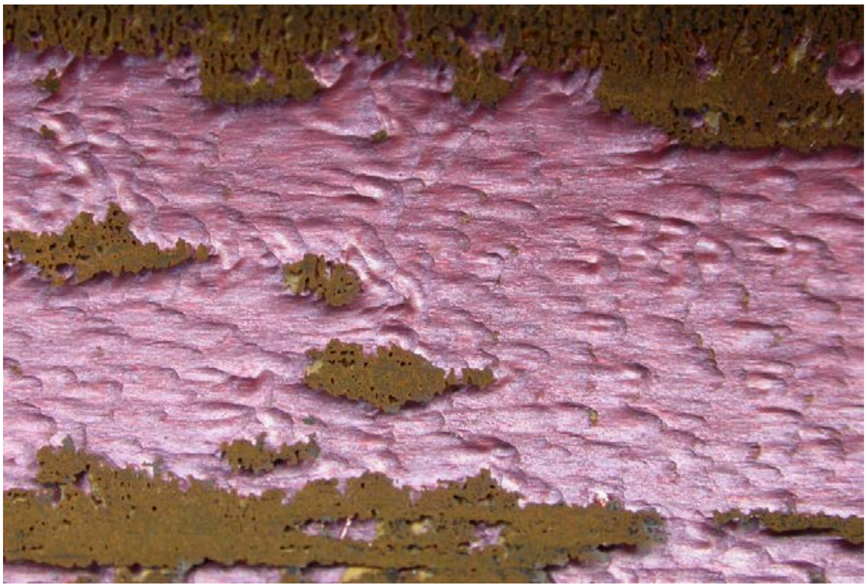
NICHOLAS CORROSION PTY LTD

THE EFFECTS OF TEMPERATURE AND VELOCITY ON THE DEGRADATION OF COPPER PIPES IN RECIRCULATING HOT WATER SYSTEMS

Report Prepared for The Institute of Plumbing Australia

April, 2015



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EXECUTIVE SUMMARY

The Institute of Plumbing Australia Inc. (IPA) has requested Nicholas Corrosion Pty Ltd to prepare a short report detailing the effects of both velocity and temperature on the degradation of copper piping when used in various hot water recirculating systems within Australia.

An examination of both the local and international Literature and current world-wide hydraulic practice has shown that when copper pipe is exposed to both excessive high velocities and high temperatures, damage through a corrosion/erosion or cavitation mechanism is probable. To mitigate against this degradation phenomena, best international practice strongly indicates that:

- Velocity should be restrained to below 0.9 metres/second , and
- Temperature should ideally be at or below 60ºC

Anecdotal evidence suggests that currently in Australia these conditions are regularly exceeded, with the outcome that premature failure of hot water recirculating systems is more prevalent here than elsewhere.

1. INTRODUCTION

The Institute of Plumbing Australia Incorporated has requested David Nicholas of Nicholas Corrosion Pty Ltd to carry out a brief review of the current understanding of the phenomena of corrosion/erosion and cavitation of copper pipe used in recirculating hot water systems. Although the theoretical aspects of these phenomena are moderately well-understood, the quantitative effects of temperature and water velocity appear not to be fully appreciated.

Whilst the use of copper as a water pipe famously extends back to King Tutankhamen in Egypt circa 1500 BCE, the cost of copper excluded it as a common plumbing pipe material in Australia until the widespread introduction of thin walled capillary tubing after the Second World War. With advantages of easy joining and perceived longevity, copper piping rapidly became the default plumbing tube, superseding the older hot dipped galvanised (HDG) pipe. Copper has in general performed extremely well as a plumbing pipe but, as with all materials, has experienced some failures. Recently, the various cuprosolvency, cold and hot water pitting and “Blue Water” issues that have occurred since the 1960’s have been reviewed (Nicholas, 2014)

Although copper has lost some of its market dominance in the last decade or so, being replaced by polymer materials such as cross-linked polyethylene (PE), this has occurred on an installed cost basis rather than any perception of general susceptibility to corrosion. Indeed, for cold water pitting and “Blue Water” in particular, over three decades of international research largely funded by both the copper industry and Australian water utilities has identified causes and remedies for most of these complex corrosion issues. An agreed water industry consensus is that copper use in *non-recirculatory* plumbing systems at velocities up to 3 metres/second velocities and temperatures up to 70^{o}C, appears to have performed satisfactorily, although quantitative evidence is lacking.

However, the situation for recirculating hot water systems, which have become the normal method of distributing hot water in large commercial buildings such as hotels and apartment complexes, is equally not considered satisfactory by many stake holders. The problems are based on the premature failure of a number of copper based recirculating hot water systems (RHWS) through corrosion/erosion or cavitation mechanisms. The purpose of this paper is to address the scientific and engineering issues relevant to these failures, which anecdotally appear to be far more prevalent in Australia than elsewhere in the World, and in particular to emphasis and quantify the effects of temperature as well as velocity on the incidence of these pipe failures.

It is worthwhile to briefly list a number of frequently raised issues that have no scientific basis and have no effect whatsoever on the internal degradation of copper tubes (Michels, 2002);

- Electrolysis
- Electrical grounding of MEN and other types of electrical systems.
- Solar flares and sunspots or interstellar radiation.
- Cheap or inferior imported copper pipes.

Note that this paper is restricted to the degradation of copper pipe in RHWS only; any collateral damage to other materials in the system such as stainless steel or polypropylene random (PPr) caused by copper ions present in the recirculating system is not included in the discussion.

2. HOT WATER PITTING

Also known as “Type 2 pitting” after Lucey’s original description (Lucey, 1967) this is a distinctive form of attack on copper which, although unrelated to velocity, is highly dependent on temperature and pH of the water supply. The present author has also observed this type of hot water pitting in recirculating hot water systems (Nicholas, 2014), which shows that corrosion/erosion is not the only degradation mechanism that can occur in RHWS, although the latter is the most prevalent. Thus, a brief description of hot water pitting is included here for completeness.

In Australia, hot water pitting was reported from Perth in the 1970’s and some theoretical modelling was carried out on this subject (Adeloju and Hughes, 1986) which showed that potential-pH (Pourbaix) diagrams in Perth water supply predict the formation of cupric oxide (Cu_2O), rather than copper carbonate above $50^{o}C$, thus leading to the formation of coarse copper oxide crystals – cuprite - which have been previously identified with cold water pitting corrosion (Harrison et al, 2004).

Some support for the deleterious influence of cupric oxide was found in recent cases involving a specific Queensland HWS manufacturer claiming that local soft water compositions with relatively, but still well-above minimum Australian drinking Water Guideline (ADWG), low pH values was responsible for pitting failure in the copper piping coils within their recuperative HWS. It was shown (Reynolds, 2007) that the principal problem was brazing techniques used by the manufacturer which favoured the formation of cuprite in the heat effected zones (HAZ). Changes in brazing technique using nitrogen gas purging avoided the formation of cuprite and thus removed the primary cause of failure. Nevertheless, it can be seen that copper is sensitive to elevated temperature issues if the metallurgical conditions in fabrication are not carefully controlled.

Figure 1: Typical Type 2 pitting corrosion product appearance on pipe experiencing hot water pitting corrosion. (Author’s collection)

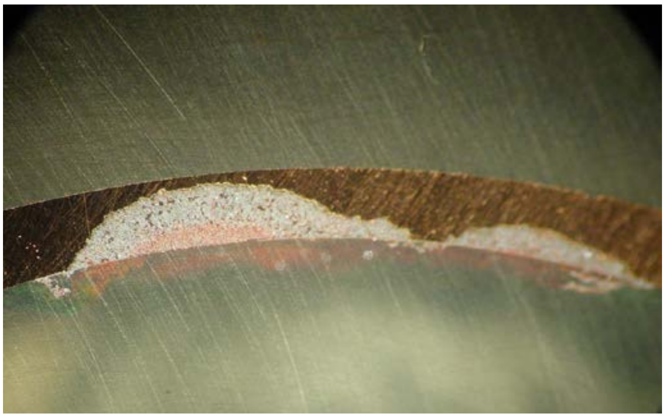

Figure 2: Cross-section of pit from under mound shown above in figure 2.

The photos of Type 2 pitting shown above in Figures 1 and 2 were taken from a RHWS in the Hunter region of NSW, where waters of pH below 7.4 and temperatures considerably in excess of 60oC were experienced leading to multiple pipe failure. In Sweden (Mattsson and Fredericksson, 1968) ratios of bicarbonate to sulphate of less than unity were blamed for this phenomena, but this has not been observed in Australia where temperature appears the main culprit. RHWS in Australia are known to be run at very high temperatures to avoid issues with Legionnaire's disease, but this can lead to issues both with the Type 2 pitting described here and corrosion/erosion of copper which is the main focus of this paper.

3. CORROSION / EROSION

3.1 GENERAL DESCRIPTION

Corrosion/Erosion of copper pipes – also described as "Impingement corrosion" in the literature (AWWARF, 1987) - is one of the more readily identifiable forms of corrosion and in appearance is quite different from hot water pitting described in the previous section. Corrosion/Erosion is normally quite independent of the basic composition of the water and thus can occur in all water types, both hard and soft. However, entrapped gases such as carbon dioxide or entrained sand particles can accelerate the effects of velocity.

Gates (2012) has described the key components of Corrosion/Erosion as follows;

- The normal formation of corrosion products (scale) on the copper pipe surface on coming into contact with water. This scale, normally composed of oxides, carbonates and sulphates, is dependent on local water composition.
- Excessive velocity of the water dislodges portions of the protective scale exposing areas of bare copper metal.
- The protective oxide scale is cathodic to the anodic metal and this galvanic couple thus leads to rapid corrosion of the bare metal component.
- Continuing high flow rates leads to further stripping of protective scales and a cycle of repeated corrosion/erosion.

- Unlike pitting corrosion, corrosion/erosion can materially increase the amount of copper ions in solution within a RHWS.

Typically, the appearance of copper pipe surfaces exposed to corrosion/erosion can be unambiguously identified, with horseshoe shaped pits with their open ends facing downstream (Gates, 2012, Nicholas, 2014, Metals Handbook, 1987). Typical photographs of corrosion/erosion are shown below in Figures 3 – 5;

Figure 3: Typical ‘scalloped ‘surface of copper pipe suffering corrosion/erosion. Note islands of scale between clean copper pits. Direction of flow is from right to left. (Gates, 2012)

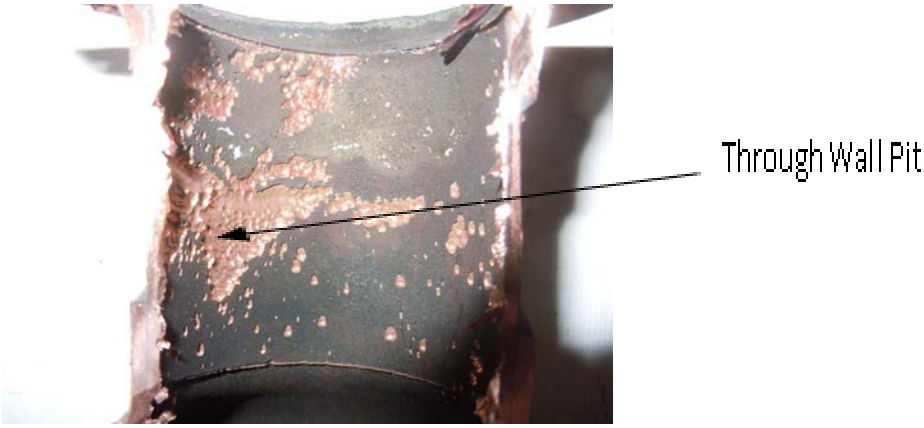

Figure 4: ‘Scalloped’ surface of copper pipe with perforation of the pipe (Nicholas, 2014)

Figure 5: Deeply 'scalloped' pipe surface, typically near pipe joint.(Nicholas, courtesy of G. Moore, 2014)

Conditions during Corrosion/Erosion of copper including high water velocity, high temperature and turbulent flow can induce **cavitation,** a sub-set of corrosion/erosion. This ccritical flow-induced failure mechanism being vaprous cavitation, which itself is a property of the fluid, not the metal surface (Gates, 2012). Vaprous cavitation is the implosion of formed water vapour bubbles which can produce enormous pressures of 10,000 atmospheres or more which can quickly and severely damage a relatively soft metal such as copper.

It should also be noted that good design and workmanship is essential to avoid protusions, abrupt changes of section and other fabrication issues that contribute to both corrosion/erosion and cavitation. (Gates, 2012, CDA, 2015, AWWARF 1987)

3.2 SPECIFIC EFFECTS OF TEMPERATURE AND VELOCITY

There have been few specific studies on the effects of temperature on Corrosion/Erosion of copper in RHWS, although all agencies seem to agree that a limit of 60^{o}C is desirable. (Gates, 2012).

Myers and Kireta (2001) point out that black cupric oxide (CuO) forms on copper pipe at temperatures above 70^{0}C rather than cuprous oxide (Cu_2O) and apparently this is less resistant to corrosion/erosion than the cuprous version. The theoretical study by Adeloju and Hughes (1986) confirms that theoretical Pourbaix diagram studies shows that there is a change from sulphate and carbonate species to oxides above 60^{0} C. The predominance of CuO at elevated temperatures is shown by a comprehensive theoretical study of Pourbaix diagrams at elevated temperatures by Beverskog and Puigdomenech (1995).

Actual practical quantitative measurement of the effects of temperature is rare, but some studies do exist and the principal study is shown below in Figure 6.

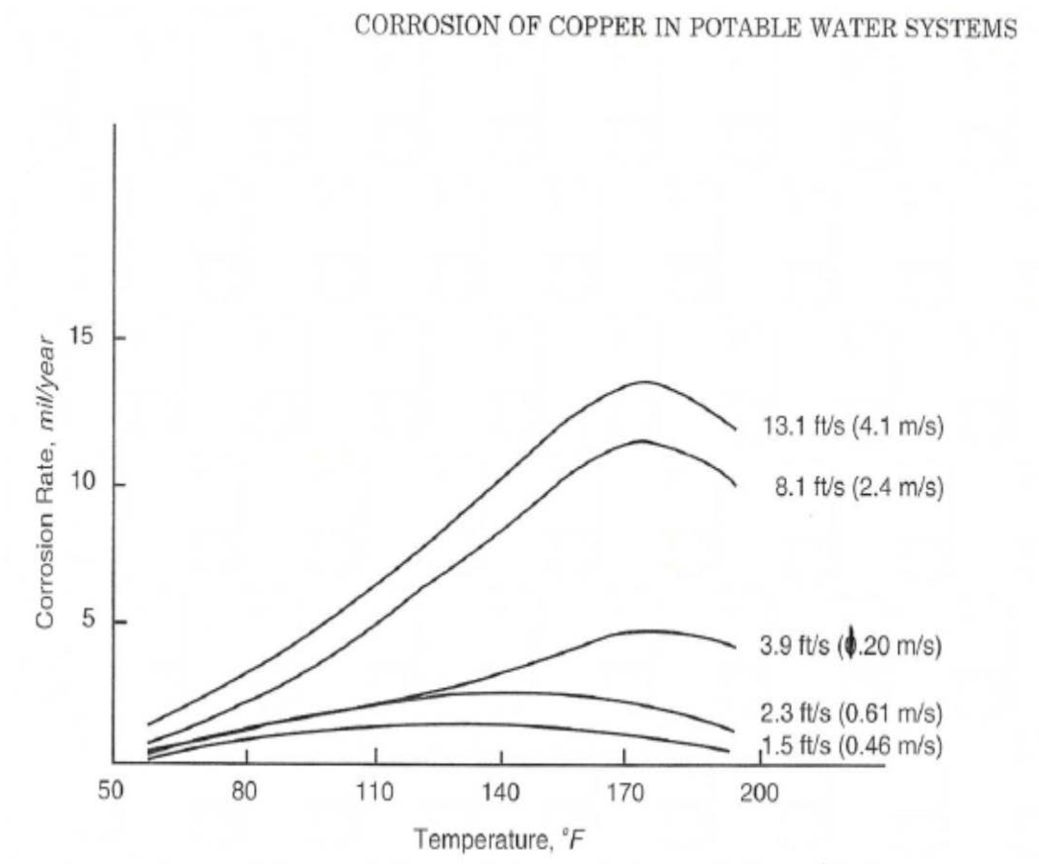

Figure 6: Corrosion rate vs temperature for a series of water velocities (AWWARF, 1985 quoting Obrecht and Quill, 1960). **Note;** The hand correction by Author as original graph incorrectly stated that 3.9ft/second was 0.2 metres/second, rather than 1.2 metres/second.

Figure 6 provides a very general statement of the effects of temperature but does strongly suggest that corrosion rates rise sharply when velocities increase to 1.2 metres /second. It also suggests that a maximum corrosion rate is found at approximately 180 °F which translates to about 80°C. As will be outlined in Section 4 of this paper, the consensus of the literature and publications by the various Copper Development Associations (CDA) unequivocally suggest velocities below 0.9 metres/second and temperatures at or below 60°C are required to avoid corrosion/erosion.

4. CURRENT RESTRICTIONS ON TEMPERATURE AND VELOCITY SET BY INTERNATIONAL AGENCIES

A number of authors have previously addressed the issue of maximum velocities and, to a lesser extent, temperatures in an effort to minimise degradation of copper pipe in recirculating hot water systems (RHWS). These have been extensively reviewed by Gates (2012) in his recent report. Coyne (2009), when describing vaprous cavitation recommended maximum velocities of about 2 metres/second at *ambient* temperatures, but did not address elevated temperatures. However, as long ago as 1987 (AWWARF, 1987) it was stated that in RHWS velocities should be restricted to 1.5 fps which is about 0.5 metres/second. They quote Landgrebe (1980) in saying this limit “seems to be safe”, but do say this limit is slightly below values given in the international literature.

It is worthwhile reiterating the maximum velocities and temperatures that are recommended in the various North American and European Copper Development Associations (CDA) and other relevant organisations that are freely available in the literature or website.

- **Canadian Copper & Brass Development Association(CCBDA) Publication IS 97-02**

  This document recommends that temperature should be ideally below 60^0C and velocities below 5 fps (1.5 metres/second), but for temperatures *above* 60^0C the maximum velocity should be reduced to between 0.9 and 1.2 metres/second.

- **Copper Development Association (CDA) Publication "What is most important when designing and installing copper piping systems", (2015)**

  Under Section 2 of this web- based document 'Water at high velocity', the recommended velocity for copper pipe is 2-3 fps (**0.7 to 1.0 metres/second)** for all temperatures above 60^0C. It is also noted in Section 5 that heating the water above 60^0C can accelerate the process of corrosion/erosion. The document also emphasises the need for good design and proper fabrication practices.

- **"Overcoming corrosion concerns in copper tube systems"(Cohen and Myers, 1996)**

  This paper deals generally with a number of copper corrosion issues but specifically addresses temperature and velocity issues under the heading 'System design and operation' and reaffirms that copper pipe systems can safely operate at temperatures up to 60 C and velocities up to 1.2 to 1.5 metres/second, but implies copper is not an appropriate material above those limits. They suggest a cupronickel material as a substitute and this is confirmed by others (Myers and Kireta, 2001), who suggest cupronickels (Alloy C70600), are appropriate when velocities are required to exceed 1.2 metres/second.

- **Causes of copper corrosion in plumbing systems, (Oliphant, 2010)**

  A practical review by the UK- based Foundation of Water Research (FWR), this document explicitly addresses Corrosion/erosion in part 2.1. To avoid corrosion/erosion incidents, the Author suggest good plumbing design and **restricting velocity to 2 metres/second in cold water and 0.5 metres/second in** hot water. Temperature is not addressed in this document.

- **NIBCO "Ahead of the Flow"**

  A commercial document produced by a USA supplier of valves, pumps and copper fittings it nevertheless contains a short summary entitled 'What makes a plumbing system fail?' It specifically states that the copper plumbing industry recommends a maximum velocity of **0.6 to 0.9 metres/second** for hot water systems operating above 60^0 C.

- **CDA, The Copper Tube Handbook. Document A4015-04/06.**

  Page 11 of the handbook from the CDA, New York reiterates the recommendation that for water temperatures 'routinely' above 60^0C, velocities should be restricted to **0.6 to 0.9 metres/second.**

5. CONCLUSIONS

Erosion/Corrosion, (impingement) degradation, including cavitation, is a flow-induced phenomenon which has been relatively well-understood at a practical level for some decades. The influence of poor design and fabrication, excessive velocities and high temperature are consistently reported in the literature even if specific research on temperature is restricted to the Obrecht and Quill paper (1960) referenced in section 3.2 of this paper. The consensus of both researchers, and various Plumbing Industry bodies is clear and can be summarised thus;

(a) The water temperature of recirculating hot water systems (RHWS) should be restricted to **60^0C.**

(b) Water flow velocities for RHWS should be in the range **0.6 to 0.9 metres/second**.

It is recognised that the current provisions of AS 3500.4: 2003, Section 4.14.1 specifically does not address recirculatory systems. Nevertheless, the limit on non-recirculatory of 3 metres/second has been used in the past as a 'de facto' limit. Although outside the brief of this present paper, it is understood limits for RHWS are under revision. It is important that the weight of evidence on overseas practice with regard to the correct limits is fully appreciated by all sections of the Plumbing Industry. Otherwise, failure of copper RHWS will continue to occur.

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