Comparison of pipe materials for cooling systems

Markus Nygård

Bachelor's Thesis

Energy and Environmental Technology

2022

DEGREE THESIS	
Arcada	
Degree Programme:	Energy and Environmental Technology
Identification number:	8168
Author:	Markus Nygård
Title:	Comparison of pipe materials for cooling systems
Supervisor (Arcada):	Mariann Holmberg
Commissioned by:	Granlund Pohjanmaa Oy

Abstract:

The risk of corrosion is higher in cooling systems than in heating systems because cold water binds oxygen and gases more easily than warm water. There is also an increased risk of corrosion on the outside surface of the pipe due to the brine in the pipes are colder than the surroundings, so the pipes may need both surface treatment and diffusion-tight insulation to prevent condensation.

The thesis examines the properties of pipe materials that are often used on the secondary side in water-borne cooling systems. The materials examined are black steel, galvanized steel, stainless steel, copper, and composite. In addition to the materials, the brines normally used in the cooling systems are also compared. These coolants are water mixtures with ethylene glycol, propylene glycol, ethanol, and saline. The thesis also presents a hypothetical cost comparison between the different pipe materials, where both material and installation costs are compared.

The goal of the thesis is to give the reader, who does not have broad prior knowledge in the field, a broader view of the costs and risks of the various pipe materials. The causes of corrosion are investigated so you get an overview of what to think about when planning and building a cooling system. The thesis' method is to investigate written sources from industry-specific companies, as well as have supportive discussions with pipe manufacturers and professionals in the plumbing industry. The thesis shows that it is advantageous to vary the choice of pipe material within a closed cooling system if the installation is performed correctly.

Keywords:	Pipe material, cooling system, coolants, corrosion
Number of pages:	49+4
Language:	English
Date of acceptance:	18.01.2022

EXAMENSARBETE	
Arcada	
Utbildningsprogram:	Energi- och miljöteknik
Identifikationsnummer:	8168
Författare:	Markus Nygård
Arbetets namn:	Comparison of pipe materials for cooling systems
Handledare (Arcada):	Mariann Holmberg
Uppdragsgivare:	Granlund Pohjanmaa Oy

Sammandrag:

Risken för korrosion är högre i kylsystem än i värmesystem, eftersom kallt vatten lättare binder syre och gaser än varmt vatten. Även utvändigt finns en förhöjd korrosionsrisk på grund av kylmedium i rören är kallare än omgivningen, så kylrören kan behöva både ytbehandling och diffusionstät isolering för att förhindra kondens som kan uppstå utanpå röret.

I examensarbetet granskas egenskaper av rörmaterial som ofta används på sekundärsidan i vattenburna kylsystem. Materialen som granskas är svart stål, elförzinkat stål, rostfritt stål, koppar, och komposit. Utöver materialen jämförs också de kylmedium som normalt används i kylsystemen. Dessa kylmedier är vattenblandningar med etylenglykol, propylenglykol, etanol, och saltlösning. I arbetet presenteras också en hypotetisk kostnadsjämförelse mellan de olika rörmaterialen, där både material- och installationskostnader jämförs.

Examensarbetets målsättning är att ge läsaren, som inte har bred förkunskap inom området, en bredare syn på de olika rörmaterialens kostnader och risker. Orsakerna till att korrosion uppstår utreds så man får en överblick på vad man ska tänka på då man planerar och bygger ett kylsystem. Examensarbetets metod är att undersöka skriftliga källor från branschspecifika företag, samt föra styrkande diskussioner med rörtillverkare och professionella inom VVS-branschen. Arbetet visar att man med fördel kan variera valet av rörmaterial inom ett slutet kylsystem om installationen är korrekt utfört.

En längre svensk sammanfattning av examensarbetet finns i slutet av arbetet.

Nyckelord:	Rörmaterial, kylsystem, kylmedium, korrosion
Sidantal:	49+4
Språk:	Engelska
Datum för godkännande:	18.01.2022

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

FOREWORD

I would like to thank Granlund Pohjanmaa Oy for the opportunity to do this Bachelor's thesis. And I would also like to thank my supervisor Mariann Holmberg at Arcada University of Applied Sciences. And a special thanks to Bent Andersson at Geberit and Jonas Mäkelä at Närpes Rör for their help and expertise.

Markus Nygård

Vaasa, December 2021

1 INTRODUCTION

In the liquid-borne systems for heating and cooling, pipes of different materials and quality are used. Many different factors come into play when choosing pipe type: the system's dimension, temperature, pressure, and location. Of course, cost is also an important factor, as is the systems estimated service life. Nothing should need to be replaced prematurely.

It is a well-known fact that sedimented corrosion products from rust attack leads to clogging of pipes and components, impaired energy transfer for heat exchangers and radiators and eventually to leakage. Cooling systems are more sensitive than the heating systems and the low-temperature systems on the heating side more often show shortcomings than the older systems with a higher temperature of the heating water. The reason is that colder water binds oxygen and other gases more easily. (Eneström Schmied, 2019)

This Bachelor’s thesis is a theoretical comparison between different pipe materials that are often used in indirect cooling systems. Joining methods for the different materials are also presented, together with the media normally used in secondary circuits and the risks that come with cooling systems.
Finally, a cost comparison made by a local pipe contractor is presented and compiled. The cost comparison is based on an actual object and compares costs on the material and installation costs. The installations are calculated with different joining methods and surface treatments, according to the collective agreement in the HVAC industry in Finland. This thesis was commissioned by Granlund Pohjanmaa and was carried out during 2021.

2 COOLING PROCESS AND SYSTEM

Our cooling needs increase in step with climate change and the average temperature rises. At the same time, we place even higher demands on indoor comfort. Using cold from nature is seen as a natural step in this process and the previously ozone-negative refrigerants have today been phased out of the market. By using indirect cooling systems with coolants, the amount of environmentally hazardous refrigerants can now be minimized. In this chapter, the fundamentals of the cooling process are explained and the difference between the direct and indirect cooling systems.

2.1 The cooling process

The principle of a cooling process is to move thermal energy from a lower temperature to a higher temperature. For this to happen, refrigerant is used in a cooling process that binds heat from the lower temperature and emits it in a higher one. The second main theorem of thermodynamics says that heat always naturally moves from a higher temperature to a lower one. For this to happen the other way around, you should always add work. In a cooling process, work is usually given from one or more compressors. In Figure 1 below you can see the four basic components of an ideal cooling process. (Åkermarck, 2018)

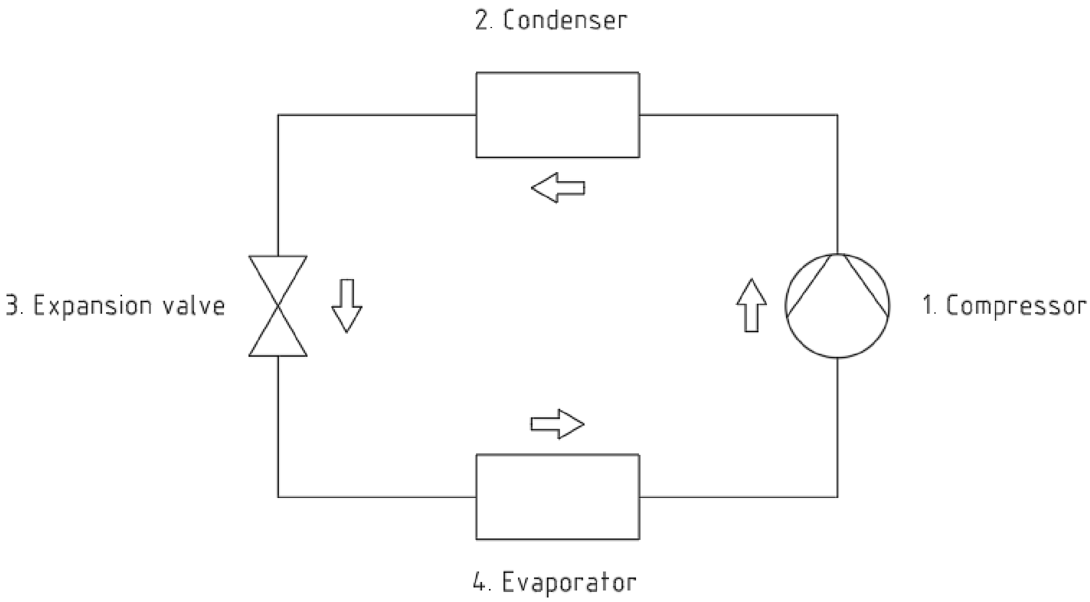


Figure 1. The principle of the cooling process

In an ideal cooling process, as seen in Figure 1, the refrigerant is sucked into the compressor (1) as saturated steam and pressed to a higher pressure. During compression, the pressure and temperature of the refrigerant rise. After compression, the refrigerant (which is in a state such as superheated steam) moves to the condenser (2) where the refrigerant condenses and emits heat to the surroundings. Thus, the refrigerant changes phase from superheated steam to saturated liquid. Thereafter, the refrigerant (which is now in liquid form) moves to an expansion valve (3). At the expansion valve, the pressure and temperature in the refrigerant fall. After the expansion valve, the refrigerant moves to the evaporator (4) where the refrigerant evaporates and binds heat from the cold room. The state of the refrigerant in the evaporator is a saturated mixture with a low proportion of steam. After this, the entire cooling process starts over. When we talk about an ideal cooling process, we are referring to a process that theoretically works without losses. In a typical cooling process, there are always small pressure and heat losses. (Åkermarck, 2018)

2.2 Cooling systems

There are essentially two principles for cooling systems, the direct and indirect (consists of a primary- and secondary circuit) systems.

Direct system

In a direct-acting cooling system, the evaporator is the cooling element that is in contact with the space to be cooled. This means that there are no extra heat exchanges on either the evaporator or condenser side. Relatively large amounts of refrigerant are needed; therefore, the direct principle is mainly used in smaller systems. (Armatec, 2008)

Indirect system

In an indirect cooling system (Figure 2), neither the evaporator nor the condenser is in direct contact with the fluid (space) to be cooled or heated. The cold is transferred to another medium and the cooling system works in two steps. First, the refrigerant cooling system cools a coolant which in turn cools connected cooling objects in a pipe system. This system has a smaller amount of refrigerant and is thus cheaper when exchanging / refilling medium and a slightly more environmentally friendly solution. In district

cooling, a heat exchanger and a brine system are installed, the connection principle can be compared with ordinary district heating. (Armatec, 2008)

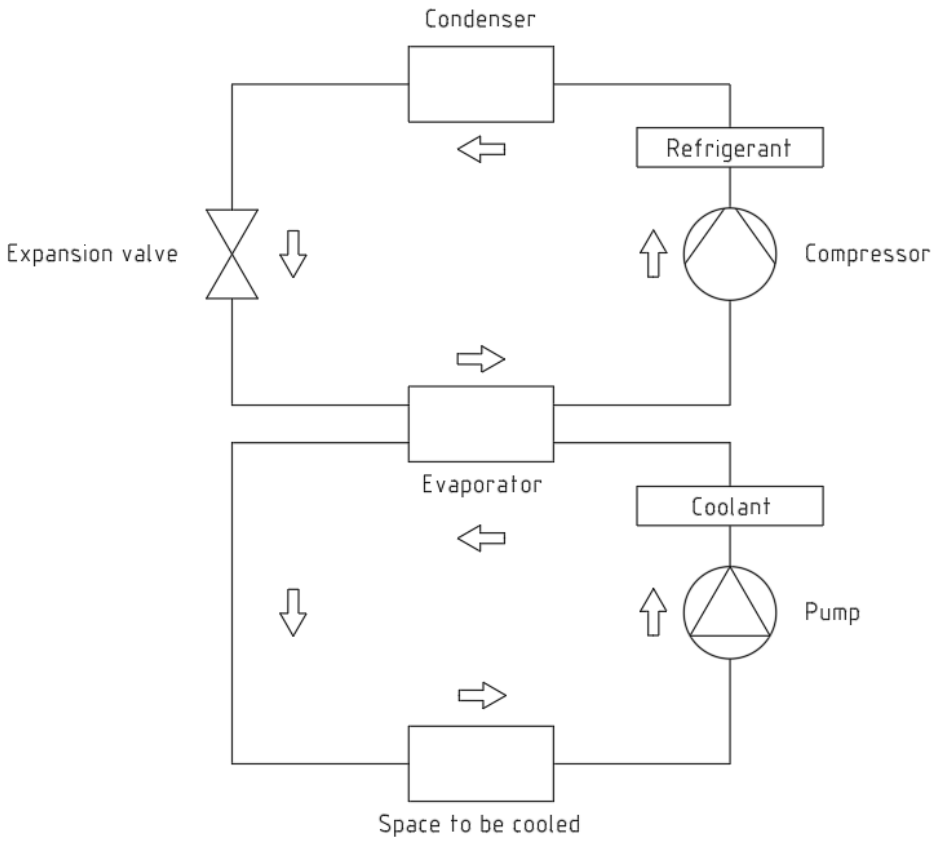


Figure 2. Principle of the indirect system

The cooling produced in a cooling machine or in a district cooling system and transferred to the refrigerant via an exchanger must be distributed to the rooms to be cooled. The operating temperature in the cooling pipes is between +6 to +18 °C. You work with a lower delta-T than with a heating system, which requires a higher flow than normal, about five times higher flow than a heating system. This in turn affects the choice of valves, pipes and components that must be dimensioned larger. We must also have the same type of safety device as for a traditional heating system such as expansion vessels and safety valve as it is a closed system where the volume of the brine changes depending on temperature. Deaeration of a brine system must be done more often than in a heating system as it is more difficult to expel air from cold water, because the water's ability to bind oxygen increases with decreasing temperature. (Lundagrossisten, 2018)

3 COOLING MEDIUM

For the direct and indirect cooling systems, as mentioned previously, different cooling mediums are used. *Coolant*, also known as *brine*, is a fluid that commonly consist of water with or without added freeze protection. Coolants are used in the secondary circuit and will be more thoroughly discussed in this thesis. *Refrigerants* that are used in the primary circuit, will only be briefly explained since it is not as relevant to this thesis.

3.1 Coolants

Clean water is an excellent coolant at operating temperatures down to 0 ˚C, but then the problems begin and the lower the temperature, the more limited the selection of suitable coolants for indirect systems. A good coolant should have the following properties:

- High volumetric heat capacity to be able to transport as much energy as possible per unit volume.

- Good heat transfer properties to reduce the temperature difference between the two fluids or to reduce the heat transfer surfaces.

- Possible to pump at low energy costs.

- Good material compatibility, i.e., does not cause corrosion.

- Environmentally friendly and safe to handle.

- Affordable.

It is worth pointing out that there is no perfect brine, all of them has some negative property, and therefore it must be decided for each individual case which properties are most important and choose the brine type based on this. Non-water-based coolants, so-called thermal oils, also occur but they have relatively poor heat transfer properties and low capacity for energy transport. (Armatec, 2008)

3.1.1 Propylene glycol $C_3H_6(OH)_3$

Propylene glycol, with its "non-toxicity", combined with corrosion inhibitors and good corrosion properties, is an excellent alternative in brine systems, especially in the food industry. However, the viscosity of the solution increases rapidly with decreasing temperature, which inhibits the heat transfer properties. This means that propylene glycol is not relevant at a temperature lower than approx. –10 ˚C. The corrosion properties allow the designer to choose relatively inexpensive types of fittings, e.g., valves, pumps, and manometers. The brine is also well proven, which gives a high reliability. (Armatec, 2008) See Table 1 for propylene glycol-based water solutions freezing point.

Table 1. Freezing Points of Propylene Glycol based Water Solutions.

Freezing Point								
Propylene Glycol Solution *(%)*	by mass	0	10	20	30	40	50	60
	by volume	0	10	19	29	40	50	60
Temperature *(°C)*		0	-3	-8	-14	-22	-34	-48

3.1.2 Ethylene glycol $C_2H_4(OH)_2$

Ethylene glycol has significantly better thermophysical properties than propylene glycol at low temperatures. The solution in combination with corrosion inhibitors has good corrosion properties, which, like propylene glycol, gives the opportunity to choose simple and cheap fittings. (Armatec, 2008)

Ethylene glycol is the most common brine for standard cooling applications. Viscosity, specific heat, and specific weight of an ethylene glycol-based water solution vary a lot with the percentage of ethylene glycol and the temperature of the fluid. The properties differ so much from clean water that the heat transfer system with ethylene glycol should be calculated carefully for actual temperature and solution. See Table 2 for ethylene glycol-based water solutions freezing point.

Table 2. Freezing Point of Ethylene Glycol based Water Solutions.

Freezing Point							
Ethylene Glycol Solution *(% by volume)*	0	10	20	30	40	50	60
Temperature *(°C)*	0	-3.4	-7.9	-13.7	-23.5	-36.8	-52.8

3.1.3 Ethanol C_2H_5OH

Ethanol is used as a coolant, primarily in the brewing industry. Due to the low flash point of ethanol, the solution is usually mixed with a maximum of 30% ethanol. Ethanol has good corrosion properties and is quite cheap but has limited heat transfer properties. (Armatec, 2008) See Table 3 for ethanol-based water solutions freezing point.

Table 3. Ethanol based Water Solutions Freezing Point.

Freezing Point							
Ethanol concentration *(% by volume)*	0	10	20	30	40	50	60
Temperature *(°C)*	0	-4	-9	-15	-23	-32	-37

3.1.4 Saline NaCl

Organic salts (Potassium acetate, potassium formate)

Organic salts have extremely low viscosity and very good thermal conductivity, which gives good heat transfer properties, which in turn results in small heat transfer surfaces and low flow resistance. It should be borne in mind that most organic salts are electrolytes and therefore the designer should carefully consider the choice of material to avoid galvanic corrosion. The low surface tension of the solution also places high demands on packing material in valves and on the shaft seals of the pumps, which means that regular service should be established. (Armatec, 2008)

Inorganic salts (Calcium chloride)

A calcium chloride solution containing water and calcium chloride has very good thermal conductivity, which provides good heat transfer properties and is often used in systems for e.g., ice rinks. However, this saline solution is very corrosive in the presence of oxygen and therefore the system should be regularly vented, and the quality of the brine checked so that the inhibitors are not consumed. (Armatec, 2008)

3.2 Refrigerants

Refrigerants are condensed gases used as heat transfer agents in cooling machines. The use of refrigerant in a cooling machine is based on the ability of the refrigerant to transfer from one phase to another (from liquid to gas). This is done by receiving heat from the cooled space, which you wish to keep at a lower temperature than the environment (evaporation). The properties of the refrigerants in a cooling process are highly dependent on pressure and temperature.

From the thermodynamic and chemical properties, a good refrigerant should i.a. have high evaporation temperature to allow smaller mass flow and thus smaller pipes can be used, and low viscosity so pressure losses in pipes and valves can be lower. It also needs to be stable, non-combustible, and non-toxic. All this for a safer use. In addition to these properties, refrigerants should also be inexpensive and environmentally friendly. Since refrigerants should have several good properties, it is understandable that not one refrigerant can contain all these properties. Therefore, the choice of refrigerants for different applications is always a form of compromise.

Refrigerants are generally divided into three different categories, depending on whether it is a one-component refrigerant or refrigerant mixtures. These groups are one-component, azeotropic and zeotropic refrigerant. Refrigerants are mainly made up of organic hydrocarbons where hydrogen atoms are processed in various ways and replaced by halogen atoms. By halogenated molecules are meant compounds that contain fluorine (F), chlorine (Cl), bromine (Br) or iodine atoms (I). Thus, many so-called halogenated hydrocarbons have been obtained. (Åkermarck, 2018)

Classification and designation of refrigerants according to chemical structure makes it easier to distinguish between refrigerants and makes it easier to understand the difference in their chemical structure. The naming of refrigerants is based on a letter code and the subsequent part of the number. The letter R, which indicates that it is a refrigerant, comes from the English word refrigerant. The official designations are granted by the American Society of Heating, Ventilation and Refrigerating Engineers (ASHRAE). A refrigerant consisting of saturated hydrocarbons and consisting of only one substance is designated

according to the example in Figure 3. Refrigerants consisting of a mixture are designated according to the example in Figure 4. (Frejd & Himmelmann, 2017)

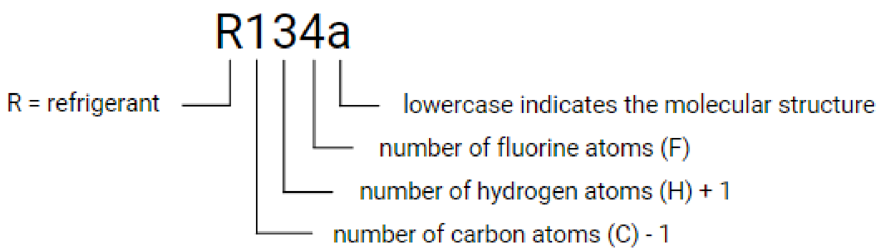


Figure 3 Designation explanation R134a (Frejd & Himmelmann, 2017)

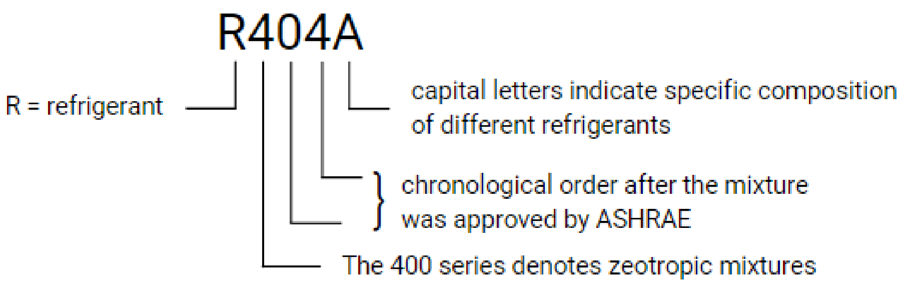


Figure 4. Designation explanation R404A (Frejd & Himmelmann, 2017)

4 PIPE MATERIAL

The fact that different pipe materials are used depends on, among other things, the area of use, costs, coolants, and the risk of corrosion. The commonly used materials are presented in this chapter.

4.1 Black steel

Steel in general is an alloy of iron (Fe) with a small amount of carbon (C) to improve its fracture toughness and strength compared with iron. Other elements can be added to change and improve its characteristics, which has been done to create e.g., stainless steel and galvanized steel. The black steel pipe, however, is made of steel that is not coated with a substrate such as zinc or paint. It is called black steel due to its dark surface that iron oxide forms during the manufacturing process. The iron oxide coating provides some corrosion resistance, whereas carbon steel requires galvanization because it is susceptible to corrosion. (Madhu, 2018)

Steel is defined as all material with an iron content of at least 50% and a carbon content of 0.03 to 2.0%. Steels are classified into different categories according to the usual grouping. When the carbon content is below 0.6%, steel is called structural steel, while steels with more than 0.6% carbon are called tool steel. All steels with more than 1.7% carbon are called cast iron. (Mäkelä, 2011)

4.1.1 Characteristics

Compared to other materials, steel pipes are strong, rigid, and inexpensive, but it is also heavy (several workers may be needed to transport it) and is at higher risk for corrosion. (Boldt & Stone, 2018)

Its thermal expansion coefficient ranges between 0,010 – 0,012 mm/(m K). The density of steel depends on the alloying constituents it contains of, but it is usually referred to 7750 kg/m^3. (Engineering ToolBox, 2003)

4.1.2 Area of use

Steel pipes are often used for closed hydronic systems since it is cheaper than other materials in systems with high pressures. Corrosion is easier to control in closed systems and especially heating system. For cooling systems there is a high risk for corrosion on the outside of the pipe and therefore it requires higher demands on surface treatment and isolation. (Boldt & Stone, 2018)

4.1.3 Corrosion

One of the properties of steel is its susceptibility to corrosion. Steel is a base metal, so it tends to release positively charged iron ions into the water, causing the pipe to rust. The most important factor for pipe rusting is the quality of the water used. Water should form a protective layer on the surface of the pipe that protects the pipe from corrosion. To achieve an optimal situation, the water should fill e.g., the following: flow rate greater than 0.5 m/s, low aggressive carbon dioxide content and pH greater than 8.5. The risk of corrosion of steel is greater the warmer the water used in the network. Efforts have been made to improve the corrosion resistance of the black carbon steel pipe by increasing its wall strength. The wall thickness of a black carbon steel pipe is at least twice that of, for example, an electro-galvanized carbon steel or copper pipe. (Mäkelä, 2011) Steel pipes must be painted twice to protect against rust. The prime coat and topcoat of the paint should form a 140-160 µm dry film thickness. It is important that the insulation is diffusion-proof. Corrosion on the outside if the pipe can occur in a humid environment. The moisture does not have to have condensed but can also acts as steam. Steel is attacked already when the relative humidity is 60%. (Gelia, n.d.)

4.2 Electrogalvanized steel

The corrosion resistance of most steel grades under natural conditions is not very good, but modern surface treatment methods can be used to successfully protect steel. A thin layer of zinc is applied on a metal where it forms a protective layer. The corrosion resistance of zinc is based on a film generated by the oxygen and element formed on the surface, which protects the metal even if there are small openings in the coating. Zinc is generally compatible with almost all metals and protects steel particularly well. Zinc

protection remains effective in conditions where zinc is highly resistant to corrosion. Such situations exist, for example, when natural water or even seawater condenses on the surface of the pipe.
Electro-galvanizing i.e., electrolytic galvanizing, is obtained by immersing a well-cleaned body to be coated in a zinc salt solution, in which the desired zinc coating is deposited on the surface of the body by means of electricity. The thickness of the coating depends on the time of the body in solution and the shape of the body. (Mäkelä, 2011)

4.2.1 Characteristics

The pipes are suitable for operating temperatures of -20… + 120 ° C with a maximum operating pressure of 16-25 bar. Depending on the manufacturer, the pipe and parts are available up to an outer diameter of 12-108 mm. (Mäkelä, 2011) Its thermal expansion coefficient is 0.012 mm/(m K). At 20 °C the heat capacity is 0.5 kJ/(kg K) and the thermal conductivity 60 W/(m K). (Geberit, 2020)

4.2.2 Corrosion

When using galvanized and black carbon steel pipe, special care must be taken to prevent the corrosion and that the system is sealed and completely oxygen-free. In a closed system, the installation order has no effect on corrosion formation. To prevent corrosion, oxygen scavengers can be added to the system to adjust the pH to the desired level. The recommended pH for a steel pipe is 8.5-9.5. (Mäkelä, 2011) Like black steel, galvanized pipes must also be painted and / or have diffusion-proof insulation.

4.3 Stainless steel

In addition to iron and carbon, chromium (Cr) is the main alloying element for stainless steel. When chromium is added to the steel melt so that the content exceeds 10.5%, a thin passive layer of chromium oxide is formed when the material comes into contact with air. If the chromium content exceeds 12%, the surface layer becomes dense. It protects the underlying steel against further oxidation. Since it is formed in contact with oxygen, the passive layer regenerates quickly if it is damaged or the steel is cut. The passive layer is extremely thin, about 0.000005 mm. But the chromium content is not the only thing that

affects the chemical resistance to corrosion, but also the carbon content. The lower the carbon content, the higher the corrosion resistance. Stainless steels should have a carbon content below 0.25%. Stainless steel is divided into the categories martensitic, ferritic, ferrite-austenitic, and austenitic based on the structure of the steel at room temperature. (BE Group, 2019)

4.3.1 Characteristics

The operating temperature 0-100°C for cooling water without antifreeze agent and -30-120°C with antifreeze agent. It has a maximum operating pressure at 16bar. (Geberit, 2020)
Steel with chromium (Cr) as the only alloying substance forms part of the stainless steels produced, but the main part also contains several other alloying substances. Two worth mentioning is nickel and molybdenum.
Nickel (Ni) mainly affects the structure and mechanical properties of steel. At a sufficiently high nickel content, stainless steel acquires an austenitic structure. Compared to the pure chrome steels, this entails significant changes in the mechanical properties - increased formability and toughness, higher heat strength, improved weldability - as well as changes in the physical properties. Nickel also increases corrosion resistance in some media.
Molybdenum (Mo) has the same effect on the structure as chromium and generally increases the corrosion resistance of both ferritic and austenitic steels. The molybdenum alloy austenitic steels are often called acid-resistant or acid-proof steels. (BE Group, 2019) Density for normal stainless-steel type X5CrNi 18-10 is 7900 kg/m^3 and 8000 kg/m^3 for type X5CrNiMo 17-12-2 that contain molybdenum and is therefore called acid-proof. (Steelnumber, 2021)

4.3.2 Area of use

In the process industry, stainless steel is the natural choice when hygiene requirements are high or when the media is aggressive. But stainless-steel pipes are also widely used in both construction and construction, especially in environments where the risk of corrosion is extra great. Using stainless steel structures has the great advantage of minimizing

maintenance costs in the long run. Austenitic steels are often a cost-effective solution and has a broader and more general area of use, such as transport of cooling water. (BE Group, 2019) Stainless steel has the best fire resistance of all metallic materials when used in structural applications, with a critical temperature above 800°C. (Aperam, n.d.)

4.3.3 Corrosion

Despite the name, stainless steel can rust. Corrosion is in principle always local but can occur quickly and cause severe damage, for example at high chloride levels, strong heat and in stagnant water. Four types of corrosion in stainless steel are oxidation (rust), crevice corrosion, point corrosion and stress corrosion. (BE Group, 2019)

4.4 Copper

Copper is a versatile pipe material. All type-approved copper pipes are suitable for almost any building services system. Applications can be, for example, a hot water, heating, or cooling system. Copper is a glowing reddish brown in color, but as it ages, the color may darken or even turn green under certain conditions.

The copper used in the copper pipe is the so-called deoxidized copper i.e., copper to which a small amount of phosphorus is most typically added. The purpose of phosphorus is to remove oxygen from molten copper. The amount of phosphorus added to the copper is 0.002 to 0.050%. The main copper in European standards is high-phosphorus, Cu-DHP (phosphorus-deoxidized copper - high residual phosphorus), which contains about 0.015 – 0.04%, and low-phosphorus Cu – DLP (phosphorus-deoxidized copper - low residual phosphorus) with a phosphorus of about 0.005–0.013%. (Mäkelä, 2011)

4.4.1 Characteristics

Copper is an element with the chemical symbol Cu and has a density of 8960 kg/m³ and a melting point of 1083 °C. Its thermal expansion coefficient at 100°C is 0.017 mm/(m °C). At 20 °C the heat capacity is 0.0385 kJ/(kg K) and the thermal conductivity 295-365 W/(m K). (Koppar.com, 2017)

The material retains its properties from -200 °C to +250 °C and has a low coefficient of longitudinal expansion 1,7mm/m at +100 °C. The smooth surface and good specific

strength of the copper tube form a low coefficient of friction for the copper. Thanks to the smooth surface, the flow capacity of the copper pipe is good even when using small pipe sizes. Copper's inherent strength compared to other materials for water and heating systems means that pipes with thinner walls and larger inner diameters can be used while maintaining the outer diameter. (Koppar.com, 2017)

4.4.2 Area of use

The large range of seamless copper pipes can be used for all types of pressurized plumbing installations. They are available in hard straight pipe lengths and in different types of soft annealed pipes in rings. The soft pipes are covered with plastic sheath with insulation and the hard ones are untreated or surface treated with chrome or paint. For luxurious purposes, they can also be specially ordered surface-treated with gold or silver. (Koppar.com, 2017)

4.4.3 Corrosion

A typical form of corrosion for copper pipes is erosion corrosion, which can occur when the flow rate in the pipe is too high (above 1.5 m/s). (Mäkelä, 2011) Another corrosion type that can happen to copper is point corrosion, that usually occurs in chlorinated environments. (Geberit, 2020)

4.5 Composite

Composite materials are usually defined as two or more physically distinguishable constituents. According to this definition, a composite pipe would be a pipe built of two or more physically distinguishable materials, such as plastic and aluminum. Composite pipes combine the stability advantages of a metal product material with the corrosion resistance of plastic. Examples of inner and outer layers of plastic are PE, PEX or PP. Composite pipes are easy to bend, remain inherently stable and greatly facilitate installation work. (Eklund, 2019)

One example of composite pipe is Geberit’s Mepla, seen in Figure 5. The outer plastic layer of polyethylene (PE) protects against corrosion and mechanical impact. The middle

layer of aluminum makes the pipe stable, bendable and diffusion tight. The inner layer, which is also made of polyethylene, is rust-protected and food-safe. There is an adhesive between the layers. (Geberit, 2018)

Figure 5. Geberit Mepla (Geberit, 2018)

In another type of composite pipe, the aluminum layer has been excluded. The middle layer here consists of a mixture of glass fiber and polypropylene (PP). On both sides of this intermediate layer there is an inner and an outer layer of pure PP. There are also composite tubes composed of inner and outer polybutene layers (PB) where the intermediate layer in the tube consists of a mixture of PB and fiberglass. A further example of composite material is glass fiber reinforced plastic where the glass fibers are held together by a thermosetting plastic. One application for this is the GAP (fiberglass reinforced plastic) pipes. (Eklund, 2019)

4.5.1 Characteristics

The Geberit Mepla composite pipe has the thermal expansion coefficient 0.026 mm/(m K) at 20-100°C and the thermal conductivity 0.43 W/(m K) at 20°C. The operating temperature 0-70°C for cooling water without antifreeze agent and -10-40°C with antifreeze agent. Its maximum operating pressure is 10 bar. Maximum allowable operating temperatures and pressures recommended by composite pipe manufacturers differ slightly between different pipes. (Geberit, 2018)

4.5.2 Area of use

Composite pipes can be used to transport most commonly used media in plumbing and cooling systems. Most types of composite pipe types are manufactured both in straight lengths (5 m) and in ring shape (50 m). The ideal working temperature for composite pipes is 15 to 25 °C. Pipes that are handled and stored at temperatures below -10 °C risk being damaged by careless handling and storage. The pipes must also not be mounted where they can be exposed externally to excessively high continuous ambient temperature. The outer plastic layers of the composite pipes are stabilized against UV radiation, but the pipes should still not be stored so that they are exposed to direct sunlight for a long time. Finished pipe installations should also be protected against UV radiation.
Cooling pipes can be installed without too much effort as no special anti-corrosion treatment is required. The biggest disadvantages of composite are the expensive price and poor recyclability of most composites. The composite contains several materials and is difficult to reuse. (Eklund, 2019)

5 INSTALLATION

Joining pipes can be done in many ways. Which joint method should be used depends on, among other things, the pipe material, medium, pipe dimension, costs, fire risk during installation, hidden or visible installation, and accessibility. (Stålbom & Kling, 2013)

5.1 Weld joint

Welding of pipelines is usually performed with gas welding, metal arc welding, and gas arc welding.

5.1.1 Gas welding

Gas welding (Figure 6) is one of the oldest welding methods. The importance of the method has diminished with the advent of new and more efficient welding methods. However, gas welding is a versatile method with simple, relatively inexpensive equipment and is well suited for repair and assembly work.

It generates its heat from a mixture of the gases acetylene and oxygen which gives a flame temperature of 3200 ° C. The welding flame, which has a lower temperature and is less concentrated than the arc during electric welding, is directed towards the joint edges which are melted, after which additive material can be added as required. The molten bath is protected from the action of the air by the reducing zone of the welding flame and by the outer flame. After welding is completed, the flame should therefore be slowly removed from the melt. The less concentrated flame gives slower cooling, which is an advantage in hardening-prone steels, but means that the method is relatively slow with greater tensile energy and risk of thermal stresses and deformations as a result. (Svetskommissionen, 2019)

Gas welding is mainly applied to carbon steels and low-alloy steels with wall thicknesses up to 5-6 mm. For wall thicknesses over 5 mm, it is often more economical and rational to metal arc welding. (Stålbom & Kling, 2013)

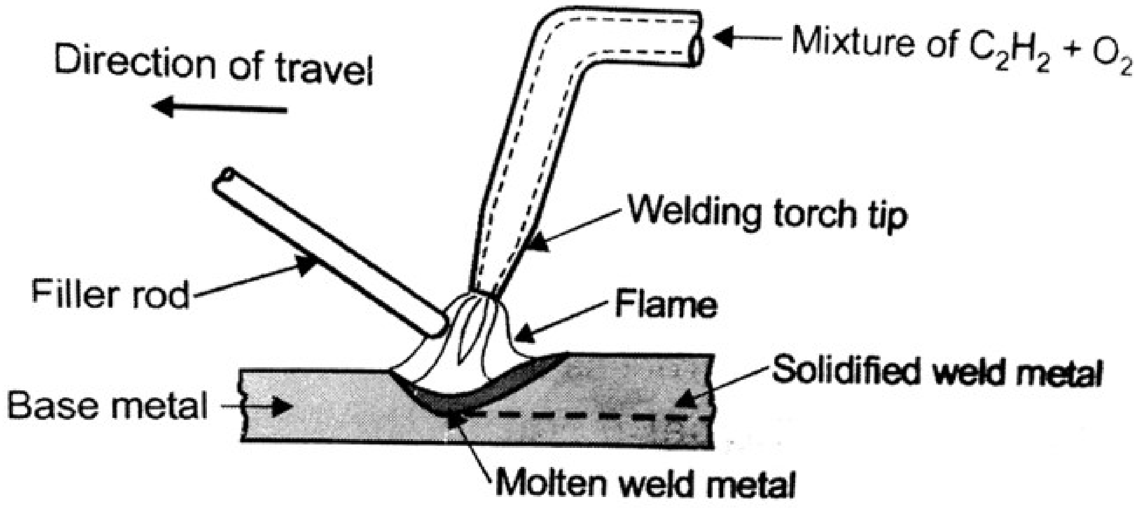


Figure 6. Gas welding (Techminy, 2018)

5.1.2 MMA welding

MMA (Manual Metal Arc), commonly referred to as arc welding or hand welding, is still the most well-known welding method. The electrode consists of a core wire with an outer sheath. When welding, an arc is lit between the electrode and the weld. This arc melts the electrode, forming the protective slag. (Meltolit, 2021)

Advantages of metal arc welding (Figure 7) are low investment cost and can be used in all welding modes. There are less stringent requirements for the purity and thorough joint preparation of the base material than other welding methods. Manual metal arc welding can be used for all non-alloy, low-alloy and stainless steel general structural steels and similar comparative steels. Steel type: Cast iron, annealed cast iron and weldable metals can also be welded. (Svetskommissionen, 2019)

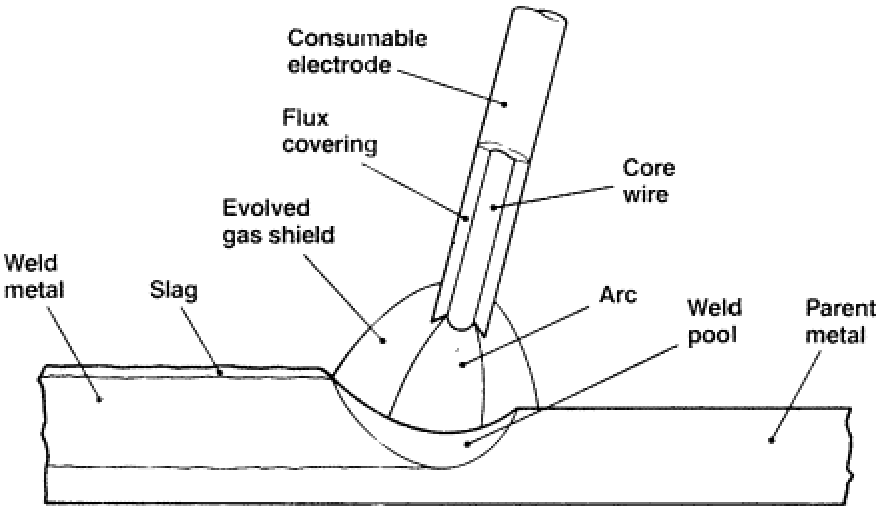


Figure 7. MMA welding (Blunt & Balchin, 2002)

5.1.3 TIG welding

TIG (Tungsten Inert Gas), also known as GTAW (Gas tungsten arc welding), is a welding method, where an electric arc is maintained between a non-melting electrode and a work-piece in an atmosphere of inert gas, i.e., the gas does not contribute to any chemical reaction in the process. The arc melts the base material and any additive material. The molten bath, like the electrode, is protected from the oxygen and nitrogen of the air by the shielding gas. The electrode can be of pure or alloyed tungsten. The gas is usually argon but helium and mixtures between helium and argon are also used. (Meltolit, 2021)

TIG welding (Figure 8) can be performed with direct current or alternating current. Direct current minus pole is used for all metals, which do not form hard-melting oxide. Metals that form hard-melting oxide, such as aluminum and magnesium, are welded with alternating current, the positive part of which provides a good oxide-breaking effect. Normally, the arc is lit with HF, a high-frequency voltage that ionizes the argon gas in the gap between the electrode and the workpiece and ignites the arc.

The TIG method provides a high welding quality, clean weld metal and good surface evenness. The method is therefore often used where the quality requirements are high, for example in the nuclear power and process industry, but also for hard-to-weld metals of type titanium, monel, copper-nickel, etc. However, the method has the greatest

application in welding stainless steels and light metals. The normal dimensional range for TIG welding ranges from 0.5-6 mm. (Svetskommissionen, 2019)

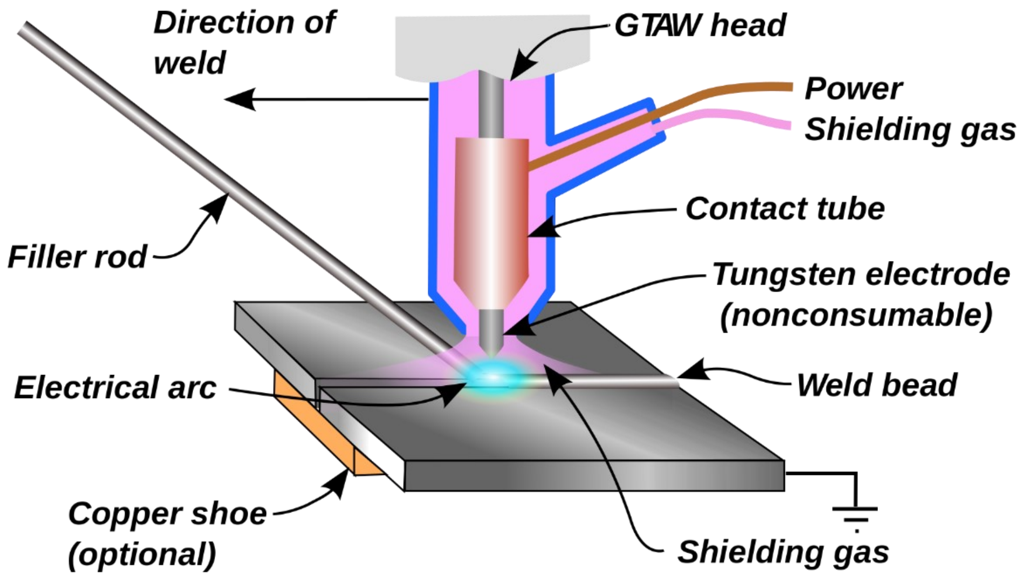


Figure 8. TIG welding (Zenele, 2015)

5.2 Press connection

Due to the easy and quick installation, the press connection is an increasingly common way for pipe connections. Press connections have been used in pipelines for more than 50 years, and today the joint can be used for copper, composite, and steel pipes. Pressing is a good option, especially when the installer is not skilled in welding. When talking about a press connection, the press and compression joints are often associated with each other, which, however, are two different things. The compression joint (Figure 9) is a press method consisting of parts made of brass, which are joined together by means of a compression bead.

The press method is based on a tool that presses the connecting part between the jaws of the tool and the pipe to each other and they form a tight and permanent connection. The aging-resistant butyl rubber O-ring at the end of the connection part ensures the tightness of the connection by forming between the pipe and the part. The press does not cause damage to the O-ring inside, as the joint has its own space for the seal. (Lyngson Oy, 2002)

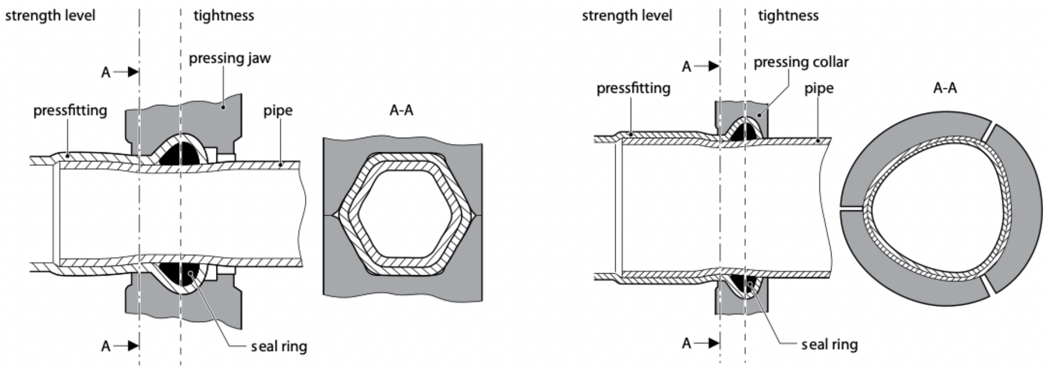


Figure 9. Cross-section of a Geberit Mapress press connection with applied pressing jaw Ø 12 - 35mm and Ø 35 - 108mm (Geberit, 2018)

The pressing tool (Figure 10) consists of a press device and press jaws or press collars. With pipe outer diameters of 12–35 mm, press jaws are used in addition to the electric press device, while larger pipes (42–108 mm) use spacers and a press collar. There is a separate jaw or collar for each pipe diameter. Pressing tools are available for manual, electric and cordless use. The press force of all pressing tools should be about 100 kN. Commonly used pressing tools have a service life of approximately 100,000 presses and must be maintained at least once a year due to the warranty period. (Lyngson Oy, 2002)

Figure 10. Geberit pressing tool (Geberit, 2021)

Installing the piping by the press method is quick and effortless. The pipes are cut to their proper length with a conventional pipe cutter, the ends are deburred, the end of the pipe is pushed into the bottom of the press coupling and the pipe is pressed into place. When using the compression method, few tools are needed and there is no need to protect the pipe environment. (Geberit, 2020)

There is a risk for leakage if the pipe is not properly pushed into the fitting or the connection has not been pressed at all. Sometimes in these cases, the joint can stand the pressure for a while before it bursts. Therefore, it is important to mark the insertion depth on the pipe and remove the pressing indicator (Figure 11) after the installation is done. This makes it easier to discover faulty joints during the ocular inspection.

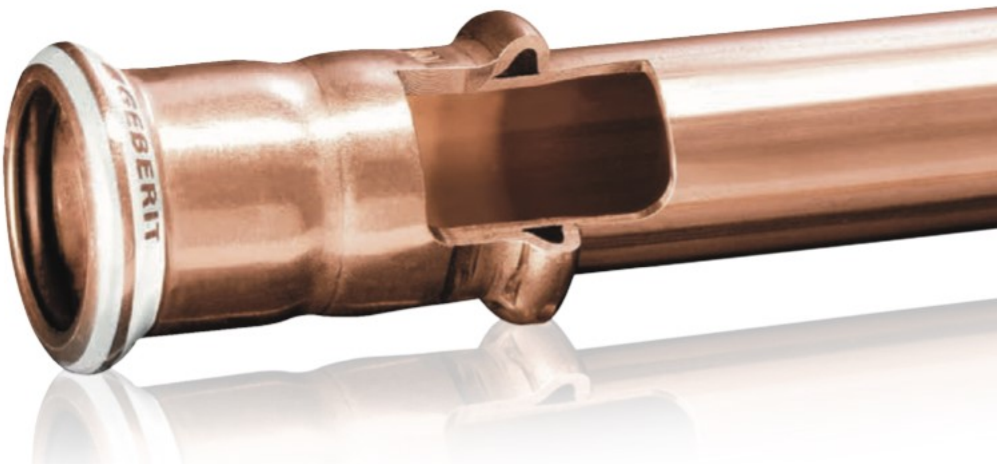


Figure 11. Copper fitting with the pressing indicator to the left (Geberit, 2020)

5.3 Threaded joint

Thread joint (Figure 12) is a common joint method for steel pipes. It can be done with either a threading machine or a manual threading tool. The threading must be performed to full thread length. The joint is sealed with PTFE-tape or linen smeared with linseed oil or special paste. The paste is used to make the linen smoother. Linen may be used at a pipeline temperature of not more than 100 °C and PTFE at not more than 185 °C. If thread joints with thread tape have come loose, new tape must be applied before retraction. With

linen, the threaded part can be turned back and forth without any leakage. With thread tape, the tape is torn with leakage as a result. (Stålbom & Kling, 2013)

Figure 12. Thread joint and hemp (Onlinebodenshop, n.d.)

5.4 Joining between two different materials

When joining pipes of different materials, the manufacturers' special transition parts must be used. Galvanic corrosion can occur when two different metals, which are far apart in the galvanic electropotential series, are in contact with each other and surrounded by moisture or water. The problems with this can be limited by using the same material, or material that is about as precious or that the materials are installed in the correct arrangement regarding the flow direction of the water. (Stålbom & Kling, 2013) This mainly applies to open circuit systems. In closed circuit systems where there is no oxygen, you should, in theory, not have this problem. But closed systems can almost never be completely tight. Automatic deaerators, radiator valves and dry circulation pumps are a couple of examples where air can enter the system. (Karob Ab, 2019)

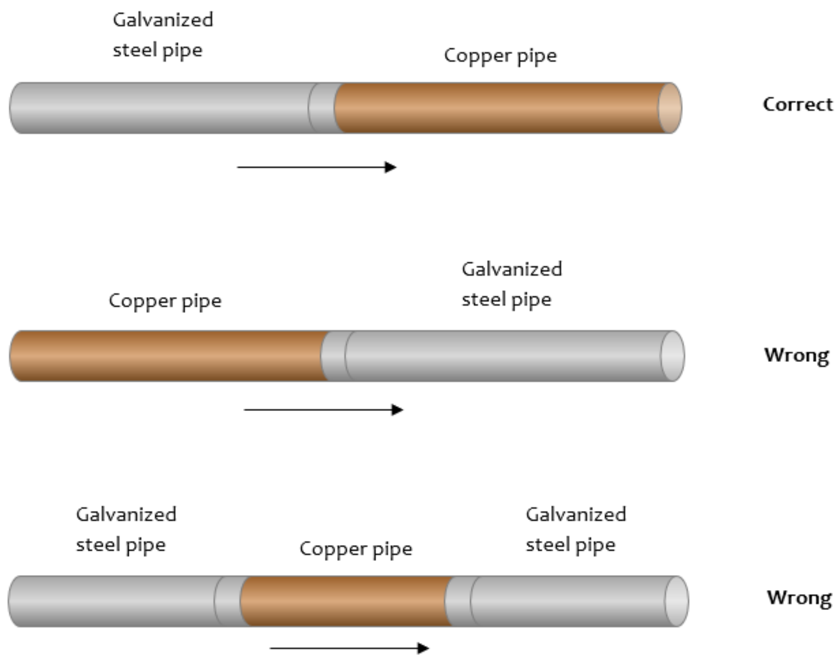
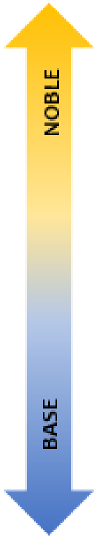


Figure 13. Example of the arrangement of pipes (Stålbom & Kling, 2013)

Stainless steel pipes can generally be combined with other metallic materials without corrosion problems. It can be connected directly to copper, brass, and red metals without the risk of galvanic corrosion. However, galvanized steel pipes that are connected directly to stainless steel in a water system can be attacked by galvanic corrosion. Ordinary steel pipes in heating systems cannot be connected directly to an expansion vessel in stainless steel. An example of pipe arrangement is seen in Figure 13. A non-metallic connection at least 50 mm long can be installed between the different pipe materials to prevent the risk of corrosion. (Stålbom & Kling, 2013) The galvanic electropotential series can be seen in Figure 14.



Stainless steel	18 Cr 10 Ni 3 Mo
Stainless steel	18 Cr 8 Ni
Stainless steel	18 Cr
Stainless steel	13 Cr
Copper-nickel	90 Cu 10 Ni
Copper	
Aluminum-brass	76 Cu 22 Zn 2 Al
Special-brass	65 Cu 31 Zn 2 Pb 2 Al 1 Sn
Brass	65 Cu 33 Zn 2 Pb
Red metal	85 Cu 5 Zn 5 Pb 5 Sn
Phosphorus copper solder	89 Cu 6 P 5 Ag
Brass	58 Cu 39 Zn 3 Pb
Soft solder	97 Sn 3 Ag
Carbon steel	
Cast iron	95 Fe 3 C 2 Si
Aluminium	
Aluminium	97 Al 3 Mg
Zinc	

Figure 14. Galvanic electropotential series for relatively hard tap water at room temperature with a pH value of about 7.5 (Stålbom & Kling, 2013)

5.5 Insulation & Surface treatment

Cooling insulation of installations that are colder than the surroundings is done so the medium in the system can maintain the intended temperature, condensation does not form on the surface of the insulation, and water vapor in the air will not be able to penetrate the insulation and condense into water. Cooling insulation is usually performed with synthetic cellular rubber. Cellular rubber insulation is available in different qualities and designs.

The hangers of cold-insulated pipes must be made so that the insulation is not broken. The pipes should be hung in special clamps that have the same insulation capacity as the insulation. If steel pipes are used, anti-corrosion painting under the clamps must be applied before the pipe is hung up and then in its entirety. All joints, even against the clamps, are glued. The clamps must be made of a material approved by the insulation manufacturer to obtain a secure joint.

An alternative to cellular rubber insulation is mineral wool insulation which is provided with a steam brake made of aluminum or plastic foil. Foils are, however, susceptible to

damage and should be protected in exposed positions against damage by, for example, plastic or aluminum sheet.

A surface cladding protects the insulation and simplifies cleaning of the surface. In plumbing applications, surface cladding of plastic (white or gray PVC) or thin patterned aluminum sheet (0.2 mm) have been common. (Stålbom & Kling, 2013)

6 RISKS

Pipes in a cooling system are highly susceptible for corrosion, both internally and externally. One reason is that colder water binds oxygen and other gases more easily, which can cause corrosion on the inside of the pipe. Externally, moisture formed because of the cold pipe can cause corrosion and damage for both the pipe and the environmental around it e.g. in concrete walls.

6.1 Corrosion

Corrosion can be defined as the degradation of a material. The degradation means a deterioration of the structure and properties of the material. Examples of this can be a reduced wall thickness in a pipe or cracking in a plastic. Corrosion usually refers to metallic materials, but it can also occur in polymers.

Corrosion processes are often of an electrochemical nature, which means that the reactions take place with the release or uptake of electrons, so-called oxidation, and reduction. This type of corrosion occurs since electrons can easily travel between points of attack, anodic and cathodic area. Metals have a great tendency to corrode as they are very good electrical conductors.

Metals corrode when used in an environment where the material is not stable. Only copper and precious metals can be found in nature in its metallic form. Other types of metals strive to return to their original more stable mineral form.

For a metal to corrode, contact with a conductive liquid and oxidizing agent is required. Water-based coolants are largely conductive as they contain ions. The most common oxidizing agent in these solutions is oxygen which is dissolved in the liquid. In general, water-based solutions with methanol and ethanol are the least conductive, while saline solutions, organic and inorganic, are the most conductive. (Gustafsson & Ohlin, 2015)

Anode reaction: $M \rightarrow Me^{2+} + 2e^-$

Cathode reaction: $2H^+ + 2e^- \rightarrow H_2$

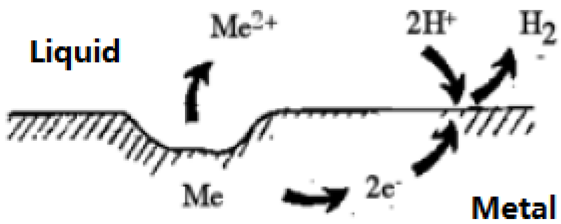


Figure 15. Corrosion process (Gustafsson & Ohlin, 2015)

General corrosion can be simply described as a corrosion cell according to Figure 15. If a metal is placed in a conductive liquid, some of the metal atoms on the surface will go into solution to form positively charged ions. Solution, the electrolyte, has a positive potential while the metal has a negative potential. The electrons travel to the cathode region and, together with the hydrogen ions, form hydrogen gas. (Gustafsson & Ohlin, 2015)

6.2 Different types of corrosion

Corrosion can look different - from patinated copper roofs to rust-red nails. The green verdigris is the copper's way of rusting and is a very slow process, while for example point corrosion and stress corrosion can have a very fast course. Corrosion can also occur in alupex systems because plastic, just like metal, will try to restore its original shape, destroying the structure of the plastic. The aluminum core can also be exposed, which must be considered in some cases. Different types of corrosion will be further explained below. (Geberit, 2020)

6.2.1 Oxidation (rust)

Oxidation is the form of corrosion that can usually be detected in black steel pipes for heating or in galvanized water pipes, while the coating for copper is greenish and for zinc white. This type of corrosion is normally a relatively slow process, but it can be aggravated by oxygen, chlorine (salts) or copper ions. The oxidation protects against point-by-point attacks by binding the oxygen to the entire surface. (Geberit, 2020)

6.2.2 Point corrosion (pitting)

Spot corrosion usually occurs in very chlorinated environments and often causes leakage in the short term (months). This type of corrosion usually occurs with copper pipes and partly with stainless steel. For copper, it is mainly due to low pH values (acidic environment). For stainless steel, point corrosion can have several causes, but chlorine can be a decisive factor. This can happen, for example, if you test pressure with water, empty the system and leave it for a few weeks without water. The water dries in and gives a very high concentration of chloride. (Geberit, 2020)

6.2.3 Crevice corrosion

Crevice corrosion occurs almost exclusively in stainless steel systems and then mainly in connection with contaminated drinking water. In such cases, there are usually bacteria in the gap, which do not normally occur in clean drinking water (this can be due to leaking water pipes or bad water from waterworks). Crevice corrosion usually occurs after 1 to 4 years of operation. Filling / test printing with filtered water and hygienic handling during installation can reduce the risk of crevice corrosion. (Geberit, 2020)

6.2.4 Galvanic corrosion

Galvanic corrosion is a type of corrosion that occurs when two metals, which are not as noble, are connected. In such a situation, the least precious metal is "dissolved" (sacrificial anode). This usually occurs in alloys between stainless steel / copper and carbon steel. Leakage usually occurs after 3 to 5 years of operation. The risk can be reduced by not using materials that are far apart in the voltage sequence. (Geberit, 2020)

6.2.5 Stress corrosion

Stress corrosion usually occurs in copper or brass. Leakage usually occurs when the metal has been subjected to "stress" in threaded couplings. Mechanical "stress" can be affected by water quality, chemicals (ammonia) or galvanic differences (stainless / brass). Stress corrosion often occurs within 1 to 5 years of operation. In working water pipes made of stainless steel or plastic (usually in very hard water), stress corrosion occurs to a greater

extent, especially in the case of brass, as there is no cathodic protection in the form of a less noble material (e.g., galvanized water pipes). (Geberit, 2020)

6.2.6 Erosion corrosion

Erosion corrosion occurs especially in copper and copper alloys, as these are susceptible to this type of corrosion. After angles or transitions between pipes and couplings (especially if the cutting is poorly done), the material cracks. The metal oxidizes but the oxide layer is constantly worn away. (Geberit, 2020)

6.2.7 Dezincification

Dezincification is usually seen in ordinary brass and depends on the water quality (pH values above 8 and by low content of hydrogen carbonate (HCO3) in relation to the chloride). The zinc is "leached", and only copper is left in a porous, spongy structure. (Geberit, 2020)

6.3 pH-value

The acidity of a liquid is measured by pH where 7 is neutral. Above this value, the liquid is alkaline and below that the solution is classified as acidic. The value should be around pH 7-9 so that the impact on corrosion is as small as possible. pH below 7 increases the risk of gas formation points and other decomposition products. A higher pH value increases the corrosion especially of copper, aluminum, and zinc. (Gustafsson & Ohlin, 2015)

6.4 Coolants

Saline solutions, such as calcium chloride or potassium acetate, are most prone to corrosion as the conductivity of these solutions is better. Less conductive substances have water mixtures of glycols, glycerin, or urea, which gives a lesser tendency to corrosion. Water-based solutions with methanol or ethanol are the least conductive liquids. (Gustafsson & Ohlin, 2015) Conductivity (μS/cm) is the ability to produce voltage and current from

the movement of the medium towards contact with the metals of the system and thus galvanic currents are formed.

- Water 150 - 350 µS/cm
- Glycol 1000 - 6000 µS/cm
- Saline 100000 - 800000 µS/cm

With increased conductivity, the production of galvanic currents increases. Glycol and saline solutions provide higher conductivity than water because they can be considered as contaminants in the water but are added to obtain a lower freezing point. (Månsson, 2007) Measurement values of the conductivity that represent good quality of the system fluid should be less than 600 µS/cm according to QTF. (Eneström Schmied, 2019)

6.5 Corrosion inhibitor

Oxygen is a reactive gas that reacts with steel in the system and corrodes and forms rust particles. To counteract this, most water-based coolants are provided with some type of corrosion inhibitor to counteract corrosion of the construction materials. (Armatec, 2008) A corrosion inhibitor is, by definition, *"a chemical substance that, when added in small concentration to an environment, effectively decreases the corrosion rate"*. The inhibitor creates a protective film on the metal, by absorbing themselves on the metallic surface. It slows the corrosion process by increasing the cathodic or anodic polarization behavior, reduces the diffusion or movement of ions on the metal surface, and increases the electrical resistance of the surface. (Singh, 2019) Organic anions, such as phosphonates, sodium sulfonates, or mercaptobenzotriazole (MBT) are commonly used in cooling waters and brine solutions. (Anon., 2011)

6.6 Condense

The air is a mixture of gases, pollutants, and vapors, which is why dry clean air only exists in theory. The gases that make up the air are mostly nitrogen (77%), oxygen (22%), argon and other gases (carbon dioxide, hydrogen, neon, helium, krypton) and water vapor (1%). There is always a certain amount of water vapor in the air. Moist air is thus a mixture of

dry air and water vapor. To understand the relationship between air temperature and humidity the mollier diagram, constructed in 1923 by the German Richard Mollier, for humid air can be used. In the diagram you can easily see the connection between the air temperature, humidity, and heat content. (IVprodukt, 2015)

As seen in Figure 16. The Mollier Diagram, the dry temperature is given in °C and is seen at the vertical axis in the diagram. The specific humidity that is shown at the horizontal axis is the amount of water in kg that exists per kg dry air. To be able to work with more manageable numbers, the specific humidity in g/kg dry air is usually stated. As can be seen in the diagram, the air's ability to contain water decreases with reduced temperature. The relative humidity indicates how much moisture the air contains in relation to the maximum possible amount of moisture at a certain temperature. For example, if the relative humidity is 10%, it means that the water vapor in the air has a pressure (= partial pressure) which is 10% of the water vapor saturation pressure at a certain temperature. The relative humidity is shown in the form of several curves in the diagram. (IVprodukt, 2015)

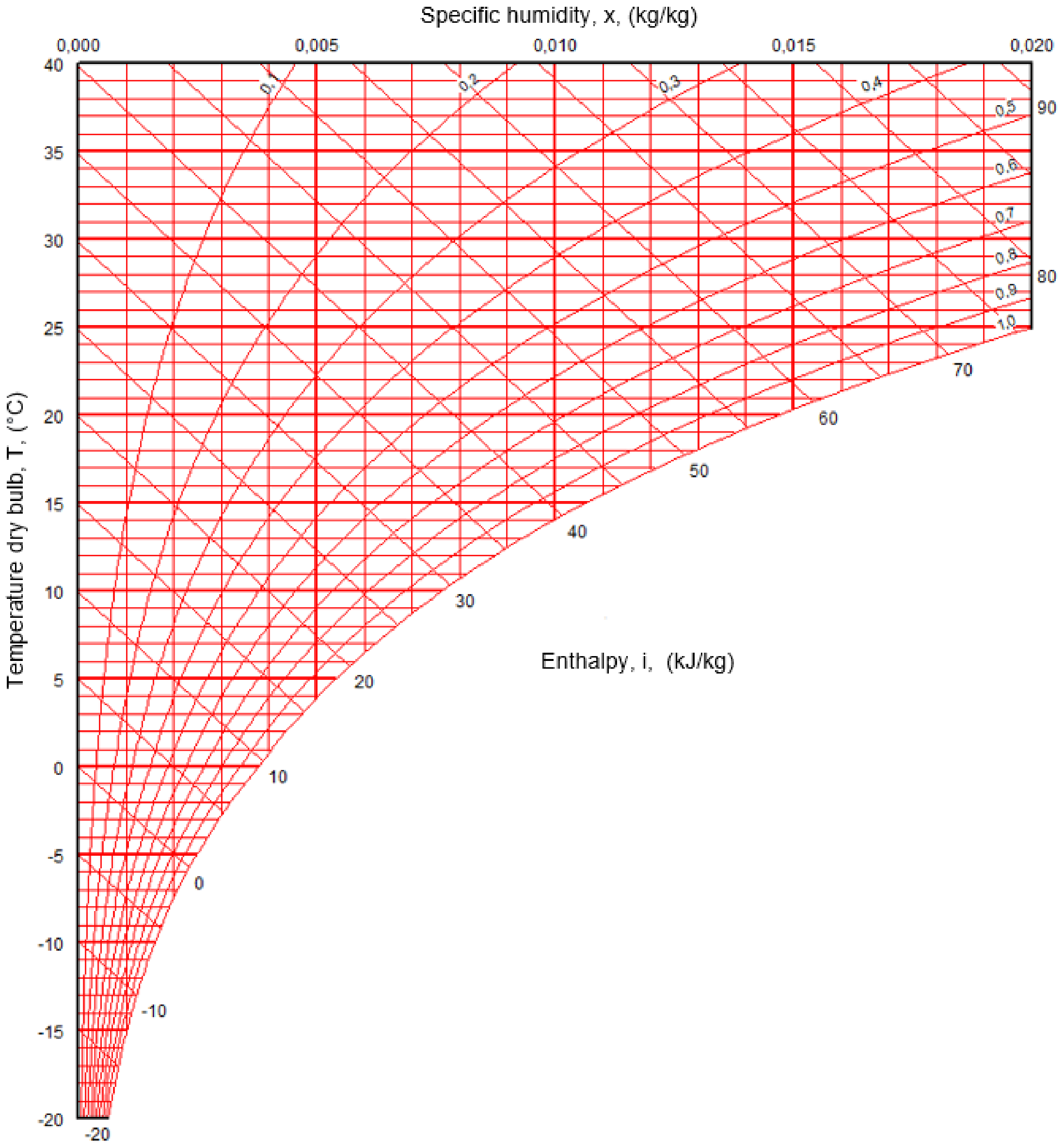


Figure 16. The Mollier Diagram

The line for 100% relative humidity is called the saturation line, where the condensation or ice formation begins. A point on the saturation line gives the highest moisture content at a certain temperature. The point where the air starts to condense is called dew point. In the diagram, the heat content of the air can also be read in kJ / kg air. This is also called enthalpy. The enthalpy is indicated by straight lines which go diagonally down to the right of the diagram. (IVprodukt, 2015)

For example, see Figure 17, an uninsulated pipe with a medium at 12°C and a surrounding air temperature at 24°C with a relative humidity at 60 rH% will cause the surrounding air

to condense when it is in contact with the pipe. The specific humidity at the initial state is circa 11g/kg and as the air is cooled it reaches the dew point at about 16°C. As the temperature of the air decreases the condensation continues following the saturation line until it reaches 12°C. At this point the specific humidity is just under 9 g/kg and the enthalpy went from 53 kJ/kg to 34 kJ/kg.

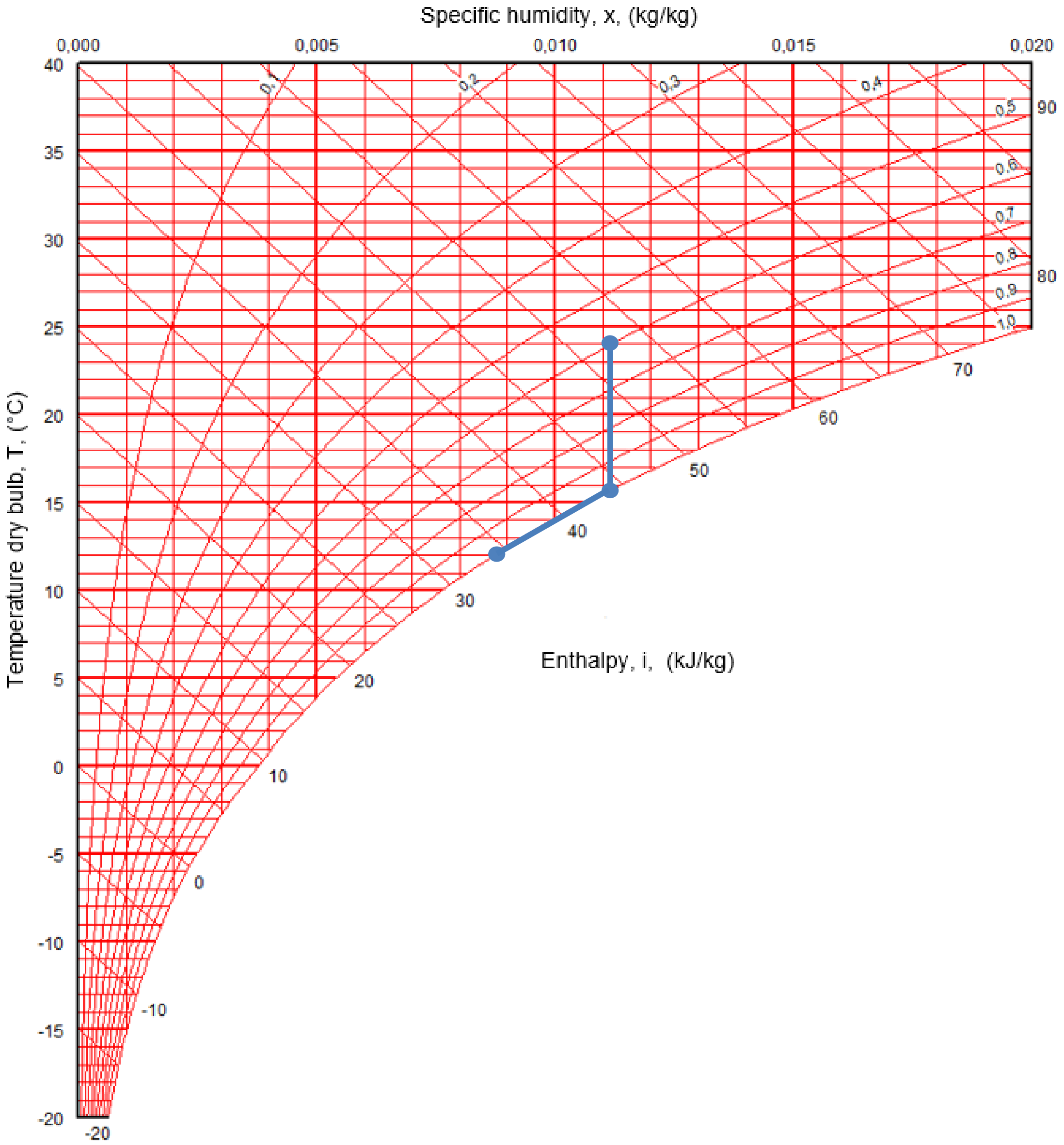


Figure 17. Mollier diagram example

7 COSTS

The cost comparison was made with the help of a local HVAC contractor and is divided into two parts, the cost of materials and the installation costs. A cooling system from an actual project was used as an example for this comparison. The system consists of a chilled water station for production and fan convectors for distribution. The pipe sizes needed for the system ranges from DN22 to DN100. The cost estimate doesn't consider the components in the cooling system, neither any exceptional working environments. Only the basic differences between the costs of the materials and its different installation methods are considered.

The material costs were compiled by the contractor. A complete list of materials was used, hence all parts were included, such as bends, T-branches, and reducers (see Appendix 1). There was a huge variety of the costs between the different materials, as can be seen in Figure 18. The most expensive material, stainless steel, is in this system about ten times more expensive than black steel.

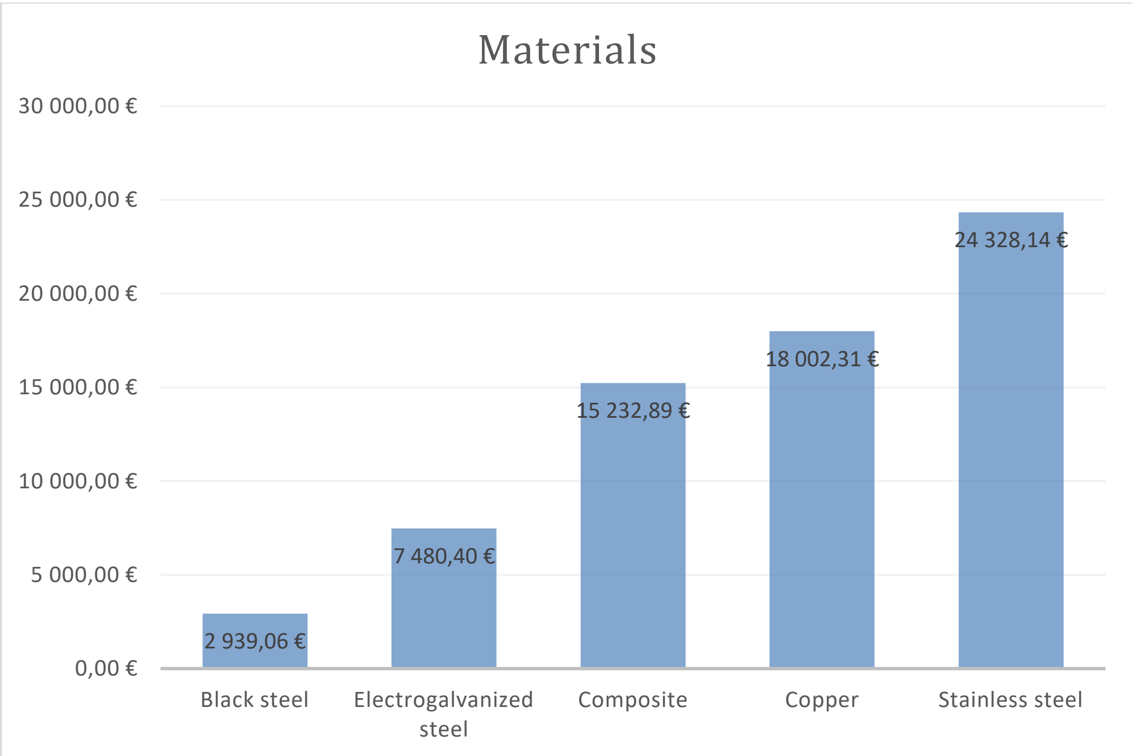


Figure 18. Costs of the pipes and insulation

One explanation to why black steel is so much cheaper than the rest is because the larger pipe sizes are kept at a lower price, which is not the case for the rest of the materials. When comparing the price rise from, for instance, size DN42 to DN65, the increase for black steel is ca. 170%, whilst the other materials have an increase between 240% - 350%. Another example is a 90-degree bend of size DN65 made of black steel cost 2,81€ and the same in stainless steel is 96,38€.

The time for installing the pipes and insulation is calculated according to the collective agreement in the HVAC industry in Finland. (LVI-Tekniset Urakoitsijat LVI-TU ry, Rakennusliitto ry, 2020) The hourly rate used in the calculation is 45€ per hour. As seen in Figure 19, the installation costs are lower for the more expensive materials. Black steel takes more time to install because it requires welding and surface treatment. The surface treatment consists of steel brushing and is painted twice, and its estimated cost is 1,5 times the pipe price. By using press connections, the installation time can be reduced significantly, as is the case for the rest of the materials.

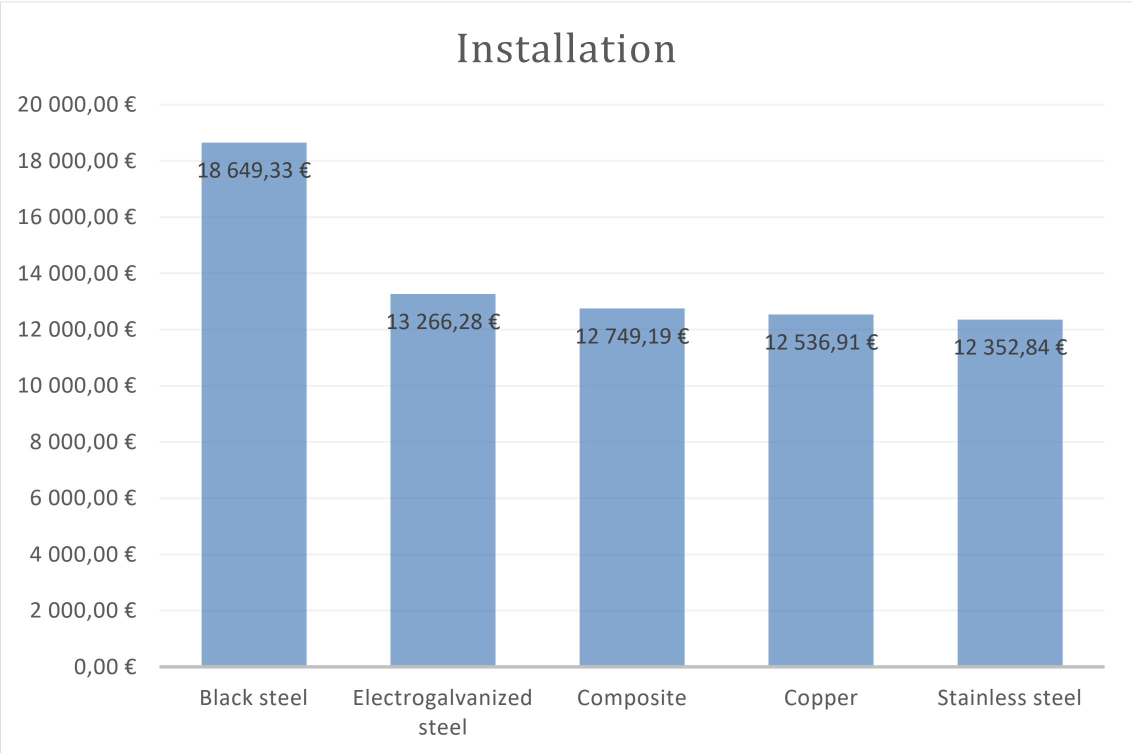


Figure 19. Costs of the installations and surface treatment

For the total costs as seen in Figure 20, the cheapest alternatives are electrogalvanized steel and black steel, whereas stainless steel is the most expensive. In this case the higher the price means better quality. The two cheapest materials are both more prone to be affected of corrosion, so one must take both the environment and the medium into account when choosing material for their cooling system.

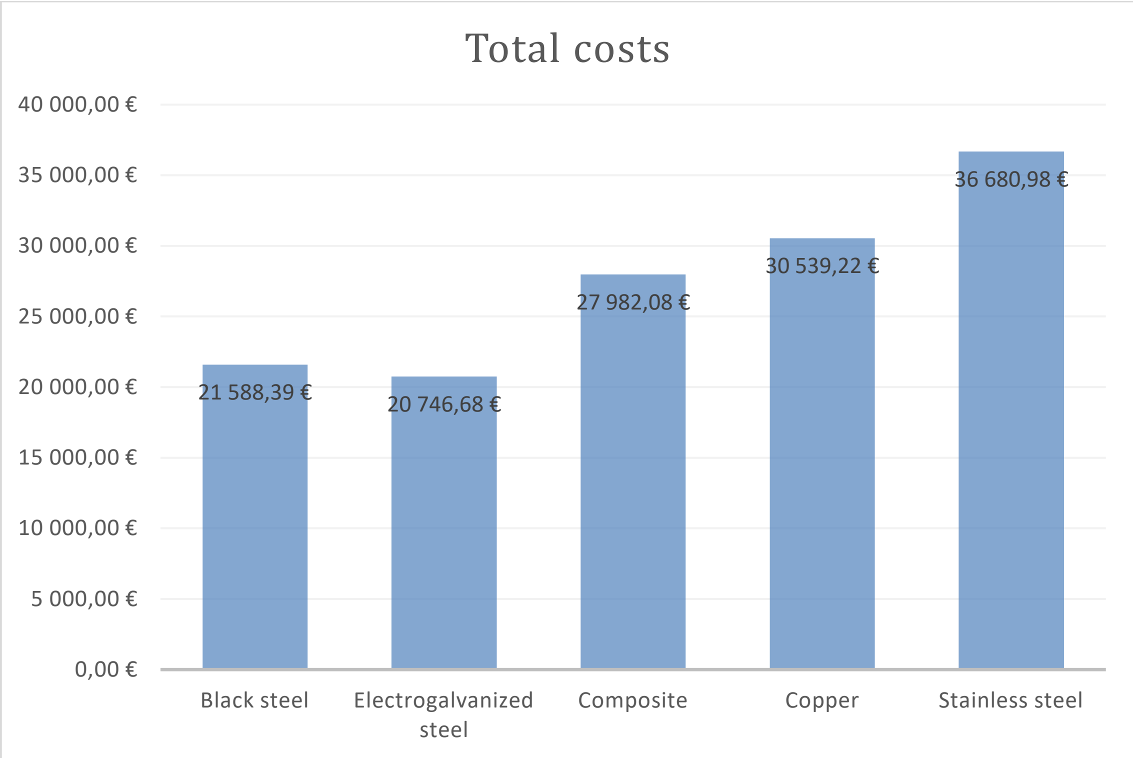


Figure 20. The total costs for each material

Note that this cost comparison is purely hypothetical. Multiply materials can be used in a closed system depending on what is best suited considering the environment, installation methods, and material costs. More about using multiply pipe materials is further discussed in chapter *5.4 Joining between two different materials*. It is worth mentioning that the material costs are constantly changing. The costs of the materials in this comparison were gathered during the spring of 2021.

8 SUMMARY

The aim for this thesis was to compare pipe materials for a cooling system and it was made for Granlund Pohjanmaa Oy. The thesis explains the difference between a direct and an indirect system, and some commonly used cooling mediums used in a secondary circuit. The five pipe materials that are compared are black steel, electrogalvanized steel, stainless steel, copper, and composite. Their characteristics, area of use, and risks are addressed as well as their various installation and connection methods. Numerous types of corrosion are described and what corrosion is caused by.

Finally, a hypothetical cost comparison was made. The comparison is based on the pipes in a cooling system that consists of a chilled water station for production and fan convectors for distribution. What makes it hypothetical is that it assumes only one material is used throughout the system, which may not be the case in a real system. The calculations are divided into material costs and installation costs, which provides an indication on how the different materials relates to each other pricewise. The conclusion of the comparison is that material with higher quality have a higher total cost i.e., after installation the cheaper materials that are more expensive to install are still significantly cheaper in the end. The material costs between the cheapest and the most expensive material differs enormously, especially in the larger sizes. The result of the cost comparison can be seen on page 36.

SAMMANFATTNING

I de vätskeburna systemen för uppvärmning och kyla används rör av olika material och kvalitet. Många olika faktorer spelar in när man väljer rör-typ: systemets dimension, temperatur, tryck, och plats. Naturligtvis är kostnaden också en viktig faktor, liksom systemens beräknade livslängd. Inget ska behöva bytas ut i förtid. Det är ett välkänt faktum att sedimenterade korrosionsprodukter från rostangrepp leder till igensättning av rör och komponenter, försämrad energiöverföring för värmeväxlare och radiatorer och så småningom till läckage. Kylsystem är känsligare än värmesystemen och systemen med lägre temperatur på värmesidan visar oftare brister än de äldre systemen med högre temperatur på värmevattnet. Anledningen är att kallare vatten lättare binder syre och andra gaser.

Det finns i huvudsak två principer för kylsystem, de direkta och indirekta (består av en primär- och sekundärkrets) system. I ett direktverkande kylsystem är förångaren kylelementet som är i kontakt med utrymmet som ska kylas. Det betyder att det inte finns några extra värmeväxlare vare sig på förångaren eller kondensorsidan. Det behövs relativt stora mängder kylmedium; Därför används den direkta principen främst i mindre system. I ett indirekt kylsystem är varken förångaren eller kondensorn i direkt kontakt med vätskan (utrymmet) som ska kylas eller värmas. Kylan överförs till ett annat medium och kylsystemet fungerar i två steg. Kylsystemet kyler ett medium som i sin tur kyler anslutna kylobjekt i ett rörsystem. Detta system har en mindre mängd kylmedium och är därmed billigare vid byte / påfyllning av medium och en lite mer miljövänlig lösning. Det här examensarbetet behandlar endast sekundärsidan av ett indirekt kylsystem.

Kylmedium som ofta används (bortsett från enbart vatten) i indirekta system är vattenlösningar som innehåller etylenglykol, propylenglykol, etanol, eller saltlösning. Propylenglykol är ogiftig och är i kombination med korrosionshämmare ett utmärkt alternativ som kylmedium, särskilt i livsmedelsindustri. Lösningens viskositet ökar dock snabbt med minskande temperatur, vilket hämmar värmeöverföringsegenskaperna. Etylenglykol har betydligt bättre termofysiska egenskaper än propylenglykol vid låga temperaturer. Lösningen i kombination med korrosionshämmare har goda korrosionsegenskaper, vilket liksom propylenglykol ger möjlighet att välja enkla och billiga kopplingar. Etylenglykol är det vanligaste kylmedium för vanliga kylsystem. Etanol har goda

korrosionsegenskaper och är ganska billigt men har begränsade värmeöverföringsegenskaper. På grund av etanolens låga flampunkt blandas vanligtvis lösningen med högst 30% etanol. Saltlösningar har extremt låg viskositet och mycket god värmeledningsförmåga, vilket ger goda värmeöverföringsegenskaper, vilket i sin tur resulterar i små värmeöverföringsytor och lågt flödesmotstånd. De flesta saltlösningar har hög konduktivitet och därav ökar korrosionsrisken avsevärt så man bör noga överväga valet av material för att undvika galvanisk korrosion. Baserat på det här examensarbetet rekommenderas att saltlösningar endast används i plast- och kompositrör.

Rör i ett kylsystem är mycket känsliga för korrosion, både internt och externt. En orsak är att kallare vatten, speciellt i kombination med glykollösningar, lättare binder syre och andra gaser vilket kan orsaka korrosion på insidan av röret. Externt kan fukt som bildas på grund av det kalla röret orsaka korrosion och skada för både röret och miljön runt det, till exempel i betongväggar. Korrosion kan definieras som nedbrytning av ett material. Nedbrytningen innebär en försämring av materialets struktur och egenskaper. Exempel på detta kan vara en minskad väggtjocklek i metallrör eller sprickbildning i plaströr. Korrosion avser vanligtvis metalliska material, men det kan också förekomma i polymerer.

Korrosionsprocesser är ofta av elektrokemisk natur, vilket innebär att reaktionerna sker med frisättning eller upptag av elektroner, så kallad oxidation och reduktion. Metaller har en stor tendens att korrodera eftersom de är mycket bra elektriska ledare. För att en metall ska korroderas krävs kontakt med en ledande vätska och oxidationsmedel. Vattenbaserade kylmedel är i stort sett ledande eftersom de innehåller joner. Det vanligaste oxideringsmedlet i dessa lösningar är syre som löses i vätskan. I allmänhet är vattenbaserade lösningar med metanol och etanol de minst ledande, medan saltlösningslösningar, organiska och oorganiska, är de mest ledande. För att motverka detta är de flesta vattenbaserade kylmedel försedda med någon typ av korrosionshämmare för att motverka korrosion av rören. Olika typer av korrosion är punktkorrosion, spaltkorrosion, galvaniskkorrosion, spänningskorrosion, turbulenskorrosion, oxidering (rost), och avzinkning. På grund av att vätskan i kylsystem ofta är kallare än omgivningen kan kondens uppstå utanpå röret. Därför krävs att rören isoleras diffusionstätt.

De rörmaterial som ofta används i kylsystem är svart stål, elförzinkat stål, rostfritt stål, koppar, och komposit. Svart stål är det billigaste av de ovannämnda materialen men också det som löper störst risk för korrosion. Därför görs rörväggarna tjockare, jämfört med de övriga materialen, för att förlänga livstiden. På grund av korrosionsrisken i svart stål måste rören utöver diffusionstät isolering, också rostskyddsmålas två gånger. Stål i allmänhet är en legering av järn (Fe) med en liten mängd kol (C) för att förbättra dess hållfasthet och styrka jämfört med järn. Andra element kan läggas till för att ändra och förbättra dess egenskaper, vilket har gjorts för att till exempel skapa rostfritt stål och galvaniserat stål. Det svarta stålröret är dock tillverkat av stål som inte är belagt med ett underlag som zink eller färg. Det kallas svart stål på grund av dess mörka yta som järnoxid bildas under tillverkningsprocessen. Järnoxidbeläggningen ger viss korrosionsbeständighet, medan kolstål kräver galvanisering eftersom det är känsligt för korrosion. Stål definieras som allt material med ett järninnehåll på minst 50% och ett kolinnehåll på 0,03 till 2,0%. Stål klassificeras i olika kategorier enligt den vanliga grupperingen. Stål med en kolhalt under 0,6% kallas konstruktionsstål, medan stål med mer än 0,6% kol kallas verktygsstål. Alla stål med mer än 1,7% kol kallas gjutjärn.

Elförzinkade stålrör har ganska långt samma egenskaper som svarta stålrör, men är som namnet antyder behandlat på utsidan med en zinkbeläggning. Zinken fungerar som offeranod och skyddar därmed stålet. Rören kan göras tunnare än svart stål och är således lättare vilket underlättar i installationen. Elförzinkat stål är dyrare än svart stål, men installationstiden kan minskas avsevärt då det är möjligt att använda presskopplingar, då svart stål antingen svetsas eller gängas.

Förutom järn och kol är krom (Cr) det främsta legeringselementet för rostfritt stål. När krom tillsätts i stålsmältningen så att innehållet överstiger 10,5% bildas ett tunt passivt lager av kromoxid när materialet kommer i kontakt med luft. Om kromhalten överstiger 12% blir ytskiktet tätt. Det skyddar det underliggande stålet mot ytterligare oxidation. Eftersom det bildas i kontakt med syre, regenererar det passiva skiktet snabbt om det skadas eller stålet skärs. Men kromhalten är inte det enda som påverkar den kemiska beständigheten mot korrosion, utan också kolhalten. Ju lägre kolhalt desto högre korrosionsbeständighet. Rostfritt stål är indelat i kategorierna martensitiskt, ferritiskt, ferrit-austenitiskt och austenitiskt baserat på stålets struktur vid rumstemperatur.

Stål med krom (Cr) som enda legeringsämne utgör en del av de rostfria stål som produceras, men huvuddelen innehåller också flera andra legeringsämnen. Två värda att nämna är nickel och molybden. Nickel (Ni) påverkar främst stålets konstruktion och mekaniska egenskaper. Vid en tillräckligt hög nickelhalt får rostfritt stål en austenitisk struktur. Jämfört med de rena kromstålen innebär detta betydande förändringar i de mekaniska egenskaperna - ökad formbarhet och seghet, högre värmebeständighet, förbättrad svetsbarhet - liksom förändringar i de fysiska egenskaperna. Nickel ökar också korrosionsbeständigheten i vissa medier. Molybden (Mo) har samma effekt på strukturen som krom och ökar i allmänhet korrosionsbeständigheten hos både ferritiska och austenitiska stål. Molybden legerade austenitiska stål kallas syrafast stål.

Koppar är ett mångsidigt rörmaterial. Alla typgodkända kopparrör är lämpliga för nästan alla byggnadssystem. Tillämpningar kan till exempel vara ett varmvatten-, värme- eller kylsystem. Koppar är en glödande rödbrun färg, men när den åldras kan färgen mörkna eller till och med bli grön under vissa förhållanden. Kopparen som används i kopparröret är den så kallade avoxiderande kopparen, dvs koppar till vilken en liten mängd fosfor vanligtvis tillsätts. Syftet med fosfor är att avlägsna syre från smält koppar. Mängden fosfor som tillsätts koppar är 0,002 till 0,050%. Koppar som vanligtvis används i europeiska standarder är högfosfor, Cu-DHP (fosfordeoxiderat koppar-hög restfosfor), som innehåller cirka 0,015 - 0,04 % och lågfosfor Cu-DLP (fosfordeoxiderat koppar-låg restfosfor) med en fosfor på cirka 0,005 – 0,013 %. Koppar har stora fördelar när det gäller korrosionsegenskaper. Kopparens inneboende styrka jämfört med andra material gör att rör med tunnare väggar och större innerdiametrar kan användas samtidigt som ytterdiametern bibehålls.

Kompositmaterial definieras vanligtvis som två eller flera fysiskt sammansatta beståndsdelar. Enligt denna definition skulle ett sammansatt rör vara ett rör byggt av två eller flera fysiskt urskiljbara material, såsom plast och aluminium. Kompositrör kombinerar stabilitetsfördelarna med ett metallproduktmaterial med plastens korrosionsbeständighet. Exempel på inre och yttre lager av plast är PE, PEX eller PP. Sammansatta rör är lätta att böja, förblir stabila och underlättar avsevärt installationsarbetet. Ett exempel på kompositrör i detta examensarbete är Geberits Mepla. Mepla består av tre skikt där det yttre plastskiktet av polyeten (PE) skyddar mot korrosion och mekanisk påverkan. Det

mellersta lagret av aluminium gör röret stabilt, böjbart, och diffusionstätt. Det inre skiktet, som också är tillverkat av polyeten, är rostskyddat och livsmedelssäkert. Det finns ett lim mellan lagren. Komposit är mer begränsat gällande stora temperaturskillnader i systemet och drifttemperaturer, men har den stora fördelen att vara korrosionshärdig och passar bra med användning av saltlösningar.

En hypotetisk kostnadsjämförelse gjordes för att se skillnaderna mellan de olika rörmaterialen och deras installationskostnader. Jämförelsen baseras på rören i ett kylsystem som består av en kylvattenstation för produktion och fläktkonvektorer för distribution. Beräkningarna är uppdelade i materialkostnader och installationskostnader, vilket ger en fingervisning på hur de olika materialen prismässigt förhåller sig till varandra. Slutsatsen av jämförelsen är att material med högre kvalitet har en högre totalkostnad, d.v.s. efter installering är de billigare materialen som är dyrare att installera fortfarande betydligt billigare i slutändan. Materialkostnaderna mellan det billigaste och det dyraste materialet skiljer sig enormt mycket, speciellt för de större storlekarna. Resultatet av kostnadsjämförelsen kan ses på sida 36.

REFERENCES

Mäkelä, I., 2011. *Lämmitysputkiston kustannusvertailu materiaalien ja asennusmenetelmien välillä.* Oulu: Oulun seudun ammattikorkeakoulu.

Eklund, L.-O., 2019. *Kompositrör - plaströr eller metallrör?.* [Online]
Available at: https://docplayer.se/112264328-Kompositror-plastror-eller-metallror.html
[Accessed 15 2 2021].

Boldt, J. & Stone, K., 2018. *Selecting pipe and piping materials.* [Online]
Available at: https://www.csemag.com/articles/selecting-pipe-and-piping-materials/
[Accessed 28 2 2021].

Madhu, 2018. *Difference Between Carbon Steel and Black Steel.* [Online]
Available at: https://www.differencebetween.com/difference-between-carbon-steel-and-black-steel/
[Accessed 28 2 2021].

Koppar.com, 2017. *Installatör – Kopparrörsskolan.* [Online]
Available at: https://www.koppar.com/utbildningsmaterial/kopparrorskolan/
[Accessed 18 12 2020].

Koppar.com, 2017. *Fakta om koppar.* [Online]
Available at: https://www.koppar.com/koppar-anvaendningsomraaden/snabbfakta/
[Accessed 18 12 2020].

Geberit, 2018. *Geberits pressrörssystem.* [Online]
Available at: https://assets.geberit.se/local-media/files/brochures/2018-brochure-supply-systems-b2b-group-en-se-sv.pdf
[Accessed 3 1 2021].

IVprodukt, 2015. *Mollierdiagrammet, beskrivning.* [Online]
Available at: https://ivprodukt.docfactory.com/#!doc/topic:Teknik_&_System-1/id:XwO9gA7VgkWBsUdDf1zTXQ
[Accessed 28 1 2021].

Geberit, 2020. *Installatörshandbok.* [Online]
Available at: https://assets.geberit.se/local-media/nedladdning/2020-1/installatoershandbok-2016-low.pdf
[Accessed 15 12 2020].

BE Group, 2019. *Handbok om rostfritt stål.* [Online]
Available at:
https://www.begroup.se/fileadmin/user_upload/images_and_files/Sweden/Documents_and_files_BE_Group_Sweden/Broschures_and_product_info/Broschyrer/Broschyr_Rostfritt_2019_uppslag.pdf
[Accessed 28 2 2021].

Geberit, 2020. *Geberit supply systems product guide.* [Online]
Available at: https://assets.geberit.co.uk/local-media/literature/product-guides/2020/geberit-supply-product-guide-april-2020.pdf
[Accessed 28 2 2021].

Engineering ToolBox, 2003. *Coefficients of Linear Thermal Expansion.* [Online]
Available at: https://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html
[Accessed 28 2 2021].

Aperam, n.d. *What is stainless steel.* [Online]
Available at: https://www.aperam.com/stainless/what-is-stainless-steel/?cn-reloaded=1
[Accessed 28 2 2021].

Stålbom, G. & Kling, R., 2013. *Teknikhandboken.* 10 ed. Sundbyberg: Wallén Grafiska.

Geberit, 2018. *Supply systems installation guide.* [Online]
Available at: https://assets.geberit.co.uk/local-media/literature/installation-guides/geberit-supply-systems-installation-guide.pdf
[Accessed 4 3 2021].

Lyngson Oy, 2002. *Puristusliitinjärjestelmän asennusohjeet.* [Online]
Available at: http://www.lyngson.fi/pdf/Asennusohje.pdf
[Accessed 4 3 2021].

Geberit, 2020. *Geberit mapress.* [Online]
Available at: https://assets.geberit.co.uk/local-media/literature/brochures/geberit-mapress-result-2020.pdf
[Accessed 4 3 2021].

Meltolit, 2021. *MMA svetsning.* [Online]
Available at: https://www.meltolit.se/produkter/mma-svetsning/
[Accessed 28 3 2021].

Frejd, T. & Himmelmann, O., 2017. *Energieffektiviteten hos konverterade kylanläggningar ombord på fartyg.* Göteborg: Chalmers tekniska högskola.

Åkermarck, A., 2018. *Användning av koldioxid i kylanläggningar.* Helsinki: Arcada.

Armatec, 2008. *armatec.com.* [Online]
Available at: https://www.armatec.com/globalassets/armatec-se/sidor/trycksaker/pdfer/vatskeburen_kyla_2008_low.pdf
[Accessed 26 4 2021].

Meltolit, 2021. *TIG svetsning.* [Online]
Available at: https://www.meltolit.se/produkter/tig-svetsning/
[Accessed 26 3 2021].

Svetskommissionen, 2019. *TIG-svetsning.* [Online]
Available at:
https://www.svets.se/kunskapsbanken/tekniskinfo/svetsning/svetsmetoder/tiggasvolframsvetsning.4.38a2e557141001d64753b47.html
[Accessed 27 3 2021].

Svetskommissionen, 2019. *MMA - manuell metallbågssvetsning.* [Online]
Available at:
https://www.svets.se/kunskapsbanken/tekniskinfo/svetsning/svetsmetoder/mma.4.38a2e557141001d64753b00.html
[Accessed 27 3 2021].

Svetskommissionen, 2019. *Gassvetsning.* [Online]
Available at:

https://www.svets.se/kunskapsbanken/tekniskinfo/svetsning/svetsmetoder/gassvetsning.4.38a2e557141001d64753a98.html
[Accessed 27 3 2021].

Geberit, 2021. *Tools and accessories.* [Online]
Available at: https://www.international.geberit.com/products/piping-systems-supply/geberit-pressing-tools/
[Accessed 4 3 2021].

Blunt, J. & Balchin, N. C., 2002. *Health and Safety in Welding and Allied Processes.* 5th Edition toim. s.l.:Woodhead Publishing.

Techminy, 2018. *oxyacetylene welding process of gas welding.* [Online]
Available at: https://techminy.com/oxyacetylene-welding-process/
[Accessed 16 4 2021].

Lundagrossisten, 2018. *VVS-kunskap.* [Online]
Available at: https://lundagrossisten.se/animated-vvssteg2/
[Accessed 21 4 2021].

Zenele, 2015. *TIG - Gas tungsten arc welding.* [Online]
Available at: http://en.zenele.cn/plus/view.php?aid=104
[Accessed 16 4 2021].

Onlinebodenshop, n.d. *Hanf im Spender.* [Online]
Available at: https://onlinebodenshop.de/Hanf-im-Spender-40-g-40-m
[Accessed 10 3 2021].

Gustafsson, I. & Ohlin, M., 2015. *Alternativa etanolbaserade köldbärare med korrosionsinhibitorer i bergvärmesystem.* Stockholm: KTH.

Gelia, n.d. *Galvanisk korrosion.* [Online]
Available at:
https://www.gelia.se/globalassets/gelia_sv/dokument/broschyr_info_gelia_pdf/geliaguide_galvanisk_korrision_1804.pdf
[Accessed 5 5 2021].

Månsson, K., 2007. *Problem med gaser i tekniska vattensystem.* Malmö: s.n.

Eneström Schmied, E., 2019. *Värna vattenkvaliteten i värme- och kylsystem.* [Online]
Available at: https://static.byggtjanst.se/amadocs/ANY_1-2019_sid_48-50.pdf
[Accessed 18 5 2021].

Anon., 2011. *Corrosion inhibitors.* [Online]
Available at: https://www.uv.mx/personal/rorozco/files
[Accessed 5 5 2021].

Singh, A., 2019. *Corrosion Inhibitors.* s.l.:IntechOpen.

Karob Ab, 2019. *Stoppa korrosion, driftstopp och ineffektiv uppvärmning med avgasning.* [Online]
Available at: https://www.karob.se/fakta/avgasning
[Haettu 17 5 2021].

Steelnumber, 2021. *European steel and alloy grades.* [Online]
Available at: http://www.steelnumber.com/en/steel_composition_eu.php?name_id=100
[Accessed 14 9 2021].

LVI-Tekniset Urakoitsijat LVI-TU ry, Rakennusliitto ry, 2020. *LVI-toimialan työehtosopimus työntekijöille.* [Online]
Available at: https://www.lvi-tu.fi/wp-content/uploads/2020/06/Talotekniikka_LVI_TES_2020_2022.pdf
[Accessed 4 12 2021].

APPENDICES

Appendix 1	Bill of Materials
Appendix 2	Table of Characteristics

Bill of Materials

VJK

Class	Size*	Quantity**
Pipe	65	27,1
Pipe	80	23,2
Pipe	100	8,8
Bend-90	65	6
Bend-90	80	11
Bend-90	100	8
T-branch-90	100/100/65	2
Joint part	80	2
Joint part	100	2
Reducer/expander	100/80	2

PKN 1st floor

Class	Size*	Quantity**
Pipe	22	40,7
Pipe	35	45,4
Pipe	42	16,2
Pipe	65	47,2
Pipe	28	2,6
Bend-45	22	4
Bend-90	22	22
Bend-90	28	2
Bend-90	35	12
Bend-90	42	4
Bend-90	65	10
T-branch-90	35/35/22	2
T-branch-90	35/35/28	2
T-branch-90	42/42/22	4
T-branch-90	65/65/22	4
T-branch-90	65/65/42	2

Joint part	22	12
Reducer/expander	35/22	2
Reducer/expander	42/35	4
Reducer/expander	65/42	2
Reducer/expander	28/22	2
Plug	35	2

PKN 2nd floor

Class	Size*	Quantity**
Pipe	28	12,6
Pipe	42	16,7
Pipe	65	53,2
Pipe	80	5,7
Bend-45	80	2
Bend-90	28	2
Bend-90	42	10
Bend-90	65	9
Bend-90	80	8
T-branch-90	42/42/28	2
T-branch-90	65/65/42	4
T-branch-90	80/80/65	2
T-branch-90	80/80	1
Joint part	28	4
Reducer/expander	28/22	2
Reducer/expander	42/28	2
Reducer/expander	42/35	2
Reducer/expander	80/65	2
Plug	28	2
Plug	28	2

**pipe sizes in nominal diameter (DN)*
***units in meter for pipes and piece(s) for pipe parts*

Characteristics table		Black steel	Galvanized steel	Stainless steel (304)	Stainless steel (316)	Copper	Composite
	Unit	Fe	FeZn8	X5CrNi18-10	X5CrNiMo17-12-2	Cu-DHP	PE-RT / Al / PE-RT
Operating temperature	°C	-20 ... +200	-40 ... +200	-196 ... +870	-60 ... 870	-200 ... +250	0 ... 70°C / -10 ... 40
Thermal expansion	mm/(m K)	0.010-0.012	0.012	0.016	0.0165	0.017	0.026
Thermal conductivity	W/(m K)	54	60	15	15	295-365	0.43
Specific heat capacity	kJ/(kg K)	0.51	0.5	0.5	0.5	0.0385	varies
Density	kg/m3	7750	7750 (Fe) / 6300 (Zn8)	7900	8000	8960	varies
Surface smoothness	mm	0.01	0.01	0.0015	0.0015	0.0015	0.007
Size range press connection	DN	DN10-100	DN10-100	DN10-100	DN10-100	DN10-100	DN12-65
Coolants suitability							
Ethylene	$C_2H_4(OH)_2$	✓	✓	✓	✓	✓	✓
Propylene	$C_3H_6(OH)_3$	✓	✓	✓	✓	✓	✓
Ethanol	C_2H_5OH	✓	✓	✓	✓	✓	✓
Saline	NaCl	X	X	X	X	X	✓