Physical water treatment science & pseudoscience

The lack of scientific support stands in stark contrast to claims.

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When rain falls through unpolluted air, it picks up carbon dioxide, a small portion of which reacts with the water to form carbonic acid. Thus, pure water in contact with the air becomes acidic, eventually reaching a pH of around 5. If the rainwater permeates into the soil, it can become even more acidic owing to the additional CO_2 produced by soil organisms.

Rocks and soil sediments contain carbonates, mostly of the “hardness ions” calcium, magnesium and iron. Limestones, which underlie soils in many regions, consist entirely of carbonates. Carbonates act as bases and, as such, react with acids. Thus, the portion of the global water cycle that transports carbon from the air into natural waters constitutes a gigantic acid-base reaction that yields hydrogen carbonate ions, commonly referred to as bicarbonate. The natural waters that result have pH values between 6 and 10 and are essentially solutions of bicarbonates.

When bicarbonate-containing solutions become too concentrated, their contents tend to deposit on surfaces. But calcium and similar bicarbonates cannot exist as solids, so what happens instead is that the hardness ions join up with carbonate ions (always present as minority species in such solutions) to form carbonate-containing scale deposits.

The other problem with such water is that the hardness ions react with soaps to form unsightly scum deposits on laundry and in bathtubs.

Conditioning of water can refer to any treatment that alters its composition in order to render it appropriate for a specific use. Softening is essentially the same thing, usually implying that the conditioning makes the water suitable for general domestic use. Most commonly, this means removing ions such as calcium and magnesium that tend to form carbonate scale deposits on surfaces, either through simple contact (as within pipes) or as evaporative residues (boilers, tea kettles, shower walls, etc.). This can be accomplished in various ways, the simplest and best-known being conventional ion exchange or reverse osmosis treatments.

Physical and “saltless” water conditioning (PWC)

These terms refer to treatment methods (usually other than reverse osmosis) that involve no direct chemical processes and which in most cases can be provided by a device that is installed in or attached to a water-supply line.

Although a wide variety of these devices have been available for some time and one might think that the question of their efficacy would now be clearly settled, this is unfortunately not the case:

• Most reports of the successful use of PWC have been anecdotal and lacking in quantitative data and proper controls.

• Most scientists who have looked into PWC remain very skeptical — as they tend to be of any field for which there is no obvious theoretical model and in which quantitative and reproducible results are hard to come by. Many scientists are put off by the stigma the field has acquired due to the claims made by some of its promoters and by the widespread promotion of various questionable applications involving magnets.

• Most water treatment engineers who have investigated magnetic water treatment (PWC) in controlled industrial settings report negative results.

• The very small number of reports that might lend credence to PWC are mostly relegated to obscure, non-mainstream journals and conference proceedings. Scientifically-validated studies of demonstrably successful PWC performance are virtually unknown.

• Few PWC vendors specify the parameters of water composition, magnetic field strength, treatment geometry and flow rate required for satisfactory performance; many fail to offer any quantitative performance data. The few "case studies" cited are rarely thoroughly researched to engineering standards, and are frequently difficult if not impossible to verify. Explanations of how the devices work are commonly simplistic and scientifically untenable.

A common claim made by PWC device managers is that the hardness ions are made to precipitate within and be carried along by the water before they have an opportunity to form adherent scale deposits. Some evidence for this in a heat-exchanger application has been published, but it has not been established generally. The presence of suspended solid carbonates would require the carbonate ion concentrations in the treated water to remain at saturation levels, so that the water would still be subject to scale formation on heated surfaces and it would form soap scum and evaporative deposits on shower walls and in teakettles.

Among the small number of scientists who have given some thought to PWC, there is no consensus about the possible mechanisms. This is not surprising; the entire process by which ions form precipitation nuclei is poorly understood and there is the additional complication that the bicarbonate ions present in hard water do not form solid precipitates, but deposit as carbonates instead. "Bare" ions do not exist in solution, but are protected by a hydration shell of loosely-attached water molecules and surrounded by an electric double layer of counter-ions which makes formation of incipient crystallization nuclei unlikely.

"Supporting" literature

Scientific and engineering studies of PWC have done little to support the various technologies involved:

• A 10-year study at the 3M Corporation involving a variety of magnetic, electronic, catalytic and electrostatic devices showed no significant effects in reducing the scale formed in side-by-side steam-heated tube shells.

• In 2001, a task force organized by the Water Quality Association (WQA) reported on a survey of 106 technical papers dealing with PWC. Of these, only 34 were judged to meet the scientific criteria established by the group. Most of these articles dealt with the effects of various factors that might influence softening or scale control; none of them directly addressed the question of whether or not PWC "works," nor was this judgment made by the Task Force, whose main objective was simply to bring together scientifically useful information that might inform further research in the field. A reading of the abstracts of these papers suggests some possibilities, but offers little support.

• The situation was nicely summed up in an article published by Mike Powell. The author provides a few references, mostly to non-refereed journals and conference proceedings of dubious quality. Powell observes that "the utter lack of published data is revealing. If it actually worked as claimed, it seems likely that it would by now be commonplace. It is not."

• Similarly, in a conference technical paper, the author states that "in contrast to the testimonials common to NCD [non-chemical devices] marketing literature, the many controlled studies undertaken by various government and industrial organizations have resulted in a consensus opinion that NCD are not capable of producing the effects claimed in the literature. In general, the theories advanced by the NCD suppliers to explain operation of their devices show a lack of agreement with accepted scientific principles. In spite of an extensive history of installation failures, findings of no effect in controlled studies and no acceptable theory of operation, new NCD are accepted in the market on a routine basis, often obtaining significant sales before the inevitable disasters result in that particular device being discredited."

• An unfortunate report issued by the U.S. Department of Energy did little to clarify the issue. It presented a suspiciously uncritical case for both magnetic and electrostatic water treatment. It provided no references to support the claims made and the explanations of how these devices are supposed to work were scientifically naïve. Although this flawed report was eventually withdrawn, copies of it are still widely distributed by some PWC device promoters.

Permanent magnets

Devices in which one or more permanent magnets produce fields that cut perpendicularly across the direction of water flow have been known for over 60 years and are now widely marketed as "magnetic water treatment" (MWT) appliances. Much of their more recent popularity can be attributed to a presentation made to a conference by Klaus Kronenberg in 1985, in which he observed that evaporation of calcium carbonate solutions that had passed through a succession of up to 16 fields produced crystalline deposits whose physical forms suggested that they would be less adherent than ordinary scale.

Water molecules are diamagnetic and are insensitive to fields of ordinary strengths. It is widely claimed that MWT works by forcing oppositely-charged ions to move in opposite directions in the water, causing them to recombine and precipitate out. This simplistic mechanism is untenable for a number of reasons. An analogous effect, known as magnetohydrodynamics, occurs in plasmas (ionized gases) but has never been observed in liquid solutions. Dissolved ions with their hydration shells are too large to diffuse rapidly through the hydrogen-bonded structure of water.

Despite the paucity of scientific support for MWT, many users of these devices claim to be satisfied with their performance — far more commonly than with other forms of PWC. It is always difficult to evaluate anecdotal reports of these kinds in the absence of reliable information both on the composition of the supply water and the criteria by which the results are judged.

Still, scientific understanding is never complete, and there may be conditions under which MWT may well be effective. In this context it is worth calling attention to a study published in a South African technical journal that describes a series of experiments in which one of two parallel heaters was fitted with a permanent magnet device showed scale formation reductions varying over a rather wide range (17-70 percent), with an average of 34 percent.

Alternating or pulsed electromagnetic fields

Electromagnetic scale-control devices are probably now more widely marketed than any other kind. They usually employ a solenoid coil that surrounds a non-ferrous tube through which the water passes. The coil is excited with an alternating current, usually in the audio-frequency range, or with pulses, often of varying duration. An alternative scheme injects a radio-frequency signal longitudinally into the water stream. Many of these devices purport to remove scale from existing installations, but this has never been satisfactorily documented.

Many of the claims about how these devices work are similar to those made for permanent magnet devices, and they suffer from the same weaknesses. In spite of the greater number of electromagnetic PWC devices on the market, the number of anecdotal reports that attest to their efficacy is very small, and there is virtually no published scientific support. In several very detailed case histories published by chemical engineer T. Keister on his website, he remarks that, in every instance, the observed reduction in scaling could be attributed to changes in operating procedures or to other aspects of water chemistry, particularly the presence of phosphates.

“Catalytic” devices

Most of the products in this category employ “precious metals” that are purported to “neutralize” Ca^{2+}, Mg^{2+} and HCO_3^- (bicarbonate) ions by supplying or removing electrons as required. The problem with this is that it is thermodynamically impossible to accomplish either of these in the presence of water, since water itself is more easily oxidized or reduced than any of these ions. The use of the term “catalytic” in this context is misleading: A catalyst can only influence the rate of a chemical process, not its final outcome, which depends entirely on thermodynamics. There is absolutely no scientific support for any of these claims.

If a truly catalytic scale-precipitation process exists, it might be one involving epitaxial crystallization. This is based on the principle that nucleation (formation of the first tiny crystallite) is aided when the solution is in contact with a surface whose crystal structure is built up from units having lattice spacings similar to that of the substance to be deposited. There is a fairly extensive scientific literature relating to the use of epitaxial crystallization in semiconductor fabrication, corrosion control and self-assembling structures, but not on precipitation from aqueous solutions.

Although no detailed studies supporting epitaxial technology for PWC have appeared in the scientific literature, some makers of these devices do claim positive lab test results.

Conclusion

The lack of credible scientific support for the efficacy of present-day PWC devices stands in stark contrast to the claims made by most vendors (and even some users) of these products. Given the potential economic benefits of a widely-applicable chemical-free softening process, especially in arid regions, such as the U.S. southwest, one would expect much more scientific and engineering support for the claims that have been made.

Still, science is never complete, and if qualified investigators could be motivated to follow up on some of the more well-founded leads that have appeared in the literature, it is possible that some of these PWC technologies could be shown to be effective, although almost certainly under very constrained conditions.

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