Scale in Domestic Water Systems: Causes and Prevention

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Introduction

Scaling can be defined as the formation of relatively thick layers of calcium carbonate and/or corrosion products on heat transfer surfaces. In this article, we are concerned solely with the formation of calcium (& magnesium) carbonate, although corrosion products, esp. iron oxides, are often associated with the carbonate scale. As described below, scaling results in loss of efficiency, reduced circulation and other detrimental effects in hot water systems.

Carbonic Acid System

Natural waters dissolve CO_2 from the atmosphere to form weak carbonic acid.

$$CO_2 + H_2O \leftrightarrow HCO_3$$

The carbonic acid dissociates into hydrogen, hydrogen carbonate and carbonate ions in the following stages:

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$
$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$$

Calcium ions in the water, dissolved from minerals, react with bicarbonate ions to form an equilibrium with calcium carbonate and carbon dioxide:

$$Ca^{2+} + 2HCO_3 \leftrightarrow CaCO_3 + CO_2 + H_2O$$

As the temperature of water increases, carbon dioxide is driven off and the equilibrium is pushed to the right. Therefore calcium carbonate precipitates in the hottest part of the system.

Water Hardness

It is common knowledge that the amount of scale produced is related to the hardness of the water but what exactly do we mean by hardness? Total hardness is the sum of all the calcium and magnesium salts in the water, which includes carbonate and bicarbonate but also other salts such as sulphates, chlorides and nitrates. Since the carbonate and bicarbonate anions precipitate as limescale on heating, the concentration of these ions is termed temporary hardness. Permanent hardness is given by the difference between total and carbonate hardness.

In the UK, domestic water supplies vary in total hardness from < 10 mg/L CaCO3 to over 500 mg/L CaCO3. Water is considered soft at <100 mg/L CaCO3, moderate at 100-200 mg/L, hard at 200-350 mg/L and very hard at >350mg/L.

Effect of Scaling

Since scale builds up primarily on heat transfer surfaces, scale deposition results poor heat transfer with a subsequent loss of efficiency. The problem is most acute in systems where hard water is constantly being replaced, such as in kettles or combi-boilers. However, even in closed recirculating heating systems, scale deposited from the initial fill water and make-up water to replace evaporative losses from the header tank, results in losses of efficiency of 2-6%. In real terms, this means increased fuel bills and higher CO_2 emissions.

Scale deposition is usually non-uniform, leading to localised hot spots on boiler surfaces. This gives rise to nucleate boiling resulting in boiler noise, especially on start-up in the morning. In extreme cases, limescale deposition has resulted in failure of cast iron heat exchangers due to thermal shock.

Reduced flow due to scaling can also occur on the hot water side of combi-boilers but it is most often noticed with showerheads, which may become totally blocked. On the secondary waterside, as pumps generate their own heat, scale also has a tendency to form within the pump housing. This can also restrict flow and reduce the life of the pump.

Prevention of Scaling

Water softeners, in which the calcium ions are replaced with sodium ions, are often used to overcome scaling problems. However, they are relatively expensive and they should not be used to soften drinking water. Hot and cold domestic water systems can also be treated with polyphosphate dosing devises. Polyphosphate, is a food grade chemical, which disrupts the growth of calcium carbonate crystals so that they do not form hard scales? This has the advantage from a health point of view that the water is not actually softened.

The use of physical water treatment devices to reduce scaling is becoming increasingly common. These are divided into three basic types: magnetic, electronic and zinc anode devices. Permanent magnet types have a generally poor record, as the magnetic signal they produce is very weak. Electronic devices pass a signal of varying waveform along one or two coils of wire wrapped around the pipe. It is thought that they work by inducing the formation of micro-crystals of calcium carbonate, which are flushed away and do not adhere as scale. Zinc anode devices may work in a similar way by producing zinc ions, which act as sites of nucleation for calcium carbonate micro-crystals. However, non-of these physical water treatment devices is a 100% reliable or 100% effective. The effectiveness may be related to water composition, such as dissolved iron concentration, although this has not been proven.

In closed recirculating heating systems, the use of corrosion and scale inhibitors can be quite effective at preventing scale formation on heat exchangers. These work by either using chelating agents (such as EDTA), which form a complex with the calcium ions, or by using low concentrations of polymers, which disperse the scale. Due to environmental reasons and because chelating agents such as EDTA can be aggressive to other metals, the use of polymers in a formulation is to be preferred.

Summary

Natural waters contain varying amounts of calcium, magnesium, bicarbonate and carbonate ions, which react to form limescale on heating.

This causes problems in domestic hot water and heating systems, such as reduced efficiency, reduced flow and blockages of components and boiler noise.

Various methods to reduce or eliminate these problems are the use of water softeners, polyphosphate dosing devices, physical water treatment devices and scale inhibitors.