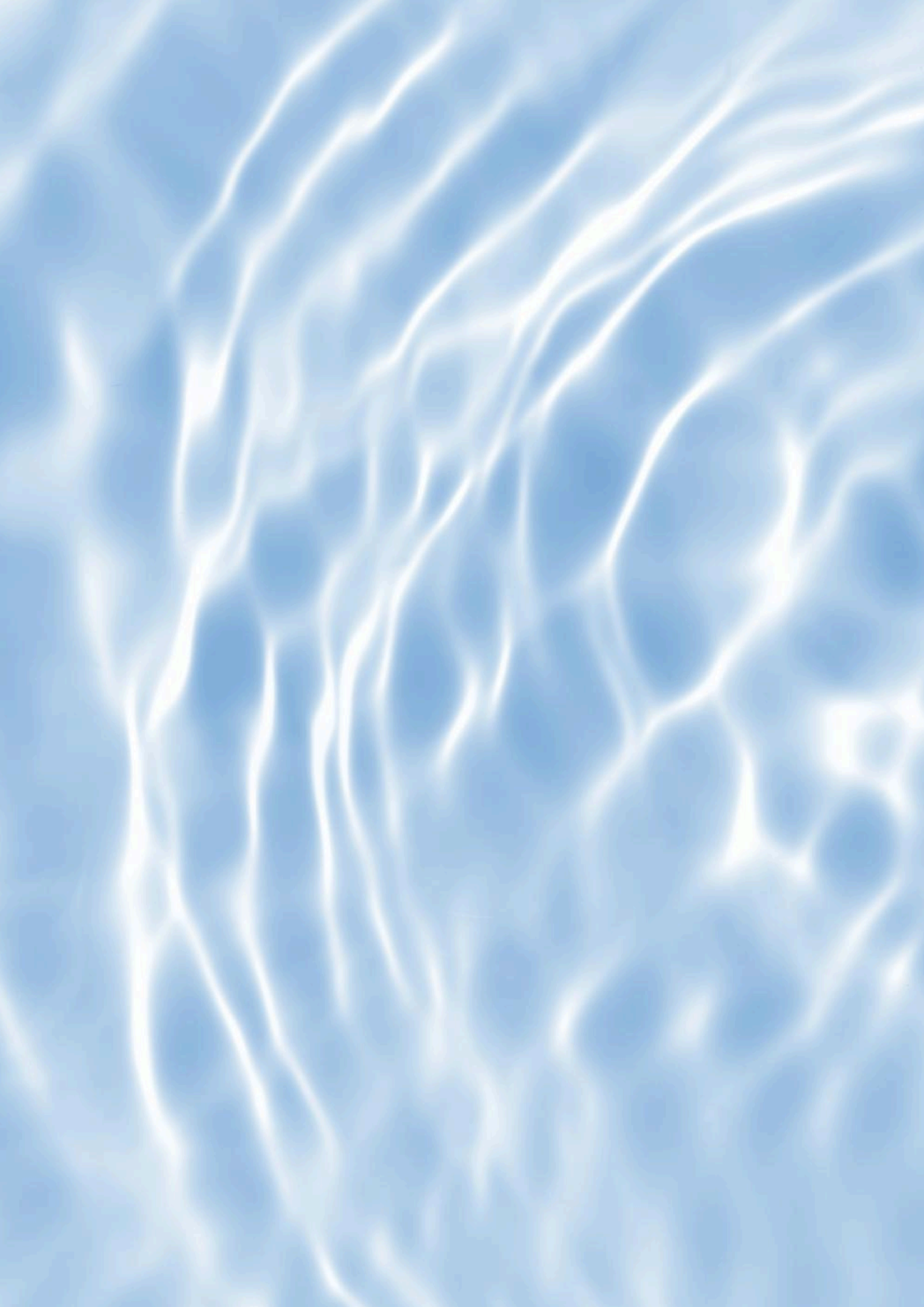
CHALLENGE EFFICIENCY

Water management for brazed plate heat exchangers in District Energy



Content

Introduction

This document aims to explain the importance of good water quality for systems involving BPHEs, with an emphasis on district energy. When steps are taken to reduce the risk of additional water contamination, a BPHE will have reduced maintenance costs, prolonged lifetime, and increase the system's performance and efficiency.

Good water quality lowers the risk of corrosion, fouling, and scaling. These three factors cause problems to the system’s components and avoiding them reduces maintenance costs and prolongs the product’s lifetime, thereby increasing the systems performance and efficiency.

Energy efficiency is constantly in the spotlight as it is an important steppingstone in reaching the 2 °C global warming limit set by the Paris agreement. This document sheds light on the issues dirty water can bring and the solutions that can be implemented to prevent corrosion, fouling and scaling in brazed plate heat exchanger (BPHE). In alignment with the United Nations sustainability goals the recommendations presented for preventing undesirable interactions between the system’s fluid and BPHE will be chemical free.

Background

The water quality in the district heating system needs to be free from the formation of deposits and corrosion to optimize the plant and operating economy in general. Any time water quality is impacted, there will be a direct impact on the efficiency and productivity of an incorporated BPHE. In some cases, the best technical solution can be difficult to implement in an old plant that has a short remaining useful life. Nevertheless, improvements will often still be attainable, with a choice of different water treatments.

The quality of circuit water can be divided into four categories, reflecting the use of different processes. The development has proceeded from untreated water to demineralized water, whereby the technological development and the need for plant optimization have increased the necessity to choose the technologically best solution.

Systems can be designed with either a closed loop or an open loop. In a closed loop it is often easier to control water quality than in an open loop, e.g. a cooling tower, where water is circulated in an open circuit between the BPHE unit and the cooling tower. Here salt content can be ten times higher than in the make-up water. In heavily polluted areas, the water may pick up dust and/or corrosive gases, such as sulphur and nitrogen compounds, during its circulation.

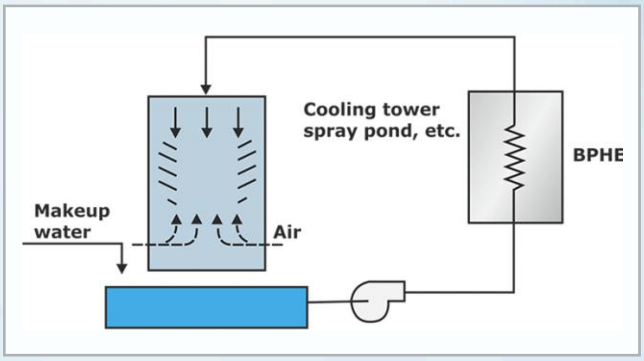


Figure 1: Cooling Tower with open loop.

Oxygen

The presence of oxygen in a hydronic heating system can trigger a corrosive reaction in the BPHE (see chapter Corrosion) and reduce the system's water circulation.

A lowered water circulation implies a decrease in the overall heat transfer efficiency. In closed systems, oxygen can enter with the addition of make-up water, through diffusion from the system's material or by unnoticed leaks. It is important to de-oxygenate the water, while in open system it is not possible. The higher the conductivity and salt content of the water, the lower the level of oxygen is recommended to avoid corrosion (see Figure 2).

Degasser as a system protection

Degasser is a device that can be placed in the system to remove gases, such as oxygen, from the liquid stream. This can be used in district heating systems to avoid corrosion in the BPHE and other equipment present in the loop. Different types of degassers are available on the market for district heating systems, one such example being membrane degasser. Membrane degasser units use microporous hollow fibre membrane that have hydrophobic properties. During operation the water will flow on the outside of the fibres while vacuum is applied to the inside. This creates a driving force that enables the gas to pass through the membrane's pores while blocking the water from penetrating.

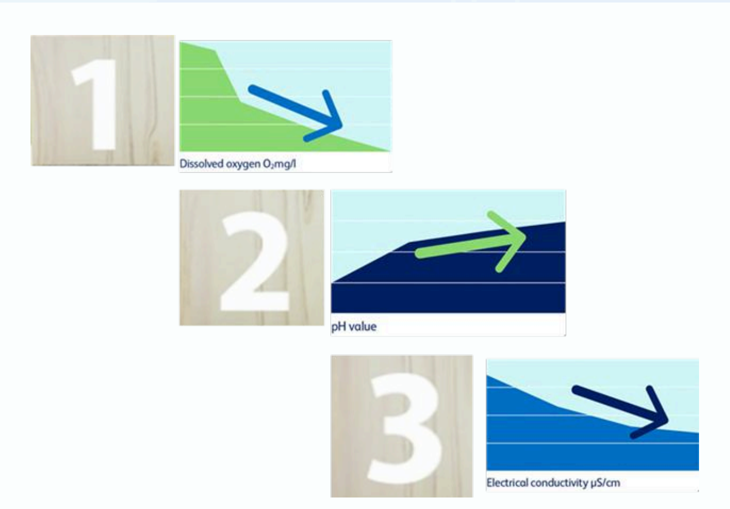


Figure 2: Three key elements that are altered in eleXion's sustainable solution that aims to protect system components and maintain high levels of efficiency.

Electrochemistry as a system protection

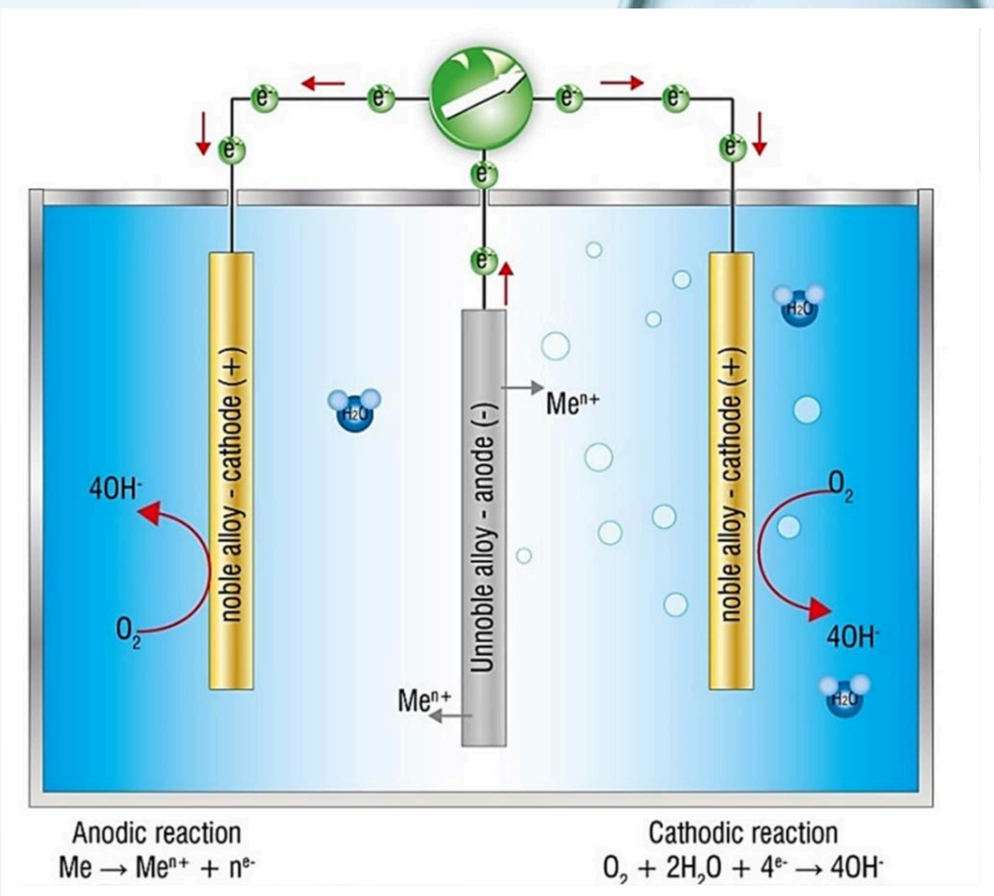
Altering the oxygen concentration in the water to mitigate the risk of corrosion can be done through electrochemistry. This is a method that constantly removes dissolved oxygen from the circulation water. Electrochemistry does not only provide corrosion control through removal of dissolved oxygen but also helps regulate the pH value and can contribute towards lowering the electrical conductivity (see Figure 3).

Electrochemistry is used to protect sealed Low Temperature Hot Water (LTHW) and Chilled Water (CHW) systems and enables clients to achieve the water quality requirements of the German VDI 2035 standard. VDI 2035 has been referenced in EN12828 "Heating Design in Buildings – Design for water-based heating systems", a standard which has been applicable to all of Europe.

Where the fill water does not meet the required parameters it can be pre-conditioned using ion exchange resin. The process removes salts and minerals along with dissolved oxygen, preconditioning the water this way also increases the pH, encouraging an environment that benefits the formation of a passive layer on the metal surface. The removal of salts and minerals implies that the overall electrical conductivity and increased pH helps mitigate a corrosive reaction, by addressing the root cause.

Dealing with the root cause of corrosion by continually removing the factors that encourage it enables prevention rather than just inhibiting it, unlike chemical-based treatments. This is a more sustainable system protection that does not require the need for harsh chemicals such as acids, biocides, or inhibitors. It also eliminates the need for large amounts of water to be discarded down the drain, as is the case with traditional chemical cleaning and treatment methods, making it a more environmentally friendly alternative.

Figure 3: Electrochemical reaction resulting in an oxygen reduction. Improving the fluid properties to mitigate the risk of corrosion.



Corrosion

Corrosion is the term for a chemical or electrochemical reaction between a material, usually a metal, and its environment, which produces a deterioration of the material and its properties. There are various forms of corrosion, a few of which occur in water-based heating and cooling systems, such as pitting and crevices or general corrosion. General corrosion is a deterioration distributed uniformly over a surface. It is more predictable than pitting; if a device has corroded 0.1 mm in one year, it will most likely corrode 0.2 mm in two years.

Corrosion damage results in a reduction in the functionality of a material or the technical system of which the material is a part (e.g. due to sludge deposits). Damage is the observable expression of corrosion, such as 'blocked' thermostat valves, jammed circulation pumps, clogged heat exchangers or leakages.

This unwanted occurrence that can lead to a decreased BPHE performance and lowered system efficiency. Stainless steel is, for instance, sensitive to high chloride content and copper is sensitive to both high sulphate content and high conductivity.

Stainless steel

Stainless steel has good corrosion resistance and is encountered frequently in district energy systems. All SWEP's BPHEs use stainless steel for their channel plates, with various grades available. However, high chloride levels can still initiate the corrosion of stainless steel. The most common form of corrosion on this material is pitting corrosion, with the chloride attacking only a small area of the steel. Pitting corrosion is hard to detect until it is too late and the units have started to leak. The table at Appendix 7.1 shows which material we recommend for a range of chloride concentrations and temperatures.

Copper

The majority of SWEP's BPHEs use copper as the brazing material, which has good resistance to corrosion in most district energy water qualities encountered. If the water quality is bad, the copper can start to corrode or leach into the water. For more information about whether a copper-brazed unit is suitable, see Appendix 7.1. SWEP follows water treatment and corrosion prevention recommendation of keeping the oxygen content below 0.02 mg/l. Copper is very sensitive to ammonia and sulphide. Ammonia may be used in district energy systems to regulate the pH. If copper is used as the brazing material, it is recommended that the ammonia level be kept very low.

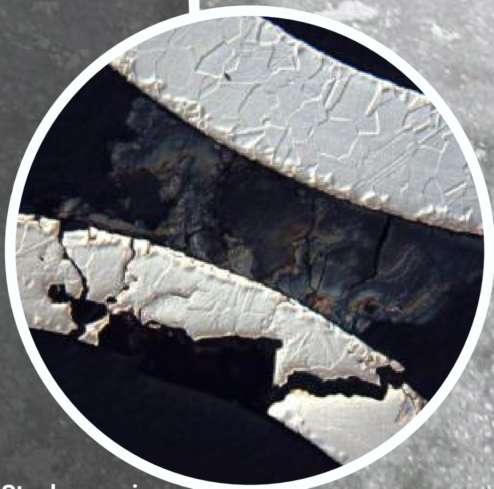
Corrosion monitoring as a system protection

Early warning of corrosion is very important, so that damage can be avoided and product failure eliminated. The electronic coupon method continuously determines electronically the mass loss of a coupon over time. This is done by permanently comparing mass measuring results to previous ones, thus directly establishing a corrosion rate. The advantage over the classic coupon method is the high temporal resolution of the material removal and the possibility of generating an alarm in case the corrosion rate exceeds a threshold value.

An annual average is used to measure corrosion rate in the system, as data collection over a longer period is a more accurate representation of the system than a one-off reading. An average yearly corrosion rate below 7 µm/year is considered to represent little chance of corrosion damage, 7 µm/year to 21 µm/year indicates that corrosion damage is probable and > 21 µm/year shows risk of corrosion failure.

Figure 4: Risycor's electronic coupon corrosion monitoring device.

Figure 5 is an example of the reading from the memory of the Risycor. This should be done once a year to analyse the corrosion behaviour of the installation. This is to gain an understanding of how the system is doing and to eliminate the possibility that the installation is corroding slowly but constantly at a rate blow the corrosion alarm. It is imperative that the corrosion alarm is connected and monitored to enable timely intervention to identify and correct the cause of the increased corrosion.



Steel corrosion.

Copper corrosion.

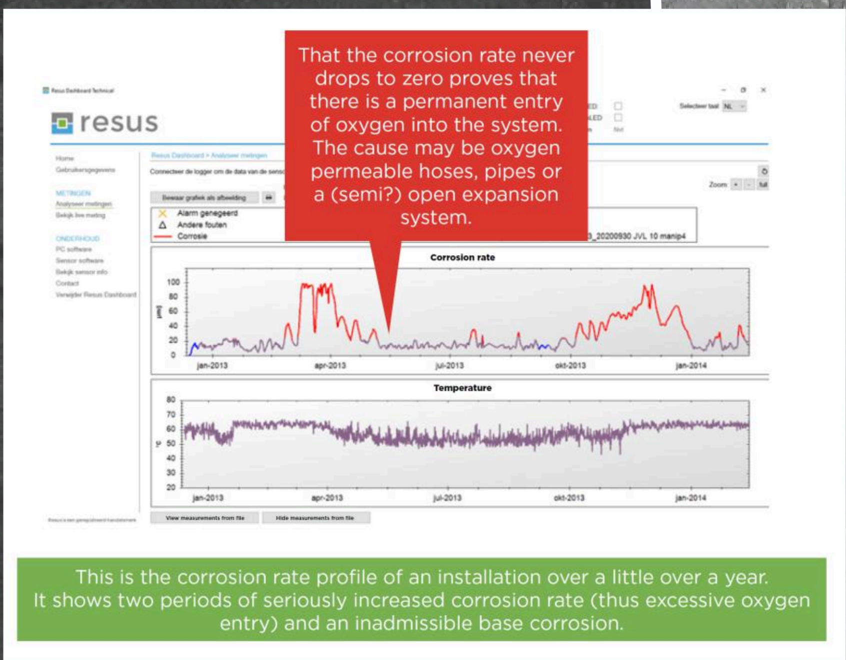


Figure 5: Reading from Risycor memory, used for corrosion monitoring.

Fouling & Scaling

Fouling is an unwanted phenomenon in the world of heat transfer. In most cases, the fluid flowing through a heat exchanger contains traces of dirt, oil, grease, chemicals or organic deposits. This can result in a coating collecting on the heat transfer surface, thereby decreasing the heat transfer coefficient and changing the pressure drop characteristics. A layer of limescale as thin as 1 mm on a water heater reduces the heat transfer efficiency by 7 % to 8 % (Hydrotec 2022). Types of fouling include biological growth, particulate fouling, scaling and corrosion.

Limescale is a good insulator, so when formation occurs on heat transfer surfaces the rates of heat transfer decrease, lowering efficiency. To maintain appropriate hot water storage and distribution temperatures the duty holder will have to use more energy.

The level of scale formation may make it difficult to maintain effective hot water storage and distribution temperatures, this can produce preferential conditions for optimal bacterial growth as pasteurisation (heating to 65°C) cannot occur. This, combined with a nutrient rich food source such as limescale, can contribute to the establishment of water borne pathogens such as legionella, pseudomonas and cryptosporidium.

SWEP BPHEs have a form of self-cleaning as they have a high degree of turbulence induced by their unique plate pattern, with the fluid performing a scouring action to keep the heat transfer surface clean. An even distribution of fluid through the exchanger is also important. SWEP BPHEs have a special pattern in the port areas, designed to ensure a well-distributed flow. Other heat exchangers may have areas sensitive to fouling due to low velocity, for example around gaskets, resulting in laminar flow. Fouling would start there and spread across the heat transfer surface.

Design criteria

Fouling and scaling can be limited by maintaining a high channel velocity. The velocity controls whether the flow is turbulent or laminar. Turbulent flow is desirable as it keeps particles in the fluid in suspension, i.e. prevents them from collecting on the surface and causing fouling. Turbulent flow also improves heat transfer.

To reduce the risk of scaling in a BPHE, a high water pressure drop is recommended. A high pressure drop implies higher shear stresses, which are beneficial in the event of scaling. The shear stresses work as a descale by constantly applying forces to the adhered material that pull the particulate material away from the surface, as shown in figure 8.

Figure 6: Limescaling in a heat exchanger

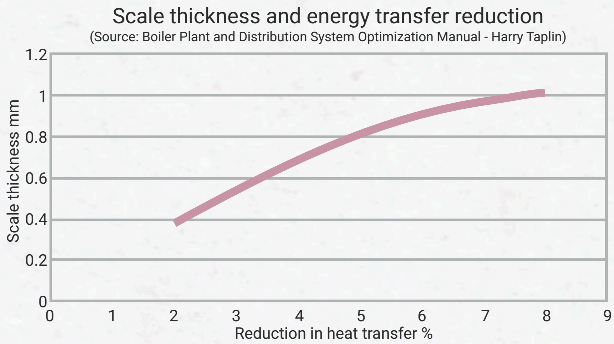


Figure 7: Scale thickness vs energy transfer reduction (courtesy by Hydrotec)

Figure 8: The effect of increased shear stress on fouling.

The shear stresses help prevent the deposit of particles by keeping them suspended in the fluid. For a BPHE with a temperature above 70 °C (158 F°) on the hot side or that is run with hard water in the system (i.e a very high risk of scaling), the pressure drop should be increased as much as possible on the cold-water side and reduced on the hot side. This reduces the wall temperature on the cooling water side and increases the shear stresses, making it more difficult for the scaling compounds to adhere. The normal practice is to have the cold water entering the lower port whenever possible, because if it enters through the upper port, it may encourage debris to enter the channels.

CIP – Cleaning in Place

In applications with a high risk of fouling or scaling, e.g. due to high temperatures, hard water, or high pH levels, cleaning may still be required to maintain efficiency. This is achieved quickly and easily with cleaning in place, a method of cleaning the interior surfaces of closed systems by circulating a fluid. CIP in large BPHEs is the most cost and time efficient way of restoring the thermal and hydraulic properties of the unit.

Indicators showing when CIP is required are when the temperature difference is smaller than specified or when higher pressure drop than expected are observed over the BPHE. A 30 % or higher increase than the nominal value is an indicator for conducting a CIP. Before deciding to clean the BPHE, it is crucial to make sure that filters are clean and pumps are functional, to rule out any other options for an increase pressure drop and decreased temperature difference.

CIP does not require disassembly of the heat exchanger and can be done at the installation site. It results in uniform removal and lower overall operating

Figure 9: CIP, Cleaning in Place.

cost. It has no risk of mechanical damage to the plates or gaskets and if fluids can pass through the BPHE, it is possible to effectively clean it.

Water conditioning as scaling protection

Another way to control scaling is to modify the structure of the hard minerals to let them flow though the system without sticking to the surfaces. This can be done with the help of electrodes or electromagnets that help form smaller scale crystals in a conditioning module.

Coating as a system protection

Coating the product with thin-film technology to seal the inner surfaces of the BPHE with a protective layer of SiO_2 enhances the resistance in terms of corrosion, scaling and leaching.

The ceramic nature of SWEP's SiO_2 based Sealix® layer improves corrosion stability. Indications that the organic functionalities improve the surface behavior in terms of scaling have been observed. The metal leaching is significantly reduced by sealing the surfaces in contact with water and oil. These benefits are achieved without affecting the thermal and hydraulic performance. The water recommendation for

Water content	Temperature	Recommended limits
pH		6.0-10
Chlorides (Cl^-)	< 60 °C < 80 °C	1000 mg/l 300 mg/l
Free chlorine (Cl_2)		< 1 mg/l
Sulphate (SO_4^{2-})		< 300 mg/l
Hydrogen sulphide (H_2S)		< 0.05 mg/l
Ammonium (NH^{4+})		< 20 mg/l
Conductivity		> 1 µS/cm

Table 1: Influence of water composition on corrosion resistance of SWEP's Sealix® range.

a SWEP Sealix® product differ from those seen in Appendix 7.1 as the coating improves their resistance towards corrosion, see Table 1.

Filters and strainer as a system protection

The water side channels in a BPHE may clog if particles such as silt, pipe slag and biological matter are not prevented from entering the unit. These particles blocking the channels can cause poor performance and increased pressure drop in the product. In a closed loop, the piping system must be properly flushed before the BPHE is connected to ensure that no additional material that could cause fouling or clogging enters the system. For open loop, and to increase safety in closed loop, the components necessary to filter out particulates must be installed before the BPHE. Strainers can provide the necessary protection against blockage. If any of the media contain particles larger than 1 mm. SWEP recommends that a strainer with a size of 20 mesh (number of openings per inch) is installed before the exchanger.

Figure 10. Fouling and clogging of a heat exchanger.

For applications with a high concentration of magnetite in the water, such as open loop or closed loop with high leak rate, a filter with a magnet function is highly recommended. It will not only prevent the BPHE from clogging but will also protect the water pump against erosion.

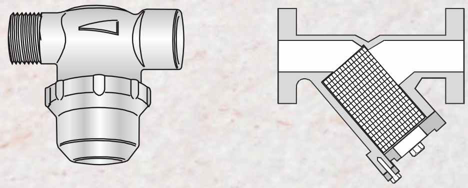


Figure 11: Illustration of a strainer.

Dirt separator as a system protection

Besides filters, SWEP recommend state-of-the-art dirt separators that remove even the smallest dirt particles, reducing maintenance needs and further boosting performance.

Summary

BPHEs bring benefits in terms of thermally efficient and compact products. Through their efficiency they help reduce the global carbon footprint. A factor that prevents a BPHEs optimal performance and efficiency is undesirable interaction between the system and the product that can yield corrosion, fouling, scaling and leaching. Understanding the importance of proper monitoring and what parameters influence the risk of these nuisances is vital to keep a smooth-running operation.

Multiple chemical-free options are available to ensure good water quality in an installation, such as the use of electrochemistry to regulate the water's pH, conductivity and oxygen level. Options to maintain a healthy system are SWEP's Sealix® and All-Stainless ranges, which enable better resistance in terms of corrosion, scaling and leaching, or using filters, as well as strainers, to help restrict fouling. To make sure to stay on top of fluctuation in the system, electronic coupon monitoring can be beneficial to identify a deterioration in the system and enable a quick response. Being able to replace older technology with newer, more efficient technology is an important part of reaching a sustainable society and a crucial element in progressing SWEP's journey towards a better future.

Appendix

The Appendix shows the corrosion resistance of stainless steels and brazing material in water at room temperature. In the table, several important chemical components are listed, however actual corrosion is a complex process influenced by many different components in combination, which cannot be fully captured in the tables. Therefore the tables in the Appendix are a considerable simplification of the factors to consider, do not constitute professional advice, and do not create any warranty.

The temperature, presence of oxidants and product form can also influence the corrosion resistance of material. The data in Appendix A is based on untreated raw material and at a water temperature of 20 °C, unless otherwise stated. Guidelines regarding the chloride content as a function of temperature are found in Appendix B and oxygen concentration guide values are found in Appendix C.

[1] Sulphates and nitrates act as inhibitors for pitting corrosion caused by chlorides in pH-neutral environments.
[2] Electrical conductivity and Total Dissolved Solids (TDS) are connected and can be converted to each other.
[3] In general low pH (below 6) increases corrosion risk and high pH (above 7.5) decreases corrosion risk.

[4] In District Energy systems, due to good control over water quality, pH values up to 10 are considered safe.

[5] Water with high hardness can cause corrosion problems due to its high ion content (Ca+2, Mg+2, Fe+2) which also means a high electrical conductivity as well as a high total dissolved solid (TDS). Too high hardness values should be avoided not only due to higher risk of scaling but also for corrosion risk. Soft water, but not necessarily cation exchange softened water, may in contrast have a low buffering capacity and be more corrosive. If the hardness values are outside the recommended range, other parameters such as oxygen content, conductivity and pH values should be considered to evaluate the corrosion risk.

[6] Fe3+ and Mn4+ are strong oxidants and may increase the risk for localised corrosion on stainless steels in combination with brazing material copper.

Appendix A – Water recommendations

+ Good resistance under normal conditions
0 Corrosion problems may occur especially when more factors are valued 0
- Use not recommended

Water content	Concentration (mg/l or ppm)	Time Limits Analyse before	Plate material		Brazing material		
			AISI 304	AISI 316	Copper	Nickel	Stainless steel
Alkalinity (HCO^{3-})	< 70	Within 24 hours	+	+	0	+	+
	70 - 300		+	+	+	+	+
	> 300		+	+	0/+	+	+
Sulphate[1] (SO_4^{2-})	< 70	No limit	+	+	+	+	+
	70 - 300		+	+	0/-	+	+
	> 300		+	+	-	+	+
HCO_3^- / SO_4^{2-}	> 1.0	No limit	+	+	+	+	+
	< 1.0		+	+	0/-	+	+
Electrical conductivity[2] (Refer to Appendix 7.3 for oxygen content guidelines)	< 10 µS/cm	No limit	+	+	0	+	+
	10 - 500 µS/cm		+	+	+	+	+
	> 500 µS/cm		+	+	0	+	+
pH[3]	< 6.0	Within 24 hours	0	0	0	+	+
	6.0 - 7.5		+	+	0	+	+
	7.5 - 9.0		+	+	+	+	+
	9.0 -10		+	+	0/+[4]	+	+
	> 10.0		+	+	0	+	+
Ammonium (NH^{4+})	< 2	Within 24 hours	+	+	+	+	+
	2 - 20		+	+	0	+	+
	> 20		+	+	-	+	+
Chlorides (Cl^-) (Refer to Appendix 7.2 for temperature dependent values)	< 100	No limit	+	+	+	+	+
	100 - 200		0	+	+	+	+
	200 - 300		-	+	+	+	+
	300 - 700		-	0/+	0/+	+	-
	> 700		-	-	0	+	-
Free chlorine (Cl_2)	< 1	Within 5 hours	+	+	+	+	+
	1 - 5		-	-	0	+	-
	> 5		-	-	0/-	+	-
Hydrogen sulphide (H_2S)	< 0.05	No limit	+	+	+	+	+
	> 0.05		+	+	0/-	+	+
Free (aggressive) carbon dioxide (CO_2)	< 5	No limit	+	+	+	+	+
	5 - 20		+	+	0	+	+
	> 20		+	+	-	+	+
Total hardness[5] (Scaling can be triggered by hardness)	4.0 - 11 °dH 70 - 200 mg/l $CaCO_3$	No limit	+	+	+	+	+
Nitrate[1] (NO_3^-)	< 100	No limit	+	+	+	+	+
	> 100		+	+	0	+	+
Iron[6] (Fe)	< 0.2	No limit	+	+	+	+	+
	> 0.2		+	+	0	+	+
Aluminium (Al)	< 0.2	No limit	+	+	+	+	+
	> 0.2		+	+	0	+	+
Manganese[6] (Mn)	< 0.1	No limit	+	+	+	+	+
	> 0.1		+	+	0	+	+

Appendix B – Chloride content

Maximum chloride concentrations as a function of temperature for different plate material (Data for SS-316 are base on Outokumpu's Corrosion handbook, 11th edition, 2015).

Chloride content	Maximum Temperature					
	20 °C	30 °C	60 °C	80 °C	120 °C	130 °C
= 10 ppm	SS 304	SS 304	SS 304	SS 304	SS 304	SS 316
= 25 ppm	SS 304	SS 304	SS 304	SS 304	SS 316	SS 316
= 50 ppm	SS 304	SS 304	SS 304	SS 316	SS 316	Ti
= 80 ppm	SS 316	SS 316	SS 316	SS 316	SS 316	Ti
= 200 ppm	SS 316	SS 316	SS 316	SS 316	Ti	Ti
= 300 ppm	SS 316	SS 316	SS 316	Ti	Ti	Ti
= 700 ppm	SS 316	SS 316	Ti	Ti	-	-
= 1000 ppm	SS 316	Ti	Ti	Ti	-	-
>1000 ppm	Ti	Ti	Ti	Ti	-	-

Appendix C – Oxygen characteristic

Oxygen concentration guide values for heating water depending on the conductivity of the water according to VDI 2035 / part 2.

		Low saline (low salt content)	Saline (High salt content)
Electrical conductivity at 25 °C	uS/cm	< 100	100 - 1500
pH value at 25 °C		8.2 – 10	
Oxygen	Mg/l or ppm	< 0.1	< 0.02

Challenge efficiency

At SWEP, we believe our future rests on giving more energy than we take – from our planet and our people. That's why we pour our energy into leading the conversion to sustainable energy usage in heat transfer. Over three decades, the SWEP brand has become synonymous with challenging efficiency.

SWEP is a world-leading supplier of brazed plate heat exchangers and prefabricated energy transfer stations for HVAC and industrial applications. With over 1,100 dedicated employees, carefully selected business partners, global presence with production, sales and heartfelt service, we bring a level of expertise and customer intimacy that's redefining competitive edge for a more sustainable future. SWEP is part of Dover Corporation, a multi-billion-dollar, diversified manufacturer of a wide range of proprietary products and components for industrial and commercial use.

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