Erosion-Corrosion of Copper Pipes in Recirculating Hot Water Systems

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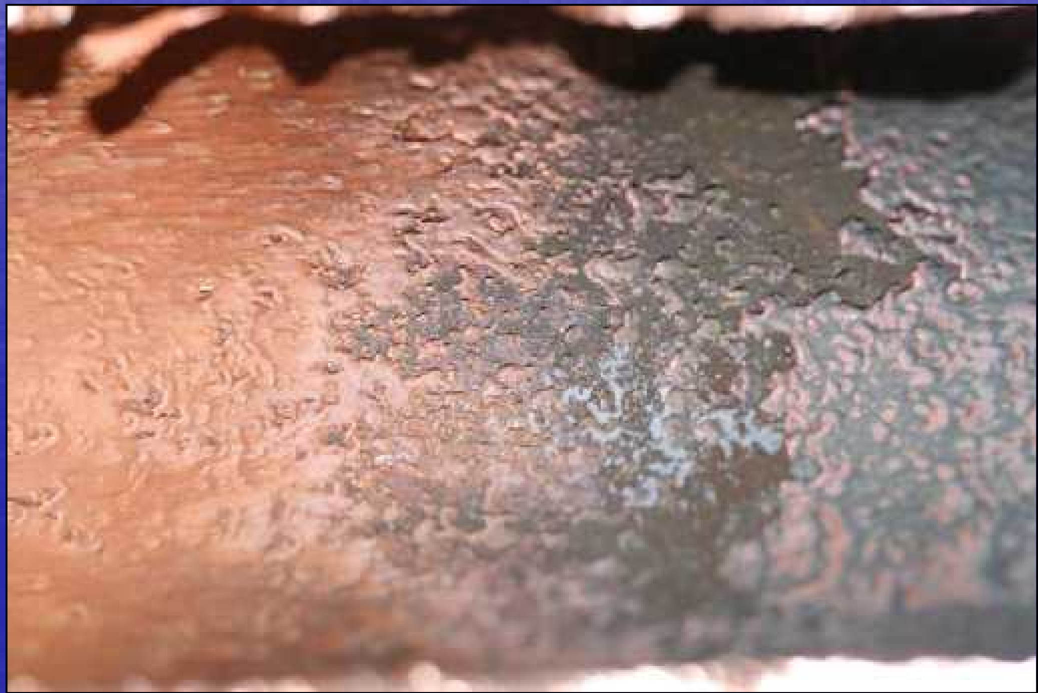

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NICHOLAS CORROSION PTY LTD

Dr David Nicholas

- Has 35 years as a Materials Engineer in the water industry.
- Published over 50 papers on corrosion related issues in the industry, including Doctorate study on corrosion of copper alloys
- Researching corrosion of copper and copper alloys since 1978

What We Will Present

- Various corrosion phenomena of copper in drinking water:
  - ‘blue’ water
  - Cold water pitting
  - Hot water (type 2) pitting
  - Erosion/corrosion
  - Cavitation erosion
- Water velocity issues
  - Published literature
  - Guidelines for maximum design velocity
  - Effects elevated temperature
- Conclusions and Recommendations

Copper As a Plumbing Material

- First known use over 4,000 years ago
- Became default plumbing tube after WW2
- Copper type (>99.9% Cu) has remained the same for 80+ years
- Success driven by ease of joining and perceived longevity
- Nevertheless, corrosion can occur!

‘Blue’ Water

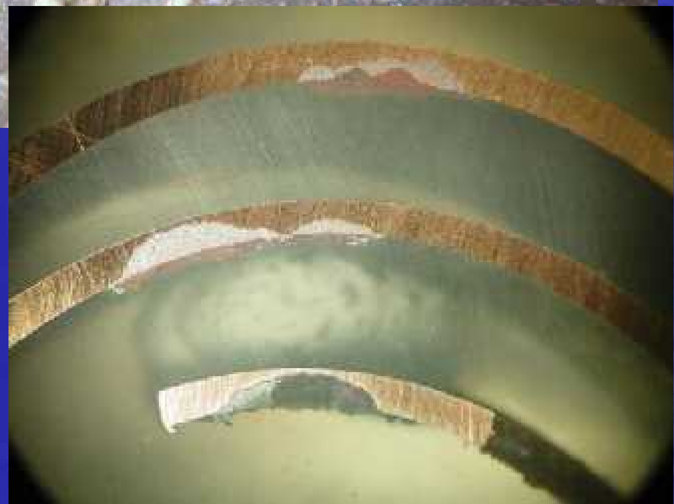
- Extensively occurred on East Coast Australia in 1970-90’s
- Widely researched by CSIRO and ICA, amongst others
- Believed to be microbiologically induced (MIC)
- Disinfection with chlorine fixed problem
- Now only found in tank water supplies

Cold Water Pitting

- Still a world-wide problem and again widely researched. Often called ‘Type 1’ pitting
- Water composition related
- Pitting and “Blue water” have been problems in Melbourne and Tasmania

Hot Water (Type 2) Pitting

- ‘Type 1, 2’ classification invented by Lucey in 1960’s.
- Type 2 almost unknown here in Australia until recently
- Now reported across Eastern Australia: all in recirculating HWS.
- Driven by pH below 7.4 and high temperatures above 60^{o}C
- Not well researched.



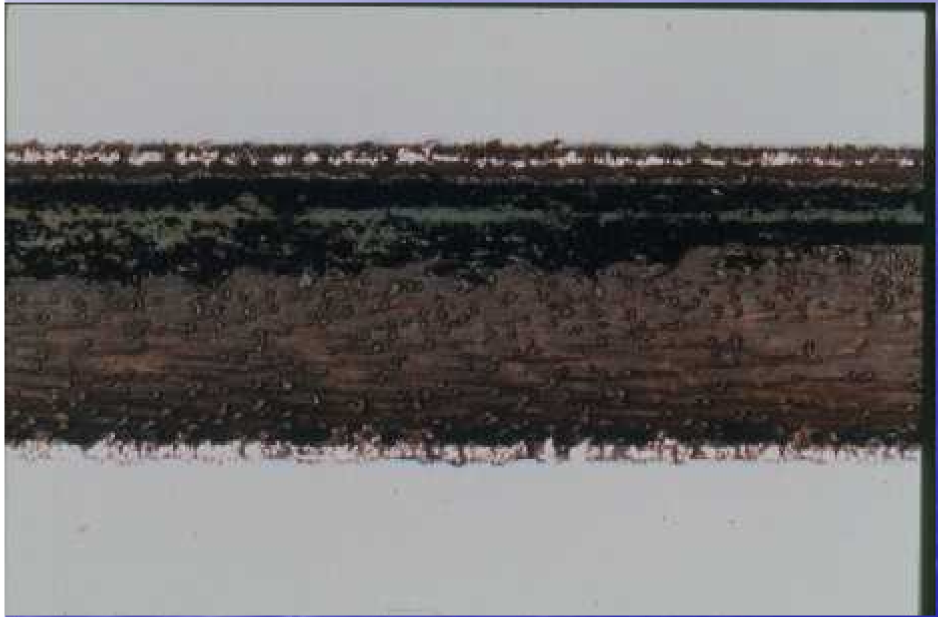
Erosion – Corrosion: Mechanism

- Copper surface corrodes and forms oxide, carbonate/sulphate protective scale in contact with water
- Excessive flow removes protective scale exposing fresh copper which promptly corrodes again. ‘Galvanic’ issues between corroded and non-corroded areas may accelerate this.
- Essential issue is the critical velocity at which erosion-corrosion occurs!
- Can happen in cold water, but more usual in hot

How Do We Identify Erosion-Corrosion

- Typically horseshoe-shaped pits with open ends facing downstream
- Type 2 pitting corrosion inevitably has corrosion tubercules over pits
- Corrosion – Erosion has clean, bare metal exposed at the horseshoe shaped pits. Corrosion products are remote from pits.
- Entrapped gas and particulate matter will exacerbate problem.
- Note that uneven joints can contribute to corrosion-erosion.

Examples of Corrosion – Erosion...



Overview of pipe samples suffering from Erosion-Corrosion. In this light the attacked bare metal areas show as bright pink while the darker brown regions are the oxide scale.

Pinhole leak at bend, viewed from outside of pipe.

Early stages of Erosion-Corrosion attack. Horseshoe-shaped pits have open end downstream.

Possible causes of Corrosion-Erosion

- Excessive water velocity in pipes
- Elevated water temperature
- Turbulence due to joint profile

Turbulence Due to Joint Profile

- Note that presence of poor or uneven joint profiles erosion – corrosion more likely
- Poor workmanship will lower allowable water velocity

Erosion-Corrosion downstream of a joint, apparently due to turbulence at the joint.

Cavitation Erosion

- A phenomenon where high velocity induced vapour bubbles implode at metal surface and produce local deformation and material loss.

- Often can be confused with erosion – corrosion, but is slightly different.

Why Does it Seem that these Corrosion (Type 2) and/or Corrosion-Erosion Events have Increased Recently?

- Whilst obviously anecdotal, the best explanations are:
  - Higher temperatures used to maintain supply and avoid Legionnaires disease
  - The use of continuous recirculating systems where velocity is constant not intermittent

Velocity Issues

- Erosion – Corrosion occurs when water velocity is sufficient and sustained to disrupt copper oxide scale. This can be due to:
  - High average water velocity
  - Localised turbulence

Published Literature – Comprehensively reviewed by Dr Gates of UQMP

- Obrecht & Quill (1960)
- Lane et al (1971)
- Singley et al (1984)
- Cruse et al (1985)
- BS 6700 (1987)
- Polan & Ansuni (1992) – ASM Handbook
- Cohen (1993)
- Ferguson et al (1996)
- AS/NZS 3500.4 (2003)
- Cohen (2005)
- CDA (2006)

Summary Table

	< 25°C	?	25 –60°C	> 60°C	Hot Recirc
US-EPA 1984		1.2			
AWWA 1985	1.8		1.2 ?		0.5
BS6700 1987†	3.0		3.0	2.0–2.5	
ASM 1987/1992	No mention of velocity or temperature effects in potable water				
Cohen 1993‡	1.5		1.2		
AWWA 1996	1.8	1.2–1.8			0.5
AS3500.4 2003/2005		3.0			
ASM 2005	2.4		1.5	0.6–0.9	
US-CDA 2006	2.4		1.5	0.6–0.9	
PHCC NSPC 2006	+ve Scaling	<25°C, Non-Scaling			
PHCC NSPC 2006	2.4	1.2	1.5	0.6–0.9	0.6

Guidelines for Maximum Design Velocity (m/s) **at Temperature**

† **This table interpolates between the temperatures mentioned in BS6700 1987.**

‡ **For Cohen 1993, the table makes assumptions about the likely relationship between design velocity and critical velocity.**

Summary of Literature and Maximum Velocity Table

- Most authors and standards suggest maximum velocity of 2.4 m/s or less for cold water and 0.9 m/s for hot water >60ºc. Some suggest even lower velocities, down to 0.5 m/s.
- Exceptions are:
  - British Standard BS 6700 (1987 Edition) which allows 2.0-2.5 m/s for water >60ºC ; this standard has been revised several times and is now superseded by BS EN 806-5:2012. latter standard does not have provision for velocity constraints!
  - Australian Standard AS 3500.4 (2005) allows 3.0 m/s for any water temperature. This flow velocity has not been revised downward!

UK based Foundation of Water Research (FWR)

- Produced review of current knowledge in 2003 on copper corrosion in plumbing
- Specifically recommended maximum flow velocities of 2m/s in cold water and 0.5m/s in hot water systems.
- Paper peer reviewed and approved by Dr Nuttall for re-issue in 2010 while supported by European Copper Institute. Clearly, they believe a velocity constraint is required even if it is absent from BS EN 806-5!

Influence of Water Temperature

- It is clear that as temperatures rise above ambient allowable velocities reduce. Precise quantitative figures are not available.
- Dr Gates considers temperature a critical component of corrosion-erosion
- Nevertheless, most authorities and references (including CDA) show that above 60ºC velocities by consensus should be reduced to 0.9 m/s maximum.
- This applies to recirculating HWS where velocity is constant.
- Some references suggest even lower velocities are advisable (0.7 m/s)

Why Does Increased Temperature Reduce Copper Pipe Resistance to Erosion – Corrosion?

- Copper, although it generally has excellent corrosion resistance, is still a relatively soft metal.
- Protective oxide films on copper change composition at around 60^{o}C ($CU_2O \rightarrow CuO$)
- There is limited research on effects constant temperature and velocity as found in recirculating systems.

Why Does AS 3500 Have Unusually High Allowable Velocities?

- AS 3500 does not differentiate between hot and cold water. At time of formulation, hot water issues were not considered a problem.
- Recirculating system with constant high velocity were not common when AS 3500 was formulated
- Possibly influenced by BS 6700?
- However, AS 3500 is clearly out of step with most International standards and established sources.

Conclusions

- In continuous recirculating hot water systems with temperatures > 60ºC it is prudent to keep constant velocities below 0.7 m/s and certainly below 0.9 m/s, regardless of limits in AS/NZS 3500
- It is known and published that velocities should not exceed 0.5-0.9m/s in recirculating hot water systems
- Dr Gates investigated failures where velocity was ~1.5m/s, well below allowable 3m/s

There needs to be independent study of allowable maximum constant velocities with a view to reducing the present limits in AS/NZS 3500.4.

Recommendations

- Hydraulic design of copper recirculating systems should limit velocities to less than 0.9m/s maximum, with 0.7m/s being preferable.
- Excessive temperature should be avoided wherever possible.
- It is prudent not to mix copper and polypropylene pipe in the same recirculating system where temperatures exceed 60ºC and water velocities exceed best practice.

QUESTIONS????

COMMENTS????

Au Reservoir !

THE END