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knowledge for a brighter future

Behaviour of Stainless Steels in Waters

Presenter Carol Powell
Southern Water, 5 July 2018

Water Industry

Water treatment

Distribution

Effluent treatment

Plumbing

Reasons for Using Stainless Steel in Water and Wastewater Treatment Plants

- Tolerate wide range of water chemistries
- Coatings not required
- Withstand high flow rates
- Excellent resistance to aeration
- Strong, yet ductile
- Can use thinner light-weight sections
- Readily welded and fabricated
- 100% Recyclable

Lake Como Potable Water Plant, Italy

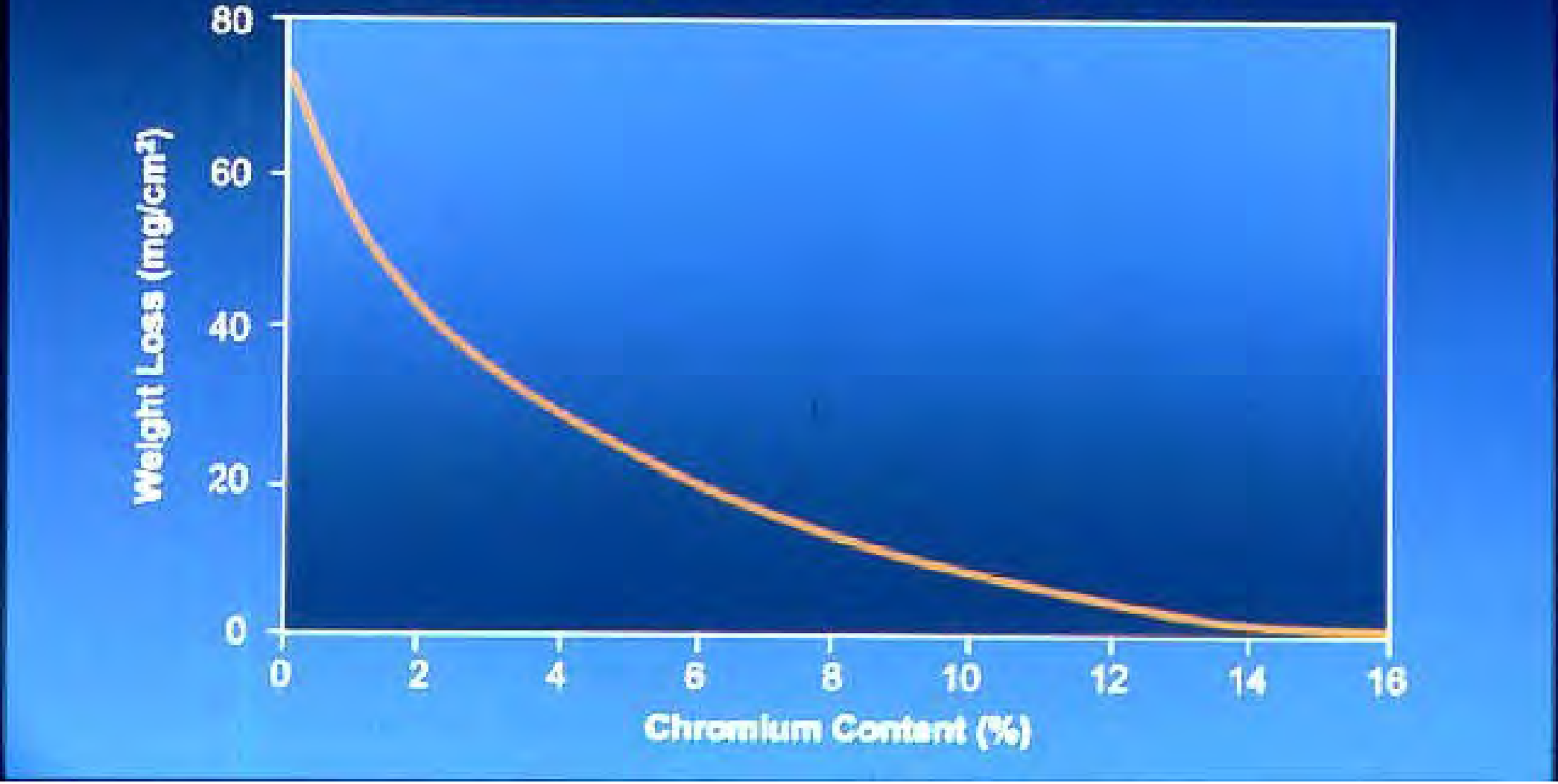
How Stainless Steel Works

Steel

Steel
+
10.5% Chromium

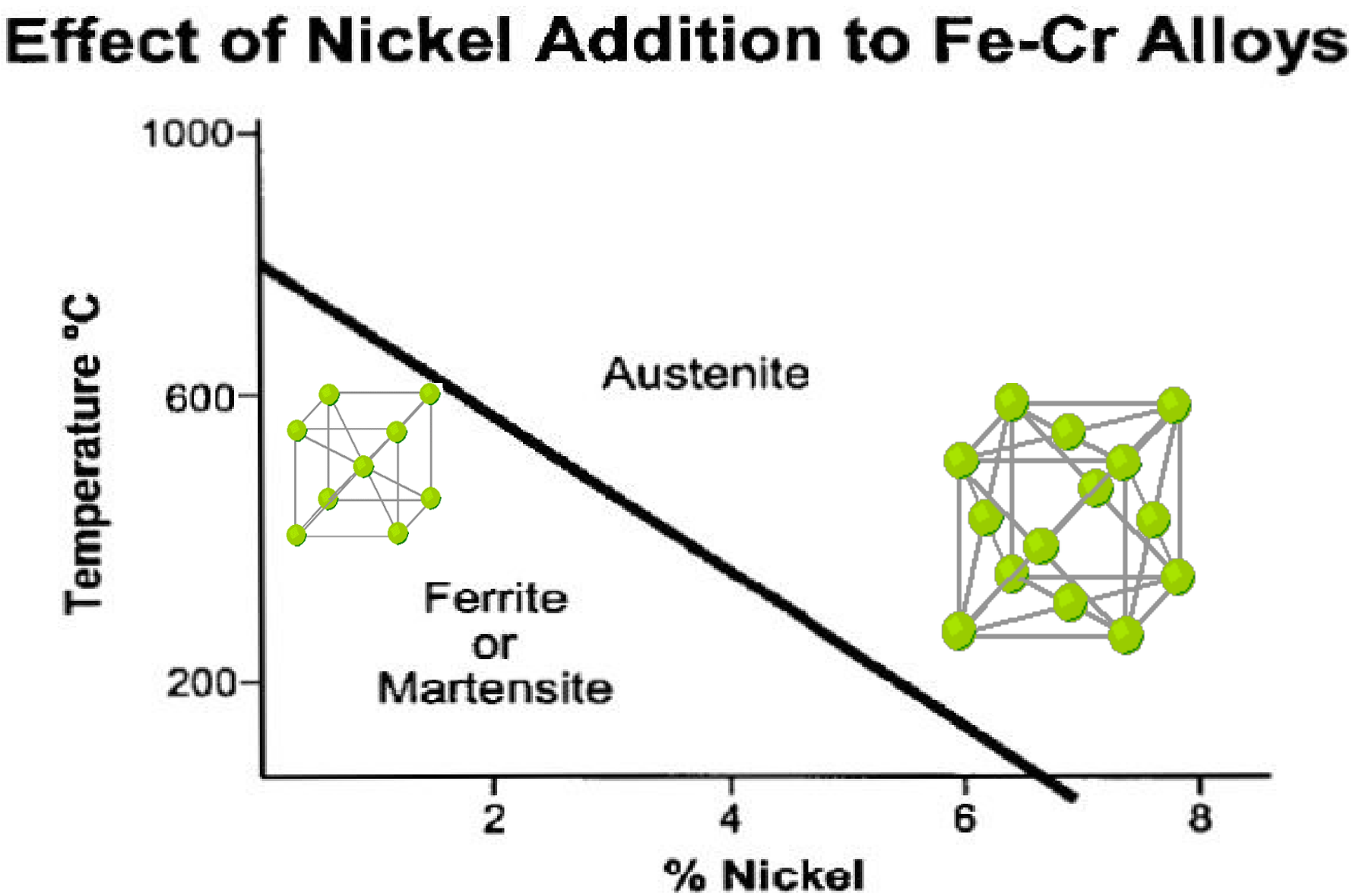
Effect of Chromium Content on Atmospheric Corrosion Behavior of Steels

250 m Lot, 44 Months Exposure



Water industry require normally more than 16% chromium

Effect of Nickel Content on Structure



Nickel allows austenite to be formed at room temperature

Austenitic Alloys readily fabricated

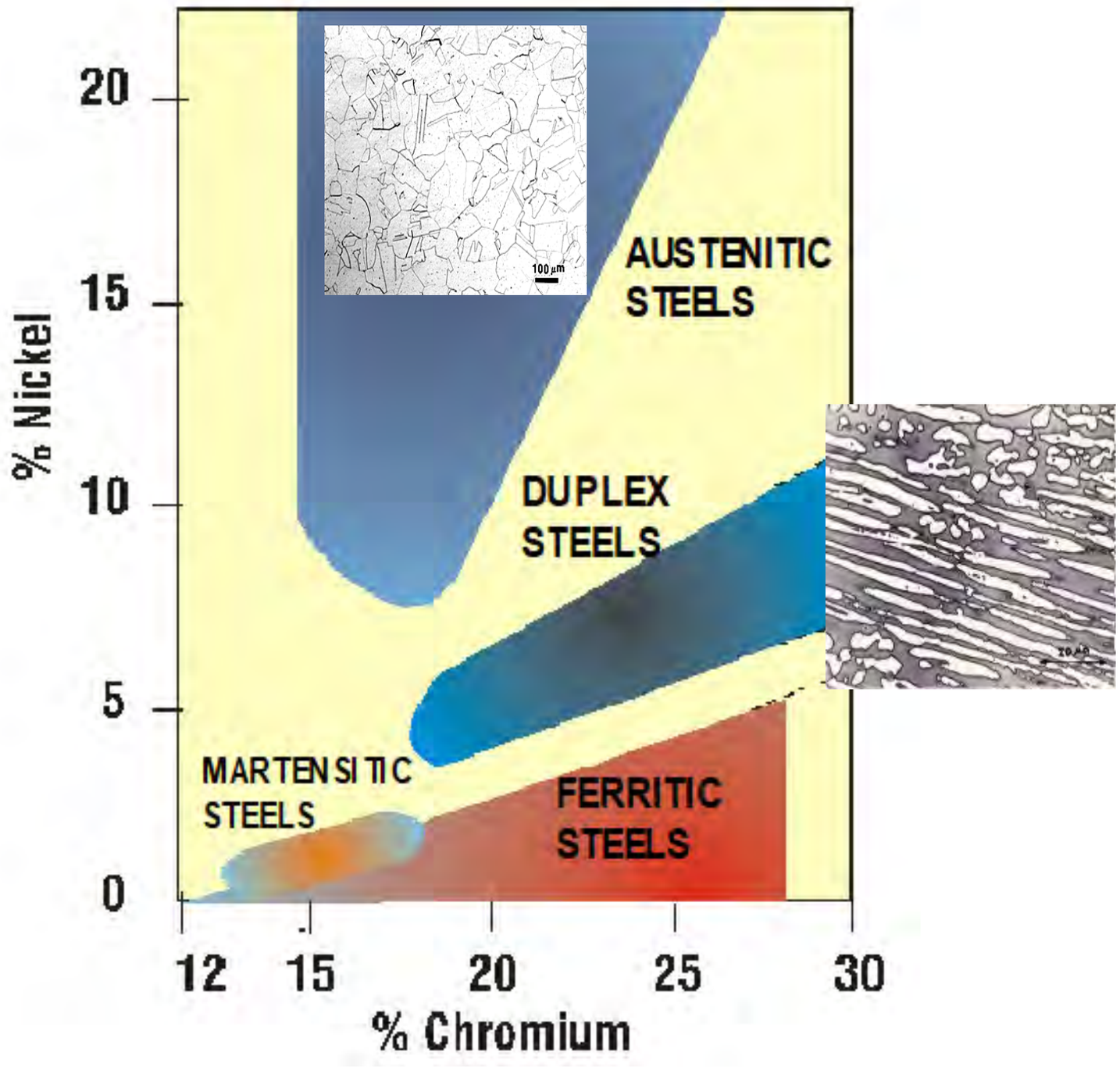
Domestic kitchen sink

Type 304 stainless steel

Type 304 Stainless steel beer kegs

- Hygienic
- Long life
- Repairable

Stainless Steel Structures



Families of stainless steels

Ferritic	Fe – Cr [4xx]
Austenitic	Fe - Cr – Ni [3xx] Fe-Cr-Mn [2xx]
Duplex	50 : 50 - ferrite : austenitie [xxyy –%Cr, %Ni]
Martensitic	Ferritic with high C [4xx]
Precipitation hardening eg. 17-4PH; grade 630	Stainless steels of various structures strengthened by the formation of fine precipitates.

hundreds of alloys: <10 account for 99% of use

Grades commonly used in water industry

Nominal compositions

Stainless Steel	C (max)	Cr	Ni	Mo	N
304L	0.03	18	9	-	
316L	0.03	17	12	2.5	
Duplex 2205	0.03	22	5	2.5	0.20

The difference some molybdenum makes!

Stainless Steel-effect of water flow

- General corrosion rates: less than 0.002mm/year
- Corrosion rate remains very low up to flow velocities greater than 40m/s

High Velocity Test Data in Seawater

Alloy	Corrosion rate mm/year	Seawater Velocity m/sec
Grey cast iron	13	38
Carbon steel	9.5	40
316 stainless steel	0.005	43

How a Stainless Steel may Corrode

- Not like carbon steels – stainless steels rarely fail by uniform corrosion
- *Corrosion allowance* is meaningless
- If they ever corrode it is usually in a localised manner

Water Corrosivity Spectrum

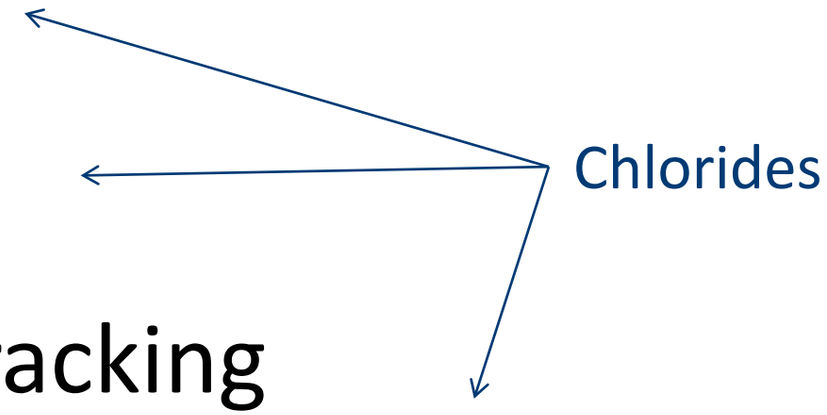
Distilled water	**Potable water - low chloride**	**Potable water - high chloride**	**Chlorinated fresh water**	**Brackish water & bore water**	**Brackish water microbes**	**Seawater & chlorinated seawater**

Ambient temperature and near neutral pH

For stainless steels, water *corrosivity* increases as chloride levels rise

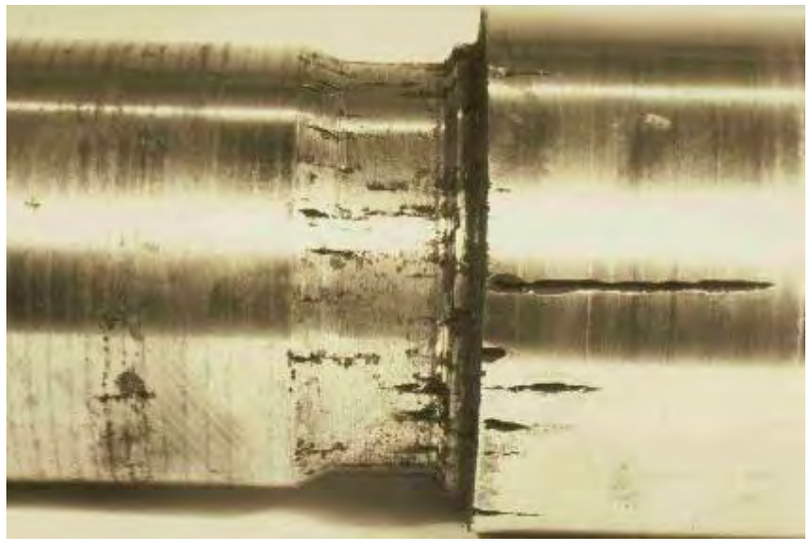
Potential Localised Corrosion Mechanisms in Waters

- Pitting corrosion
- Crevice corrosion
- Stress corrosion Cracking
- Microbiologically Influenced Corrosion
- Galvanic Corrosion (not the stainless)



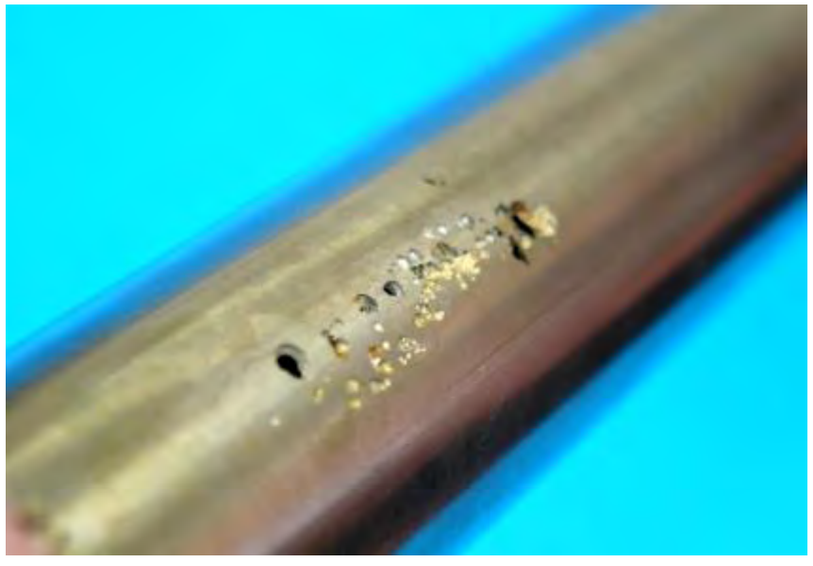
Pitting Corrosion - Possible Causes in Waters

- Pits start at some weak point in the passive film:
  - Embedded iron
  - Surface inclusions such as manganese sulphide
- Often caused by:
  - chloride (Cl^-) levels too high for the particular stainless steel, or
  - over chlorination, or
  - surface contamination



Rolled Alloys

MnS inclusions in machining grade 303 .
Enhanced machinability grades with controlled sulphur and calcium treatment are available.

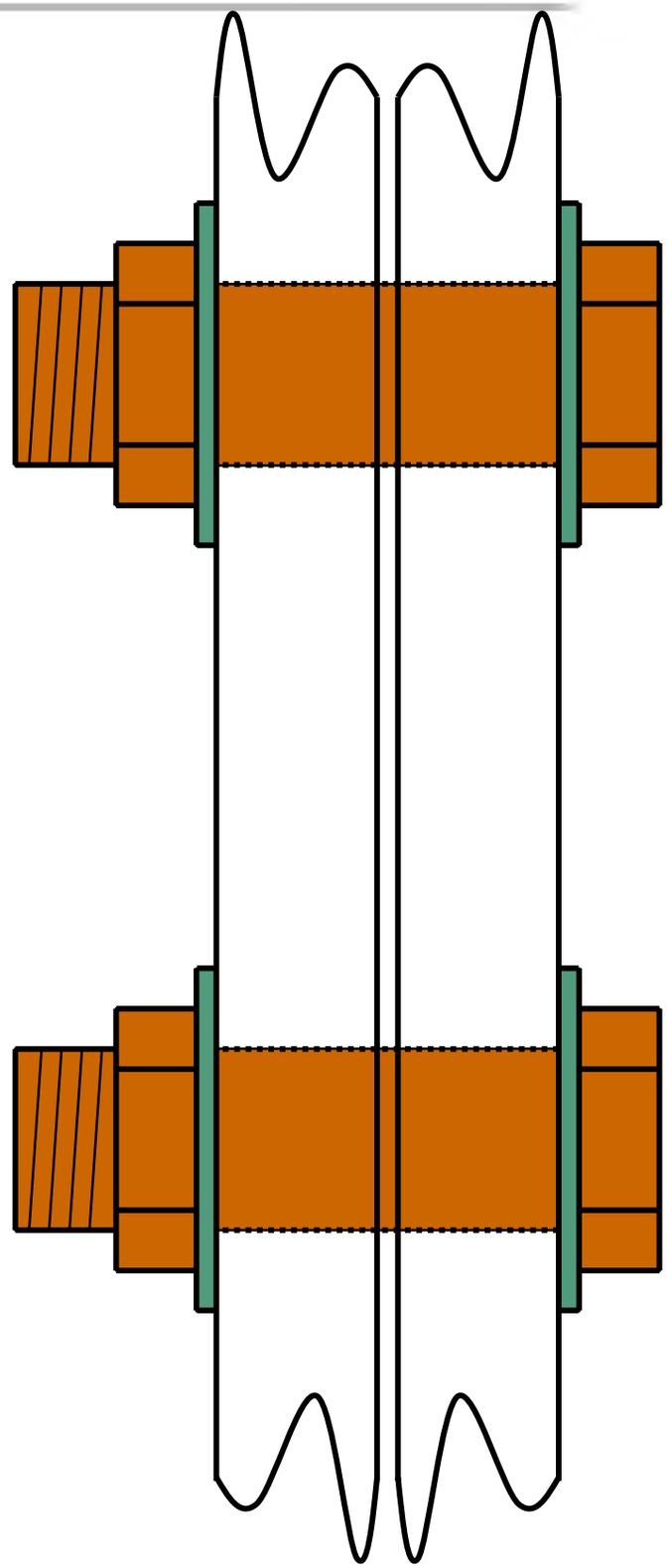


ASSDA

Concentrated bleach (chlorine) attack on 316 after a few weeks

Crevice Corrosion

Occurs in areas which are wet and where it is difficult for oxygen to reach – such as under the head of a bolt or under a deposit



Crevice corrosion

Crevice corrosion can occur when the wrong grade of stainless steel is selected for the conditions

Type 316 used in a Victaulic coupling for seawater reverse osmosis desalination. It was successfully replaced with a 6% Mo stainless steel.

Solution 2- Choose a more resistant grade

Pitting Resistance Equivalent

PREN = %Cr + 3.3 %Mo + 16 %N

- PREN values are an approximation and assist in selecting stainless steels in environments known to cause localised corrosion
- Higher PREN gives more corrosion resistance
- With tungsten present the PREN is %Cr + 3.3 (%Mo + 0.5%W) + 16 %N

PREN = %Cr + 3.3 (%Mo + 0.5%W) + 16 %N

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Alloy	Cr	Ni	Mo	N	C	Other	PREN
Austenitic and Super-Austenitic							
304L	18	8			0.03		18
316L	17	11	2		0.03		23
6%Mo Alloy	20	18	6	0.20	0.02	Cu	42
6%Mo Alloy	21	24	6	0.20	0.03		43
Duplex & Super-Duplex							
2205	22	5	3	0.15	0.03		34
25%CrAlloy	25	7	3.5	0.25	0.03	Cu,W	41

Grade selection guidelines for immersed conditions

Chloride content of the water is most important parameter

Practical experience and tests show crevice corrosion is unlikely at pH > 6 and ambient temperature if:

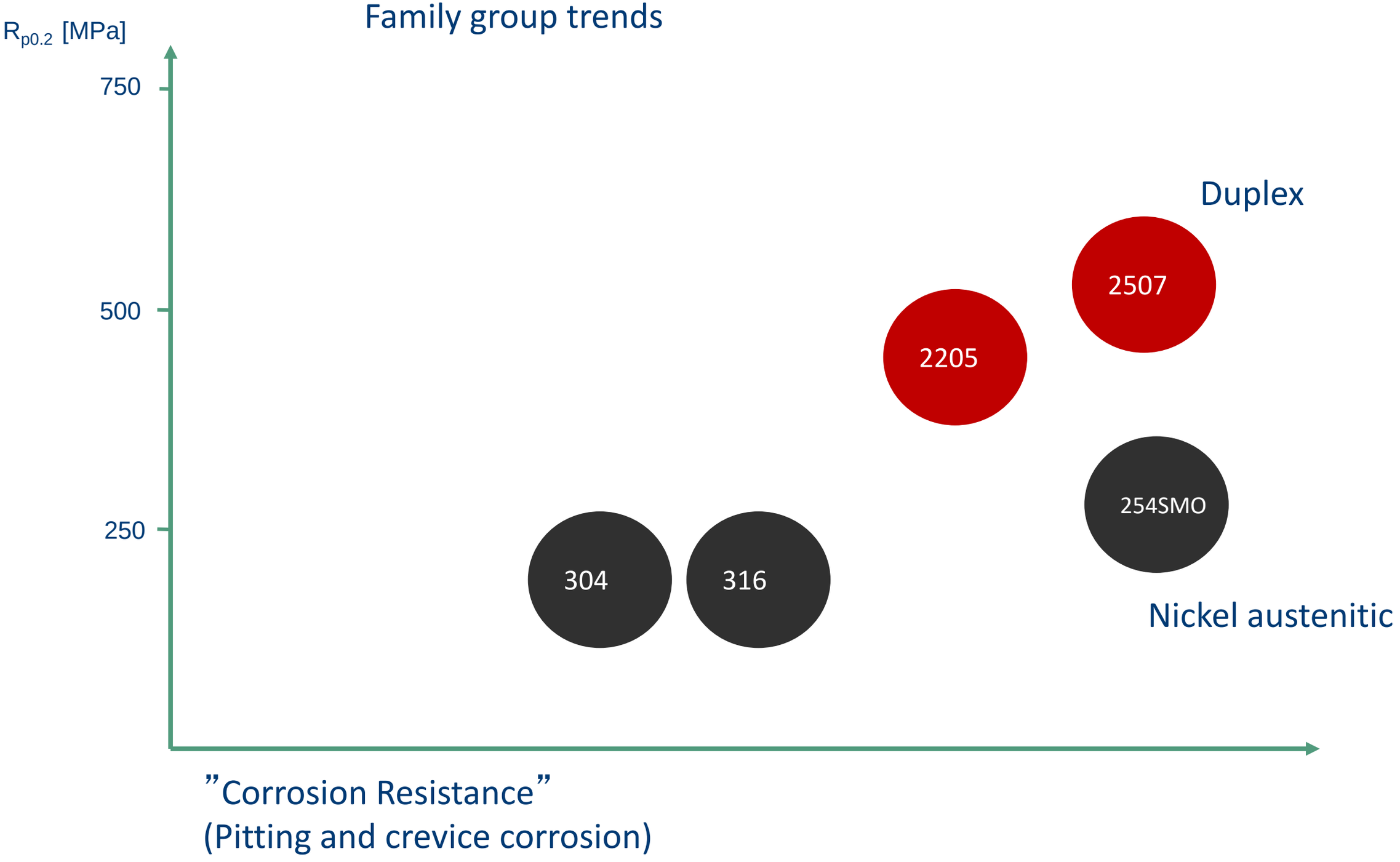
Chloride level	**Suitable grades**
<200 ppm	304,
<1000 ppm	316
< 3600 ppm	duplex 2205
>3600 ppm and seawater	6% Mo superaustenitic, superduplex

Maximum chloride Cl- levels mg/L Guidelines in plumbing systems

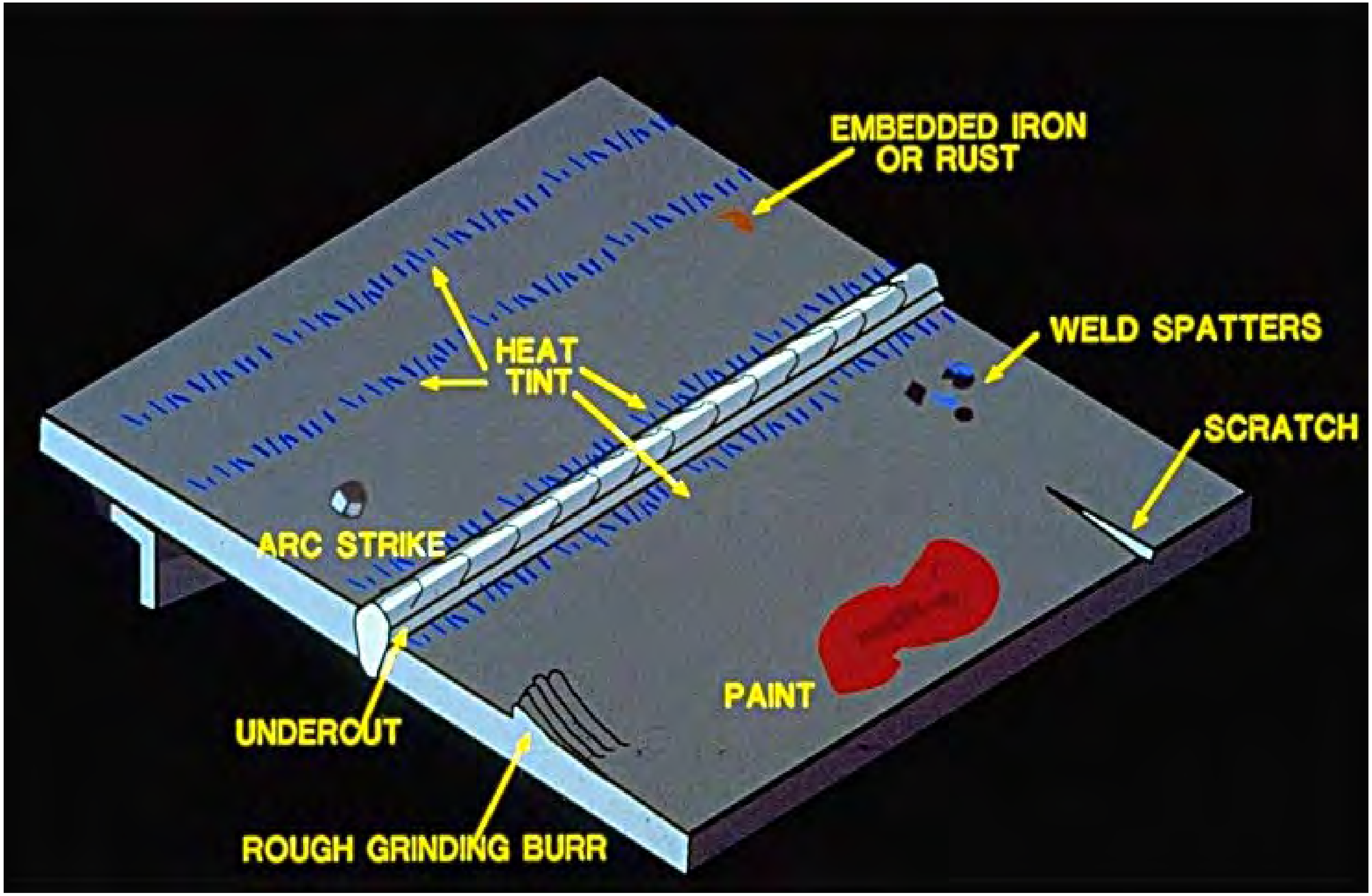
	Cold water	Hot water
Type 304L	200	50
Type 316L	1000	250

When materials may be used in either hot or cold water lines, the guidelines for hot water should be used

Duplex and austenitic 0.2% proof strength



Fabrication Defects cause Crevices



Good fabrication practices are essential

Solution 1-Minimising Crevices

- Prefer loose open crevices
- Avoid static conditions
- Seal weld static crevices
- Use full penetration welds
- Provide good flow and turbulence

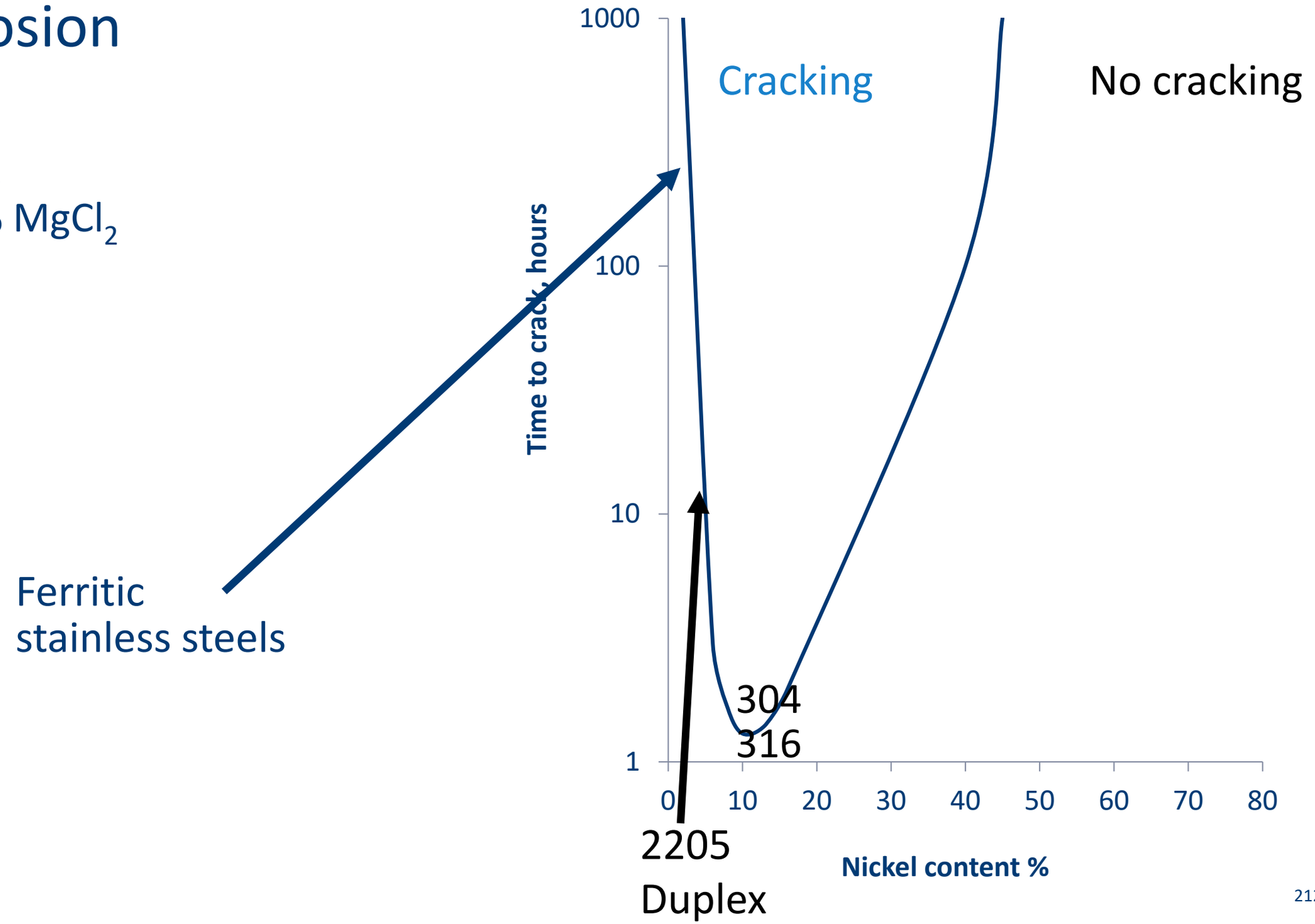
Stress Corrosion Cracking

- Susceptible Alloy
- Tensile Strength
- Specific Environment
  - chemical (chlorides)
  - temperature (>50°C)

Copson U Curve

– effect of nickel content on chloride stress corrosion cracking

18-20% Cr wires
in a boiling 45% $MgCl_2$ solution



Chloride Cl^- Stress Corrosion Cracking (SCC)

- SCC is rare inside pipes which are full of liquid as the chlorides cannot concentrate on the surface
- SCC is more of an issue from the outside of the pipe, if chlorides can concentrate through evaporation:
  - Use low-chloride insulation
  - If the insulation may get wet, use an aluminium foil barrier on the stainless steel pipe
  - Use a duplex grade

Guidelines for sea water:

• 316L	50-60°C
• 2205	100°C
• Superduplex	110°C
• 6%Mo	120°C

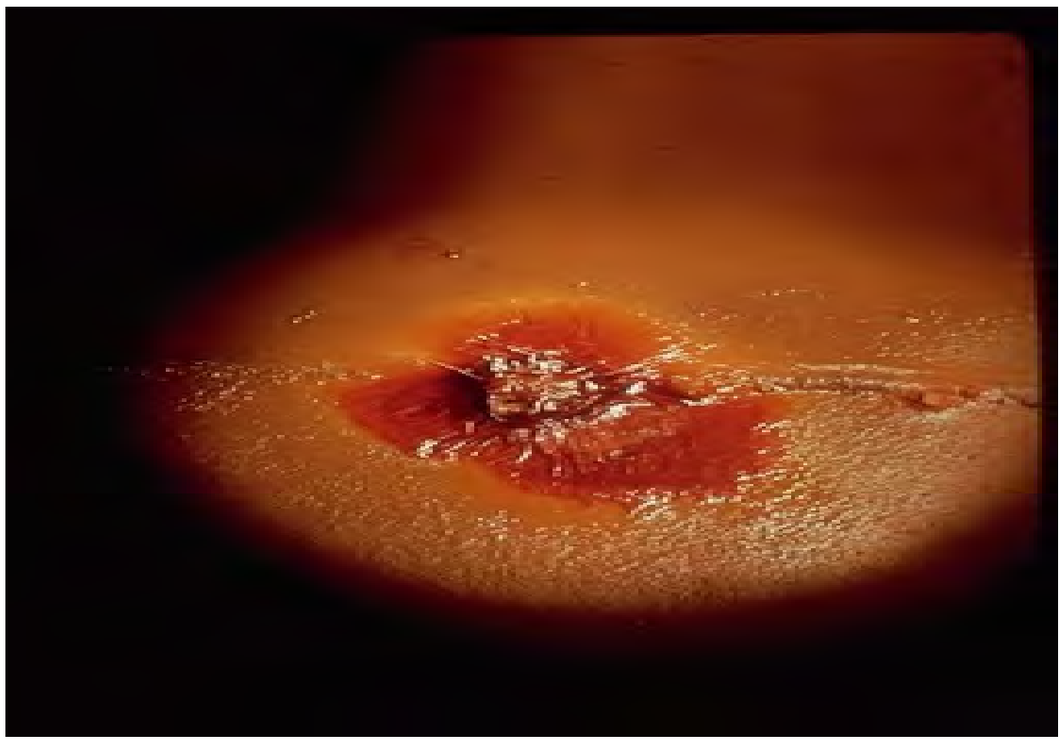
Les Boulton & Associates Ltd

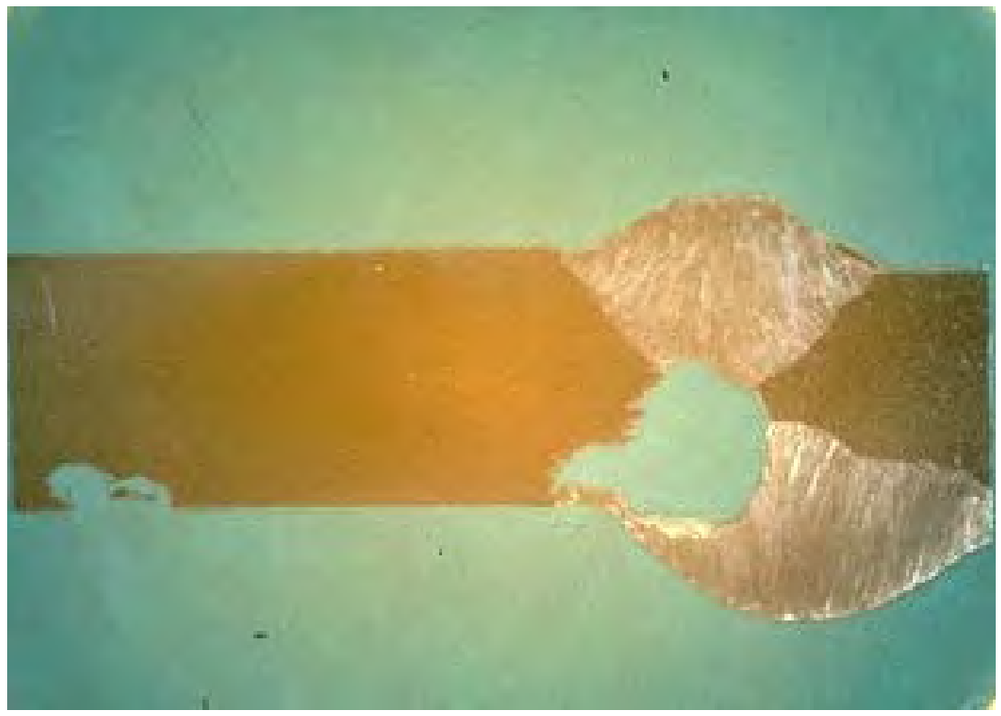
Cl^- SCC which formed from the outside of 2 year old Type 304 pipe carrying water at 90°C in a winery.

Microbiologically Influenced Corrosion

Stagnant conditions with raw waters can lead to microbiologically influenced corrosion (MIC)

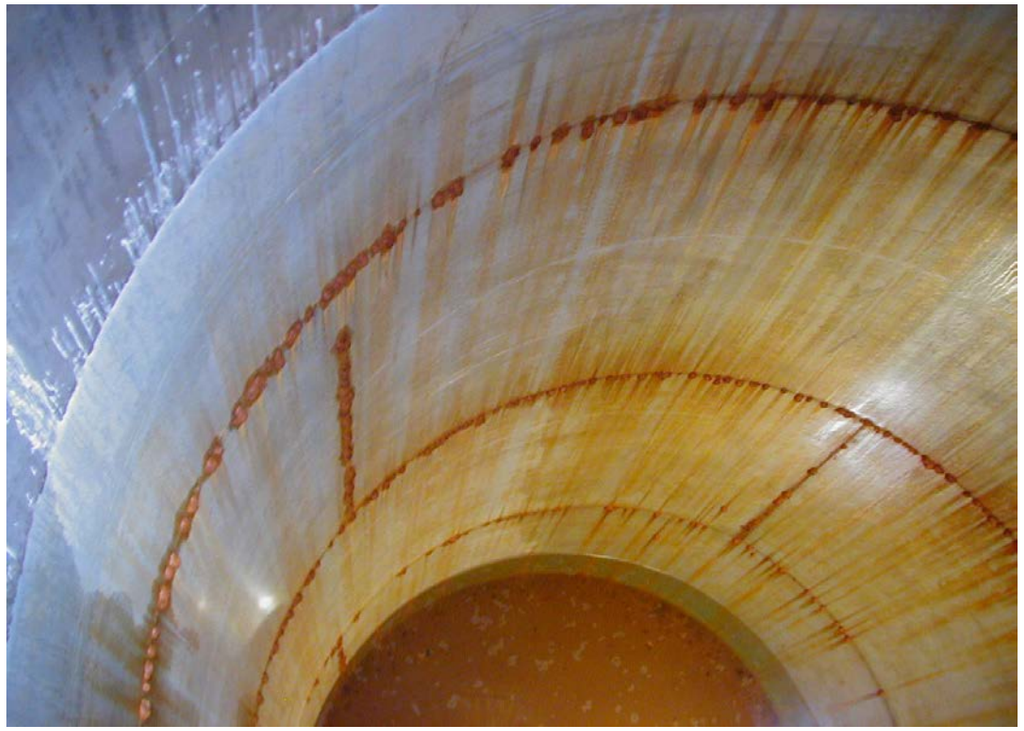
MIC Corrosion by Well Water, USA





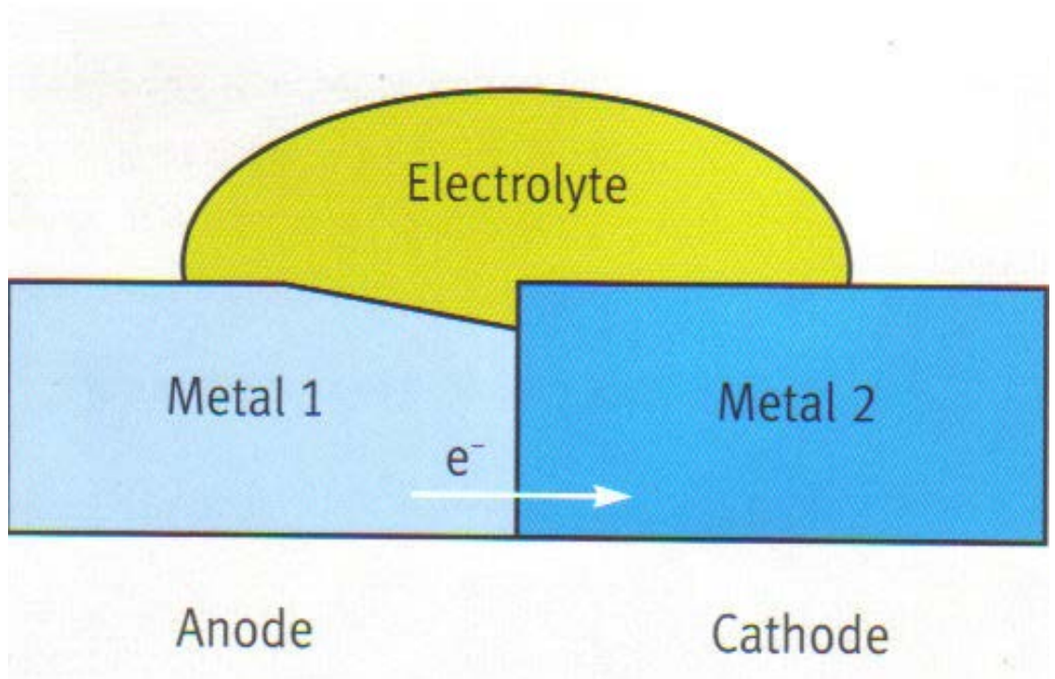
Preventing MIC in Stainless Steels

- Remove heat tint
- Avoid prolonged stagnant conditions
- Biocide treatment
- Standby or shutdown:
  - Drain and dry
  - Circulate water 1hour/each day



Galvanic corrosion

- Two or more metals in electrical contact
- Wet
- Sufficient potential difference (voltage) between the metals for a current to flow
- The more corrosion resistant (noble) metal, the cathode, eg. stainless steel, will have a lower corrosion rate than it normally would
- The less corrosion resistant (sacrificial) metal, the anode, eg. galvanised steel, will corrode faster than it normally would



Eurolnox

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Galvanic corrosion between a carbon steel support ring and the large Type 304 hot water storage tank to which is was welded. The tank was lagged with fibreglass and water leaked into the lagging.

Electrochemical (galvanic) series for fresh water

ANODIC - SACRIFICIAL

Magnesium

Zinc

Aluminium

Carbon steel and cast iron

Copper alloys

400-series stainless steels (ferritic)

300-series stainless steels (austenitic)

Graphite

CATHODIC - NOBLE

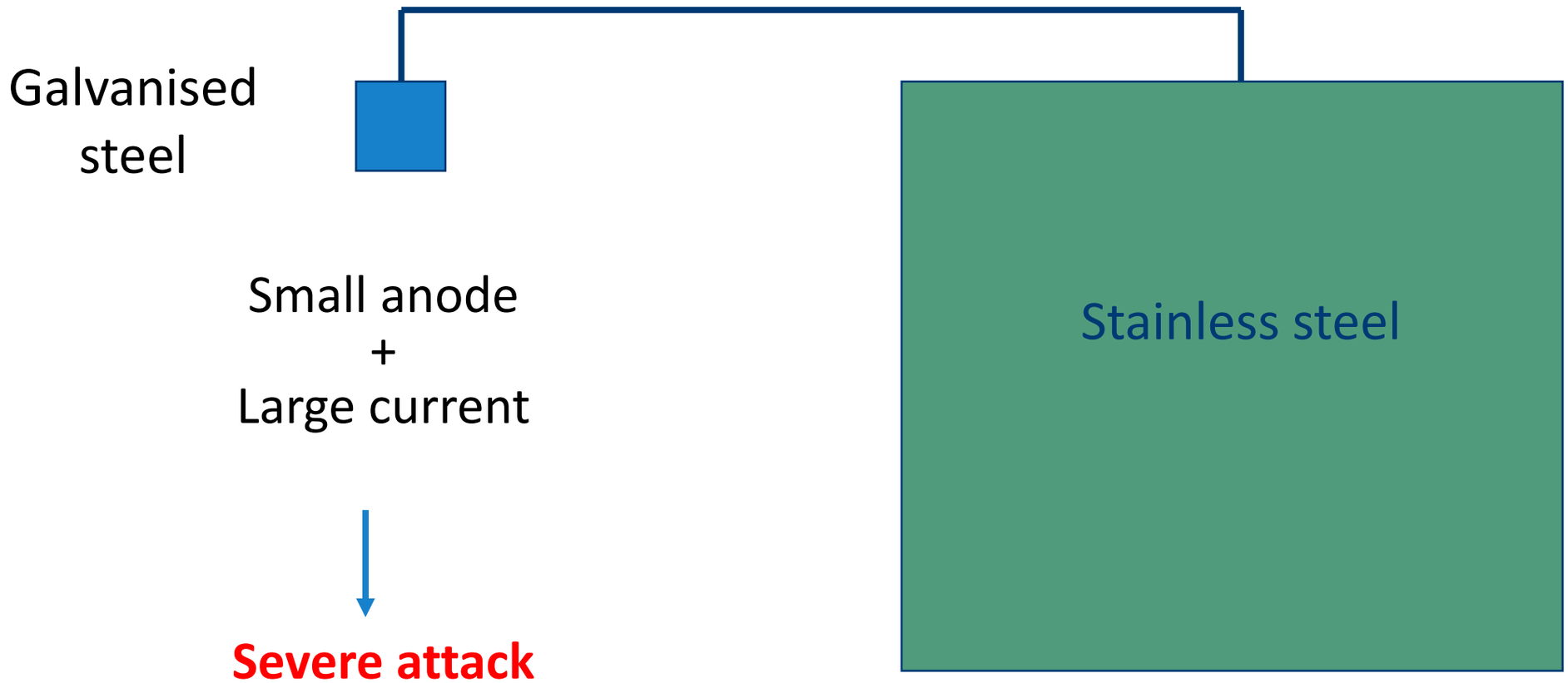
No

OK

Relative surface areas of anode and cathode influence the degree of corrosion

Galvanic corrosion – surface area effect 1

Large cathode – small anode
Severe attack



Galvanic corrosion – surface area effect 2

Small cathode – large anode

OK

Stainless steel

Small cathode produces small current

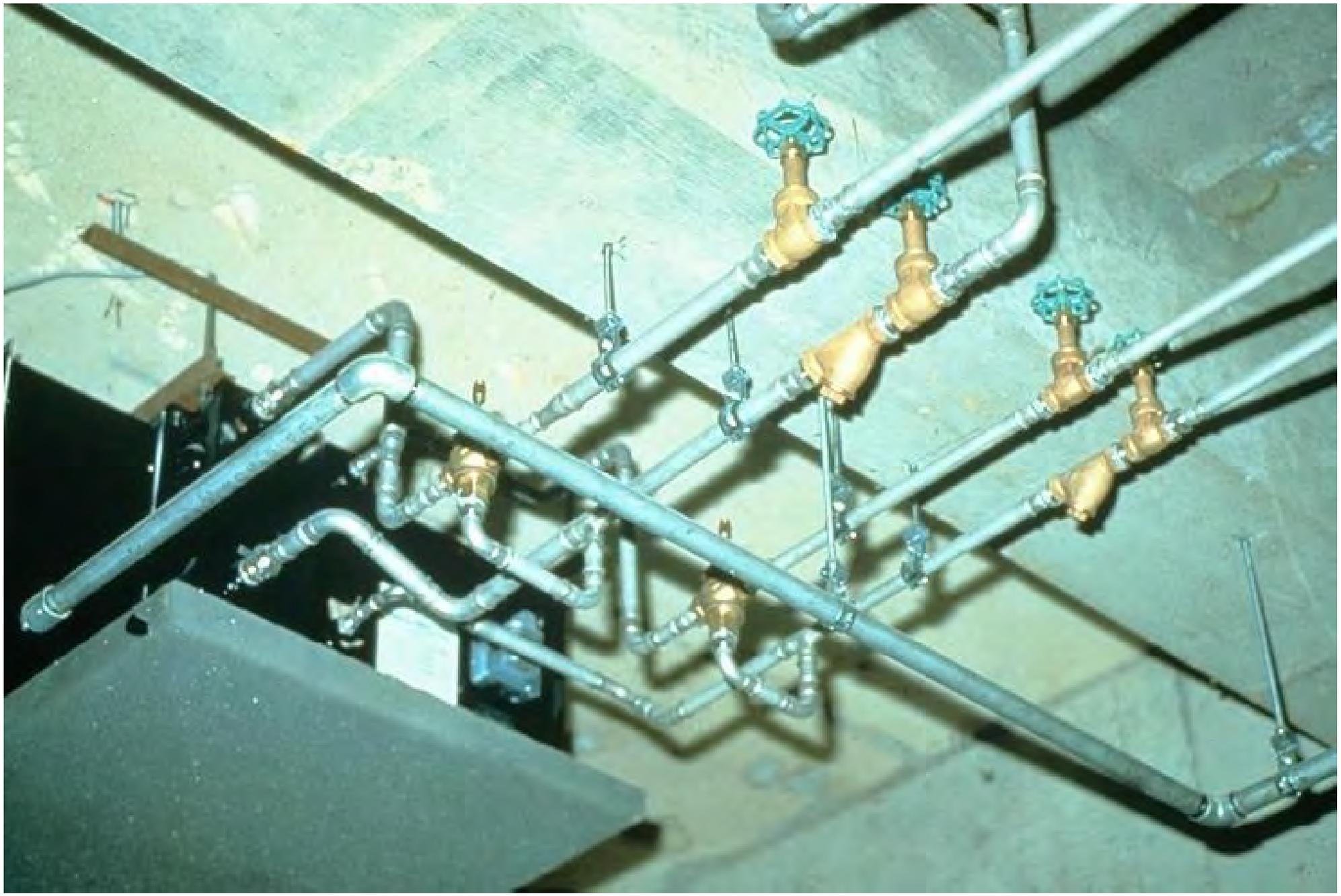
Large anode
+
Small current

No significant attack

Galvanic Corrosion in potable water systems

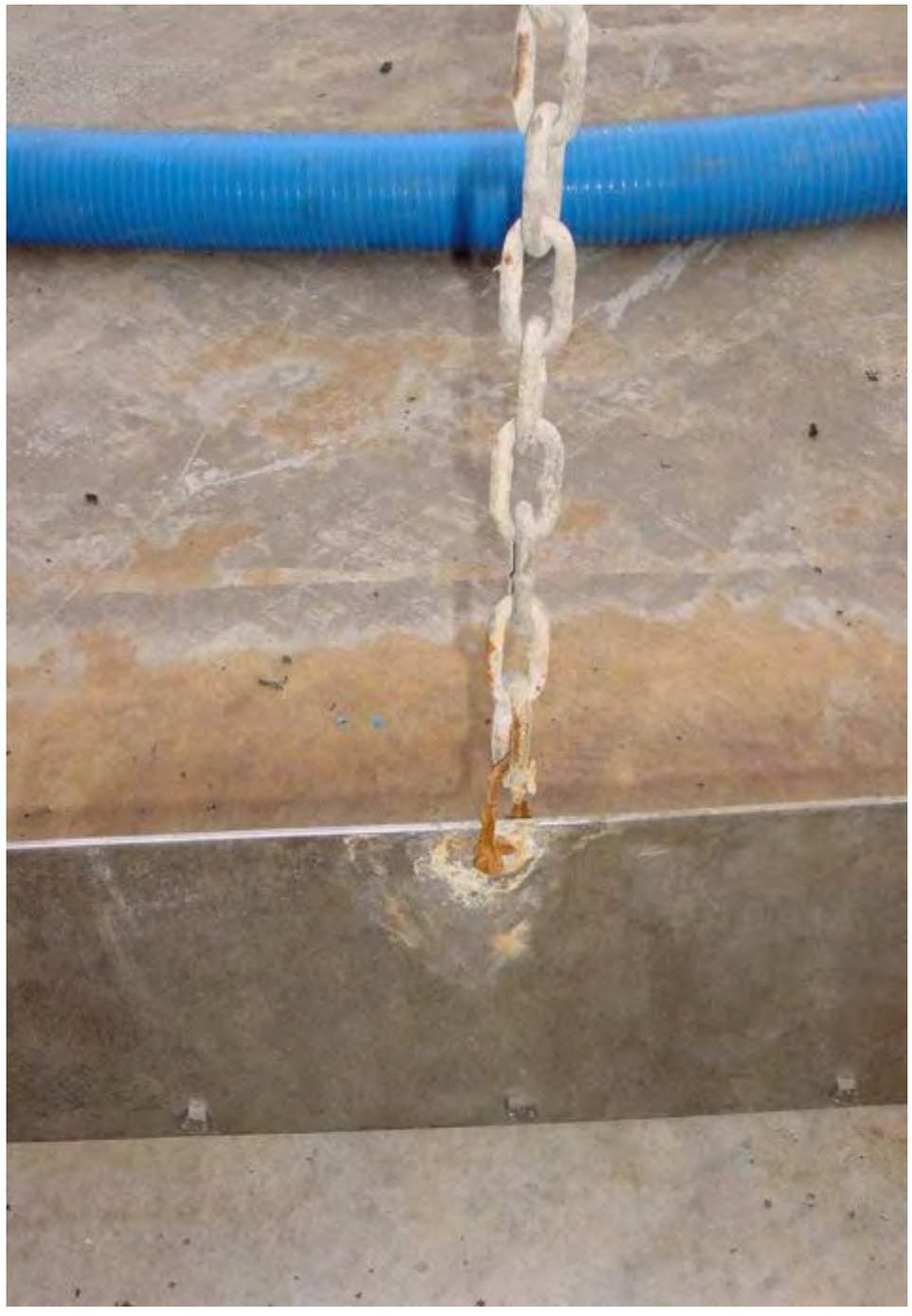
- Stainless steel is more noble than galvanised steel, steel and cast iron:
  - It should be electrically insulated from such materials to prevent their corrosion
- In practice, the galvanic difference between stainless steels and copper alloys is not significant:
  - Stainless steel pipe can be used with:
    - Copper-based fittings
    - Copper hot water cylinders

Copper alloy (brass / bronze) valves and fittings used with stainless steel water pipe

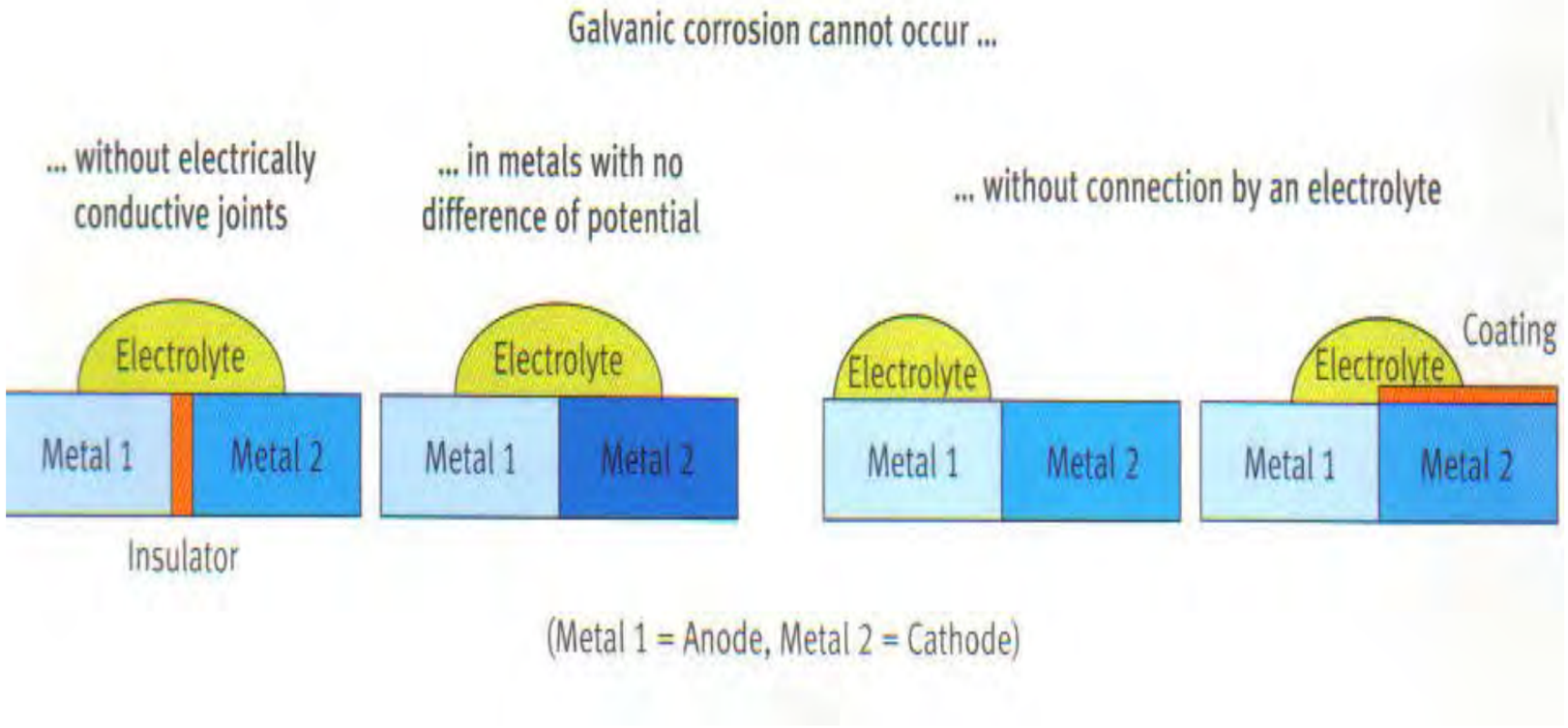


Galvanic Corrosion of Steel Chain

WWTP Clarifier Tank, NZ



Guidelines to avoid galvanic corrosion



EuroInox

- When coatings are used to protect against galvanic corrosion, do not coat anode alone
- Make the key component (eg. fasteners) from a more noble material (e g. stainless steel)
- Ensure the less noble material (eg. galvanised steel) is present in a much larger surface area than the more noble material (eg. stainless st.)

Low Leaching from Stainless Steels

- European Drinking Water Directive
  - Cr < 50 µg/l
  - Ni < 20 µg/l
- Research pipe rig tests showed Cr and Ni leaching values < 5% of maxima for 304 and 316 in both hot and cold water

Scottish Hospital

Summary Guidelines for the use of Stainless Steels in Waters

- 304L and 316L are the common grades
- 304 L < 200 ppm Cl^-
  316L < 1000 ppm Cl^-
  2205 < 3600 ppm Cl^-
- Ensure good fabrication practices and avoid crevices where possible
- Maintain flow – avoid stagnant water
- Protect against galvanic corrosion.

Applications of Stainless Steels in Water Treatment Plants

- Well components
- Gates, weirs, overflows
- Screens, scrapers,
- Fasteners, piping
- UV and Ozone generators
- Chemical treatment lines
- Platforms, bridges, covers
- Pressure doors, frames
- Pumps, valves
- Tanks, vessels
- Ladders, railings

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