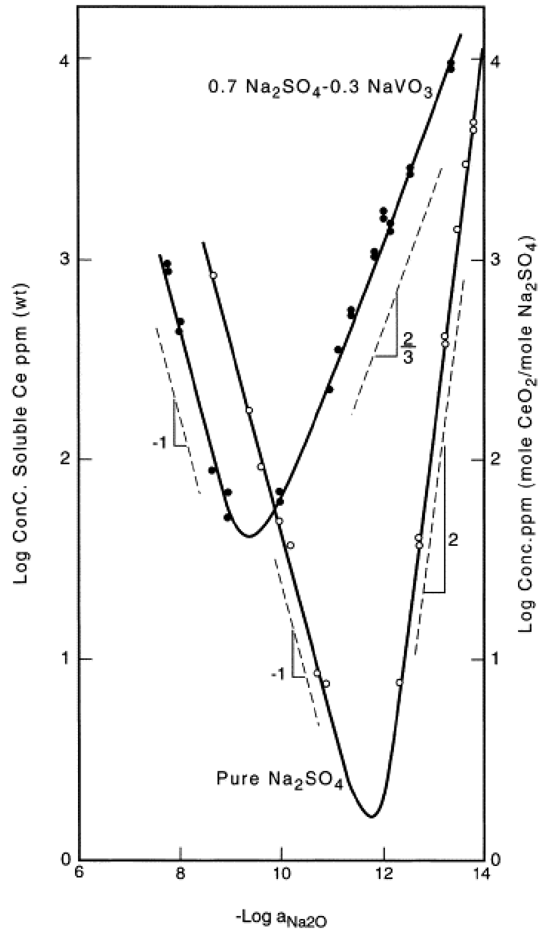


Figure 6 Solubility of CeO_2 in Na_2SO_4 With and Without $NaVO_3$ Showing the Change in Solubility on the Acidic Reaction [15]

The metal oxides that form complex ions have high vapor pressures and will form diffusion gradients similar to a negative solubility gradient as they evaporate from the salt. Despite the effects of complex ions, chromium is considered a beneficial element because it can undergo additional reactions. [19] The oxidation of trivalent to hexavalent chromium is given as:

$Cr_2O_3 + Na_2O + 3/2\ O_2 = Na_2Cr_2O_7$

This reaction is dependent on the partial pressure of oxygen and the salt is more reducing at the salt/oxide interface. Chromate ion will then experience a positive solubility gradient instead of a negative one.

2.7 Hot Corrosion in the Paper Industry

A paper mill's recovery boiler is used to convert black liquor into smelt, which is dissolved in water to become green liquor and to turn the heat of black liquor combustion into steam. The steam can be used for many purposes in the plant including paper drying and power production. A recovery boiler is unique in that there are several areas in the boiler that undergo molten salt corrosion with each salt occurring at a different temperature with a different composition. Two of the locations occur in the lower furnace and two are in the upper furnace. The first location is at the bottom of the furnace with the molten smelt. The smelt is in a reducing environment and is where the combustion products Na_2SO_4 and Na_2CO_3 are converted to Na_2S and NaOH. Since the smelt is required to continue the Kraft cycle, it is neither possible to remove the smelt, nor change its chemistry to make it less corrosive. The boiler is typically lined with metal and not oxide ceramic due to construction limitations, although some boilers do use ceramic liners to protect the boiler bottom. The best protection from corrosion in this area is to allow the smelt around the sides of the furnace to freeze on the metal surface and make a protective barrier against molten smelt. [20] The frozen smelt is still corrosive but not as much as if it was liquid.

Another location in the recovery boiler that experiences molten salt corrosion is in the air ports. The salt that develops is a NaOH condensation from a backflow of air from the furnace into the air-port. [11] The difficulty with corrosion in this region is that it is difficult to obtain samples from the lower regions of the boiler and there are significant temperature fluctuations that allow for many other salts to exist in the melt. Lastly, NaOH can decompose after sampling to form Na_2CO_3 which limits the accuracy of chemical tests. Also because of the oxygenated air moving through the port, the conditions are oxidative rather than reductive even though the air ports are in the lower furnace.

A third location for molten salt corrosion is in the cooler regions of the upper furnace. At around 250^{o}C acidic sulphates can form that have a low enough melting point to be liquid in these regions. [21] The main component for this type of corrosion is $NaHSO_4$ which is an acidic form of hydrated Na_2SO_4. The major issue with this salt is that it is sticky and will adhere tightly with anything that it settles on.

The last location in the recovery boiler which this study will concentrate at is in the superheater. The superheater is in a difficult position because this part of the boiler needs to be efficient to produce steam. The superheater then needs to be both hot and have limited amounts of fly ash deposits at the surface of the tubes. [20] Steps are taken to prevent deposits from forming like soot blowers and screens but inevitably some ash will land on the superheater tubes. If the ash is solid, it will be fairly loose and can be readily removed but if it is molten, any ash will adhere tightly to the tubes. Hot corrosion in the superheater is more important than the others because it has a direct effect on operations and efficiency of the recovery boiler.

Fuel considerations are important for any combustion type power plant. Different types of fuel can give different amounts of energy per unit mass and will have varying amounts and types of impurities. Energy mass is an important factor because it determines the fuel efficiency of the plant but the impurities can lead to unexpected or unwanted corrosion issues. Biomass boilers, like the recovery boiler in a paper mill, utilize an inferior fuel than a coal burning power plant. Black liquor inherently contains less combustible material than coal but contains large amounts of more harmful chemicals. Currently, a biomass reactor is typically limited to around 500^{o}C steam temperature [22] while a supercritical coal fired plant can reach nearly 600^{o}C. At the current temperature limitations for each plant, they are below or almost at the first melting point of their respective ash deposits. [23] The ash of both systems is Na_2SO_4 based but the other components of the ash is different. Black liquor ash contains significant amounts of chlorides, carbonates, and potassium based salts while the only additional salt for coal is $CaSO_4$. The additional impurities, especially chlorides, have a great effect on the first melting point of the ash deposit.

The phase diagrams for alkali salts have a few general rules that determine their melting behaviors. For salt mixtures two types of mixing are common: minimum-melting and eutectic. Minimum-melting occurs when the components are similar to each other. They have the same charge the difference between their anions or cations is relatively small (<30%). [24] The two salts must also have a similar crystallographic structure. If these conditions are met, the components of each salt can readily substitute for each other in the lattice. The system NaCl-KCl forms a minimum-melting mixture and Figure 7 gives an example of the phase diagram. Minimum melting is important because the melting point changes gradually with an increase or decrease in a particular salt. For instance, if NaCl is the major ash with a KCl impurity, then reducing the KCl amount will increase the melting point and allow the boiler to reach a higher steam temperature.

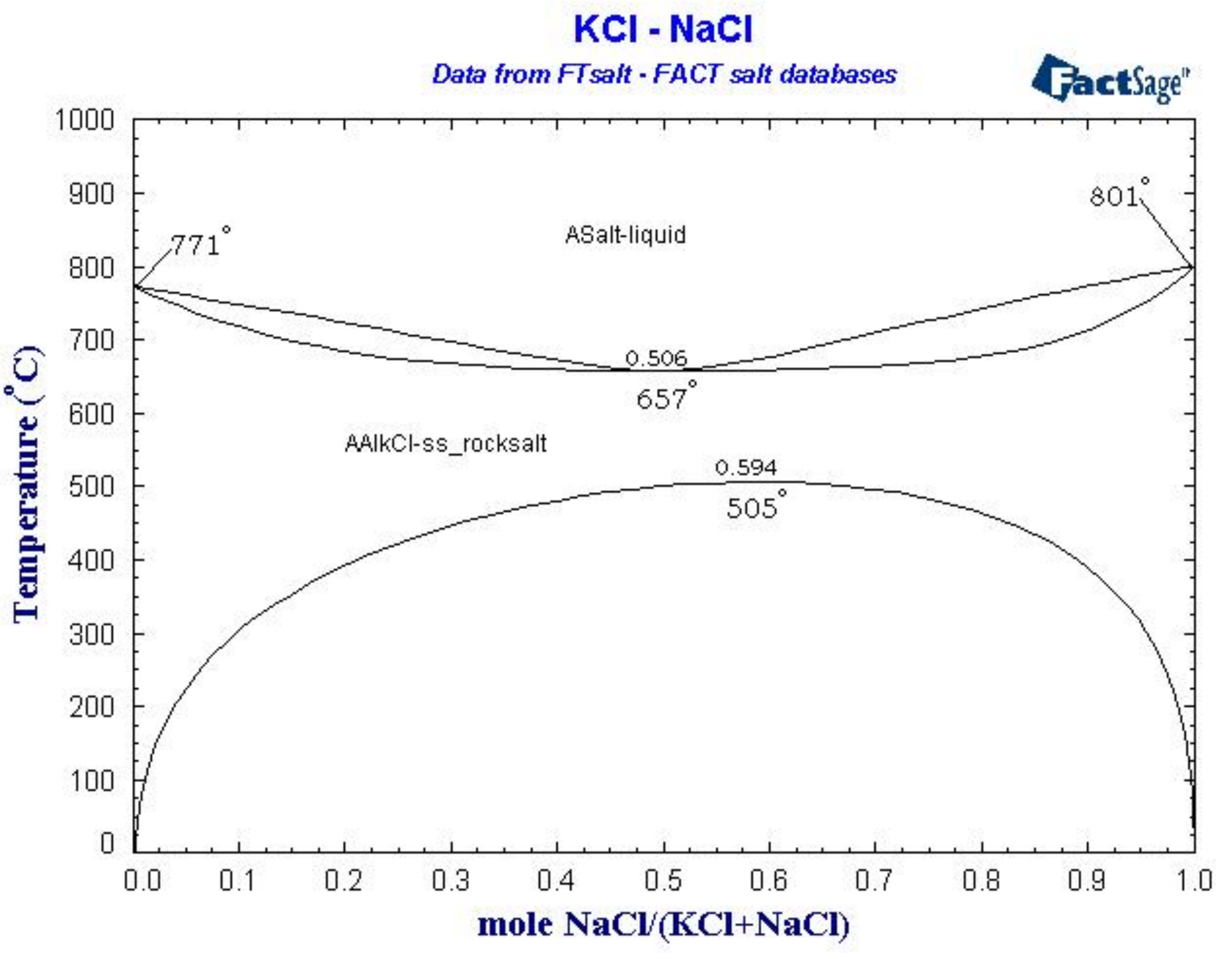


Figure 7 NaCl-KCl Phase Diagram Showing a Minimum Melting Mixture.

Eutectic systems are formed when the salts do not want to mix in solid state. This behavior occurs when the valences of the anions or cations are different, the size difference between the anions or cations is too large, or if the crystal structure for the two salts is different. An example of a eutectic mixture is $NaCl$-Na_2SO_4. Figure 8 shows an example of the eutectic phase diagram. A eutectic system will have a region where the first melting point is fixed for a range of compositions, given by the eutectic isotherm. However, complete melting (given by the liquidus line) of this mixture strongly depends on the composition. Between the eutectic isotherm and the liquidus, the only change with compositions for this situation is the amount of liquid that is formed. Eutectic mixtures will have a larger change in melting point compared to a minimum-melting mixture but that first melting point is inflexible for a range of compositions.

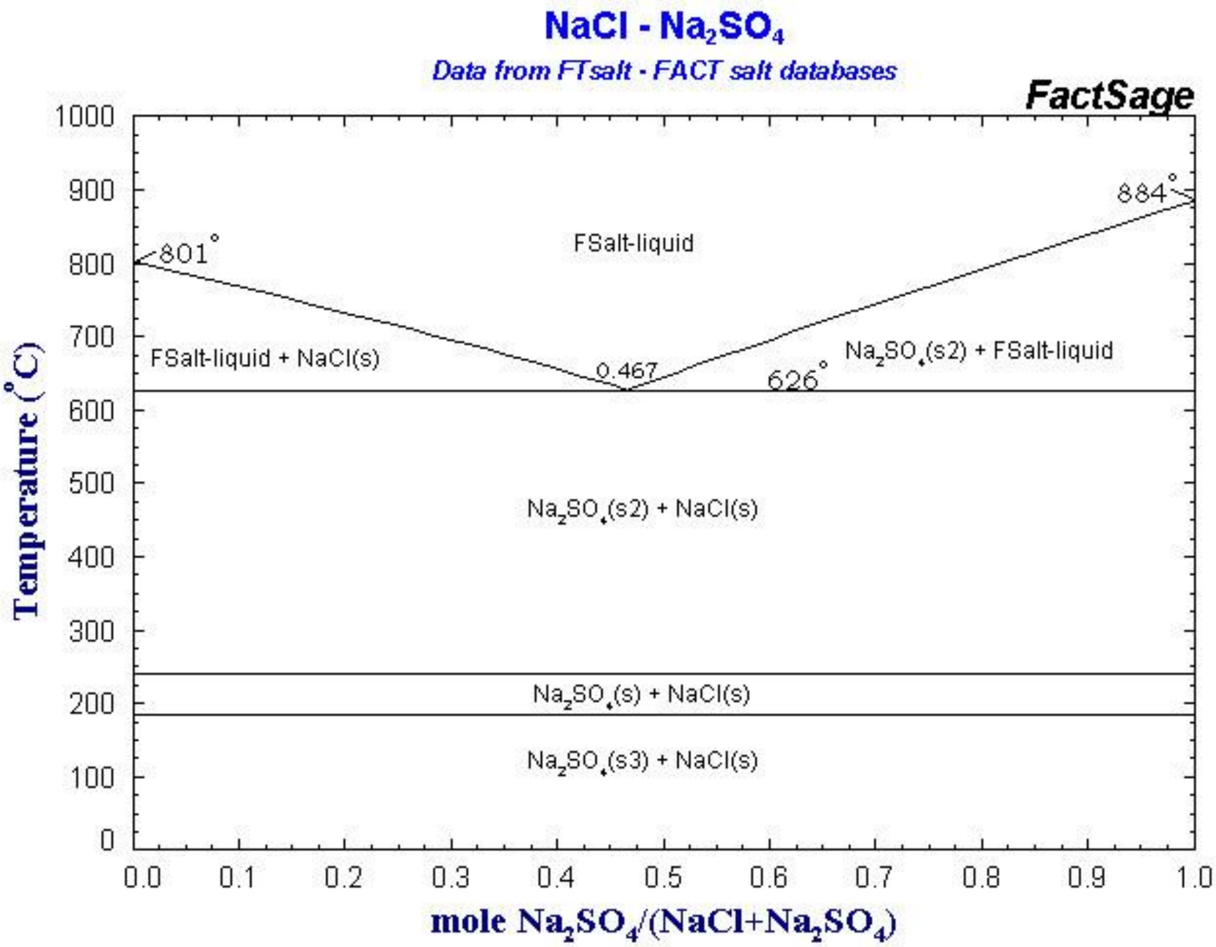


Figure 8 NaCl-Na_2SO_4 Phase Diagram Showing a Eutectic Mixture

Black liquor ash contains mostly Na_2SO_4 with significant amounts of potassium salts, chlorides, and carbonates. Chlorides will form eutectics with Na_2SO_4 and are an obvious source of concern. Once within the eutectic region, the change in melting point compared to pure Na_2SO_4 is about 260^{o}C. The advantage of being in the eutectic region is that only large variations in chlorides can affect the melting point. Removing chlorides from the black liquor is impractical but once they are in the system, chloride fluctuations are inconsequential. Potassium and carbonates form minimum-melting mixtures with Na_2SO_4. Their additions will not affect the first melting point as much as chlorides but the melting point will change proportionally to the amount of salt. The implication of this is that if the boiler is running very close to the first melting point then small variations in potassium or carbonate composition can cause the salt to melt unexpectedly.

CHAPTER 3

EXPERIMENTAL APPROACH

3.1 Solubility Testing of Metal Oxides in Molten Salt

The solubility of different oxides in salt mixtures was determined from solubility tests where a known amount of metal oxide was added to a known amount of salt. Figure 9 is an image and schematic of the solubility setup. Two alumina crucibles were used: an inner crucible to hold the salt, and an outer crucible to encapsulate the inner crucible and provide a seal for the apparatus. Sand was used in between the crucibles to make an even surface and to soak up any salt in case the inner crucible leaked. An aluminum top plate was used to hold fittings for gas and a ball valve for sampling. The seal was created by bolting the top plate to the outer crucible. A Viton gasket was used to improve the seal however if the gasket became too hot, it would warp and crack to the point it could not be used further. Under conditions where the gasket would become too hot, the gasket was removed. Ultra-high purity nitrogen was flowed into the crucible to fix the atmosphere.

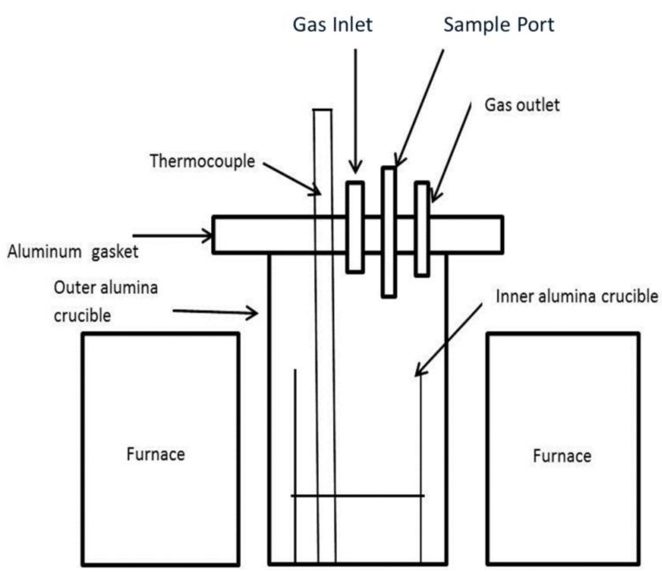


Figure 9 Top: Picture of Furnace Setup, Bottom: Schematic of Solubility Experiment Setup

200g of salt mixture was used in each solubility test and the salt mixture was heated to the test temperature and held for several days to equilibrate with the atmosphere before adding in the metal oxide. 1g of metal oxide was typically used and if the salt mixtures remained molten. The oxide would settle to the bottom of the crucible within an hour. To determine the amount of oxides dissolved in molten salt mixture, samples of molten salt were carefully removed. Sampling was done with an alumina rod dipped approximately 1cm above the bottom of the crucible. The rod was removed quickly after insertion to that some salt would remain on the rod. The salt was allowed to cool and then was dissolved into a known mass of water. Efforts were made to ensure that only dissolved metal oxide was sampled and no particles of metal oxide were in the samples salt. For that the salt was not mixed during testing to prevent bringing up oxide particles from the bottom of the crucible. Testing in NaOH required the salt to be dissolved quickly after testing due to its hydroscopic nature as the added mass may affect measurements and this precaution was also taken with the recovery boiler salts.

The temperature selected for the solubility tests was 500^{O}C for NaOH and 750^{o} for the recovery boiler salts. The temperatures were more than 200^{o}C higher than the reported melting temperatures of each salt or mixture. The increased temperature allowed the tests to be performed quickly and with fewer errors. Increasing the temperature increased the time to saturation for each test. This is important for the NaOH test because increasing the temperature from 350^{o}C to 500^{o}C, decreased the time to saturation from nearly a month to several days (matt estes' dissertation). The increased temperature helped to ensure that the recovery boiler salt was completely molten. Near the eutectic point, slight variations in composition can dramatically change the liquidus temperature and also which solid-liquid 2-phase field the salt resides in. If the salt is completely molten, local variations due to poor mixing of the salt are reduced. Sampling becomes easier with a completely molten salt because it prevents errors associated with picking up either the solid metal oxide or solid salt. The final reason for increasing the salt temperature is because adding a solid metal oxide tends to solidify the melt. The recovery boiler salt would solidify at 700^{o}C with only 1g of oxide in 200g of salt. Increasing the test temperature to 750^{o}C was sufficient to allow the mixture to completely melt. Decreasing the amount of oxide in the salt would help to decrease the effects of solidification but to ensure saturation; a balance needs to be found.

Five metal oxides were chosen for solubility testing. Fe_2O_3, Cr_2O_3, and NiO were chosen, because these metals are the typical alloying elements and protective oxides that form in stainless steels and nickel alloys. Al_2O_3 and SiO_2 were chosen for two reasons, first as newer alloys with higher Al or higher Si (also known as alumina formers or silica formers) have been selected for a number of high temperature applications; secondly Al and Si are the major elements in the crucibles that were used in this study. As the salt reacts with the added metal oxide, the salt can also react with and dissolve the crucible. Evaluating for these refractory oxides allowed for evaluation of any synergistic reaction and to see if they are protective compared to the other metal oxides.

3.2 ICP Measurements for Metal Oxide Solubility

Inductively coupled plasma optical emission spectroscopy (ICP-OES) was used to measure the concentration of dissolved oxide. The particular ICP-OES used as a Perkin Elmer Optima 3000. ICP-OES uses Ar plasma to break apart inorganic compounds and emit characteristic UV radiation. The major downsides to ICP-OES are that the sample needs to be dissolved in acid and must be inorganic. Solids or organic compounds will stop the plasma and prevent sampling. Elements like H, O, and Ar cannot be evaluated because they are introduced in the torch or are a part of the solution matrix. Despite the disadvantages, ICP-OES is virtually free of matrix effects and the relationship between concentration and signal intensity is linear for approximately 6 orders of magnitude. Calibrations can be performed using 2 standards including a blank solution at minimum. The range of sensitivity in an ICP-OES is dependent on the particular element but part per million to parts per billion sensitivity can be expected. All elements are evaluated in parallel and the number of elements sampled is irrelevant except when the peaks intersect. The standards used were a blank solution, a 1ppm standard, a 5ppm standard, and a 10ppm standard with a 20ppm standard solution to check the calibration every 9 samples. The elements: Al, Fe, Ni, Cr, and Si were all calibrated and evaluated together to make the standards simpler. For the most part, the additional elements did not affect the results except when Al from the crucible was found in the salt. The wavelengths for each element are: Fe-259.939nm, Cr-267.716nm, Ni-231.604nm, Al-396.153nm and Si-251.611nm. The wavelength of Al was chosen even though it is not the primary wavelength of 308.215 nm because it provided a higher intensity and therefore a more reliable measurement.

3.3 Exposure Testing

The exposure tests were done using similar conditions to the solubility tests for the recovery boiler salt. Two tests were performed at different temperatures. The first temperature was at the solubility test temperature of 750^{o}C and the other test was done at 550^{o}C. These temperatures were chosen to allow for evaluation of the solubility test and for a more practical temperature. The tests evaluated 3 pure metals: Fe, Ni and Cr as well as 9 commercial alloys. The commercial alloys were a mix of austenitic stainless steels and nickel alloys. Table 1 gives the names and nominal compositions of the commercial alloys. The samples were cut from tubes and were curved, as shown in Figure 10. Each sample was placed into a 4” tall 3” diameter crucible and covered with salt. Figure 11 shows a schematic of how the samples were placed concave down in the crucible. The samples were tested for 24 hours at temperature at 750^{o}C or for 1 week at 550^{o}C. Nitrogen gas was used to fix the atmosphere during the tests. After the test, the samples were removed from the crucibles and photographed verify any changes.

Figure 10 Image of a Received Tube Sample Showing How the Samples Were Curved

Table 1 Alloys Used During Exposure Testing and Their Respective Compositions

Alloy	Fe	Ni	Cr	Mn	Al	Co	Mo	C
347H	Bal	9-13	17-19	2	N/A	N/A	N/A	0.08
310H	Bal	19-22	24-16	2	N/A	N/A	N/A	0.04-0.1
Esshite 1250	Bal	9.5	15	6.3	N/A	N/A	1	0.1
Sanicro28	Bal	31	27	2	N/A	N/A	3.5	0.02
HR120	33	37	25	0.7	0.1	N/A	2.5	0.05
HR160	2	37	28	0.5	N/A	29	1	0.005
Haynes 214	3	Bal	16	0.5	4.5	N/A	N/A	0.05
690	11	Bal	27-31	0.5	N/A	0.5	N/A	0.05
602CA	8-11	Bal	24-26	0.15	1.8-2.4	N/A	N/A	0.2

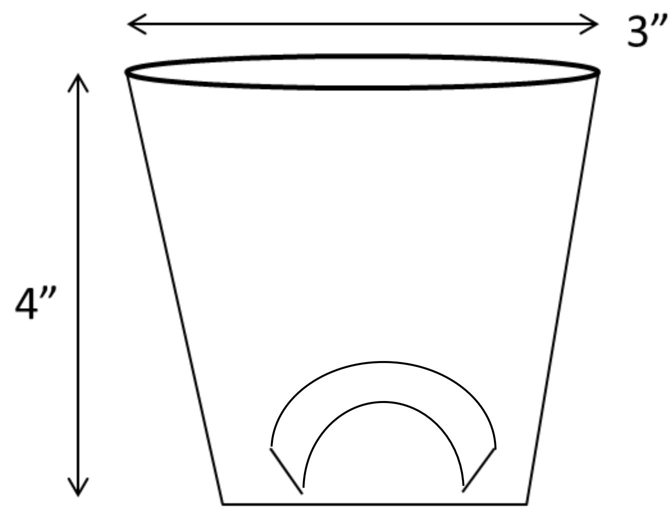


Figure 11 Schematic of a Metal Sample in Salt with Concave Curve Facing the Bottom of the Crucible

Thickness measurements were taken before and after the test to verify the corrosion rate. The samples were cut without water using a high speed saw. The salt was not removed from the samples to preserve the salt and oxide films however when the metal gauge was measured with calipers, the salt was removed. Samples with large amounts of oxidation were measured under the microscope to evaluate the remaining metal thickness directly. Samples that showed little corrosion were measured with calipers. Calipers were used instead of a microscope to prevent apparent changes in thickness due to imprecise cutting.

The oxides were characterized using XRD and EDS. XRD was used on the samples with large amounts of oxide to evaluate the entire oxide instead of a small portion of it.

XRD was also used to determine phases and compositions of the corrosion products. EDS was used on the samples with relatively small oxides to determine composition and spatial distribution of elements in the oxide. Several of the oxides were too small to characterize using EDS and were unable to be evaluated.

CHAPTER 4

RESULTS

4.1 Solubility Results

The solubility curves for selected metal oxides in the recovery boiler salt and NaOH are given in Figures 12 and 13 with the measured data in Appendix A. The solubility curves indicate that saturation or near saturation occurred within 8 hours and most of the saturation occurred within 1 hour. The solubility data indicates that NiO was the least soluble and SiO_2 was the most soluble. Chromium and aluminum oxide were similar and Fe_2O_3 was less soluble than either of them in the recovery boiler salt. The solubilities of the metal oxides in NaOH were different than in the recovery boiler salt. Chromium was the most soluble while the other oxides had similar solubilities.

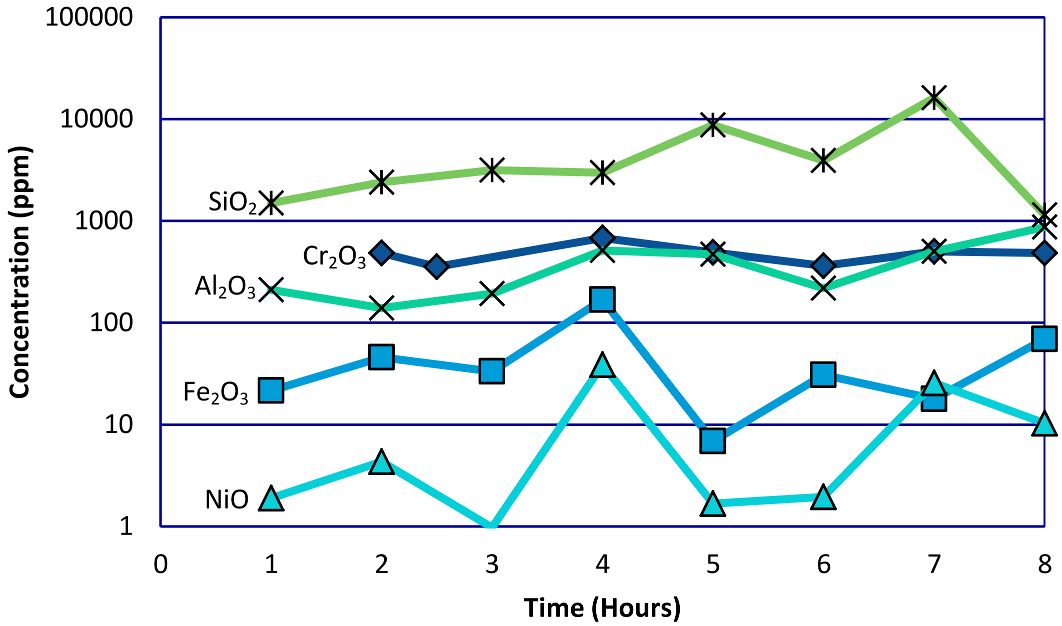


Figure 12 Solubility of SiO_2, Cr_2O_3, Al_2O_3, Fe_2O_3 and NiO in a Recovery Boiler Salt at 750^oC for 8 Hours

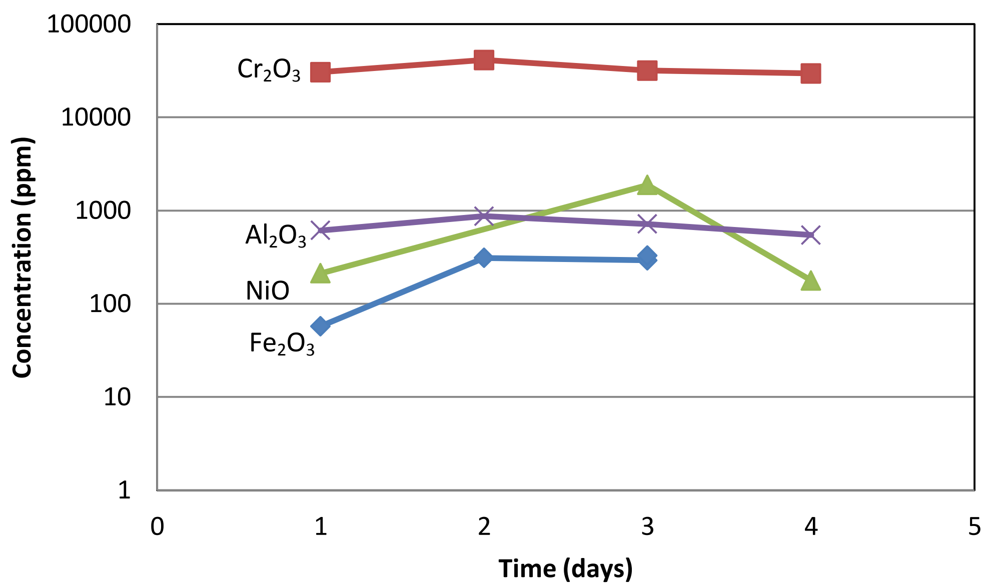


Figure 13 Solubility of Fe_2O_3, Cr_2O_3 NiO and Al_2O_3 in NaOH Over 4 day

Measurements were taken of Al_2O_3 from the crucible in the recovery boiler salt and NaOH. Figures 14 and 15 show these results. The addition of another metal oxide in Al_2O_3 caused the solubility of Al_2O_3 to decrease from only Al_2O_3. The only additional oxide that did not decrease the solubility of Al_2O_3 was Cr_2O_3. The change in solubility indicates that some sort of reaction occurred between the metal oxide and Al_2O_3. If there was no reaction, the final solubility of the Al_2O_3 would remain constant while the time to saturation of the Al_2O_3 would increase because dissolution would take place on the smooth crucible wall. It is unknown what reactions are taking place. A possibility is that a synergistic reaction is taking place but a synergistic reaction should only affect reaction rate and not necessarily overall solubility.

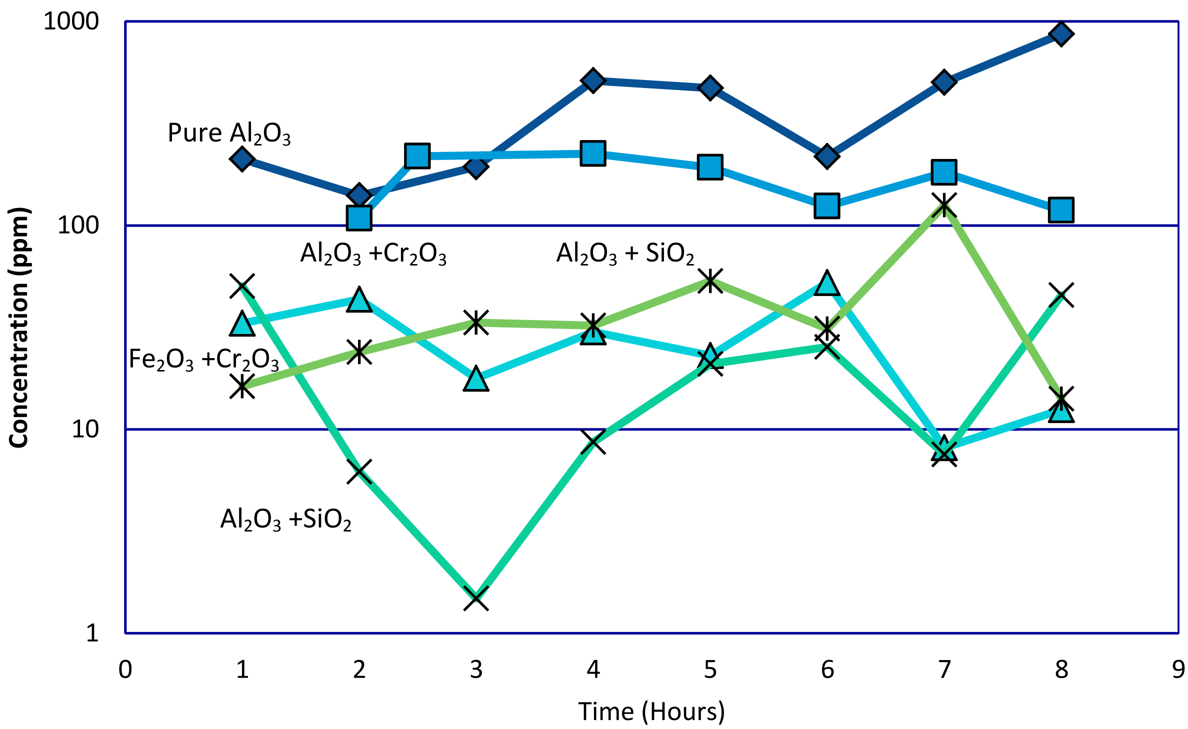


Figure 14 Average Solubility of Al_2O_3 with the Addition of Other Oxides in 8 hours at 750^{o}C

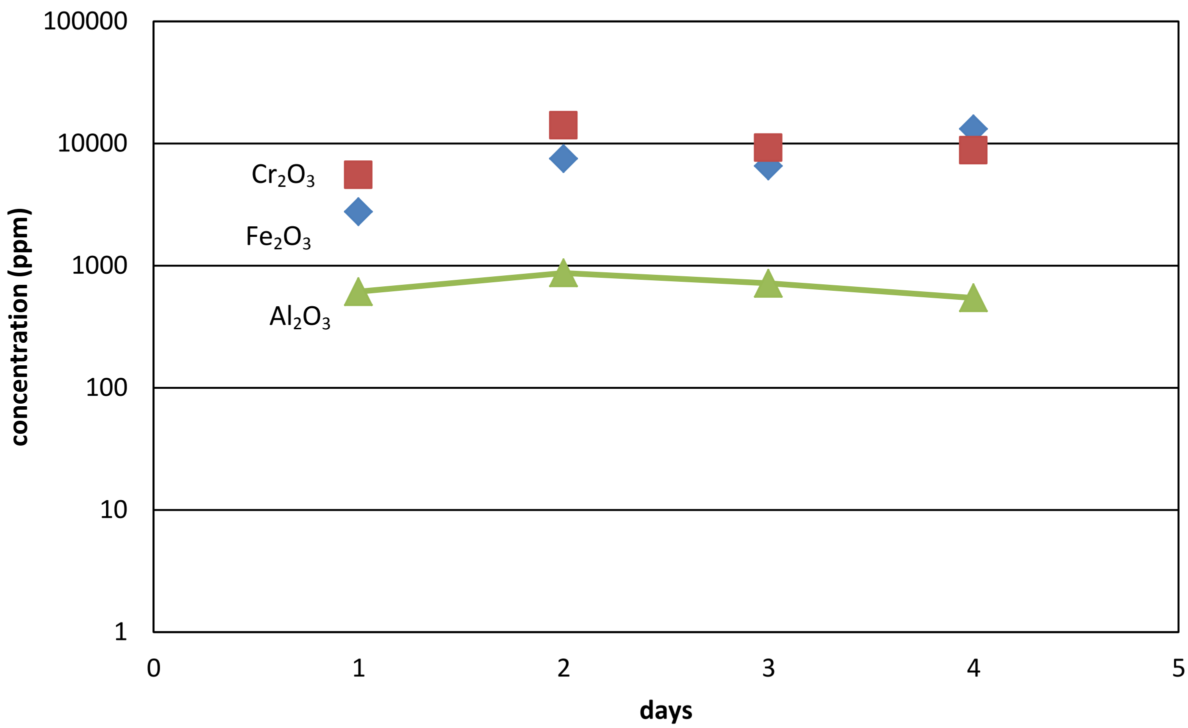


Figure 15 Average Solubility of Al_2O_3 with the Addition of Other Oxides in 8 hours at 550^oC

4.2 Errors in Measuring Solubility

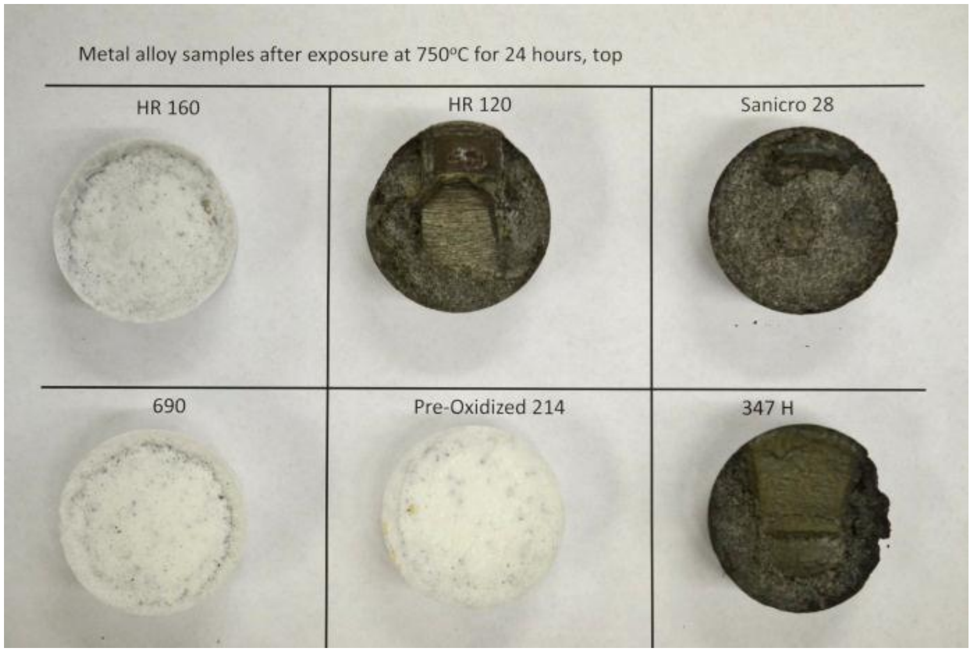
The solubility tests have the potential issue of accidentally including small amounts of microscopic oxide particles. These particles would increase the measured concentration of oxide artificially and could skew the results. The tolerance of the solubility test can be determined by calculating the mass and size of an oxide particle that would increase the test data by at least 50%. By testing for three levels of starting concentration: 50, 500, and 5000 ppm a 50% increase would be an added concentration of: 25, 250 and 2500 ppm. First this can be evaluated by excluding the effects of the salt and considering just a solution where the concentration of metal is equal to measured concentration multiplied by volume of solution. This is known because ppm is defined by µg of mass per mL or g of solution. In these experiments, between 10 – 15 mL of dilution was used and therefore to increase the concentration by 50% a mass of 0.325 µg of metal for 25 ppm, 3.25µg for 250 ppm and 32.5 µg for 2500 ppm. For NiO, 0.325 µg of Ni is equivalent to 5.5 nanomoles of Ni or 0.413 µg of NiO or 4.13µg of NiO for a 250 ppm increase or 41.3µg for a 2500 ppm increase. Considering that 40µg is much smaller than the sample size of approximately 10 mg, it is not unreasonable that some of the variation may be from accidental pick up of oxide. Despite the potential for large amounts of variation due to this type of error, the solubility results from the recovery boiler salt should still be reliable because the oxides are separated by nearly an order of magnitude.

4.3 Exposure Test Results

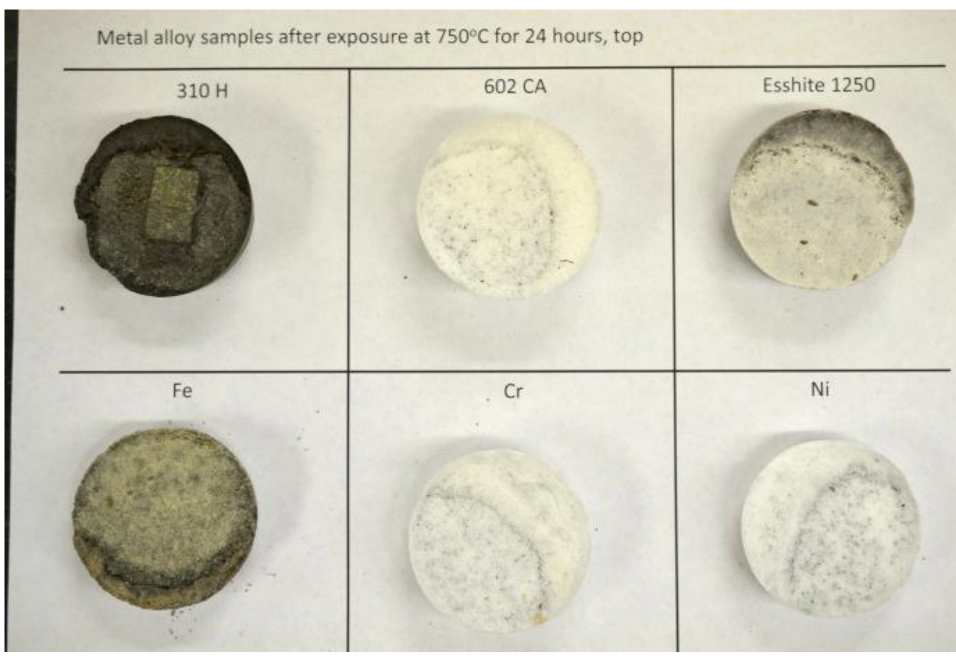
4.3.1 Before and After Images

Figures 16, 17, and18 show the changes in the samples and salt after exposure. Figure 16 shows the material before testing, Figure 17 shows the top of the salt after testing, and Figure 18 shows the top of the salt after testing. Of the samples evaluated, several were machined (HR160,602CA, and Esshite1250), the Haynes 214 was pre-oxidized, and the other materials were in an as received condition. The pure metal samples were all unoxidized before testing.

Figure 16 Metal Samples Before Exposure Testing

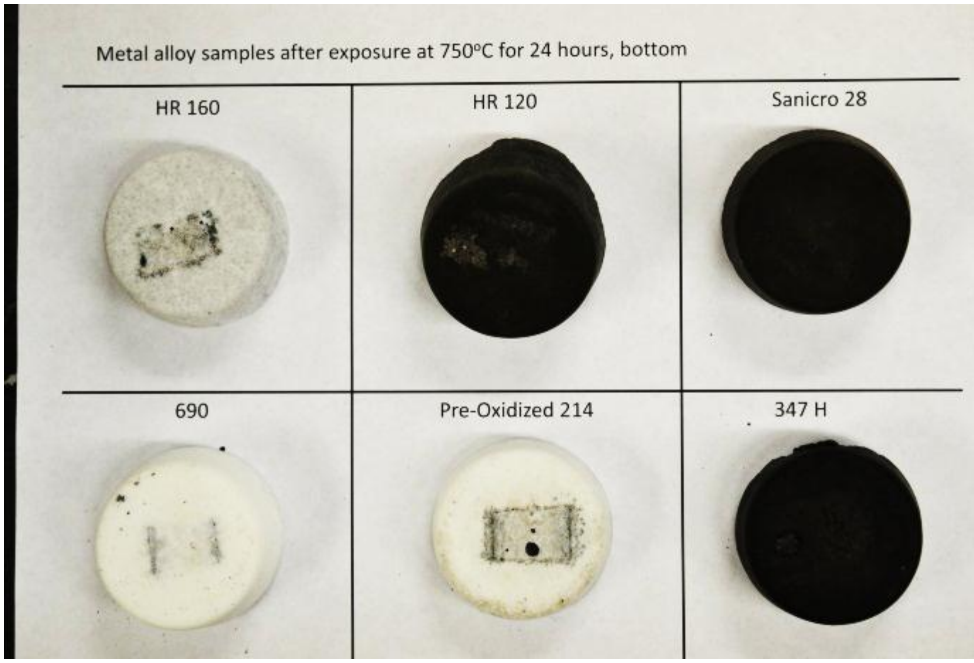


(1)



(2)

Figure 17 Top Down Images of the Exposure Test Samples (1) and (2) after 24 hours at 750^{o}C



(1)

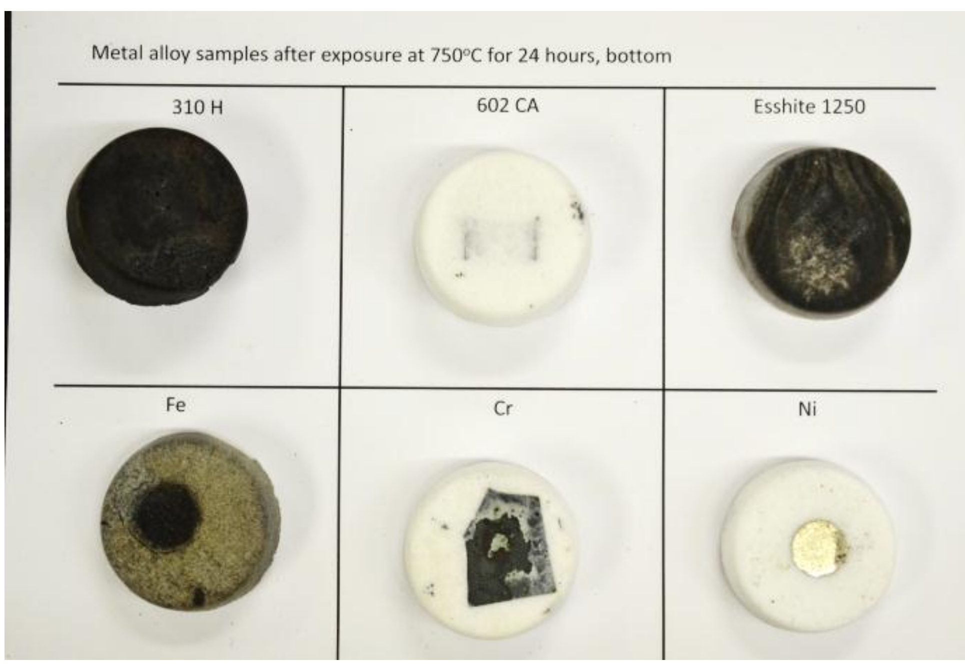


Figure 18 Bottom Images of the Exposure Test Samples (1) and (2) After 24 hours at 750^{o}C

No images were taken of the samples at 550^{o}C because the salt did not show any remarkable differences after exposure.

4.3.2 Exposure Tests at 750^{o}C

4.3.2.1 Pure Metals

4.3.2.1.1 Chromium

Chromium did not exhibit any corrosion except tarnishing at at 750^{o}C. Figure 19 shows the cross-section after exposure at 750^{o}C.

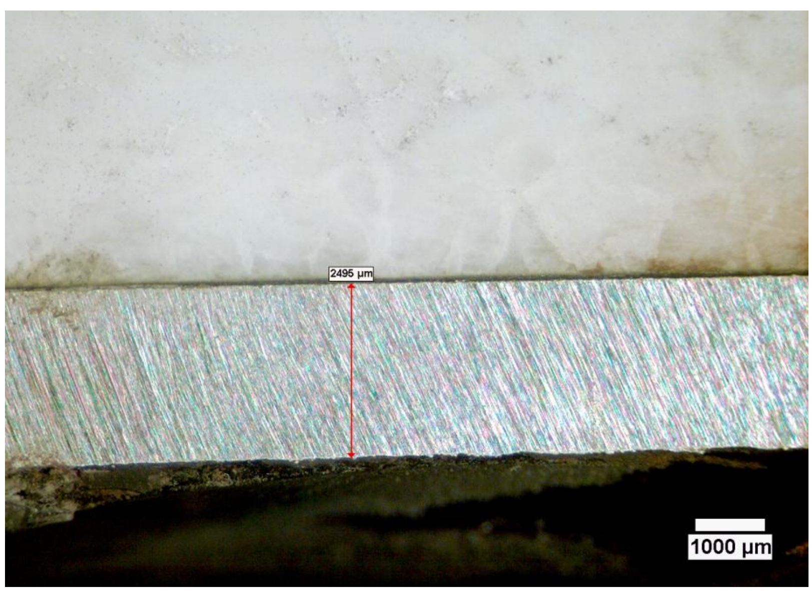


Figure 19 Micrograph of Pure Cr Exposed to Recovery Boiler Ash for 24 Hours at 750^{o}C

4.3.2.1.2 Iron

Iron was severely corroded after the exposure test despite its low solubility with a corrosion rate of 0.38mm/day. This indicates that iron oxide tends to form a negative solubility gradient in this recovery boiler ash under these conditions. Figure 20 shows the cross-section of the iron sample after testing.

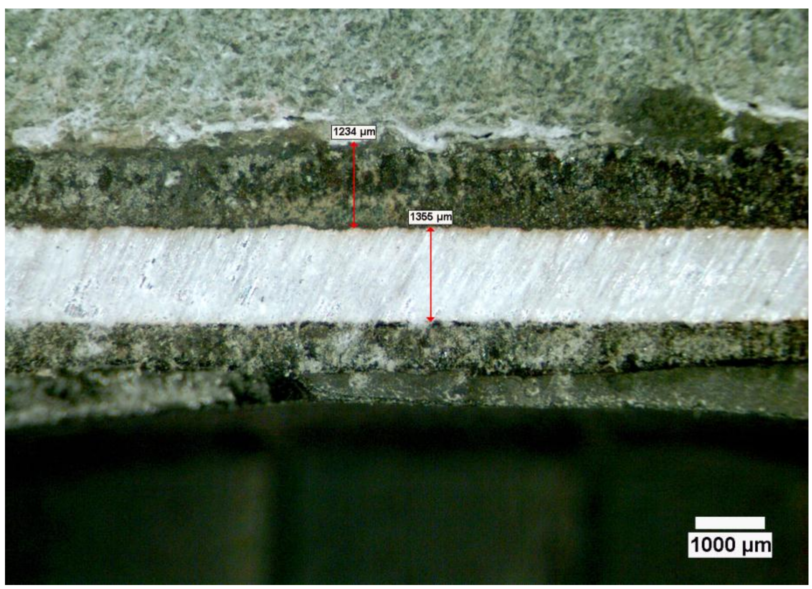


Figure 20 Micrograph of Pure Iron Sample Exposed to a Recovery Boiler Ash at 750^{o}C for 24 hours

4.3.2.1.3 Nickel

Nickel behaved like chromium in the exposure test where it did not corrode much except tarnish the outside of the metal. Figure 21 shows the cross-section of nickel after testing

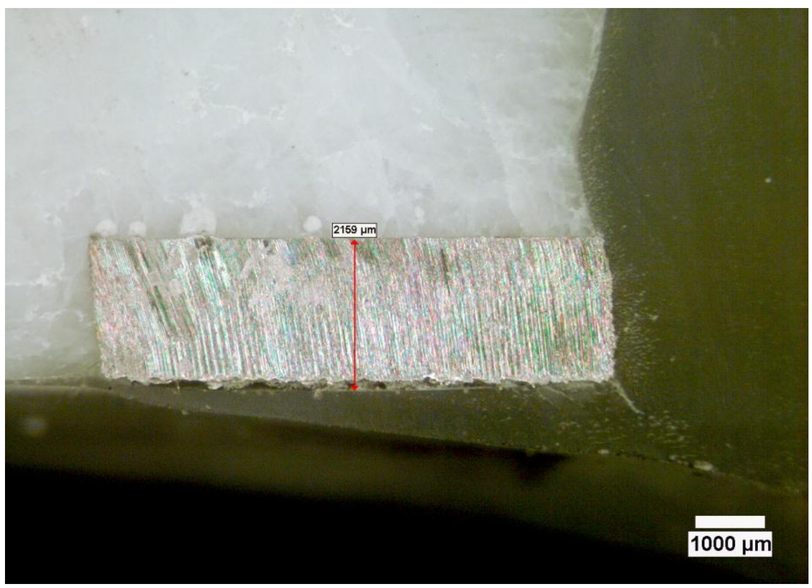


Figure 21 Micrograph of a Pure Nickel Sample Exposed to a Recovery Boiler Ash at 750^{o}C for 24 hours

4.3.2.1.4 Manganese

Manganese showed corrosion similar to Iron where very little of the metal was left. Manganese had a corrosion rate of 0.75mm/day Figure 22 shows the Manganese sample after 24 hours of exposure.

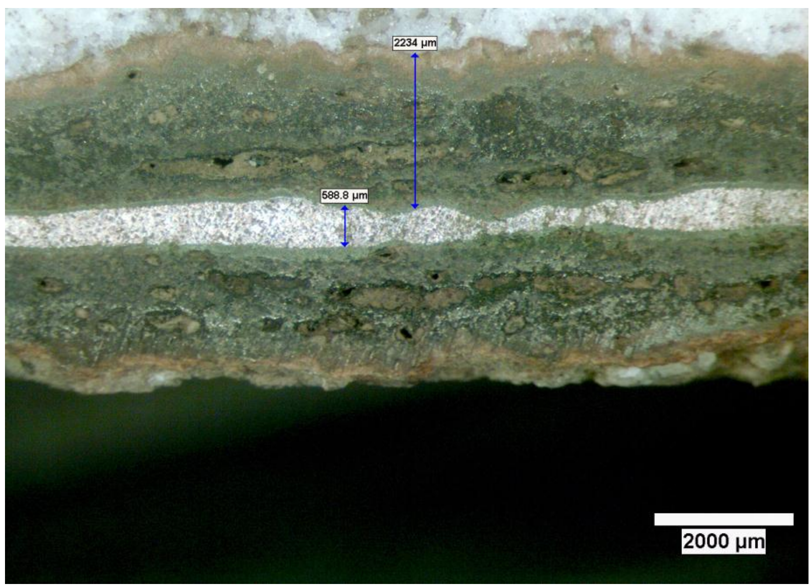


Figure 22 Micrograph of Pure Manganese Exposed to a Recovery Boiler Ash at 750^{o}C for 24 hours

Overall the exposure tests of the pure metals show the effects of solubility and the possibility of diffusion effects. Both nickel and chromium were untouched while iron and manganese were corroded severely. This indicates that solubility is not the major issue with these oxides. If only solubility dictates corrosion rate, then chromium would be the most corroded while iron would have a similar corrosion rate to nickel. The most reasonable answer is that iron and manganese form a negative solubility gradient instead of a positive gradient like nickel or chromium.

4.3.2.2 Austenitic Stainless Steels

4.3.2.2.1 Sanicro28

Sanicro28 was completely dissolved in 24 hours at 750^{o}C indicating at least a corrosion rate of 1.85 mm/day. Despite losing the sample, the remaining oxide was visible outside of the salt. Figure 23 shows the Sanicro 28 samples after exposure testing at 750^{o}C

Figure 23 Micrograph of Sanicro 28 Exposed for 24 hours at 750^{o}C

4.3.2.2.2 310H

310H was severely corroded at 750^{o}C with as little as 2mm of metal remaining indicating a corrosion rate of 0.75mm/day. Figure 24 shows 310H after exposure testing.

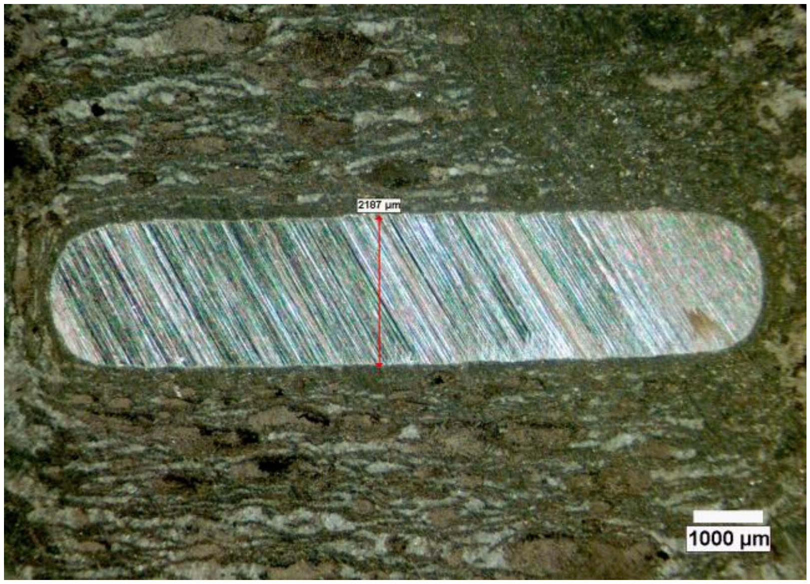


Figure 24 Micrograph of 310H Exposed in a Recovery Boiler Ash for 24hours at 750^{o}C

4.3.2.2.3 347H

347H was severely corroded at 750^{o}C with more corrosion than 310H but less than Sanicro28. 347H had a corrosion rate of 1.7mm/day. Figure 25 shows 347H after exposure testing

Figure 25 Micrographs of 347H Exposed in a Recovery Boiler Ash for 24 hours at 750^{o}C

4.3.2.2.4 Esshite 1250

Esshite 1250 was the least corroded of the stainless steels at 750^{o}C. The corrosion rate at that temperature was 0.06mm/day. Figure 26 shows Esshite 1250 after exposure testing.

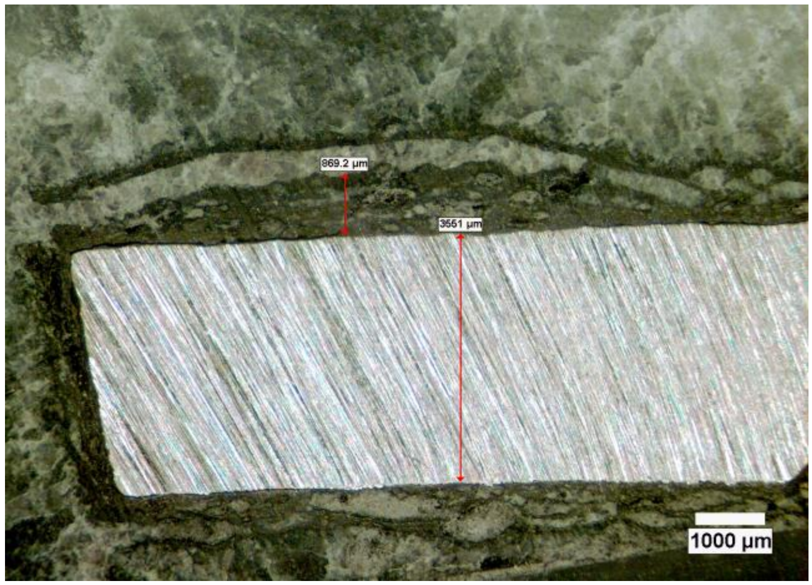


Figure 26 Micrograph of Esshite 1250 After Exposure to a Recovery Boiler Ash for 24 hours at 750^{o}C

4.3.2.2.5 HR120

HR120 was considered a stainless steel despite the fact that it contains more nickel than iron is because it had similar exposure data to the stainless steels. At 750^{o}C, the sample was lost after 24 hours indicating a corrosion rate of 1.83mm/day. Figure 27 shows HR120 after exposure.

Figure 27 Micrograph of HR120 Exposed to a Recovery Boiler Ash for 24 hours at 750^{o}C

Overall, the stainless steels were severely corroded at 750^{o}C and several of the alloys were completely dissolved. The alloy that performed the best was Esshite 1250 followed by 310H. A likely cause of the drastic increase of corrosion of the stainless steels compared to nickel alloys is due to the amount of iron in the alloys. From the exposure tests of the pure elements, iron showed less corrosion resistance than chromium even though it was less soluble. In fact, the alloys showed even less corrosion resistance than pure iron indicating that other mechanisms were at work. A possible cause of the increased corrosion rate is from a synergistic reaction with another oxide. This would cause an increase in the reaction rate and exacerbate the effects of the negative solubility gradient.

Esshite 1250 was the most corrosion resistant than the other stainless steels but the exact cause of its increased corrosion resistance is unknown. A possibility is from the addition of manganese in the alloy. Manganese is considered because Esshite 1250 has the most manganese of all the alloys with 6.3 wt% compared to at most 2 wt% from any of the other alloys. However, manganese showed little corrosion resistance as a pure element and this indicates that even if a manganese oxide film forms it is not protective under these conditions. The most probable cause of the reduced corrosion of Esshite 1250 is that it contains less of the element that forms a synergistic reaction with iron. Esshite 1250 is a low nickel austenitic stainless steel which substitutes manganese for nickel and uses less chromium to stabilize the austenitic phase. This means that either chromium or nickel is what causes the synergistic effect. Chromium is the more likely of the two because first it is easier to form Cr_2O_3 than NiO as seen in the exposure tests of pure elements. Chromium can oxidize further from $Cr3^+$ to $Cr6^+$ in the form of chromates. The additional oxidation further increases chromium solubility and allows chromium to act as an acidic oxide. If chromium acts as a detrimental acidic oxide it will increase the corrosion rate further and provide an additional negative solubility gradient.

4.3.2.3 Nickel alloys

4.3.2.3.1 690

690 showed little corrosion at 750^oC with a corrosion rate of 0.083mm/day. Figure 28 shows 690 after exposure testing.

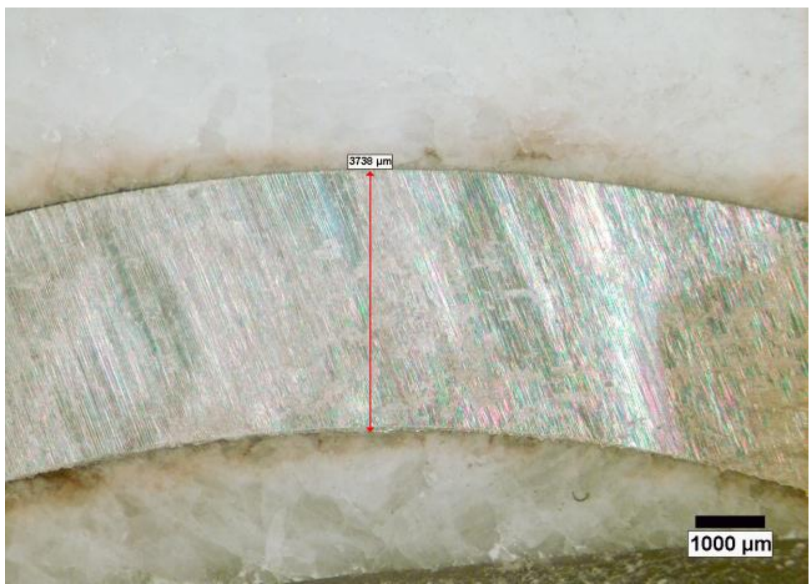


Figure 28 Micrograph of 690 Exposed to a Recovery Boiler Ash for A) 24 hours at 750^oC

4.3.2.3.2 602CA

602CA showed negligible corrosion at 750^oC with a corrosion rate of 0.057mm/day.

Figure 29 shows 602CA after exposure testing

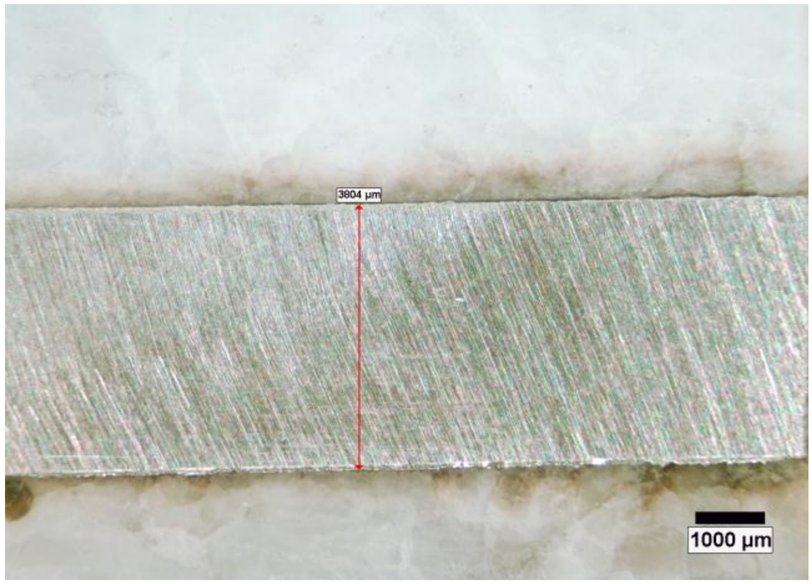


Figure 29 Micrograph of 602CA Exposed to a Recovery Boiler Ash for A) 24 hours at 750^{o}C

4.3.2.3.3 HR 160

HR160 showed some corrosion at 750^{o}C with a corrosion rate of approximately 0.5 mm/day. Figure 30 shows HR160 after exposure. It is unknown why HR 160 had a variable oxide thickness. The reason for the roughness may be from poor machining of the as received sample. The HR160 sample did not have a uniform thickness. HR160 contains significant amounts of cobalt and it is currently unknown what effect cobalt has on corrosion resistance in this case.

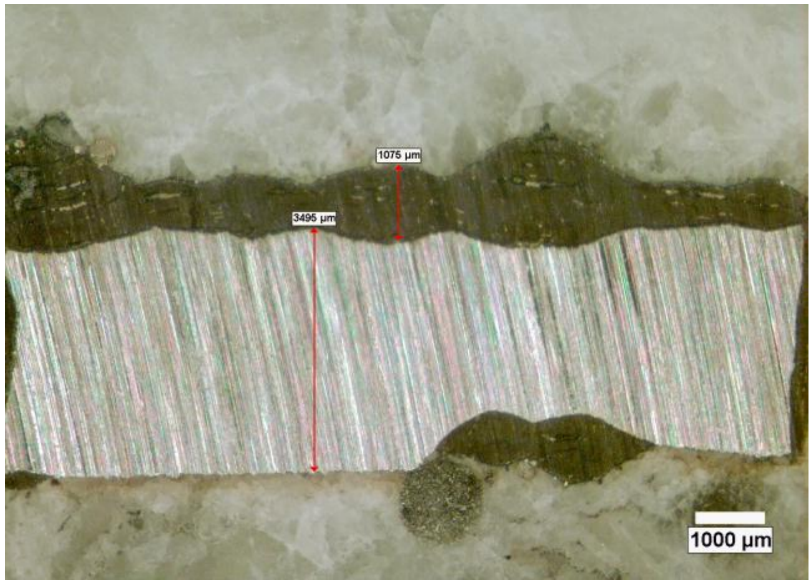


Figure 30 Micrograph of HR160 Exposed to a Recovery Boiler Ash for 24 hours at 750°C

4.3.2.3.4 Pre-oxidized Haynes 214

Pre-oxidized Haynes 214 showed some general corrosion at 750°C with a corrosion rate of 0.2mm/day. The oxide that developed on Haynes 214 at 750°C was from general corrosion and not from the pre-oxidation treatment. Comparing the cross-sections between 550°C (Figure 32I) and 750°C (Figure 31) verifies the oxide growth during testing. The oxide growth of the Haynes 214 and HR160 were similar and were much more than the other nickel alloys. The increased oxidation shows that different oxides may develop between the different nickel alloys. Chromium and aluminum oxides had similar solubility in the recovery boiler salt and this suggests that HR160 had a chromium based scale while the Haynes 214 had an aluminum based oxide.

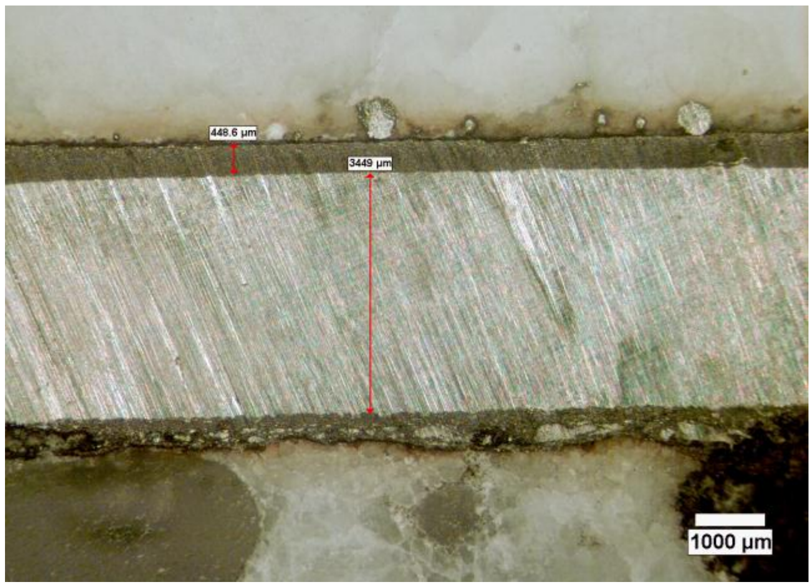
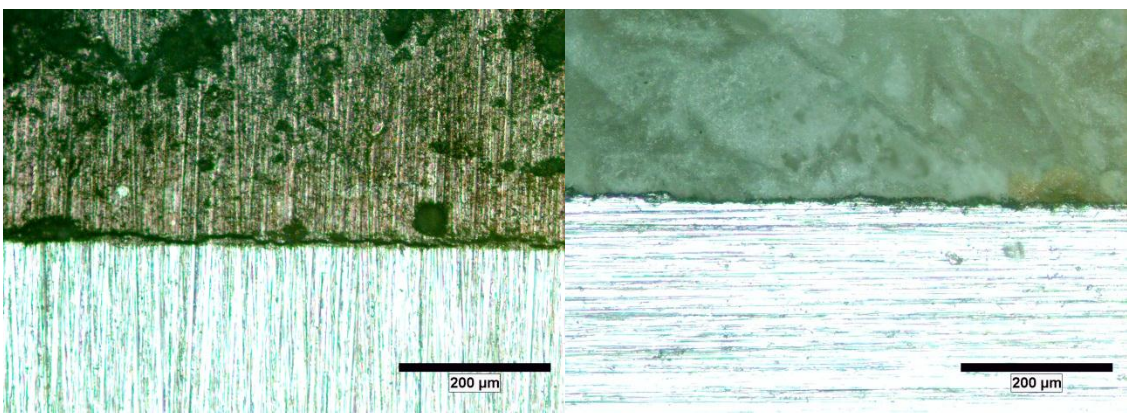


Figure 31 Micrograph of Pre-oxidized Haynes 214 Exposed to a Recovery Boiler Ash for 24 Hours at 750^{o}C

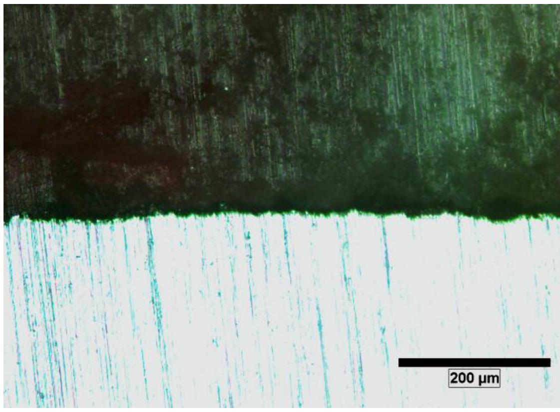
Overall, the nickel alloys showed more corrosion resistance than the stainless steels at 750^{o}C. At 750^{o}C, 690 and 602CA showed little corrosion but HR160 and the pre-oxidized 214 had noticeable amounts of corrosion. The difference between the nickel alloys is likely due to alloying and what protective oxide forms at the salt interface. Haynes 214 is an alumina former and that may be the reason for its increased corrosion rate.

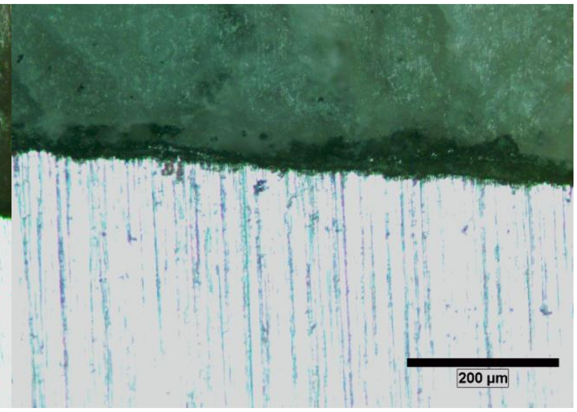
4.3.3 Exposure Tests at 550^{o}C

All of the alloys showed little corrosion after 1 week at 550^{o}C. Alloys such as HR120 and Sanicro28 showed a drastic reduction in corrosion rate while the nickel alloys continued to demonstrate little corrosion. Figure 32 shows the cross-sections of every commercial alloy exposed to the recovery boiler salt at 750^{o}C for 1 week.



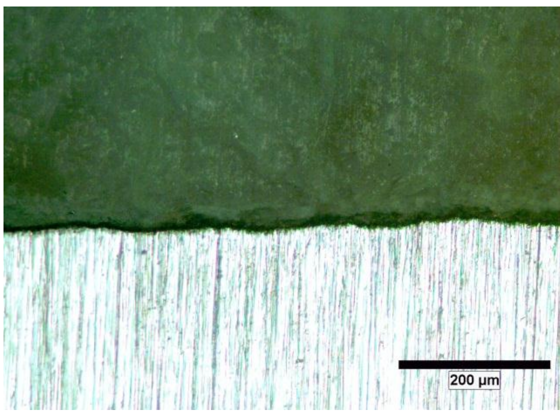
(A) (B)

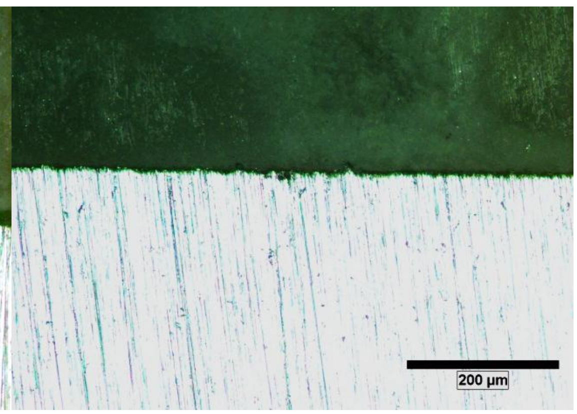




(C)

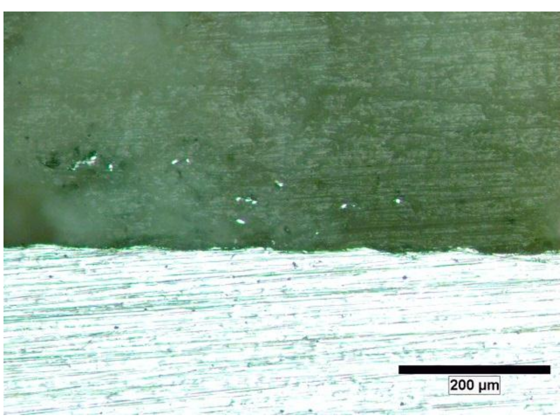
(D)

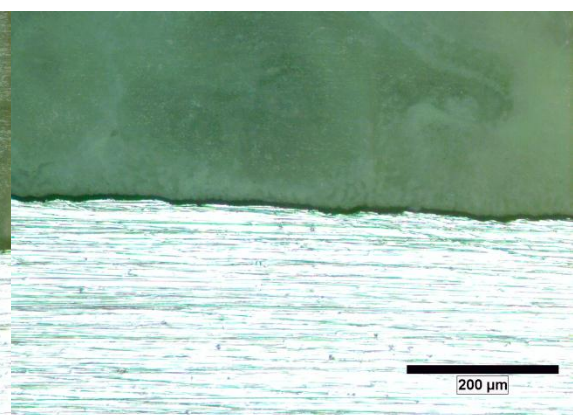




(E)

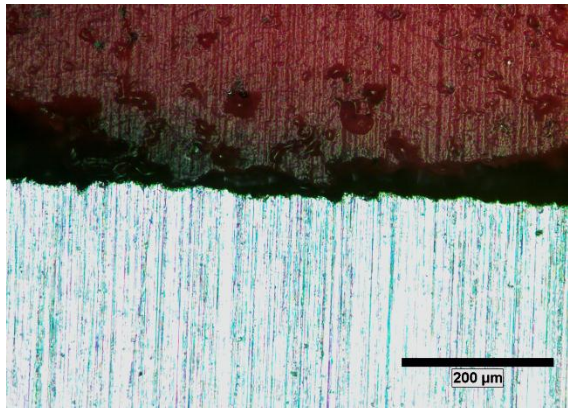
(F)





(G)

(H)



(I)

Figure 32 Optical Micrographs of (A) Sanciro28 (B) 310H (C) 347H (D) Esshite 1250 (E) HR120 (F) 690 (G) 602CA (H) HR160 and (I) Haynes 214 Exposed to a Recovery Boiler Ash for 1 Week at 550^{o}C

4.4 Chemical Characterization of the Oxide Films

4.4.1 XRD Results

X-Ray diffraction was performed on the alloys that showed excessive corrosion namely Sanicro28, 347H, 310H and HR120. Figures 33 through 36 show the XRD spectrums of each of the alloys. For each of the spectra, the characterized peaks are labeled in the figure while the unlabeled peaks are unknown.

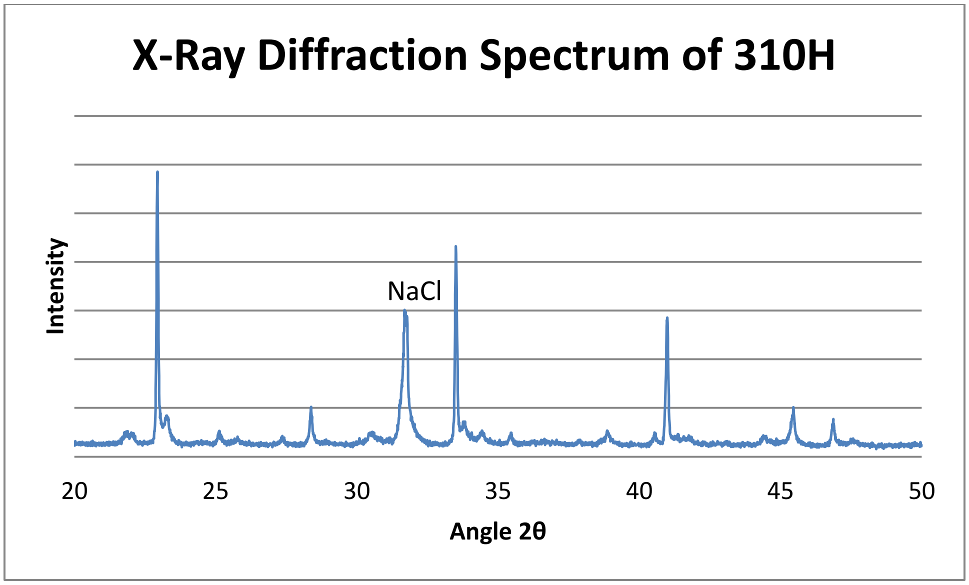


Figure 33 XRD Spectrum of 310H

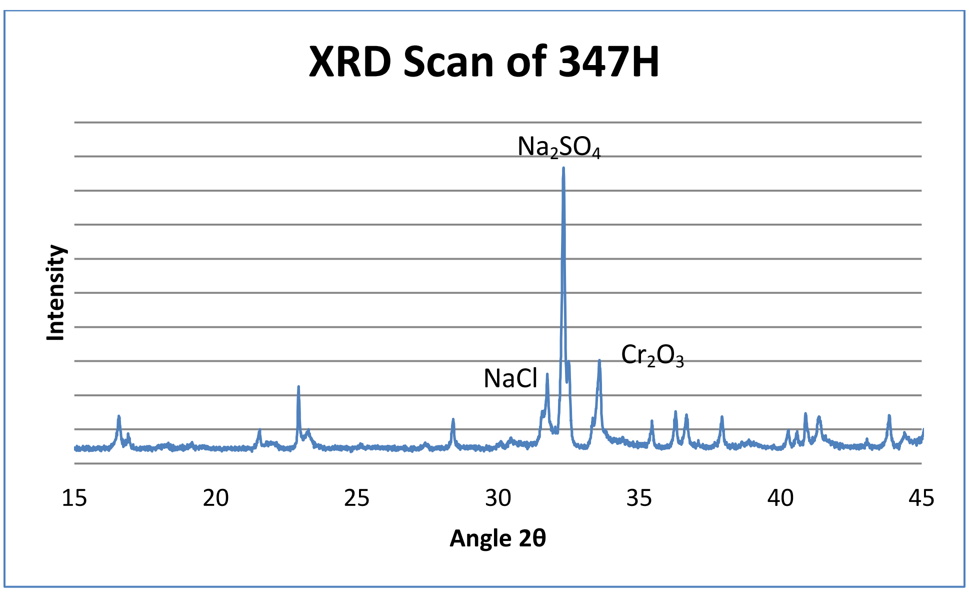


Figure 34 XRD Spectrum of 347H

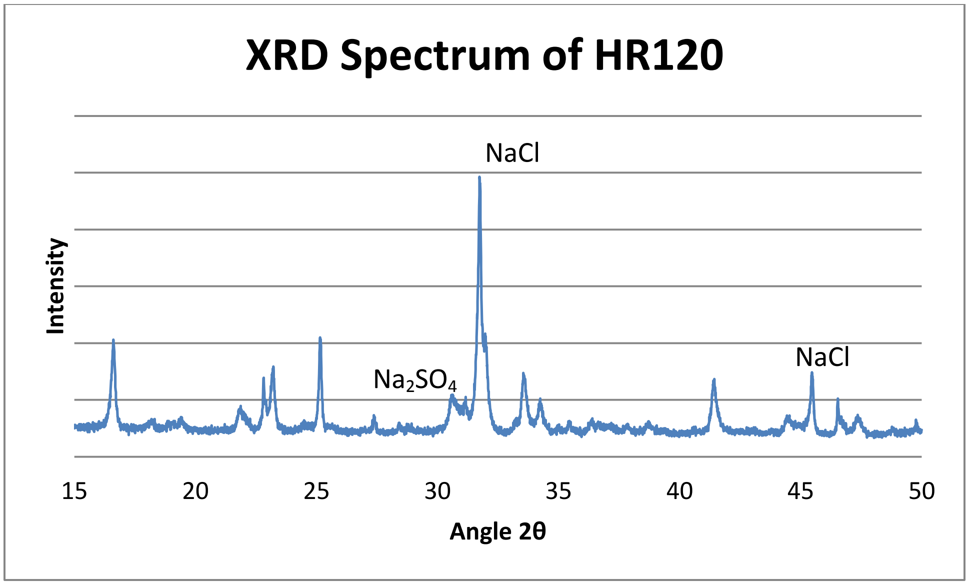


Figure 35 XRD Spectrum of HR120

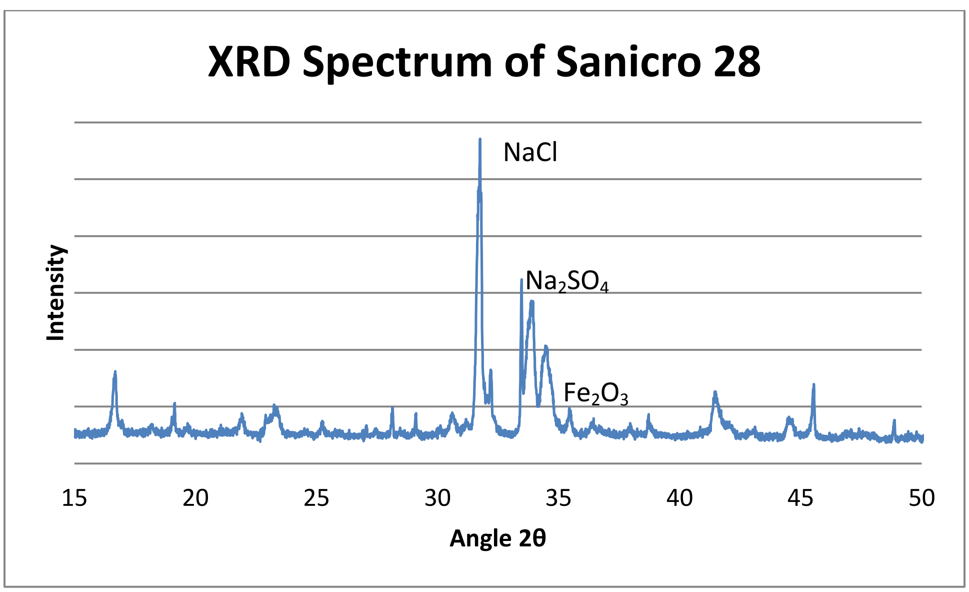


Figure 36 XRD Spectrum of Sanicro28

Many of the peaks from each alloy were unable to be evaluated however some information can be gleaned. Each of the samples contained some NaCl which was not a component in the salt mixture. This indicates that the contamination was from cutting with a high speed oxide blade. It is possible that the NaCl came from the coolant or in the binder of the saw.

4.4.2 EDS Results

EDS was performed on the alloys that showed smaller amounts of corrosion. The alloys that were evaluated using EDS were Haynes 214, HR160 and Esshite 1250. Figures 37 through 39 show the EDS analysis on several parts of the samples namely: base metal, oxide and salt. Gold peaks were observed in the EDS data because the samples were sputter coated with gold to make them conductive. Sodium was observed in the spectra both in the base metal and in the oxide unexpectedly. The sodium peaks are likely due to salt contamination during cutting and polishing. The salt was determined by looking for potassium, sulphur, and chlorine because these elements were only found in the salt.

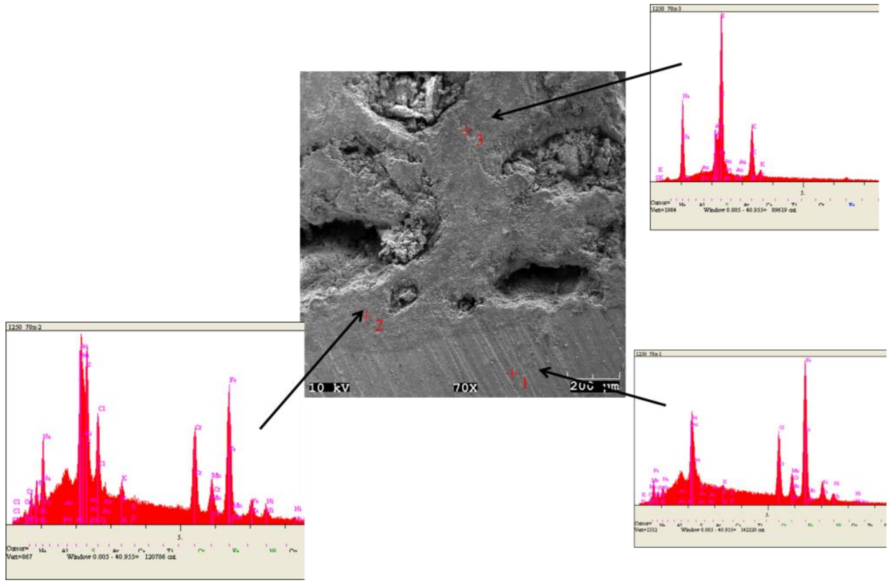


Figure 37 SEM Micrograph of Esshite 1250 and EDS spectrum of the Base Metal, Oxide, and Salt

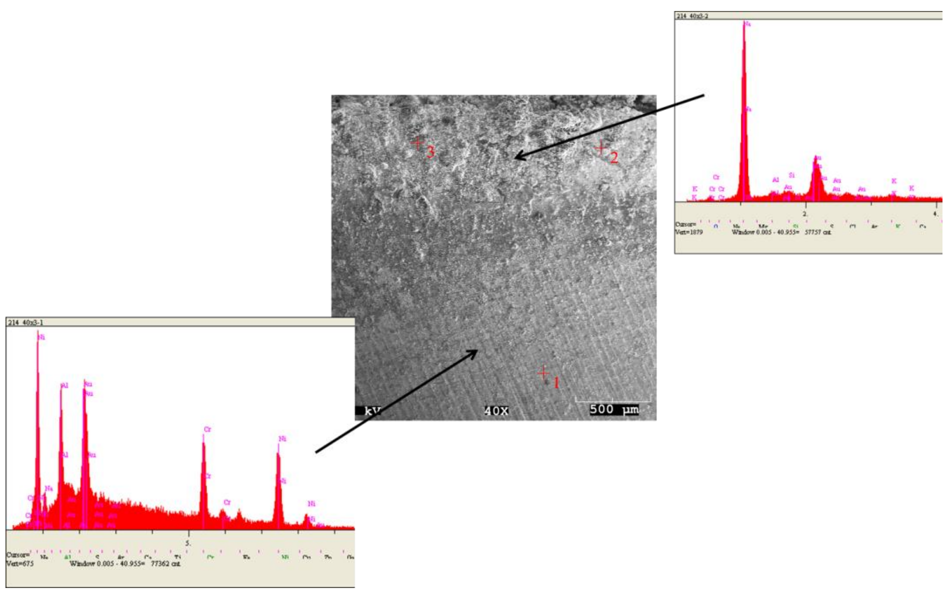


Figure 38 SEM Micrograph of Haynes 214 and EDS spectrum of the Base Metal and Oxide

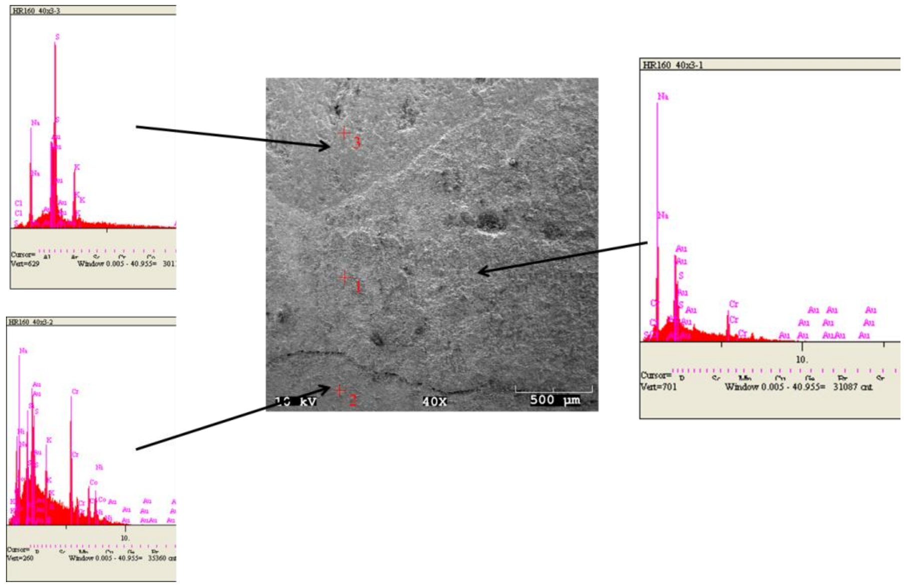


Figure 39 SEM Micrograph of HR160 and EDS Spectrum of the Base Metal, Oxide, and Salt

The EDS analysis of the Esshite 1250 showed a combination of elements in the oxide namely chromium, nickel, iron and manganese. Manganese as stated before is not the primary reason why Esshite 1250 has better corrosion resistance than the other stainless steels. Because manganese was found in the oxide it may act to modify the oxide. Whether or not manganese is actually beneficial this way is unknown.

Haynes 214 showed very little in the oxide except aluminum and the two known contaminants. If the oxide is entirely Al_2O_3, this may explain the large degree of oxide formation. Because aluminum cannot be tested at 750^oC it is difficult to verify if alumina forms a negative solubility gradient. However, because the oxide is solid and not porous, a negative solubility gradient is unlikely.

HR160 had a large Cr_2O_3 layer as an oxide. Like Haynes 214, HR160 had a large, solid oxide. Because the two alloys used different protective oxides but similar oxidation properties, the corrosion rate is controlled by solubility of Cr_2O_3 and Al_2O_3. HR160 contained a significant amount of cobalt which was not observed in the oxide. If cobalt has an effect on corrosion resistance then it may be near the metal/oxide interface.

Of the four nickel alloys that were tested, 690 and 602CA had superior corrosion properties than HR160 and Haynes 214. The difference between the alloys may be due to the oxide that develops. The metals did not have enough iron to form a negative solubility gradient like the stainless steels. 690 and 602CA should have formed a NiO film or did not form a similar Cr_2O_3 or Al_2O_3 film like HR160 and Haynes 214. An ideal alloy for a recovery boiler application would be similar to 690 and 602CA where the alloy is mostly nickel with some chromium. Chromium is useful for general corrosion resistance and sulphidation resistance in nickel alloys. Sulphidation is an issue in the recovery boiler because the environment contains large amounts of sulphur compounds. An issue that can arise from poor firing conditions is when unconsumed black liquor ends up on the superheater tubes. The presence of black liquor turns the oxidizing environment into a reducing environment. Chromium then helps to preserve the nickel tubes under these circumstances.

4.5 Conclusions

4.5.1 Solubility Measurements

Solubility of metal oxides in a recovery boiler salt affects the corrosion resistance of nickel alloys and stainless steels. In the recovery boiler salt, NiO was the least soluble followed by Fe_2O_3, Cr_2O_3, Al_2O_3 and SiO_2. Al_2O_3 and Cr_2O_3 had similar solubilities in the recovery boiler salt. Cr_2O_3 was the most soluble oxide in NaOH whereas the other oxides: Al_2O_3, NiO and Fe_2O_3 had similar solubilities. These results indicate that NiO based alloys are the most protective in the recovery boiler salt and that carbon steel is more protective than stainless steel. The results are a bit different in NaOH where all of the other metal oxides are more protective than Cr_2O_3. The tests in NaOH are consistent with previous measurements however; NiO should be less soluble than Fe_2O_3.

4.5.2 Pure Metal Exposure Tests

Nickel and chromium were the least corroded of the pure metals while iron and manganese showed little corrosion resistance. The reduced protection of Fe was surprising because it was less soluble than Cr. This indicated that Fe_2O_3 and therefore Fe based metals were susceptible to a negative solubility gradient under these conditions. This means that stainless steels should be more protective than carbon steel because it could rely on Cr_2O_3 formation instead of Fe_2O_3 even though the protective oxide is more soluble. Despite these results, NiO based metals will remain the best choice under these conditions because the oxide has little solubility and exhibits a positive solubility gradient.

4.5.3 Commercial Alloy Exposure Tests

All of the stainless steels exhibited some degree of negative solubility gradient. An important distinction is between HR120 and Esshite 1250. HR120 was heavily alloyed with less Fe than Ni but was more corroded than Esshite 1250 which was the least alloyed with Cr and Ni of any commercial alloy tested. The reversal of corrosion resistance with alloying was because either Ni or Cr creates a synergistic reaction with Fe_2O_3. This synergistic reaction increases the reaction rate of the negative solubility gradient and explains why these stainless steels were more corroded than pure Fe.

The nickel alloys were the least corroded of the tested alloys and showed solid oxides when present. Between HR160 and Haynes 214, they both showed corrosion with oxide formation while 602 CA and 690 were practically untouched. The difference may be from the oxide layer that develops. HR160 created a Cr_2O_3 based oxide while Haynes 214 had an Al_2O_3 based oxide which had similar solubility and therefore similar corrosion rates. 690 and 602CA may have formed NiO instead of Cr_2O_3 or Al_2O_3 and would then be the most protected. There must be a threshold of Fe needed to create a negative solubility gradient because HR120 exhibits a negative solubility gradient at 33 wt% Fe while 690 does not have a negative solubility gradient but has 11 wt% Fe. Based on the results shown, the best alloy should be mostly nickel with some chromium. Nickel should be used to improve molten salt corrosion resistance while chromium should be used to improve general gaseous corrosion and to improve sulphidation corrosion.

Some care must be taken with chromium because it further can oxidize from Cr^{3+} to Cr^{6+}. While Cr_2O_3 based refractories are frequently used, they cannot be used when it forms Cr^{6+}. Systems like recovery boilers where the metal can be aerosolized in the air are larger issues because Cr^{6+} affects humans more when it is inhaled. Despite the worries there are caveats to this particular system. First, the conversion from Cr^{3+} to Cr^{6+} is slower than the kinetics for it to dissolve in the molten salt. If the salt is fluid and not sticky, the dissolved chromium will fall into the lower furnace and either remain in its reduced form or be collected in the smelt. Another point to make about chromium oxidation is that the basicity to promote this oxidation may not be near the minimum solubility and the conditions to make Cr^{3+} oxidize may make chromium more soluble and therefore less protective. At that point it would be more advantageous to remove chromium from a corrosion perspective than an environmental one.

Chapter 5

Overview and Future Work Recommendations

5.1 Big Picture

The data indicates that solubility and diffusion effects are important in determining which metal oxides are suitable for use in molten salts. Of the metal oxides tested, NiO and therefore nickel based alloys were the most protective both from the solubility tests and exposure tests. Fe_2O_3 and austenitic stainless steels showed negative solubility gradients as well as synergistic reactions with another oxide in the system. If stainless steels are to be used, they should be alloyed as little as possible to reduce the effects of any synergistic reactions. Low nickel, high manganese alloys like Esshite 1250 may give adequate corrosion resistance with reduced cost compared to nickel based alloys. While chromium may be less protective than nickel, it should be alloyed with nickel to improve its sulphidation resistance.

5.2 Future Work

Despite the work that has been done there are still questions than can be answered to further explain the behavior of the alloys tested. Further work can entail:

1) More solubility work on the Covington recovery boiler salt composition particularly adding the effects of basicity.

2) Exposure tests that take into account flue gas composition and using binary alloys to determine which oxide undergoes synergistic reactions with Fe_2O_3.
3) Further testing of Manganese and low nickel austenitic alloys like Esshite 1250 to verify the exact cause of the increased corrosion resistance with reduced Chromium and Nickel additions.
4) Evaluation of the oxide films that formed on 690 and 602CA by XPS or Auger spectroscopy techniques to determine what oxides or species are present.

Appendix A

Date	Element	mass sample	mass added water	measured ppm	actual ppm
Recovery boiler salt, Al					
AL 1-1	Al 308.215	0.3831	13.0678	12.01569	413.5613
	Cr 267.716	0.3831	13.0678	0.046018	1.583868
	Fe 259.939	0.3831	13.0678	0.049376	1.699434
	Ni 231.604	0.3831	13.0678	0.029183	1.004441
	Si 251.611	0.3831	13.0678	0.12121	4.171851
	Mn 257.610	0.3831	13.0678	0.012711	0.43751
	Mo 202.031	0.3831	13.0678	0.29642	10.20232
	Al 396.153	0.3831	13.0678	12.12649	417.3747
AL 1-2	Al 308.215	0.2039	13.1098	1.206234	78.27623
	Cr 267.716	0.2039	13.1098	0.039457	2.560488
	Fe 259.939	0.2039	13.1098	0.025822	1.675663
	Ni 231.604	0.2039	13.1098	-0.03574	-2.3195
	Si 251.611	0.2039	13.1098	0.1673	10.85661
	Mn 257.610	0.2039	13.1098	0.007308	0.474232
	Mo 202.031	0.2039	13.1098	0.148815	9.657052
	Al 396.153	0.2039	13.1098	1.387208	90.02021
AL 1-3	Al 308.215	0.1784	13.1541	1.559024	115.9821
	Cr 267.716	0.1784	13.1541	0.026293	1.956011
	Fe 259.939	0.1784	13.1541	0.000457	0.034007
	Ni 231.604	0.1784	13.1541	0.004036	0.300246
	Si 251.611	0.1784	13.1541	0.172852	12.85913
	Mn 257.610	0.1784	13.1541	0.006678	0.496767
	Mo 202.031	0.1784	13.1541	0.070701	5.259749
	Al 396.153	0.1784	13.1541	1.696608	126.2176
AL 2-1	Al 308.215	0.2383	13.1766	6.433846	359.1047
	Cr 267.716	0.2383	13.1766	0.033092	1.847032
	Fe 259.939	0.2383	13.1766	0.007981	0.44544
	Ni 231.604	0.2383	13.1766	0.025671	1.43282
	Si 251.611	0.2383	13.1766	0.049563	2.766352
	Mn 257.610	0.2383	13.1766	0.008617	0.480956
	Mo 202.031	0.2383	13.1766	0.300491	16.77191

	Al 396.153	0.2383	13.1766	6.499231	362.7542
AL 2-2	Al 308.215	0.173	12.9798	0.293619	22.23378
	Cr 267.716	0.173	12.9798	0.017277	1.308272
	Fe 259.939	0.173	12.9798	0.002778	0.210395
	Ni 231.604	0.173	12.9798	-0.04341	-3.2874
	Si 251.611	0.173	12.9798	0.207197	15.68963
	Mn 257.610	0.173	12.9798	0.007251	0.549071
	Mo 202.031	0.173	12.9798	0.290041	21.9628
	Al 396.153	0.173	12.9798	0.533937	40.43137
AL 2-3	Al 308.215	0.0862	12.778	0.079367	11.87579
	Cr 267.716	0.0862	12.778	0.00466	0.697277
	Fe 259.939	0.0862	12.778	-0.01533	-2.29397
	Ni 231.604	0.0862	12.778	-0.01335	-1.99745
	Si 251.611	0.0862	12.778	0.04943	7.396268
	Mn 257.610	0.0862	12.778	0.002124	0.317844
	Mo 202.031	0.0862	12.778	0.308434	46.15131
	Al 396.153	0.0862	12.778	0.108185	16.18783
AL 3-1	Al 308.215	0.1283	13.0959	-0.01398	-1.43994
	Cr 267.716	0.1283	13.0959	0.016184	1.666835
	Fe 259.939	0.1283	13.0959	-0.00852	-0.87783
	Ni 231.604	0.1283	13.0959	-0.0071	-0.73158
	Si 251.611	0.1283	13.0959	0.11697	12.04717
	Mn 257.610	0.1283	13.0959	0.005556	0.572284
	Mo 202.031	0.1283	13.0959	0.085434	8.799134
	Al 396.153	0.1283	13.0959	0.088022	9.065667
AL 3-2	Al 308.215	0.1006	12.8706	-0.03249	-4.195
	Cr 267.716	0.1006	12.8706	0.008239	1.063816
	Fe 259.939	0.1006	12.8706	-0.02924	-3.77573
	Ni 231.604	0.1006	12.8706	-0.02629	-3.39475
	Si 251.611	0.1006	12.8706	0.013912	1.796352
	Mn 257.610	0.1006	12.8706	0.003163	0.408427
	Mo 202.031	0.1006	12.8706	0.133331	17.21589
	Al 396.153	0.1006	12.8706	0.068823	8.886555
AL 3-3	Al 308.215	0.1676	12.9998	7.264072	568.678
	Cr 267.716	0.1676	12.9998	0.01874	1.467059
	Fe 259.939	0.1676	12.9998	0.023022	1.802287
	Ni 231.604	0.1676	12.9998	0.019281	1.509457
	Si 251.611	0.1676	12.9998	0.166002	12.99571

	Mn 257.610	0.1676	12.9998	0.005936	0.464685
	Mo 202.031	0.1676	12.9998	0.201559	15.77936
	Al 396.153	0.1676	12.9998	7.186073	562.5717
20PPM	Al 308.215	0.3831	13.0678	20.10289	691.9098
20PPM	Cr 267.716	0.3831	13.0678	19.88213	684.3116
20PPM	Fe 259.939	0.3831	13.0678	19.74387	679.553
20PPM	Ni 231.604	0.3831	13.0678	20.20531	695.4352
20PPM	Si 251.611	0.3831	13.0678	19.36269	666.4334
20PPM	Mn 257.610	0.3831	13.0678	19.55535	673.0646
20PPM	Mo 202.031	0.3831	13.0678	19.6982	677.981
20PPM	Al 396.153	0.3831	13.0678	19.88856	684.533
AL 4-1	Al 308.215	0.2281	12.9174	13.49493	770.8203
	Cr 267.716	0.2281	12.9174	0.040231	2.297956
	Fe 259.939	0.2281	12.9174	0.034651	1.979217
	Ni 231.604	0.2281	12.9174	-0.06563	-3.74888
	Si 251.611	0.2281	12.9174	0.052866	3.019679
	Mn 257.610	0.2281	12.9174	0.0101	0.576905
	Mo 202.031	0.2281	12.9174	0.29283	16.72624
	Al 396.153	0.2281	12.9174	13.25841	757.3102
AL 4-2	Al 308.215	0.2085	12.9168	12.37571	773.8112
	Cr 267.716	0.2085	12.9168	0.027215	1.701664
	Fe 259.939	0.2085	12.9168	0.008711	0.544665
	Ni 231.604	0.2085	12.9168	-0.03863	-2.41553
	Si 251.611	0.2085	12.9168	0.08694	5.436082
	Mn 257.610	0.2085	12.9168	0.008892	0.555998
	Mo 202.031	0.2085	12.9168	0.236838	14.80866
	Al 396.153	0.2085	12.9168	12.09272	756.1168
AL 4-3	Al 308.215	0.1261	12.9121	0.034044	3.515845
	Cr 267.716	0.1261	12.9121	0.024049	2.483639
	Fe 259.939	0.1261	12.9121	-0.02642	-2.72891
	Ni 231.604	0.1261	12.9121	-0.05889	-6.08168
	Si 251.611	0.1261	12.9121	0.180886	18.68084
	Mn 257.610	0.1261	12.9121	0.005178	0.534729
	Mo 202.031	0.1261	12.9121	0.196034	20.24531
	Al 396.153	0.1261	12.9121	0.239585	24.74298
AL 5-1	Al 308.215	0.1656	12.8205	0.031255	2.441769
	Cr 267.716	0.1656	12.8205	0.025515	1.993324
	Fe 259.939	0.1656	12.8205	-0.01588	-1.2409

	Ni 231.604	0.1656	12.8205	-0.04398	-3.43601
	Si 251.611	0.1656	12.8205	0.134671	10.5211
	Mn 257.610	0.1656	12.8205	0.006919	0.540539
	Mo 202.031	0.1656	12.8205	0.205033	16.01808
	Al 396.153	0.1656	12.8205	0.165642	12.94072
AL 5-2	Al 308.215	0.2277	13.0442	16.93441	978.9976
	Cr 267.716	0.2277	13.0442	0.021079	1.218623
	Fe 259.939	0.2277	13.0442	0.042841	2.476707
	Ni 231.604	0.2277	13.0442	0.03078	1.779425
	Si 251.611	0.2277	13.0442	0.093549	5.408182
	Mn 257.610	0.2277	13.0442	0.01027	0.593717
	Mo 202.031	0.2277	13.0442	0.200253	11.57686
	Al 396.153	0.2277	13.0442	16.52941	955.5841
AL 5-3	Al 308.215	0.206	12.915	7.080438	448.0646
	Cr 267.716	0.206	12.915	0.022782	1.441707
	Fe 259.939	0.206	12.915	-0.00117	-0.07414
	Ni 231.604	0.206	12.915	-0.0119	-0.75331
	Si 251.611	0.206	12.915	0.13547	8.572788
	Mn 257.610	0.206	12.915	0.006028	0.381454
	Mo 202.031	0.206	12.915	0.303554	19.2095
	Al 396.153	0.206	12.915	7.01589	443.9798
AL 6-1	Al 308.215	0.0556	12.7585	1.787029	413.9094
	Cr 267.716	0.0556	12.7585	0.004818	1.115873
	Fe 259.939	0.0556	12.7585	0.002057	0.476424
	Ni 231.604	0.0556	12.7585	-0.05826	-13.4948
	Si 251.611	0.0556	12.7585	0.153663	35.59128
	Mn 257.610	0.0556	12.7585	0.004231	0.980069
	Mo 202.031	0.0556	12.7585	0.183346	42.46636
	Al 396.153	0.0556	12.7585	1.696994	393.0556
AL 6-2	Al 308.215	0.1029	12.8404	1.93248	243.2934
	Cr 267.716	0.1029	12.8404	0.01155	1.454122
	Fe 259.939	0.1029	12.8404	-0.02281	-2.87161
	Ni 231.604	0.1029	12.8404	0.013791	1.736228
	Si 251.611	0.1029	12.8404	0.06781	8.537036
	Mn 257.610	0.1029	12.8404	0.005218	0.656965
	Mo 202.031	0.1029	12.8404	0.055647	7.005745
	Al 396.153	0.1029	12.8404	1.839933	231.642
AL 6-3	Al 308.215	0.0672	13.0337	0.204824	40.09245

	Cr 267.716	0.0672	13.0337	0.005619	1.099858
	Fe 259.939	0.0672	13.0337	-0.02902	-5.68126
	Ni 231.604	0.0672	13.0337	-0.00819	-1.6032
	Si 251.611	0.0672	13.0337	0.054227	10.61446
	Mn 257.610	0.0672	13.0337	0.003474	0.680008
	Mo 202.031	0.0672	13.0337	0.232027	45.41716
	Al 396.153	0.0672	13.0337	0.141462	27.68999
AL 7-1	Al 308.215	0.1782	12.8685	0.102904	7.499781
	Cr 267.716	0.1782	12.8685	0.025786	1.879313
	Fe 259.939	0.1782	12.8685	-0.04143	-3.01981
	Ni 231.604	0.1782	12.8685	0.054855	3.997955
	Si 251.611	0.1782	12.8685	0.032852	2.3943
	Mn 257.610	0.1782	12.8685	0.006787	0.494638
	Mo 202.031	0.1782	12.8685	0.249089	18.15399
	Al 396.153	0.1782	12.8685	0.192049	13.99686
20PPM	Al 308.215	0.3831	13.0678	20.97135	721.801
20PPM	Cr 267.716	0.3831	13.0678	20.68066	711.7957
20PPM	Fe 259.939	0.3831	13.0678	20.49573	705.4309
20PPM	Ni 231.604	0.3831	13.0678	20.34427	700.2177
20PPM	Si 251.611	0.3831	13.0678	19.51429	671.6513
20PPM	Mn 257.610	0.3831	13.0678	20.28731	698.2573
20PPM	Mo 202.031	0.3831	13.0678	20.00397	688.5053
20PPM	Al 396.153	0.3831	13.0678	20.60417	709.1631
AL 7-2	Al 308.215	0.2059	12.9177	20.07493	1271.048
	Cr 267.716	0.2059	12.9177	0.032021	2.027437
	Fe 259.939	0.2059	12.9177	0.036601	2.317395
	Ni 231.604	0.2059	12.9177	0.014305	0.905701
	Si 251.611	0.2059	12.9177	0.247431	15.66613
	Mn 257.610	0.2059	12.9177	0.011189	0.708418
	Mo 202.031	0.2059	12.9177	0.241328	15.27971
	Al 396.153	0.2059	12.9177	19.52797	1236.418
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AL 7-3	Al 308.215	0.1045	12.9947	2.089774	262.2116
	Cr 267.716	0.1045	12.9947	0.011163	1.400636
	Fe 259.939	0.1045	12.9947	-0.00141	-0.17668
	Ni 231.604	0.1045	12.9947	-0.00225	-0.28286
	Si 251.611	0.1045	12.9947	0.050245	6.304377
	Mn 257.610	0.1045	12.9947	0.006888	0.864301
	Mo 202.031	0.1045	12.9947	0.142977	17.93987
	Al 396.153	0.1045	12.9947	2.060983	258.5992

AL 8-1	Al 308.215	0.0312	13.1358	6.002479	2549.745
	Cr 267.716	0.0312	13.1358	0.030226	12.83944
	Fe 259.939	0.0312	13.1358	-0.01403	-5.95867
	Ni 231.604	0.0312	13.1358	-0.03783	-16.0704
	Si 251.611	0.0312	13.1358	0.055536	23.59082
	Mn 257.610	0.0312	13.1358	0.005073	2.154811
	Mo 202.031	0.0312	13.1358	0.179862	76.40203
	Al 396.153	0.0312	13.1358	5.946978	2526.169
AL 8-2	Al 308.215	0.2936	13.0953	0.522936	23.52854
	Cr 267.716	0.2936	13.0953	0.025185	1.133174
	Fe 259.939	0.2936	13.0953	-0.01853	-0.83369
	Ni 231.604	0.2936	13.0953	-0.01127	-0.50723
	Si 251.611	0.2936	13.0953	0.070917	3.190782
	Mn 257.610	0.2936	13.0953	0.007489	0.336976
	Mo 202.031	0.2936	13.0953	0.036506	1.642531
	Al 396.153	0.2936	13.0953	0.670237	30.15608
AL 8-3	Al 308.215	0.1398	12.8881	0.385261	35.83837
	Cr 267.716	0.1398	12.8881	0.006981	0.649438
	Fe 259.939	0.1398	12.8881	-0.02568	-2.38915
	Ni 231.604	0.1398	12.8881	-0.02269	-2.11101
	Si 251.611	0.1398	12.8881	0.013741	1.278267
	Mn 257.610	0.1398	12.8881	0.003573	0.332416
	Mo 202.031	0.1398	12.8881	0.053695	4.994925
	Al 396.153	0.1398	12.8881	0.461042	42.88782
AL 1D-1	Al 308.215	0.1755	12.722	0.061018	4.465058
	Cr 267.716	0.1755	12.722	0.01146	0.83863
	Fe 259.939	0.1755	12.722	-0.02592	-1.8966
	Ni 231.604	0.1755	12.722	-0.02957	-2.16354
	Si 251.611	0.1755	12.722	0.022724	1.662841
	Mn 257.610	0.1755	12.722	0.007608	0.556756
	Mo 202.031	0.1755	12.722	0.175553	12.84626
	Al 396.153	0.1755	12.722	0.223733	16.3719
AL 1D-2	Al 308.215	0.1387	13.0156	0.292627	27.71079
	Cr 267.716	0.1387	13.0156	0.020135	1.90671
	Fe 259.939	0.1387	13.0156	-0.02992	-2.83316
	Ni 231.604	0.1387	13.0156	-0.03199	-3.02949
	Si 251.611	0.1387	13.0156	0.096496	9.137829
	Mn 257.610	0.1387	13.0156	0.003839	0.363537

	Mo 202.031	0.1387	13.0156	0.039988	3.786701
	Al 396.153	0.1387	13.0156	0.412412	39.05396
AL 1D-3	Al 308.215	0.162	13.0594	2.278082	185.329
	Cr 267.716	0.162	13.0594	0.016651	1.354574
	Fe 259.939	0.162	13.0594	-0.02317	-1.88504
	Ni 231.604	0.162	13.0594	-0.01245	-1.01302
	Si 251.611	0.162	13.0594	0.194474	15.82109
	Mn 257.610	0.162	13.0594	0.005862	0.476924
	Mo 202.031	0.162	13.0594	-0.04065	-3.30693
	Al 396.153	0.162	13.0594	2.272878	184.9056
20PPM	Al 308.215	0.3831	13.0678	19.93892	686.2663
20PPM	Cr 267.716	0.3831	13.0678	19.78656	681.0224
20PPM	Fe 259.939	0.3831	13.0678	19.67003	677.0115
20PPM	Ni 231.604	0.3831	13.0678	20.71408	712.9461
20PPM	Si 251.611	0.3831	13.0678	19.79641	681.3613
20PPM	Mn 257.610	0.3831	13.0678	19.48525	670.6517
20PPM	Mo 202.031	0.3831	13.0678	20.58955	708.66
20PPM	Al 396.153	0.3831	13.0678	19.85516	683.3834
AL 2D-1	Al 308.215	0.1618	12.8948	8.153641	655.9398
	Cr 267.716	0.1618	12.8948	0.028267	2.274013
	Fe 259.939	0.1618	12.8948	-0.00172	-0.13862
	Ni 231.604	0.1618	12.8948	-0.01991	-1.60151
	Si 251.611	0.1618	12.8948	0.248852	20.01951
	Mn 257.610	0.1618	12.8948	0.007521	0.60505
	Mo 202.031	0.1618	12.8948	0.206858	16.64117
	Al 396.153	0.1618	12.8948	7.975074	641.5745
AL 2D-2	Al 308.215	0.273	13.1994	9.158144	446.5283
	Cr 267.716	0.273	13.1994	0.034386	1.676558
	Fe 259.939	0.273	13.1994	0.000409	0.019943
	Ni 231.604	0.273	13.1994	0.012317	0.600537
	Si 251.611	0.273	13.1994	0.067312	3.281974
	Mn 257.610	0.273	13.1994	0.009156	0.44641
	Mo 202.031	0.273	13.1994	0.06651	3.242885
	Al 396.153	0.273	13.1994	9.063013	441.89
AL 2D-3	Al 308.215	0.2232	12.9844	5.222969	306.5312
	Cr 267.716	0.2232	12.9844	0.029592	1.736698
	Fe 259.939	0.2232	12.9844	0.007472	0.438542
	Ni 231.604	0.2232	12.9844	-0.02655	-1.55823

	Si 251.611	0.2232	12.9844	0.164754	9.669252
	Mn 257.610	0.2232	12.9844	0.007126	0.418228
	Mo 202.031	0.2232	12.9844	-0.00125	-0.0733
	Al 396.153	0.2232	12.9844	5.300166	311.0618
AL 3D-1	Al 308.215	0.1004	13.0878	0.045271	5.954064
	Cr 267.716	0.1004	13.0878	0.017895	2.353558
	Fe 259.939	0.1004	13.0878	-0.02853	-3.75288
	Ni 231.604	0.1004	13.0878	0.039381	5.179518
	Si 251.611	0.1004	13.0878	0.081945	10.7776
	Mn 257.610	0.1004	13.0878	0.004683	0.615942
	Mo 202.031	0.1004	13.0878	0.179266	23.57742
	Al 396.153	0.1004	13.0878	0.079007	10.39119
AL 3D-2	Al 308.215	0.0856	13.0645	0.058882	9.065469
	Cr 267.716	0.0856	13.0645	0.003289	0.506368
	Fe 259.939	0.0856	13.0645	-0.03277	-5.04591
	Ni 231.604	0.0856	13.0645	-0.0663	-10.2082
	Si 251.611	0.0856	13.0645	0.026761	4.120116
	Mn 257.610	0.0856	13.0645	0.003974	0.611848
	Mo 202.031	0.0856	13.0645	0.086716	13.35071
	Al 396.153	0.0856	13.0645	0.037305	5.743373
AL 3D-3	Al 308.215	0.2918	12.9625	5.071004	227.2794
	Cr 267.716	0.2918	12.9625	0.038658	1.732606
	Fe 259.939	0.2918	12.9625	0.011417	0.511715
	Ni 231.604	0.2918	12.9625	-0.0653	-2.92659
	Si 251.611	0.2918	12.9625	0.227042	10.17591
	Mn 257.610	0.2918	12.9625	0.011425	0.512065
	Mo 202.031	0.2918	12.9625	0.26256	11.76778
	Al 396.153	0.2918	12.9625	5.15246	230.9302
Recovery boiler salt, Si					
SI 1-1	Al 308.215	0.0509	13.0108	0.331	85.38748
	Cr 267.716	0.0509	13.0108	0.006324	1.631346
	Fe 259.939	0.0509	13.0108	0.075072	19.36613
	Ni 231.604	0.0509	13.0108	-0.00128	-0.33089
	Si 251.611	0.0509	13.0108	8.177737	2109.599
	Mn 257.610	0.0509	13.0108	0.002802	0.722882
	Mo 202.031	0.0509	13.0108	-0.00669	-1.72541
	Al 396.153	0.0509	13.0108	0.119442	30.8122
SI 1-2	Al 308.215	0.0889	13.1551	0.178765	26.44837

	Cr 267.716	0.0889	13.1551	-0.00438	-0.64792
	Fe 259.939	0.0889	13.1551	0.038273	5.662528
	Ni 231.604	0.0889	13.1551	-0.01332	-1.97124
	Si 251.611	0.0889	13.1551	8.936197	1322.115
	Mn 257.610	0.0889	13.1551	0.003554	0.525822
	Mo 202.031	0.0889	13.1551	-0.08664	-12.8188
	Al 396.153	0.0889	13.1551	0.083731	12.38798
SI 1-3	Al 308.215	0.1097	13.2442	0.169273	20.59974
	Cr 267.716	0.1097	13.2442	0.008631	1.050341
	Fe 259.939	0.1097	13.2442	0.047976	5.838421
	Ni 231.604	0.1097	13.2442	0.003624	0.440991
	Si 251.611	0.1097	13.2442	8.636943	1051.077
	Mn 257.610	0.1097	13.2442	0.003579	0.435519
	Mo 202.031	0.1097	13.2442	-0.01824	-2.2201
	Al 396.153	0.1097	13.2442	0.04589	5.584616
SI 2-1	Al 308.215	0.0585	12.7145	0.420954	92.31115
	Cr 267.716	0.0585	12.7145	0.004092	0.897408
	Fe 259.939	0.0585	12.7145	0.096413	21.14251
	Ni 231.604	0.0585	12.7145	0.01949	4.274014
	Si 251.611	0.0585	12.7145	13.94193	3057.333
	Mn 257.610	0.0585	12.7145	0.002312	0.507011
	Mo 202.031	0.0585	12.7145	-0.09013	-19.7655
	Al 396.153	0.0585	12.7145	0.156695	34.36182
SI 2-2	Al 308.215	-0.0119	12.7426	0.371969	-401.858
	Cr 267.716	-0.0119	12.7426	0.005045	-5.45031
	Fe 259.939	-0.0119	12.7426	0.038837	-41.9575
	Ni 231.604	-0.0119	12.7426	-0.03309	35.74705
	Si 251.611	-0.0119	12.7426	7.033501	-7598.66
	Mn 257.610	-0.0119	12.7426	0.003201	-3.4582
	Mo 202.031	-0.0119	12.7426	-0.09643	104.1808
	Al 396.153	-0.0119	12.7426	0.103509	-111.826
SI 2-3	Al 308.215	0.1429	12.7337	0.309175	27.79847
	Cr 267.716	0.1429	12.7337	0.011429	1.027592
	Fe 259.939	0.1429	12.7337	0.15248	13.70977
	Ni 231.604	0.1429	12.7337	-0.05575	-5.0122
	Si 251.611	0.1429	12.7337	19.22349	1728.419
	Mn 257.610	0.1429	12.7337	0.005183	0.465981
	Mo 202.031	0.1429	12.7337	0.04741	4.262735
	Al 396.153	0.1429	12.7337	0.150867	13.56473

SI 3-1	Al 308.215	0.1113	13.0969	0.328929	39.0415
	Cr 267.716	0.1113	13.0969	0.022415	2.660456
	Fe 259.939	0.1113	13.0969	0.17121	20.32135
	Ni 231.604	0.1113	13.0969	0.02462	2.922157
	Si 251.611	0.1113	13.0969	20.47815	2430.607
	Mn 257.610	0.1113	13.0969	0.004273	0.507173
	Mo 202.031	0.1113	13.0969	-0.02083	-2.47239
	Al 396.153	0.1113	13.0969	0.210026	24.92854
SI 3-2	Al 308.215	0.0305	12.9305	0.359915	154.0258
	Cr 267.716	0.0305	12.9305	-0.00143	-0.61236
	Fe 259.939	0.0305	12.9305	0.070466	30.15612
	Ni 231.604	0.0305	12.9305	0.019765	8.458434
	Si 251.611	0.0305	12.9305	10.58841	4531.32
	Mn 257.610	0.0305	12.9305	0.000852	0.364647
	Mo 202.031	0.0305	12.9305	-0.09502	-40.6618
	Al 396.153	0.0305	12.9305	0.123152	52.70282
SI 3-3	Al 308.215	0.0887	12.8875	0.339822	49.81023
	Cr 267.716	0.0887	12.8875	0.006546	0.959434
	Fe 259.939	0.0887	12.8875	0.123998	18.17523
	Ni 231.604	0.0887	12.8875	0.009497	1.39208
	Si 251.611	0.0887	12.8875	17.16243	2515.622
	Mn 257.610	0.0887	12.8875	0.003239	0.474708
	Mo 202.031	0.0887	12.8875	0.022775	3.338235
	Al 396.153	0.0887	12.8875	0.152504	22.3536
20PPM	Al 308.215	0.0509	13.0108	19.43826	5014.461
	Cr 267.716	0.0509	13.0108	19.40665	5006.307
	Fe 259.939	0.0509	13.0108	19.33752	4988.471
	Ni 231.604	0.0509	13.0108	19.33847	4988.718
	Si 251.611	0.0509	13.0108	18.56217	4788.455
	Mn 257.610	0.0509	13.0108	19.1228	4933.082
	Mo 202.031	0.0509	13.0108	19.01816	4906.086
	Al 396.153	0.0509	13.0108	19.44628	5016.529
SI 4-1	Al 308.215	0.063	12.9134	0.451008	93.29916
	Cr 267.716	0.063	12.9134	0.017407	3.600903
	Fe 259.939	0.063	12.9134	0.210235	43.49085
	Ni 231.604	0.063	12.9134	0.008621	1.783492
	Si 251.611	0.063	12.9134	16.95682	3507.827
	Mn 257.610	0.063	12.9134	0.007397	1.530152

	Mo 202.031	0.063	12.9134	0.039634	8.199033
	Al 396.153	0.063	12.9134	0.214892	44.45426
SI 4-2	Al 308.215	0.0925	13.1005	0.421201	60.18487
	Cr 267.716	0.0925	13.1005	0.002954	0.422054
	Fe 259.939	0.0925	13.1005	0.195461	27.92922
	Ni 231.604	0.0925	13.1005	0.028508	4.073471
	Si 251.611	0.0925	13.1005	18.64819	2664.615
	Mn 257.610	0.0925	13.1005	0.004126	0.589626
	Mo 202.031	0.0925	13.1005	0.076593	10.9443
	Al 396.153	0.0925	13.1005	0.193017	27.58
SI 4-3	Al 308.215	0.1563	12.9173	0.464869	38.7611
	Cr 267.716	0.1563	12.9173	0.026785	2.233318
	Fe 259.939	0.1563	12.9173	0.26884	22.41604
	Ni 231.604	0.1563	12.9173	-0.02239	-1.86684
	Si 251.611	0.1563	12.9173	32.99685	2751.3
	Mn 257.610	0.1563	12.9173	0.004743	0.395445
	Mo 202.031	0.1563	12.9173	-0.04199	-3.5013
	Al 396.153	0.1563	12.9173	0.29739	24.79655
SI 5-1	Al 308.215	0.0102	12.9949	0.441163	566.9285
	Cr 267.716	0.0102	12.9949	-0.00074	-0.95452
	Fe 259.939	0.0102	12.9949	0.085959	110.4642
	Ni 231.604	0.0102	12.9949	-0.05472	-70.3184
	Si 251.611	0.0102	12.9949	12.76037	16398.07
	Mn 257.610	0.0102	12.9949	0.00323	4.15131
	Mo 202.031	0.0102	12.9949	0.076367	98.13712
	Al 396.153	0.0102	12.9949	0.072582	93.27348
SI 5-2	Al 308.215	0.022	13.0773	0.409293	245.4902
	Cr 267.716	0.022	13.0773	-0.00136	-0.81384
	Fe 259.939	0.022	13.0773	0.065375	39.21118
	Ni 231.604	0.022	13.0773	0.018815	11.28519
	Si 251.611	0.022	13.0773	9.984163	5988.41
	Mn 257.610	0.022	13.0773	0.000321	0.19263
	Mo 202.031	0.022	13.0773	-0.0107	-6.41656
	Al 396.153	0.022	13.0773	0.075633	45.36369
SI 5-3	Al 308.215	0.0504	13.0039	0.385974	100.4903
	Cr 267.716	0.0504	13.0039	0.015456	4.023922
	Fe 259.939	0.0504	13.0039	0.109767	28.57828
	Ni 231.604	0.0504	13.0039	-0.02627	-6.83956

	Si 251.611	0.0504	13.0039	14.44565	3760.999
	Mn 257.610	0.0504	13.0039	0.000987	0.256907
	Mo 202.031	0.0504	13.0039	-0.05589	-14.5523
	Al 396.153	0.0504	13.0039	0.081926	21.32988
SI 6-1	Al 308.215	0.0604	12.9559	0.37472	81.09764
	Cr 267.716	0.0604	12.9559	0.00851	1.841697
	Fe 259.939	0.0604	12.9559	0.142196	30.77443
	Ni 231.604	0.0604	12.9559	-0.0051	-1.10326
	Si 251.611	0.0604	12.9559	17.47402	3781.765
	Mn 257.610	0.0604	12.9559	0.003551	0.768587
	Mo 202.031	0.0604	12.9559	-0.02143	-4.63802
	Al 396.153	0.0604	12.9559	0.124405	26.92395
SI 6-2	Al 308.215	0.2059	13.0409	0.562339	36.11425
	Cr 267.716	0.2059	13.0409	0.02108	1.353795
	Fe 259.939	0.2059	13.0409	0.395224	25.38184
	Ni 231.604	0.2059	13.0409	-0.03236	-2.07806
	Si 251.611	0.2059	13.0409	43.97801	2824.332
	Mn 257.610	0.2059	13.0409	0.006946	0.44611
	Mo 202.031	0.2059	13.0409	0.051607	3.314277
	Al 396.153	0.2059	13.0409	0.438889	28.18608
SI 6-3	Al 308.215	0.0258	13.0329	0.34253	174.5627
	Cr 267.716	0.0258	13.0329	-0.00099	-0.50658
	Fe 259.939	0.0258	13.0329	0.058994	30.0649
	Ni 231.604	0.0258	13.0329	-0.06557	-33.4179
	Si 251.611	0.0258	13.0329	10.11186	5153.286
	Mn 257.610	0.0258	13.0329	-0.00052	-0.2638
	Mo 202.031	0.0258	13.0329	0.13072	66.61851
	Al 396.153	0.0258	13.0329	0.074931	38.18703
20PPM	Al 308.215	0.0509	13.0108	19.14872	4939.768
	Cr 267.716	0.0509	13.0108	19.17573	4946.735
	Fe 259.939	0.0509	13.0108	19.06135	4917.229
	Ni 231.604	0.0509	13.0108	19.21919	4957.948
	Si 251.611	0.0509	13.0108	18.54759	4784.695
	Mn 257.610	0.0509	13.0108	18.84274	4860.835
	Mo 202.031	0.0509	13.0108	18.8304	4857.652
	Al 396.153	0.0509	13.0108	19.19775	4952.417
SI 7-1	Al 308.215	0.0319	12.891	0.507069	206.784
	Cr 267.716	0.0319	12.891	0.009785	3.990442

	Fe 259.939	0.0319	12.891	0.32255	131.5368
	Ni 231.604	0.0319	12.891	0.027984	11.41195
	Si 251.611	0.0319	12.891	41.14238	16777.97
	Mn 257.610	0.0319	12.891	0.007471	3.046561
	Mo 202.031	0.0319	12.891	-0.0714	-29.1174
	Al 396.153	0.0319	12.891	0.369164	150.5461
SI 7-2	Al 308.215	0.046	13.1704	0.347663	100.4466
	Cr 267.716	0.046	13.1704	0.006814	1.968668
	Fe 259.939	0.046	13.1704	0.090374	26.11069
	Ni 231.604	0.046	13.1704	0.049131	14.19488
	Si 251.611	0.046	13.1704	15.49805	4477.69
	Mn 257.610	0.046	13.1704	0.001869	0.539994
	Mo 202.031	0.046	13.1704	-0.03966	-11.4588
	Al 396.153	0.046	13.1704	0.120369	34.77691
SI 7-3	Al 308.215	0.0051	13.2312	0.397315	1039.47
	Cr 267.716	0.0051	13.2312	-0.01076	-28.1383
	Fe 259.939	0.0051	13.2312	0.05886	153.9928
	Ni 231.604	0.0051	13.2312	0.003173	8.30245
	Si 251.611	0.0051	13.2312	10.45852	27361.95
	Mn 257.610	0.0051	13.2312	0.000422	1.102829
	Mo 202.031	0.0051	13.2312	0.217742	569.6642
	Al 396.153	0.0051	13.2312	0.073361	191.93
SI 8-1	Al 308.215	0.1575	13.0325	0.380007	31.71743
	Cr 267.716	0.1575	13.0325	0.001566	0.13068
	Fe 259.939	0.1575	13.0325	0.085177	7.109294
	Ni 231.604	0.1575	13.0325	0.007359	0.61424
	Si 251.611	0.1575	13.0325	13.74181	1146.966
	Mn 257.610	0.1575	13.0325	0.001552	0.129569
	Mo 202.031	0.1575	13.0325	0.085661	7.149711
	Al 396.153	0.1575	13.0325	0.169295	14.1303
SI 8-2	Al 308.215	-0.0741	13.208	0.534656	-96.0433
	Cr 267.716	-0.0741	13.208	0.018264	-3.28091
	Fe 259.939	-0.0741	13.208	0.105914	-19.0259
	Ni 231.604	-0.0741	13.208	-0.01425	2.560445
	Si 251.611	-0.0741	13.208	24.231	-4352.75
	Mn 257.610	-0.0741	13.208	0.00274	-0.49224
	Mo 202.031	-0.0741	13.208	0.008341	-1.49827
	Al 396.153	-0.0741	13.208	0.257247	-46.2107

SI 8-3	Al 308.215	-0.0338	12.9289	0.352305	-135.944
	Cr 267.716	-0.0338	12.9289	-0.00165	0.636954
	Fe 259.939	-0.0338	12.9289	0.059124	-22.8142
	Ni 231.604	-0.0338	12.9289	-0.06365	24.55926
	Si 251.611	-0.0338	12.9289	12.6797	-4892.71
	Mn 257.610	-0.0338	12.9289	-1.21E-05	0.004681
	Mo 202.031	-0.0338	12.9289	-0.17517	67.59165
	Al 396.153	-0.0338	12.9289	0.080371	-31.0126
SI 1D-1	Al 308.215	0.0404	13.0524	0.71513	233.0084
	Cr 267.716	0.0404	13.0524	0.016135	5.25737
	Fe 259.939	0.0404	13.0524	0.094528	30.79961
	Ni 231.604	0.0404	13.0524	0.03437	11.19858
	Si 251.611	0.0404	13.0524	29.04477	9463.563
	Mn 257.610	0.0404	13.0524	0.002399	0.781635
	Mo 202.031	0.0404	13.0524	-0.15383	-50.1218
	Al 396.153	0.0404	13.0524	0.422636	137.706
SI 1D-2	Al 308.215	0.0077	13.0953	0.540789	927.9242
	Cr 267.716	0.0077	13.0953	0.012521	21.48454
	Fe 259.939	0.0077	13.0953	0.026949	46.24026
	Ni 231.604	0.0077	13.0953	-0.0041	-7.02649
	Si 251.611	0.0077	13.0953	17.701	30372.62
	Mn 257.610	0.0077	13.0953	0.001806	3.099336
	Mo 202.031	0.0077	13.0953	0.073947	126.8826
	Al 396.153	0.0077	13.0953	0.244417	419.3879
SI 1D-3	Al 308.215	0.0164	13.068	0.591122	475.1974
	Cr 267.716	0.0164	13.068	0.00127	1.020787
	Fe 259.939	0.0164	13.068	0.038337	30.81881
	Ni 231.604	0.0164	13.068	-0.01878	-15.099
	Si 251.611	0.0164	13.068	18.16094	14599.4
	Mn 257.610	0.0164	13.068	0.001082	0.870047
	Mo 202.031	0.0164	13.068	0.004595	3.694133
	Al 396.153	0.0164	13.068	0.299611	240.8543
20PPM	Al 308.215	0.0509	13.0108	19.29145	4976.587
	Cr 267.716	0.0509	13.0108	19.3099	4981.347
	Fe 259.939	0.0509	13.0108	19.1911	4950.701
	Ni 231.604	0.0509	13.0108	19.36645	4995.936
	Si 251.611	0.0509	13.0108	18.56563	4789.349
	Mn 257.610	0.0509	13.0108	18.96465	4892.285
	Mo 202.031	0.0509	13.0108	18.97406	4894.71

	Al 396.153	0.0509	13.0108	19.32348	4984.85
SI 2D-1	Al 308.215	0.0317	12.8844	0.876946	359.675
	Cr 267.716	0.0317	12.8844	0.001291	0.529702
	Fe 259.939	0.0317	12.8844	0.056242	23.06727
	Ni 231.604	0.0317	12.8844	-0.00345	-1.41402
	Si 251.611	0.0317	12.8844	24.69386	10128.06
	Mn 257.610	0.0317	12.8844	0.003877	1.590144
	Mo 202.031	0.0317	12.8844	0.017147	7.032893
	Al 396.153	0.0317	12.8844	0.563256	231.0168
SI 2D-2	Al 308.215	0.0652	12.9951	1.16525	234.2832
	Cr 267.716	0.0652	12.9951	0.018156	3.650398
	Fe 259.939	0.0652	12.9951	0.075628	15.20556
	Ni 231.604	0.0652	12.9951	0.033782	6.792163
	Si 251.611	0.0652	12.9951	27.55225	5539.607
	Mn 257.610	0.0652	12.9951	0.00182	0.365863
	Mo 202.031	0.0652	12.9951	0.058612	11.78446
	Al 396.153	0.0652	12.9951	0.883475	177.6299
SI 2D-3	Al 308.215	0.0505	12.6495	1.203278	304.1553
	Cr 267.716	0.0505	12.6495	0.019569	4.946524
	Fe 259.939	0.0505	12.6495	0.112011	28.31326
	Ni 231.604	0.0505	12.6495	-0.02785	-7.03876
	Si 251.611	0.0505	12.6495	24.91602	6298.079
	Mn 257.610	0.0505	12.6495	0.002278	0.575836
	Mo 202.031	0.0505	12.6495	-0.11489	-29.0419
	Al 396.153	0.0505	12.6495	0.962233	243.2259
SI 3D-1	Al 308.215	0.1564	12.7342	1.503565	123.5548
	Cr 267.716	0.1564	12.7342	0.031403	2.580512
	Fe 259.939	0.1564	12.7342	0.145877	11.98737
	Ni 231.604	0.1564	12.7342	-0.03018	-2.48035
	Si 251.611	0.1564	12.7342	69.66126	5724.383
	Mn 257.610	0.1564	12.7342	0.004411	0.362433
	Mo 202.031	0.1564	12.7342	-0.03086	-2.5358
	Al 396.153	0.1564	12.7342	1.492276	122.6271
SI 3D-2	Al 308.215	0.0912	12.8517	1.135655	161.4448
	Cr 267.716	0.0912	12.8517	0.01119	1.590759
	Fe 259.939	0.0912	12.8517	0.060628	8.618873
	Ni 231.604	0.0912	12.8517	0.016544	2.351851
	Si 251.611	0.0912	12.8517	32.83061	4667.202

	Mn 257.610	0.0912	12.8517	0.002635	0.374611
	Mo 202.031	0.0912	12.8517	-0.13608	-19.3456
	Al 396.153	0.0912	12.8517	0.870276	123.7185
SI 3D-3	Al 308.215	0.0776	12.8288	1.01377	169.0345
	Cr 267.716	0.0776	12.8288	0.005348	0.891787
	Fe 259.939	0.0776	12.8288	0.039216	6.538741
	Ni 231.604	0.0776	12.8288	-0.00672	-1.12026
	Si 251.611	0.0776	12.8288	34.16093	5695.94
	Mn 257.610	0.0776	12.8288	0.002304	0.3842
	Mo 202.031	0.0776	12.8288	0.005658	0.943425
	Al 396.153	0.0776	12.8288	0.707089	117.8988
20PPM	Al 308.215	0.0509	13.0108	19.10124	4927.519
	Cr 267.716	0.0509	13.0108	19.19099	4950.672
	Fe 259.939	0.0509	13.0108	19.04947	4914.164
	Ni 231.604	0.0509	13.0108	19.60009	5056.207
	Si 251.611	0.0509	13.0108	18.84862	4862.351
	Mn 257.610	0.0509	13.0108	18.82474	4856.192
	Mo 202.031	0.0509	13.0108	19.20592	4954.523
	Al 396.153	0.0509	13.0108	19.2214	4958.516

Recovery boiler salt, Cr

3-30 1-1	Al 308.215	0.1507	25.148	1.229076	205.1016
	Cr 267.716	0.1507	25.148	1.27591	212.9169
	Fe 259.939	0.1507	25.148	0.003926	0.655155
	Ni 231.604	0.1507	25.148	-0.06365	-10.6213
	Si 251.611	0.1507	25.148	8.210099	1370.057
	Mn 257.610	0.1507	25.148	0.003599	0.600521
	Mo 202.031	0.1507	25.148	0.07658	12.77925
	Al 396.153	0.1507	25.148	0.990646	165.3137
3-30 1-2	Al 308.215	0.1588	25.9594	1.033362	169.0588
	Cr 267.716	0.1588	25.9594	5.72638	936.8401
	Fe 259.939	0.1588	25.9594	0.016669	2.727054
	Ni 231.604	0.1588	25.9594	-0.04865	-7.95841
	Si 251.611	0.1588	25.9594	7.611765	1245.291
	Mn 257.610	0.1588	25.9594	-0.00038	-0.06181
	Mo 202.031	0.1588	25.9594	0.08492	13.89297
	Al 396.153	0.1588	25.9594	0.866739	141.7992
3-30 1-3	Al 308.215	0.1214	25.5193	1.139774	240.2389

	Cr 267.716	0.1214	25.5193	1.442667	304.0819
	Fe 259.939	0.1214	25.5193	0.023634	4.98154
	Ni 231.604	0.1214	25.5193	-0.01603	-3.37935
	Si 251.611	0.1214	25.5193	8.274178	1744.011
	Mn 257.610	0.1214	25.5193	-0.00034	-0.07225
	Mo 202.031	0.1214	25.5193	0.083962	17.69728
	Al 396.153				
3-30 2-1	Al 308.215	0.0491	26.2085	0.96362	516.1923
	Cr 267.716	0.0491	26.2085	0.805018	431.2323
	Fe 259.939	0.0491	26.2085	-0.00918	-4.91731
	Ni 231.604	0.0491	26.2085	-0.05072	-27.1695
	Si 251.611	0.0491	26.2085	5.791493	3102.389
	Mn 257.610	0.0491	26.2085	9.58E-06	0.005131
	Mo 202.031	0.0491	26.2085	0.154178	82.59024
	Al 396.153	0.0491	26.2085	0.647675	346.9466
3-30 2-2	Al 308.215	0.1464	25.9719	1.059192	188.4666
	Cr 267.716	0.1464	25.9719	1.860697	331.082
	Fe 259.939	0.1464	25.9719	0.002895	0.515045
	Ni 231.604	0.1464	25.9719	-0.05063	-9.00794
	Si 251.611	0.1464	25.9719	6.410541	1140.656
	Mn 257.610	0.1464	25.9719	-0.00056	-0.0992
	Mo 202.031	0.1464	25.9719	0.020436	3.636229
	Al 396.153	0.1464	25.9719	0.781466	139.0498
3-30 2-3	Al 308.215	0.1663	24.4744	1.419977	209.7707
	Cr 267.716	0.1663	24.4744	2.060586	304.4067
	Fe 259.939	0.1663	24.4744	0.005249	0.775358
	Ni 231.604	0.1663	24.4744	-0.04963	-7.33195
	Si 251.611	0.1663	24.4744	10.23126	1511.446
	Mn 257.610	0.1663	24.4744	-0.00163	-0.24122
	Mo 202.031	0.1663	24.4744	0.092365	13.64487
	Al 396.153	0.1663	24.4744	1.135307	167.7169
3-30 3-1	Al 308.215	0.1712	26.4801	1.440219	223.806
	Cr 267.716	0.1712	26.4801	2.785003	432.7817
	Fe 259.939	0.1712	26.4801	0.031055	4.825931
	Ni 231.604	0.1712	26.4801	-0.05914	-9.18967
	Si 251.611	0.1712	26.4801	9.406953	1461.814
	Mn 257.610	0.1712	26.4801	0.000502	0.077976
	Mo 202.031	0.1712	26.4801	0.121525	18.88472
	Al 396.153	0.1712	26.4801	1.177317	182.9517

3-30 3-2	Al 308.215	0.0869	26.4841	0.840694	256.2144
	Cr 267.716	0.0869	26.4841	2.042446	622.4666
	Fe 259.939	0.0869	26.4841	-0.00703	-2.14221
	Ni 231.604	0.0869	26.4841	-0.0417	-12.7091
	Si 251.611	0.0869	26.4841	4.617797	1407.344
	Mn 257.610	0.0869	26.4841	-0.00188	-0.57342
	Mo 202.031	0.0869	26.4841	0.073661	22.44922
	Al 396.153	0.0869	26.4841	0.568368	173.2187
3-30 3-3	Al 308.215	0.0477	26.3142	0.823511	454.2986
	Cr 267.716	0.0477	26.3142	1.788304	986.5362
	Fe 259.939	0.0477	26.3142	0.013881	7.657786
	Ni 231.604	0.0477	26.3142	-0.07993	-44.0969
	Si 251.611	0.0477	26.3142	4.458867	2459.78
	Mn 257.610	0.0477	26.3142	-0.00093	-0.51305
	Mo 202.031	0.0477	26.3142	0.078024	43.04286
	Al 396.153	0.0477	26.3142	0.577835	318.7687
3-30 5-1	Al 308.215	0.075	25.1496	1.11423	374.8328
	Cr 267.716	0.075	25.1496	1.751807	589.3173
	Fe 259.939	0.075	25.1496	0.051179	17.21682
	Ni 231.604	0.075	25.1496	-0.01108	-3.72657
	Si 251.611	0.075	25.1496	6.637286	2232.819
	Mn 257.610	0.075	25.1496	-0.0021	-0.70791
	Mo 202.031	0.075	25.1496	0.011891	4.000058
	Al 396.153	0.075	25.1496	0.780039	262.4094
3-30 5-2	Al 308.215	0.1372	26.7001	1.04839	204.2664
	Cr 267.716	0.1372	26.7001	2.146958	418.3093
	Fe 259.939	0.1372	26.7001	-0.00404	-0.78749
	Ni 231.604	0.1372	26.7001	-0.05383	-10.4882
	Si 251.611	0.1372	26.7001	6.561689	1278.468
	Mn 257.610	0.1372	26.7001	-0.00209	-0.40801
	Mo 202.031	0.1372	26.7001	0.060688	11.82434
	Al 396.153	0.1372	26.7001	0.736599	143.5176
3-30 5-3	Al 308.215	0.1364	23.7588	1.250915	218.6267
	Cr 267.716	0.1364	23.7588	2.641346	461.6371
	Fe 259.939	0.1364	23.7588	0.034196	5.976567
	Ni 231.604	0.1364	23.7588	-0.01392	-2.43225
	Si 251.611	0.1364	23.7588	8.771295	1532.99
	Mn 257.610	0.1364	23.7588	0.000435	0.075986

	Mo 202.031	0.1364	23.7588	0.076841	13.42975
	Al 396.153	0.1364	23.7588	0.978594	171.0323
3-30 6-1	Al 308.215	0.1479	25.0294	1.335527	226.3245
	Cr 267.716	0.1479	25.0294	2.796134	473.8455
	Fe 259.939	0.1479	25.0294	0.008314	1.408943
	Ni 231.604	0.1479	25.0294	-0.04691	-7.94964
	Si 251.611	0.1479	25.0294	9.380707	1589.697
	Mn 257.610	0.1479	25.0294	0.001894	0.321005
	Mo 202.031	0.1479	25.0294	0.100819	17.08521
	Al 396.153	0.1479	25.0294	1.029608	174.4821
3-306-2	Al 308.215	0.1884	26.429	1.362887	191.822
	Cr 267.716	0.1884	26.429	3.061794	430.9377
	Fe 259.939	0.1884	26.429	-0.00344	-0.48482
	Ni 231.604	0.1884	26.429	-0.04365	-6.14408
	Si 251.611	0.1884	26.429	9.905281	1394.137
	Mn 257.610	0.1884	26.429	0.000601	0.084581
	Mo 202.031	0.1884	26.429	0.094826	13.34639
	Al 396.153	0.1884	26.429	1.055158	148.5101
3-30 6-3	Al 308.215	0.3117	25.2862	0.912485	74.02401
	Cr 267.716	0.3117	25.2862	2.256885	183.0864
	Fe 259.939	0.3117	25.2862	-0.00618	-0.50106
	Ni 231.604	0.3117	25.2862	-0.02837	-2.30159
	Si 251.611	0.3117	25.2862	4.701657	381.4149
	Mn 257.610	0.3117	25.2862	-0.00047	-0.03807
	Mo 202.031	0.3117	25.2862	0.180919	14.67676
	Al 396.153	0.3117	25.2862	0.605019	49.08126
3-30 7-1	Al 308.215	0.1826	28.0509	1.28822	198.6131
	Cr 267.716	0.1826	28.0509	2.776214	428.0266
	Fe 259.939	0.1826	28.0509	0.039909	6.153085
	Ni 231.604	0.1826	28.0509	-0.06314	-9.73439
	Si 251.611	0.1826	28.0509	8.733612	1346.516
	Mn 257.610	0.1826	28.0509	-0.00016	-0.0245
	Mo 202.031	0.1826	28.0509	0.093657	14.43964
	Al 396.153	0.1826	28.0509	1.008323	155.4596
3-30 7-2	Al 308.215	0.1076	25.8074	1.128154	271.2203
	Cr 267.716	0.1076	25.8074	2.389223	574.3949
	Fe 259.939	0.1076	25.8074	-0.00862	-2.07331

	Ni 231.604	0.1076	25.8074	-0.05594	-13.4497
	Si 251.611	0.1076	25.8074	7.567176	1819.231
	Mn 257.610	0.1076	25.8074	-0.00113	-0.27064
	Mo 202.031	0.1076	25.8074	0.053631	12.89353
	Al 396.153	0.1076	25.8074	0.861082	207.0135
3-30 7-3	Al 308.215	-0.0276	23.2677	0.668185	-563.302
	Cr 267.716	-0.0276	23.2677	1.65058	-1391.49
	Fe 259.939	-0.0276	23.2677	-0.00084	0.711353
	Ni 231.604	-0.0276	23.2677	-0.02971	25.04319
	Si 251.611	-0.0276	23.2677	3.306209	-2787.24
	Mn 257.610	-0.0276	23.2677	-0.00055	0.465572
	Mo 202.031	-0.0276	23.2677	0.003992	-3.36575
	Al 396.153	-0.0276	23.2677	0.438241	-369.452
3-30 8-1	Al 308.215	0.1451	26.1751	0.158805	28.64741
	Cr 267.716	0.1451	26.1751	2.186323	394.3986
	Fe 259.939	0.1451	26.1751	-0.00982	-1.77072
	Ni 231.604	0.1451	26.1751	-0.05289	-9.54117
	Si 251.611	0.1451	26.1751	4.135305	745.9822
	Mn 257.610	0.1451	26.1751	-0.00061	-0.11023
	Mo 202.031	0.1451	26.1751	-0.05315	-9.58728
	Al 396.153	0.1451	26.1751	0.464161	83.7317
3-30 8-2	Al 308.215	0.2094	27.0264	-0.11337	-14.6738
	Cr 267.716	0.2094	27.0264	2.244313	290.4917
	Fe 259.939	0.2094	27.0264	0.014403	1.864306
	Ni 231.604	0.2094	27.0264	0.012444	1.610681
	Si 251.611	0.2094	27.0264	4.668288	604.2379
	Mn 257.610	0.2094	27.0264	-0.00192	-0.24812
	Mo 202.031	0.2094	27.0264	0.041685	5.395521
	Al 396.153	0.2094	27.0264	0.373801	48.38282
3-30 8-3	Al 308.215	0.1209	25.9002	-0.34177	-73.3676
	Cr 267.716	0.1209	25.9002	0.447948	96.16055
	Fe 259.939	0.1209	25.9002	-0.01377	-2.95591
	Ni 231.604	0.1209	25.9002	-0.02718	-5.83452
	Si 251.611	0.1209	25.9002	0.705462	151.441
	Mn 257.610	0.1209	25.9002	-0.00248	-0.5314
	Mo 202.031	0.1209	25.9002	0.09617	20.6447
	Al 396.153	0.1209	25.9002	0.047287	10.15113
	Al 308.215	0.1209	25.9002	1.424773	305.8549
	Cr 267.716	0.1209	25.9002	3.5442	760.8303

	Fe 259.939	0.1209	25.9002	0.007661	1.64459
	Ni 231.604	0.1209	25.9002	-0.04	-8.58701
	Si 251.611	0.1209	25.9002	5.693713	1222.264
	Mn 257.610	0.1209	25.9002	0.000364	0.078097
	Mo 202.031	0.1209	25.9002	0.097768	20.98768
	Al 396.153	0.1209	25.9002	1.040285	223.3171
4-2 3d-1	Al 308.215	0.1268	26.0593	1.288918	265.8516
	Cr 267.716	0.1268	26.0593	13.84202	2855.048
	Fe 259.939	0.1268	26.0593	0.022739	4.690183
	Ni 231.604	0.1268	26.0593	-0.04516	-9.31475
	Si 251.611	0.1268	26.0593	8.365082	1725.377
	Mn 257.610	0.1268	26.0593	-0.00218	-0.45031
	Mo 202.031	0.1268	26.0593	0.016324	3.367081
	Al 396.153	0.1268	26.0593	0.918755	189.502
4-2 3d-2	Al 308.215	0.156	27.2372	1.289536	225.8018
	Cr 267.716	0.156	27.2372	16.22255	2840.621
	Fe 259.939	0.156	27.2372	0.027379	4.794115
	Ni 231.604	0.156	27.2372	-0.03367	-5.8966
	Si 251.611	0.156	27.2372	8.703129	1523.946
	Mn 257.610	0.156	27.2372	-0.0006	-0.10532
	Mo 202.031	0.156	27.2372	0.07273	12.73524
	Al 396.153	0.156	27.2372	0.937375	164.1374
4-4 5d-1	Al 308.215	0.192	22.8616	1.598987	191.2139
	Cr 267.716	0.192	22.8616	26.35165	3151.245
	Fe 259.939	0.192	22.8616	0.108849	13.01663
	Ni 231.604	0.192	22.8616	-0.03447	-4.12176
	Si 251.611	0.192	22.8616	12.07235	1443.665
	Mn 257.610	0.192	22.8616	-0.00088	-0.10482
	Mo 202.031	0.192	22.8616	0.078397	9.375011
	Al 396.153	0.192	22.8616	1.337276	159.9173
4-4 5d-2	Al 308.215	0.224	25.8995	1.533171	177.9348
	Cr 267.716	0.224	25.8995	27.5502	3197.385
	Fe 259.939	0.224	25.8995	0.070412	8.171803
	Ni 231.604	0.224	25.8995	-0.02741	-3.18137
	Si 251.611	0.224	25.8995	12.17985	1413.553
	Mn 257.610	0.224	25.8995	-0.00104	-0.12111
	Mo 202.031	0.224	25.8995	0.027918	3.24007
	Al 396.153	0.224	25.8995	1.285185	149.1544

4-4 5d-3	Al 308.215	0.1228	25.6212	1.326721	277.7633
	Cr 267.716	0.1228	25.6212	16.53683	3462.163
	Fe 259.939	0.1228	25.6212	0.034355	7.192504
	Ni 231.604	0.1228	25.6212	-0.0586	-12.2683
	Si 251.611	0.1228	25.6212	9.478258	1984.375
	Mn 257.610	0.1228	25.6212	-0.00148	-0.30986
	Mo 202.031	0.1228	25.6212	0.063622	13.31995
	Al 396.153	0.1228	25.6212	0.999201	209.1934

Recovery boiler salt, Ni

ni 1-1	Al 308.215	0.1485	12.5344	1.618472	137.3674
	Cr 267.716	0.1485	12.5344	0.009233	0.783682
	Fe 259.939	0.1485	12.5344	0.299098	25.3859
	Ni 231.604	0.1485	12.5344	0.022854	1.939765
	Si 251.611	0.1485	12.5344	0.38517	32.69118
	Mn 257.610	0.1485	12.5344	0.011422	0.96947
	Mo 202.031	0.1485	12.5344	-0.00866	-0.73535
	Al 396.153	0.1485	12.5344	1.742985	147.9354
4-10 ni 1-2	Al 308.215	0.1882	12.6047	-0.21645	-14.658
	Cr 267.716	0.1882	12.6047	0.001528	0.103505
	Fe 259.939	0.1882	12.6047	0.009848	0.666927
	Ni 231.604	0.1882	12.6047	-0.00489	-0.33101
	Si 251.611	0.1882	12.6047	0.406452	27.52448
	Mn 257.610	0.1882	12.6047	0.002893	0.195933
	Mo 202.031	0.1882	12.6047	-0.0239	-1.6185
	Al 396.153	0.1882	12.6047	0.013058	0.884295
ni 1-3	Al 308.215	0.1621	13.0417	-0.15609	-12.6847
	Cr 267.716	0.1621	13.0417	0.002596	0.210945
	Fe 259.939	0.1621	13.0417	0.004331	0.351984
	Ni 231.604	0.1621	13.0417	0.022631	1.839148
	Si 251.611	0.1621	13.0417	0.128017	10.40365
	Mn 257.610	0.1621	13.0417	0.005954	0.483908
	Mo 202.031	0.1621	13.0417	-0.18066	-14.6818
	Al 396.153	0.1621	13.0417	0.025854	2.101118
ni 2-1	Al 308.215	0.1603	12.8476	0.021167	1.715319
	Cr 267.716	0.1603	12.8476	0.020448	1.784624
	Fe 259.939	0.1603	12.8476	0.012452	1.164425
	Ni 231.604	0.1603	12.8476	0.028677	2.86069

	Si 251.611	0.1603	12.8476	0.139544	14.79064
	Mn 257.610	0.1603	12.8476	0.003418	0.383588
	Mo 202.031	0.1603	12.8476	-0.01705	-2.01979
	Al 396.153	0.1603	12.8476	0.113328	14.13281
ni 2-2	Al 308.215	0.0999	12.5392	-0.02143	-2.71441
	Cr 267.716	0.0999	12.5392	0.006896	0.873296
	Fe 259.939	0.0999	12.5392	0.044675	5.657849
	Ni 231.604	0.0999	12.5392	0.037425	4.739725
	Si 251.611	0.0999	12.5392	0.188845	23.91645
	Mn 257.610	0.0999	12.5392	0.004044	0.512134
	Mo 202.031	0.0999	12.5392	-0.19402	-24.5719
	Al 396.153	0.0999	12.5392	0.019218	2.43385
ni 2-3	Al 308.215	0.1755	13.3346	-0.0554	-4.20915
	Cr 267.716	0.1755	13.3346	0.005934	0.450885
	Fe 259.939	0.1755	13.3346	0.006957	0.528568
	Ni 231.604	0.1755	13.3346	0.070616	5.365433
	Si 251.611	0.1755	13.3346	0.382839	29.08832
	Mn 257.610	0.1755	13.3346	0.005002	0.380072
	Mo 202.031	0.1755	13.3346	0.03778	2.870516
	Al 396.153	0.1755	13.3346	0.026187	1.9897
ni 3-1	Al 308.215	0.0748	12.8307	-0.02657	-4.60403
	Cr 267.716	0.0748	12.8307	0.022098	3.829693
	Fe 259.939	0.0748	12.8307	0.005094	0.882844
	Ni 231.604	0.0748	12.8307	-0.07607	-13.1827
	Si 251.611	0.0748	12.8307	0.123354	21.37773
	Mn 257.610	0.0748	12.8307	0.003285	0.569341
	Mo 202.031	0.0748	12.8307	-0.08544	-14.8075
	Al 396.153	0.0748	12.8307	0.01508	2.613483
ni 3-2	Al 308.215	0.1452	13.185	-0.02306	-2.11187
	Cr 267.716	0.1452	13.185	0.017435	1.596989
	Fe 259.939	0.1452	13.185	0.013985	1.280978
	Ni 231.604	0.1452	13.185	0.00729	0.667713
	Si 251.611	0.1452	13.185	0.148808	13.63019
	Mn 257.610	0.1452	13.185	0.004261	0.390305
	Mo 202.031	0.1452	13.185	0.007679	0.703388
	Al 396.153	0.1452	13.185	0.01725	1.580011
ni 3-3	Al 308.215	0.1411	13.1076	-0.1065	-9.99502
	Cr 267.716	0.1411	13.1076	0.01456	1.366467

	Fe 259.939	0.1411	13.1076	0.001693	0.158921
	Ni 231.604	0.1411	13.1076	0.013665	1.282471
	Si 251.611	0.1411	13.1076	0.253186	23.76218
	Mn 257.610	0.1411	13.1076	0.003751	0.352052
	Mo 202.031	0.1411	13.1076	-0.23896	-22.4273
	Al 396.153	0.1411	13.1076	0.002696	0.253062
20ppm	Al 308.215	0	0	19.20355	#DIV/0!
	Cr 267.716	0	0	19.22198	#DIV/0!
	Fe 259.939	0	0	19.22499	#DIV/0!
	Ni 231.604	0	0	19.17753	#DIV/0!
	Si 251.611	0	0	19.28934	#DIV/0!
	Mn 257.610	0	0	19.1485	#DIV/0!
	Mo 202.031	0	0	19.61867	#DIV/0!
	Al 396.153	0	0	19.21408	#DIV/0!
ni 4-1	Al 308.215	0.1454	13.02	0.135001	12.22113
	Cr 267.716	0.1454	13.02	0.016115	1.45884
	Fe 259.939	0.1454	13.02	0.01883	1.704597
	Ni 231.604	0.1454	13.02	0.057303	5.187451
	Si 251.611	0.1454	13.02	0.200383	18.13994
	Mn 257.610	0.1454	13.02	0.009322	0.84388
	Mo 202.031	0.1454	13.02	-0.07005	-6.34102
	Al 396.153	0.1454	13.02	0.212118	19.2022
ni 4-2	Al 308.215	0.1668	13.3941	-0.07002	-5.67927
	Cr 267.716	0.1668	13.3941	0.01954	1.584987
	Fe 259.939	0.1668	13.3941	0.041322	3.351775
	Ni 231.604	0.1668	13.3941	0.016701	1.354657
	Si 251.611	0.1668	13.3941	0.239046	19.38992
	Mn 257.610	0.1668	13.3941	0.005865	0.475721
	Mo 202.031	0.1668	13.3941	-0.09962	-8.08086
	Al 396.153	0.1668	13.3941	0.032179	2.61014
	Al 308.215	0.1239	12.7844	-0.01308	-1.36505
ni 4-3	Cr 267.716	0.1239	12.7844	0.006754	0.704856
	Fe 259.939	0.1239	12.7844	0.002254	0.235241
	Ni 231.604	0.1239	12.7844	1.048698	109.4455
	Si 251.611	0.1239	12.7844	0.192618	20.10222
	Mn 257.610	0.1239	12.7844	0.003163	0.330126
	Mo 202.031	0.1239	12.7844	0.078326	8.174314
	Al 396.153	0.1239	12.7844	0.039806	4.154314

ni 5-1	Al 308.215	0.0885	12.9258	0.271749	40.13286
	Cr 267.716	0.0885	12.9258	0.005837	0.861974
	Fe 259.939	0.0885	12.9258	0.011043	1.630901
	Ni 231.604	0.0885	12.9258	0.021306	3.146526
	Si 251.611	0.0885	12.9258	0.260581	38.48348
	Mn 257.610	0.0885	12.9258	0.002666	0.39367
	Mo 202.031	0.0885	12.9258	-0.10905	-16.1045
	Al 396.153	0.0885	12.9258	0.356658	52.67252
ni 5-2	Al 308.215	0.2518	13.2274	-0.16109	-8.55571
	Cr 267.716	0.2518	13.2274	0.028912	1.535506
	Fe 259.939	0.2518	13.2274	0.010706	0.568589
	Ni 231.604	0.2518	13.2274	0.025145	1.335474
	Si 251.611	0.2518	13.2274	0.318466	16.91383
	Mn 257.610	0.2518	13.2274	0.004601	0.244372
	Mo 202.031	0.2518	13.2274	-0.15993	-8.49379
	Al 396.153	0.2518	13.2274	0.070762	3.758203
ni 5-3	Al 308.215	0.1327	12.9686	0.032379	3.164375
	Cr 267.716	0.1327	12.9686	0.019558	1.911424
	Fe 259.939	0.1327	12.9686	0.029509	2.883923
	Ni 231.604	0.1327	12.9686	0.005599	0.547173
	Si 251.611	0.1327	12.9686	0.325257	31.78694
	Mn 257.610	0.1327	12.9686	0.004625	0.452013
	Mo 202.031	0.1327	12.9686	0.034097	3.332275
	Al 396.153	0.1327	12.9686	0.066142	6.463936
ni 6-1	Al 308.215	0.1989	13.0857	0.881155	58.6892
	Cr 267.716	0.1989	13.0857	0.039811	2.651636
	Fe 259.939	0.1989	13.0857	0.056106	3.736949
	Ni 231.604	0.1989	13.0857	0.094032	6.262978
	Si 251.611	0.1989	13.0857	0.185744	12.37144
	Mn 257.610	0.1989	13.0857	0.006163	0.410505
	Mo 202.031	0.1989	13.0857	-0.12898	-8.59076
	Al 396.153	0.1989	13.0857	0.922366	61.43403
ni 6-2	Al 308.215	0.1097	12.674	0.170185	19.88838
	Cr 267.716	0.1097	12.674	0.007309	0.854129
	Fe 259.939	0.1097	12.674	-0.00551	-0.64352
	Ni 231.604	0.1097	12.674	-0.00371	-0.43369
	Si 251.611	0.1097	12.674	0.134528	15.72138
	Mn 257.610	0.1097	12.674	0.004478	0.523305
	Mo 202.031	0.1097	12.674	-0.16432	-19.203

	Al 396.153	0.1097	12.674	0.141471	16.53271
ni 6-3	Al 308.215	-0.791	14.1256	-0.00751	0.135529
	Cr 267.716	-0.791	14.1256	0.026264	-0.47421
	Fe 259.939	-0.791	14.1256	0.009435	-0.17036
	Ni 231.604	-0.791	14.1256	-0.00122	0.022089
	Si 251.611	-0.791	14.1256	0.24532	-4.42944
	Mn 257.610	-0.791	14.1256	0.004746	-0.0857
	Mo 202.031	-0.791	14.1256	0.135659	-2.44943
	Al 396.153	-0.791	14.1256	0.103285	-1.8649
20ppm	Al 308.215	0	0	19.7005	#DIV/0!
	Cr 267.716	0	0	19.68527	#DIV/0!
	Fe 259.939	0	0	19.64879	#DIV/0!
	Ni 231.604	0	0	19.43585	#DIV/0!
	Si 251.611	0	0	19.60428	#DIV/0!
	Mn 257.610	0	0	19.56009	#DIV/0!
	Mo 202.031	0	0	20.39333	#DIV/0!
	Al 396.153	0	0	19.64558	#DIV/0!
ni 7-1	Al 308.215	0.1933	12.8764	-0.09379	-6.31267
	Cr 267.716	0.1933	12.8764	0.034775	2.340625
	Fe 259.939	0.1933	12.8764	0.012033	0.809922
	Ni 231.604	0.1933	12.8764	0.090638	6.100566
	Si 251.611	0.1933	12.8764	0.28133	18.93559
	Mn 257.610	0.1933	12.8764	0.011107	0.74758
	Mo 202.031	0.1933	12.8764	-0.08864	-5.96631
	Al 396.153	0.1933	12.8764	0.067436	4.538924
ni 7-2	Al 308.215	0.1631	13.1907	0.10067	8.335268
	Cr 267.716	0.1631	13.1907	0.015074	1.248083
	Fe 259.939	0.1631	13.1907	0.016923	1.401158
	Ni 231.604	0.1631	13.1907	0.830074	68.72818
	Si 251.611	0.1631	13.1907	0.269316	22.29876
	Mn 257.610	0.1631	13.1907	0.005873	0.486278
	Mo 202.031	0.1631	13.1907	-0.13919	-11.5246
	Al 396.153	0.1631	13.1907	0.151753	12.5648
ni 7-3	Al 308.215	0.1203	12.8635	0.022028	2.341204
	Cr 267.716	0.1203	12.8635	0.008835	0.939018
	Fe 259.939	0.1203	12.8635	0.007457	0.792491
	Ni 231.604	0.1203	12.8635	0.020178	2.14458
	Si 251.611	0.1203	12.8635	0.253422	26.93396

	Mn 257.610	0.1203	12.8635	0.006059	0.643957
	Mo 202.031	0.1203	12.8635	-0.1058	-11.2448
	Al 396.153	0.1203	12.8635	0.051834	5.508971
ni 8-1	Al 308.215	0.0886	13.0514	0.425572	63.35303
	Cr 267.716	0.0886	13.0514	0.021802	3.245597
	Fe 259.939	0.0886	13.0514	-0.01031	-1.53461
	Ni 231.604	0.0886	13.0514	0.024587	3.660146
	Si 251.611	0.0886	13.0514	0.180497	26.8698
	Mn 257.610	0.0886	13.0514	0.003509	0.522307
	Mo 202.031	0.0886	13.0514	-0.11395	-16.9625
	Al 396.153	0.0886	13.0514	0.320212	47.66858
ni 8-2	Al 308.215	0.2137	12.9051	0.165279	10.08398
	Cr 267.716	0.2137	12.9051	0.036212	2.209375
	Fe 259.939	0.2137	12.9051	0.024122	1.471742
	Ni 231.604	0.2137	12.9051	0.377382	23.02472
	Si 251.611	0.2137	12.9051	0.207278	12.64641
	Mn 257.610	0.2137	12.9051	0.005778	0.352553
	Mo 202.031	0.2137	12.9051	0.047026	2.869126
	Al 396.153	0.2137	12.9051	0.290087	17.6987
ni 8-3	Al 308.215	0.1438	12.8511	0.891257	80.65439
	Cr 267.716	0.1438	12.8511	0.015805	1.430298
	Fe 259.939	0.1438	12.8511	0.018539	1.67771
	Ni 231.604	0.1438	12.8511	0.04599	4.161853
	Si 251.611	0.1438	12.8511	0.202308	18.3079
	Mn 257.610	0.1438	12.8511	0.004204	0.380463
	Mo 202.031	0.1438	12.8511	0.235571	21.31802
	Al 396.153	0.1438	12.8511	0.787162	71.23434
ni 1d-1	Al 308.215	0.1595	12.9079	0.364152	29.82968
	Cr 267.716	0.1595	12.9079	0.012259	1.004172
	Fe 259.939	0.1595	12.9079	0.013739	1.125471
	Ni 231.604	0.1595	12.9079	0.045745	3.747246
	Si 251.611	0.1595	12.9079	0.156885	12.85126
	Mn 257.610	0.1595	12.9079	0.006549	0.536452
	Mo 202.031	0.1595	12.9079	0.134284	10.99991
	Al 396.153	0.1595	12.9079	0.404019	33.09538
1d-2	Al 308.215	0.1841	13.0462	0.094295	6.722298
	Cr 267.716	0.1841	13.0462	0.029976	2.13702
	Fe 259.939	0.1841	13.0462	0.007034	0.501466

	Ni 231.604	0.1841	13.0462	0.039041	2.78327
	Si 251.611	0.1841	13.0462	0.193499	13.79456
	Mn 257.610	0.1841	13.0462	0.006782	0.483516
	Mo 202.031	0.1841	13.0462	-0.06787	-4.83854
	Al 396.153	0.1841	13.0462	0.215341	15.35166
1d-3	Al 308.215	0.1347	13.1048	0.256837	25.32904
	Cr 267.716	0.1347	13.1048	0.012743	1.256732
	Fe 259.939	0.1347	13.1048	-0.00264	-0.26031
	Ni 231.604	0.1347	13.1048	0.065949	6.503879
	Si 251.611	0.1347	13.1048	0.284259	28.03337
	Mn 257.610	0.1347	13.1048	0.005733	0.565428
	Mo 202.031	0.1347	13.1048	-0.42627	-42.0385
	Al 396.153	0.1347	13.1048	0.232123	22.89174
20ppm	Al 308.215	0	0	20.05266	#DIV/0!
	Cr 267.716	0	0	19.94892	#DIV/0!
	Fe 259.939	0	0	19.89863	#DIV/0!
	Ni 231.604	0	0	19.25835	#DIV/0!
	Si 251.611	0	0	19.3591	#DIV/0!
	Mn 257.610	0	0	19.7969	#DIV/0!
	Mo 202.031	0	0	20.18191	#DIV/0!
	Al 396.153	0	0	19.88704	#DIV/0!
2d-1	Al 308.215	0.1832	12.8757	0.322487	22.29701
	Cr 267.716	0.1832	12.8757	0.020272	1.401625
	Fe 259.939	0.1832	12.8757	0.020834	1.440479
	Ni 231.604	0.1832	12.8757	0.076112	5.262445
	Si 251.611	0.1832	12.8757	0.302544	20.91816
	Mn 257.610	0.1832	12.8757	0.008933	0.617608
	Mo 202.031	0.1832	12.8757	0.23997	16.5917
	Al 396.153	0.1832	12.8757	0.37813	26.1442
2d-2	Al 308.215	0.1487	12.9082	1.935715	170.2583
	Cr 267.716	0.1487	12.9082	0.030304	2.665407
	Fe 259.939	0.1487	12.9082	0.021823	1.919448
	Ni 231.604	0.1487	12.9082	0.037801	3.324878
	Si 251.611	0.1487	12.9082	0.294804	25.92985
	Mn 257.610	0.1487	12.9082	0.006385	0.561558
	Mo 202.031	0.1487	12.9082	0.028183	2.47888
	Al 396.153	0.1487	12.9082	1.798571	158.1956
2d-3	Al 308.215	0.1852	12.8114	0.393569	27.52288

	Cr 267.716	0.1852	12.8114	0.012224	0.854821
	Fe 259.939	0.1852	12.8114	0.021073	1.473697
	Ni 231.604	0.1852	12.8114	0.014229	0.995074
	Si 251.611	0.1852	12.8114	0.229668	16.06098
	Mn 257.610	0.1852	12.8114	0.008269	0.578248
	Mo 202.031	0.1852	12.8114	0.075174	5.257019
	Al 396.153	0.1852	12.8114	0.457183	31.97144
3d-1	Al 308.215	0.2182	12.5889	0.955963	55.85682
	Cr 267.716	0.2182	12.5889	0.027762	1.622127
	Fe 259.939	0.2182	12.5889	0.014601	0.853125
	Ni 231.604	0.2182	12.5889	0.013876	0.810798
	Si 251.611	0.2182	12.5889	0.369004	21.56086
	Mn 257.610	0.2182	12.5889	0.008079	0.472081
	Mo 202.031	0.2182	12.5889	-0.0358	-2.09152
	Al 396.153	0.2182	12.5889	1.039232	60.72219
3d-2	Al 308.215	0.2631	12.9455	3.172238	154.7391
	Cr 267.716	0.2631	12.9455	0.03322	1.620441
	Fe 259.939	0.2631	12.9455	0.07779	3.79452
	Ni 231.604	0.2631	12.9455	0.025713	1.254248
	Si 251.611	0.2631	12.9455	0.290915	14.19059
	Mn 257.610	0.2631	12.9455	0.009562	0.466427
	Mo 202.031	0.2631	12.9455	-0.17152	-8.36653
	Al 396.153	0.2631	12.9455	3.124724	152.4214
3d-3	Al 308.215	0.3107	12.9767	0.929756	39.13324
	Cr 267.716	0.3107	12.9767	0.05487	2.309456
	Fe 259.939	0.3107	12.9767	0.026148	1.100581
	Ni 231.604	0.3107	12.9767	0.042602	1.793097
	Si 251.611	0.3107	12.9767	0.364965	15.36132
	Mn 257.610	0.3107	12.9767	0.009796	0.412321
	Mo 202.031	0.3107	12.9767	-0.17558	-7.39031
	Al 396.153	0.3107	12.9767	1.069315	45.00726

Recovery boiler salt, Fe

4-24 fe

1-1	Al 308.215	0.0842	13.1176	0.24162	38.17367
	Cr 267.716	0.0842	13.1176	0.009203	1.453951
	Fe 259.939	0.0842	13.1176	0.189816	29.98914
	Ni 231.604	0.0842	13.1176	0.018447	2.914464
	Si 251.611	0.0842	13.1176	0.100888	15.93931

	Mn 257.610	0.0842	13.1176	0.008761	1.38413
	Mo 202.031	0.0842	13.1176	0.201301	31.80363
	Al 396.153	0.0842	13.1176	0.342837	54.16499
fe 1-2	Al 308.215	0.0913	12.9677	0.19137	27.5795
	Cr 267.716	0.0913	12.9677	0.002478	0.357179
	Fe 259.939	0.0913	12.9677	0.100509	14.48493
	Ni 231.604	0.0913	12.9677	0.049543	7.139921
	Si 251.611	0.0913	12.9677	0.079571	11.46745
	Mn 257.610	0.0913	12.9677	0.007212	1.039365
	Mo 202.031	0.0913	12.9677	0.156867	22.60713
	Al 396.153	0.0913	12.9677	0.277744	40.02731
fe1-3	Al 308.215	0.1578	12.7595	-0.10208	-8.37307
	Cr 267.716	0.1578	12.7595	0.060888	4.994437
	Fe 259.939	0.1578	12.7595	0.24299	19.93145
	Ni 231.604	0.1578	12.7595	-0.00774	-0.63469
	Si 251.611	0.1578	12.7595	0.174223	14.29078
	Mn 257.610	0.1578	12.7595	0.012338	1.012021
	Mo 202.031	0.1578	12.7595	0.150648	12.35704
	Al 396.153	0.1578	12.7595	0.062839	5.154471
fe 2-1	Al 308.215	0.0716	12.8057	0.249368	45.24535
	Cr 267.716	0.0716	12.8057	0.026947	4.889221
	Fe 259.939	0.0716	12.8057	0.267809	48.59123
	Ni 231.604	0.0716	12.8057	-0.03192	-5.79079
	Si 251.611	0.0716	12.8057	0.247427	44.89306
	Mn 257.610	0.0716	12.8057	0.006528	1.184469
	Mo 202.031	0.0716	12.8057	0.177141	32.14048
	Al 396.153	0.0716	12.8057	0.273397	49.60516
fe 2-2	Al 308.215	0.0807	12.973	0.398629	64.99535
	Cr 267.716	0.0807	12.973	0.006678	1.088774
	Fe 259.939	0.0807	12.973	0.155993	25.43425
	Ni 231.604	0.0807	12.973	-0.00608	-0.99182
	Si 251.611	0.0807	12.973	0.270151	44.0474
	Mn 257.610	0.0807	12.973	0.009209	1.501522
	Mo 202.031	0.0807	12.973	0.130147	21.22003
	Al 396.153	0.0807	12.973	0.412261	67.21804
fe 2-3	Al 308.215	0.1085	12.9675	0.001836	0.222405
	Cr 267.716	0.1085	12.9675	0.032384	3.923254
	Fe 259.939	0.1085	12.9675	0.520164	63.01659

	Ni 231.604	0.1085	12.9675	0.00536	0.649307
	Si 251.611	0.1085	12.9675	0.118071	14.30396
	Mn 257.610	0.1085	12.9675	0.011084	1.342807
	Mo 202.031	0.1085	12.9675	0.085008	10.29847
	Al 396.153	0.1085	12.9675	0.111223	13.47433
fe 3-1	Al 308.215	0.0763	13.379	0.140488	24.94779
	Cr 267.716	0.0763	13.379	0.005236	0.929804
	Fe 259.939	0.0763	13.379	0.041381	7.348372
	Ni 231.604	0.0763	13.379	-0.00872	-1.54919
	Si 251.611	0.0763	13.379	0.159429	28.31122
	Mn 257.610	0.0763	13.379	0.007514	1.334383
	Mo 202.031	0.0763	13.379	0.030234	5.368945
	Al 396.153	0.0763	13.379	0.185564	32.95232
fe 3-2	Al 308.215	0.0315	12.7721	0.036138	14.85905
	Cr 267.716	0.0315	12.7721	0.003722	1.530271
	Fe 259.939	0.0315	12.7721	0.024768	10.18418
	Ni 231.604	0.0315	12.7721	0.006447	2.650931
	Si 251.611	0.0315	12.7721	0.051926	21.35101
	Mn 257.610	0.0315	12.7721	0.005285	2.173216
	Mo 202.031	0.0315	12.7721	0.115271	47.39683
	Al 396.153	0.0315	12.7721	0.027939	11.48798
fe 3-3	Al 308.215	0.0478	12.9288	0.023684	6.446528
	Cr 267.716	0.0478	12.9288	0.021719	5.911726
	Fe 259.939	0.0478	12.9288	0.301569	82.08553
	Ni 231.604	0.0478	12.9288	-0.00996	-2.71149
	Si 251.611	0.0478	12.9288	0.264148	71.89964
	Mn 257.610	0.0478	12.9288	0.005742	1.563057
	Mo 202.031	0.0478	12.9288	0.224456	61.09574
	Al 396.153	0.0478	12.9288	0.033005	8.983749
20ppm	Al 308.215	0	0	19.068	#DIV/0!
20ppm	Cr 267.716	0	0	18.80102	#DIV/0!
20ppm	Fe 259.939	0	0	18.87582	#DIV/0!
20ppm	Ni 231.604	0	0	18.8761	#DIV/0!
20ppm	Si 251.611	0	0	18.59387	#DIV/0!
20ppm	Mn 257.610	0	0	18.77093	#DIV/0!
20ppm	Mo 202.031	0	0	19.21787	#DIV/0!
20ppm	Al 396.153	0	0	18.85083	#DIV/0!
fe 4-1	Al 308.215	0.1855	13.1224	-0.3423	-24.5403

	Cr 267.716	0.1855	13.1224	0.02891	2.072671
	Fe 259.939	0.1855	13.1224	0.124646	8.936248
	Ni 231.604	0.1855	13.1224	0.022179	1.590105
	Si 251.611	0.1855	13.1224	0.094868	6.801396
	Mn 257.610	0.1855	13.1224	0.017438	1.250198
	Mo 202.031	0.1855	13.1224	0.051541	3.695162
	Al 396.153	0.1855	13.1224	0.067135	4.813114
fe 4-2	Al 308.215	0.0958	12.9078	0.2616	35.73766
	Cr 267.716	0.0958	12.9078	0.024566	3.356019
	Fe 259.939	0.0958	12.9078	0.084024	11.47865
	Ni 231.604	0.0958	12.9078	0.025822	3.527613
	Si 251.611	0.0958	12.9078	0.157723	21.54684
	Mn 257.610	0.0958	12.9078	0.010801	1.475575
	Mo 202.031	0.0958	12.9078	-0.00974	-1.33052
	Al 396.153	0.0958	12.9078	0.501918	68.56789
fe 4-3	Al 308.215	0.16	13.0554	-0.16404	-13.5887
	Cr 267.716	0.16	13.0554	0.042771	3.543066
	Fe 259.939	0.16	13.0554	5.830175	482.9608
	Ni 231.604	0.16	13.0554	-0.0227	-1.88031
	Si 251.611	0.16	13.0554	0.187149	15.5031
	Mn 257.610	0.16	13.0554	0.01684	1.394987
	Mo 202.031	0.16	13.0554	0.082505	6.834588
	Al 396.153	0.16	13.0554	0.20088	16.64048
fe 5-1	Al 308.215	0.0707	12.7492	0.037114	6.78728
	Cr 267.716	0.0707	12.7492	0.018757	3.430176
	Fe 259.939	0.0707	12.7492	0.042247	7.725795
	Ni 231.604	0.0707	12.7492	-0.01403	-2.56615
	Si 251.611	0.0707	12.7492	0.211775	38.7282
	Mn 257.610	0.0707	12.7492	0.008827	1.614147
	Mo 202.031	0.0707	12.7492	-0.02681	-4.90255
	Al 396.153	0.0707	12.7492	0.167171	30.5712
fe 5-2	Al 308.215	0.0789	13.2278	-0.05271	-8.96559
	Cr 267.716	0.0789	13.2278	0.013777	2.343224
	Fe 259.939	0.0789	13.2278	0.042967	7.307713
	Ni 231.604	0.0789	13.2278	0.055706	9.474381
	Si 251.611	0.0789	13.2278	0.038502	6.548298
	Mn 257.610	0.0789	13.2278	0.010622	1.80651
	Mo 202.031	0.0789	13.2278	-0.04483	-7.62464
	Al 396.153	0.0789	13.2278	0.131796	22.41576

fe 5-3	Al 308.215	0.0941	13.4632	-0.15927	-23.106
	Cr 267.716	0.0941	13.4632	0.030379	4.407278
	Fe 259.939	0.0941	13.4632	0.038318	5.558902
	Ni 231.604	0.0941	13.4632	0.028136	4.081763
	Si 251.611	0.0941	13.4632	0.209395	30.37784
	Mn 257.610	0.0941	13.4632	0.009762	1.416237
	Mo 202.031	0.0941	13.4632	-0.05609	-8.13734
	Al 396.153	0.0941	13.4632	0.109757	15.92297
fe 6-1	Al 308.215	0.2308	13.0005	1.832047	104.6656
	Cr 267.716	0.2308	13.0005	0.06433	3.675179
	Fe 259.939	0.2308	13.0005	0.728579	41.624
	Ni 231.604	0.2308	13.0005	-0.00924	-0.52776
	Si 251.611	0.2308	13.0005	0.275536	15.74151
	Mn 257.610	0.2308	13.0005	0.023469	1.34082
	Mo 202.031	0.2308	13.0005	0.013765	0.786391
	Al 396.153	0.2308	13.0005	2.23333	127.5911
fe 6-2	Al 308.215	0.4752	12.7795	0.080245	2.204985
	Cr 267.716	0.4752	12.7795	0.100765	2.768832
	Fe 259.939	0.4752	12.7795	0.890616	24.47246
	Ni 231.604	0.4752	12.7795	0.029614	0.813726
	Si 251.611	0.4752	12.7795	0.200451	5.508023
	Mn 257.610	0.4752	12.7795	0.045672	1.254972
	Mo 202.031	0.4752	12.7795	0.055646	1.529058
	Al 396.153	0.4752	12.7795	0.788455	21.66526
fe 6-3	Al 308.215	0.3571	13.0161	-0.33126	-12.2415
	Cr 267.716	0.3571	13.0161	0.065944	2.436932
	Fe 259.939	0.3571	13.0161	0.705308	26.06439
	Ni 231.604	0.3571	13.0161	0.016927	0.625518
	Si 251.611	0.3571	13.0161	0.185133	6.841539
	Mn 257.610	0.3571	13.0161	0.035779	1.322192
	Mo 202.031	0.3571	13.0161	0.044033	1.627226
	Al 396.153	0.3571	13.0161	0.208976	7.722648
20ppm	Al 308.215	0	0	19.62839	#DIV/0!
20ppm	Cr 267.716	0	0	19.40444	#DIV/0!
20ppm	Fe 259.939	0	0	19.45571	#DIV/0!
20ppm	Ni 231.604	0	0	19.19036	#DIV/0!
20ppm	Si 251.611	0	0	18.81363	#DIV/0!
20ppm	Mn 257.610	0	0	19.3624	#DIV/0!

20ppm	Mo 202.031	0	0	19.46161	#DIV/0!
20ppm	Al 396.153	0	0	19.35459	#DIV/0!
fe 7-1	Al 308.215	0.3373	13.0193	-0.40823	-15.9821
	Cr 267.716	0.3373	13.0193	0.069865	2.735217
	Fe 259.939	0.3373	13.0193	0.677977	26.54303
	Ni 231.604	0.3373	13.0193	0.013104	0.513012
	Si 251.611	0.3373	13.0193	0.328928	12.87762
	Mn 257.610	0.3373	13.0193	0.035075	1.373183
	Mo 202.031	0.3373	13.0193	0.04916	1.924623
	Al 396.153	0.3373	13.0193	0.132922	5.203953
fe 7-2	Al 308.215	0.183	13.1393	-0.29241	-21.2929
	Cr 267.716	0.183	13.1393	0.036362	2.647757
	Fe 259.939	0.183	13.1393	0.037679	2.743659
	Ni 231.604	0.183	13.1393	-0.03062	-2.2294
	Si 251.611	0.183	13.1393	0.13621	9.918447
	Mn 257.610	0.183	13.1393	0.018542	1.350186
	Mo 202.031	0.183	13.1393	0.002891	0.210529
	Al 396.153	0.183	13.1393	0.03158	2.29958
fe 7-3	Al 308.215	0.3571	13.0161	-0.00942	-0.3482
	Cr 267.716	0.3571	13.0161	0.063601	2.350363
	Fe 259.939	0.3571	13.0161	0.659257	24.3626
	Ni 231.604	0.3571	13.0161	-0.02341	-0.8652
	Si 251.611	0.3571	13.0161	0.445447	16.46132
	Mn 257.610	0.3571	13.0161	0.037829	1.397952
	Mo 202.031	0.3571	13.0161	-0.02864	-1.05834
	Al 396.153	0.3571	13.0161	0.456192	16.8584
fe 8-1	Al 308.215	0.0983	12.9036	-0.11347	-15.1059
	Cr 267.716	0.0983	12.9036	0.029453	3.921084
	Fe 259.939	0.0983	12.9036	0.099384	13.23076
	Ni 231.604	0.0983	12.9036	0.003047	0.405674
	Si 251.611	0.0983	12.9036	0.130611	17.38796
	Mn 257.610	0.0983	12.9036	0.012582	1.675012
	Mo 202.031	0.0983	12.9036	-0.01175	-1.5645
	Al 396.153	0.0983	12.9036	0.077433	10.30852
fe 8-2	Al 308.215	0.1101	13.1265	-0.10986	-13.2768
	Cr 267.716	0.1101	13.1265	0.025537	3.086123
	Fe 259.939	0.1101	13.1265	1.210751	146.3205
	Ni 231.604	0.1101	13.1265	-0.01156	-1.39678

	Si 251.611	0.1101	13.1265	0.128838	15.57017
	Mn 257.610	0.1101	13.1265	0.011643	1.407076
	Mo 202.031	0.1101	13.1265	-0.04107	-4.96367
	Al 396.153	0.1101	13.1265	0.053637	6.482067
fe 8-3	Al 308.215	0.1055	12.8348	0.01234	1.522471
	Cr 267.716	0.1055	12.8348	0.026998	3.330892
	Fe 259.939	0.1055	12.8348	0.383077	47.26229
	Ni 231.604	0.1055	12.8348	-0.00517	-0.63786
	Si 251.611	0.1055	12.8348	0.170175	20.99537
	Mn 257.610	0.1055	12.8348	0.015367	1.895915
	Mo 202.031	0.1055	12.8348	-0.03824	-4.71758
	Al 396.153	0.1055	12.8348	0.167824	20.70532
1d-1	Al 308.215	0.1097	13.0004	-0.13652	-16.399
	Cr 267.716	0.1097	13.0004	0.03242	3.894383
	Fe 259.939	0.1097	13.0004	0.495389	59.50677
	Ni 231.604	0.1097	13.0004	0.036571	4.392977
	Si 251.611	0.1097	13.0004	0.388712	46.69262
	Mn 257.610	0.1097	13.0004	0.018783	2.25619
	Mo 202.031	0.1097	13.0004	-0.01428	-1.71563
	Al 396.153	0.1097	13.0004	0.011002	1.321564
1d-2	Al 308.215	0.1465	12.7489	1.467811	129.6453
	Cr 267.716	0.1465	12.7489	0.043816	3.870103
	Fe 259.939	0.1465	12.7489	0.413099	36.48724
	Ni 231.604	0.1465	12.7489	0.04269	3.770608
	Si 251.611	0.1465	12.7489	0.18791	16.59725
	Mn 257.610	0.1465	12.7489	0.022738	2.008312
	Mo 202.031	0.1465	12.7489	-0.12262	-10.8309
	Al 396.153	0.1465	12.7489	1.604038	141.6776
1d-3	Al 308.215	0.0567	12.9772	0.195382	45.44329
	Cr 267.716	0.0567	12.9772	0.030448	7.081905
	Fe 259.939	0.0567	12.9772	0.032386	7.532646
	Ni 231.604	0.0567	12.9772	-0.00169	-0.39408
	Si 251.611	0.0567	12.9772	0.132545	30.82829
	Mn 257.610	0.0567	12.9772	0.012399	2.883758
	Mo 202.031	0.0567	12.9772	0.111666	25.97203
	Al 396.153	0.0567	12.9772	0.289812	67.4067
20ppm	Al 308.215	0	0	19.06846	#DIV/0!
	Cr 267.716	0	0	18.83236	#DIV/0!

	Fe 259.939	0	0	18.87353	#DIV/0!
	Ni 231.604	0	0	19.08903	#DIV/0!
	Si 251.611	0	0	18.71438	#DIV/0!
	Mn 257.610	0	0	18.7849	#DIV/0!
	Mo 202.031	0	0	19.32875	#DIV/0!
	Al 396.153	0	0	18.82113	#DIV/0!
2d-1	Al 308.215	0.0918	12.7267	-0.17407	-24.4837
	Cr 267.716	0.0918	12.7267	0.020898	2.939321
	Fe 259.939	0.0918	12.7267	0.272624	38.34557
	Ni 231.604	0.0918	12.7267	0.002483	0.349294
	Si 251.611	0.0918	12.7267	0.091172	12.82367
	Mn 257.610	0.0918	12.7267	0.018927	2.662152
	Mo 202.031	0.0918	12.7267	0.096103	13.51719
	Al 396.153	0.0918	12.7267	0.01572	2.211093
2d-2	Al 308.215	0.1641	12.9398	-0.20637	-16.5119
	Cr 267.716	0.1641	12.9398	0.036073	2.886266
	Fe 259.939	0.1641	12.9398	0.350223	28.02187
	Ni 231.604	0.1641	12.9398	0.016973	1.358019
	Si 251.611	0.1641	12.9398	0.108615	8.690483
	Mn 257.610	0.1641	12.9398	0.028711	2.297246
	Mo 202.031	0.1641	12.9398	0.014352	1.148347
	Al 396.153	0.1641	12.9398	0.046385	3.711305
2d-3	Al 308.215	0.0543	13.1342	-0.07163	-17.5722
	Cr 267.716	0.0543	13.1342	0.017196	4.21853
	Fe 259.939	0.0543	13.1342	0.057654	14.14361
	Ni 231.604	0.0543	13.1342	-0.00375	-0.92099
	Si 251.611	0.0543	13.1342	0.183276	44.96067
	Mn 257.610	0.0543	13.1342	0.012298	3.017002
	Mo 202.031	0.0543	13.1342	-0.0825	-20.2387
	Al 396.153	0.0543	13.1342	0.022331	5.478162
3d-1	Al 308.215	0.0373	12.8481	-0.04265	-14.9104
	Cr 267.716	0.0373	12.8481	0.01826	6.384022
	Fe 259.939	0.0373	12.8481	0.04284	14.97734
	Ni 231.604	0.0373	12.8481	0.029302	10.2444
	Si 251.611	0.0373	12.8481	0.15388	53.79871
	Mn 257.610	0.0373	12.8481	0.010004	3.497545
	Mo 202.031	0.0373	12.8481	0.012079	4.223162
	Al 396.153	0.0373	12.8481	0.055075	19.255

3d-2	Al 308.215	0.2825	12.8942	0.678224	31.4146
	Cr 267.716	0.2825	12.8942	0.053708	2.487702
	Fe 259.939	0.2825	12.8942	0.208592	9.661774
	Ni 231.604	0.2825	12.8942	0.042135	1.951654
	Si 251.611	0.2825	12.8942	0.203037	9.404464
	Mn 257.610	0.2825	12.8942	0.042528	1.96984
	Mo 202.031	0.2825	12.8942	-0.03032	-1.40441
	Al 396.153	0.2825	12.8942	1.08698	50.34776
3d-3	Al 308.215	0.113	13.0634	0.389087	45.6206
	Cr 267.716	0.113	13.0634	0.025127	2.946128
	Fe 259.939	0.113	13.0634	0.237844	27.88736
	Ni 231.604	0.113	13.0634	0.033037	3.873576
	Si 251.611	0.113	13.0634	0.198938	23.32558
	Mn 257.610	0.113	13.0634	0.022093	2.590366
	Mo 202.031	0.113	13.0634	-0.00065	-0.07666
	Al 396.153	0.113	13.0634	0.49381	57.89946

Date	mass sample	mass added water	measured ppm	actual ppm
NaOH, Fe				
1d	0.29	0.0772	15.2369	57.29340674
2d-1	0.366	0.03	30.4988	372.26836
2d-2	0.608	0.0919	29.6498	196.2589597
2d-3	0.786	0.0661	30.3985	361.6491831
3d-1	0.692	0.0861	31.2287	251.110806
3d-2	0.645	0.045	36.5972	524.7748667
3d-3	0.196	0.0593	31.0287	102.6064958
4d-1	0.534	0.0505	30.8454	326.3258139
4d-2	0.299	0.0198	32.0183	483.7351869
4d-3	0.732	0.128	30.8531	176.5269469
8d-1	0.425	0.0918	30.6204	141.8305556
8d-2	0.38	0.1075	31.1593	110.1975256

8d-3	0.619	0.082	31.2518	236.0262098
NaOH, Cr				
1d-1	0.05	31.5027	41.12	26072.30048
1d-2	2.0446	30.7701	40.67	616.039307
1d-3	0.0317	32.5931	33.77	34934.47909
2d-2	0.0182	31.853	25.26	44486.74615
2d-3	-0.012	31.5425	6.813	-18021.8044
2d-4	0.028	32.0005	32.97	37916.08875
3d-1	0.0003	31.6282	21.23	2252375.62
3d-2	0.0354	32.238	39.3	36011.67797
3d-3	0.0414	32.349	35.05	27556.58092
4d-1	0.0414	32.5021	34.68	27393.93304
4d-2	0.0481	31.8811	37.14	24771.14457
4d-3	0.0306	31.7717	34.86	36422.66216
9d-1	0.0167	31.7061	31.11	59437.05216
9d-2	0.0338	31.588	31.13	30474.24379
9d-3	0.0431	31.4986	38.78	28521.38534
10d-1	0.047	30.7927	39.56	26086.62153
10d-2	0.0319	31.1986	30.78	30296.20401
10d-3	0.0009	33.0815	19.53	722208.55
NaOH Ni				
1d-1	0.0411	24.3207	0.468	280.3672993
1d-2	0.0085	25.0957	0.048	143.4369882
3d-1	-0.0402	25.3984	0.038	-24.2823781
3d-2	0.0031	24.6995	0.233	1879.573419
3d-3	-0.0242	23.8944	0.052	-51.9731405
4d-1	0.0045	18.7239	0.042	177.59
4d-2	-0.0138	16.5935	0.368	-450.530667
4d-3	-0.014	16.7895	0.071	-86.7097643

5d-1	-0.0073	17.2803	0.468	-1125.37332	
5d-2	1.0946	18.5465	-0.013	-0.22375297	
5d-3	-0.0213	16.417	1.289	-1011.3022	
6d-1	0.0802	18.2837	0.05	11.58709476	
6d-2	0.098	18.3091	0.641	121.8514837	
6d-3	0.1266	17.4877	-0.022	-3.09247709	
7d-1	0.1091	18.1178	0.072	12.14298808	
7d-2	0.1153	18.5875	0.084	13.76689332	

NaOH,
Al

Al 1-1	Al 308.215	0.1055	18.848	5.821338992	1044.067
	Cr 267.716	0.1055	18.848	0.007748519	1.38971
	Fe 259.939	0.1055	18.848	0.052081942	9.340983
	Ni 231.604	0.1055	18.848	0.045619731	8.181974
	Si 251.611	0.1055	18.848	76.98743328	13807.82
	Mn 257.610	0.1055	18.848	0.083061129	14.89715
al 1-2	Al 308.215	0.1263	16.8576	4.465063371	606.7961
	Cr 267.716	0.1263	16.8576	0.009241588	1.255919
	Fe 259.939	0.1263	16.8576	-0.01347872	-1.83174
	Ni 231.604	0.1263	16.8576	0.023398896	3.179878
	Si 251.611	0.1263	16.8576	99.25435823	13488.53
	Mn 257.610	0.1263	16.8576	0.083994386	11.41472
al 1-3	Al 308.215	0.1331	18.8158	5.347458252	764.3812
	Cr 267.716	0.1331	18.8158	0.001768246	0.252758
	Fe 259.939	0.1331	18.8158	0.023182255	3.313739
	Ni 231.604	0.1331	18.8158	0.037365905	5.341191
	Si 251.611	0.1331	18.8158	111.3241972	15913
	Mn 257.610	0.1331	18.8158	0.081368162	11.631
Al 3-1	Al 308.215	0.0917	18.3677	5.18354623	1055.03
	Cr 267.716	0.0917	18.3677	0.011288668	2.297632
	Fe 259.939	0.0917	18.3677	0.269458838	54.84413

	Ni 231.604	0.0917	18.3677	0.041446323	8.43575
	Si 251.611	0.0917	18.3677	75.28945711	15323.99
	Mn 257.610	0.0917	18.3677	0.082167249	16.72386
Al 3-2	Al 308.215	0.1251	18.6599	3.761971627	570.2469
	Cr 267.716	0.1251	18.6599	0.010097193	1.530552
	Fe 259.939	0.1251	18.6599	-0.02905107	-4.40362
	Ni 231.604	0.1251	18.6599	0.022893277	3.470207
	Si 251.611	0.1251	18.6599	89.7260301	13600.85
	Mn 257.610	0.1251	18.6599	0.080332725	12.17699
Al 3-3	Al 308.215	0.1208	18.1362	4.291435334	654.9199
	Cr 267.716	0.1208	18.1362	0.007189935	1.097263
	Fe 259.939	0.1208	18.1362	-0.00795128	-1.21345
	Ni 231.604	0.1208	18.1362	-0.0083842	-1.27952
	Si 251.611	0.1208	18.1362	85.35351281	13025.88
	Mn 257.610	0.1208	18.1362	0.080231505	12.2442
20 PPM	Al 308.215	0	0	19.53621521	#DIV/0!
	Cr 267.716	0	0	20.29717099	#DIV/0!
	Fe 259.939	0	0	19.78648677	#DIV/0!
	Ni 231.604	0	0	29.54736684	#DIV/0!
	Si 251.611	0	0	20.39829311	#DIV/0!
	Mn 257.610	0	0	16.86639342	#DIV/0!
Al 4-1	Al 308.215	0.1016	19.5417	1.60749657	313.8479
	Cr 267.716	0.1016	19.5417	0.010743192	2.097502
	Fe 259.939	0.1016	19.5417	-0.03987758	-7.78571
	Ni 231.604	0.1016	19.5417	-0.02086746	-4.07417
	Si 251.611	0.1016	19.5417	59.96997814	11708.55
	Mn 257.610	0.1016	19.5417	0.082309597	16.07014
Al 4-2	Al 308.215	0.1347	17.8422	5.622974372	757.6447
	Cr 267.716	0.1347	17.8422	0.011715215	1.578519
	Fe 259.939	0.1347	17.8422	0.015808855	2.130099
	Ni 231.604	0.1347	17.8422	0.000949267	0.127905
	Si 251.611	0.1347	17.8422	97.63944801	13156.03
	Mn 257.610	0.1347	17.8422	0.080148026	10.79922

Al 4-3	Al 308.215	0.1333	18.1492	4.488662616	621.2067
	Cr 267.716	0.1333	18.1492	0.014958665	2.070198
	Fe 259.939	0.1333	18.1492	-0.01747066	-2.41784
	Ni 231.604	0.1333	18.1492	0.02026678	2.804813
	Si 251.611	0.1333	18.1492	87.9343228	12169.64
	Mn 257.610	0.1333	18.1492	0.081915569	11.33667
Al 5-1	Al 308.215	0.1465	17.9846	5.454331542	681.2218
	Cr 267.716	0.1465	17.9846	0.00376208	0.469867
	Fe 259.939	0.1465	17.9846	0.007325916	0.914974
	Ni 231.604	0.1465	17.9846	-0.01762062	-2.20074
	Si 251.611	0.1465	17.9846	116.4291956	14541.49
	Mn 257.610	0.1465	17.9846	0.079703951	9.95467
Al 5-2	Al 308.215	0.1019	19.6747	6.227631609	1220.304
	Cr 267.716	0.1019	19.6747	0.011061206	2.167443
	Fe 259.939	0.1019	19.6747	0.045342447	8.88485
	Ni 231.604	0.1019	19.6747	-0.00303338	-0.59439
	Si 251.611	0.1019	19.6747	69.84758733	13686.63
	Mn 257.610	0.1019	19.6747	0.081610135	15.9915
Al 5-3	Al 308.215	0.1499	18.9896	6.573039148	846.0891
	Cr 267.716	0.1499	18.9896	0.004914023	0.632539
	Fe 259.939	0.1499	18.9896	0.007921785	1.019701
	Ni 231.604	0.1499	18.9896	0.00850181	1.094363
	Si 251.611	0.1499	18.9896	110.3606993	14205.76
	Mn 257.610	0.1499	18.9896	0.078736144	10.13501
Al 6-1	Al 308.215	0.1484	19.5342	6.185075948	825.9535
	Cr 267.716	0.1484	19.5342	0.006846938	0.914338
	Fe 259.939	0.1484	19.5342	0.018543252	2.476261
	Ni 231.604	0.1484	19.5342	-0.02220307	-2.96499
	Si 251.611	0.1484	19.5342	105.770168	14124.52
	Mn 257.610	0.1484	19.5342	0.078882093	10.5339
Al 6-2	Al 308.215	0.1042	17.5803	5.127092847	879.8524

	Cr 267.716	0.1042	17.5803	0.004525247	0.776571
	Fe 259.939	0.1042	17.5803	0.024913574	4.27538
	Ni 231.604	0.1042	17.5803	-0.02058678	-3.53286
	Si 251.611	0.1042	17.5803	77.36855509	13277.1
	Mn 257.610	0.1042	17.5803	0.080680676	13.84549
Al 6-3	Al 308.215	0.1855	17.1263	12.06783979	1134.286
	Cr 267.716	0.1855	17.1263	0.011204969	1.053183
	Fe 259.939	0.1855	17.1263	0.038943373	3.660383
	Ni 231.604	0.1855	17.1263	0.004605158	0.43285
	Si 251.611	0.1855	17.1263	120.9051928	11364.18
	Mn 257.610	0.1855	17.1263	0.080711184	7.586242
20 PPM	Al 308.215	0	0	18.80626659	#DIV/0!
	Cr 267.716	0	0	19.25072712	#DIV/0!
	Fe 259.939	0	0	18.73704756	#DIV/0!
	Ni 231.604	0	0	28.48791756	#DIV/0!
	Si 251.611	0	0	19.476292	#DIV/0!
	Mn 257.610	0	0	15.13937698	#DIV/0!
Al 7-1	Al 308.215	0.123	18.2086	4.202362249	632.5546
	Cr 267.716	0.123	18.2086	0.009355362	1.408203
	Fe 259.939	0.123	18.2086	-0.01455368	-2.19067
	Ni 231.604	0.123	18.2086	0.012055166	1.814587
	Si 251.611	0.123	18.2086	84.08305918	12656.48
	Mn 257.610	0.123	18.2086	0.08190311	12.32835
Al 7-3	Al 308.215	0.1513	17.4411	6.913130048	810.408
	Cr 267.716	0.1513	17.4411	0.011682093	1.369461
	Fe 259.939	0.1513	17.4411	0.033491212	3.926086
	Ni 231.604	0.1513	17.4411	-0.00180613	-0.21173
	Si 251.611	0.1513	17.4411	101.0750985	11848.77
	Mn 257.610	0.1513	17.4411	0.080794692	9.471349
Al 8-2	Al 308.215	0.1336	18.1854	5.312703116	735.5032
	Cr 267.716	0.1336	18.1854	0.002505546	0.346874
	Fe 259.939	0.1336	18.1854	0.019253038	2.665436
	Ni 231.604	0.1336	18.1854	-0.01737777	-2.40582

	Si 251.611	0.1336	18.1854	89.57569841	12401.07
	Mn 257.610	0.1336	18.1854	0.079309993	10.97986
Al 8-3	Al 308.215	0.1396	17.8611	6.681581566	868.3711
	Cr 267.716	0.1396	17.8611	0.003155244	0.410071
	Fe 259.939	0.1396	17.8611	0.004022456	0.522778
	Ni 231.604	0.1396	17.8611	-0.02509806	-3.26187
	Si 251.611	0.1396	17.8611	102.2939402	13294.62
	Mn 257.610	0.1396	17.8611	0.080504595	10.46277
1d-1	Al 308.215	0.1174	18.6913	4.176716156	675.5927
	Cr 267.716	0.1174	18.6913	0.008113456	1.312369
	Fe 259.939	0.1174	18.6913	-0.01414271	-2.28761
	Ni 231.604	0.1174	18.6913	0.014985103	2.423872
	Si 251.611	0.1174	18.6913	76.86624126	12433.28
	Mn 257.610	0.1174	18.6913	0.079422011	12.84668
1d-2	Al 308.215	0.1106	16.3247	3.651242598	549.063
	Cr 267.716	0.1106	16.3247	0.00637736	0.959008
	Fe 259.939	0.1106	16.3247	-0.03577274	-5.3794
	Ni 231.604	0.1106	16.3247	-0.01041352	-1.56595
	Si 251.611	0.1106	16.3247	82.90691252	12467.3
	Mn 257.610	0.1106	16.3247	0.078152534	11.75235
1d-3	Al 308.215	-29.8729	16.3712	4.550960232	-2.54209
	Cr 267.716	-29.8729	16.3712	0.012402987	-0.00693
	Fe 259.939	-29.8729	16.3712	-0.0015286	0.000854
	Ni 231.604	-29.8729	16.3712	-0.06359585	0.035524
	Si 251.611	-29.8729	16.3712	84.85386808	-47.3979
	Mn 257.610	-29.8729	16.3712	0.080122255	-0.04475
20PPM	Al 308.215	0	0	19.15317421	#DIV/0!
	Cr 267.716	0	0	19.45227039	#DIV/0!
	Fe 259.939	0	0	18.9323446	#DIV/0!
	Ni 231.604	0	0	27.78402049	#DIV/0!
	Si 251.611	0	0	18.92990302	#DIV/0!
	Mn 257.610	0	0	15.05562238	#DIV/0!

2d-1	Al 308.215	0.1211	18.2091	4.245883749	660.1736
	Cr 267.716	0.1211	18.2091	0.008592801	1.336056
	Fe 259.939	0.1211	18.2091	0.075464363	11.73362
	Ni 231.604	0.1211	18.2091	0.021323665	3.315522
	Si 251.611	0.1211	18.2091	75.30129869	11708.26
	Mn 257.610	0.1211	18.2091	0.08237612	12.8083
2d-2	Al 308.215	0.121	18.0945	4.579701407	708.1657
	Cr 267.716	0.121	18.0945	0.01444379	2.233464
	Fe 259.939	0.121	18.0945	0.034130427	5.277636
	Ni 231.604	0.121	18.0945	0.006391518	0.988329
	Si 251.611	0.121	18.0945	74.54842369	11527.53
	Mn 257.610	0.121	18.0945	0.080220588	12.40462
2d-3	Al 308.215	0.11	17.4105	7.59597974	1245.568
	Cr 267.716	0.11	17.4105	0.017318293	2.839806
	Fe 259.939	0.11	17.4105	0.064510298	10.57822
	Ni 231.604	0.11	17.4105	0.003905913	0.640481
	Si 251.611	0.11	17.4105	72.14435632	11830.03
	Mn 257.610	0.11	17.4105	0.079838096	13.09163
3d-1	Al 308.215	0.129	17.6608	5.363227154	746.9603
	Cr 267.716	0.129	17.6608	0.002584405	0.359942
	Fe 259.939	0.129	17.6608	-0.0100708	-1.4026
	Ni 231.604	0.129	17.6608	-0.04321634	-6.01893
	Si 251.611	0.129	17.6608	80.5087882	11212.81
	Mn 257.610	0.129	17.6608	0.080877852	11.26422
3d-2	Al 308.215	0.1087	16.5994	4.613500254	717.6985
	Cr 267.716	0.1087	16.5994	0.00956239	1.487572
	Fe 259.939	0.1087	16.5994	-0.01264868	-1.96769
	Ni 231.604	0.1087	16.5994	-0.03937351	-6.12513
	Si 251.611	0.1087	16.5994	83.43085256	12978.91
	Mn 257.610	0.1087	16.5994	0.079372558	12.34758
3d-3	Al 308.215	0.1173	18.3807	4.309542462	686.2239
	Cr 267.716	0.1173	18.3807	0.019682934	3.134184
	Fe 259.939	0.1173	18.3807	-0.02469309	-3.93197

	Ni 231.604	0.1173	18.3807	-0.00579363	-0.92254
	Si 251.611	0.1173	18.3807	72.89642091	11607.56
	Mn 257.610	0.1173	18.3807	0.079005855	12.58039
4d-1	Al 308.215	0.1301	18.6212	5.394873246	785.1842
	Cr 267.716	0.1301	18.6212	0.001443506	0.210092
	Fe 259.939	0.1301	18.6212	0.006765569	0.984679
	Ni 231.604	0.1301	18.6212	-0.01749943	-2.54691
	Si 251.611	0.1301	18.6212	87.69585271	12763.49
	Mn 257.610	0.1301	18.6212	0.080218864	11.67527
4d-2	Al 308.215	0.1115	15.9669	3.392456448	495.0674
	Cr 267.716	0.1115	15.9669	-0.00081862	-0.11946
	Fe 259.939	0.1115	15.9669	-0.02959839	-4.31935
	Ni 231.604	0.1115	15.9669	-0.04217061	-6.15403
	Si 251.611	0.1115	15.9669	75.07225174	10955.43
	Mn 257.610	0.1115	15.9669	0.080226895	11.70766
4d-3	Al 308.215	0.1008	17.7048	1.987335822	354.8952
	Cr 267.716	0.1008	17.7048	0.014065146	2.511731
	Fe 259.939	0.1008	17.7048	-0.04093229	-7.30962
	Ni 231.604	0.1008	17.7048	-0.03385782	-6.04627
	Si 251.611	0.1008	17.7048	62.95862931	11243.05
	Mn 257.610	0.1008	17.7048	0.078656957	14.04643
20 PPM	Al 308.215	0	0	18.82588746	#DIV/0!
	Cr 267.716	0	0	19.05851765	#DIV/0!
	Fe 259.939	0	0	18.51032204	#DIV/0!
	Ni 231.604	0	0	27.49987959	#DIV/0!
	Si 251.611	0	0	18.63709959	#DIV/0!
	Mn 257.610	0	0	14.54918513	#DIV/0!

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