05

WSAA Materials Fact Sheet No. 05

Corrosion of Copper Pipe in Australian Drinking Waters

Introduction

More than 90% of all Australian buildings have a copper component within their plumbing system. In most cases the material provides a long lasting and trouble-free means of delivering clean and untainted drinking water. From time to time problems do occur with copper and the purpose of this Fact Sheet is to detail these issues, possible causes and potential remedies for existing pipe. Copper corrosion in its varied forms is extraordinarily complex and by no means have all the scientific issues been settled, the main problem being the isolated and seemingly random and sporadic nature of corrosion incidents. Nevertheless, extensive scientific research has helped to identify a number of factors that will assist in minimising the risk of corrosion of copper water pipes.

Copper Pipe

Although copper has been used as a plumbing material for over 3,500 years, it was only following the Second World War that with the introduction of thin-walled capillary pipe it became the default plumbing material. It has remained the pipe material of choice up until the early 1990's when plastic plumbing systems became more widely accepted, but copper still maintains an important part of the plumbing trade. Copper pipes are easy to fabricate, simple to join and have an extensive range of fittings. In comparison to the galvanised steel pipe they replaced, copper pipes don't rust and block up. However, no material is entirely problem free and the widespread use of copper pipe has paradoxically resulted in the relatively few failures becoming significant in their own right. The problems are made more difficult because of the extraordinarily complex and incompletely understood mechanisms by which copper corrodes. Some of the general and health issues for copper have been previously outlined in WSAA Drinking Water Fact Sheet No 10.

Corrosion Issues with Copper

There are four (4) main mechanisms through which a copper pipe can cause corrosion problems for consumers, although there are other rare forms of corrosion that may occasionally have an impact in specific cases such as air conditioning systems.

Blue Water

"Blue water", also described as "blue-green water" (BGW) is characterised by a blue-green colouration in the water when first drawn from a tap. The blue water is a result of a finely divided insoluble flocculent of copper corrosion products suspended in water. It is more frequently observed in pipes with patterns of low use. Often it will be visible when a tap is used after even a short period of stagnation.

Example of Blue Water

The colour of the water, which can vary from a pale blue through to dark green/blue, is characterised by settlement of the flocculent (particles) if the container is left to stand overnight. The type of corrosion products depend on the actual water composition, but are most likely to be copper hydroxides with some silicates and perhaps sulfates. Blue water is characterised by elevated levels of copper which often exceed the Australian Drinking Water Guidelines (ADWG) recommended limit of 2 mg/L. This limit is based on a lifetime consumption of water with this level of copper so only in rare circumstances does this represent a significant medical issue.

Blue water was first reported in New Zealand and the Hunter Region in the late 1960's and early 1970's. Today it is documented as a worldwide phenomenon occurring exclusively in cold, soft, poorly stabilised or of low buffering capacity waters. Not all copper pipes experience this problem; indeed the random and sporadic nature of occurrences is one of the reasons that identification of the causes becomes so difficult. Incidences can at times be seen to cluster around parts of the distribution system where residual disinfectant is low and pH is elevated, which provided a clue as to the prime cause of the problem.

Minimising 'Blue Water'

It has been demonstrated that flushing the system with hot water at temperatures >60^{o}C, followed by the disinfection of the water to provide a free chlorine or chloramine residual, will stop the appearance of blue water in nearly all cases. However, if the residual disinfection is not maintained, the blue water will return.

In the absence of a chlorine residual, bicarbonate dosing appears to inhibit corrosion product release, as an increase in alkalinity helps reduce acidic conditions at the pipe surface but possibly not the corrosion itself.

It is important to understand that other types of corrosion, including pitting, may still be taking place despite the absence of blue water.

Research evidence is now clear, at least in Australasia, that the release of copper corrosion products to form blue water and possibly the corrosion itself is due to microbial activity interacting with the copper pipe. The evidence for microbiologically influenced corrosion (MIC) includes:

- absence of blue water at temperatures >60^{o}C
- absent or lowered rates of blue water in the presence of free chlorine and chloramine
- As the corrosion products often appear in a non- uniform manner on the pipe surface, this also suggests differences in the internal surface of the pipe may play a part.

Work recently concluded by the CSIRO and others show that "Blue water", or BGW, is fundamentally due to MIC.

These research results do offer potential remediation measures. Changes in water chemistry and disinfection are one possibility, and this has actively occurred in the Water Industry since the mid-1980's with lime/carbon dioxide water stabilisation being introduced to combat very soft waters together with increased effectiveness of disinfection systems.

WSAA and the Copper Development Centre have supported research on the remediation of domestic and commercial copper plumbing systems to minimise the likelihood of blue water formation. Apart from the need to maintain proper disinfection regimes within the water distribution network, the work also recognised the need to improve cleanliness of pipe surfaces from residual drawing lubricant and the real importance of using clean water when copper plumbing systems are first charged. This has led to amendments to the copper pipe Standard, AS 1432 and the introduction of a new installation

Standard, AS 4809-2003It should be noted that the remedial measures detailed above have led over the past decade or so to a very large reduction in the reported incidents of "Blue water' within Australia.

Pitting Corrosion

Cold water pitting corrosion is a far more destructive form of corrosion that often results in the perforation of the pipe wall with a corresponding leak. Pitting can share many attributes with "blue water" and often, but not always, occurs in conjunction with it. Pitting was generally far less prevalent than "blue water", but since the virtual elimination of the latter issue in municipal water supplies this is no longer the case. While pitting can also occur in hot water, it is most common in cold, soft waters of neutral to slightly alkaline pH. As with blue water, pitting in soft waters is recognised as a worldwide problem, which also occurs in a sporadic and random pattern, sometimes in clusters at the extremities of water distribution systems, which does tend to endorse the idea that both pitting and "blue water" have a common cause through an association with MIC.

However, in North American and some European waters of quite different water composition, cold water pitting has different causes some of which continue to be poorly understood.

Minimising 'Pitting'

The results of recent research have proposed a mechanism for soft water pitting, which emphasises the role of the formation of a stable oxide film if pitting is to be avoided.

Internal pitting of copper pipe surface

As with blue water, avoidance can be accomplished by increasing the buffering capacity of the water through calcium bicarbonate additions, and this measure has been practiced both in Australia and overseas for some time. The actual benefits are hard to quantify. The average time to perforation of an actively pitting pipe is 11 years, and can be as long as 25 years – or as short as one year. Nevertheless, increasing the buffering capacity is at least partially effective and represents one of very few bulk water treatment options available.

Unlike blue water there is no evidence that a free residual disinfectant will either prevent or stop pitting corrosion once the pitting has started, but probably pays a pivotal role in the initiation stages as is the case for "blue water". It should be noted that the total reported incidents of pitting corrosion in the major urban utilities has also decreased over the last decade

The WSAA initiative on the copper pipe standards and installation codes is aimed at reducing the risk of both pitting and blue water corrosion. This approach is especially important to avoid pitting corrosion, where remedial measures, once a pit is actively growing and close to perforation, are unlikely to be effective with replacement often the only viable option.

Erosion-Corrosion

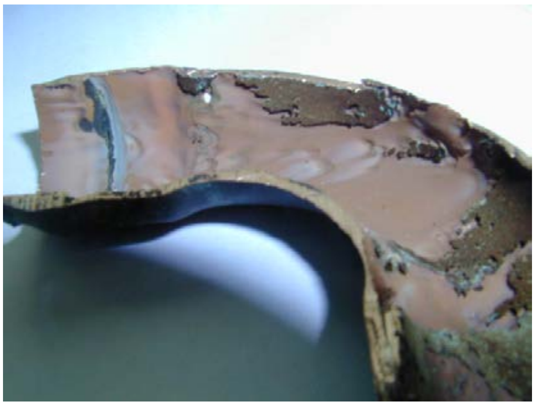
Erosion-corrosion is a rare form of failure that can occur in both hot and cold copper water pipes, although it is more often observed in hot waters. Erosion-corrosion can be identified by the presence of smooth grooves, gullies, waves or rounded holes on the inside of the pipe that usually exhibit a directional pattern. Often there are horseshoe shaped pits with the closed ends facing upstream. Failure can occur relatively quickly.

Factors that can contribute to this type of corrosion are:

- Piping design—excessive velocity can cause erosion-corrosion. Pipes and pumps should be sized to ensure water velocity does not exceed 3 m/s, although for recirculating hot water systems (RHWS) it should be less than 1 metre/second. Sharp changes in direction, burrs inside joints and dents in the wall can contribute to this type of corrosion.
    - Temperature. In RHWS temperatures should be less than 65^{o}C. Note that in Australia, there is a tendency to run RHWS very hot in relation to the

operating temperatures used in most other countries. This is an attempt to avoid legionnaire's disease, but the net effect is to increase the likelihood of adverse corrosion issues within copper pipe systems. The bacteria responsible for legionnaire's disease thrive on water temperatures below 50°C but are unlikely to be an issue at temperatures above 55°C.

- Dissolved gases— entrained air and high levels of carbon dioxide in the water can cause erosion-corrosion as they continually break down the normal protective films formed inside copper pipes. A similar process can occur if air is drawn into water through pumps and valves.
- Particulate matter—sand, grit or other debris carried in copper pipe can also break down protective films.



Typical erosion-corrosion of copper pipe

Cuprosolvency

Cuprosolvency generally involves a slow rate of uniform corrosion. The rate of corrosion is so small that the affected pipe will not physically fail in its normal lifetime. Cuprosolvency is recognised by the blue staining of baths, hand basins and tile grouts. It is often associated with a dripping tap or a particular soap that can react with low levels of copper. It is characterised by slightly elevated levels of dissolved copper that can occasionally exceed the Australian Drinking Water Guidelines (ADWG) recommended maximum limit of 2mg/L. There is no discernible change to the colour of the water where cuprosolvency is present. Cuprosolvency is more prevalent when new copper pipes are exposed to relatively hard waters with a high proportion of bicarbonate or in waters with low pH < 7.0. In these harder waters the problem usually abates in a year or two. In some cases blue staining has been overcome by:

- regular flushing;
- using a liquid soap instead of cake soap.

Problems with cuprosolvency may persist where water softeners are used.

Facts and Fantasies

There was a considerable program of research, largely sponsored by WSAA and individually by some of its members, has produced a far clearer picture of the causes of blue water and pitting corrosion than was available even a few years ago. We are now in a position to list some of the factors known to promote these phenomena, and equally importantly, some of those that don't. Here are just a few:

Fluoride—Work carried out by Hunter Water Corporation over two decades ago has shown that fluoridation of water supplies has no influence.

Water usage patterns – Blue green water and cuprosolvency effects can be enhanced where properties or parts of a household or commercial plumbing system have areas of low use or extended periods of stagnation.

Stray electric current—frequently quoted as a cause of corrosion. While currents *do* run along the external surfaces of pipework with an electrical system earthed via copper water pipe, this is unlikely to cause blue water or pitting corrosion on the internal surfaces of pipes. Although outside the scope of this fact sheet, electrical earthing on pipework, particularly at metering points, is an important issue with relation to avoiding maintenance personnel electrocution.

The copper itself—the copper used for making copper water pipes is virtually pure copper. It has a minimum copper content of 99.90%. Small amounts of phosphorus in the range of 0.015 – 0.04% are added in the manufacturing process as a deoxidant. The same material is used worldwide for copper water pipe.

Water temperature—blue water never occurs once the temperature of the water is above about 60°C. Pitting can occur in hot water but it is relatively uncommon, although recently there have been cases of hot water pitting (termed Type 2 pitting in the literature) in RHWS with high operating temperatures.

Copper pipe surface condition—the internal surface condition of copper pipe may have an effect on the formation of blue water. There is evidence that residual lubricant used in the manufacture of the pipe (often referred to as carbon films) may initiate some form of cold water pitting corrosion and blue water formation. The formation of these films is more likely in the annealed and bendable grades of copper pipe. Careful interpretation is needed as blue water and pitting corrosion are known to occur on clean surfaces with no carbon films. Nevertheless a research program in cooperation with the pipe manufacturers is being carried out to better understand this issue.

Water chemistry—a fairly wide range of soft waters can experience blue water, although a pH range of 9–9.5 and an absence of residual disinfectant is a worst case scenario. Alkalinity is known to be a factor, and dosing calcium bicarbonate to improve the buffering capacity of the water and restrict pH fluctuation (and hence corrosion) at the pipe surface is one of the few bulk water corrosion inhibition measures that can be safely taken by water supply authorities. However, too much bicarbonate can be counter-productive and treatments need to be carefully designed and controlled. In some cases it may be necessary to chlorinate or chloraminate water in addition to bicarbonate dosing. The optimum range of pH for waters is dependent on the overall water characteristics but as a general rule of thumb, pH in the range of 7.4 to 8.3 is considered preferable.

Rainwater – A Special Case

Rainwater is collected and widely used in regions without municipal water supplies, but is becoming increasingly popular in urban areas. While this is not necessarily a concern for WSAA members it is appropriate to mention the effects of rainwater on copper pipes. Rainwater is characterised by low pH of 5–6. Depending on the collection and storage materials the pH and microbiological quality can change considerably by the time the water enters the plumbing system. There have been documented incidences of pitting corrosion and cuprosolvency of copper by rainwater stored in concrete or polyethylene tanks, and the majority of "blue water" and cold water pitting incidents now seem to come from tank water supplies. See also WSAA Materials Fact Sheet 4.

Alternative Materials

WSAA Materials Fact Sheet 6 gives advice on a range of alternative plumbing materials that can be used instead of copper. There is no such thing as an ideal plumbing pipe and all the alternative metal and plastic pipes have both their advantages and limitations.

References

- Taylor R, O'Halloran R, Smith F, Goodman N, Jaeger H. 'The effectiveness of Bicarbonate dosing as a preventative / remedy for Copper Corrosion. Report CMST-C-C-2000-28 CSIRO, March 2001.
- Bell GEC, Duranceau SJ, 'Effect of grounding and electrical properties on water quality'. Journal AWWA May 2002.
- Harrison, D H, Nicholas D M and Evans GM 'Pitting corrosion of copper pipes in soft drinking waters – corrosion mechanism' JAWWA 2001.
- Harrison, D H 'Pitting of copper in potable waters' PhD Thesis, University of Newcastle, 2001.
- Nicholas, D M and Carlyle, G "Management of 'blue water' issues – the Evans Head experience' ACA Conference '99, Sydney, 1999.
- RJ Taylor, R J O'Halloran, F L Smith, N B Goodman, and H Jaeger, "Blue-Green Water - Investigations undertaken by CSIRO for City West Water. Stage 2 Research", Consultancy Report CMST-C-C-2000-42, January 2001.
- R J Taylor, R.J O'Halloran, F L Smith, N B Goodman and H Jaeger, "The effectiveness of bicarbonate dosing as a preventive/remedy for copper corrosion", Report CMST-C-C-2000-28, August 2000.
- R J O'Halloran, P L Larkins, F L Smith and N B Goodman, "Investigation of the role of microbial influenced corrosion on 'bluewater' copper corrosion in Australian potable waters: Stage 1 Report and Recommendations to WSAA", March 2000.
- R J Taylor, R J O'Halloran, B A Sexton and F L Smith, "Blue-greenwater - Investigations undertaken by CSIRO for City West Water. Stage 1Report", Consultancy Report CMST-C-C-98-21 August 1998.
- D.M. Nicholas, "Corrosion of copper in Australasian drinking waters; a review. ACA Conference, Darwin, 2014.
- WSAA Drinking Water Fact Sheet No 10 'Copper'.

- WSAA Materials Fact Sheet No 6 'Domestic Pipe Materials'.
- WSAA Materials Fact Sheet No 4 'Materials For Rainwater Collection'.

Useful Websites

www.copper.org

Disclaimer

This Fact Sheet is produced by the Water Services Association of Australia Limited ("WSAA") for use by members of WSAA. This Fact Sheet is intended to provide general information in relation to its subject matter and includes information obtained from a number of sources.

Over time, changes in industry standards and legislative requirements, as well as technical advances and other developments or factors relevant to the information contained in this Fact Sheet, may have affected the accuracy of that information. Accordingly caution should be exercised in relation to the use of the information in this Fact Sheet.

Any views expressed do not represent the views or policy of WSAA, or any member of WSAA. No responsibility is accepted by WSAA, the editor, author, individual contributors or the suppliers of information, for the accuracy of any information contained in this Fact Sheet or the consequences of any person relying upon any information.

Copyright