BUILDING WATER SERVICES

A Seminar to look beyond minimum standards

Perth, Western Australia – 28 February 2018

2 of 3 - Copy of Slides provided by Second Speaker:

Guest Speaker: James Paschal **P.E., LEED AP – Chief Technology Officer for Aquatherm in North America**

Mr. Paschal received his BS in Aerospace Engineering from Iowa State University, and MSE in Plastics Engineering from the University of Michigan. He is a registered professional engineer, LEED accredited professional, and certified manager of quality/organizational excellence. He has over 30 years of experience in the plastic piping industry, including 14 years with NSF conducting research, testing and certification of materials and piping systems, failure analysis, and development and verification of manufacturer quality assurance programs. He then spent five years as Principal Engineer with Bodycote Materials Group (now Exova) conducting research, failure analysis and forensic engineering related to plastic piping systems.

Mr. Paschal then spent 10 as the President and Principal Engineer for Paschal Engineering & Forensic Consulting providing consulting services in the areas of piping system design, applications development, materials processing, quality assurance, failure analysis and litigation support. During this time, he worked extensively with polypropylene piping systems, creating standards, developing code requirements, and providing technical support as these products were introduced in North America.

There is no Audio available and the following slides are provided for information only and as a memory jogger for those who attended. Further Seminars will be held during 2018 in different parts of Australia.

DESIGN CONSIDERATIONS WHEN USING PP-R IN CHLORINATED HOT WATER SYSTEMS

Integration of other systems or components with PP-R piping

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Topics

- Temperature
  - Strength vs. temperature
  - Sources of excessive temperature
    - Pump deadheading
    - Boiler malfunction (**NA Tech Bulletin**)
    - Tests, limits and allowances, ratings
    - Operator
- Pressure
  - Return to strength vs. temperature relationship
  - Water hammer, pressure surge and low pressure, transient
  - Cavitation (**Australia TechNews No. 1 & 2, 2017**)
- Flow
  - Hydraulic balancing
  - Velocity in copper must account for temperature, water conditions
- Water Chemistry
  - Oxidation, pH, ORP
    - Copper, steel, plastics
  - Sources of oxidizing chemicals
  - Accelerating effects of temperature, catalysts
  - Mixed systems, copper & PP-R (**NA Tech Bulletin, NA Webinar**)
    - Plastics Pipe Institute (PPI, plasticpipe.org)
  - Chlorine tests, ratings and requirements
- Pipe supports
  - Proper clamps
  - Seismic bracketing, spacing
  - Remember strength vs. temperature
- PP-R, PP-RCT handbook (PPI project)
- Using IoT (Internet of Things) to protect your building

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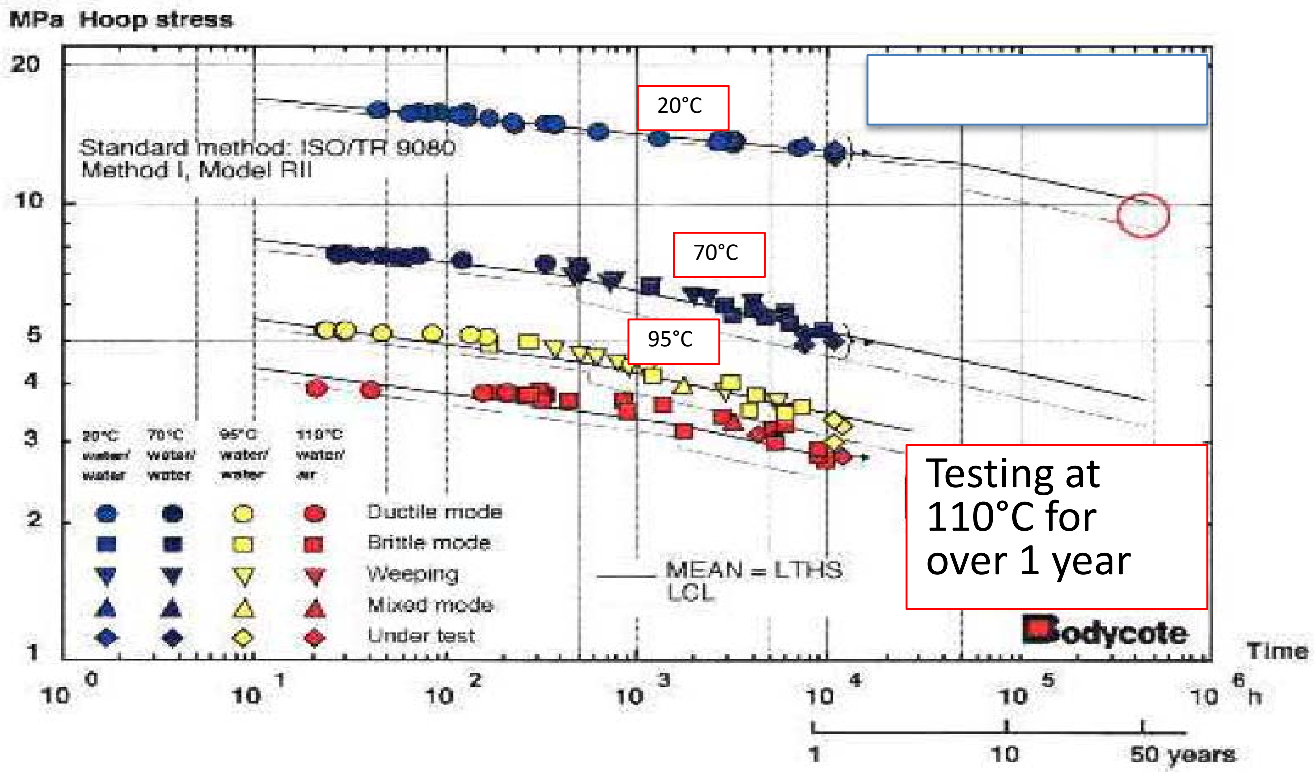
Temperature

- Strength vs. temperature
- As temperature increases, long-term strength decreases



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Temperature

- Sources of excessive temperature
  - Pump deadheading (operating with little or no flow)
  - Temperature rise =
    (5.1 x Pump HP) / (Vol x spec. heat x spec. gravity)
  - Assume 20 HP pump, 10 meters of 125mm pipe
  - Temperature rise = 2.6°C/min, or 157°C/hr
  - After 2 hours, temperature would exceed ~300°C, and internal pressure would exceed ~4000 kPa!

Duty Pump with 'Remains' of Standby Pump

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Temperature

- Sources of excessive temperature
  - Pump deadheading (operating with little or no flow)
  - PP-R piping, pipe rupture, significantly less system damage

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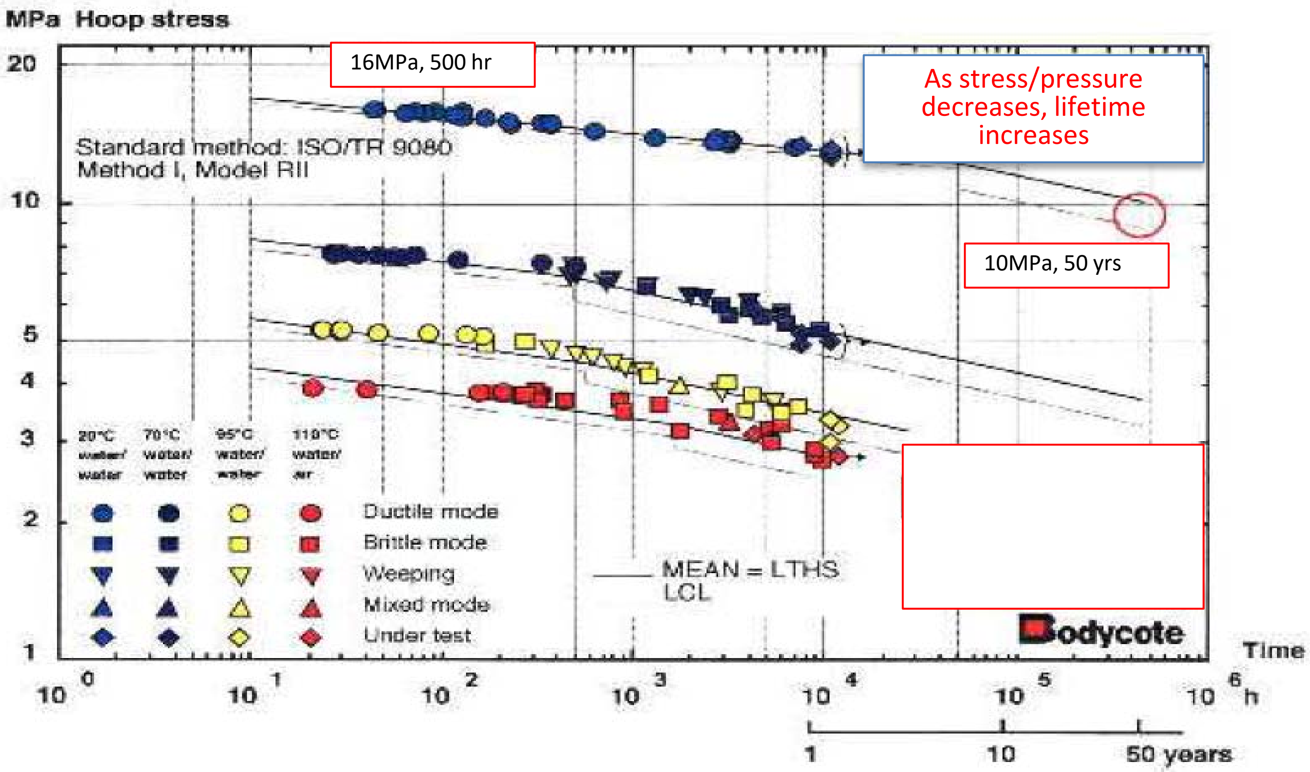
Temperature

- Sources of excessive temperature
  - Boiler malfunction (**NA Tech Bulletin**)
  - Tests, limits and allowances, ratings
    - Tested at 110°C for > 1 year
    - Pressure ratings include 100 hr @ 100°C (Application Class 5)

  - Operator/User
    - Complaints of lack of hot water
    - Typically due to improper flow balancing or maintenance issue
    - Response is often to increase boiler temperature rather than address root cause
    - Hot water disinfection temperature maintained for extended period rather than recommended 1 hr / day

Pressure

- Strength vs. temperature
- As stress (pressure) increases, expected lifetime decreases (at constant temperature)
- As temperature increases, long-term strength decreases



Pressure

- Pressure surge, water hammer
- Sources:
  - Quick-closing valves;
  - Pump shut-off, start-up if not controlled
  - Sudden demand from nearby buildings
  - Air in pipelines can substantially magnify the pressure surge effects
- Surge pressure (high pressure)
  - Allowance in design, standards
    - Pressure rating + 50% for recurring surge (ie pump start/stop, control valves)
    - Pressure rating + 100% for occasional surge
  - Magnitude
    - Function of <u>velocity change </u>and <u>pipe material</u>:

$$P_{surge} = a \bullet \rho \left(\frac{\Delta v}{144\ g} \right)$$

    - For 1 m/s velocity change:
      - Copper surge pressure = 1260 kPa, Steel = 1400 kPa, PP-R = 550 kPa

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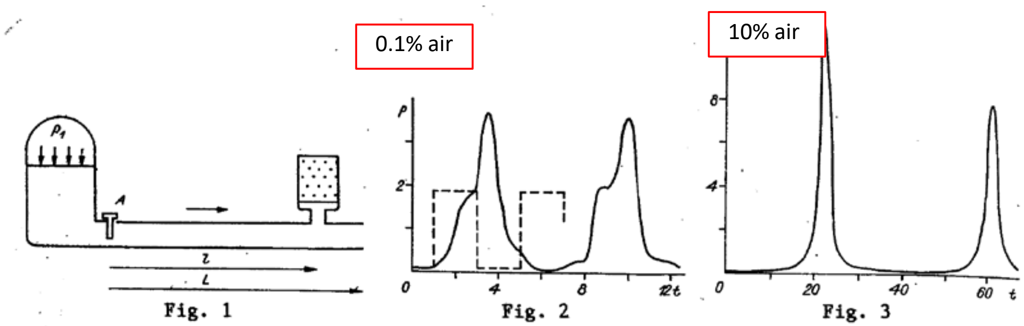
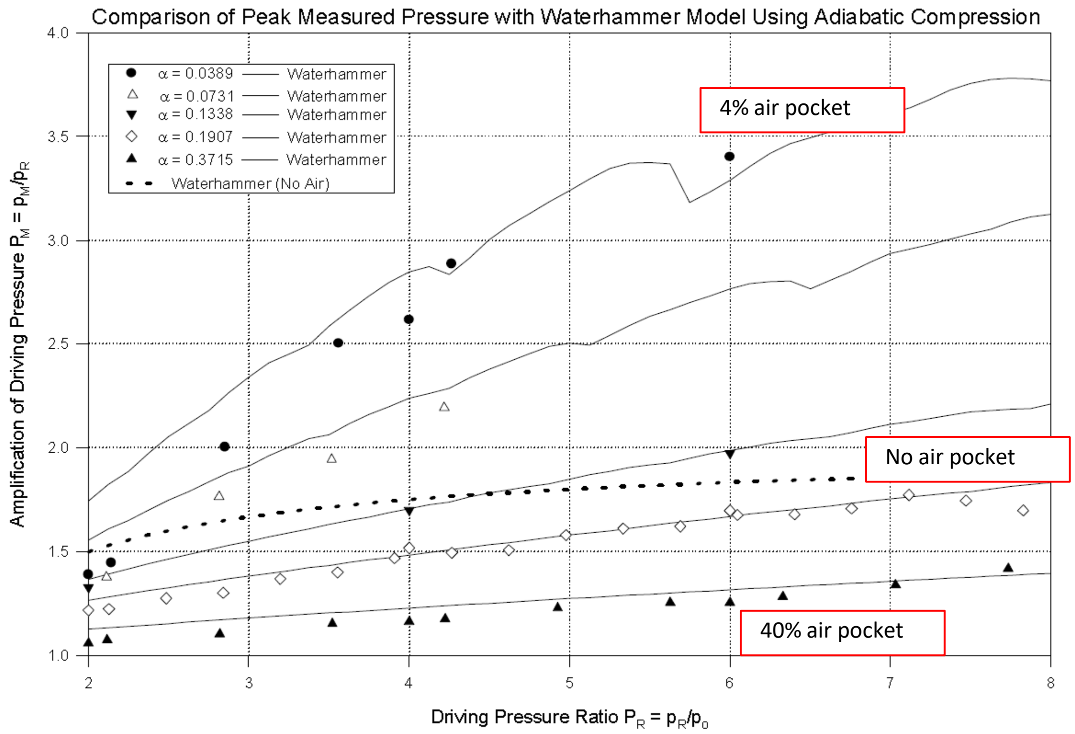
Pressure

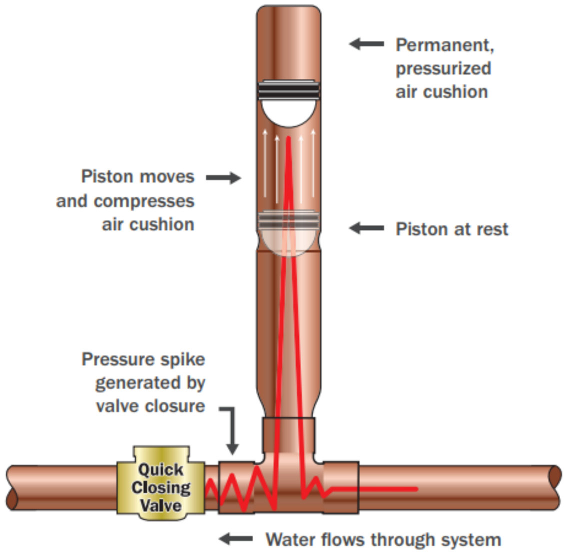
- Pressure surge, water hammer
- Sources:
  - Air in pipelines can substantially magnify the pressure surge effects
  - Without air, surge ~2x operating pressure;
  - With 10% air pocket, surge > 10x operating pressure



Pressure

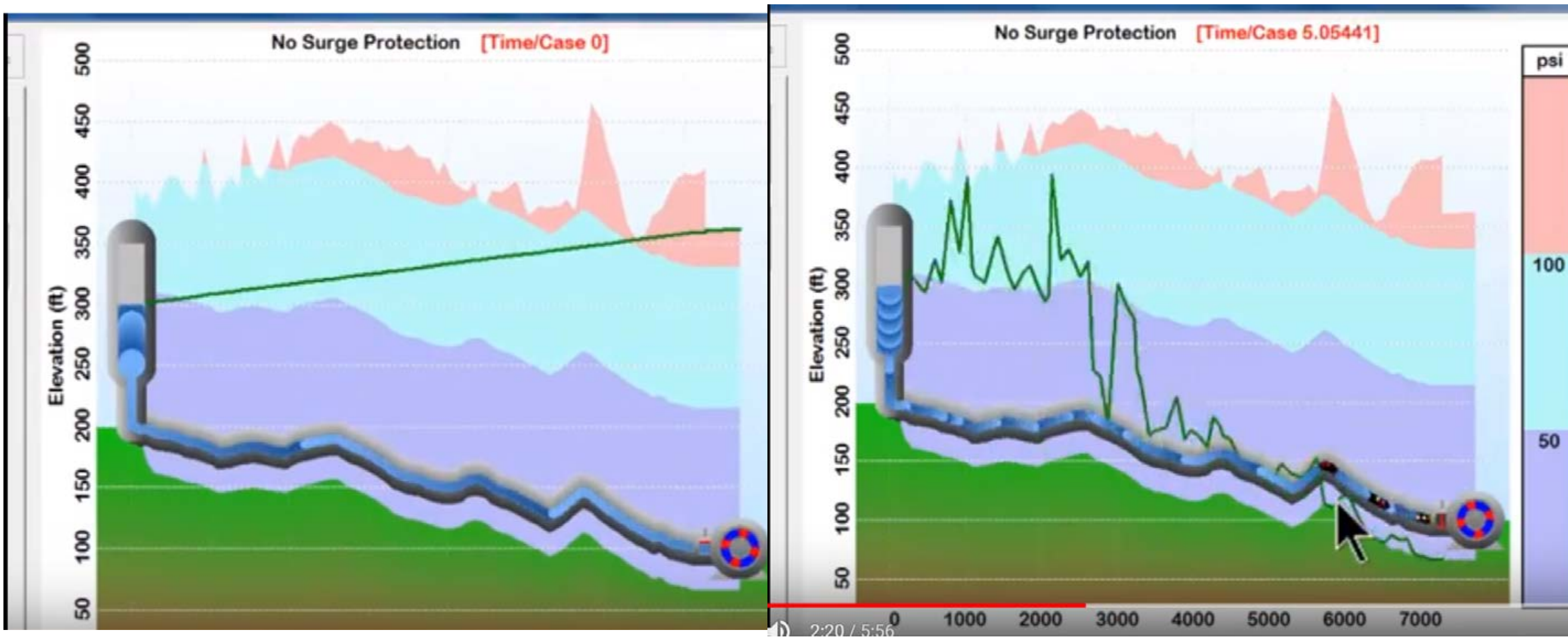
- Pressure surge, water hammer
- If air in pipelines can substantially magnify the pressure surge effects, why do water hammer arresters work?





Pressure

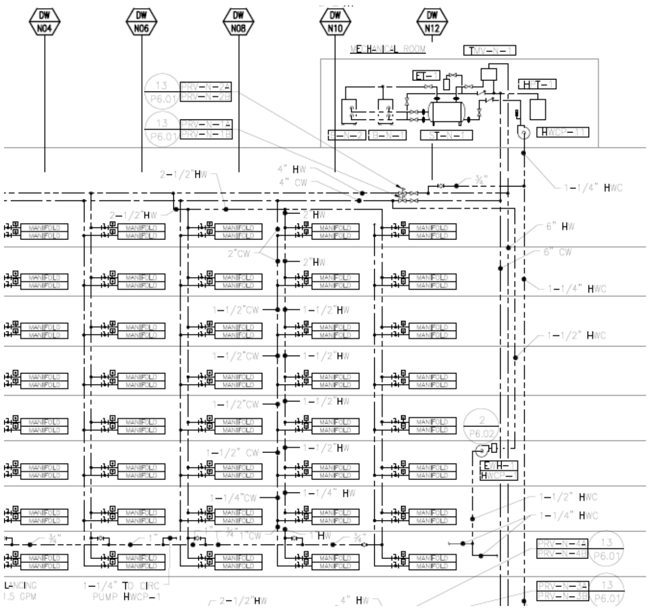
- Conversely, transient pressure surges, water hammer will also cause low pressure events
- Cavitation (low pressure)



Flow

- Balanced flow is critical for:
  - Maintaining proper temperatures,
  - System operation at best efficiency point (energy savings), and
  - Reducing or eliminating damage to piping.
- Common in hydronic heating/cooling systems, information and data readily available
- Much less common in plumbing hot water circulating systems
- Balancing valves
  - Flow restrictors (flow balancing)
  - Temperature maintenance (thermal balancing, flow modulation)

- Oversized circulating pumps, or flow imbalance
  - High velocity in some legs, low or no flow in others
  - High velocity areas can erode/corrode piping, introduce copper into water



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Mixed Systems

- General Concepts re: mixed systems
- Domestic Hot Water Recirculation (DHWR) mixed systems
  - Design considerations for other materials
  - Hydraulic balancing
  - Flow and pressure surges, cavitation effects
- First occurrences, background
- Investigation, timeline, findings
- Identification of oxidative degradation
- Codes, standards, guidelines
- Current status
- Next steps and product usage

Update

- Technical Bulletin – global use, Domestic Hot Water Recirculation (DHWR)
  - http://www.aquatherm.com/technical-bulletins

Aquatherm Technical Bulletin

201207C - AQTTB

Title: Integration of other systems or components with Aquatherm piping for pressure pipe applications

Date issued: 22 August 2012

- Integration and mixed systems
- Temperature recommendations
- Acceptable copper levels
- Hydraulics, cavitation
- Combining DWHR/heating systems
- Warranty coverage voided

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- What are mixed systems?
  - Mechanical connection required (flange, threads, barbed, groove, compression or solder)
  - Steel, copper, other plastics
    - Steel, no issues, corrosion inhibitors acceptable
    - Other plastics, no issues
    - Copper
  - **Hydronic heating, no issue (little or no chlorine)**
  - **Domestic cold water, no issue (no high temp)**
    - **Copper cold water supply pipe to building is not an issue**

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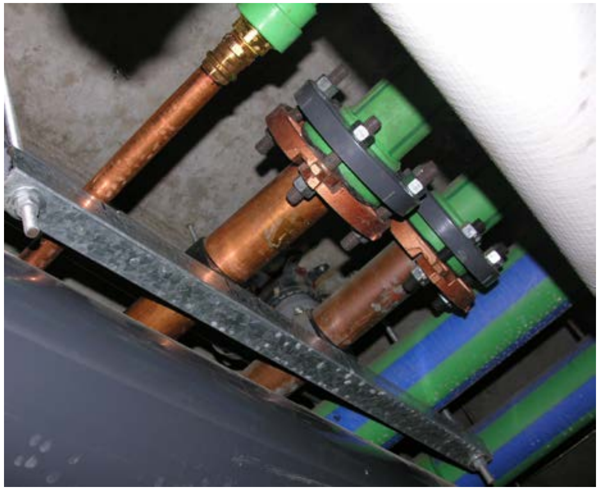
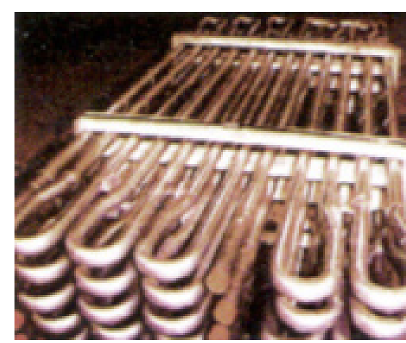
General Concepts (cont.)



- Copper (cont.)
  - Domestic hot water recirc.
  - Continuous circulation
  - Temperature >120°F (49°C)
  - Active copper erosion/corrosion
    - Erosion/corrosion
      - Flow-induced corrosion
      - Corrosion due to aggressive water
      - Erosion, cavitation
    - Flow velocity in excess of Copper Development Association (CDA & Canadian CBDA) recommendations;
    - Piping undersized, multi-speed pump at wrong setting;
    - Aggressive water
      - pH, alkalinity, carbonate, TDS, chloramine/chlorine, dissolved oxygen
  - EPA, WHO, European regulatory action levels

General Concepts (cont.)

- Copper (cont.)
  - Copper tube boilers
    - Not generally an issue
    - Designed to avoid excessive [illegible] ast the copper tubes
    - Can still be problem in aggressive/corrosive water conditions, prefer alternate materials (SS or Al)



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Why is copper an issue and what is done about it?

- Copper compounds (CuCl2, Cu(OH)2) in water provide reactive sites to help accelerate the oxidation/degradation process
- "Turn Over Number", TON ~ conversion to oxidized polymer

Copper Catalyst	Temperature	TON
Cu(OH)2	Room temp	1.5 (no sig. effect)
CuCl2	70°C (158°F)	9,770

- Complexing/chelating agents; metal deactivators scavenge copper and react with it so no longer active catalyst site

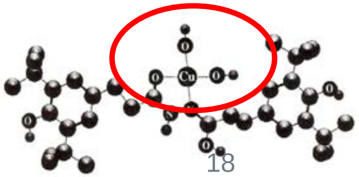

Fig. 4.1. Cu^{2+}-complex with metal deactivator MD-1

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Why is steel NOT an issue?

- Iron reacts quickly with other elements in the water to form oxides and calcium/silicate compounds that precipitate out of solution to form scale, tuberculation, rust
- Iron less noble than copper (galvanic series)
- See chemical resistance charts, iron chloride, iron hydroxide, iron nitrates, sulfates

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First occurrences, background

- First occurrence in Australia, 2008-09
  - Holy Spirit Brisbane Hospital, DWH recirc system
  - Multiple leaks reported in aquatherm piping
  - No prior experience with this anywhere
  - Findings:
    - Excessive temperature, pressure;
    - High flow velocities;
    - Unbalanced flow, no control on velocity, pressure;
    - Overclamping, excessive localized stress;
    - Copper erosion/corrosion, leaks, replacement
    - Undersized pipe, no regulatory control of flow velocity or pipe sizing

First occurrences, background

- Next occurrence in Australia, 2010
  - Jacksons Landing, Sydney, DHW recirc system
  - Multiple leaks reported in riser piping
  - Findings:
    - Overclamping, excessive localized stress;
    - Copper erosion/corrosion, leaks, replacement x2 times
    - Excessive temperature, 167°F (75°C);
    - High flow velocity, 7 ft/sec (2 m/s);
  - Piping has been replaced with copper twice since then, leaks continue due to design/operation issues

Investigation

- Multiple experts across 3 continents
  - Prof. George, Professor Emeritus, Polymer Science
    - Queensland University, Australia
  - Dr. Gates, UQ Materials Performance
    - Queensland, Australia
  - Dr. Brüll, Manager, Materials Analytics Group
    - Fraunhofer LBF, Darmstadt, Germany
  - James Paschal, P.E., Principal Engineer
    - Paschal Engineering, MI, USA
  - Dr. Thomas Walsh, President
    - Walsh Associates, TX, USA
  - Dr. Richard Heiden, Principal Investigator
    - RW Heiden Associates, PA, USA

Investigation – Prof. George

- Research
  - DSC OIT, residual stabilizer
  - FTIR, level of carbonyl formation, extent of damage
  - Copper analysis of inner pipe surface
- Conclusions
  - Mechanical damage, over-tightened metal clamps, no allowance for pipe expansion when heated;
  - Excessive flow rates in copper pipe causing erosion/corrosion
  - Oxidative degradation from excessive metal ion concentration in the presence of chlorine and oxygen at high temperature

Investigation – Dr. Gates

- Research
  - Inspection and examination of multiple commercial plumbing systems experiencing copper tubing leaks
- Conclusions
  - Pinhole leaks in copper tubing caused by erosion/corrosion
  - In hot water recirculating systems, water velocity must be kept **below 0.5-0.6 m/s (2 ft/sec) in copper**
  - At temperatures above 60°C (140°F) and velocity above 1.2 m/s (4 ft/sec), erosion/corrosion of copper is inevitable
  - Urgent need to update codes to restrict hot water velocity in copper tubing

Investigation – Dr. Brüll

- Research
  - Stabilizer, metal deactivator study
  - Polymer changes under excessive heat exposure
  - Degradation extent through wall thickness
- Conclusions
  - Aquatherm piping stabilized at or above state of the art
  - Presence of metal deactivators did not stop degradation
  - No other products contained metal deactivators at that time
  - Degradation at outer wall confirms excessive temperature

Investigation – J. Paschal

- Research
  - Water analysis
  - FTIR, carbonyl index, extent of degradation
  - DSC Oxidative Induction Time (OIT) across wall thickness
- Conclusions
  - High copper concentration in hot water, confirming erosion/corrosion
  - Erosion/corrosion damage in copper piping
  - Water velocity 8 ft/sec or higher in hot water recirc
  - Aggressive water, high pH, high chloramine
  - Pipe was properly stabilized at manufacture

Investigation – Dr. Walsh

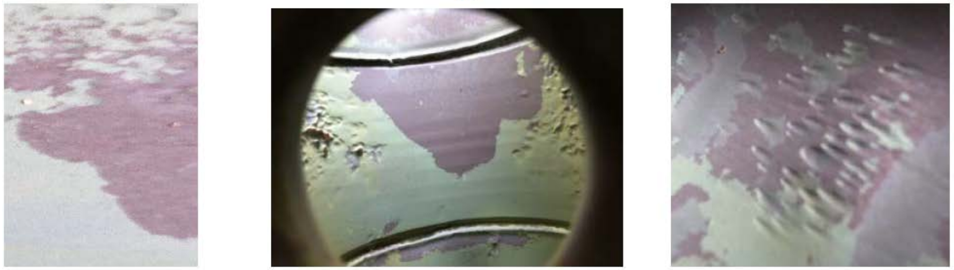
- Research
  - Melt flow, density, OIT, HPLC (stabilizer content), EDS (metals)
  - No damage to heating water system, mixed system with steel pipe, same supply water
- Conclusions
  - Copper-induced environmental stress cracking
  - Source of copper is piping in DW system

Investigation – Dr. Heiden

- Research
  - Microscopy, FTIR, XFR (scale, oxidation layer)
- Conclusions
  - Erosion of scale and oxide layer on copper, exposing copper to water and corrosion
  - Calcium Carbonate Precipitation Potential indicates scale would be sufficient to protect copper under proper flow conditions

FIGURES 1 A-C Photos of Interior Copper Surfaces

A B C

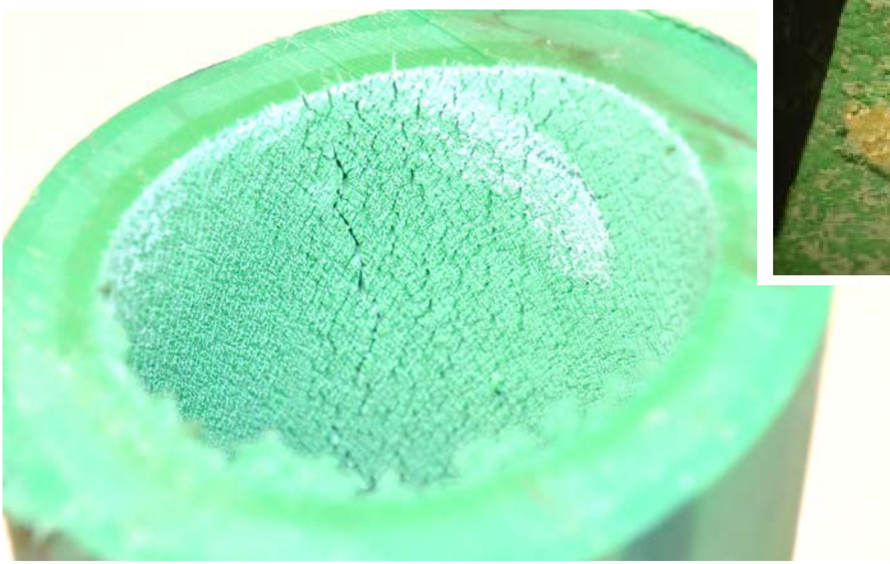


Identification

- Extensive micro-cracking on interior,
- rough interior surface around entire pipe, not localized,
- green or white residue on inner surface that will come off on finger,
- typically additional copper/brown/red color residue in some portions,
- o-rings/gaskets will also be degraded

Identification

- Oxidative degradation, severe interior cracking, but only small exterior crack at leak



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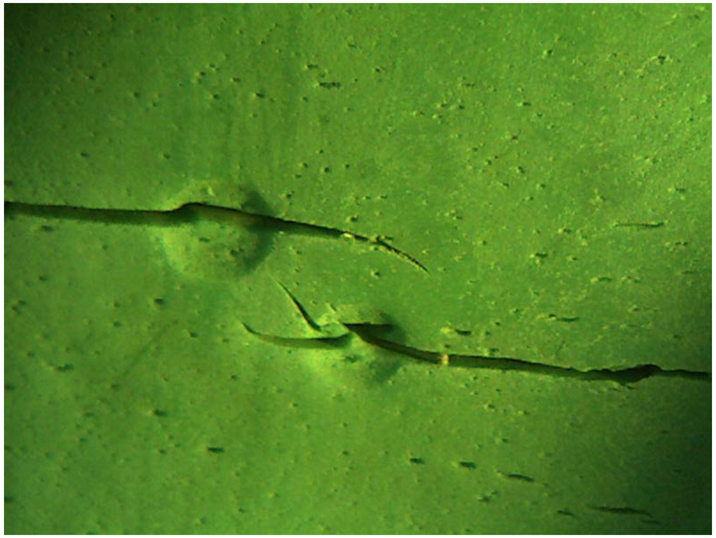
Identification

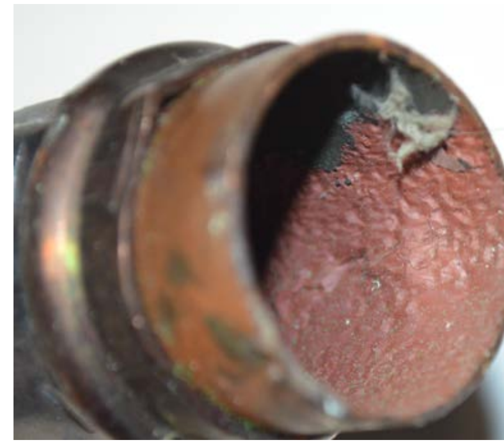
- Mechanical stress under elevated temperature, over-tightened clamp
- Cracks, degradation at clamp location
- Thermal oxidation, excessive temp

Identification

- Cavitation-initiated cracks, degradation
- Cavitation "dimple" at crack origin
- Localized excessive stress, susceptible to crack propagation and oxidative degradation



- Copper erosion/corrosion, pinhole leaks
  - In most cases, copper leaks occur and piping must be replaced prior to any leaks in Aquatherm piping. <u>This should be considered a warning sign in mixed systems.</u>



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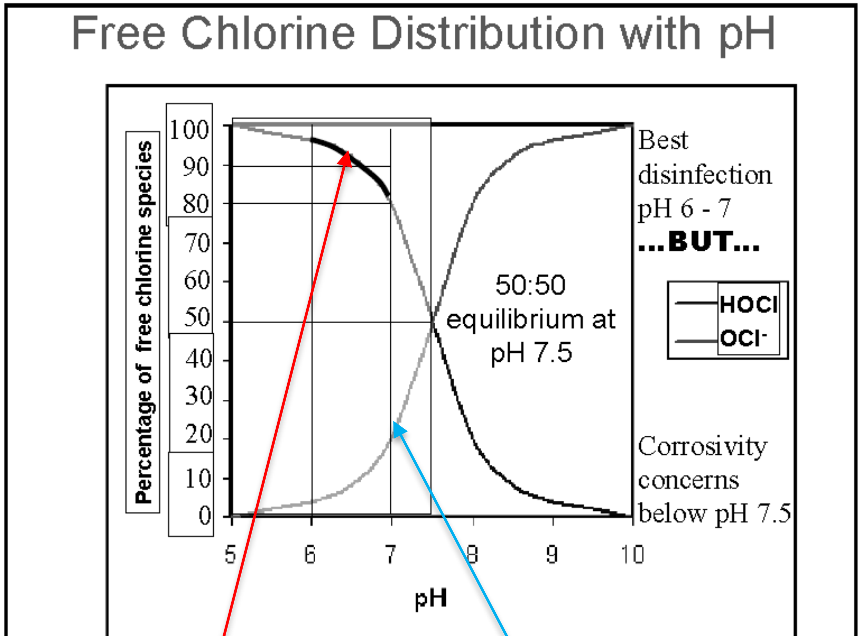
Oxidative Resistance (chlorine) Tests, Ratings

1. Basis for ASTM F2023 testing
    a) Mechanism
    b) PB history, PEX means of proving not a repeat
    c) Shell, Bodycote method development
    d) NSF P171, history of inclusion of ORP
    e) AWWA 1996
        i. 4100 utilities, 1 reported 4ppm,
        ii. pH range 6-9, min @ 6-7, not continuous
    f) AWWA 2007 – average FAC 1.0 at utility
    g) Purpose of treating at higher level, to maintain minimum residual at building (e.g. 0.2 FAC)
    h) Background, reactions, ORP, variation in pH, Cl

Chlorine disinfectant



Hypochlorous acid, HOCl

Hypochlorite ion, OCl^-

Reaction of chlorine/hypochlorite on addition to water

Gas chlorine

$Cl_2 + H_2O \rightarrow$

$HOCl + H^+ + Cl^-$

$\downarrow$

$HOCl \Leftrightarrow H^+ + OCl^-$

The generation of free H^+ ions help to lower pH.

Hypochlorite

$Ca(OCl)_2 + 2H_2O \rightarrow$

$2HOCl + Ca^{++} + \boxed{2OH^-}$

$\downarrow$

$HOCl \Leftrightarrow H^+ + OCl^-$

$NaOH \Rightarrow Na^+ + \boxed{OH^-}$

$NaOCl + H_2O \rightarrow$

$HOCl + Na^+ + \boxed{OH^-}$

$\downarrow$

$HOCl \Leftrightarrow H^+ + OCl^-$

$NaOH \Rightarrow Na^+ + \boxed{OH^-}$

NOTE: Sodium hydroxide (NaOH) is used as a stabilizing agent. On reaction with water, NaOH ionizes to Na^+ and OH^-, thereby adding to the available OH^- ions and further raising the pH.

Free OH^- ions means pH is raised

Lower pH $\rightarrow$ better disinfection (HOCl is predominant)

<u>80-100x more effective disinfectant</u>

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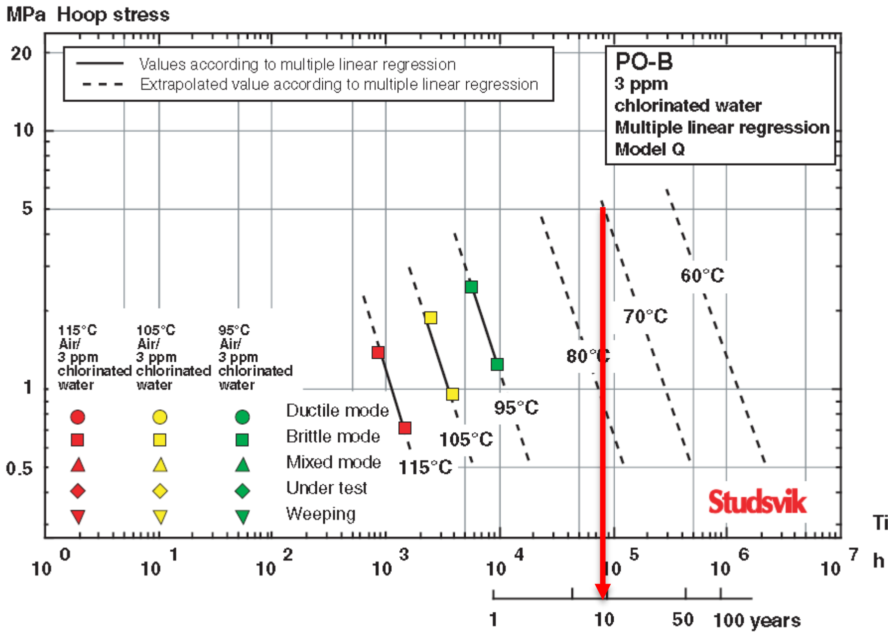
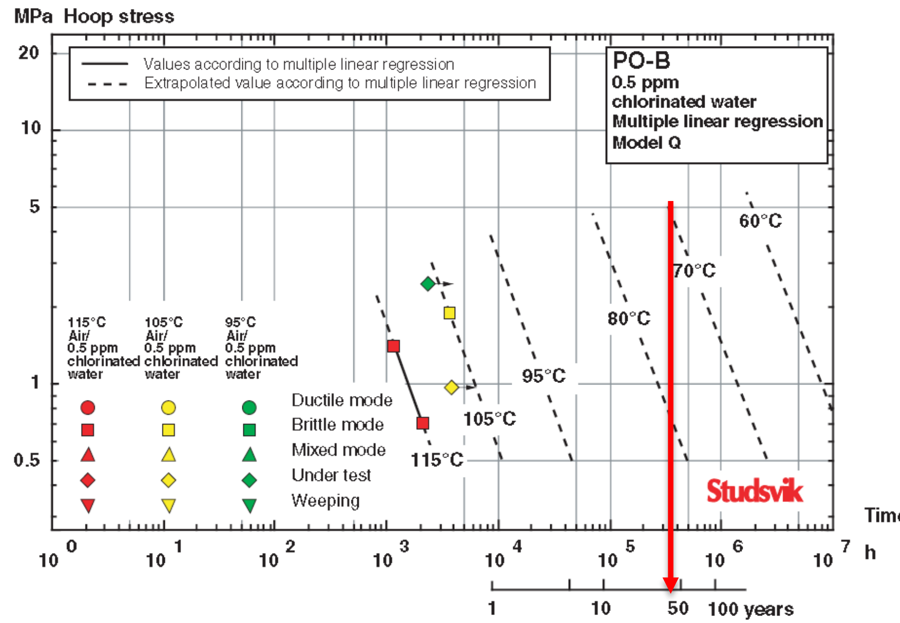
Chlorine level





$$pressure = \frac{2 * (hoop\ stress)}{(SDR\ - 1)}$$

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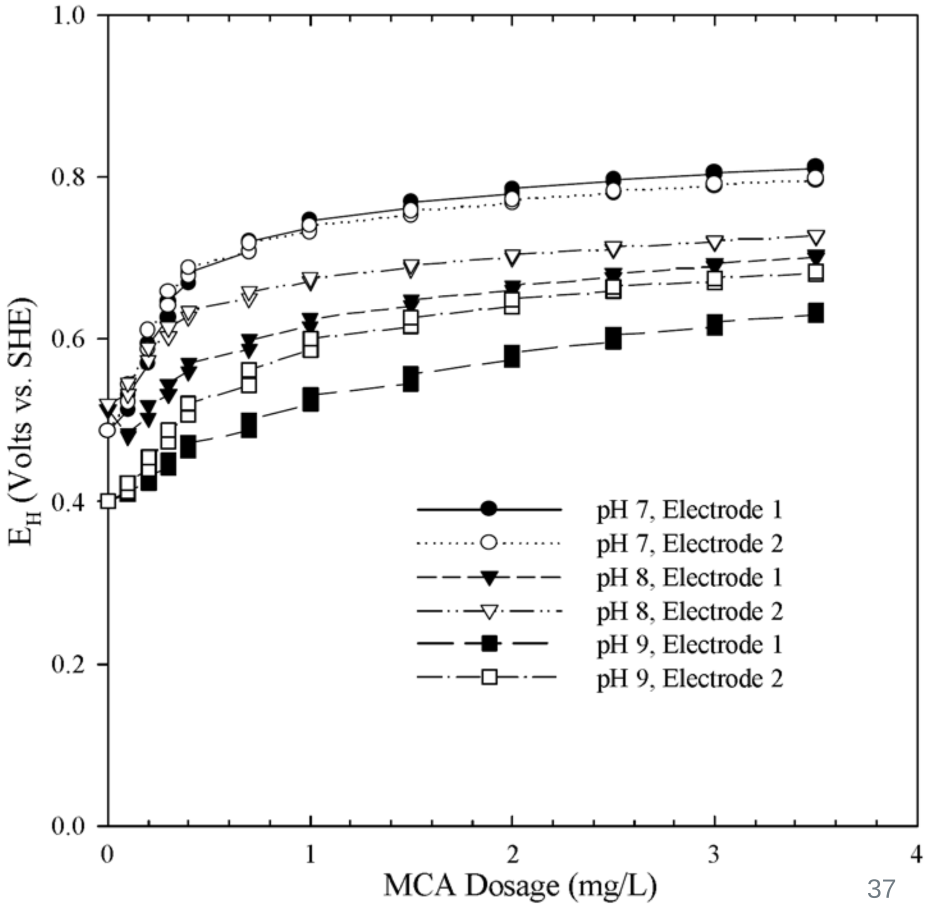
Chlorine level, ORP



$$E_H = E^o - \frac{RT}{nF} \ln(Q)$$

$$E = E° - \left(\frac{0.05916}{2}\right) log \left[\frac{(OCl^-)(H^+)^2}{Cl^-}\right]$$

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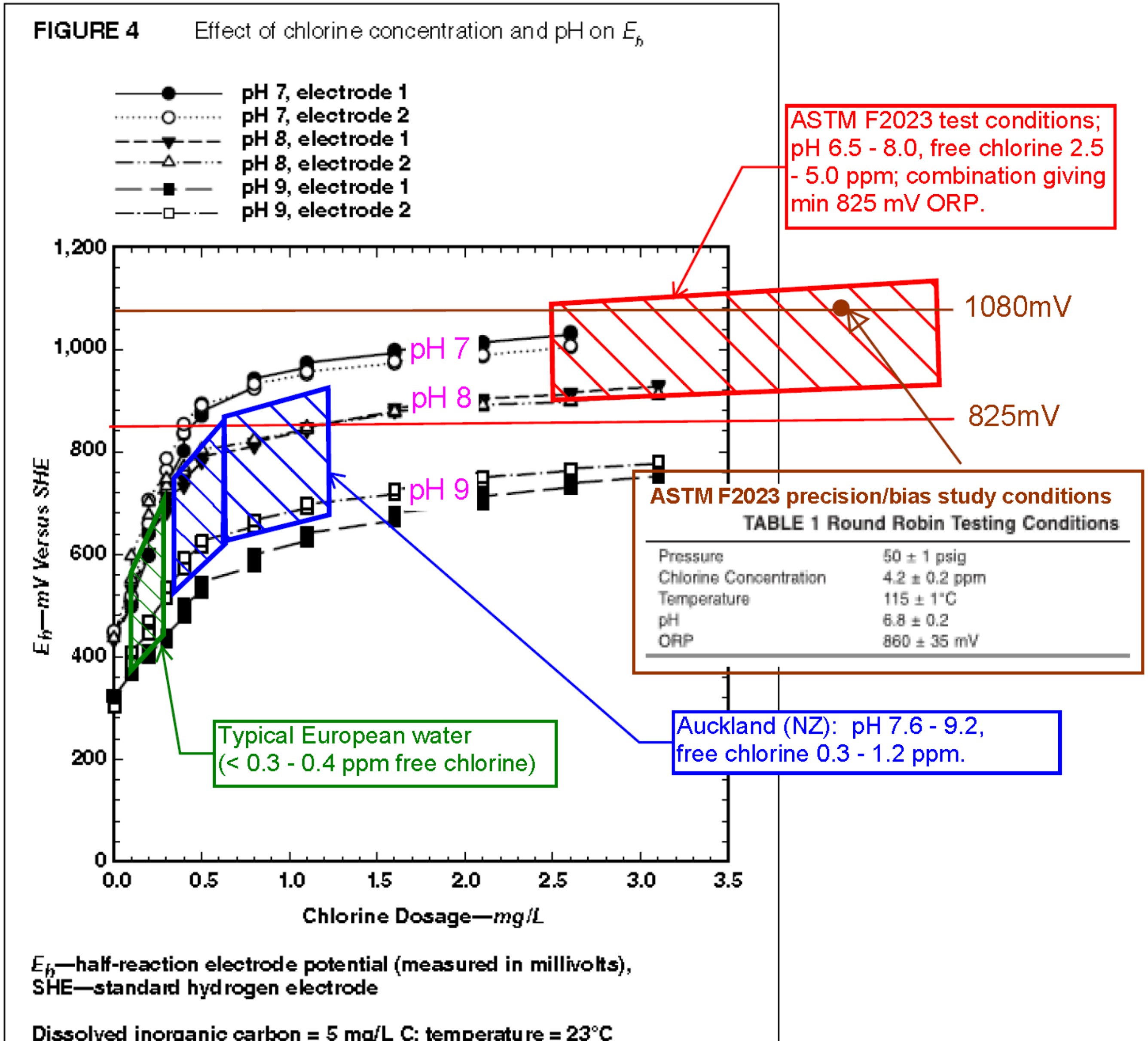

FIGURE 4 Effect of chlorine concentration and pH on E_h
pH 7, electrode 1
pH 7, electrode 2
pH 8, electrode 1
pH 8, electrode 2
pH 9, electrode 1
pH 9, electrode 2
1,200
1,000
800
600
400
200
0
E_h—mV Versus SHE
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Chlorine Dosage—mg/L
pH 7
pH 8
pH 9
ASTM F2023 test conditions; pH 6.5 - 8.0, free chlorine 2.5 - 5.0 ppm; combination giving min 825 mV ORP.
1080mV
825mV
ASTM F2023 precision/bias study conditions
TABLE 1 Round Robin Testing Conditions
Pressure 50 ± 1 psig
Chlorine Concentration 4.2 ± 0.2 ppm
Temperature 115 ± 1°C
pH 6.8 ± 0.2
ORP 860 ± 35 mV
Typical European water (< 0.3 - 0.4 ppm free chlorine)
Auckland (NZ): pH 7.6 - 9.2, free chlorine 0.3 - 1.2 ppm.
E_h—half-reaction electrode potential (measured in millivolts), SHE—standard hydrogen electrode
Dissolved inorganic carbon = 5 mg/L C; temperature = 23°C

Rating Requirements

Description	Reference	% of time at 23°C	% of time at 60°C	ORP, mV	Minimum Time, yrs
PP-R CL-TD PEX Class 1	ASTM F2389 ASTM F876	75%	25%	825	50
PEX Class 3	ASTM F876	50%	50%	825	50
PP-R CL-R PEX Class 5	ASTM F2389 ASTM F876	0%	100%	825	50

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ASTM F2023 Extrapolations

Temperature, °C	Chlorine, ppm	ORP, mV	Pressure, bar	Extrapolated time, yrs
23 (cold)	4	860	5.5	19,601
23 (cold)	4	860	8	12,256
23 (75%), 60 (25%)	1.5	565	8	345.2
60 (100%)	4	860	5.5	53.1
68 (100%)	1.5	491	8	74.3

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Codes, Standards, Guidelines

- Australia update
  - No codes, copper industry against;
  - D&C (design & contractor)
  - Nicholas Corrosion study, Institute of Plumbing Australia (IPA)
- Copper Development Association
- AWWARF
- U.S. & Canada codes (8 fps), no provision for lower velocity at higher temp
- German DIN 1988 & DVGW W551
  - 0.2-0.5 m/s for hot water
  - Circulation pumps max 8 hrs operation per 24 hour period
  - Max. temperature drop, $\Delta T < 5°C$ (9°F)
- Without formal regulation and inspection:
  - Pipe downsized to save money, increase profit
  - Pumps upsized to account for increased losses over time (metal pipe scale/corrosion), leads to higher velocity and exacerbates problem
  - Boiler controls easily accessed and modified by building staff and occupants, increase temperature to accommodate peak demand due to system undersized (piping), then left at higher setpoint

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Codes, Standards, Guidelines

- Copper Development Association

Water Velocity Limitations — To avoid excessive system noise and the possibility of erosion-corrosion, the designer should not exceed flow velocities of 8 feet per second for cold water and 5 feet per second in hot water up to approximately 140°F. In systems where water temperatures routinely exceed 140°F, lower flow velocities such as 2 to 3 feet per second should not be exceeded. In addition, where 1/2-inch and smaller tube sizes are used, to guard against localized high velocity turbulence due to possibly faulty workmanship (e.g. burrs at tube ends which were not properly reamed/deburred) or unusually numerous, abrupt changes in flow direction, lower velocities should be considered. Locally aggressive water conditions can combine with these two considerations to cause erosion-corrosion if system velocities are too high.

Due to constant circulation and elevated water temperatures, particular attention should be paid to water velocities in circulating hot water systems. Both the supply and return piping should be sized such that the maximum velocity does not exceed the above recommendations. Care should be taken to ensure that the circulating pump is not oversized, and that the return piping is not undersized, both common occurrences in installed piping systems.

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Codes, Standards, Guidelines

- EPA Lead and copper rule (LCR)
  - If lead concentrations exceed an action level of 15 ppb or **copper concentrations exceed an action level of 1.3 ppm** in more than 10% of customer taps sampled, the system must undertake a number of additional actions to control corrosion.

Mitigation, Remediation

- Avoid use of copper, or follow codes/guidelines on acceptable use/velocity to avoid copper corrosion
- Lower temperature
- Larger pipe size to reduce velocity
- Water treatment
  - Reduce aggressiveness towards copper
  - Remove copper from water
- Technical Bulletin:
  - When adding PP-R to an existing copper system in a DHWR-application, the level of copper in the water should be tested. These levels should not exceed 0.1 mg/L (ppm).
  - **Damage caused by copper in the water resulting from erosion/corrosion or other degradation of copper components in the DHWR system will void the Aquatherm warranty.**

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Mitigation, Remediation

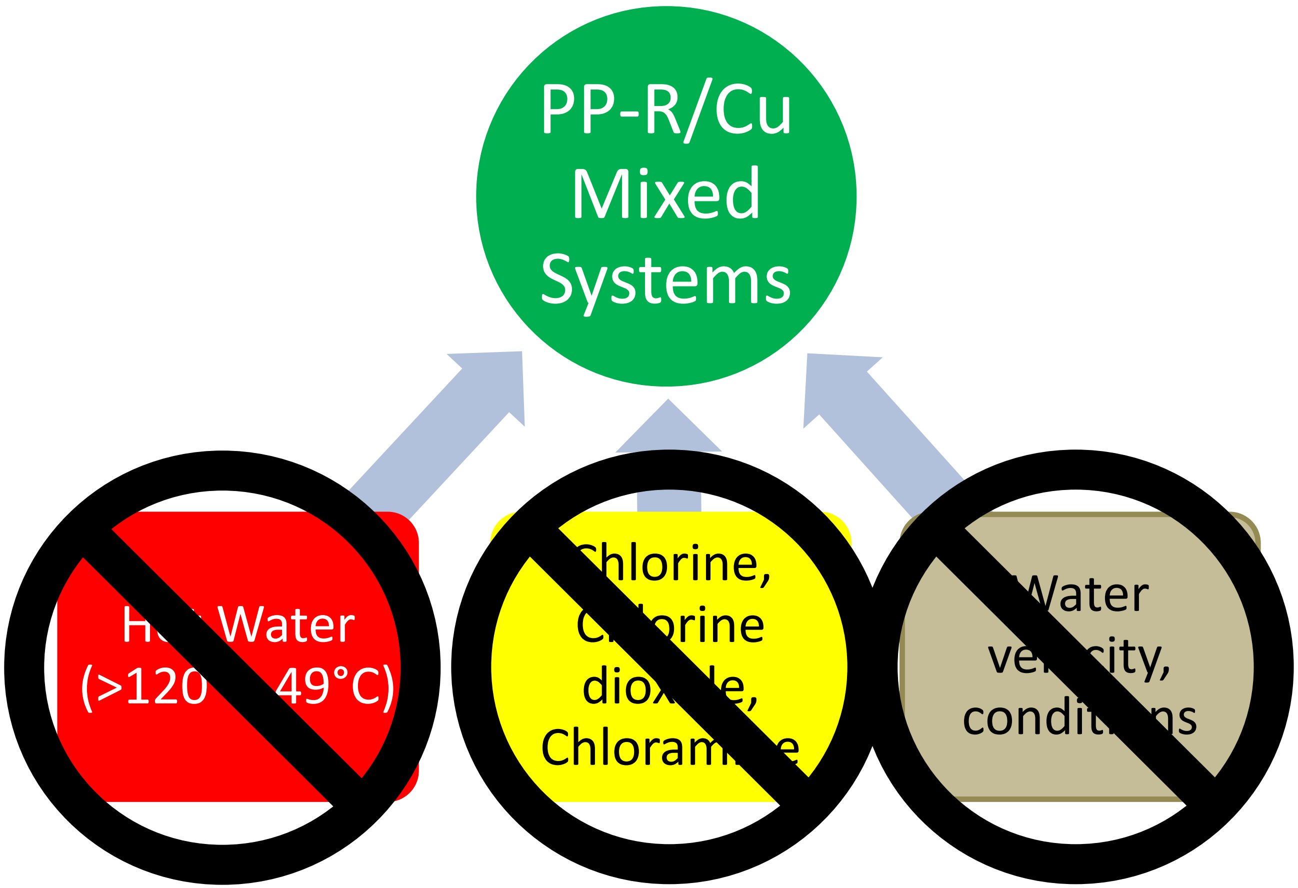
- If a problem is found, or system has been installed where all the conditions are met for copper corrosion, high velocity, high temperature, chlorine, and Aquatherm piping, remediation steps will generally include:
  - Scope the Aquatherm piping beginning nearest the heat source and copper (generally the boilers and mechanical room), looking for degradation on the interior wall of the pipe;
  - Determine the extent of piping that has been degraded and replace;
  - Replace all copper with Aquatherm piping;
  - Lower the operating temperature if possible;
  - Use “smart” circulating pump technology to reduce or eliminate circulation during low or no demand periods
  - Incorporate balancing valves on all recirc lines to ensure equal, low-velocity flow rates

Summary

- First seen in 2008-09, nothing in prior 30 yrs
- Must have combination of copper, chlorine, and high temperature
- Copper source is erosion/corrosion of piping; simply having copper or brass components in system is not an issue
  - Water velocity
  - Turbulence (fittings)
  - Aggressive water chemistry

aquatherm
we've got a pipe for that

Summary



Domestic cold water systems – OK
Proper system design, installation, operation, water temperature, water treatment
Hydronic Heating – OK, no replenishment of chlorine
Chilled water, condenser water, etc.

Summary

- Other sources, and other metals?
  - Copper/silver ion generators used as secondary disinfectant
    - If used with primary disinfectant that has residual in water such as chlorine or chloramine, then same issues/restrictions as copper pipe;
    - If used with primary disinfectant that does not maintain a residual such as ozone, then may be acceptable depending on other water conditions - Submit request.
  - Other metals
    - Other metals in the water such as iron, magnesium, and inorganics such as chlorides not a concern
    - NOTE: chloride ≠ chlorite, hypochlorite
  - Water utility changes to treatment methods are not normally known at building design, use of copper tubing/components should assume worst-case
  - Combined DWHR/heating systems not recommended, contrary to most acceptable design practices (ASPE, ASHRAE) and heating components such as fan coils, boilers may not be suitable for exposure to more aggressive DHWR water conditions.

PPI Polypropylene Piping Handbook

- Format similar to PE Handbook, Copper Handbook
- Introduction
  - Resin types, manufacturing, applications
- Materials
  - Ratings
  - Mechanical & Thermal Properties
  - Chemical Resistance
- Design and Installation
  - Fusion techniques
  - Flow characteristics
  - Expansion/contraction
  - Fire properties
  - Underground
- Codes & Standards
  - Mechanical, Plumbing, Energy Conservation
  - Life Cycle Analysis, EPD, HPD

Is this enough?
Using IoT to protect your building

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Aquarius Spectrum: Providing Real-time Water Leak Alerts

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Connected Water – How sensors and IoT protect a precious resource

By: Ericsson | 30 August, 2016 | Society , Technology , Utilities | connected water, ctia, innovation, SDGs, sustainability, Sustainable Development Goals, water

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