"Taking the Salt out of Softening"

an informative two part article
written by: Jonny Seccombe.

As seen in Plumbing Systems & Design the monthly Magazine of ASPE the American Society of Plumbing Engineers.

November 2010 Issue

December 2010 Issue

TAKING THE SALT OUT OF SOFTENING

PART 1: HOW PHYSICAL WATER CONDITIONERS CAN BE AN EFFECTIVE ALTERNATIVE TO WATER SOFTENERS

BY JONNY SECCOMBE

Physical water conditioners (PWCs) for the treatment of hard water, or "no-salt softeners" as they sometimes are called, have attracted increasing interest from many engineers, contractors, and building owners. Hard water causing scale buildup has always been recognized as a problem, but the conventional treatment—water softening—can be expensive. However, with the need for energy-efficient equipment and the desire to reduce maintenance costs, owners are looking at new methods for hard water treatment.

In addition, many jurisdictions are considering restricting the use of water softeners to maximize opportunities for recycling water. In parts of the United States, softener bans have either been introduced, such as in Santa Clarita, California, or are being proposed or discussed by water utilities, such as in Inland Empire, California, to reduce the level of chlorides in wastewater discharge. These bans on self-regenerating water softeners are expected to become more widespread—thus the concern to seek alternatives to conventional water treatment technology.

A recent Battelle Institute study published by the Water Quality Association (WQA) identifies the benefits of reducing hard water scaling, including energy savings and a reduced use of chemicals for cleaning. While the study links these benefits of water treatment with conventional water softeners, the majority of the benefits also can be delivered simply and economically and with less damage to the environment by using PWCs to inhibit scaling.

However, widespread installation of PWCs is hindered by a lack of knowledge about how they work and their benefits. This lack of knowledge about their operational effectiveness is aggravated further by the complete absence of any standard by which their performance can be measured.

This article explores the science behind these devices and explains why PWCs can be an effective alternative to water softening in many applications. The second part of this series (to be published in the December 2010 issue) will explain some of the important characteristics of many of the more commonly available devices and review their capabilities and limitations as currently known. It also will look at the problems of developing an effective test standard and the likelihood of creating one that could be adopted in the future.

WHAT IS HARD WATER?

In nature, many compounds can be dissolved in water, but the principle one that results in scaling (calcium buildup) is calcium bicarbonate. It is caused by rainwater, which is slightly acidic, falling on calciferous rocks such as limestone or chalk and dissolving the calcium as it passes through the strata. Runoff water in rivers as well as underground aquifers can be hard, but generally areas with non-calciferous rocks are unaffected by hard water.

Figure 1 illustrates the extent of hard and soft water in the United States. Areas colored in red and white generally always require water treatment for hardness, while areas in blue and light blue might only need it sporadically.

To many people's surprise, hard water may not contain any calcium carbonate at all. Calcium bicarbonate is the dissolved form of calcium that causes the problems of hard water. Calcium carbonate always appears as a solid, a particulate powder or a rock, and once formed it is relatively inert. Calcium bicarbonate, on the other hand, has two unusual characteristics: It is less soluble in hot water than cold (in contrast, most things such as salt and sugar dissolve better in hot water), and when it comes out of solution (precipitates), it must do so onto a surface. It won't precipitate spontaneously on its own, which is the reason it sticks to surfaces and causes problems.

The general chemistry involved in hard water and scaling is illustrated in Figure 2. As shown, dissolved calcium bicarbonate precipitates to calcium carbonate, with the by-products of the chemical reaction being water and carbon dioxide. The precipitation occurs because of what can be described as a "scaling event" due to one, or a combination, of three reasons:

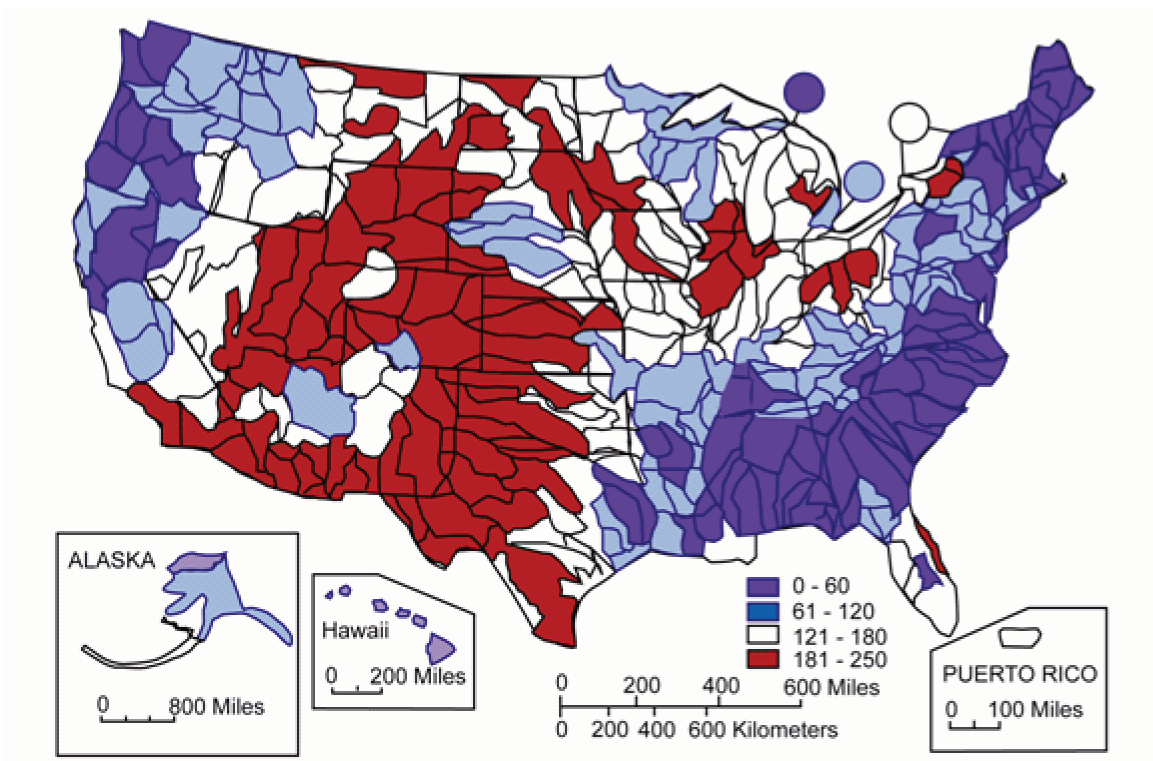


Figure 1 Concentration of hardness as calcium carbonate, in milligrams per liter
Source: U.S. Geological Survey

The description "hardness as calcium carbonate" used in the figure as a measure of hardness can be confusing. Many different dissolved compounds can cause hard water, but rather than list them individually, the general convention is to convert them to a common index by reference to their atomic weight. The most commonly used index is calcium carbonate, which is expressed as an equivalent to calcium. To convert calcium to a calcium carbonate equivalent (CCE), multiply the level of calcium (measured in parts per million [ppm]) by 2.5. For example, a calcium level of an apparently innocuous 80 ppm actually means that the water has a hardness of 200 ppm CCE, which is pretty hard and needs treatment. (200 ppm CCE equates to 11.6 grains per gallon.)

- If water is heated above approximately 130°F, precipitation commences, and as the temperature rises, the rate of scaling accelerates significantly.
- If the water pressure is reduced suddenly, such as when water passes out of a shower nozzle or through a pipe restriction or as a result of turbulent flow, scale also will form. For this reason, it is common to find a hot water line blocked up just after a right-angle pipe bend with little or no scale upstream of the bend.

- If the pH is increased due to chemical additives such as some cleaning fluids, or by evaporation from a wetted surface such as a shower door, scale also will form.

PROBLEMS CAUSED BY SCALING

The biggest problem caused by scale is that it sticks to surfaces, coating heat exchangers and pipes with layers of immovable calcium carbonate. Scale is about 400 times less conductive of heat than copper per unit thickness, so heat exchangers can suffer significantly reduced efficiency. Just ⅛ inch of scale can equate to a 12 percent loss of heating efficiency.

Manufacturers seeking ever-increasing efficiency are becoming frustrated that they spend large amounts of money creating more efficient products when all of the increased efficiency can be negated by scale buildup within a few months of installation. The attitude prevails in many parts of the country that if you get five years of use out of a water heater before it scales up, there is no point in treating the water. However, this ignores the fact that from the moment the heater is connected, its efficiency starts to decline, and more and more energy is wasted.

Figure 3 shows a picture of scale from a plate-and-frame heat exchanger that had been installed for one year.

The increasing use of tankless water heaters, with their high propensity for scaling, also has focused attention on the problems caused by hard water. Some of the design features that make these heaters work so efficiently are also hugely encouraging for scale formation. The rate at which scale forms increases significantly at the higher temperatures used by tankless heat exchangers, and this is aggravated by the deliberate encouragement of turbulence in the water flow to assist in heat transfer. This turbulence also creates low pressure zones, which encourages more scale formation.

Of less concern for the design engineer but vitally important to building owners and maintenance personnel is the visible manifestation of scale on showerheads, faucets, and other wetted surfaces. Scale holds dirt and bacteria, making fixtures unsightly as well as unhealthy, so cleaning times and costs are increased. Figure 4 shows a showerhead from a five-star hotel where no water treatment has been used.

CONVENTIONAL FORMS OF WATER TREATMENT

Conventional methods of water treatment focus on the removal of calcium from the water by substituting it with sodium or potassium using an ion-exchange media. These processes are well understood and documented, and if the equipment is properly calibrated, maintained, and supplied with salt, they are very efficient and effective. However, they also have drawbacks. Capital equipment costs can be high, and constant maintenance and servicing of the supply of salt are required. The biggest health drawback of a conventional water softener using salt regeneration is that it increases the amount of sodium in the softened water, and sodium-rich water is not recommended for consumption by infants, the elderly, those on a salt-restricted diet, and some hospital patients. In particular, the concern in a number of states, in the Southwest in particular, is the contamination of wastewater by the chloride effluent during regeneration, which restricts the capability of recycling the water.

"SCALING EVENTS"

$CA(HCO_3)_2$ CALCIUM BICARBONATE
(Dissolved)
Becomes
$CACO_3$ CALCIUM CARBONATE +
(Solid)
CO_2 CARBON DIOXIDE +
H_2O WATER

DUE TO

TEMPERATURE RISE
Above 130 F
PRESSURE DROP
pH INCREASED

Figure 2 The chemistry of hard water

ALTERNATIVE WATER TREATMENT

For these reasons and more, interest in alternatives to conventional water softeners is increasing, specifically nonchemical treatment, commonly known as physical water conditioning.

In contrast to the United States, use of PWCs in the United Kingdom is widespread and has been so for many years. Approximately 95 percent of all commercial facility hard water treatment is done by PWCs, while conventional water

Figure 3 Scale buildup on one-year-old plate-and-frame heat exchanger

softeners are being phased out in many commercial premises. The move toward PWCs is not for any regulatory reason, but because engineers recognize that they are cost-effective, easy to install, and require little maintenance, while delivering perfectly adequate protection against scaling.

In the United States there is widespread scepticism and a lack of understanding of the performance and mechanisms of PWCs. Some of this scepticism is well founded, given the number and variety of ineffective products on offer by many suppliers who often are uninformed or ignorant of the performance of their own products. However, a significant amount of research and documentation is available on many of the more effective PWCs.

HOW PHYSICAL WATER CONDITIONERS WORK

PWCs come in many forms, but the feature that most of them share is that they act directly on the process of scale formation, not on the calcium bicarbonate itself. They operate by generating nucleation seeds around which the scale precipitates in preference to the surfaces of pipes, heaters, etc. where it normally would form. Remember that scale must start forming onto something other than itself, normally pipes or heater surfaces, but scale forms more easily on nucleation seeds than on other surfaces.

The scale thus formed remains as calcium carbonate (a particulate) in suspension in the water. Once formed, it can't adhere to any other surface. The particles can grow by attracting more scale, and in static water they can settle to the bottom of a vessel as a wet sludge. Normally in an active water supply, the scale is carried away in the flow of water. It can be consumed, run to waste, or deposit due to evaporation as a light, nonadhesive powder. The scale particles are not harmful; they are actually beneficial to health as they provide easily absorbed calcium to the body. They are most easily described as being like talcum powder, normally invisible in the water but apparent as a light dusting on shower screens or surfaces. For process water, these particles can be filtered out using ultrafine filters or reverse osmosis. For typical commercial and domestic water services, it is normal to leave them in the supply.

Figure 4 Scale buildup on hotel showerhead

The important fact to understand is that PWCs operate in two stages. First, they generate nucleation seeds at a submicroscopic level, and then a scaling event must occur. As noted above, PWCs do not inhibit scale formation. They can actually encourage scaling, but as a suspended particulate that is relatively harmless. If these two stages occur close in both time and distance, the process will be more effective.

Some PWCs can be so effective at generating seeds that scaling is actually stimulated, so more precipitation occurs than otherwise would be the case. Less dissolved calcium remains in the water; therefore, the water is chemically softer, although the total calcium remains the same. The benefits of softer hot water can be detected through better lathering, less scum, and improved skin condition. The softening of the water is a side effect of the main process of some PWCs—it is not a function of the process itself as performed by a conventional water softener.

An additional benefit of some PWCs is the reduction and removal of existing scale from an already scaled system. The scale is not dissolved. It appears to exfoliate or become detached from the surfaces where it previously formed. In heavily scaled locations it is important to plan a strategy to deal with the possible problems that the detached scale can cause. Strainers and aerators need to be checked, and it is possible for heaters and lines to become completely clogged, requiring them to be taken out of service and cleaned. Vigilance and awareness are vital. The descaling process happens within a few weeks of installation, so it should not cause repetitive long-term problems. It is important to remember that scale traps dirt and bacteria, so there is a very small potential for the water to be less palatable for a few weeks.

Figure 5 shows photos of a valve taken before treatment by a PWC and again 10 weeks after treatment commenced. Virtually all the scale has fallen out of the valve, which is fully operable again after having been jammed solid with scale.

NEXT ISSUE

I hope this article has helped you understand the science of hard water and the possible benefits provided by the use of physical water conditioning versus water softening. In my next article, I will discuss some of the more commonly available devices, review their capabilities and limitations, and offer some ways to evaluate the different products. I also will look at the problems of developing an effective test standard and the likelihood of creating a standard that could be adopted in the future. PSD

Figure 5 A valve before and after physical water conditioning treatment

REFERENCES

1. Meldrum, Fiona C. and Richard P. Sear, "Now You See Them," *Science Magazine,* Vol. 322, December 19, 2008.
2. MacAdam, J. and S.A. Parsons, "Calcium Carbonate Scale Control, Effect of Material and Inhibitors," *Water Science and Technology,* Vol. 49, No 2, 2004.
3. Coatzee et al.
4. *ASHRAE Transactions,* Vol. 105, Pt. 2: *An Innovative Electronic Descaling Technology for Scale Prevention in a Chiller*, 1999.
5. Busch, K. et al., *Evaluation of the Principles of Magnetic Water Treatment*, API Report 960, American Petroleum Institute, 1985.
6. Aqua-Rex LLC: aqua-rex.com

Jonny Seccombe has worked in the water treatment industry for almost 20 years, specializing in non-chemical hard water treatment. He is accredited by the Chartered Institute of Building Services Engineers and the Institute of Plumbing and Heating Engineering as a provider of continuing professional development. He currently is President of Aqua-Rex LLC and Chair of its UK parent, Lifescience Products Ltd. For more information or to comment on this article, e-mail **articles@psdmagazine.org.**

TAKING THE SALT OUT OF SOFTENING

PART 2: PHYSICAL WATER CONDITIONER TYPES

BY JONNY SECCOMBE

As noted in the first article of this two-part series in the November 2010 issue, physical water conditioners (PWCs) for the treatment of hard water, or “no-salt softeners” as they sometimes are called, have attracted increasing interest from many engineers, contractors, and building owners. While conventional treatment methods such as water softening are well understood and documented—and if the equipment is properly calibrated, maintained, and supplied with salt, they are very efficient and effective—they also have drawbacks. Capital equipment costs can be high; constant maintenance and servicing for the supply of salt are required; salt regeneration increases the amount of sodium in the softened water; and chloride effluent contamination restricts the possibilities of reusing the wastewater.

For these reasons and more, interest in alternatives to conventional water softeners is increasing, specifically non-chemical treatment, commonly known as physical water conditioning. This article explains some of the important characteristics of the more commonly available devices and reviews their capabilities and limitations as currently known. It also looks at the problems of developing an effective test standard and the likelihood of creating one that could be adopted in the future.

TYPES OF PHYSICAL WATER CONDITIONERS

Whereas most conventional water softeners look very similar in their overall design, varying usually only in the size and number of resin tanks, PWCs come in a confusing range of types, sizes, and prices. The apparent uncertainty of their methods of operation adds to the confusion, and no assistance is offered to the engineer/specifier in the form of a generally accepted performance standard.

The common characteristic that most PWCs share, as explained in Part 1, is that they work by generating nucleation seeds in the water that attract the formation of scale in suspension, thus discouraging it from forming on the surfaces where it would normally occur. Scale forms as a submicroscopic particulate in suspension in the water where it is relatively harmless and no longer displays any adhesive properties. It is important to understand that it is a two-stage process. First, a nucleation seed is formed, and then a second process referred to as a “scaling event,” usually heating the water, has to take place for the scale to form on the nucleation seed.

It is convenient to classify most PWCs into distinct categories based on the type of nucleation seeds that they generate. The principal seeds are zinc, iron, and calcium carbonate.

Magnetic Water Conditioners

Zinc dosed into hard water is well established as an effective nucleation seed. What is variable is the way the zinc is introduced. Most magnetic PWCs (see Figure 1) work by making use of the mild electric current that is generated when water passes through the magnetic field. Research has shown that the anti-scale effect is due to the electric field induced by the ionic species crossing the magnetic flux lines. The electric field creates anodic and cathodic zones within the magnet itself or the magnet housing and consequently galvanic corrosion. If a zinc source is present, it will be corroded into the water flow. Similarly, electrolytic devices use a zinc anode and copper cathode to generate the electric field and therefore release zinc as a corrosion by-product.

The drawback of most magnetic devices is that the dosing is impossible to control and seldom relates to the requirement specified by the hardness of the water and its flow rate. To overcome this, a process has been developed leading to devices with a controlled electric field that can be varied according to the hardness of the water and the flow rate (see Figure 2).

Generally, the problems with any zinc-dosing device are twofold. First, the zinc anode becomes exhausted and requires changing, and many PWCs have no provision for their replacement. Those that do have such a provision may not indicate when the replacement is required.

Worse, however, is the effect of passivity. Expressed most simply, this is the tendency for the zinc anode itself to “scale up” so that the zinc corrosion process slows and eventually stops. Contaminants in the water determine how rapidly

Figure 1 An inline magnetic water conditioner

this passivity occurs—more quickly in water with high levels of minerals other than calcium such as iron, phosphates, and other commonly occurring solubles. Typically in the United Kingdom, zinc-dosing devices have a life of about two years. In the United States, their life span can be significantly shorter in areas such as Southern California and Southern Nevada where water quality is generally poor.

As a short-term solution, magnetic or electrolytic devices can be reasonably effective and inexpensive, and they are used widely by house builders in the United Kingdom. For longer-term protection and especially where water contains many contaminants, their performance can be disappointing.

For magnets applied externally to pipes, the evidence suggests that they rely on a zinc source in the plumbing, sometimes a heater anode or brass fitting, to be effective. Their performance is therefore very variable.

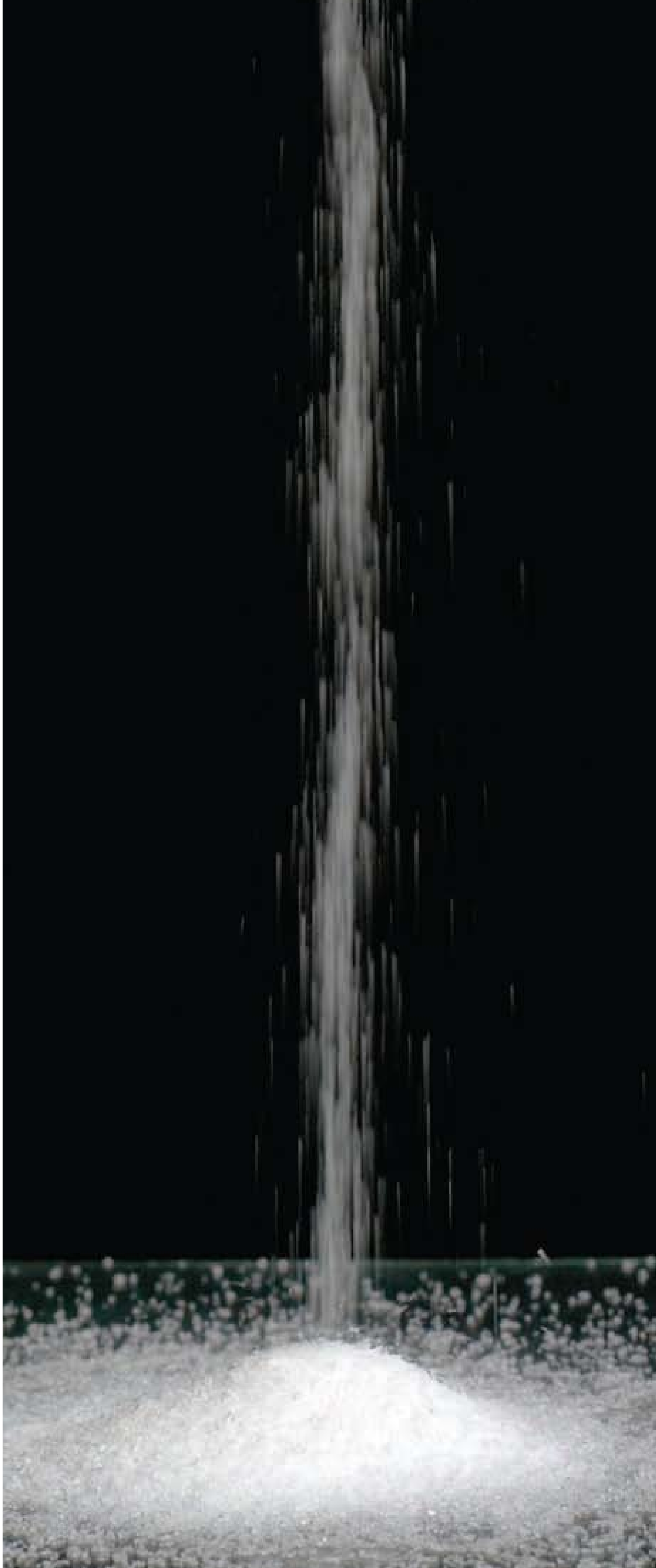
Template-assisted Crystallization

Template-assisted crystallization (TAC) is a relatively new process. It uses conventional water softener tanks, sometimes in parallel, partially filled with a specially developed media that can stimulate scale formation in cold water on the surface of the media. The scale grows larger by accretion until it is too large to be retained on the media, at which point it is released into the water flow and goes on to act as a seed to attract more scale during the scaling event. Some versions of this process work better when the water around the media is heated (see Figure 3).

After this product was launched in the United Kingdom in 2007, it was found to be very vulnerable to contamination from phosphates and copper in the water supply, so its performance in any location is very unpredictable. Generally, the life of the media is difficult to measure, so regular servicing is advisable. The product can be effective in home systems, but the need to match it to flow rates means that it can become very expensive for large systems.

Cathodic Process

Another class of PWCs, described most simply as using a cathodic process, also generates calcium carbonate micro-crystals for seeding. These devices pass an electrical charge from a non--corroding anode to a cathode around which a short-lived high pH is generated in the water. This causes scale to form locally, and seeds flow toward the scaling event. Some of these seeds accrete to the cathode, and



various mechanical means are used to disperse them, with varying degrees of success. The associated problems are that these devices require a relatively high level of maintenance and servicing, and they often can handle only a very limited range of flow rates.

Figure 2 A zinc-dosing device with controller to vary the rate of corrosion

Electromagnetic Process

The fourth class of devices can be described as electromagnetic or electronic. They act on minerals in solution in the water other than calcium, especially iron. Iron on its own is a weak scale inhibitor, but if it is excited by an electric charge, it appears to change its characteristics and act as a very effective nucleation seed.

For this process to be effective, it is necessary for iron to be present in the water naturally. In the United States, iron is usually sufficiently plentiful, resulting in highly effective treatment. However, in places where the iron content is exceptionally low, less than 10 parts per billion (ppb), the effectiveness can be reduced.

A characteristic of many electronic devices is that once the charge is removed, the seeds can revert to their previously ineffective form. The location of such devices is therefore absolutely critical to their effective performance. In particular, pumps and booster sets have a very negative impact on the treated water, significantly reducing the effectiveness of many of these devices, which therefore need to be located on the discharge side of the pump. Some equipment, such as dishwashers, can only be treated if the unit is installed inside on the re-circulating system after the pump. Dishwasher manufacturers generally disapprove of such intrusions on their equipment, although some have successfully embraced the technology as OEM installations.

These devices come in a variety of forms. Some are intrusive (see Figure 4) and are installed inline, but they are subject to maximum flow rates and cause a reduction in water pressure. Others are nonintrusive (see Figure 5) and are installed externally on pipes, able to accept unlimited flow rates and leaving pressures unaffected. Some of these devices are comparatively inexpensive. Typically a home can be treated with a single system costing $300, while a high-rise hotel with 2,500 rooms might require 10 units costing $8,000 each. Running costs are negligible, and no servicing or maintenance is required over a life span that can easily exceed 25 years.

PERFORMANCE CERTIFICATION

It would seem to be a relatively simple job to design a test protocol that would rank the performance of PWCs. Unfortunately, the opposite is the case. Many variables can

Figure 4 An intrusive electromagnetic unit

Figure 3 A template-assisted crystallization unit treating a gas tank water heater affect the performance of PWCs, especially water quality in terms of contaminants other than calcium bicarbonate. The performance of some PWCs can deteriorate over time, and some react differently to the high temperatures often used in test rigs. The only nationally accepted test is the German DVGW W-512, which in practice is found to be far too discriminatory. Most products fail W-512, but many of them actually work reliably in the field. Some products that pass W-512 are found to need high levels of maintenance and can break down easily.

While no other country has adopted a performance test protocol, projects are underway to develop a test protocol in the United States. However, it is doubtful if they will deliver a useful, discriminatory test in the near future. In the meantime, plumbing engineers need advice as to which products to specify.

PRODUCT EVALUATION

Thus, some basic product evaluation guidelines may be helpful.

- Price is not necessarily a good indicator of performance. Many low-price products easily outperform far more expensive products.
- Make sure the manufacturer has a clear idea of the mechanism that the product employs and can substantiate their claims. If the manufacturer is not clear about the mechanism, then they are not able to anticipate the

Figure 5 A nonintrusive electronic device

failure modes. All products have failure modes!

- Ask the manufacturer to discuss the types of applications for which their system is appropriate. Not all systems work in all applications. Some systems may have health or manufacturing risks associated with how the hard water is treated and how it is changed in the process.
- Get a clear idea of the maintenance requirements. Ideally, a good PWC should have no maintenance or servicing requirements. Any maintenance that may be required is likely to be irregular and therefore likely to be forgotten or ignored. Also get an idea of the cost of maintenance, supplies, repairs, replacement parts, energy consumption, etc.
- Make sure that flow rates and pressure drops are fully explained in the product literature. Some products are not limited by flow rates and cause no pressure drop. Others can be severely restricted, and some can't handle continuously flowing water.
- Make sure you fully understand the critical nature of where the product is located. Many products have critical locations, but many manufacturers are ignorant of them.
- Unless you are happy about your client being an experimental guinea pig, make sure you specify a product that has a proven track record over a long period of time and is well understood by the manufacturer. Ask the manufacturer about recent studies, tests, and similar installations.

CONCLUSION

PWCs have a poor reputation in the United States. Some bad products are out there, even some that can cause serious detrimental corrosion in a plumbing system. On the other hand, a number of good products with excellent track records can deliver highly effective water treatment in hard water areas. The lack of a performance standard should be no barrier to their investigation by plumbing engineers. In the future, the development of a performance standard would help plumbing engineers feel more comfortable specifying them for their projects, but it could be a long wait for this to happen. PSD

REFERENCES

Meldrum, Fiona C. and Richard P. Sear, "Now You See Them," *Science Magazine,* Vol. 322, December 19, 2008.

MacAdam, J. and S.A. Parsons, "Calcium Carbonate Scale Control, Effect of Material and Inhibitors," *Water Science and Technology,* Vol. 49, No 2, 2004.

Coatzee et al.

ASHRAE Transactions, Vol. 105, Pt. 2: *An Innovative Electronic Descaling Technology for Scale Prevention in a Chiller,* 1999.

Busch, K. et al., *Evaluation of the Principles of Magnetic Water Treatment,* API Report 960, American Petroleum Institute, 1985.

Aqua-Rex LLC: aqua-rex.com

Jonny Seccombe has worked in the water treatment industry for almost 20 years, specializing in non-chemical hard water treatment. He is accredited by the Chartered Institute of Building Services Engineers, and Institute of Plumbing and Heating Engineering as a provider of continuing professional development. He currently is President of Aqua-Rex LLC and Chairman of its UK parent Lifescience Products Ltd. For more information or to comment on this article, e-mail a**rticles@psdmagazine.org.**

AQUA REX

PROVEN TECHNOLOGY THAT YOU CAN SPECIFY WITH CONFIDENCE

The Electronic Physical Water Conditioner

- its not a magnet!

Over 250,000 units in use worldwide with a sixteen year track record of successful installations in the UK.

Scale forms in suspension in the water
- it doesn't stick to surfaces.

It cleans out old scale from a system
- check out case studies on our website www.aqua-rex.com

Its simple to install, no pipes to cut, no servicing or maintenance required, a design life in excess of 25 years and annual electrical running costs of about $25.00

Visit us online: www.aqua-rex.com
Call Us Today: 1-877-640-2170

AQUA REX THE TECHNOLOGY YOU CAN TRUST TO TREAT HARD WATER