Non-chemical Water Treatment Systems: Histories, Principles and Literature Review

Loraine A. Huchler, P.E., MarTech Systems, Inc., Lawrenceville, NJ

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Abstract

There are numerous systems using combinations of electrical, magnetic and mechanical means to replace water treatment chemicals. This paper will describe currently-marketed devices, their proposed mechanisms of operation, review the literature for clear evidence of effective action in laboratory and field applications and provide recommendations for evaluations in cooling towers.

Introduction

The history of non-chemical water treatment systems (NCWTS) is long and controversial, marked by many claims for and against the effectiveness of such systems. Many investigators have examined the effectiveness of these systems with mixed results. Welder and Partridge in 1953,[1] Wilkes and Baum in 1979,[2] and Limpert and Raber in 1985[3] presented reviews of operating principles and claims for similar "new generation water conditioning devices." This paper provides a similar review for currently available commercial devices.

The purpose of this paper is not to provide a comprehensive review of the literature because there are good reviews of the current science,[4] technologies, and their field applications.[5] Nor is the purpose to refute or corroborate claims by manufacturers about the effectiveness of these devices. Rather, the intent is to provide:

- an introduction to the current technologies and devices used in cooling and boiler systems,
- provide descriptions of the mechanical and electrical principles by which they operate,
- discuss possible mechanisms for action,
- describe situations in which clear evidence of effective action is demonstrated in lab and field situations and
- provide recommendations for evaluating the claims of these devices in field situations.

Non-chemical Water Treatment System Description

There is no single term that describes all of these devices. The awkward term "non-chemical water treatment systems" describes a host of technologies including magnetic, electromagnetic, electrostatic, and AC induction. Welder and Partridge used the term "water conditioning gadgets; Wilkes and Baum, the term "water conditioning devices." "Physical water treatment" and "electronic water treatment" are also general terms currently used by some proponents of these devices.

For this paper, only those devices that operate on mechanical and electrical principles are discussed. Devices that generate chemicals in-situ such as electrolytic zinc or silver ion generators are excluded; these are simply chemical treatments in another form. Nor does this paper include equipment where the mechanism and effectiveness of action[6] is well understood such as deaerators, ion-exchange softening units, reverse-osmosis units, magnetic separators, or cathodic corrosion control units.

Claims for mechanical and electrical-based devices have not changed much since Wilkes and Baum wrote their

[1] Welder, B. Q., Partridge, E. P, "Practical Performance of Water Conditioning Gadgets" 14th Ann. Water Conf., Engrs' Soc. of West. Penn. (1953)
[2] Wilkes, F. J., Baum, R, "Water Conditioning Devices – An Update," 40th Ann. Water Conf., Engrs' Soc. of West. Penn. (1979)
[3] Limpert, G. J. C., Raber, J. L., "Tests of Non-Chemical Scale Control Devices in a Once-Through System," Corrosion'85, Paper 250, NACE, Boston, MA
[4] Baker, J. S, Judd, S. J., "Magnetic Amelioration of Scale Formation" Water Resources V.30 pp. 247-260 (1996)
[5] Smothers, Kent W., Curtiss, Charles D., Gard, Brian T., Strauss, Robert H., Hock, Vincent F., "Demonstration and Evaluation of Magnetic Descalers, ERDC/CERL TR-01, US Army Corps of Engineers, Construction Engineering Research Laboratory, Jun. 2001

[6] Puckorius, P., "Mechanical devices for water treatment: Just how effective are they?" Power, Jan. 1981 pp 60-62

review in 1979. These claims include the prevention of corrosion, scaling, and fouling (mineral and microbiological) with

- little or no effect of operating results on water chemical composition,
- little or no operator oversight of the program,
- minimal or no energy input required and
- energy savings through the reduction of blowdown flow rates from cooling towers or boilers.

Changing from chemical treatment to a NCWTS is generally claimed to

- Eliminate handling of hazardous chemicals used in conventional chemical-based treatments and
- Eliminate disposal costs or pollution from chemical-based systems

Given these claims, it is easy to understand why this class of devices continues to generate interest from owners and operators of systems requiring water treatment.

As noted in the reviews described earlier, a considerable body of literature has been developed over the years examining the mechanisms, and lab and field performance of these devices. From this literature, the following generalizations can be drawn.

- The performance of these devices under both controlled laboratory conditions and field conditions has been unpredictable.
- In applications with positive results, basic mechanical and chemical information on the systems has been lacking, compromising the credibility of these results. In addition, the experimental designs have been questionable.
- Some manufacturers have made extravagant claims leading to a discrediting of the industry. For instance, some manufacturers claim that the use of such devices will soften water (i.e. eliminate hardness from the treatment stream).

The controversy about these devices extends beyond the efficacy in field applications to include the mechanism by which they work. While well-accepted physical and chemical principles can explain the operation of deaerators, ion-exchange equipment, magnetic separators, or reverse osmosis units, the mechanisms for the non-chemical systems continue to be sharply debated. Since the 1979 review, investigators have developed hypothesis of operating principles from laboratory experiments.

The focus of this paper will be on three specific categories of devices: magnetic (either permanent or electro-magnetic), electrostatic, and a newer type of device, alternating current (AC) induction where alternating currents of different magnitudes and frequencies pass through a coil wrapped around a pipe. While the magnetic fields generated by such devices are minimal, manufacturers claim that the imposition of complex fields prevent fouling, scaling and in some cases microbiological (MB) growth and corrosion.

This paper will focus on cooling and hot water systems. Most of the magnetic devices are applied on residential hot water systems while most of the other technologies are used on open-circuit cooling systems. There are a few manufacturers that claim application in steaming boiler systems, however, this manuscript will not include these applications.

Currently Marketed Devices

Table 1 contains a listing of the devices currently available from a web-based search or contact with the manufacturers; about 30 manufacturers were found. As shown in Figure 1, more than half of these devices are direct current (DC) magnet-based (permanent or electro-magnetic). The manufacturers have targeted the consumer marketplace with a few claims for use in commercial systems. About 30% of the manufacturers offer AC induction units while 18% offer electrostatic systems.

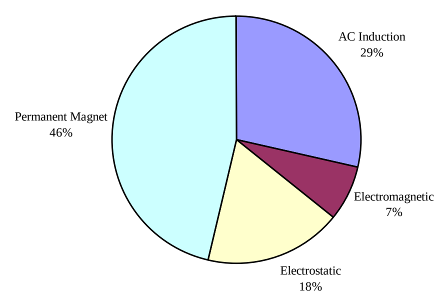

Figure 1 NCWTS Marketplace (based on number of different devices)

The manufacturers are almost evenly divided between the United States (US), the United Kingdom and rest of the world. Most companies have been in business for 10 to 30 years. One manufacturer (Solavite) claims to have sold a device since 1936. A few of the devices are currently patented, mostly in the US. Consumers can purchase devices using the Internet with prices ranging from $100 up to $4000.

In the next section, the following information is provided.

- A brief review of the technologies and patents
- Evidence of efficacy
- Currently understood mechanism
- Technology applications

Table 1 – NCWTS Survey

Product Name	Company	Country	Starting year	Website/Telephone Number
DC Magnetic				
"CEPI" and "M" series	Q-Trade Ltd	Israel	n/s	Q-Trade.co.il
Aqua-Flo	Aqua Flow Inc.	US	1981	aqualfloinc.com
ClearScale (Cu pipe)	HDL Fluid Dynamics, Ltd	Ireland, UK	1973	www.treatwater.com
Colloid-a-Tron	HDL Fluid Dynamics, Ltd	Ireland, UK	1973	www.treatwater.com
Descal-A-Matic	Descal-a-matic Corp.	US	1970	descal-a-matic.com watec.com
Ecotec	Ecotec, Inc	US	n/s	ecotec-inc.com
EnviroScaleFree Scale Prevention System	Rain Dane Water Systems, Inc	US	n/s	magneticwatersystems.com
GMX Model 800	GMX International	US	n/s	gmxinternational.com
Hydrascale	Hydroscale, NA	US	1988	Hydrascale.com
Kemtune	Kemtune, Incorporated	US	n/a	n/a
LimeMaster	Salamander Engineering, Ltd	UK	n/s	salamander-engineering.co.uk
Linear Kinetic Cell	Ener Tec	US	1978	ener-tec.com
Mag-Sol	Magnetic Solutions	US	n/a	scalefighter.com
Magstream (SS pipe)	HDL Fluid Dynamics, Ltd	Ireland, UK	1973	www.treatwater.com
Monopole Hard Water Conditioning System	Magnetizer Inc	US	>20 yr	magnetizer.net
ScaleTron	HDL Fluid Dynamics, Ltd	Ireland, UK	1973	www.treatwater.com
Electrostatic				
AW series	Aquasan	Spain	n/s	acquasan.com
Chem-Free	Chem-Free	US	n/s	chemfreewatersystems.com
Dolphin	Clearwater Systems, LLC	US	n/s	clearwater-dolphin.com
Ion Stick	York Energy Conservation Advanced Water Tech., Inc.	Canada	1978	ionstick.com
Zeta Rod	zetacorp	US	1990	zetacorp.com
AC Induction				
	Flo-Logix Int'l Ltd.	UK	1992	flo-logix.com
Aqua-4D (w/ vortex)	Aqua-Cycle	Switzerland	N/s	aqua-cycle.ch
Clearwave-HD	Multiple distributors	n/s	n/s	ddchem.com or fieldcontrols.com
ScaleBan	Ecosoft Systems	US	1987	ecosoftsystems.com
Scalewatcher	Fast Systems, Ltd	UK	1989	scalewatcher.co.uk
Scalewatcher Enigma	Environmental Treatment Concepts	UK	1989	electronicdescaler.com
Water Imp	Water Imp	UK	N/s	Waterimp.co.uk
Waterwave	Salamander Eng., Ltd	UK	N/s	salamander-engineering.co.uk
Other				
Bon-Aqua	Bon Aqua Int'l, Inc.	US	n/s	919-294-7575
SESI	Salamander Eng., Ltd	UK	n/s	salamander-engineering.co.uk
Solavite	Environteck	France	1936	solavite.fr
VRTX	A. W. Chesterton Company	US	n/s	VRTX-technologies.com
Water Vitalizer	Environturn Systems	n/s	n/s	enviroturn.com

n/s – not specified

Magnetic Water Treatment

Description and Claims

Magnetic water treatment devices are the oldest of the three categories of devices with the first US patent on an electromagnetic water treatment device in 1890.[7] The use of magnets for water treatment appears simple. The application requires a magnet (permanent or electrically induced) placed in or around a non-magnetize-able pipe. The water to be treated flows through the pipe. The manufacturers claim that the magnetic flux through which the water supersaturated with calcium flows alters the water or particles and induces bulk water crystallization of calcium carbonate. The empirical evidence of treatment is claimed to be the formation of a "softer" scale, i. e. a scale that is easily suspended and removed in the bleed stream.

Although the claims vary widely among manufacturers, there appears to be general agreement that the device only works with calcium carbonate or calcium sulfate precipitation, but not with silica-based precipitates. In some units, the entire flow of water is exposed to the magnetic treatment while in other applications, part of the flow is diverted and exposed to the magnetic field.

The patent literature for magnetic treatments is almost entirely devoted to various ways to improve the intensity of the magnetic field and or the exposure of treated water to the field. All of the patents reviewed assume that a connection has been established between the strength and exposure to the magnetic field and the inhibition of scale on heat transfer surfaces. For example, Sanderson describes[8] a "fully shielded multiple core water conditioner" that isolates the magnetic lines of force produced by the respective magnets from each other. This results in the lines of force intersecting the water flowing through the treatment chambers in a more radial direction. Ehresmann describes[9] an "adjustable magnetic water treatment system" with both the alternating current magnet and a direct current magnet means in parallel lines. Garrett et al. describes[10] a device using a pulsed DC magnetic field in a pipe filled with balls of un-magnetized steel balls that provides "a tortuous path…where the magnetic field is concentrated at the nodes defined by the pole pieces and the spheres through which the magnetic flux path is completed from pole piece to pole piece."

Science

Of the three types of devices, magnetic devices are by far the most widely studied in the laboratory. The most extensive review of laboratory work is by Baker and Judd in 1996.[11] They describe the specific effects claimed by various researchers over time that have included demonstrated positive effects on

- physical and chemical water properties,
- nucleation and growth of precipitated particles,
- crystalline characteristics of formed calcium carbonate particles,
- scaling kinetics and equilibrium,
- coagulation and
- corrosion.

Baker and Judd describe the effects of various contaminants and solution properties including iron corrosion products, magnesium and zinc ions, ionic strength, temperature, and magnetic field strength. They also cite evidence from laboratory studies showing that the effectiveness of the treatment depends on the intensity of the magnetic field, the length of time that the water is exposed to the field, and the water flow rate.

Other published lab results describe the effects of magnetic fields on the aggregation of particles in colloidal systems and crystal growth modification. While some manufacturers claim that magnets reduce surface tension of water, there is no credible laboratory evidence to support this assertion.

The reviewed studies suggest that the positive effects are enhanced by prolonged or repeated exposure to the magnetic field, that a threshold magnetic field is required to achieve a response and that flowing systems provide a better response. Most intriguing is the observation by some investigators that the effect of the magnetic field on the zeta potential and diffusivity of latex particles is retained by the water for up to 143 hrs[12] after the magnetic field has been withdrawn.

Investigators have proposed various mechanisms for these effects. As noted by Baker and Judd, the interpretation of results and evaluation of proposed mechanisms is compromised (often severely) by "inadequate or unspecified control of solution chemistry, in particular the solution pH and the level of contamination by scale adjusting ions."

Baker and Judd conclude that, "in some cases, magnetic water treatment can exert significant scale-inhibiting effects." However, they also conclude that the application of this scale-inhibiting effect to specific systems is very difficult. It has been difficult to define optimum

[7] Faunce, A. and S. Cabell, US Patent 48,579 issued 1890
[8] Sanderson et al. US Patent 4,455,229 issued June 19, 1984
[9] Ehresmann, US Patent *4,485,012* issued November 27, 1984
[10] Garrett et al. US Patent 4,299,701 issued November 10, 1981

[11] Baker, J. S., Judd, S. J., "Magnetic Amelioration of Scale Formation," Wat. Res. 30, pp 247-260 (1996)
[12] K. Higashitani, et al. , Magnetic Effects on Zeta Potential and Diffusivity of Nonmagnetic Colloidal Particles, J. Of Colloid and Interfacial Science 172 383-388 (1995)

operating conditions with respect to magnetic field strength, orientation, treatment time, and fluid flow velocity because experiments have proved to be so irreproducible between different laboratories. Baker and Judd conclude that magnetic treatment is most effective when

- fluid flow is orthogonal to the magnetic field and
- exposure to the field is prolonged or the solution is recirculated.

Application of Technology

While an understanding of the science of magnetic water treatment seems to have evolved over the past 20 years, its application to real-world installations remains sharply debated. Donaldson and Grimes,[13] Grutsch and McClintock,[14] and Raisen[15] have reported positive published field results.

Many more studies have resulted in negative conclusions. The most recent study by the U. S. Army Corp of Engineers[16] found no positive effects for two magnetic devices. Two previous studies by this group (1984 and 1996) did not find positive results. However, the positive lab results described above and the continued interest by the water treatment community resulted in a third pilot-scale study of a hot water distribution system typical of institutional installations under well-controlled chemical and physical conditions.

These researchers carefully controlled the variables and conducted discussions with manufacturers of the devices regarding test parameters and conditions. Measurements included visual inspection of corrosion coupons and quantitative measurements of scale quantity, composition, and crystalline nature by X-ray diffraction (XRD). XRD measurements are of critical importance because many suppliers of devices claim that the magnetic field favors the formation of calcite, a compound that is softer than other crystalline calcium carbonate deposits. The results were peer-reviewed by experts in academia, industry, government and professional associations. No positive effects were noted in any of the monitored parameters.

A review of the manufacturers showed a focus on the residential market with no commercial or industrial case histories.

[13] Donaldson, J. D., Grimes S. "Lifting the Scale from our Pipes" New Scientist 117 pp 20-24 (1988)
[14] Grutsch, J. F. McClintock, J. W. "Corrosion and Deposition Control in Alkaline Cooling Water Using Magnetic Water Treatment at Amoco's Largest Refinery" Corrosion '84, Paper 330, NACE, New Orleans, LA
[15] Raisen, E. "The Control of Scale and Corrosion in Water Systems Using Magnetic Fields," Corrosion'84 Paper 117, NACE, New Orleans, LA
[16] Smothers, K. W. et al. "Demonstration and Evaluation of Magnetic Descalers" Sep. 2001, http://www.cecer.army.mil

Electrostatic Water Treatment

Description and Claims

In a typical electrostatic water treatment system, a cylindrical electrode with an insulating coating on the outer surface is positively charged with a high positive voltage (e.g. up to 30,000 volts) but a low current. This electrode is placed at the center of an externally grounded cylindrical metal housing and the water to be treated flows in the annulus between the housing and the electrode.

The use of electrostatic energy to separate a water-in-oil emulsion is a well-established technology. For example, Winslow describes[17] an electrical field device to treat water-in-oil emulsions. Hodgson describes[18] a dual field electric treatment device that creates pulse intervals that enhances the separation of a water-in-oil emulsion in a conventional multi-tray emulsion treater by reducing the formation of damaging continuous water threads between electrodes.

The current flow is very low (micro-amps) unless there is a breakdown of the dielectric material in these devices. These devices usually have detectors that disconnect the electrical supply if the current exceeds the maximum safe limit. The integrity and strength of the insulation between the water and one of the two electrodes is crucial for the continued operation of a system because the voltage applied to the electrodes is very high. Any breakdown of the dielectric layer will cause a short circuit through the water body and the inevitable shutdown of the system.

One problem noted by Eades[19] was water leaking either into the electrode or between the electrode and the insulating coating. This causes shorting to ground and a resulting decrease in the efficiency of the system. Another problem is the formation of small air pockets between the electrode and the insulating coating. A corona discharge may occur at the location of an air pocket, resulting in arcing and cutting a hole through the electrode and the insulation and causing a total breakdown of the system. Several patents have been granted on various technologies to reduce the risk of an electrical discharge.

Claims for electrostatic devices are similar to claims for magnetic water treatment devices: the removal of calcium carbonate deposits from pipes and heat transfer surfaces and the prevention of additional deposits. Many manufacturers also claim reductions in mineral and bio-fouling (deposition of particles).

[17] Winslow, Jr., US Patent 4,049,535 issued Sep. 20, 1977
[18] Hodgson, US Patent 4,056,451 issued Nov. 1, 1977
[19] Eades, US Patent 4,579,640 issued Apr. 1, 1986

Science

The science of electrostatic water treatment is much less established than magnetic water treatment with very little laboratory data supporting manufacturers' claims. There are literally hundreds of papers investigating the mechanisms for magnetic water treatment; however, a search of the literature showed only one patent[20] by Frame containing data in a controlled laboratory setting demonstrating the removal of scale through the use of electrostatic water treatment. In the patent, Frame exposed a heated glass coil to a scale-forming solution, and then used the device to remove scale as demonstrated by an increase in effluent hardness concentration and alkalinity.

There are no papers demonstrating the basic operating principles of electrostatic devices, namely the change in surface charge of particles by exposure to the device. All of the manufacturers postulate a mechanism that involves the electrostatic interactions between suspended particles and the walls of the piping network. For instance, an early patent on this technology Means claims[21] that "…Thus, an electrostatic field suitably impressed across a section of flowing water is believed to primarily affect not only the water, but mainly suspended, especially colloidal size, particles immersed in water. The effect of the field will depend, in large measure, upon the relationship of the natural electrostatic charge on such immersed particles to the electrostatic charge on the various surfaces of the treater and how the latter charge induces a response on the liquid contacting surfaces of the piping network. If relative conditions are proper, the particles will be urged by the field to remain in suspension or migrate toward a charged electrode isolated from the walls of the piping network, thus reducing the tendency to form flow restricting deposits. The reduction of colloid particles which are capable of acting as seeds for nucleation of scale building crystal formations results in reduced tendency for scale deposition."

Thus Means is claiming that the electrostatic devices maintain colloidal particles in suspension, a necessary condition for homogeneous nucleation. Experts' contend[22] that deposition is a competition between heterogeneous (on the heat transfer surface) and homogeneous (in bulk solution) nucleation and that the ideal treatment would remove the supersaturated calcium carbonate by bulk precipitation.

Manufacturers appear to argue that electrostatic water treatment devices should work similarly to electrostatic devices in other applications like breaking water-in-oil emulsions or the well-known lab technique, electrophoresis. However, such analogies ignore an important difference between these applications and water-based applications where the mobile charge carriers include not only the particles to be dispersed or agglomerated but also ions in solution. For example, Pitts of the Zeta Corporation in an article[23] posted on the company's website described the existence of a double layer on particles in solution. In the analysis of the electric fields in the system, he ignores the fact that the electric field will be greatly compressed to a fraction of an inch surrounding the electrode rather than extending into the solution as suggested by his diagram. Thus very little of the solution and the suspended particles flowing past the electrode will be exposed to the strong electric field.

Application of technology

The applications cited by manufacturers are not well documented. The evidence is anecdotal, provided as testimonials or case histories with minimal data that would allow an evaluation of the effects of other variables such as changes in water chemistry, temperature, system load and other operating conditions. In addition to scale control, manufacturers claim efficacy of these devices for control of corrosion and microbiological populations. The explanations, when offered, are speculative and lack clear postulates for mechanisms.

The Zeta Corporation website lists numerous case histories for a variety of systems: cooling towers, heat exchangers, water purification, leaching processes and wastewater. The site also lists a large number of case histories by technology, including biological control, corrosion control, flocculation, scale control and suspended solids control. Close examination reveals three relevant case histories for cooling systems, with performance data for two of the applications. Unfortunately, the data sets are incomplete, showing no scale control or heat transfer efficiency data and no baseline data and many of the conclusions are qualitative. In one case history[24], the independent consultant's report described the chiller as having "proper efficiencies."

One of the four case histories on the Ion Stick web-site[25] is relevant: a chiller that had poor chemical treatment for seventeen years. Ninety percent (90%) of the deposits were removed in five months, however, there is no information about water chemistry or system operating conditions. This site has some information about application guidelines. The manufacturer strongly recommends sidestream filtration for optimal results. The

[20] Frames, J. R. US Patent 4,419,206 issued Dec. 6, 1983
[21] Means, E. A., et al., US Patent 4,073,712 issued Feb. 14, 1978
[22] Frayne, Colin, "Cooling Water Treatment," Chemical Publishing Co., Inc., New York, NY ©1999

[23] Pitts, M. M. "Fouling Mitigation in Aqueous Systems Using Electrochemical Water Treatment," www.zetacorp.com, April, 1995
[24] Pitts, M. M., Zeta Rod™ – performing at the Los Angeles Convention Center, www.zetacrop.com/LACC_ZD.shtml, ©1999
[25] York Energy Conservation, www.ionstick.com

website lists very little explanation of the mechanism of action and no peer-reviewed technical papers.

The website[26] for the Chemfree Water Systems, Inc. device lists case histories with very limited operating data. Similar to other manufacturers, the website claims efficacy against corrosion, scale and microbiological populations with limited explanations of mechanisms.

AC Induction

Description and Claims

AC induction methods (alternatively called electronic water treatment) treat scale-forming water by exposure to an energized solenoid cable wrapped around pipe. While similar to DC electromagnets, the systems have two distinct characteristics.

1. A lack of contact with the treated solution (wires are wrapped around or near the pipe).
2. Voltage on the coils are varied quickly (in the hertz (Hz) to megahertz (MHz) frequencies) and sometimes in very complex ways.

There are a variety of electromagnetic signals used in these types of devices. Morse patented[27] a device using variable high frequency (MHz) electromagnetic energy. The patent describes directing electromagnetic test signals of varied frequency into one location and monitoring the current intensity at a second location some distance from the first to provide an energy absorption/emission profile of the liquid and select a treatment frequency. The removal of scale from a previously scaled boiler tube and hot water heater is provided as evidence of the efficacy of the device. The pipes and heater treated with the Morse device showed scale removal but there was no scale removal in the untreated system. The patent did not show any water chemistry.

Niessen patented[28] a device using two coils, one inside the other with adjustable resonant pulses of various shapes, frequencies, and amplitude. De Baat Doelman patented[29] a device that varies the induced magnetic field as a function of flow rate. Similarly, Shulte patented[30] a device using two coils to vary the frequency and amplitude of the magnetic field dependent on the water hardness and flow rate. Pandolfo patented[31] a device where the resonance frequency can be varied more easily. Jefferson patented[32] a device generating "a complex triangular waveform output signal that varies continuously in frequency and amplitude...to neutralize existing scale and prevent formation of new scale." Crewson and others patented[33] a device generating inductive "ringing" giving rise to complex electromagnetic signals with frequencies into the megahertz region that prevents scaling. Cho and others patented[34] two devices allowing switching frequencies to promote better de-scaling and for minimizing corrosion due to carbon dioxide (CO_2) generation during de-scaling. None of the patents presented data on scale removal for these AC induction devices, although one investigator has developed a considerable body of research literature as described below.

Science

The mechanism proposed for all of these devices is the same as that for the permanent magnet and electrostatic devices: the transformation of calcium carbonate crystal form to a non-scaling type (presumably aragonite) and/or the reduction in scale forming tendency of the water. With the exception of the device patented by Cho et. al., there is no lab data available to support a claim that these devices promote scale inhibition or de-scaling.

Cho, a professor at Drexel University, Philadelphia, Pennsylvania, has published a number of papers in support of his claims about his device that is described generically as Electronic Anti-fouling Technology (EAF). These publications present evidence showing the efficacy of the device to improve the cleanliness of ribbed[35] and smooth[36] heat transfer tubes by a reduction in

- the thickness of scale by a small but significant amount and
- the rate of the loss of heat transfer efficiency and
- the effort required to return the tube to optimum heat transfer efficiency using brush punch cleaning.

Significantly, researchers controlled and evaluated water chemistry and expended considerable effort to obtain reliable heat transfer measurements in both studies.

In a highly detailed lab study, Cho and Choi describe[37] the effect on the device of flow velocity, calcium ion concentration, and temperature in a once-through pilot scale heat exchanger system using both shell-and-tube and plate-

[26] Chemfree Water Systems, Inc., www.chemfreewatersystems.com
[27] Morse, D. E., US Patent 4,865,748 issued Sep. 12, 1989
[28] Niessen, US Patent 4,938,875 issued Jul. 3, 1990
[29] De Baat Doelman, US Patent 5,074,998 issued Dec. 24, 1991
[30] Schulte, US Patent *5,171,431* issued Dec. 15, 1992
[31] Pandolfo, US Patent 5,702,600 issued Dec. 30, 1997
[32] Jefferson, N., US Patent *5,738,766* issued Apr. 14, 1998

[33] Crewson, Walter F. J., Munisteri; Joseph G., Ricci; Italo US Patent 6,063,267 issued May 16, 2000
[34] Cho, et al. US Patent 5,725,778 issued Mar. 10, 1998 and US Patent 5,670,041 issued Sep. 23, 1997
[35] Cho, Y. I., Liu, R. "Control of Fouling in a Spirally-ribbed Water Chilled Tube with Electronic Anti-fouling Technology" Int. J. of Heat and Mass Transfer, 42 pp 3037-3046 (1999)
[36] Liu, R., Cho, Y. I. "Combined Use of an Electronic Anti-fouling Technology and Brush Punching for Scale Removal in a Water-cooled Plain Tube" Exp. Heat Transfer 12 pp. 203-213, (1999)
[37] Cho, Y. I., Choi. B. G., "Validation of an Electronic Anti-fouling Technology in a Single-tube Heat Exchanger" Int. J. Heat Mass Transfer, 42 pp. 1491-1499 (1999) and G-B Choi "A Study of Fouling Control in Heat Exchangers with Electronic Anti-Fouling Technology" Ph. D. Thesis, Drexel Univ. (1998)

and-frame exchangers.[38] Above a critical velocity of 0.28 meters per second, they found a 20% to 38% improvement in the heat transfer efficiency (fouling resistance) with EAF treatment. As the investigators increased the concentration of calcium from 750 to 1000 parts per million (ppm) the effect of the EAF treatment on heat transfer efficiency decreased from 38% to 20%. Scanning Electron Microscopy photographs of the scale show a transformation from aragonite (formed without treatment) to clusters of elliptical-shaped crystals created with EAF treatment. They also demonstrated a substantial decrease in pressure drop and improved heat transfer coefficient across the plate-and-frame heat exchanger with EAF treatment.

Cho, Fan, and Choi have proposed[39] a mechanism involving "controlled precipitation" whereby the oscillating electric field "agitates" dissolved mineral ions, improving "collisions" and crystallization in the bulk (homogeneous) solution (as opposed to crystallization on the heat transfer surface). Researchers reported the results of a lab study[40] describing the physical nature of the crystals formed during evaporation of the treated and untreated water on a microscope stage after sampling from a once-through flow system. Investigators measured the number and size of crystals formed as a function of the distance between the treatment coil and the sample port. From this work, the researchers concluded that the diameter of crystals formed in solution (homogeneous crystallization) increased from a range of 1-10 microns (μm) to 10-20 μm as a result of the treatment. In addition the mass of precipitate produced was roughly 50% higher.

Based on these studies, Cho et. al. appear to have addressed some of the major concerns of critics of non-chemical water treatments including demonstration of the effects of operating conditions (flow and hardness dependence), a proposed mechanism, and demonstrated field results on scaling.

Application of Technology

A product named Scalewatcher Enigma from Environmental Treatment Concepts is a direct application of Cho's work. Surprisingly, their website[41] makes a brief reference to the research, but does not list any technical papers or include any technical supporting information.

The chiller case history describes a reduction in the scale over several weeks as shown by the head pressure measurements. Unfortunately, there is no water chemistry or other operating para-meters shown, and the website shows hypothetical rather than actual energy cost savings. It appears that the majority of the applications are residential.

The devices marketed by Clearwater Systems use pulsed power at lower voltage than similar devices developed to pasteurize orange juice. Clearwater Systems has published two technical papers[42] [43] describing the efficacy of AC induction devices on microbiological population control, with very limited corrosion or heat transfer data to substantiate claims of corrosion and scale control. A case history on the website for a comfort cooling system in Pittsburgh, Pennsylvania, presents a more complete assessment of the efficacy of the technology, although it lacks baseline corrosion data and any quantitative measurement of scaling. Additionally, the authors do not comment on the reduction in the biological populations from the elimination of the chemical treatment, a major source of food for organisms.

Obstacles to Advancement of Non-Chemical Water Treatment System Technology

There are several obstacles to the advancement of technology for non-chemical water treatment systems. The most critical obstacle is financial, i. e. funding of well-designed and executed lab studies. Acceptance of new technology by a technical community requires validation of the effectiveness and limitations of the device under controlled lab conditions. Most of the manufacturers of NCWTS are small companies with limited resources. Some manufacturers have enlisted the assistance of university researchers and various grant programs to conduct the mechanistic studies and pilot studies to substantiate claims of efficacy. It is critical that these pilot studies accurately model field applications in water chemistry, heat transfer rate, flow rate, evaporation rate, system metallurgy and typical monitoring tools.

A second obstacle is the lack of comprehensive field studies. These field trials are *de rigueur* in the chemical water treatment industry to validate the efficacy of a technology and confirm the application guidelines for a specific technology. Customers and the technical community would be well served if manufacturers would conduct defensible field trials with adequate monitoring and an appropriate baseline. The National Association of Corrosion Engineers (NACE) recently published a tech-

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[38] This study differs from Cho's other work; the calcium and carbonate are mixed in-line immediately upstream of the EAF treatment. Thus the super-saturation condition exist for a very short time before exposure to EAF treatment or the heat transfer surfaces.
[39] Cho, Y. I., Fan. C., Cap, B-G "Theory of Electronic Anti-fouling Technology to Control Precipitation Fouling in Heat Exchangers" Int. Comm. Heat Mass Transfer 24 pp 757-770 (1997)
[40] Fan, C.., Cho, Y. I. "Microscopic Observation of Calcium Carbonate Particles: Validation of an Electronic Antifouling Technology" Int. Comm. Heat Mass Transfer 24, pp. 747-756 (1997)
[41] Electronicdescaler.com
[42] Lane, John, "A Non-chemical Water Treatment Device," TP00-03, Cooling Technology Institute Annual Conference, Houston, TX (2000)
[43] Lane, John, Opheim, Ph. D., Dennis, "Biological Control in Cooling Towers Treated with Pulsed-Power Systems," IWC-01-54, IWC, Pittsburgh, PA, 2001

nical committee report from Task Group T-7K-3 on Control Factors in Performance Testing of Nonchemical Water Treatment Devices that provides some examples of evaluation criteria for these applications.[44]

It is well-known that executing a well-controlled field trial is extremely difficult for any treatment, either conventional or non-conventional and it may seem that the NCWTS are being held to a higher standard of proof than other devices.[45] However, the lack of mechanistic data for these devices has resulted in the technical community demand for a higher standard of proof in the field than other more conventional technologies such as polymers.

Investigators would strengthen their experimental design by including a control experiment that allows a comparison of the NCWTS to either chemical treatment or no treatment. In addition, researchers may need to rethink some basic assumptions about the control of deposition in a heat exchanger-cooling tower system. With chemical treatment, investigators assume that the water chemistry is uniform throughout the system: tower basin, tower fill, sump and heat exchanger. Manufacturers operate NCWTS under the assumption that local changes in chemistry at and immediately downstream of the device result in changes in other parts of the system. Proper design of experiments must consider various sampling locations to validate this heterogeneous system chemistry, i. e. precipitated contaminants in the fill and sump and suspended precipitates and dissolved contaminants at the heat transfer surface.

Experimental Design of Field Trials

The goal of a field trial is the development of application guidelines for the NCWTS. The perfect evaluation site consists of two similarly-loaded parallel systems. This configuration allows a direct comparison of a chemically-treated or untreated system to a NCWTS system. Failing such symmetry, two systems at the same site will provide a basis for comparison of conventional and non-traditional methods. Obviously, the two systems must have the same source of make-up water and the same level of monitoring and inspection. For all field trials, it is imperative that the investigators establish a sufficiently large set of baseline data. Typically a year of baseline data is required because cooling tower performance varies according to the season.

Conformance to the control limits and system health is critical for all systems. Typically, operating personnel conduct routine monitoring once per month, resulting in an inadequate characterization of the system performance for a field trial. A properly designed baseline and trial study requires daily measurements of all operating parameters including the scaling tendency, or scaling index of the cooling water and monthly system health parameters.

Monitoring system health during the baseline and trial period includes testing for corrosion, deposition, and microbiological populations. Microbiological monitoring is easily accomplished using dip slides or reactive tests. Corrosion monitoring requires metal coupons in a specially designed test rack that controls the linear flow rate. An instantaneous corrosion meter may supplement corrosion coupons to provide real-time data.

There are several scaling indices available: Langelier Saturation Index[46], the Stability Index by Ryznar[47], and the Practical Scaling Index[48]. NCWTS systems operate under alkaline conditions, creating a naturally non-corrosive water chemistry. Thus, the primary requirement for a NCWTS is to control scale. Controlling scale directly correlates to improved heat transfer. [49]

Deposition testing requires a model heat exchanger that receives a side stream flow from the return line. These devices are not used for routine monitoring, and investigators would need to plan to install a unit for a year before initiating a field trial. Deposition testing is a critical part of a baseline and trial study because all of these NCWTS operate with water chemistry that has strong scaling tendencies. These model heat exchangers offer a more flexible method of field testing an NCWTS (e. g. changes in heat transfer rates), allowing the testing period to be compressed from years to months. Operations personnel are not always able to install the model heat exchanger in parallel with the condenser to achieve dynamic similarity in flow. If the flow velocity is lower in the model heat exchanger, the test conditions will produce more severe scaling than the operating conditions of the condenser.

Another measure of efficacy of NCWTS to control deposition is measuring the electrical energy required to operate a chiller, normalized for the ambient conditions. A reduction in the normalized chiller load is necessary but not sufficient evidence to prove efficacy of NCWTS devices. For example, if the water chemistry is scale-dissolving as described by the Ryznar index, then the chiller efficiency may improve due to cleaner tubes, but the corrosion rate is unacceptably high. Investigators must mon-

[44] Task Group T-7K-2, “Control Factors in Performance Testing of Nonchemical Water Treatment Devices," NACE Mar. 1997
[45] Task Group T-7K-3, "Predictably Effective Equipment and In Situ Processes Applied to Water Systems,” NACE Jun. 1998

[46] Langelier, J. of the Am. Water Works Assoc., 28 10 (1936): p. 1500.
[47] Ryznar, J. of the American Water Works Assoc. 36, 4 (1946) p. 126
[48] Puckorius and Brooke, “A New Practical Index for Calcium Carbonate Scale Prediction in Cooling Tower Systems,” CORROSION/90, Paper. 99 (Houston, TX:NACE International)
[49] Task Group T-7K-2, “Control Factors in Performance Testing of Nonchemical Water Treatment Devices," NACE Mar. 1997, p. 3

itor water chemistry and other system health parameters to confirm NCWTS performance.

Test results from water chemistry monitoring in NCWTS are conspicuously absent as compared to reports of field trials with conventional chemical treatments. Many NCWTS manufacturers claim that monitoring of water chemistry is not required because the devices work without changing water chemistry even though calcium carbonate and calcium sulfate are precipitating. Basic scaling chemistry dictates that any precipitation requires a change in the soluble ion concentrations (calcium, carbonate, sulfate) and a change in pH due to a reduction in the concentration of carbonate alkalinity. Testing filtered water samples to remove suspended precipitates is especially important.

Manufacturers could enhance the credibility of their claims of performance of an NCWTS by including annual inspection reports of all equipment in the system: cooling towers, condensers and chillers. Inspection reports should describe the findings, deposit analyses if appropriate, and photographs of all heat transfer surfaces, tubesheets, cooling tower basin, fill and distribution box.

The application of a non-chemical device on scaled systems occasionally results in a rapid removal of existing deposits from heat transfer surfaces and/or cooling tower fill. These deposits often collect in the cooling tower basin or in a filter. This phenomenon occurs upon initial installation of a NCWTS in a heavily scaled system or after re-start after operating without the unit. Manufacturers would strengthen their claims of efficacy of scale control by repeating this phenomenon to confirm the cause and effect. Additionally, investigators would strengthen their conclusions about the efficacy of these devices by analyzing and quantifying the constituents of these deposits and reporting local changes in water chemistry.

Field Applications

Successful field application of these technologies requires a clear set of guidelines. These guidelines describe the required water chemistry, level of monitoring, operating conditions, specific heat exchangers to be protected and the number and location of each NCWTS device. Proper application of the NCWTS requires an evaluation of each prospective site to determine the suitability of the system for the technology. For example, systems with high rates of process intrusion or very corrosive make-up water may not be good candidates for these devices. As shown in Table 2, manufacturers must measure some basic parameters in the make-up water and specify the control ranges for the operating parameters for cooling water.

Table 2 – Minimum Required Operating Parameters for Make-up Water and Control Ranges for Cooling Water[50]

Parameter	Make-up Water	Cooling Water
Conductivity or Total Dissolved Solids	X	X
Total Alkalinity	X	X
pH	X	X
Calcium Hardness	X	X
Total Hardness	X	X
Chloride Concentration	X	X
Chemical Treatment Concentrations		X
Water Temperature	X	X

System health monitoring (Table 3) includes microbiological populations, corrosion rate and deposition rate. Some systems that use non-chemical devices may require chemical treatment for microbiological control. If chlorine or bromine is used, operations personnel must monitor the concentration of oxidizing biocide. If the cooling tower serves the manufacturing process or a heat exchanger/chiller with a heat transfer fluid such as glycol, operations personnel must have a procedure to monitor for leaks and corrective actions in the event of a leak.

Table 3 – Required System Health Monitoring

Parameter	Procedure
Microbiological Population	Dip Slide, ATP, BART[TM, 51]
Corrosion Rate	Corrosion Coupons or Instantaneous Corrosion Meter
Deposition Rate	Model Heat Exchanger or Scaling Coupons or Chiller Electrical Load
Process Leak	Chemical Test

Conclusions

Manufacturers continue to market these NCWTS devices despite the lack of peer-reviewed laboratory data, mechanistic explanations and documented field studies. Distributors, customers and manufacturers continue to make erroneous conclusions about efficacy based on applications with uncontrolled variables. Users often install these units as a response to misapplied chemical water treatment programs, to obtain a more environmentally acceptable method of water treatment or to simplify system monitoring.

Clearly the manufacturers, the users and the technical community would be well-served from properly designed and documented field trials and applications that confirm efficacy of these NCWTS devices.

[50] Assumes calcium carbonate dominated water chemistry. Some manufacturers explicitly disclaim efficacy in water with significant concentrations of silica or iron.
[51] Trademark of Broycon Bioconcepts, Inc., distributed by Hach Company, Loveland, CO, www.hach.com