Water Treatment in Commercial Heating Systems

CIBSE South East

15th September 2021
CPD Overview

Section 1
- Why water treatment is so critical
- Industry guidelines

Section 2
- Corrosion in closed heating systems
- Costs of poor water treatment and case study

Section 3
- The Impact of limescale
- Scale in secondary hot water systems
- Treating limescale and case study

Section 4
- Key actions to takeaway today
Section 1
The need for treatment and industry guidelines
Why water treatment is so critical.

- System issues are caused by a combination of:
  - water impurities
  - heat
  - different metals
  - The introduction of dissolved oxygen

- In closed heating systems these chemical reactions lead primarily to corrosion.

- In ‘once through’ heating or domestic hot/cold water systems or leaking closed systems, limescale becomes a major problem.
Consequences of poor water treatment

- Reduced efficiency
- Increased energy costs.
- Environmental penalties (CO₂ emissions).
- Failures outside of warranty - Boiler manufacturer’s warranties are now up to 10 Years and are linked to water quality.
Consequences of poor water treatment

- Loss of efficiency
- System downtime.
- Complete boiler failure – even within just a few months of commissioning.
- Liability for remedial/replacement works and associated costs.
- Damage to reputation.
“Central heating systems should be thoroughly cleaned and flushed out before installing a new boiler.”

“…a chemical water treatment formulation should be added to the primary circuit to control corrosion and the formation of scale and sludge.”

Water treatment guidelines in Part L
“...cleaning is achieved through a process of flushing and chemical cleaning (where required) followed by the addition of biocides and inhibitors.”

“The success of ...cleaning is inferred from water samples that are analysed for a range of parameters including suspended solids, iron and bacteria.”

BSRIA Water Treatment for Closed Heating and Cooling Systems (BG 50/2013)
BSRIA Pre-Commission Cleaning of Pipework Systems (BG 29/2020)
BS 8552:2012 Sampling and monitoring of water from building services closed systems
Cleaning Precautions for thin-walled carbon steel.
- Only chemicals recommended by the manufacturer to be used to clean the surfaces prior to application of Biocide and inhibitor

Closed-loop Pre-treatment Cleaning (CPC).
- Cleaning and biocide treatment in combination with filter to remove contaminants
Summary of additional topics covered under BG29/2020 (Cont’d)

- **Corrosion Monitoring**
  - Technology can be used to Monitor system and provide a warning if corrosion rises above acceptable limits.

- **Reference to VDI 2035**
  - Reference made to the German standard and confirmation the measures to achieve and maintain compliance fall outside the scope of BG29
Water treatment guidelines in ICOM

1. Biocide pre-wash - systems vulnerable to microbiological contamination or which have been idle for several weeks

2. Pre-chemical clean dynamic flush - use a suitable supply water

3. Chemical clean - use a dynamic circulation & neutralisation procedure then flush!

4. Post chemical clean - with dynamic flush using a suitable supply water

5. Passivation regime - should be considered for some systems!

6. FLUSH - check that all chemicals have been flushed from the system

7. Final fill - with a suitable water supply and the addition of appropriate inhibitors and biocides

Visual inspection of system water
Section 2

The impact of Corrosion
Corrosion: An Introduction

Corrosion is the degradation of metal surfaces.

It is a natural process of wastage which occurs when metal is exposed to a reactive environment.

Water systems provide a highly reactive environment for most metals, unless treated.
What causes corrosion in closed heating systems?

- The primary cause of corrosion is the introduction of dissolved oxygen from raw water makeup.

- A corrosion cell arises when two metals with dissimilar compositions or microstructures come into contact in the presence of an electrolyte.
Heating systems are composed of a wide variety of metals which will react with each other if not treated.

### Electrochemical table

<table>
<thead>
<tr>
<th>Anodic</th>
<th>Cathodic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactive</strong></td>
<td><strong>More easily protected</strong></td>
</tr>
<tr>
<td>Magnesium</td>
<td>Stainless Steel (passive)</td>
</tr>
<tr>
<td>Zinc</td>
<td>Gold</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Copper Nickel Alloys</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>Titanium</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>Silver</td>
</tr>
<tr>
<td>Stainless Steel (active)</td>
<td>Bronze</td>
</tr>
<tr>
<td>Lead</td>
<td>Copper</td>
</tr>
<tr>
<td>Brass</td>
<td></td>
</tr>
</tbody>
</table>
Corrosion of mild steel and iron

- Mild steel and iron corrode rapidly in untreated/poorly treated systems.
- This often releases small flakes of rust into the water - particularly harmful in the area of pump shaft seals.
- Corrosion of mild steel radiators can sometimes be illustrated by pin-holing
Sludge in heating systems

Oxide is approximately 5x heavier than system water, which leads to:

- Blockages in pumps, valves, radiators (see cold spot).
- Reduced water velocity.

As a result:
- Pumps have to work harder, which causes higher energy consumption.
- Heat output reduces.
Baked on deposits in heating systems

Heavier black magnetite builds in the lowest points of a heating system (usually the boiler), forming a tough layer of baked on deposit.

This can inhibit water flow, leading to:

- Blockages of the system.
- Over heated boiler.
- Cracked heat exchanger.
Aluminium is an ideal choice for high efficiency heat exchangers.

- Its protective oxide layer is pH dependant
- If this layer is disrupted, corrosion occurs rapidly (aluminium has high anodic value).

Causes of disruption include:

- Base exchange softened water can lead to higher system water pH.
- Insufficient flushing of alkaline cleaners.
- Inhibitors that elevate pH values.
Alloying with chromium (11% minimum) to yield stainless steel, results in a chromium rich oxide layer that is:

- highly stable
- corrosion resistant.

S/S is vulnerable to localised or pitting corrosion, due to aggressive constituents such as:

- chloride
- sulphate.
pH vs. rate of corrosion

Optimum range of pH of water in a closed system.
The cost of poor water treatment
Basic cost implications of ineffective water treatment

<table>
<thead>
<tr>
<th>COST OF REPLACEMENT</th>
<th>COST OF PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material and labour costs to replace this failed heat exchanger:</td>
<td>Cost for high-quality chemicals:</td>
</tr>
<tr>
<td>£3,500</td>
<td>£300</td>
</tr>
</tbody>
</table>

Cost of prevention is less than 10%

In the case of a failed heat exchanger in a 70kW boiler, one OEM quoted:

“for ease and expediency, the complete boiler would be replaced rather than just the heat exchanger ....”
Counting the cost of carbon from scale and sludge

There are government schemes related to energy consumption and CO₂ emissions of commercial buildings:

*CRC*
*ErP*
*ESOS*

The example opposite illustrates costs associated with a 500kW boiler at 85% design efficiency, with reduced performance of 10% due to system fouling.

**FINANCIAL COST**

Additional gas costs per annum*:

£7,000

**ENVIRONMENTAL COST**

Additional CO₂ emissions per annum**:

48,000 kg

*Based on 3418 load hours with gas tariff at £0.035 per kW.
**1 kW of gas produces 0.185 kg of CO₂.
The Solution
Cleaning and flushing

**New systems**
- Flux residues
- Greases
- Installation debris
- Metal swarf
- Mineral oil

**Existing systems**
- Magnetite sludge
- Corrosion debris
- Limescale
- Slimes
- Bio-fouling
Inhibitor provides protection to systems to prevent the build up of scale, sludge and corrosion.

- Strength of pH buffer varies between brands considerably.
- OEMs do endorse select inhibitors in line with their warranties.
- Total system volume can be estimated using 12L per kW boiler output.
- Dosage varies depending on chemical used, typically a minimum 1% of system volume.
Monitoring – test kits

Test kits are available on the market and can be used to verify and certify the water treatment process.

- Monitor quality of system before treatment.
- Make recommendations from test results.
- Implement treatment.
- Use test kits for on-going monitoring PPM (Planned Preventative Maintenance).
Case study – Education Facility
Timeline of failure

- Brand new £250K traditional boiler / heating complex installed in education facility.
- Commissioned in the Autumn term.
- Heat exchanger fails in the following Spring.

Heat exchanger after a few months
Assessing the problem – test results

Water sample analysis

- pH: 9.6
- Aluminium: 20.1 ppm
- Total hardness: 20.0 ppm
- Copper: 1.5 ppm
- Iron: 0.14 ppm
- Conductivity: 1770 us

Deposit analysis

- Aluminium: 31%
- Calcium: 1.4%
- Copper: 11%
- Iron: 0.19%
- Phosphorus: 0.9%
- Zinc: 0.16%

Why did it fail?

Little or no pH buffer
The sample analysis revealed that:

- Ineffective flushing of cleaner was carried out.

**Remedial recommendations:**
- Replace heat exchanger.
- Flush and inhibit the system.
- Ongoing dosage monitoring.

### 1. Brand Y

<table>
<thead>
<tr>
<th>mls/litre</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>6.80</td>
</tr>
<tr>
<td>0.50</td>
<td>8.18</td>
</tr>
<tr>
<td><strong>0.60</strong></td>
<td><strong>8.44</strong></td>
</tr>
<tr>
<td>0.70</td>
<td>8.80</td>
</tr>
<tr>
<td>0.80</td>
<td>9.27</td>
</tr>
<tr>
<td>0.90</td>
<td>9.75</td>
</tr>
<tr>
<td>1.00</td>
<td>10.09</td>
</tr>
</tbody>
</table>

### 2. Sentinel X100

<table>
<thead>
<tr>
<th>mls/litre</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>6.82</td>
</tr>
<tr>
<td>2.00</td>
<td>7.35</td>
</tr>
<tr>
<td>3.00</td>
<td>7.55</td>
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<tr>
<td>4.00</td>
<td>7.76</td>
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<tr>
<td>5.00</td>
<td>7.94</td>
</tr>
<tr>
<td>6.00</td>
<td>8.11</td>
</tr>
<tr>
<td>7.00</td>
<td>8.32</td>
</tr>
<tr>
<td><strong>8.00</strong></td>
<td><strong>8.54</strong></td>
</tr>
<tr>
<td>9.00</td>
<td>8.78</td>
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<td>10.00</td>
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<tr>
<td>11.00</td>
<td>9.31</td>
</tr>
<tr>
<td>12.00</td>
<td>9.63</td>
</tr>
<tr>
<td>13.00</td>
<td>10.03</td>
</tr>
<tr>
<td>14.00</td>
<td>10.59</td>
</tr>
</tbody>
</table>

1. Titration of 100mls of 1% v/v Brand Y with 0.1 M NaOH
2. Titration of 100mls of 1% v/v X100 with 0.1M NaOH
Tips for success – closed heating systems

1. Check existing water conditions
2. Plan cleaning and subsequent treatment process
3. Select appropriate products
4. Verify water treatment product has been applied & dosed appropriately
5. Test and monitor appropriate water conditions are in place on an ongoing basis (PPM)
Section 3
The Impact of Limescale
What is limescale?

- Mains water contains varying levels of calcium salt.
- Calcium salts exhibit inverse solubility when water temperature rises.
- The carbonates are deposited as off-white solids on the inside surfaces of pipes and heat exchangers.

**Solubility of Calcium Carbonate**

\[
\text{Ca}(\text{HCO}_3)_2 \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}
\]
Water treatment guidelines – Part L / HSE

Part L:
“Where incoming mains water hardness exceeds 200ppm, provisions ... should be made to treat the water” including, electrolytic devices.

HSE:
“In hard water areas... scale control should be considered and suitable measures implemented to control legionella risk.”
The scale of the problem

Hard water affects more than 60% of England.

Most commercial buildings in the South, East and Midland areas of the UK will be subject to the detrimental effects of limescale if left untreated.

软到中等软
0-100mg/l as calcium carbonate equivalent

稍微硬到中等硬
100-200mg/l as calcium carbonate equivalent

硬到非常硬
> 200mg/l as calcium carbonate equivalent
Fuel wastage vs. scale thickness

% fuel wasted

% scale thickness

0 1.5 3 7 10 13

70
52.5
35
17.5
How does limescale form in heating systems?

- Scale deposits can form initially during the first test firing of a new installation.
- Limescale builds significantly in ‘once through’ water heaters as these heat large quantities of fresh water.
- Scale also causes issues in closed heating systems if not properly controlled.
How does limescale affect hot water systems?

- Impaired operation (especially in hot water cylinders/calorifiers).
- Reduced energy efficiency.
- Pumps have to work harder leading to increased energy consumption, reduced longevity.
- Heat exchanger failure due to overheating.
- System noise (kettling).
- On continuous flow water heaters, scale presence will result in immediate lockout
Additional consequences of limescale

Limescale deposits accumulate quickly in appliances such as water heaters, immersion heaters and sanitary fittings.

Limescale accumulation could lead to:

- Downtime.
- Replacement costs.
- Unplanned maintenance/repairs.
- Costs associated with cleaning ‘visible’ limescale.
Treating limescale in secondary hot water
Temporary solutions to combat limescale

Include: **Magnetic, & H.F impulse field.**

- Condition water temporarily through ‘ionisation’.
- Ionisation is lost if water is stored or flows through directional changes in pipework.
- May require several devices upstream of each water heater / calorifier / plate heat exchanger to provide protection = additional cost.
- Require a positive LSI water chemistry
- These may not treat modern high efficiency water heaters
LSI – Langelier Saturation Index

- LSI is a measure of a water's ability to dissolve or deposit calcium carbonate.
- Positive LSI is required for many conditioning devices, such as magnetic, electromagnetic and radiowaves, to control scale formation.
- The formula to calculate the LI uses:
  - pH
  - Alkalinity
  - Calcium concentration
  - Total Dissolved Solids
  - Water temperature

Only at +35 to 45 °C would some devices begin to prevent scale.
Permanent solutions to combat limescale

**Ion exchange water softener**
- Proven effective.
- Requires regular salt top up (plus labour and H&S) = high costs.
- Regeneration takes 90 minutes.
- Water wasted during regeneration.
- Water is not potable.
- Disposability issues.
- Requires regular water testing.

**Other methods**
- Reverse osmosis
- CTU
- Point of use filters
Permanent solutions to combat limescale

KalGUARD

- WRAS approved – water is potable.
- Methodology recommended in Part L.
- Uniquely powered electrolytic system
- Zinc anode lasts 10/12 years.
- Requires no salt.
- Does not waste water.
- Non LSI dependant
- Permanent treatment i.e. does not decay in storage or pumping.
- As a result of the above a single KalGUARD can be installed on the MCWS as it enters the building.
KalGUARD technology process

KalGUARD delivers low levels of stable zinc into water electrolytically via a zinc anode and copper cathode.

Zinc holds much of the calcium carbonate in solution, minimising formation of crystals.

The calcium carbonate which does precipitate develops as soft non-deposit forming aragonite, instead of hard deposit-forming calcite.

Untreated: Calcite deposit:

KalGUARD: treated water, no deposit.
KalGUARD technology process

CALCITE
highly crystalline

ARAGONITE
more amorphous
Case study – Whitbread
Problem / Solution / Savings

Problem:
- Previously used ion exchange softeners to prevent limescale.
- Programme was not being monitored or managed correctly.
- Solution was ineffective.

Solution:
- Ion exchange softeners were switched with KalGUARD’s for a trial period.
- KalGUARD systems have now been specified and installed in Premier Inn hotels for 10 years.

Savings achieved with KalGUARD:

<table>
<thead>
<tr>
<th></th>
<th>Savings Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>£3,000,000</td>
</tr>
<tr>
<td>Asset life increased</td>
<td>£250,000</td>
</tr>
<tr>
<td>Salt NOT purchased</td>
<td>£700,000+</td>
</tr>
<tr>
<td>Reduced water heating servicing</td>
<td>£200,000</td>
</tr>
<tr>
<td>Room rate refunds</td>
<td>£500,000</td>
</tr>
<tr>
<td>Fewer plumber call-outs</td>
<td>£300,000</td>
</tr>
<tr>
<td><strong>Total Saving</strong></td>
<td><strong>£5,000,000+</strong></td>
</tr>
</tbody>
</table>
Section 4
Key actions to takeaway today
Specification:

• Check hardness levels for limescale control & specify a proven technology.
• Refer to OEMs’ warranty requirements for chemical inhibitors and cleaners.

Water usage / make up to LTHW system:

• Fit a water meter to boiler make up line to enable make-up volumes to be monitored.

Corrosion risks:

• Ensure plastic pipe has oxygen barrier.

Testing/Monitoring:

• Use test kits to establish initial water conditions and to subsequently, check suitable protection remains in place.
Thank you
&
Any Questions