WQA
Magnetics
Task Force Report

The
Water Quality Association
Magnetics Task Force

March 2001

WATER QUALITY
ASSOCIATION ®

The Water Quality Association

The Water Quality Association (WQA) is the not-for-profit trade association representing the household, commercial, light industrial, and small system water treatment industry.

WQA's primary objectives are to:

- Ensure fairness in legislative, regulatory, and media coverage of the industry,
- Foster dedication to integrity by expanding education opportunities, enhancing technical expertise, substantiation of product performances, and ethical standards in responsible marketing and advertising, and
- Broaden acceptance of the industry through consumer confidence and trust in water treatment products and services.

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PREFACE

The content of the following report has been prepared by a special task force established by the Water Quality Association and represents the review by the members of the task force of a bibliography of scientific papers and information generally available to the public or released by the authors themselves. The views of the individual members of the task force, as well as their collective views contained in the text of the report and summaries herein, are intended solely as an aid, among others, in understanding the state of scientific research in the field of the possible effects of magnetic devices in the treatment of water. WQA recognizes that the development of science in this area is in its relative infancy and that much additional research is required for a fuller, more complete understanding of the relevant science. It, therefore, encourages readers of this report to conduct their own review of the entire body of scientific literature, including all original source materials, and to conduct or have conducted their own independent research before forming opinions or drawing conclusions regarding the efficacy of any affected technology, process, or device.

Although WQA strives to provide accurate, timely, and authoritative information, it cannot warrant the content or conclusions of this report, nor can it be responsible for inaccurate statements, errors, or omissions either with respect to the accuracy of the content herein or of the underlying source information reviewed. The content contributed by individual members of the task force represents their opinions, findings, and conclusions based upon their knowledge and experience in the discipline of the scientific method, and their contribution, as with the subject matter of the entire report, is limited strictly to a review of the science against that discipline and methodology. This report is not a substantive review of or opinion regarding the ultimate validity of the underlying science as applied to any technology, process, or device and should not be represented as such. The report is solely for educational and background information purposes and is presented in the academic spirit of free, open, and uncensored debate and exchange on scientific matters. As such, this report must not be used out of context and may not be cited, quoted, referenced, or used by anyone except in its entirety, which must include this disclaimer, without the prior express written permission of WQA.

WQA Magnetics Task Force Report
March 2001

In February 1999, the Water Quality Association established a special task force of scientists to review the scientific literature underlying the use of magnetic water treatment devices.

Following are the members of the Magnetics Task Force: Daniel T. Carty, Ph.D., Brita Products Co. (The)/Clorox Serv. Co.; Professor Young I. Cho, Ph.D., Department of Mechanical Engineering and Mechanics, Drexel University; Joseph A. Cotruvo, Ph.D., NSF International (formerly Director of Drinking Water Standards, U.S. Environmental Protection Agency); Robert V. Herman, CWS-I, Drinking Water Treatment Unit Program, NSF International; Raymond G. Jaglowski, Ph.D., Access Business Group, Amway Corporation; Joseph L. Katz, Ph.D., Department of Chemical Engineering, Johns Hopkins University; Professor Wolfgang Kuhn, Ph.D., and Ivo Wagner, Ph.D., DVGW, Germany; Kent W. Smothers, Illinois State Water Survey; and Joseph F. Harrison, P.E., CWS-VI, Water Quality Association. Dr. Carty served as chair of the task force.

The task force established a single objective -- to identify, through a bibliographic format, the published, but not proprietary and not anecdotal, scientific studies and papers that the task force members judge to have followed sound scientific method in the field of magnetic and physical water treatment. The task force agreed not to review or include in the working bibliography narrative reports and conclusions which may not be rigorously objective and scientifically valid. Most importantly, the task force's charter was not to express views on the relative or ultimate merits of the underlying science or to reach any conclusion on efficacy, but simply to provide a compendium and comprehensive review of available scientific papers written on the subject of magnetic water treatment technology and to make recommendations to WQA on possible next steps.

The task force has completed its bibliographical reviews against the scientific method and the process of reaching consensus on 106 papers identified through a literature search on magnetic water treatment. This study, the review of papers, and the task force's conclusions also cover other physical water conditioning methods, such as electronic, electrolytic, electromagnetic, catalytic, and radio frequency devices, as well as the magnetic technologies. Consensus has been reached that thirty-four of these papers represent studies meeting the criteria for demonstrating scientifically valid analytical procedures, including the collection of measurable quantitative data through observation and experiment, formulation of hypotheses, and the testing and confirmation of the hypotheses formulated. These thirty-four accepted papers are summarized in the text of this report. The remaining papers, which themselves may provide helpful information, insights, data, and areas of further inquiry, are included along with the summarized papers in the working bibliography following the report.

Magnetic Treatment of Fluids
(no date)

Paper #20
Author: Donaldson, J. D.

This was a presentation at a symposium organized in the United Kingdom by HDL Fluid Dynamics, a magnetic device manufacturer. Article starts out in a favorable tone right away.

- Refers to few very positive field demonstrations first.
- Reports on "laboratory" studies.
- Experimental procedures not clearly spelled out.
- Reports results showing changes in particle size, crystallinity, crystal morphology, crystal phase, solubility, and rate of precipitation.
- Changes in crystal morphology is shown by studying the x-ray diffraction of particles subjected to magnetic treatment for 30, 40, and 150 minutes.
- Solubility of $Ca_3(PO_4)_2$ is reported to be affected significantly by magnetic treatment applied for 24 and 120 hours.
- Rest of the changes reported are not based on numbers, but words.

Performance Analysis of Permanent Magnet Type Water Treatment Devices
(1981)

Paper #29
Authors: Gruber, Carl E.
Carda, Dan D.

This is a straightforward performance test of:

- Class I (clamps on to the outside of a pipe and produces a longitudinal magnetic field).
- Class III (radial with annular flow tube consisting of a series of alternately poled cylindrical magnets along the axis of the unit).
- water softener against no treatment.

Water(s) coming out were heated to 62°C in separate heaters and:

- flow was during four, ten-minute periods within 24 hours.
- total volume per day was 70 gallons through each heater.
- test period was July 6 through August 27.

Results:

Unit	Weight Loss at Anode	Scale on Heaters	Scale on Temperature Sensor
Softener	16.9 g	0.5 g	0.0
Class III	5.0 g	6.3 g	0.7 ± 0.1 g
Raw	6.2 g	4.5 g	0.4 ± 0.1 g
Class I	5.6 g	3.4 g	0.2 ± 0.1 g

Other measurements included boiling point depression, surface tension, water conductivity, and "scaling rate". There was no difference noted between raw and the two magnets.

Based on all of these and appearance of scale in the tanks, heating rods, sensor, etc., the paper concludes that there is no measurable effect in these circumstances resulting from the selected magnetic devices.

A Revue of Scale Formation and Scale Prevention, with Emphasis on Magnetic Water Treatment

(1983)

Paper #24
Author: Ellingsen, Frank

This is from a person employed by a magnetic water treatment device (POLAR) manufacturer in Norway. Initial discussion of scale formation and scale prevention is technically good.

Gives a definition of nonchemical water treatment as "A method based on mechanical (e.g. vibration), electrical, or magnetic principles." (May be useful later for discussing protocol common for physical or nonchemical devices).

Has done laboratory work. But not clearly explained as to what was done. Very confusing. Used different magnetic strength treatment to a naturally hard water raised to pH levels nine or higher by hydroxides.

- Shows in one graph, the higher the magnetic strength, the lower will be the pH after about 20 minutes. But also claims that the magnet accelerates the rate of precipitation.
- Talks about turning point with zeta potential at zero at that point. But, pH is very high.

In another example, water flows through what is called a crystal growth cell. Shows photos with larger crystals in magnetic treated waters.

Not clear as to what the hypothesis is. In one test, higher precipitation due to magnets. In another, less crystals due to magnets. It is not clear as to what is concluded in the conclusion section. This paper is not entirely useful for water treatment assessment.

Research Reports: Quantitative Assessment of the Effectiveness of Permanent Magnetic Water Conditioning Devices
(1985)

Paper #1
Author: Alleman, James E.

Six unidentified magnetic water conditioner devices were tested compared to untreated hard water each followed by their own water heaters equipped with coupons of different kinds. Testing lasted 240 days of operation. Both water quality parameters and scaling on coupons were monitored during the study.

No beneficial effect was seen for the magnetic treatment process.

One of the six units yielded higher scaling conditions. No explanation was given as to why.

Type of units tested were:

1. Exterior mounted circumferential
2. In line mounted circumferential
3. In line mounted axial
4. In line mounted axial and circumferential

Effectiveness of Magnetic Water Treatment in Suppressing $CaCO_3$ Scale Deposition/The Performance of a Magnetic Water Conditioner under Accelerated Scaling Conditions
(1985)

Papers 31 & 32
Authors: Hasson, David
Bramson, Dan

These two papers are actually from the same work.

- One magnetic device (orthogonal unit – Class II) was tested in the laboratory under the following conditions:
- pH – 9.0, 9.5 – 9.7, 10.2
- Ca^{++}: 200 - 250 ppm, Mg^{++}: 165 -175 ppm, Alk: 300 -340 ppm, TDS: 800 - 900 ppm.
- pH adjustment with NaOH to 9.0 and higher.
- In all but one test, sodium sulfite was added at high levels of 150 - 300 ppm to prevent the effect of rust contamination, which in their opinion will have an effect of scale tenacity.
- Magnetic unit was preceded and followed by test segments. Segments prior to magnetic were before treatment for comparison with the segments afterward.
- Flow rate 2 m/s or 15gpm through 1 inch diameter pipe.
- Test temperature - 19 to 23°C

Conclusions

- No magnetic effect evident.
- Precipitation rate is dependent on pH. Same as before and after magnetic test.
- In one test, recycling through magnet did not yield any favorable result.

Comment

- Good study except for the addition of the sulfites.

Studies of a Water Treatment Device that Uses Magnetic Fields
(1986)

Paper # 5
Author: Busch, K. W.
Busch, M. A.
Darling, R. E.
McAtee, J. L., Jr.
Parker, D. H.

- Appears to be a good laboratory effort.
- Tested one orthogonal magnetic treatment device (MTD) (different variations) in a laboratory set up where flow rate can be varied.
- Bulk of the tests were with a magnetic device that was altered to have a plastic housing in place of a metal housing.
- Measured voltages, current, and surface pH near the electrodes.
- Voltages were in the range of 0 to 13 mV for flow velocities of 0 to 5 fps.
- Current levels reached as high as 450 mA for 4fps.
- Surface pH values changed as high as –1 unit on one electrode and as high as + 3.0 on the other. Significant variations.

Hypothesis is that with these types of values, it can lead to $CaCO_3$ nucleation centers from the cathode due to high localized alkaline pH values. Or, iron corrosion can lead to iron microprecipitation in the anodic region leading to iron neucleation centers and adsorption of calcium onto the iron particles. Both of these actions may lead to precipitation of scale in the bulk of water instead of on the surfaces.

No data of the operation of the unit leading to lower scaling were presented.

The Effect of Magnetic Fields on Calcium Carbonate Scale Formation
(1989)

Paper #18
Authors: Dalas, Evangelos
Koutsoukos, Petros G.

- Bench scale study with magnetic fields generated with power input.
- All tests were done in a glass vessel at 25 ± 0.1°C.
- Magnetic field was applied by a power supply, which consisted of 83 percent continuous and 17 percent alternating with a frequency of 100 Hertz. Not explained at all as to what this means. Did say that other fields (continuous, alternating, and varying frequencies) did not yield any effect. No reason as to why.
- Magnetic field intensity was varied from 0 to 18.6 telsa (T) (0 to 186,000 gauss (G)).
- $CaCO_3$ concentration was varied from 1.5 to 3.0 M × 10^{-3} (1.5 to 3.0 millimolar), pH: 8.5.
- Calcite crystals were added and the rate of $CaCO_3$ precipitation from solution was measured while the solution conditions were maintained by adding calcium carbonate.
- The calcium carbonate precipitation rate decreased up to 50 percent due to the presence of this magnetic field when it is higher than 10 T.
- It is hypothesized that this field may be influencing the dehydration step leading to the kinetics being affected.
- No conclusions drawn as to how this would lead toward permanent magnetic devices inhibiting scale formation, except by inference.

Magnetic Water Treatment: The Effect of Iron on Calcium Carbonate Nucleation and Growth
(1989)

Paper #34
Authors: Herzog, Ruth E.
Katz, Joseph L.
Patel, Jay N.
Shi, Qihong

- An excellent study, except it does not measure the magnetic water treatment process directly.
- If magnetic devices can generate ferric hydroxide particles, they can provide nucleation sites for $CaCO_3$ crystals to grow and thus reduce the scaling on surfaces - hypothesis that was tested.

- In elegant experiments, this theory was tested using synthesized ferric hydroxide particles of different kinds in supersaturated $CaCO_3$ suspensions. None were shown to have an effect on nucleation and growth of calcite particles.
- Similar testing with intermediate products during oxidation of Fe^{2+} to Fe^{3+} in the presence of a magnetic field also did not yield any effect. But, a side observation found was that Fe^{2+} inhibited the formation of calcite particles.
- Further test with Fe^{2+}, Fe^{3+}, calcite, and aragonite showed:
  - Fe^{2+} at 5.6 ppm or higher inhibited the calcite growth rate.
  - Fe^{3+} had a similar effect, but lower effect.
  - Fe^{2+} did not have similar effect on aragonite growth, but did inhibit the transformation from aragonite to calcite.
- But, not clear how magnetic devices can liberate enough iron to inhibit such scale growth. No data or information given in the paper about iron release by magnetic devices.

Effect of a Weak Magnetic Field on Hematite Sol in Stationary and Flowing Systems

(1991)

Paper #68

Authors: Tombacz, E.
Busch, K. W.
Busch, M. A.
Ma, C.

- Laboratory bench study with recirculating flowing stream compared to stationary nonflowing system.
- Uses dilute, but fairly turbid hematite suspension (78 mg of Fe_2O_3/dm^3, that is 78 mg/L of Fe_2O_3). Turbidity levels ranged from 40 NTU to over 100 NTU during the tests.
- KCL was used as the salt in the water ranging from 0 to 60 $mmol/dm^3$. Concentrations higher than 50 induced coagulation of hematite sol or colloids without any further treatment.
- Flow tests were done with magnetic exposure for 120 minutes. Rate of flow was 40.5 ml/sec, calculated to be turbulent flow in a smooth tube. pH of the sol stayed at 4.06 to 4.24 (unusual pH for water supply treatment purposes, normally).
- Magnetic induction varied between 0.11 telsa (T) and 0.16 T (1100 to 1600 gauss).
- Electrophoretic mobility (zeta potential), light scattering (turbidity) and particles size distribution were measured.
- After 30-60 minutes of magnetic exposure, light scattering measurement showed aggregation of particles at a KCl concentration of 1, 10, and 30 $mmol/dm^3$(75, 750, and 2200 mg/L). This effect was not there if no magnets were present or if there was no flow.

- Particle size distribution measurement showed the presence of larger particles after magnetic exposure of 120 minutes.
- Zeta potential also showed measurable differences with the greatest increase detected in the millivolt zeta potential measurements observed under flowing conditions through the magnetic field.
- Interaction with the particles' double layer electrical surface charge was hypothesized as the mechanism.

Effects of a Magnetic Field on the Formation of $CaCO_3$ Particles (1993)

Paper #35
Authors: Higashitani, Ko
Hatade, Shintaro
Imai, Katsunori
Kage, Akiko
Katamura, Shinichi

- Bench scale static tests with magnetic fields generated by an electromagnet (no details about the device).
- Magnetic flux density was varied from 0 to 0.6 telsa (T) (0 to 6000 gauss).
- Exposure was for 10 minutes generally, but up to 60 minutes.
- $CaCO_2$ and Na_2CO_3 solutions were the subject of exposure (concentration: 8×10^{-3} mol/liter).
- Temperature was maintained at 30°C and the solutions were separately exposed to the magnetic field and then later mixed together.
- After mixing $CaCO_3$, crystal formation was measured by measuring the absorbency of suspensions of $CaCO_3$ particles. They were also photographed in cells and their structure was analyzed by spectrophotometer.
- Absorbence levels were always higher without magnetic field than with. For 10 minutes or higher exposure of 0.2 T or higher, the decrease in absorbency was 30 percent. This decrease was seen when mixing was done even when 120 hours had elapsed after exposure.
- It was found Na_2CO_3 was the solution that lead to such an effect. Not $CaCl_2$. No reasons why.
- Crystal photos show more crystals for unmagnetized, while fewer but larger crystals for magnetized.
- There were more aragonite structures among the $CaCO_3$ crystals in the magnetized suspensions.

Reduction of Soluble Mineral Concentrations in $CaSO_4$ Saturated Water Using a Magnetic Field
(1995)

Paper #28
Authors: Gehr, Ronald
Finch, James A.
Rao, S. Ram
Zhai, Ziqi A.

- Laboratory study using the magnetic field of a Nuclear Magnetic Resonance Spectrophotometer (NMRS). Unusual! (Is this comparable to water treatment types of devices?)
- Saturated solutions of $CaSO_4$ (3 g/l) at 21°C at a pH of 4.8 were used for the tests.
- These solutions were subjected to magnetic field of NMRS which has a fixed magnetic field strength of 4.75 telsa (T) [47,500 gauss (G)]. These sample tubes (10 ml solution in 40 ml centrifuge tube) were rotated at 1200 rpm. Exposure time was two minutes. Controls were also rotated at the same speed for the same time using a simple electric drill motor except these samples were contained in 1.35 cm inside diameter and 15.0 cm long pyrex glass tubes. These tests were done in multiples of five samples for each so that different measurement can be done after the exposures.
- Conductivity and the calcium concentration of the supernatant were measured after the tubes were centrifuged. Total suspended solids (TSS) was also measured of the whole sample. Zeta potential of the solids was also measured.
- Results showed that the effect of magnetic field can be quantified:

Conductivity	- 7.3 %
Ca concentration	- 9.8 %
TSS	+ 25.5 %
Zeta potential	- 22.7 %

- Conclusion: Shows that magnetic exposure can induce precipitation of solids, resulting in less scaling on surfaces.

Magnetic Treatment of Water and Scaling Deposit
(1994)

Paper #53
Authors: Paiaro, Gastone
Pandolfo, Luciano

- Brief Report. Does not give too much information about the experimental approach. Gives reference to an earlier study by these authors for such information (earlier study may be in Italian published in 1987).

- Test was with 200 mg/L $Ca(HCO_3)_2$ and iron at 0.015 mg/L. pH ranged from 7.6 to 9.2 adjusted with NaOH.
- Magnetic device used had a magnetic strength of 0.36 tesla (T). [Tesla (T) is the International System of Units term for magnetic flux density or magnetic induction, and is equal to volts · seconds per square meter. One telsa (T) equals 10^4 gauss (G).] Flow rate through the device was four liters per minute.
- Water after magnetic treatment of control was evaporated at 60°C in a rotating evaporator under vacuum.
- One table shows the type of crystals seen in different tests with and without magnetic treatment. Not easy to tell any difference from the table itself.
- Discussion and conclusion indicate that with iron present in low amounts, magnetic treatment produces crystals that do not adhere to the walls and tubes. The nucleating effect of iron ions in the formation of $CaCO_3$ crystals is considered as the reason for this effect. It is implied that if iron is not present at least in these low levels, the magnetic treatment may not work.

Calcite Growth and the Inhibiting Effect of Iron (III)
(1994)

Paper #67
Authors: Takasaki, Shinichi
Katz, Joseph L.
Parsiegla, Katrin I.

- An interesting study, but has little bearing on magnetic devices. There is no mention of magnetism in the paper.
- Inhibition of calcite crystal growth by ferric iron in the presence of calcite $CaCO_3$ seed crystals in supersaturated solutions of $CaCO_3$ has been studied. Iron levels of 1µmolar(M) to 9.6 µM (0.06 to 0.5 milligrams per liter) were tested.
- Seed crystals ranged from 0 to 20 grams per liter.
- Without seed crystals, there was no calcite precipitation. With increasing seed levels, growth rate of calcite increases.
- Addition of ferric iron to the solution prior to the addition of seed crystals inhibits the growth of crystals from the supersaturated solution. Proper levels of iron completely inhibits the growth.
- Interesting. But more work needs to be done if iron is to be used in this manner in real life water treatment situations.
- It is intriguing however, that any process that would inadvertently impart iron into water (e.g., magnet housing hardware?), may also coincidentally inhibit $CaCO_3$ scale precipitation in supersaturated solutions of calcium carbonate, if the imparted iron concentrations are sufficiently high.

Management of Scale Deposits by Diamagnetism: A Working Hypothesis
(1994)

Paper #A13
Authors: Benson, Robert F.
Carpenter, Roland K.
Martin, Barbara B.
Martin, Dean F.

- Small amount of data presented on a laboratory study of magnesium hydroxide solution subjected to magnetic field.
- Most of the paper is dealing with solubility equations for $Mg(OH)_2$, $CaCO_3$, $Ca(HCO_3)_2$, and with mathematical equations of Zeeman Effect (which evidently is the splitting of an energy level of an atom or molecule, and hence a splitting of spectral lines arising from that level, as a result of the application of an external magnetic field).
- 1.0 g of $Mg(OH)_2$ was added to 55 ml of double distilled water placed in a 42 millimeters diameter glass apparatus which was covered with N_2 gas. After pH measurement, a pair of magnets (supplied by Aqua Magnetics International, Inc.) were placed around the base and pH measurements with probes inside were continued.
- Results: pH increased from 10.2 to 10.8. When the magnetic field was removed, there was a pause, then pH decreased back to 10.2. Same effect with $CaCO_3$ (but no data shown).
- Conclusion: This increase in the pH would result in dissolution or dissolving of $Mg(OH)_2$ or $CaCO_3$. So there is a measurable effect due to magnetic field.
- Not much laboratory work.

Magnetic Amelioration of Scale Formation
(1996)

Paper # 2
Authors: Baker, John S.
Judd, Simon J.

- A good comprehensive literature study, even though there is a bias toward wanting to show positive effect.
- Classifies magnetic devices into four classes:
  Two of them are magnets strapped externally, while the other two are intrusive where water flows by or through the magnets. Also tries to include distinction based on the relationship to the direction of flow. Intrusive ones are referred as orthogonal to the direction of flow.

- Makes a big difference between recirculating systems and once through system.
- Effects reviewed include effects on physiochemical properties of water and solutions, effects of nucleation and growth of particles, effects on crystallinity, effects on scaling kinetics and equilibrium, effect on coagulation, effect on corrosion, influence of contaminants.
- Tries to propose mechanisms, but simply reviews all the above again in a briefer manner. Four mechanisms proposed include changes in electron configuration, contamination effects due to magnetically enhanced dissolution, changes in coordination of water with ions, and distortion of the double layer around particles.
- Tries to conclude positively, even through acknowledges confusion in data.
- States (without good proof) that orthogonal devices in recirculating systems are most effective.

Influence of the Heat Transmission Factor on the Effect of Magnetical Water Treatment
(1996)

Paper #A5c
Author: Adriaenssens, Eddy

- Author is president of CEPI - CO Ltd. He had this work done by the Belgian Building Research Institute under the supervision of K. De. Cuyper.
- Study was done in 1988 with magnetic treatment and in 1990 without magnetic treatment.
- Approach was to have the 200 liters of hard water heated in a commercial boiler operating at 80°C, dump, refill, and reheat 30 times. Then remove the heating coil and reweigh the heating coils to calculate the amount of scale.
- This was done with two different heating intensities of the coils.
- At 2.3 to 2.6 watts/cm^2, the scale produced was 5 grams and 0 grams for control and magnetic treatment respectively.
- At 5.2 to 5.8 watts/cm^2 , the scale produced was 38 grams and 11.35 grams respectively for the same.
- Even though no data was shown, it has been stated that at 6.5 watts/cm^2, there was no difference between control and magnetic treatment.
- The conclusion is that the heating flux (power intensity) has to be controlled for magnetic treatment to be useful.

The Role of Zinc in Magnetic and Other Physical Water Treatment Methods for the Prevention of Scale

(1996)

Paper #15
Authors: Coetzee, P.P.
Howell, S.
Yacoby, M.

- Very interesting work. Explained clearly and appears to show a mechanism for consideration.
- Three units were tested: Polar Model PD15, Aquasal Type 90-2 (an electrically operated unit with stainless steel electrodes which produces wave pulses of 14 volts positive and 18 volts negative between the electrodes. Electric current values of up to one ampere were measured when conductive flow was present), and a PTH model, PTH 20A, catalytic conversion unit.
- The Polar unit is described well, with a sketch of the inside mechanisms. It contains a magnetic rod with a zinc anode (this was apparently for corrosion protection). The magnetic field in the active region was 0.7 telsa (T) (7,000 gauss).
- Flow rates were two liters per minute (l/min) for the Polar unit, six l/min for the Aquasal unit, and 35 l/min for the PTH unit.
- The $CaCO_3$ concentration was typically 150 mg/L.
- Exposure time was 10 minutes. After exposure, samples were maintained at 37°C for 15 minutes, pH measurements were made for up to six hours.
- pH values increased reaching a peak after several minutes and then started going down in all tests.
- The time differences to reach peak pH value, that also corresponds with the level at which $CaCO_3$ starts to precipitate, is seen as the effect of magnetic treatment.

  <u>Time delays for noncoated magnetic devices compared to the control</u>

Polar -	35 ± 4 min
Aquasal -	6 ± 2 min
PTH -	20 ± 1 min
Zn added -	33 ± 4 min
(chemical additive test)	

- Magnetic units, coated (with silicone based Dow Corning R43117 liquid polymer) and noncoated units also were compared for this time difference. By eliminating direct contact with internal surfaces (but presumably not interfering with magnetic fields induction), the delay times for all coated devices were reduced to zero. This means no observable difference when compared with the controls.
- All magnetic treatments were found to yield higher than 50 percent of $CaCO_3$ as aragonite while nonmagnetic controls yielded 100 percent calcite.

- Amount of zinc and other metals in μg/l released by these magnets in 0.001 M KCL solution for each device shown as:

	Zinc	Cobalt	Cu	Ni
Polar	589	54	< 5	< 10
Aquasal	124	< 5	< 5	< 10
PTH	118	< 5	24	78

- Hypothesis is that $ZnCO_3$ adsorbs on the surface of $CaCO_3$ crystals leading to slower crystal growth and more aragonite crystals.
- "No measurable effect on the crystallization reaction for calcium carbonate ascribable to the magnetic fields caused by the devices under investigation could be found." However, the magnetic fields may have caused zinc to be imparted into the water, which did in turn effect $CaCO_3$ crystallization.

Magnetic Treatment of Calcium Carbonate Scale-Effect of pH Control

(1997)

Paper #A19

Authors: Parsons, Simon A.
Judd, Simon J.
Stephenson, Tom
Wang, Bao-Lung

- This laboratory study at Cranfield University is an extension of the one in Reference A5a. Better described here.
- Two identical rigs - one for control and another for the magnetic treatment. The recirculating flow rate was 15 liters per minute (l/m).
- Nonintrusive electromagnet providing a field strength of 7000 gauss (0.7 telsa).
- Heat exchangers maintained at 60°C. Cooling system cooled the water to 28° to 30°C before being returned to the recirculating reservoir.
- Three tests were done. One at a controlled pH of 8.0, another at a controlled pH of 8.5, and the third without controlling pH values (starting pH was 8.0).
- Calcium concentration was 300 ppm and alkalinity was also 300 ppm initially in the reservoirs. Base was added in the first two tests to control pH as required.
- Scale formation in the heat exchangers and the reservoirs was measured at the end of each run.
- These three tests were done twice with similar results. Each test lasted about 25 hours.
- Results show that when pH is controlled, there is no difference shown in scaling due to magnetic treatment. At pH 8.5, more scale was on the heating surfaces than in the reservoir. But, in both pH tests there was virtually no difference seen due to magnetic treatment.

- In the uncontrolled pH tests, it is shown that the scale is reduced by about 48 percent. pH was measured and shown to decrease in the magnetic loop from 8.0 to 7.5 in 30 minutes or so and then slowly increased back to 8.0 in about 125 hours of treatment.
- Also shown is the amount NaOH needed to maintain the pH in the first two tests, which was 2.5 times more for the magnetic system compared to that of the control.
- Conclusion is that magnetic treatment reduces pH resulting in reduction in scale formation. No explanation of the mechanism is given.

Magnetically Augmented Water Treatment

(1997)

Paper #'s A5a & 55
Author: Parsons, S.A.
Judd, S. J.
Stephenson, T.
Udol, S.
Wang, B-L.

- Laboratory study in Cranfield University does not explain the experimental procedure completely.
- Magnetic field is provided by nonintrusive electromagnet with maximum field strength at 7000 gauss (0.7 telsa). No sketch or other details.
- Calcium concentration varied from 250 to 400 ppm.
- Heat exchanger surface temperature varied from 40°- 60°C.
- Water recirculated with a cooling system between the heat exchanger and the reservoir. Flow rate was 12 liters per minute (l/min). Not known how long the water was recirculated. There were two identical flow loops each with a 70 liter reservoir. One was used for control, the other for magnetics.
- Results are shown in a table indicating percent differences observed in the rate constant and scale reduction. At 250 ppm $CaCO_3$, no difference in scale reduction. At 300 ppm, 10 to 34 percent scale reduction. At 350 ppm, 38 to 81 percent scale reduction is indicated in the table. At 400 ppm at 60°C, there was a reduction of 81 percent.
- Zeta potentials measured are shown to be reduced by magnetic treatment by 250 to 400 mV. This is stated to be 16 percent average.
- It is concluded that such zeta potential reduction led toward nucleation and crystal growth reduction, thus scale reduction. But, the report also shows particle size data indicating larger particle presence in the magnetic treated side.

Microscopic Observation of Calcium Carbonate Particles: Validation of an Electronic Anti-Fouling Technology
(1997)

Paper #7
Authors: Fan, Chunfu
Cho, Young I.

- Not exactly a magnet. But, it is physical water treatment.
- 18 gauge wire is wrapped around a 1.27 centimeter outside diameter copper tube 60 times once and then after a gap of 0.1 meter another 60 times. A square wave signal is used that produces an oscillating electric field inside the pipe. This is the electronic antifouling (EAF) technology.
- Hypothesis is that this treatment converts dissolved mineral ions into insoluble crystals through an improved collision process. EAF treated water thus will have less dissolved minerals in the water leading to lower scaling when heated.
- Tap water is spiked with $CaCl_2$ and $NaHCO_3$ to 500 ppm as $CaCO_3$ and then pumped through an EAF unit from a 50 liter reservoir at a flow rate of 2 gpm.
- Samples were taken after the treatment at a distance of 0.9 meter, 1.8 meter, 3.6 meter, and 5.5 meter. Samples with and without EAF were compared for the crystal growth rate observed under a microscope at 100 power magnification. They were also photographed sequentially at different time periods of zero to 30 minutes and compared.
- More smaller sized crystals were seen in untreated water, whereas more larger size crystals were evident in treated water as time progressed.
- Mass of particles from untreated vs treated was 475 and 725 respectively, meaning 53 percent more precipitation in the treated supply.

Laboratory Studies on Magnetic Water Treatment and Their Relationship to a Possible Mechanism for Scale Reduction
(1997)

Paper #4
Authors: Busch, Kenneth W.
Busch, Marianna A.

- An extension of paper #5, and #68 by the same group out of Baylor University. Summarizes #5, and #68 as phase I and extends further.
- Phase II of their test used a bank of laboratory stills with one liter heating kettle and copper heating coils. A magnetic unit, an unmagnetized unit (otherwise same as the real unit), and a PVC pipe were the three comparative test conditions. A synthetic water with $CaCl_2$, NaCl, $NaHCO_3$ and a natural river water (prefiltered) were used in

the tests. Several duplicates were run with reproducibility. It is concluded that both magnetic (22 percent reduction) and nonmagnetic (17 percent reduction) units did better than PVC pipe control for synthetic water test. When natural river water was used, scaling was much more with no differences discernable for any of the three.

- Phase III tests studied colloidal hematite, latex, and cholesterol particles under static and dynamic conditions with and without magnetic field and with different electrolyte concentrations. These particles aggregated to form larger particles best when magnetic field was applied to recirculating flowing stream with high electrolyte concentrations. Differences between identical tests with and without a magnetic field showed only small differences.
- The conclusions reached on the basis of all three phases apply only to the magnetic treatment devices in which magnetic field is orthogonal to the fluid flow (as per the authors). Their study looked at intrusive orthogonal magnetic devices.
    1. MTD will require fast and continuous flow of liquid to be effective.
    2. Solution must have sufficient electrolytes in solution.
    3. Under these conditions, variety of corrosion products like Zn, Al, and Fe can be released. They can affect the scale formation.
    4. Localized high pH in the cathode can also lead toward seed crystal generation.
    5. Continuous recirculated systems may perform better than once through system with intermittent flow schemes.
    6. Turbulence created by the placement of magnets in the stream itself may play a role in the stability of the suspension.

Electronic Anti-Fouling Technology to Mitigate Precipitation Fouling in Plate-and-Frame Heat Exchangers

(1998)

Paper #10
Authors: Cho, Young I.
Choi, Byung-Gap

- An extension of paper #7
- Effect of electronic anti-fouling technology (EAFT) on a plate and frame heat exchanger was studied by using tap water fortified with $CaCl_2$ and $NaHCO_3$ to a hardness level of 1000 ppm as $CaCO_3$. A test solution of 180 liters was prepared and used for four hours of recirculation test. Flow rate was 1.5 gallons per minute. It took 50 minutes for each cycle of circulation. Temperature of the heat exchanger was 80°C, while the input to the EAFT was 26°C.
- During eight-hour test periods with and without EAFT, the pressure drop across the heat exchanger was measured. Pressure drop increased from 52 (mm of H_20) to 65 mm during the first four hours and then to 86 mm during the next four hours for the test without EAFT. With the device, these numbers were 52, 59, and 71 respectively.

- When the universal heat transfer coefficient was measured, there was a significant difference between the clean exchanger and the non EAFT exchanger operation. But, there was no difference for EAFT exchanger. This was attributed to the lack of interference by the thin scaling in the EAFT operation.

Scale Reduction and Scale Modification Effects Induced by Zinc and Other Metal Species in Physical Water Treatment

(1998)

Paper #A3
Authors: Coetzee, P.P.
Howell, S.
Mubenga, S.
Yacoby, M.

- An extension of paper #15. No magnetic device was studied in this project, however.
- Effect of Zn and other metal ions on the nucleation rate and crystal type was studied.
- Ca concentration was varied from 75 mg/dm^3 to 300 mg/dm^3 (mg/L). Zn concentration was also varied from 10 to 500 µg/l. Other ions tested include Ag, Ni, Mg, Cu, Fe, PO_4, EDTA. Bulk of the work was with Zn.
- Testing program similar to the one described in #15, where the mixed solution is placed in 37°C bath where it is heated from 22°C to 37°C. pH of the solution is measured until a constant pH is reached. Three controls and three test solutions are always tested together. The time required to reach the pH at which precipitation starts is measured and compared with the same for control. Δ T between the test and control is indicated as due to the presence of the impurity (Zn or other ions) and its concentration.
- There was a measurable Δ T for Zn concentration as low as 10 µg/l with Ca concentrations as high as 300 mg/L. At ratios of about 3 µg of Zn/mg of Ca, the effect levels off with reaching a Δ T value of about 120 minutes.
- At calcium levels of 300 mg/L or higher, there is no effect by Zn because of super saturation and precipitation of $CaCO_3$.
- Zinc levels were found to decrease in the solution over time indicating that it is involved in the crystal formation.
- At Zn/Ca ratios of 0.5 or larger (µg of Zn/mg of Ca) aragonite crystals were the only crystals produced. No calcite present.
- Other ions such as copper, copper-zinc, magnesium-zinc, had measurable significant effect. Iron, magnesium, silver and nickel had only small effects, if at all. Phosphates, however, even in very small concentrations had a very high effect, as would be expected.
- The conclusion is that magnetic devices, if they release zinc in measurable concentration, can have an effect in the quality and the rate of crystal growth.

Validation of an Electronic Anti-Fouling Technology in a Single-Tube Heat Exchanger
(1999)

Paper #9
Authors: Cho, Young I.
Choi, Byung-Gap

- Extension of paper #7 and #10.
- Test done in once through manner.
- Calcium hardness tested was 7.5 and 10.0 mmol/l.
- Flow velocities through the exchanger tested were 0.28, 0.52, 0.65 and 0.78 m/s.
- Heated water flow and temperature was also varied in different tests.
- For 10 mmol/l at a velocity of 0.78 m/s the fouling resistance was reduced by 20 percent by EAFT. With 7.5 mmol/l, this percentage improvement increased to 38 percent.
- At lower flow rates, especially at 0.28 m/s, there was less or no help by the use of EAFT.
- One finding (different from other papers) was that without EAFT, the scale produced was aragonite, while EAFT treatment produced a cluster of loosely connected small elliptic particles. Authors state that aragonite is dense and difficult to remove. Other researchers said calcite was difficult, while aragonite was considered not so.

Control of Fouling in a Spirally-Ribbed Water Chilled Tube With Electronic Anti-Fouling Technology
(1999)

Paper #11
Authors: Cho, Young I.
Liu, Rong

- Companion paper to #7, #10, and #9.
- These experiments were done with two tubes, one with EAFT and the other without, on a side by side basis. Brush punching to clean after fouling to restore was also studied.
- Ca concentration was maintained at 7.5 mmol/l and this water was recirculated through the chilled tube and returned to the reservoir after appropriate heat adjustment. Additional hardness was put into the tank to replace the lost amount to scaling.
- Two separate series of tests were done, one more fouling than the other. Temperature and flow rate were changed to achieve these conditions.

- Fouling resistance was reduced by 28 percent by EAFT and it was 34 percent less after "brush punching" type cleaning in the severe fouling test.
- These improvements were more dramatic at 54 percent and 68 percent in the moderate fouling test.
- Authors concluded that with EAFT and brush punching, the system can be restored to 90 percent of the initial value. Without EAFT, the chiller can never return to the original value once the value is reduced by 30-40 percent.

The DVGW Standard W512 — A Tool for Testing the Efficiency of Physical Water Conditioners

(1999)

Paper #16f
Author: Wagner, Ivo

- Developed by Germany's DVGW technical committee in 1994. Method is applicable to all types of scale control processes, such as water softeners, polyphosphate feeders, membrane technology, magnetic devices, electrical fields, etc. Title of the protocol is "Testing Procedure for the Evaluation of the Effectiveness of Water Conditioning Devices for the Diminution of Scaling".
- Uses water with hardness of 3.5 mmol/l. Magnesium hardness cannot exceed 25 percent.
- Water is split into four streams, two for control and two for test devices. This sequence is changed in the second test to opposite positions for control and tests.
- Four water heaters with 10 liter stainless steel boilers, surface power density of the electric coils not higher than 6.5 W/cm^2.
- Maximum water temperature in the boiler is 80°C. (Manufacturer can select a lower temperature, but must show the same on the label.)
- 130 liters per day to be drawn into each boiler at five liters per minute during a 16-hour period each day. Set protocol for this is shown.
- After 21 days of operation in each test, the boilers are opened. Scale in the boiler, at their walls, and on the heating coils removed and dissolved in dilute nitric acid. Particulate matter from inside the boilers is dried in advance and sieved through 0.5 mm mesh screen. Retained matter is added to the diluted solution. Rest is evaluated as extra data. (This is not very clear. May need some more explanation.)
- Test stand originally validated to yield "uniform" data from the four boilers as controls. Three blind tests. Variation allowed between each test ± 30 percent. Within each test it has to be ± 20 percent.
- A device must show improvement of at least 66 percent to be considered as positive.
- Four out of 20 physical devices tested have met the requirements. These were not magnets, but formed seed crystals leading to reduction in scaling on heat transfer surfaces.

- May be a good base protocol that can be developed further to meet the needs of the U.S. industry.

The Role of Zinc in Physical Water Treatment
(1999)

Paper #16b
Author: Coetzee, Paul

- Companion to his earlier papers.
- All the zinc data is from his earlier works reported in 1996 and 1998 (papers 15 and A3). Includes some new work also.
- One new work is the effect of electromagnetic field on Barium Oxalate precipitation. Barium concentration in solution was measured over a time of eight minutes in solutions that were subjected to a small external field of 3mT and found that there was no effect.
- Another part of the study was to measure the surface charge in a unique testing of the repulsive force between the tip of a cantilever and the substrate. Magnetic field was shown to induce a 60 percent reduction in the repulsive force through contraction of the double layer. This effect, however, disappeared when the treated solution was sonicated for five minutes. Author concluded that this requires more study and confirmation prior to reaching any firm conclusions.
- Author also said that zinc ions released by PWT devices as a result of electrochemical reactions induced by the field can cause a reduction in nucleation rate and thus scale reduction.

Impact of Physical Conditioning on Small Particles and Consequences for Flocculation and Corrosion
(1999)

Paper #16e
Author: Gregory, Ross

- Unusual work investigating the effect of magnetic treatment on flocculation of iron, corrosion of water, lead leaching. No explanation given as to why magnetic treatment would affect these factors.
- Three types of magnetic devices were used alone or in combination:
  - Hydroflow C30 - produces at a radio frequency.
  - Scalewatcher Unit - coil around a pipe connected to a power source.
  - Block magnets - (1.87 K Gauss) with steel plates.
- Floculation test was done where deposits were allowed to build for 24 hours and then flushed out at flow rate increments. Control and conditioning was altered daily.

According to the author, Hydroflow and block magnets increased the retention of flocs by 37 percent, while scalewatcher by itself reduced it by 18 percent. Not clear as to whether it is compared to control.

- Corrosion tests were done with iron coupons in slow and fast flow sections. Magnetic treatment was compared to no treatment. In low flow area, magnetic treatment increased corrosion while the reverse occurred in high flow area. No explanation as to why such a difference.
- Lead corrosion was tested in an elaborate test set up with low and high alkaline waters with and without magnetic treatment. Both Hydroflow and permanent magnets were used in this test. But after many, many tests, it was concluded that magnetic treatment did not affect the lead leached from the pipes. However, photomicrographs of lead pipe section showed some differences in the structure of how they leached out from these surfaces. Not explained as to its significance, however.

Molecular Mechanisms of Magnetic Water Treatment
(1999)

Paper #16c
Author: Colic, Miroslav

- This paper is not easy to understand.
- It presents high levels of discussion about the mechanism related to possible memory effect.
- Reports work done with magnesium carbonate sols. Also reports work with zinc oxide and silica.
- Based on some of the observations, author has concluded that magnetic water treatment modified gas/liquid interface and produces reactive hydrogen and oxygen species. This, as per the author, would result in changes in the thickness of the hydration layers near ions, surfaces, or in changes of the chemical reactivity of the water. Results in this study suggest changes in chemical reactivity of the water and the solubility of inorganic materials. (Not very clear as to how this has been shown.)

A Review of Some of the Analytical Methods Used to Assess the Influence of Magnetic Treatment
(1999)

Paper #16g
Author: A-Barrett, Rebecca
Hillis, Peter
Parsons, Simon

- Both static and flowing tests have been performed.
- Many different measurements techniques were employed: Absorbence, particle size, SEM, zeta potential, force distance (surface change), turbidity.
- Solutions of Na_2CO_3 and $CaCl_2$ (8×10^{-3}M) were prepared for many of tests.
- In some test hematite sol was used.
- An electromagnet with an average flux density 0.5T and two permanent magnets fitted in a spectrophotometer with a density of 0.35 T were used for the different tests.
- Absorbence measurements made for the different sols showed no difference at 90 percent confidence levels.
- SEM analysis was found to be subjective and was considered of no value.
- Particle size analysis and zeta potential measurements showed no difference.
- Force distance method may be very useful, but hasn't been developed adequately yet.
- In flowing stream, particle size of the hematite sols were measured. It was concluded that any aggregation was due to the influence of turbulence, but not due to the presence or absence of magnetic field.
- This study attempted to arrive at useful methodology, but concluded that surface charge measurements if and when developed may be useful to check out the memory effect. None of the other methods were considered useful by the author.

Overview of Recent Magnetic Treatment Research at Cranfield University
(1999)

Paper #16a
Author: Parsons, Simon A., Dr.

- This is a review paper with considerable amount of data from papers #A19, #A5a, and #55 along with some new work.
- Additional tests included eight once-through runs using different configuration of magnets and different levels of alkalinity and hardness. Duration of these tests was two to eight weeks. Results showed 53 percent decrease to 38 percent increase. The decrease was in the first two runs, which could not be duplicated later. The last test, which showed no change, was indicated the most comprehensive one.

- Some tests done to examine types of scale concluded magnetic treatment produces less hard scale, but equal in the total amount. Test conditions and protocols were not given.
- Static magnetic tests reported, showed some effect confirming a study by Ko Higashitani, Shintaro Hatade, Katsunori Imai, Akiko Kage, and Shinichi Katamura (paper #35).
- Electronic antifouling technology device along with a ion exchange water softener were tested and compared. EAFT did not reduce hardness, while ion exchange did.

The Effect of Magnetic Water-Conditioning on Selected Properties of Water in Contact With a Heat Exchange Surface

(2000)

Paper #A11
Authors: Ritchie, I.M., Ph.D.
Lehnen, R.G., Ph.D.

- A 120 gallon galvanized steel tank via 1 inch galvanized steel manifold supplies water to the conditioning units (one magnetic, the other a nonmagnetic dummy) on its way two distillation units (1000 watts each), operating at 100°C at atmospheric pressure. No bleed off from the boilers.
- Water enters first a condensation chamber in each distiller. The steam from the boiler goes through a coil that is inside this chamber immersed in this water. Steam condenses and gets collected in five gallon bottles. Water in the condensation chamber gets heated by this activity before it enters the boiler.
- Magnetic unit is a single pass where water passes through a series of alternating reversing polarity fields that are orthogonal to the water flow. Core is a single bar cobalt alloy permanent magnet. The capacity is 15 gph. Velocity in the chamber is 2m/sec and the magnetic field associated with each of the five poles in 1800 Gauss.
- Raw water has a total hardness of 510 mg/L as $CaCO_3$, calcium - 301 mg/L, magnesium 209 mg/L, TDS - 0.52 g/L, pH - 7.03, alkalinity - 351 mg/L and conductivity was 1.03 ms/cm.
- Results show analysis of seventeen paired data points from a single experimental run of 250 hours. Samples were taken from the two condensation reservoirs (one with, the other without magnetic water treatment).
- Graphs were shown for the variation of total hardness, calcium, magnesium, conductivity, pH, and alkalinity.
- Concentration of hardness in the magnetically treated water in the condensation chamber was 21 percent, 22 percent and 16 percent lower in terms of total magnesium, calcium hardness, than the control as per the authors.
- It has been stated that the build up of scale in the boiler feed tube with magnetically treated water was half the thickness compared to that of the dummy unit.

- Mean production of distilled water in the magnetic unit was 34 percent higher than that from the dummy unit.
- Conductivity was 21 percent lower in the magnetically treated system, while alkalinity was 5 percent lower for the dummy water system (not significant).
- Temperature of the water samples from the condensate reservoirs were not shown in this paper. They were, however, reported to be the same for both units.
- No explanation was given as to why.
    - Total hardness went up as high as 2500 mg/L in these chambers.
    - Such up and down values were shown for all parameters during the 250 hour run time.
    - While calcium levels stayed close to the influent concentration of 300 ppm, magnesium went up as high as 2000 mg/L and mostly stayed around 1000 to 1500 mg/L.
    - Conductivity was also high around 4 ms/cm.
    - Alkalinity stayed around 100 to 300 mg/L.
    - Whether a mass balance of minerals and scaling was made to account for what happened to the minerals entering the distillers in view of the distillation process and no blow down action.
- These questions need to be reviewed with the authors.

Discussion

A review of these 34 papers has shown that researchers have attempted several different approaches to begin to answer a number of fundamental questions about the performance of magnetic water treatment devices. These approaches include full scale side by side comparisons of magnetic devices connected to water heaters or pipe segments to discern whether and how they may yield improvements such as lower scaling on the heating or other surfaces over prolonged use (papers #29, #1, #31, #31, #16a, #A5c, #A11). In some of these studies, no measurable affirmative results were reported, while Adriaenssens (#A5c) and Ritchie, et al (#A11) reported positive effects due to magnetic treatment. The work done in #A5c is not a very controlled study regarding the parameters, but the study reported in #A11 appears well planned and executed. However, there are some unexplained factors shown in the graphs of that paper requiring further description for better understanding.

Four studies (papers #7, #9, #10, #11) have been conducted by Cho et al. using an Electronic Anti-Fouling Technology unit and have indicated an effect due to the use of this device. This device is reported to induce precipitation of the dissolved ions resulting in nucleation centers leading to precipitation of more dissolved ions in the body of the water and thus preventing their adherence to the surfaces. While these studies are very interesting, it is not shown that these results may be applied to permanent magnetic devices as used in the domestic and commercial water treatment industry. Such nucleation crystal production by these devices in household water usage patterns has not yet been demonstrated by any of the researchers. More scientific study in this area would be very helpful.

Several other studies report bench scale static tests mostly to illustrate a specific action and to hypothesize a mechanism (papers #18, #35, #28, #A13, #16c, #16g). Mechanisms proposed by these studies are valuable, except they sometimes contradict each other. In some studies, it was reported that $CaCO_3$ precipitation was affected negatively, while in others just the opposite was reported. In the first case, it is a straightforward conclusion of lower scaling because of lower precipitation, while in the second case, higher precipitation in the body of the water is expected to lead toward lower scaling on heating or other surfaces. More work needs to be carried out to clarify what exactly is necessary to demonstrate a magnetic water treatment effect and how it can be achieved.

Some studies were carried out using recirculating systems (papers #A19, #A5a, #55) to demonstrate scale reduction in such systems as well as to look for mechanisms. Recirculating the water several times through these magnetic devices has shown in this set of studies significant scale reduction under certain conditions. Dr. Cho believes his experiments have shown that a constant water flow velocity of at least seven feet per second, water turbulence, and blow downs may be necessary and even critical to prevent the fine powder-like scale particles created by magnetic treatment from reaccumulating and sintering or cementing together onto the heating elements and conduit walls, and, thereby, nullifying any possible effects of magnetic water treatment. The task force could not find applicability of this technology as described to the needs of domestic water treatment usage patterns and household plumbing designs though further study and analysis of this technology and other available technologies and solutions would prove helpful.

Domestic and small commercial uses of water, especially heated water, is once-through (not recirculated) and intermittent (not continuous). A treatment system applied in such uses should be capable of providing the intended benefits under intermittent operation in a once-through manner. The science for possible technologies needs to be developed in these conditions to be more applicable for domestic and small commercial uses of water.

There were very few studies that employed such once-through intermittent operation. Of those, the studies discussed in paper #A11 indicated positive effects by magnetic treatment.

However, several studies conducted by different researchers have shown some unique characteristics. Busch and coworkers (papers #5, #68, #4) showed that intrusive orthogonal magnetic treatment devices under flowing conditions exhibited an electrical potential, even though small in magnitude. They also showed under flowing conditions when particles are present in the stream that magnetic fields influence the particles' surface charges. Busch's overall research program has concluded that the magnetic devices with good turbulent flow in a water system, with sufficient dissolved minerals, can lead to two effects that may favor scale reduction. One is that a variety of corrosion products like zinc, aluminum, and iron can be released by these products under such operating conditions. Another is that, due to localized high pH near the cathode, seed crystals can be generated. These two effects can play a measurable role in scale reduction.

Similarly, Katz and coworkers (papers #34 and #67) showed that if iron is present in a water system where $CaCO_3$ precipitation may be occurring, it could inhibit the growth of scale crystals further. Dr. Katz reports the same effect can also be influenced by copper ions. Paiaro and Pondolfo (paper #53) reported independently that iron, even in very low levels, does interfere with the calcite formation in the presence of a magnetic field.

Coetzee and coworkers (papers #15, #A3, #16b) demonstrated that the magnetic devices they tested imparted small amounts of zinc and other ions due to the presence of the magnetic fields. The zinc and other ions, when present, were shown by these researchers to inhibit the rate of $CaCO_3$ crystal formation and its characteristics. These were not classic once-through intermittent studies. However, their approach and efforts could be projected to show the possibility of such a result under certain operating and water quality conditions. It is possible that the work done by Busch, Katz, Coetzee and their coworkers, when examined collectively, may point toward a mechanism for these products and their potential effect under certain conditions.

Finally, many of these studies have good experimental design and were conducted in a research-like manner. They all differed from each other, however, in terms of their details of approach in setting up bench scale, flow rate, recirculating versus once-through, water quality, parameter monitoring, and the other test conditions for their demonstrative studies. A standardized protocol needs to be developed for each of these types of tests by the researchers so that one can compare the results of different studies to reach an overall conclusion.

At least for the demonstrative studies without any regard to mechanism or process, one such protocol has been developed and has been in use for several years though there has been some controversy associated with its use (paper #16f). The DVGW Standard W512 may not be completely comprehensive in its specifications and consistent control of alkalinity and carbon dioxide in the challenge waters, of water flow rates and turbulence, and of the drinking water analytes to be monitored, but it is recognized as one protocol that might be used as a starting point for development of a standard for use in the U.S. and elsewhere. Such a standardization is badly needed for the advancement of magnetic and other physical water treatment processes, devices, and equipment and for their understanding and acceptance by the scientific and regulatory communities.

Conclusion

The Magnetics Task Force submits its review of the physical treatment of water literature in fulfillment of its objective. Thirty-four papers of 106 papers reviewed in the task force's opinion met the scientific criteria established by the task force.

Fortunately, the goal of this task force did not include an evaluation of science applied to specific technologies, processes, or devices or a determination of "whether magnetic and other physical water treatment processes work." The thirty-four papers that met the task force's criteria for being scientifically valid did not address or answer that question. In that body of literature, there are indications that physical water treatment does work, that it does not work, that it may work, but only in certain circumstances, and that it may work in conjunction with or as a result of coincidental trace chemical or ionic leaching mechanisms or other combination technologies. There is, of course, always the question of what does it mean "to work," what are the applications? the specific processes, technologies and devices at issue? the expected and desired results? the uses and claims made for such technologies? These questions are not answered by this report.

The task force is encouraged to find that there are enough scientifically valid papers that offer insights and techniques of study to make it possible, the task force believes, to work toward developing a standard for certifying claims, perhaps limited, but ones that could be reproducibly substantiated. One paper in the review discusses a standard already in use by the German DVGW to test and measure scale diminution effects of water treatment devices. The development of such a standard in the United States will require investment from industry members, standards making and certifying agencies, and third-party laboratories. The task force is convinced that industry and the marketplace should take "physical water treatment" to the level of having a certification standard. The literature review suggests that development of a standard is technically possible, but the industry itself must determine this step.

The task force believes that additional scientific study can unify some of the observations already in the literature about physical water treatment. If this happens, it is possible that new improved devices with more consistent and predictable performance and new applications can be introduced.

The task force, therefore, suggests three actions which it believes will further improve the status quo of the "physical treatment of water" segment of our industry:

1. The task force believes that a consensus standard under the American National Standards Institute (ANSI) process should be developed by representatives of the magnetic and other physical water treatment industries and the regulatory and user communities working together in such a process. The task force has not found sufficient scientific evidence to otherwise determine the efficacy of the physical water treatment technologies in practical water treatment applications without the factual substantiation of performance claims as would be tested and demonstrated under a sanctioned ANSI drinking water treatment unit standard for magnetic and other physical water treatment

products. It may, indeed, be necessary to distinguish between categories of systems, such as those for industrial applications or those for home uses; products that test successfully under one condition may not be as functional in another.

2. The task force believes that interested academics and academic institutions, industrial device and process manufacturers and users, standards makers and certifying bodies, and federal government and state agencies should be encouraged by WQA to fund additional fundamental research aimed at increasing the scientific understanding of the physical treatment of water.

3. The task force urges that WQA, with the goal of developing further research interest in physical treatment of water, make this report available to the authors of the thirty-four papers cited in the report and to others who may request a copy with a view toward advancing the science reviewed in this report.

Finally, the task force, believing it has met its limited goal, recommends its dissolution.

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