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# Handling of Chemicals in a Process Facility – Factors to Consider During Design

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## Abstract

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The purpose of the thesis was to streamline and consolidate the currently scattered information on materials for the Hydrometallurgical Business Line of Metso to require less extensive searches. By condensing this data, the goal was to enhance productivity, minimize errors, and decrease risks in material selection.

A few hazardous chemicals often used by Metso were selected for closer inspection. The three chemical compounds selected were sulphuric acid ( $\text{H}_2\text{SO}_4$ ), sodium hydroxide ( $\text{NaOH}$ ), and ammonia ( $\text{NH}_3$ ). Efforts were made to gather relevant information and special factors regarding the handling of these chemicals.

Data for the project was gathered from various sources on the internet, including academic publications, industry guidelines, and online databases. Additionally, internal company files were accessed to extract relevant information especially regarding past projects' handling of the chemicals in question.

The resulting practical part created in Microsoft Excel contains various examples of how past Metso projects handled the three aforementioned chemicals and data such as their corrosivity. The Excel file also includes a unit converter to convert the chemicals' concentrations from grams per litre to weight percentage and vice versa as this has proven to be a problem in certain old projects.

The Excel file serves as a foundation to which company employees can add information on the already inspected chemicals as well as other widely used chemicals such as hydrochloric acid ( $\text{HCl}$ ) could be added in the future to increase the usefulness of the file.

Keywords: sulphuric acid, sodium hydroxide, ammonia, handling of chemicals, corrosion

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Opinnäytetyön tarkoituksena oli tehostaa ja koota Metson hydrometallurgian osaston materiaaleihin liittyvää hajanaista tietoa, jotta tarvittavaa tietoa ei tarvitsisi etsiä kaikkialta. Tämän tiedon tiivistämisen tavoitteena oli parantaa tuottavuutta, minimoida virheitä ja vähentää riskejä materiaalien valinnassa.

Tarkempaa tarkastelua varten valittiin muutama vaarallinen kemikaali, joita Metso käyttää usein. Valitut kolme kemikaalia olivat rikkihappo ( $H_2SO_4$ ), natriumhydroksidi (NaOH) ja ammoniakki ( $NH_3$ ). Näiden kemikaalien käsittelyyn liittyvää olennaista tietoa sekä erityisvaatimuksia pyrittiin keräämään opinnäytetyöhön.

Projektin tiedot kerättiin internetistä eri lähteistä, joihin kuuluivat esimerkiksi tieteelliset julkaisut, alan suositukset ja verkkotietokannat. Lisäksi yrityksen sisäisiä tietoja käsiteltiin olennaisen tiedon poimimiseksi erityisesti aiempien projektien käsittelystä.

Microsoft Excelissä luotu käytännöllinen osa sisältää erilaisia esimerkkejä siitä, miten Metson aiemmat hankkeet käsittelivät kolmea edellä mainittua kemikaalia, sekä tietoa niiden ominaisuuksista kuten syövyttävyydestä. Mukana on myös yksikkömuunnin kemikaalien pitoisuuksien muuntamiseksi grammaa per litrasta painoprosenttiin ja päinvastoin, koska tämä on osoittautunut ongelmalliseksi joissakin vanhoissa projekteissa.

Excel-tiedosto toimii perustana, johon yrityksen työntekijät voivat tulevaisuudessa lisätä tietoa jo tarkastelluista kemikaaleista ja muista laajalti käytetyistä kemikaaleista, kuten suolahaposta (HCl), mikä lisäisi tiedoston hyödyllisyyttä.

Avainsanat: rikkihappo, natriumhydroksidi, ammoniakki, kemikaalien käsittely, korroosio

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## List of Abbreviations

ASTM	<i>American Society for Testing and Materials.</i> International standards organisation that publishes technical standards.
HDPE	<i>High-density polyethylene.</i> Thermoplastic polymer known for its high strength and chemical resistance.
EN	<i>European Norm.</i> European collection of standards.
FRP	<i>Fibre-reinforced plastic.</i> Composite material made of polymer matrix reinforced with fibres.
PFD	<i>Process Flow Diagram.</i> Simplified chart indicating the general flow of plant processes and equipment.
P&ID	<i>Piping and Instrumentation Diagram.</i> Detailed chart which shows piping and process equipment together with the instrumentation and control devices.
PTFE	<i>Polytetrafluoroethylene.</i> Synthetic fluoropolymer known for its nonstick properties, high chemical resistance, and hydrophobicity.
SCC	<i>Stress corrosion cracking.</i> Form of environmentally induced cracking in materials under the combined influence of tensile stress and corrosive environments, leading to brittle fracture.
SDS	<i>Safety Data Sheet.</i> Document containing detailed information about the chemical properties, hazards, safe handling, and emergency procedures related to a chemical.
UNS	<i>Unified Numbering System.</i> Alloy designation system widely accepted in North America.

XLPE      *Cross-linked polyethylene*. Polymer characterized by enhanced strength, chemical resistance, and heat tolerance due to a molecular structure formed through cross-linking.

# 1 Introduction

The purpose of this thesis was to consolidate and gather information on materials and their usability with various chemicals for the Hydrometallurgical Business Line of Metso. Currently the information is very scattered and often relevant information needs to be searched from far and wide. Consolidating the available information would increase productivity and reduce errors and risks in the selection and application of materials for different chemical environments.

A large amount of valuable information a company has is also stored as tacit knowledge, meaning the knowledge is not written down anywhere and is instead stored in the memory of employees with a large amount of first-hand experience. While this sort of information was not collected in this thesis, it could be useful to gather it in the future as this type of knowledge is lost upon the departure of the person from the company.

This thesis was made for Metso whose focus as a company is being a frontrunner in sustainable technologies, end-to-end solutions and services for the aggregates, minerals processing and metals refining industries around the globe. Metso's purpose is to enable sustainable modern life through their planet-positive offering, aiding customers in reducing energy consumption, CO<sub>2</sub> emissions, water usage, and pollution. These values can be seen in Figure 1.

[1.]



## Metso – Enabling sustainable modern life

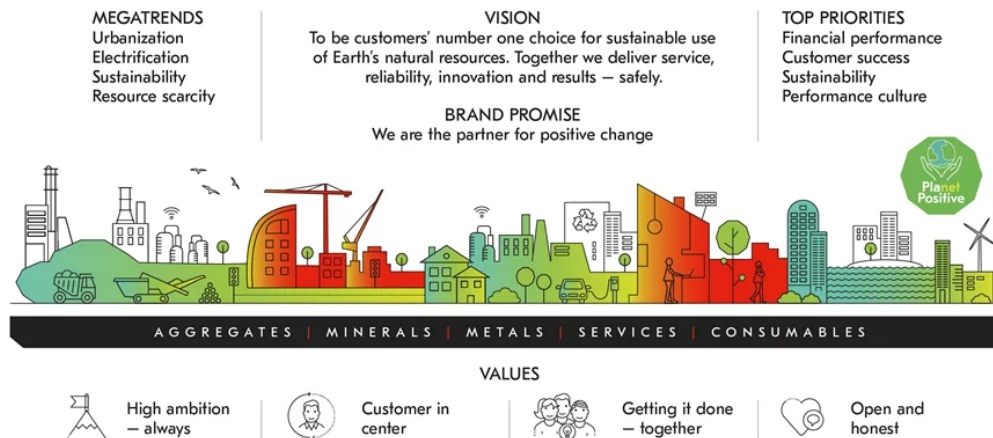


Figure 1. Metso's strategy regarding sustainability [2].

The first part of the thesis will focus on researching factors that need to be considered when storing potentially hazardous chemicals. Along with general storage procedures, further research will be conducted on the storage and the chemical properties of three specific chemicals included in the thesis. These chemical compounds are sulphuric acid ( $H_2SO_4$ ), sodium hydroxide ( $NaOH$ ), and ammonia ( $NH_3$ ).

The thesis will also include comparisons of chemical handling in projects executed by Metso's Hydrometallurgy Business Line. Under inspection will be 21 different projects from the past seven years where any of the aforementioned chemicals were used. Some of the projects were only designed until the basic phase, after which the client finished the detail design with the help of another company. In such projects the information available might be incomplete or not specific enough. For example, the type of material might be listed as carbon steel even though there are several types of carbon steel available. Some projects were also excluded because the customer had taken care of the chemical storage part themselves and thus Metso did not have the equipment specifications available.

In addition, the thesis will contain a practical part which will aim to create a design guideline where relevant information for each chemical will be collected for future projects. This part will be created in Microsoft Excel and present a large amount of the information covered in this thesis in easy-to-read data format. The Excel file will work as a baseline with the possibility of being expanded in the future by employees of the company. More information on the already discussed chemicals may be added in the future in addition to other chemicals that were not included in this thesis.

## **2 Factors to consider when storing chemicals**

### **2.1 Safety and hazards**

When storing chemicals, it is crucial to consider various aspects of safety. Ensuring compatibility between stored substances is vital to prevent dangerous reactions. Proper labelling with clear information about the chemical's identity and handling instructions is essential. Adequate ventilation in storage areas helps disperse harmful fumes, while maintaining appropriate temperatures ensures chemical stability. Using secure, tightly sealed containers prevents spills and leaks, reducing the risk of accidents and environmental harm. [3.]

Additionally, having emergency equipment like eyewashes, showers, and fire extinguishers readily available is essential. Personnel handling chemicals should receive thorough training in storage protocols and emergency procedures. Compliance with local regulations is mandatory to meet safety standards and avoid legal issues. Regular inspections of storage areas and containers are necessary to identify potential hazards promptly. Developing a comprehensive emergency response plan and ensuring all staff are aware of it can minimize risks and facilitate a swift, safe response in case of accidents or spills. [3.]

Across the globe, organizations like the European Chemicals Agency (ECHA) in the European Union, alongside counterparts such as the U.S. Environmental

Protection Agency (EPA) and the Finnish Safety and Chemicals Agency (Tukes), deal with a variety of standards and rules. These agencies are responsible for various regulations and acts such as Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) in Europe and Toxic Substances Control Act (TSCA) in the USA, collectively ensuring global chemical safety standards and practices. [4; 5.]

The usage of diverse chemical safety standards around the world is influenced by a multitude of factors, including regional regulations, industrial practices, and environmental concerns. Various countries adhere to specific standards tailored to their unique needs. The aforementioned agencies work to match their practices with international guidelines. This variety in standards highlights the importance of these entities keeping track of both local rules and global best practices. This careful attention ensures chemicals are handled, stored, and transported safely worldwide. [6.]

Safety Data Sheets (SDS) are important documents providing essential information about chemical properties and hazards. They play a crucial role in guiding safe handling, storage, and emergency responses. For workers, understanding SDSs ensures proper handling, reducing accidents and injuries. Regulatory compliance with SDSs also supports legal standards, enhancing workplace safety and environmental protection. Overall, SDSs are necessary tools, promoting awareness and responsibility in chemical management. [7.]

## 2.2 Corrosion

Corrosion is defined as the destruction or deterioration of a material due to reaction with the surrounding environment. Corrosion can be rather quick, extremely slow or anywhere in between. A material that is not corrosion-resistant placed in a very hostile acidic environment can be rendered unusable in a matter of hours while certain structures have stood the test of time over thousands of years when erected in perfect conditions. [8, p. 4.]

Corrosion is typically divided into two groups: wet corrosion and high-temperature corrosion. In wet corrosion the damage is done in the presence of a liquid containing free ions making it electrically conductive, an electrolyte. High-temperature corrosion refers to chemical attack from gases, slags, molten salts or molten metals. It generally occurs at temperatures above 400 °C making it irrelevant in the scope of this thesis due to the selected chemicals' extremely limited usability at those temperatures and thus will not be discussed further. [9; 10.]

Uniform corrosion occurs evenly across a material's surface due to exposure to elements like moisture and oxygen. Galvanic corrosion happens when two dissimilar metals in contact experience differential corrosion due to a difference in their electrochemical potentials. Erosion corrosion occurs in high-speed fluid environments, causing accelerated material damage due to a combination of chemical degradation and mechanical wear. [8; 11.] Extra care should be taken when pipes have an abrasive material such as slurry flowing through them as this causes erosion corrosion to be a bigger factor [12, p. 86].

Pitting corrosion leads to localized pits or craters on a material's surface, weakening it significantly. Crevice corrosion occurs in confined spaces, intensifying corrosion due to lack of oxygen circulation. Intergranular corrosion affects grain boundaries due to impurities or alloy depletion, weakening the material's structure. An example of all the corrosion types mentioned in this and the previous paragraph can be seen in Figure 2. [8; 11.]

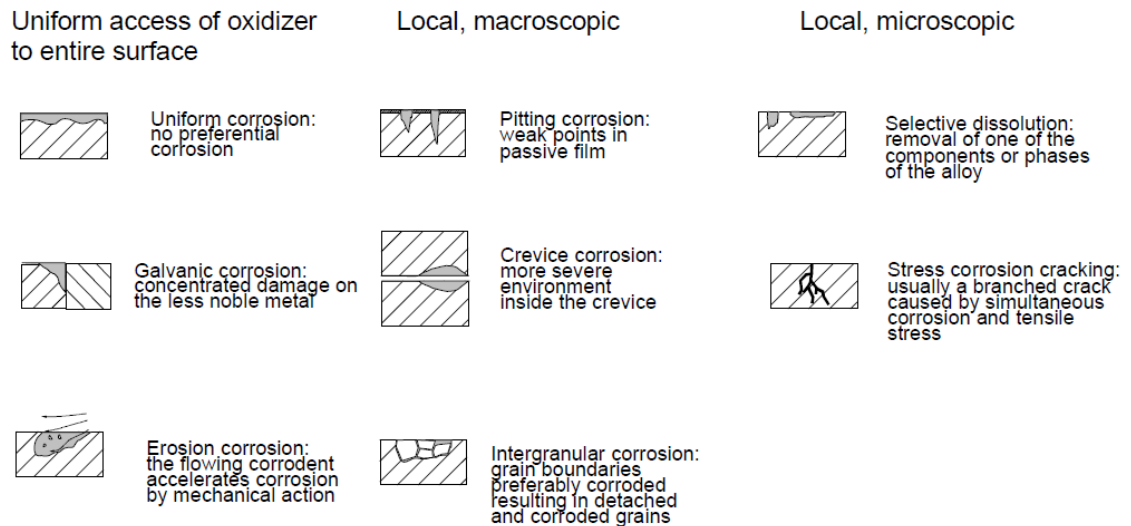


Figure 2. Different types of corrosion [11].

The amount of corrosion is typically displayed in an isocorrosion diagram where a line represents a corrosion rate of 0.1 mm/year. In American documents these lines often represent a corrosion rate of 5 mils/year (0.127 mm/year). At temperatures and concentrations below the line the material is expected to perform well but above the line the material is no longer sufficient or will suffer from reduced service life. The further above the line the conditions are, the higher the yearly corrosion which directly correlates with the service life of the equipment. An example of an isocorrosion diagram can be seen in Figure 3. [13.]

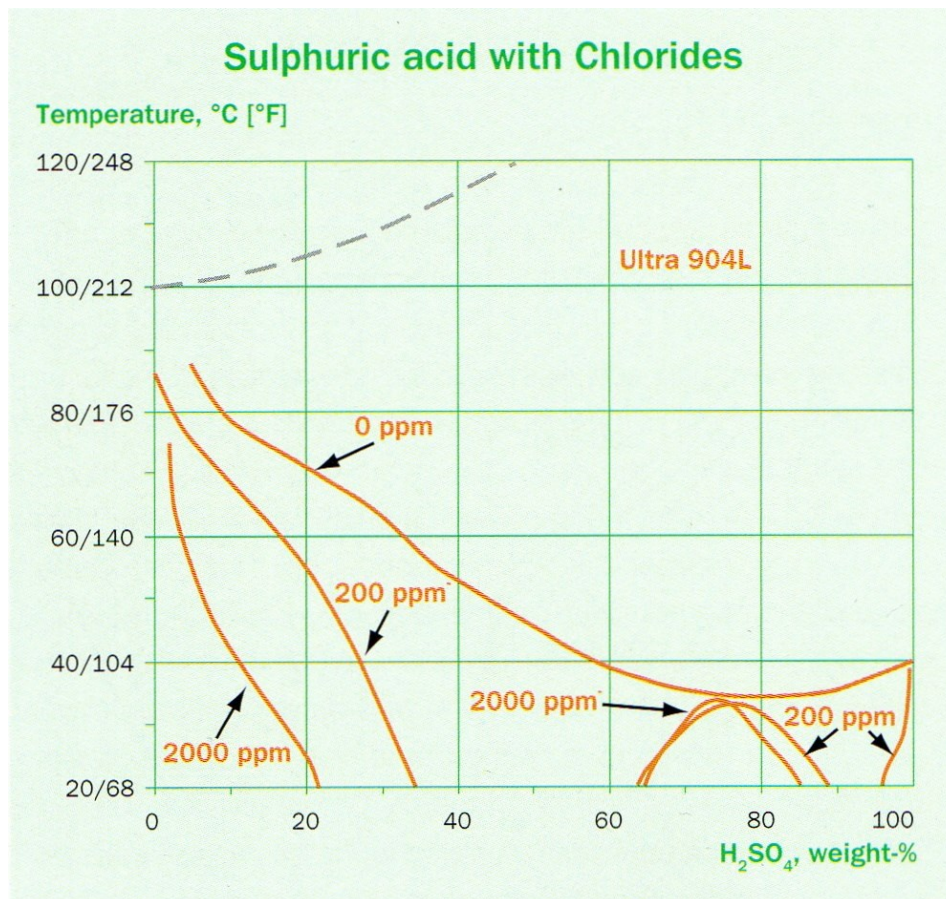


Figure 3. Effects of chloride contaminant on pure sulphuric acid's corrosion on stainless steel 904L (EN 1.4539). The solid lines represent 0.1 mm/year of corrosion. The broken line represents the boiling point. [12.]

A point to bear in mind when using isocorrosion diagrams is that they are based on tests made in laboratories where the conditions are constant, and the chemicals used are pure. In the real world there may, for example, be contaminants and variations in the process that affect the conditions. Some contaminants will make the conditions considerably more aggressive. For example, a sulphuric acid solution with chloride contaminants will corrode materials more than just pure sulphuric acid [12, p. 86].

The opposite can happen sometimes as well. A slight amount of chromic acid or copper sulphate contaminant will decrease the corrosivity of sulphuric acid. The addition of metal ions, Fe<sup>2+</sup>, Fe<sup>3+</sup>, and Cu<sup>2+</sup> for example, have an inhibitive effect on uniform corrosion of stainless steel when added to sulphuric acid.

Sometimes this effect is increased the more contaminant is introduced into the solution and sometimes the opposite will happen. Chromic acid contaminant is the most effective at reducing corrosion with only 0.2—0.5 wt% added into the solution with the amount of protection decreasing with further chromic acid introduction into the solution as can be observed in Figure 4. [12; 14, p. 86]

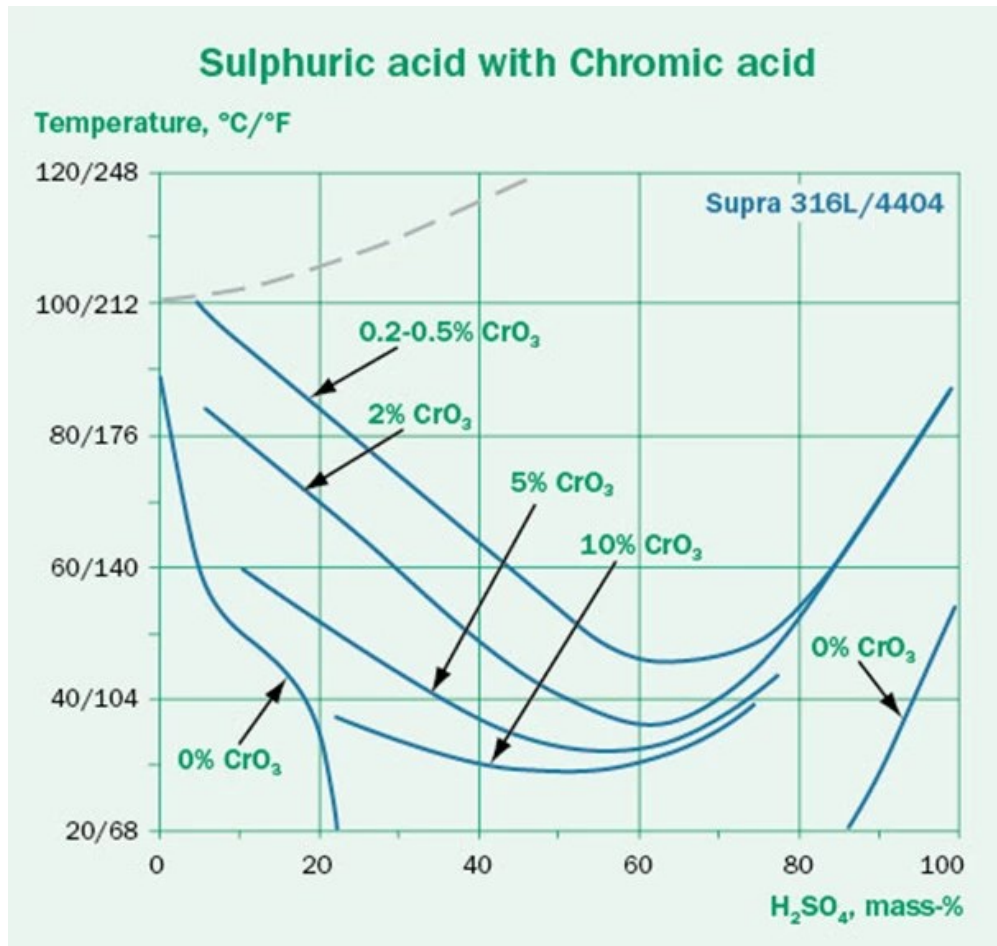


Figure 4. Effects of chromic acid contaminant on pure sulphuric acid's corrosion on stainless steel 316L (EN 1.4404). The solid lines represent 0.1 mm/year of corrosion. The broken line represents the boiling point. [14.]

Corrosion rates for uniform corrosion can be predicted to a decent degree using isocorrosion diagrams from tests done in a laboratory. Localized corrosion types that might occur follow more complex mechanisms are thus less predictable. For example, localized pitting and crevice corrosion might occur when chloride contaminants are introduced to the solution. [14.]

Stainless steels are not fundamentally noble materials capable of resisting corrosion on their own like gold would. Instead, they get their corrosion resistance from their ability to form a thin, invisible and insoluble layer rich in chromium, iron oxides and hydroxides on their surfaces. The layer, commonly called the passive film or passive layer, protects the stainless steel making it non-reactive or passive in many environments. The steel is protected from corrosion as long as the layer holds but chemicals such as chlorides, acids or bases can breach the layer and start corroding the steel. [14; 15.]

### 2.3 Material selection

The most important part of selecting a material is to pick the most cost-effective one available. The material should withstand the environment it is placed in well while not being too overqualified for the job. Opting for a basic carbon steel that is not very corrosion resistant for storing a potent acid might be cheap, but it could also backfire and create a catastrophe at the plant. Selecting an expensive, difficult to manufacture alloy that is specially suited for corrosive environments would likely work very well, but it may not be necessary.

While it is recommended that a material resisting corrosion well enough should be selected, it might not always be possible. At certain temperatures and concentrations, a material that would perform ideally might not exist. Selecting a material for conditions above its recommended values will result in an ever-elevating rate of corrosion the farther from the suggested the working conditions are. This in turn will lead to reduced service life and higher possibility of an accident. While not as bad as picking an underqualified material, picking an overqualified material is also ill-advised as it will increase costs, possibly by a large margin. It is always advisable to discuss the material selection with the supplier to find the perfect material for the project. [13; 14.]

Even better than a simple consultation would be to conduct tests with the actual solution used containing all the impurities it will have during the real process on various materials. Weighing and examining the test specimens under a



microscope after being exposed to the process solution provides invaluable information on the corrosion risks to expect. [16.]

Various materials are used in process piping, each selected for specific attributes to ensure optimal performance in many industrial applications. Carbon steel is commonly selected for its high strength, cost-effectiveness, and ease of fabrication. Stainless steel, valued for its corrosion resistance, is particularly prevalent in the chemical and petrochemical sectors where durability is very important. Additionally, fibre-reinforced plastics (FRPs), which consist of a polymer matrix reinforced with fibres like glass or carbon, offer high strength-to-weight ratios and corrosion resistance, making them suitable for demanding environments. Many more types of materials do exist, these are just some of the commonly used ones especially by Metso. [17.]

Stainless steels, the most common piping materials for corrosive chemicals, are categorized based on their microstructure, leading to various types tailored for specific applications. Ferritic stainless steels, alloyed with chromium and sometimes molybdenum, exhibit magnetic properties and moderate corrosion resistance. Martensitic stainless steels, known for their hardness, contain chromium with small additions of nickel and molybdenum. Duplex stainless steels have a balanced ferritic-austenitic microstructure, offering high resistance to stress corrosion cracking. Austenitic stainless steels feature subcategories like Cr-Ni steels (general purpose), Cr-Mn steels (with reduced nickel content), and Cr-Ni-Mo steels (with improved corrosion resistance due to molybdenum). High-performance austenitic steels, developed for demanding environments, possess high resistance to various types of corrosion. Additionally, high-temperature austenitic steels, designed for extreme heat, demonstrate exceptional oxidation and creep resistance. [12, p. 11-12]

Stainless steels commonly serve as the primary construction materials in environments exposed to acids due to their ability to withstand such conditions. Their use in hydrometallurgical settings offers notable advantages in terms of design and process flexibility. In more extreme conditions, superduplex or

superaustenitic stainless steels are preferred, while less severe environments may utilize lower alloyed steels. [12, p. 86.]

## 2.4 Noteworthy physical characteristics

In designing chemical processes, careful consideration needs to be done regarding various physical characteristics to ensure safety and efficiency. Factors such as boiling and melting points guide equipment selection, while vapour pressure influences containment strategies for potentially hazardous fumes. Density influences storage and transport decisions, and solubility impacts solvent and separation method choices. Reactivity assessments prevent unintended reactions, and considerations of corrosivity guide material selection. Toxicity evaluations inform exposure limits, and an understanding of flammability is crucial for safe storage. Viscosity affects flow dynamics, while particle size and shape impact handling and reaction mechanisms. Attention to hygroscopicity ensures proper storage conditions. [18.]

Balancing the previously mentioned factors creates a safe and effective chemical processing environment. Some of these factors will be explored further when discussing a relevant chemical.

## 2.5 Isolation from the process

During the engineering of a plant, it should be taken into account that all equipment must be able to be isolated safely for reasons such as maintenance operations. Periodic inspections of pressure equipment may also require isolation from process. The method for isolation is based on hazard analysis of the current case. Potential types for isolation are presented in Figure 5. [19.]


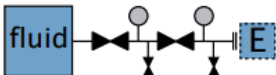
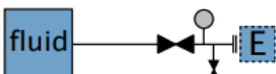
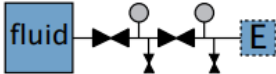

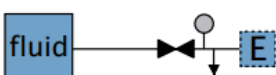
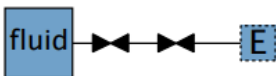

Category	Features	Method	Illustrative example
<b>I Positive isolation</b>	Complete separation of the plant/ equipment to be worked on from other parts of the system.	Physical disconnection (eg spool removal)	
	Valved isolation of an appropriate standard is required during the installation of positive isolation.	Double block, bleed and spade	
		Single block and bleed and spade	
<b>II Proved isolation</b>	Valved isolation. Effectiveness of valve closure(s) can be confirmed via vent/ bleed points before intrusive work commences.	Double block and bleed (DBB)	
	Within this isolation category the level of mechanical security is greatest for DBB and lowest for SBB.	Double seals in a single valve body with a bleed in between	
	As a general rule, SBB should not be used with hazardous substances (see paragraph 120).	Single block and bleed (SBB)	
<b>III Non- proved isolation</b>	Valved isolation. No provision to confirm effectiveness of valve closure prior to breaking into system.	Double valve	
	Where possible, double valve isolation should be used rather than single valve.	Single valve	

Figure 5. Process isolation methods [19].

Secondary containment for chemicals is a safety measure implemented in industrial settings to prevent environmental contamination and ensure compliance with regulations. It involves creating a secondary barrier, such as a containment basin or bund, around primary storage units like tanks that hold hazardous substances. In the event of a spill or leakage, the secondary containment system captures and contains the released chemicals, preventing them from spreading and causing harm to the environment or nearby workers. [20; 21.]

Secondary containment solutions need to consider the volume and properties of the stored chemicals, ensuring that they can effectively withstand any accidental release. Both the European Union and Finnish regulations provide recommendations and general principles regarding secondary containment to

safeguard against environmental hazards, but they do not prescribe specific requirements. In Germany and the United Kingdom for example, the minimum volume for secondary containment is 110% of the maximum capacity of the largest container. Making them from the same material as the primary containment is made of is usually a reliable option but not required. [20; 21.]

Another way to help isolate the process is by using flange covers. Flange covers, also known as flange guards or safety shields, are safety devices used to protect workers, equipment, and the environment from potential hazards associated with pressurized pipelines. These covers are specifically designed to enclose flanges, valves, and other connection points in pipelines, preventing leakages and sprays that can result from pipe failures or unexpected releases of hazardous substances. [22.]

### **3 Sulphuric acid**

Sulphuric acid ( $H_2SO_4$ ) is a strong inorganic acid that is the most widely used and produced chemical in the world with 231 million tonnes produced in 2011. Half of it is used to produce phosphoric acid which in turn will be used to produce phosphate fertilizers. 10 % of the sulphuric acid produced worldwide is used in metal processing in processes such as copper manufacturing, zinc manufacturing and pickling. [23.] Due to its relative low cost, sulphuric acid is the most important acid used in hydrometallurgical processes and it is often produced on site [12, p. 86].

Leaching is the liberation of metals from raw materials by chemical dissolution. In these leaching processes, sulphuric acid can be used as a solvent to dissolve minerals from ores, allowing the extraction of valuable metals such as zinc, copper, and nickel. The acid reacts with the ore, breaking down its mineral structure and freeing the metal ions, which can then be further processed for refinement. [12, p. 86-89.]

Sulphuric acid is also the most widely used acidic neutralizing chemical today due to it being cheaper, easier and safer to use than its competitors. In pH regulation and neutralization processes its primary function lies in adjusting the pH of solutions, either making them more acidic or neutralizing alkalinity. When added to alkaline solutions, it reacts with the bases, neutralizing their pH and making them more neutral. This pH control is essential in chemical reactions where specific pH conditions are necessary for the reaction to proceed efficiently. For example, in various chemical manufacturing processes, maintaining a particular pH ensures that the reaction yields the intended products. [24; 25.]

### 3.1 Safety and hazards

The hazards of sulphuric acid include its exothermic reaction with water, violent spurting during dilution will occur if the acid is added into water instead of the opposite. It also has powerful dehydrating properties and reacts with various substances and can generate flammable hydrogen gas with metals. The concentrated acid and its solutions can cause severe tissue damage, chemical and thermal burns, particularly to the eyes and skin. Additionally, exposure to sulphuric acid vapours, may result in various health issues such as eye irritation, respiratory problems, and potential carcinogenic effects. [26, p. 3-4.]

Safety precautions involve careful dilution, appropriate materials for storage, usage of appropriate protective gear and storing it away from incompatible substances. Immediate medical attention is important in case of exposure with specific first aid measures for inhalation, skin contact, eye exposure, and ingestion. These include measures such as eye wash stations and safety showers to be readily available. Adherence to safety regulations and proper guidance on emergency management, including spill response, is essential. Usage should be confined to well-ventilated areas, and proper disposal procedures must be taken to prevent harm to aquatic life. Regular inspection and maintenance are necessary for plant equipment to prevent containment failures. [26, p. 4.]

## 3.2 Corrosion

Generally, the corrosiveness of the acidic environment increases with increasing temperature, while the effect of concentration is variable but most often increases with the concentration as well. Sulphuric acid is an example of an acid in which corrosion does not necessarily increase with increasing concentration. Its corrosivity starts similar to that of a regular acid by becoming more corrosive the stronger the acid becomes but at a certain point, the acid starts to become less corrosive. [12, p. 17.]

Sulphuric acid is reducing at low and medium concentrations but oxidising when concentrated above approximately 90 wt%. Furthermore, the degree of ionisation reaches a maximum at intermediate concentrations. The exact point the corrosivity peaks is dependent on the material but most materials are corroded the most when exposed to intermediate concentrations of sulphuric acid. Stainless steels for example corrode the most at approximately 30—80 wt% which can be observed in Figure 6. [12, p. 17, 89.]

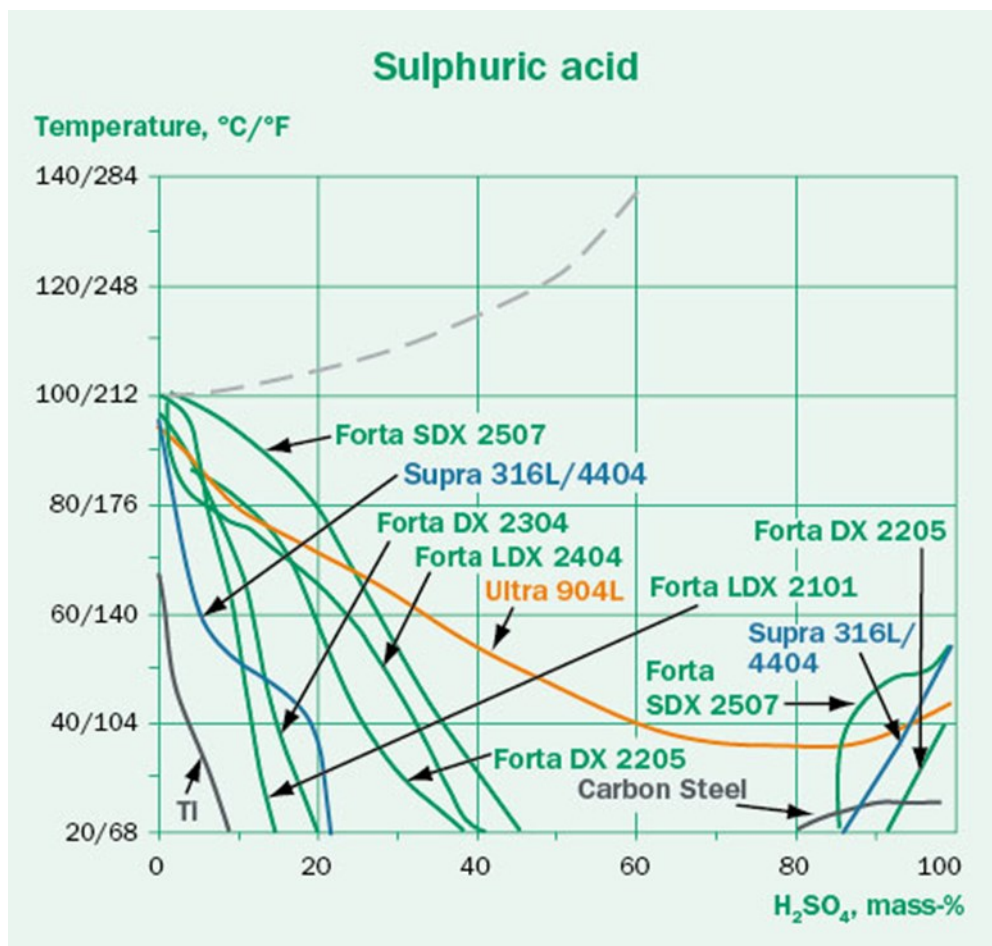


Figure 6. Corrosion resistance of selected materials. The solid lines represent 0.1 mm/year of corrosion. The broken line represents the boiling point. [27.]

Sulphuric acid is normally stored at 93—98.5 wt% due to it being less corrosive on the storage tank at very high concentrations. It can alternatively be stored at lower concentrations where the corrosivity is also lowered but doing so will increase the storage capacity required due to dilution. [28.]

### 3.3 Material selection

Carbon steel tanks are a common option for storage capacity above 45,000 litres, primarily for solutions of 93 wt% and above, although they require regular maintenance due to gradual corrosion. This corrosion will generate hydrogen gas and the tank must have a vent to avoid pressure buildup due to the hydrogen. The interior of carbon steel storage tanks should be lined with an

acid-resistant material such as glass or polytetrafluoroethylene (PTFE, also known as Teflon) when iron content in the acid needs to be kept at a minimum. [28; 29, p. 26-28.]

Smaller tanks with a capacity of under 45,000 litres can be built from high-density polyethylene (HDPE) or various stainless steels. These provide resistance to chemical reactivity, avoiding issues like hydrogen gas or iron sulphate generation. However, HDPE tanks have a maximum service temperature of around 55 °C, requiring caution in applications that involve elevated temperatures. Fibre-reinforced plastic (FRP) tanks are suitable for concentrations up to 80 wt%, but dilution in FRP tanks is not advised due to potential structural compromise from the heat generated during the process. [28; 29, p. 26-27.]

The heightened corrosiveness in more diluted solutions requires materials with enhanced resistance. The performance of certain materials can be observed in Figure 7 where this becomes clear by looking at the gap between approximately 70—90 wt% especially at higher temperatures. Only a few of the selected materials are able to handle this extreme environment. [29, p. 27.]



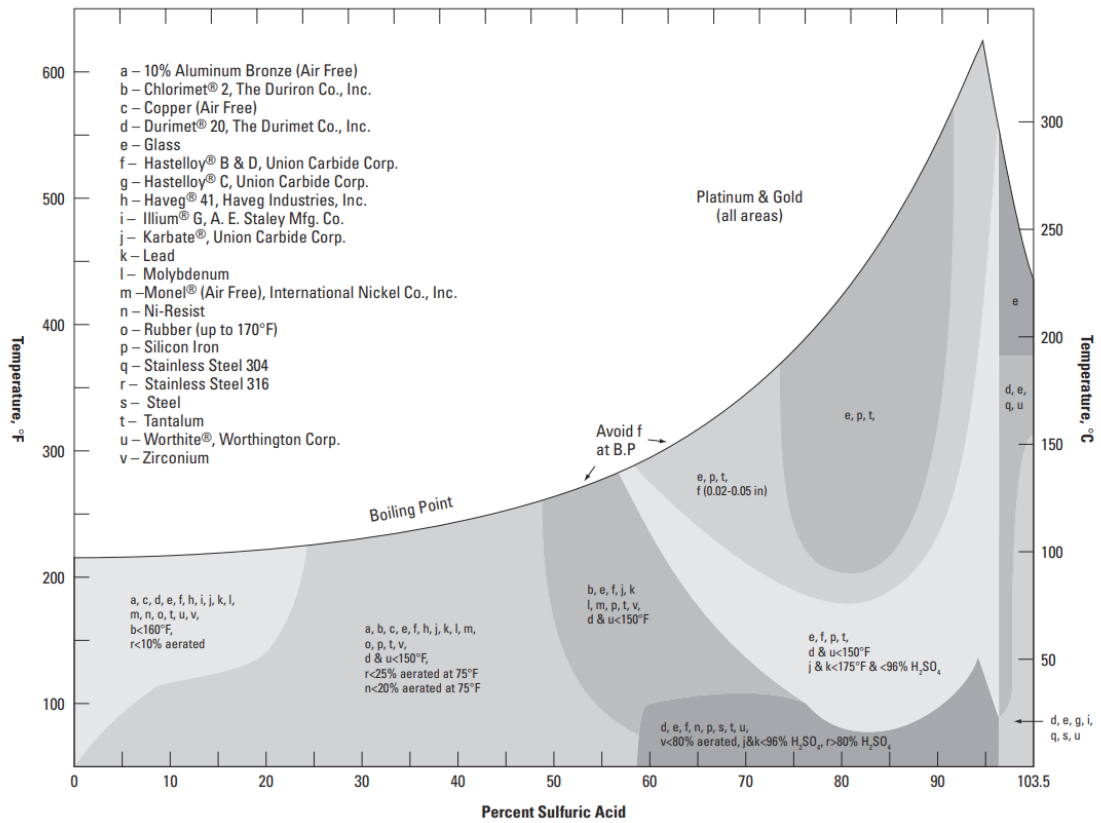


Figure 7. Preferred materials of construction for use with sulphuric acid at different temperatures and concentrations. (Corrosion rate less than 0.5 mm/year). [29, p. 28.]

### 3.4 Noteworthy physical characteristics

The high density of sulphuric acid needs to be considered when designing processes. At 25 °C, pure sulphuric acid has a density of 1830 kg/m<sup>3</sup>, almost double of what water at the same temperature would have. Equipment such as pumps and pipes used in handling sulphuric acid need to be specifically engineered to handle its weight. Storage tanks are recommended to have a specific gravity rating of 1.9 or higher, indicating their density relative to water, to adequately withstand the weight of the chemical. [28.]

Due to sulphuric acid's hygroscopicity, any moisture that enters the tank will be quickly absorbed into the solution. If a tank containing sulphuric acid is not filled or stirred often it can cause the top layer of acid to become diluted and thus

more corrosive. As the acid content in the tank sits idle, the diluted topmost layer may corrode a ring around the inner wall of the tank. [30.] In open-topped containers self-dilution of sulphuric acid can happen more easily due to the increased amount of moist air circulating [31].

The changing level in a tank caused by liquid being moved in and out also causes the amount of air in the tank to change. This change brings contaminated and humid air into the tank from outside. This also happens to a lesser extent as the air in a tank's headspace expands and contracts due to the temperature changes especially if the tank is stored outside. This can be combatted with equipment designed to remove moisture from the containers such as a desiccant breather. Allowing the air to pass through a desiccant breather would adsorb the humidity and filter out contaminants which could cause harm to the tank or its contents. [30; 32.]

### 3.5 Isolation from the process

Container evaluation should account for potential mixing or dilution of  $H_2SO_4$  solutions, provided the exothermic reaction involved. Storage areas must be cool, dry, and away from sunlight, heat, and ignition sources. Although sulphuric acid is not flammable, it should be separated from incompatible materials such as organic materials, nitrates, carbides, chlorates or metal powders. Contact between sulphuric acid and any of these materials may cause ignition. [28; 33, p. 25.]

Bulk storage necessitates secondary containment measures for exposure mitigation in case of a release. The secondary containment's exact specifications depend on local regulations but generally it should be able to contain at least 110 % of the volume of the largest storage tank. In the event of a leak, the acid should be neutralized and drained out before it reaches a sewer or waterway. [28; 33, p. 24.]

### 3.6 Current situation at Metso

As can be observed in Table 1, a commonly used material by Metso is EN 1.4404 (316L). It handles sulphuric acid without much corrosion if the concentration is kept high or low enough and the temperature is at reasonable levels which can be seen in Figure 6 (p. 16). In addition, all of the projects store sulphuric acid at very high or low concentrations due to the aforementioned reasons. In Metso's projects some common uses for sulphuric acid were as a leaching reagent or as a neutralizing agent to decrease the pH of an alkaline solution.

Table 1. Materials, concentrations and water removal used in sulphuric acid storage tanks in various projects.

<b>Project</b>	<b>Level of Design</b>	<b>Material(s) used</b>	<b>Concentration(s)</b>	<b>Water removal</b>
1	P&ID	EN 1.4404 EN 1.0038 Edmeston SX	98 wt% 20 wt%	No
2	PFD	FRP	98 wt% 25 wt% 15 wt%	No
3	P&ID	FRP		No
4	PFD	Painted carbon steel	98 wt%	No
5	PFD	EN 1.4401 EN 1.4162	92 wt% 98.5 wt%	Yes
6	P&ID	ASTM A36 ASTM A106 Gr. B	96—98 wt%	No
7	P&ID	EN 1.4404	96 wt%	No
8	PFD	Carbon steel	93 wt%	No
9	PFD	EN 1.4404	92.5—94 wt%	No

Project	Level of Design	Material(s) used	Concentration(s)	Water removal
10	P&ID	EN 1.4404	98 wt%	No
11	P&ID	FRP	99 wt%	Yes

The table also includes a separate column to indicate the presence of a water removal tank. This had only been adapted into two projects designed by Metso, but it might become more common in the future because it has been noticed that the water diluting the topmost layer has caused increased corrosion due to the reasons mentioned in chapter 3.4.

## 4 Sodium hydroxide

Sodium hydroxide (NaOH), also known as caustic soda or lye, is a strong base. It is a versatile and widely used chemical compound in various industries, including chemical engineering. In chemical engineering, sodium hydroxide serves as an important reagent in many processes such as pH regulation and gas scrubbing. [34.]

Just like sulphuric acid was the most used acidic neutralizing chemical, sodium hydroxide is the most used alkaline neutralizing chemical currently due to its low cost, ease of handling and effectiveness. Additionally, in wastewater treatment, sodium hydroxide is used to neutralize acidic pollutants, preventing environmental contamination and aiding in the removal of harmful substances. [24; 35.]

Gas scrubbing is a process where gas streams interact with a liquid, known as a scrubbing solution, to eliminate unwanted pollutants. This liquid, which can be water or a chemical solvent, is sprayed into the gas stream, causing pollutants to be absorbed. Afterward, the liquid is separated from the gas stream, and pollutants are removed. For example, in removing acid gases like hydrogen sulphide (H<sub>2</sub>S), sodium hydroxide can be used as the scrubbing solution. Sodium hydroxide reacts with dissolved hydrogen sulphide, forming sodium

hydrosulphide (NaHS) and sodium sulphide (Na<sub>2</sub>S). The resulting sodium hydrosulphide can often be sold provided it is of high quality. [36.]

#### 4.1 Safety and hazards

Working with sodium hydroxide presents inherent dangers that can lead to severe personal injuries, particularly among individuals who might underestimate the risks due to prolonged familiarity with the substance. Sodium hydroxide solutions or particles in contact with the skin can result in severe burns, while even a small quantity in the eyes may cause permanent vision damage. Prevention of accidents is crucial, necessitating regular equipment maintenance to avoid leaks, personnel training in proper handling procedures, and immediate cleanup of liquid spills to prevent slippery surfaces that could lead to serious falls and extensive body burns. [34, p. 10-11.]

In case of contact with sodium hydroxide, swift and thorough treatment is the key to mitigate the severity of burns, emphasizing the need for immediate washing with plenty of water. Protective measures, including the use of safety goggles, masks, protective clothing, and well-maintained eye-washing fountains and spray showers, should be always complied with. Additionally, an understanding of proper first aid procedures is important, with fast action being the key to reducing the risk of serious permanent damage resulting from exposure. If ingestion occurs, providing plenty of water and seeking medical attention promptly is advised, with the avoidance of inducing vomiting to prevent further damage to the throat, mouth, and digestive tract. [34, p. 11-12.]

#### 4.2 Corrosion

Sodium hydroxide, while not as corrosive as sulphuric acid, still corrodes materials that are not corrosion resistant even at lower temperatures when the concentrations are high enough. However as can be seen in Figure 8, at lower temperatures, sodium hydroxide displays a notably reduced corrosive impact on corrosion resistant materials, even up to its solubility point. [37.]

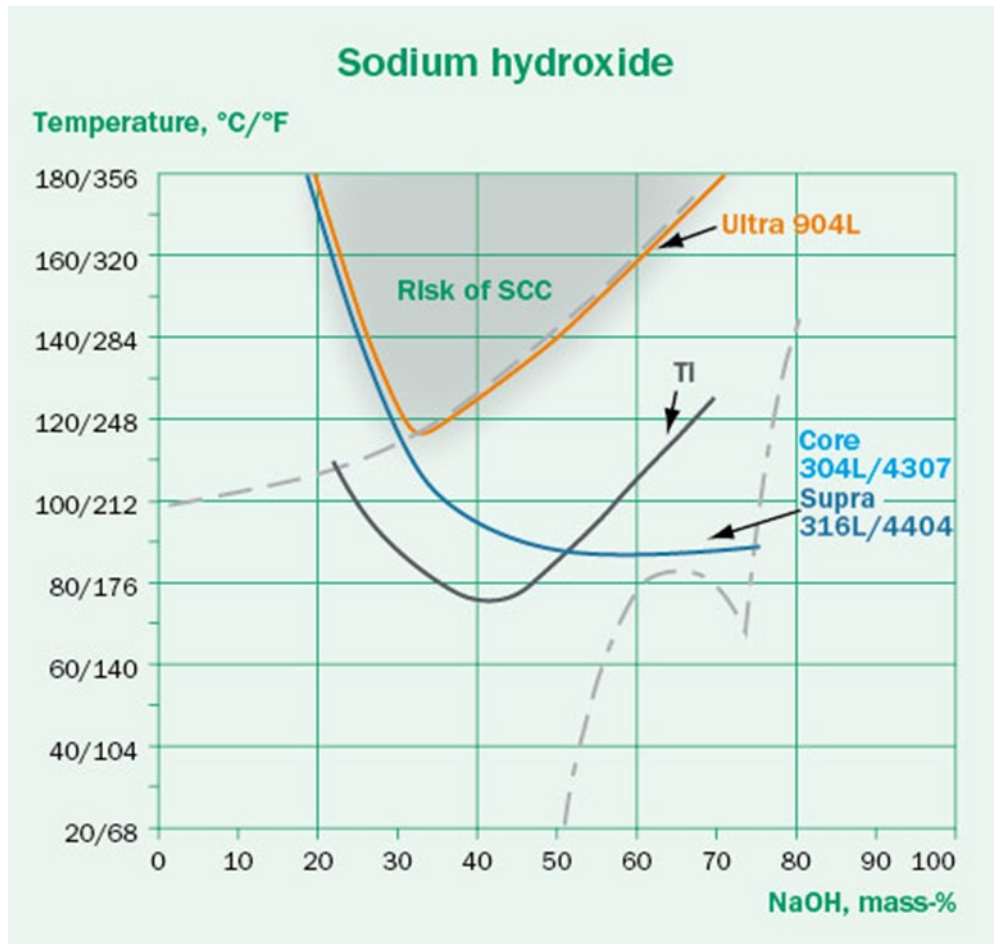


Figure 8. Corrosion resistance of selected materials. Lines represent 0.1 mm/year of corrosion. The broken line represents the boiling point. The chain line curve represents solubility. The shaded area indicates a greatly increased risk for stress corrosion cracking. [37.]

Sodium hydroxide can also cause a special type of corrosion called caustic corrosion, a type of stress corrosion cracking (SCC). This type of corrosion occurs in metal equipment that is exposed to high pH levels, resulting in an operating medium that is highly alkalized. Caustic corrosion happens due to the liquid evaporating, leaving behind salts that are then deposited on the equipment's internal metallic surface. These solids can then cause metallic stresses during normal operation and lead to damages. Caustic corrosion happens most often in equipment where a solution containing sodium hydroxide is heated to high temperatures such as a boiler or steam-generating equipment including heat exchangers. In Figure 8 this can be seen as the shaded area above the boiling point. [38; 39, p. 69.]

Coils made of nickel or nickel alloys, like Monel and Inconel, exhibit high resistance to caustic corrosion, even at elevated temperatures. Coils located too near the side of the tank can cause SCC and accelerated corrosion thus proper coil placement is crucial. Coating the tank's interior with specialized materials, such as phenolic epoxy, can eliminate both metallic contamination and stress corrosion. Areas of unrelieved high stress, particularly welds, are susceptible to caustic corrosion, and stress-relieving measures, either during fabrication or field welding, can enhance tank integrity and minimize the risk of failure. [34, p. 15]

### 4.3 Material selection

Carbon steel and iron are generally safe for handling sodium hydroxide but may be chemically attacked at elevated temperatures. While sodium hydroxide is considered stable and does not naturally form hazardous decomposition products, regular maintenance and inspection of storage tanks are essential. Successful storage involves using specific gravity tanks made of high-density polyethylene (HDPE), cross-linked polyethylene (XLPE), fibre-reinforced plastic (FRP), carbon steel, or titanium, along with compatible materials for components. Storage temperatures should be maintained below 40 °C for polyethylene tanks and 50 °C for carbon steel tanks. To prevent metallic contamination during transit, tank cars and barge tanks employ multiple types of liners on their interiors. While tank trucks are typically made of stainless steel, their interiors may also feature lining. [34; 40, p 14.]

Certain metals, such as aluminium, lead, tin, zinc, brass, bronze, galvanized steel, magnesium and chromium should be avoided due to chemical reactions with sodium hydroxide. Materials containing silica, like glass, brick, and tile, are slowly attacked by sodium hydroxide, initially contaminating it with silica, leading to eventual material failure. While copper may not be severely attacked, it can contaminate sodium hydroxide, making it harmful to processes vulnerable to contaminants. [34; 40, p. 15.]

#### 4.4 Noteworthy physical characteristics

In parts of the world where the ambient temperature can drop below 20 °C sodium hydroxide should not be stored outside without special equipment due to the low freezing point of the solution. At its common storage concentrations of 30—50 wt%, the freezing point of the liquid will vary between 0—15 °C which can be seen in Figure 9. For this reason, indoor storage is preferred due to temperature stability. If outdoor storage is required, the tanks should be insulated, heat traced, and protected from direct sunlight. [40.] Steam coils made of nickel submerged in the solution are a common method of heating. A steam or hot water heat exchanger and a circulating pump are also valid options. [34, p. 15.]

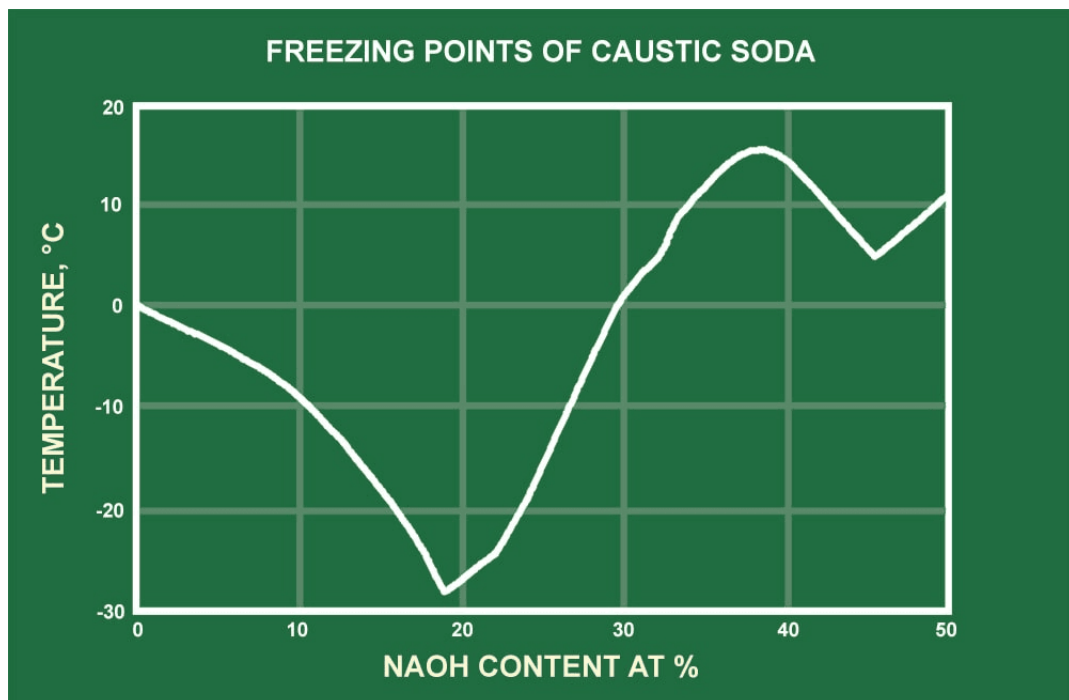


Figure 9. Freezing point of sodium hydroxide solution at various concentrations [40].

Another effective way of avoiding freezing is diluting the solution to a lower concentration. A concentration of 20 wt% would provide the solution a freezing point of approximately -28 °C. A downside to this method is the additional storage capacity it requires. Diluting the solution could also possibly allow more



leeway in the material selection due to lessened corrosion of diluted sodium hydroxide. [34, p. 15.]

Just barely keeping the solution's temperature above the freezing point is not enough. If the solution's temperature is allowed to fall near the freezing point, sodium hydroxide can start to precipitate out of the solution. This can cause solid to build up in the equipment which can end up causing stress corrosion cracking, blockages or other failures. [40.]

Sodium hydroxide also has a considerable viscosity at high concentrations, and it should be considered when designing a system for its storage and transportation. At a temperature of 20 °C, a 50 % sodium hydroxide solution's viscosity is approximately 78 mPas. For comparison, at the same temperature water will have a viscosity of approximately 1 mPas. The high viscosity can contribute to equipment malfunctions, pump failures and accumulation of solids. [40.] The temperature of a 50 % sodium hydroxide solution should be kept at around 30—35 °C so it retains fluidity and functionality. This will provide the solution a viscosity around 30—40 mPas. The temperature should not be allowed to go over 60 °C if stored in a tank made of material containing iron due to increasing iron pickup by the sodium hydroxide solution. [34; 40, p. 15.]

Much like sulphuric acid, the density of sodium hydroxide might need to be taken into account when designing process equipment such as tanks and pipes. Sodium hydroxide's lesser solubility, approximately 50 wt% at 20 °C, means that higher concentrations rarely need to be factored. At this temperature, the density of 50 wt% sodium hydroxide solution is approximately 1520 kg/m<sup>3</sup>. Due to the high density, a storage tank with specific gravity rating of 1.9 or higher is recommended. [40.]

#### 4.5 Isolation from the process

New piping installations should always be tested with water for leaks before sodium hydroxide is introduced into the piping. Plastic covers on flanged joints,

as well as guards over pump packing glands, prevent spraying of sodium hydroxide if leaks develop. To enhance safety during spills, setting a curbing around a tank is recommended, enabling sodium hydroxide recovery and minimizing disposal hazards. Adherence to containment regulations is crucial, and after removing most of the spill, thorough cleanup with water is advised. Remaining traces can be neutralized with dilute acid or sodium bicarbonate solutions. Disposal should strictly follow applicable laws and regulations. [34, p. 14, 16.]

Sodium hydroxide storage tanks should have adequate venting and overflow protection. Sodium hydroxide is a “leak-seeking” chemical that requires secondary containment measures such as sumps, basins, double-walled tanks, or concrete dikes. The secondary containment should be able to hold at least 110% of the tank volume and be compatible with sodium hydroxide. [40.]

#### 4.6 Current situation at Metso

Sodium hydroxide is likely the most widely used chemical in processes designed by Metso’s Hydrometallurgy Business Line. As can be observed in Table 2, EN 1.4404 (316L) stainless steel is also used often to store sodium hydroxide in project designed by Metso. The concentrations vary wildly, but the most common storage concentrations range from 30—50 wt%. The most common use for the chemical was for pH neutralization or gas scrubbing in the observed projects.

Table 2. Materials and concentrations used in sodium hydroxide storage tanks in various projects.

<b>Project</b>	<b>Level of Design</b>	<b>Material(s) used</b>	<b>Concentration(s)</b>
1	PFD	Carbon steel EN 1.4401	50 wt%
2	PFD	EN 1.4404	45—46 wt%
3	P&ID		35 wt%

Project	Level of Design	Material(s) used	Concentration(s)
			17 wt%
4	PFD	Carbon steel	32 wt% 24 wt%
5	P&ID	EN 1.4404	50 wt% 4 wt%
6	PFD	EN 1.4301 EN 1.4162	20 wt% 50 wt%
7	PFD	EN 1.4404	30 wt% 6 wt%
8	P&ID	EN 1.4404	20 wt% 6 wt%
9	PFD		24 wt%
10	PFD		50 wt% 30 wt%
11	PFD		50 wt% 30 wt%
12	PFD		24 wt%
13	PFD	Stainless steel	50 wt%
14	P&ID	EN 1.4404	50 wt%
15	PFD	EN 1.4404	50 wt%

## 5 Ammonia

Ammonia (NH<sub>3</sub>) is the second most produced chemical in the world just behind sulphuric acid. It is a widely used compound with applications in various industries. Its most common use is in agriculture as a key component in fertilizers. Beyond agriculture, ammonia serves as a precursor in the production

of various chemicals. It can also be used in gas scrubbing, pH regulation or as an alternative fuel among other uses. [41.]

Ammonia ( $\text{NH}_3$ ) is stored either as anhydrous ammonia which contains no water or as a solution with water known as aqueous ammonia, ammonia hydroxide or ammonia solution. This thesis will mostly cover aqueous ammonia. Ammonia's concentration is often measured on the Baumé scale with the most common commercial strengths being 21 °Bé (19,68 wt%) and 26 °Bé (29,4 wt%). [42, p. 2.]

Just like sulphuric acid and sodium hydroxide, aqueous ammonia can be used for pH neutralization. It is, however not an optimal choice as it is relatively expensive, challenging to handle, can emit noxious and corrosive gases, and functions as a relatively weak base. The storage and treatment tanks must have effective ventilation due to potential hazards from leaks. [43.]

A future use for ammonia could be as a cleaner and greener fuel in maritime and power plant applications, with Wärtsilä actively researching its potential. Collaborative trials, set to commence in the near future with shipping companies, will assess ammonia's viability as a ship fuel. Subsequent evaluations will explore its application in power plants, covering aspects like storage, distribution systems, emissions, energy efficiency, and safety. While ammonia is currently primarily produced from fossil sources, there's optimism for a reduced carbon footprint when generated using renewable energy. However, adopting ammonia as an industrial fuel requires extensive research due to challenges related to its toxicity, corrosiveness, and potential impacts on emissions. [44.]

## 5.1 Safety and hazards

Ammonia, whether in gas form or as an aqueous solution, poses significant health risks as it is irritating and corrosive to the skin, eyes, respiratory tract, and mucous membranes, potentially causing severe burns and injuries.

Exposure to ammonia can worsen existing skin and respiratory conditions. Notably, ammonia vapour can become flammable when mixed with air within specific limits (15—28% gaseous ammonia by volume). Extreme caution is essential, especially during activities like welding near tanks containing or previously holding aqueous ammonia. Prior to any work, tanks, lines, and equipment must be thoroughly purged of aqueous ammonia and its vapours. [42, p. 4.]

Aqueous ammonia will react exothermically with acids; therefore neutralizing of the solution must be handled with care. Additionally, ammonia can form explosive compounds if it comes in contact with certain chemicals such as mercury, chlorine, iodine, bromine, silver oxide and hypochlorites. [45, p. 35.]

Precautions include wearing protective gear, storing it away from incompatible materials, avoiding mixing with other chemicals, and using it with proper ventilation. Disposal must adhere to regulations, avoiding harm to waterways. In case of exposure, immediate medical attention is crucial, with specific first aid measures for inhalation, skin, eyes, and ingestion. Prolonged exposure may lead to chronic health issues, emphasizing the importance of limiting exposure and monitoring workers' health. [46.]

## 5.2 Corrosion

Corrosion on stainless steels and iron caused by aqueous ammonia is negligible but it can rapidly react with other materials such as zinc, copper, copper alloys such as brass and galvanized surfaces. It is crucial to use materials like steel or ductile iron for ammonia containers, valves, fittings, and piping, as ammonia does not corrode these. [42, p. 2, 4.]

## 5.3 Material selection

It is advisable to use carbon steel, stainless steel cast iron or aluminium for storage tank construction. If alternative materials are used, their compatibility

with aqueous ammonia must be confirmed by the storage tank manufacturer. Tanks should possess a pressure rating of 2 bar, along with safety relief valves and a vacuum breaker designed for that pressure. Proper grounding is essential for steel tanks. Storage tanks made of different materials or with lower pressure ratings require careful design considerations. [45, p. 35-36.]

Aqueous ammonia should not be stored in containers made of galvanized surfaces, copper, brass, bronze alloys, or certain types of elastomers due to its corrosive reaction with these materials. [45, p. 35-36.]

#### 5.4 Noteworthy physical characteristics

Some substances, such as ammonia, have a very high vapour pressure meaning they have a low boiling point. The pressure of the vapour phase in equilibrium with its liquid phase is called the vapour pressure of the substance. Should the surrounding pressure go above the vapour pressure, all of the substance would turn into liquid. The opposite happens when the surrounding pressure goes below the vapour pressure turning all of the substance into vapour. As temperature increases, the vapour pressure also rises. This means that a substance with low boiling point will need an ever-increasing amount of pressure to keep it in liquid form. [47, p. 110.]

Due to ammonia's high vapour pressure, pure anhydrous ammonia has a boiling point of  $-33\text{ }^{\circ}\text{C}$  at a pressure of one atmosphere [48, p. 4]. Diluting anhydrous ammonia in water increases this point and helps keep the ammonia in liquid state at higher temperatures. This can be observed in Figure 10 where the bubbling line represents the temperature at which a solution starts the vaporization process. Most of the vapour will be ammonia due to its boiling point being lower than that of water. In the same figure the effect of pressure on the bubble point can also be seen. For example, by drawing a straight line from the most common aqueous ammonia concentration of 26 °Bé (29,4 wt%) on the x-axis to the bubbling line at 1 bar of pressure, followed by another straight line to

the y-axis yields a temperature of approximately 29 °C. At a pressure of 2 bar this temperature increases to approximately 47 °C.

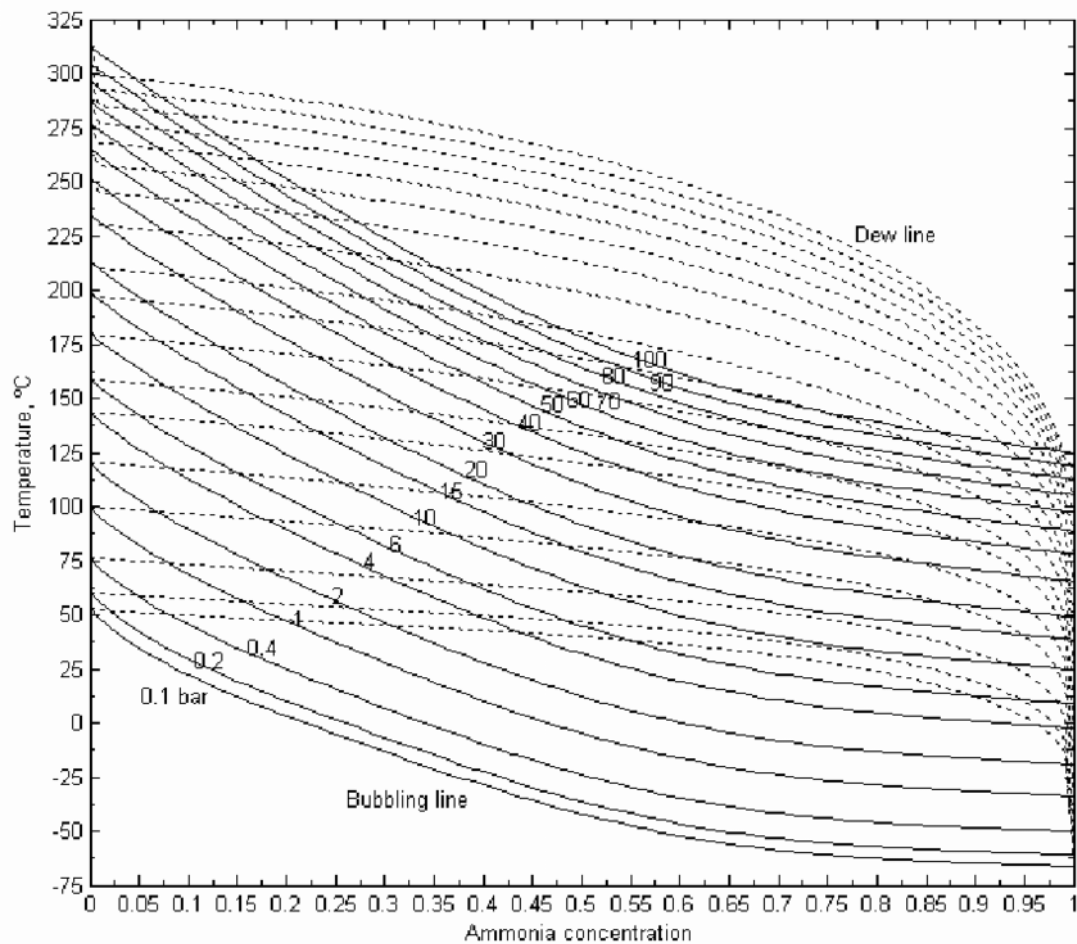


Figure 10. Txy phase diagram of ammonia and water at various pressures [49].

Ammonia might need to be stored in a pressure vessel depending on the solution's concentration, the storage temperature and the desired state of matter. Usually, aqueous ammonia should be stored in a closed container with the temperature being noticeably lower than the boiling point. Should ammonia gas escape the solution, the material strength will be reduced. [42, p. 2.]

The freezing point of 21 °Bé (19.68 wt%) aqueous ammonia is approximately -35 °C so unless the process handles very low concentrations or very low ambient temperatures this should not pose a problem. For any concentrations above 30 wt% the freezing point is approximately -80 °C or lower. [42, p. 2.]

## 5.5 Isolation from the process

To ensure safe storage and handling of aqueous ammonia, it must be stored in closed containers due to its vapour pressure being similar to atmospheric pressure. It is crucial to store it in a dry and cool area. If stored in a closed building, adequate ventilation, either natural or mechanical, should be provided to prevent the accumulation of ammonia vapour. Caution is necessary to avoid trapping ammonia vapour under floors, roofs, or similar structures, which could lead to hazardous concentrations. Notably, ammonia vapour can ignite when mixed with air in concentrations ranging from 15% to 28%. Hence, it is important to exclude sparks or ignition sources in areas where these concentrations could potentially exist, emphasizing the significance of strict safety protocols to prevent accidents and ensure workplace safety. [42, p. 6.]

## 5.6 Current situation at Metso

Ammonia is the least used chemical of the three in Metso's projects. In both the example projects presented in Table 3, the chemical was used in solvent extraction processes to control the pH values. EN 1.4404 (316L), the material used for one of the projects, is likely an overkill but will definitely work.

Table 3. Materials and concentrations used in ammonia storage tanks in various projects.

<b>Project</b>	<b>Level of Design</b>	<b>Material(s) used</b>	<b>Concentration(s)</b>
1	P&ID	EN 1.4404	20—25 wt%
2	PFD		20 wt%



## 6 Practical Part

### 6.1 Chemical Data

The practical part of this thesis was to create an Excel file which could act as a sort of database for information about different chemicals including factors that need to be considered when designing equipment to handle various chemicals at different circumstances.

Currently mostly corrosion data exists in the Excel file. The file contains the data of various materials and how they perform in different environments. An example of this can be seen in Figure 11. The various factors include different concentrations of the chemical in question, temperature variations, and the introductions of different contaminants. The file also includes the corresponding pipe codes from different standards where applicable as these can sometimes be hard to find. An example of this would be the austenitic stainless steel EN 1.4404 that has the ASTM code 316L and the UNS code S31603.

The material is corrosion resistant. Corrosion rate less than 0,1 mm/year.												
The material is not corrosion resistant, but useful in certain cases. Corrosion rate 0,1 - 1,0 mm/year.												
Serious corrosion. The material is not usable. Corrosion rate over 1,0 mm/year.												
No data.												
Pure sulphuric acid												
H2SO4												
H2SO4 (mass-%)				0,1	0,5	0,5	0,5	1	1	1	1	
Temperature (°C)				100	100	20	50	100	20	50	70	85
Name of material	EN code	ASTM code	UNS code	BP	BP			BP				
Carbon steel												
(1)	1.4000	410S	S41008									
(2)	1.4016	430	S43000									
(3)	1.4307	304L	S30403									
	1.4521	444	S44400									
(4)	1.4404	316L	S31603									
(5)	1.4438	317L	S31703									
	1.4539	904L	N08904									
	1.4547	-	S31254									
	1.4565	-	S34565									
	1.4652	-	S32654									
	1.4162	-	S32101									
	1.4362	-	S32304									
	1.4662	-	S82441									
	1.4462	2205	S32205									
	1.4410	2507	S32750									
Titanium												
(1) also covers:	EN code	ASTM code	UNS code									
	1.4512	409	-									
	1.4003	410L	S40977									
	1.4589	-	S42035									
(2) also covers:	EN code	ASTM code	UNS code									
	1.4511	-	-									
	1.4520	430Ti	-									
	1.4510	439	S43035									
	1.4509	-	S43940									
(3) also covers:	EN code	ASTM code	UNS code									
	1.4301	304	S30400									
	1.4311	304LN	S30453									
	1.4541	321	S32100									
	1.4303	305	S30500									
	1.4306	304L	S30403									
(4) also covers:	EN code	ASTM code	UNS code									
	1.4401	316	S31600									
	1.4406	316LN	S31653									
	1.4436	316	S31600									
	1.4432	316L	S31603									

Figure 11. A sample of the Excel file containing corrosion data.

The materials and concentrations featured in the tables of this thesis are also included, and the file will hopefully be expanded in the future. Future versions of the file could incorporate practical examples from real-world scenarios, including both successful and unsuccessful instances. This could be done by taking pictures of P&I diagrams from past projects after receiving feedback from the plant itself.

## 6.2 Unit converter

Across various projects, the unit of concentration for used chemicals was not standardized. In some projects the unit of measurement was grams per litre and others had them as weight percentages which had proven to be a problem in past projects. Converting the units is not straightforward as the density of the solution changes depending on the concentration and temperature so empirical data was needed. A converter was created in the Excel file to easily switch between the two units using one of two methods depending on which way the conversion is being done.

**TABLE 2-55 Sulfuric Acid (H<sub>2</sub>SO<sub>4</sub>)\***

%	0°C	10°C	15°C	20°C	25°C	30°C	40°C	50°C	60°C	80°C	100°C
1	1.0074	1.0068	1.0060	1.0051	1.0038	1.0022	0.9986	0.9944	0.9895	0.9779	0.9645
2	1.0147	1.0138	1.0129	1.0118	1.0104	1.0087	1.0050	1.0006	0.9956	0.9839	0.9705
3	1.0219	1.0206	1.0197	1.0184	1.0169	1.0152	1.0113	1.0067	1.0017	0.9900	0.9766
4	1.0291	1.0275	1.0264	1.0250	1.0234	1.0216	1.0176	1.0129	1.0078	0.9961	0.9827
5	1.0364	1.0344	1.0332	1.0317	1.0300	1.0281	1.0240	1.0192	1.0140	1.0022	0.9888
6	1.0437	1.0414	1.0400	1.0385	1.0367	1.0347	1.0305	1.0256	1.0203	1.0084	0.9950
7	1.0511	1.0485	1.0469	1.0453	1.0434	1.0414	1.0371	1.0321	1.0266	1.0146	1.0013
8	1.0585	1.0556	1.0539	1.0522	1.0502	1.0481	1.0437	1.0386	1.0330	1.0209	1.0076
9	1.0660	1.0628	1.0610	1.0591	1.0571	1.0549	1.0503	1.0451	1.0395	1.0273	1.0140
10	1.0735	1.0700	1.0681	1.0661	1.0640	1.0617	1.0570	1.0517	1.0460	1.0338	1.0204
11	1.0810	1.0773	1.0753	1.0731	1.0710	1.0686	1.0637	1.0584	1.0526	1.0403	1.0269
12	1.0886	1.0846	1.0825	1.0802	1.0780	1.0756	1.0705	1.0651	1.0593	1.0469	1.0335
13	1.0962	1.0920	1.0898	1.0874	1.0851	1.0826	1.0774	1.0719	1.0661	1.0536	1.0402
14	1.1039	1.0994	1.0971	1.0947	1.0922	1.0897	1.0844	1.0788	1.0729	1.0603	1.0469
15	1.1116	1.1069	1.1045	1.1020	1.0994	1.0968	1.0914	1.0857	1.0798	1.0671	1.0537
16	1.1194	1.1145	1.1120	1.1094	1.1067	1.1040	1.0985	1.0927	1.0868	1.0740	1.0605
17	1.1272	1.1221	1.1195	1.1168	1.1141	1.1113	1.1057	1.0998	1.0938	1.0809	1.0674
18	1.1351	1.1298	1.1271	1.1243	1.1215	1.1187	1.1129	1.1070	1.1009	1.0879	1.0744
19	1.1430	1.1375	1.1347	1.1318	1.1290	1.1261	1.1202	1.1142	1.1081	1.0950	1.0814
20	1.1510	1.1453	1.1424	1.1394	1.1365	1.1335	1.1275	1.1215	1.1153	1.1021	1.0885
21	1.1590	1.1531	1.1501	1.1471	1.1441	1.1410	1.1349	1.1288	1.1226	1.1093	1.0957
22	1.1670	1.1609	1.1579	1.1548	1.1517	1.1486	1.1424	1.1362	1.1299	1.1166	1.1029
23	1.1751	1.1688	1.1657	1.1626	1.1594	1.1563	1.1500	1.1437	1.1373	1.1239	1.1102
24	1.1832	1.1768	1.1736	1.1704	1.1672	1.1640	1.1576	1.1512	1.1448	1.1313	1.1176
25	1.1914	1.1848	1.1816	1.1783	1.1750	1.1718	1.1653	1.1588	1.1523	1.1388	1.1250
26	1.1996	1.1929	1.1896	1.1862	1.1829	1.1796	1.1730	1.1665	1.1599	1.1463	1.1325
27	1.2078	1.2010	1.1976	1.1942	1.1909	1.1875	1.1808	1.1742	1.1676	1.1539	1.1400
28	1.2160	1.2091	1.2057	1.2023	1.1989	1.1955	1.1887	1.1820	1.1753	1.1616	1.1476
29	1.2243	1.2173	1.2138	1.2104	1.2069	1.2035	1.1966	1.1898	1.1831	1.1693	1.1553
30	1.2326	1.2255	1.2220	1.2185	1.2150	1.2115	1.2046	1.1977	1.1909	1.1771	1.1630
31	1.2409	1.2338	1.2302	1.2267	1.2232	1.2196	1.2126	1.2057	1.1988	1.1849	1.1708
32	1.2493	1.2421	1.2385	1.2349	1.2314	1.2278	1.2207	1.2137	1.2068	1.1928	1.1787
33	1.2577	1.2504	1.2468	1.2432	1.2396	1.2360	1.2289	1.2218	1.2148	1.2008	1.1866
34	1.2661	1.2588	1.2552	1.2515	1.2479	1.2443	1.2371	1.2300	1.2229	1.2088	1.1946

Figure 12. A sample of sulphuric acid solution's density by concentration and temperature used to convert the units between one another. [49.]

The used data was sourced from various websites and books and interpolated to fit the values not specifically found in the data. For example, in the data presented in Figure 12 it is not possible to directly find the density of 11.3 wt%

sulphuric acid solution at a temperature of 67 °C, but the unit converter makes this easy as can be seen in Figure 13. Finding the density also requires the interpolation of two axes which would be time consuming to do by hand.

Sulphuric Acid (wt% → g/l)		
Weight Percentage	11,3 wt-%	(1-100)
Temperature	67 °C	(0-100)
<b>Density (Solution)</b>	<b>1050,295 g/l</b>	
<b>Concentration (H2SO4)</b>	<b>118,683 g/l</b>	

Sulphuric Acid (g/l → wt%)		
Concentration	118,7 g/l	
Temperature	67 °C	(0-100)
<b>wt% (H2SO4)</b>	<b>11,306 wt%</b>	

Figure 13. User interface of the sulphuric acid unit converter.

All of the data was at a pressure of 1 atmosphere, which means that the conversions will be more or less inaccurate at different pressures due to the density of a liquid increasing as pressure increases. Impurity of the solution will also make the conversion inaccurate due to one of the units being dependent on both volume and mass while the other is only dependent on mass.

To convert from weight percentage to grams per litre, a data value is read in from a table such as the one in Figure 12 and interpolated if needed using the temperature and weight percentage provided by the user. That value is then converted using Formula 1:

$$a = b * \frac{c}{100}, \quad (1)$$

Where      a = concentration of the chemical (g/l)  
               b = density of the solution (g/l) – read in from the data table or interpolated if not directly available

$c$  = concentration of the chemical (wt%) – provided by the user

For example, converting sulphuric acid with a concentration of 11.3 wt% at a temperature of 67 °C would first have the solution density read in from the data table and then interpolated by Excel formulas if needed, resulting in the solution's density being approximately 1050 g/l. Then this value would be divided by the user-provided concentration of 11.3 wt% resulting in sulphuric acid concentration of 118.7 g/l.

To do the conversion in the opposite way, the table's data is first converted from the solution's density to the chemical's concentration by multiplying each data point by the corresponding weight percentage for easier usage. This data is then directly used in combination with the values provided by the user to find the desired weight percentage on the y-axis after interpolating if needed.

## 7 Summary

The thesis aimed to centralize and organize dispersed information on materials related to chemicals used by Metso's Hydrometallurgical Business Line, reducing the need for extensive searches. This consolidation aimed to improve productivity, reduce errors, and mitigate risks in material selection. The three chemicals selected for further research were sulphuric acid ( $H_2SO_4$ ), sodium hydroxide (NaOH), and ammonia ( $NH_3$ ).

The resulting Excel file collects data from various online sources as well as internal company documents to consolidate information on the selected chemicals. The data includes tables and charts with information about corrosion of select materials at various different environments. The file also includes the unit converter and data from various past projects designed Metso's Hydrometallurgy Business Line.

The Excel file will hopefully prove to be a vital asset to the company. In the future the file might further be expanded upon to include other chemicals such as hydrochloric acid (HCl), which was considered to be included in the project at

the start but was then replaced with ammonia ( $\text{NH}_3$ ) instead. More information on the already existing chemicals could be added as well to include factors that were not included in this thesis.

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