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BULLETIN #1
CHILLER & CLOSED-CIRCUIT CORROSION
EFFECT, COST, AND CONSEQUENCES

ICS Cool Energy understand the importance of water treatment for your chillers and closed circuits to avoid corrosion. Not looking after these sufficiently can cause wider effects, higher costs, and knock-on consequences.

This technical bulletin forms part of an upcoming series of technical bulletins on the subject of water treatment and we start by looking at corrosion.

WHAT IS CORROSION?

Efficiency, longevity, and safe operation of closed-circuit process chillers is critical, and should be top of mind for those who are responsible for them. It is important to understand how chillers are so susceptible to corrosive attacks, the ramifications to efficiency and the consequences of their ultimate failure.

A £150M critical care hospital in Northern Ireland suffered delays in completion due to corrosion in the closed water system and subsequent problems with the pipework.

“Significant delays in the completion of this project have been due to problems with corrosion in the closed water systems. The opening of the £150m critical care unit at the Royal Victoria Hospital in Belfast was delayed due to a problem with pipework”.

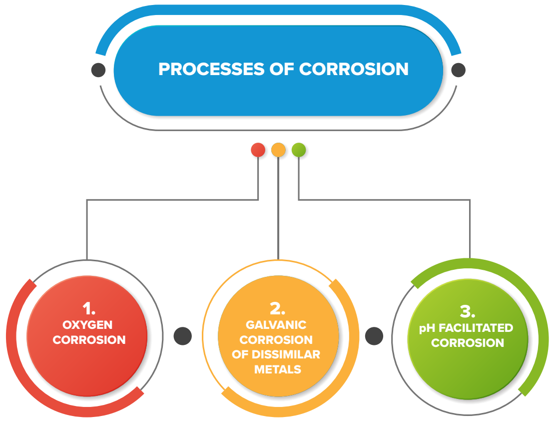
“A construction firm has settled its legal action over being denied insurance cover for a £10m bill to fix pipework at Northern Ireland’s new critical care unit”.

Understanding the principles of corrosion is the first step in avoiding such outcomes.

“Corrosion is a natural process that converts a refined metal into a more chemically stable oxide. It is the gradual destruction of materials (usually a metal) by chemical or electrochemical reaction with their environment”.

As a result, it is essential to find a way to help inhibit this natural process and following a few pragmatic steps, this can be achieved.

There is no avoiding the fact that metals are subject to corrosion, and with that, a variety of consequences can occur. The management and control of corrosion ultimately lies in the water. Water is an ideal heat transfer medium for closed circuits having many unique features and attributes. However, there are several disadvantages of using water for the purpose of heat control. One important factor is that water is an electrolyte, in that it actively aids corrosion in closed systems if not treated appropriately. However, the electrolyte property of water is not the only concern here, and these other factors will be addressed throughout this material.



OXYGEN CORROSION

Corrosion of metals in the presence of oxygen is termed oxygen-induced corrosion. Even though we see magnetite form as a ‘protective’, albeit passive layer on steel in water, (note steel is typically made up of 98% *iron), in oxygen-deficient environments we typically see black sludge being produced. Such sludge can result in poor flow, thus reducing heat transfer effectiveness as well as encouraging pockets of accelerated corrosion spots.

In the presence of an abundance of dissolved oxygen red iron oxide haematite Fe2O3 is formed. The corrosion of *Iron (rusting) is the product of a series of chemical reactions in which metallic Iron (Fe), loses electrons to form Iron ions, Fe2+ and Fe3+.

e = ELECTRON

THE PROCESS OF OXYGEN CORROSION

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This process takes place in the presence of oxygen and water and is accelerated at acidic pH (below 7).

The result of rusting is the formation of an iron oxide (red rust) layer. This layer is permeable to water and oxygen so that once rust has formed on a surface it continues to corrode underneath, creating pits in the metal surface. When pitting continues to occur, it results in pipe wall perforation, this is when we see ultimate failure in the form of a leak.

Even though systems with recorded levels of high dissolved oxygen content, leakage due to pitting in standard mild steel is still rare. This is because pit proliferation rates slow over time. The production of magnetite and haematite leads to further acute levels of sludge with the potential to further reduce flow rates and at worst; create localised blockages.

Blockages can result in partial or full system failure. Such sludge also increases the levels of suspended solids, which not only tend to settle in low flow parts of a closed system (elbows, around valves, pipework serving terminal units etc) but is where we see under-deposit corrosion concentrate as well as increasing rates of erosion, which is a further contributor of pipe wall deterioration.

Closed systems should be airtight to prevent ingress of oxygen as this helps to keep corrosion to a minimum. For iron protection, most systems operate at an alkaline pH, usually above pH 8, to prevent acidic conditions.

In summary, if oxygen, water, and a low pH are present, iron will corrode because the iron is trying to return to a stable, low energy state.

Where we have focused in detail on the corrosion profile of steel, other materials are all subject to corrosion in one form or another as we can see in the table below. This has been taken from BSRIA's BG50 2021 guidance document for closed heating and cooling systems.

GALVANIC CORROSION OF DISSIMILAR METALS

MATERIAL	WHERE USED	CORROSION RESISTANCE	OTHER ISSUES
Aluminium	Some boiler and heat exchangers and radiators	Good overall corrosion resistance in oxygenated waters of neutral or slightly alkaline pH. Should not be exposed to pH >8.5	Exposure to high pH causes rapid loss of metal and formation of aluminium hydroxide sludge
Copper and copper alloys	Copper tube, brass valves and fittings	Good overall corrosion resistance of neutral or moderately alkaline pH. In aerated water copper is subject to attack from erosion corrosion, flux residues and under deposit corrosion	Copper ions entering the water can result in pitting corrosion of steel. Brass can be subject to stress corrosion cracking due to external contamination
Mild steel and cast iron	Steel pipe, boiler heat exchangers, circulating pumps	Low levels of dissolved oxygen result in uniform corrosion and the production of magnetits sludge. High levels of DO result in pitting attack under tubercles	Formation of insoluble iron oxides as suspended solids increases wear in pumps and the risk of under-deposit corrosion in low flow areas where sedimentation occurs
Galvanised steel	Some piping systems	Internally galvanised pipes and fittings should not be used in heating systems (see section 3.1.1)	Formation of zinc hydroxide as suspended solids
Stainless Steel (SS)	Plate heat exchangers, pump casings, minor parts.Occasionally pipework	Very good resistance to general corrosion but may be susceptible to pitting, crevice corrosion and stress corrosion cracking at high chloride concentrations	None
Plastic	Plastic pipe including underfloor heating. Minor parts	Resistant to corrosion but may be subject to physical degradation eg. by sunlight	Oxygen permeation through plastic pipe. Pressure resistance decreases with temperature
Rubber	Flexible hose liners (EPDM), O-rings and seals	Resistant to corrosion but may be subject to gradual chemical and physical degradation leading to loss of flexibility and cracking	Amenable to the formation of biofilm

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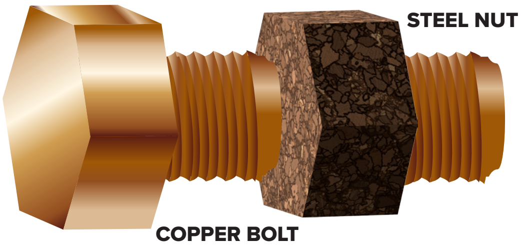
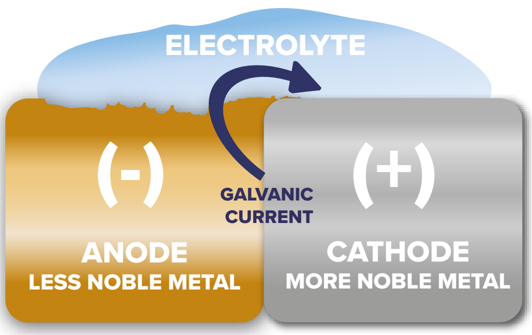
Galvanic Corrosion (also known as bimetallic corrosion) is an electrochemical process whereby one metal corrodes when in contact with another dissimilar metal through an electrolyte (water). During this process, one metal can experience severe corrosion, while the other remains relatively unaffected. This is clearly demonstrated with this nut and bolt of differing metals.



Electrons flow continuously from the most reactive metal (the anode) to the less reactive metal (the cathode) thus fuelling the corrosive process. This potential difference causes electrons to migrate across two dissimilar metals. Below is a simple diagram of this electrochemical process:



This appears to be a simple process but there are many complex variables that can accelerate or interfere with this electrochemical (galvanic) cell creation.

The main two influencers of this process are the selection of metals involved, as all have different electrical potentials that can be quantified in the presence of a conductive electrolyte.

The Galvanic Series of Metals lists metals and alloys in decreasing order of electrical activity in a particular medium. Metals and alloys nearer the top of this list have a greater negative electrical potential than the more noble or stable metals below. When two metals of broader electrical potentials are combined, under the right conditions, a more server corrosion effect is created.

The pathway in which these cathodes and anodes connect is via the type of electrolyte medium, which will accelerate this process, e.g., the higher the conductivity of the water the quicker & more reactive the process.

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PH FACILITATED CORROSION

As pH decreases acidity increases the corrosion rate also increases. The reason for this is that low pH solutions (as we move further away from neutral pH 7) accelerate corrosion by providing hydrogen ions. Hydrogen attacks and damages the surface of steel and increases the corrosive effect. Two metals commonly seen within heat transfer loops are copper and aluminium due to their conductive performance. However, these two metals are particularly sensitive to pH reduction. Copper is resistant to corrosion in the presence of oxygen in water due to the fact copper forms a stable layer of copper oxide on its surface, thus reducing the oxygen effect we see in other construction materials. Below pH 6.5 however this 'protective' copper oxide layer breaks down and with it the creation of a galvanic corrosion cell. The galvanic cell process is initiated where copper oxide settles out on a different type of metal within the circuit: anode and cathode potential start the process we have highlighted previously.

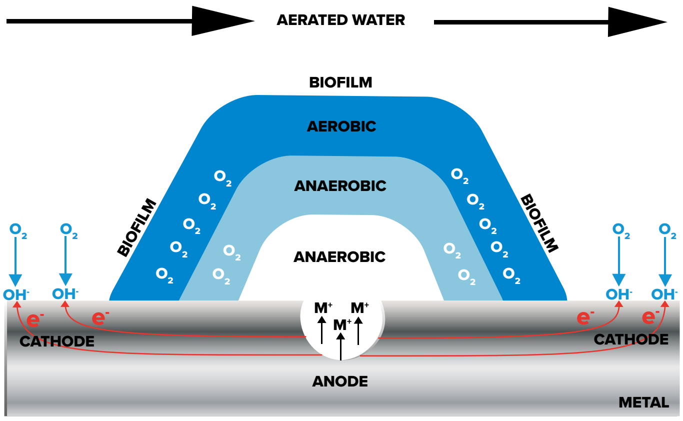
BACTERIAL ATTACK

The presence and more importantly proliferation of certain bacteria in closed systems can have a number of damaging and costly effects on closed circuits. Not only do we see the acceleration of corrosion but the impact of efficiency too. For the purpose of this document, we stay focused on the topic of corrosion and the two main features where we see certain bacteria manifest as corrosive entities.

The collective term covering the bacterial corrosive effect is termed Microbiologically Induced Corrosion or MIC for short. The two main pathways we see are where a certain bacteria have a direct impact on metal surfaces (Direct MIC) and where we see certain bacteria breaking down one of the common corrosion-inhibitor chemicals, thus leaving metal surfaces without or reduced protection, this is known as Indirect MIC.

DIRECT MIC

We have seen previously where we have allowed an environment to support an electrochemical mechanism, it is to the detriment of a closed system. This time we see it created under a microbiological biofilm. A biofilm is where we see the growth of mass bacteria. When a significant amount of biofilm has formed an area of oxygen starvation can occur at the meeting between the biofilm and that of the metal surface. This is where we see differing oxygen potentials: between the inside and outside of the biofilm. In this situation, inside of the biofilm can be seen as the anode and the outside of the biofilm is the cathode. This is where we observe this model electrolytic corrosion cell created once again.



The second Direct MIC is with a bacterium synonymous with this phenomenon: Sulphite Reducing Bacteria (SRB). Once an SRB is present and the correct environment is stable enough for its growth, we can see a rapid and damaging effect. SRB relies on the absence of oxygen; we have seen this where biofilm is present previously. This is because such bacteria are known as anaerobic, where they grow in the absence of oxygen.

The evidence of SRB attack shows as a pit on the surface of typically mild and stainless steel. SRB in general grow by using a carbon source as energy and then by reducing sulphate common in water to hydrogen sulphide (H2S). It is to be noted that additional nutrients in water also act as food sources by SRB, namely phosphorus and nitrogen. H2S is highly corrosive and can directly cause corrosion by reducing the pH in a localised area, we refer to this as pitting.

INDIRECT MIC

Where we have seen microbes directly attack metallic surfaces, we now spotlight bacteria that have an indirect, but no lesser effect on the integrity of a system. One of the most common forming biofilm bacteria is known as Pseudomonas; this is a family name of bacteria present in water. Within this family, there is a bacteria called NRB (Nitrite Reducing Bacteria) and as it suggests, this is exactly what it does, using nitrite as a source of nutrient. Given that NRBs ics cool energy

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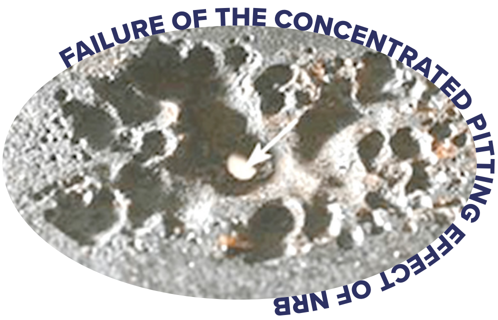
are ubiquitous; constituting up to 50% of the microbial population present in aquatic systems we should not underestimate their presence in our water systems.



IN CONCLUSION

The reason this is key to those looking to protect closed systems with a water treatment programme that uses corrosion inhibitor chemicals is that one of the most common products used to protect closed systems is nitrite based. There is a double concern here as not only does NRB actively and rapidly decrease the levels of nitrite used to protect systems, but in doing so reduces the nitrite it consumes converting it to ammonia and nitrate. Ammonia can be particularly aggressive to both copper and its derived alloys. We commonly see stress corrosion cracking of brass valves in such instances taking note that any Ammonia levels > 1 ppm induce stress corrosion cracking in copper-bearing alloys.

We know full well that understanding the chemical makeup of what might look like water is complicated. We simplify this for you, we take a sample, send it off to an independent laboratory and issue a report than you can understand with clear advice to maintain your equipment or carry out a repair. All of which we do in house be it glycol, inhibitor, biocide or a full flush.

Water quality affects the longevity, efficiency, and reliability of your process equipment. It's essential that your system fluid is checked, maintained and treated regularly to avoid problems such as corrosion, bacteria and system fouling which will ultimately lead to equipment and process system failure, inconvenience and expense.

The first step to good quality water is to implement a water treatment plan. As part of our planned preventative maintenance contracts, ICS Cool Energy now carry out as standard, sampling and independent laboratory analysis. An easy-to-read report is issued, indicating any defects which fall outside of the recommended parameters.

A detailed action plan is then created and can be implemented for you – returning and maintaining the quality of your water to best practice standards.

BENEFITS

- Prevent system degradation by regular monitoring and treatment
- Increase system efficiency
- Increase the life of your system and equipment
- Reduce maintenance and repair costs
- Protect the quality of your process system

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