SYMMETRY

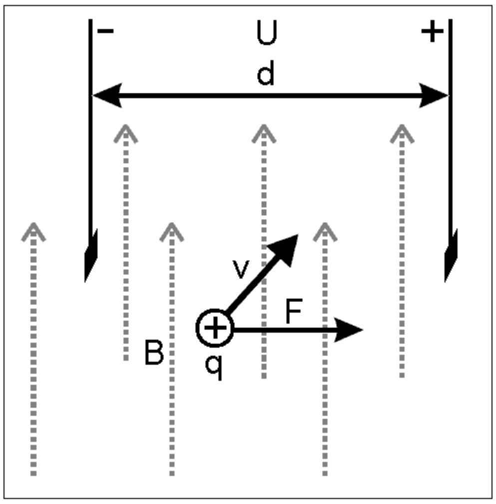
Projektovanje i proizvodnja elektronske opreme
Leskovac

ELECTROMAGNETIC WATER TREATMENT

19 March 2010

1 Mechanisms of action

1.1 Effect of the magnetic field on moving charged particle [Electromagnetics]:



$$\vec{F} = q \cdot \vec{E}$$
$$\left|\vec{E}\right| = \frac{U}{d}$$
$$\left|\vec{F}\right| = q \cdot \frac{U}{d}$$

$$\vec{F} = q \cdot \vec{v} \times \vec{B}$$
$$\left|\vec{F}\right| = q \cdot |\vec{v}| \cdot \left|\vec{B}\right| \text{ for } \angle(\vec{v}, \vec{B}) = 90^\circ$$

$$q \cdot \frac{U}{d} = q \cdot |\vec{v}| \cdot \left|\vec{B}\right| \text{ for } \angle(\vec{v}, \vec{B}) = 90^\circ$$
$$U = d \cdot |\vec{v}| \cdot \left|\vec{B}\right| \text{ for } \angle(\vec{v}, \vec{B}) = 90^\circ$$

Figure 1. Moving electricaly charged particle is forced to the right by action of an magnetic field.

1.2 Water and crystallization process

[Kronenberg]:

Water molecules has tendency to form complexes $(H_2O)_n$ with 20 < n < 200. Hydrogen bonds hold neighboring H_2O molecules together, forming clusters. The complexes form cage-like structures preferrably around ions and foreign particulate matter.

Crystals of $CaCO_3$ is the main component of the mineral content of most waters.

Ordinary water is characterized by the scarcity of nucleation centers; super-saturation develops and accordingly the minerals start to solidify at the substrate in the form of dendritic crystallization. They grow to form thick, interconnected crystals and are firmly attached to the point where the nucleation started.

After passing magnetic fields, solidification nucleii in the volume of the water start the formation of separate, unattached crystals of calcium carbonate, mostly in the form of circular discs. 10^8 discs per cm^3 may contain the entire $CaCO_3$ content of a water with 500 parts per million total dissolved solids. Assuming that 50 % of the water molecules are bound in complexes of about 200 molecules each, the active nucleation centers are released from their encaging complexes in sufficient numbers if one in 10^{13} complexes is fractured.

It has been shown theoretically that the interaction between magnetic fields and the hydrogen bonds between the water molecules are by orders of magnitude too weak for direct, significant effects. The weak interaction between the magnetic fields and the hydrogen bonds is amplified to the breaking point by resonance. The frequency of the internal vibrations of a 200-molecule water complex held together by hydrogen bonds of 4 x 10^{-20} J would be in the order of 10 kHz if the complex had a spherical shape. If it had the shape of a flat disc its frequency could be as low as 100 Hz.

Effective magnetic treatment results in a separation of formerly dissolved minerals from the liquid water by forming microcrystals which move with the water in suspension. The energy for this entropy reduction is provided by the kinetic energy of the moving water.

The liquid water is then depleted of its mineral content, and it is therefore able to dissolve minerals. The capability of magnetically treated water to redissolve old lime scale deposits is often observed and reported.

The internal seeding effect of the magnetic water treatment lasts for up to two days. The microscope observation reveals that the circular disc-shaped microcrystals of $CaCO_3$ deteriorate slowly by a solid state transformation into bundles of $CaCO_3$-needles called aragonite. The reduction of surface tension and viscosity by up to 2 % and changes of the electro-optical values of the water last only for a few minutes after the magnetic treatment. They are caused by the existence of fractured complexes before they recombine again to form the normal size complexes.

[Gabrielli]:

In general, people agree on the fact that magnetic treatments lead to the formation of calcium carbonate particles in the bulk of the scaling water, which cannot precipitate on the walls of distribution pipes and other equipment. These particles are carried away by the water flow and can be eliminated by removing or filtering the resulting calcareous mud.

Ferreux (1992) has proposed that a magnetic term be involved in the activation energy, which allows the critical radius of nucleation to be lowered. From the microscopic point of view, the magnetic field was shown to influence significantly the zeta potential and size distribution of the particles formed in solution.

[Wang]:

Under the influence of an external magnetic field, several kinds of crystals (eg. calcium carbonate, aluminum sulphate, borax) precipitated in different shapes from those without the treatment.

Ratio of calcite to aragonite precipitated from a saturated solution was influenced by magnetic treatment. Since the crystal nuclei were electrically charged, they would interact with the magnetic field. The resultant Lorentz force would modify the preferential surface of crystal growth, consequently altering the shape and size of crystals. A magnetically treated solution favored aragonite growth. Three dynamic rates play important roles in the crystallization process: these are association, dissociation and nucleation rates.

[de Baat Doelman]:

The crystallization of dissolved solids follows three very distinct phases. The Scalewatcher unit works by changing the nucleation phase.

$$Solution\_phase \rightarrow Nucleation \rightarrow Crystal\_growth$$

Nucleation is the very initiation of crystal formation. During the nucleation process, the dissolved ions are constantly colliding with each other. Only a small portion of the collisions will result in nuclei, since the molecules must have a certain amount of energy and must be oriented properly to begin forming the proper crystal structure. The rate that nuclei are formed is given by the following equation.

$$Rate\_of\_nucleation = Collision\_factor \cdot e^{\frac{Energy\_of\_activation}{k \cdot T}}$$

The collision factor represents the fraction of collisions which results in a nucleus formation. The factor generally depends on the total number of collisions and on how the ions are oriented when they collide.

The energy of activation signifies how much energy is needed to get the nucleus started. Once this energy is put in, the nucleus will then continue to grow into a crystal. If this amount of energy is not available, the nucleus will re-dissolve back into a solution. The energy is the result of the kinetic energy from the moving ions, the energy released when the ions bond together, and the energy required to form the outer surface of the nucleus.

2 Review of diferent equipment

2.1 Currently marketed devices [Huchler]:

As shown in Figure 2, 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. 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. 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.

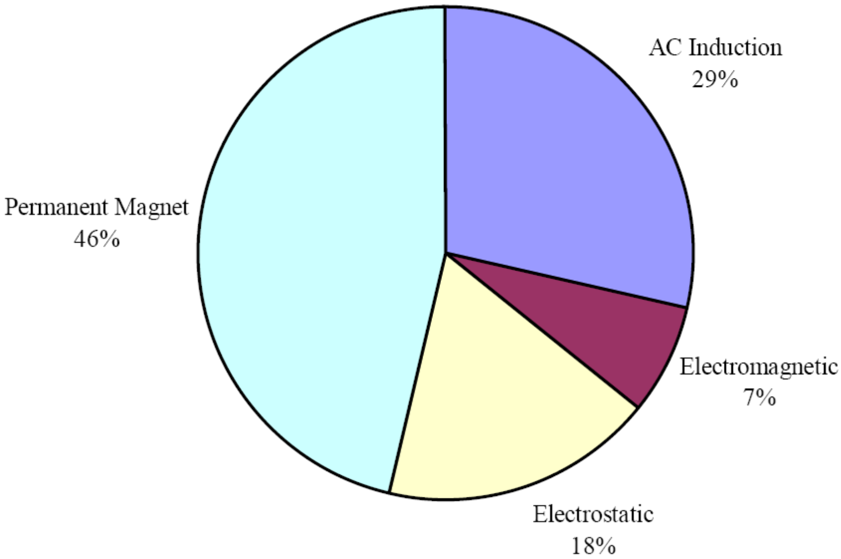


Figure 2. Non-chemical water treatment systems marketplace (based on number of different devices).

2.2 Permanent magnetic field water treatment

[Huchler]:

The application requires a magnet (permanent or electrically induced) placed in or around a non-magnetizeable 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.

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. Threshold magnetic field is required to achieve a response.

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.

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 after the magnetic field has been withdrawn.

[Kronenberg]:

Unquestionable benefits have been reported such as medical uses in China, agricultural improvements and desalination of soil, but mainly for the prevention of hard lime scale. We have quantitatively determined the effectivity E of a number of commercially available devices for magnetic water treatment. Most of them use the stray fields of permanent magnets. In these devices only small amounts of water happen to hit a resonance between their complex-vibrations and the magnetic field sequence. Accordingly, they achieve effectivities E of only 10 to 50%. However, even the low effectivities lead to benefits like preventing lime scale if given sufficient time.

In general, magnetically treated water makes most chemical additions more effective. This is most noticeable for detergents (steamcleaners), fertilizers, feed stuffs, and softening agents. The wetting capability is improved for most powdery materials and surfaces. This shortens drying time when the water leaves a thinner film after running offsurfaces. More subjective observations, such as diminished taste and smell from chlorine and sulfitic contaminations can be explained as a result of the secondary crystallization of these substances on the $CaCO_3$-seed crystal.

[Wang]:

For commercial magnetic fluid conditioners, several cases of failure have been reported. Duffy (1977) found that the devices he tested had no effect on water-scale deposition but accelerated the corrosion of steel pipes. Similarly, Eliassen et al. (1958), Gruber and Carda (1981) and Hasson and Bramson (1985) rejected other commercial devices based on deposition tests. However, positive control of scaling in refinery cooling towers has been claimed by a major oil company in the United States (Grutch and McClintock, 1983).

2.2.1 Experiment of Kronenberg [Kronenberg]:

Waters with various mineral contents were forced to flow through a number of magnetic fields of permanent magnets. Systematic variations of the number of the fields, their sequences, field strength, and gradients, and of the water flow velocity were applied.

50 microliters of tapwater with about 500 parts per million total dissolved solids typically evaporate leaving a ring of 500 prismatic crystals along its perimeter; a small amount of the minerals forms dendritic structures on the center of the drop.

If the same water had moved through magnetic fields it evaporates with some of its mineral content solidifying in the form of circular, disc-shaped crystals. They may number in the millions, and their location is not confined to the perimeter even though the larger ones are found there. The prismatic crystals are less in number depending on the amount of minerals crystallized in the form of the disc-shaped, separate crystals.

The magnetic fields were provided by ferrite-type ringmagnets, magnetized axially and placed around the water conduit. A cylindrical bar of soft steel in the center of the water conduit assured the magnetic fields of up to 0.1 T to penetrate the entire water flow cross section.

Of major importance was the sequence of the polarity of the fields. Effectivities E above 80% were achieved with sequences of the type shown in Figure 5. The effectivity increased decisively with the number of magnets increasing from 2 to 8.

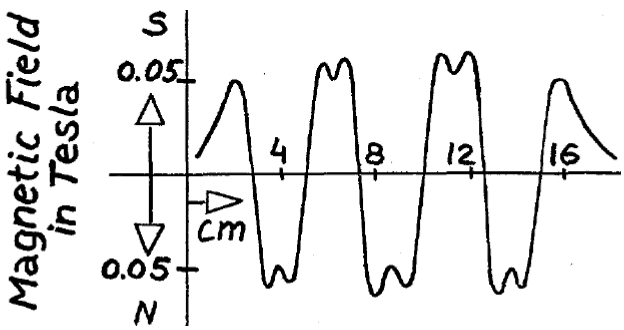


Figure 5. Distribution of magnetic fields of 6 magnets along the water conduit.

All effectivity values depended sharply on the velocity with which the water had moved through the field sequence. The magnetic treatment is usually most effective when the water passes through 12 fields in about 0.1 seconds. So, the frequency of the magnetic influences is of the order of 100 Hz.

The more immediate effects of nearly 100 % change in crystallization mode reported here are only observed with devices based on resonance. We have achieved the breaking loose of cm-thick lime scale deposits from the walls of old cooling towers which did not respond to the usual acid wash any more. Water circulation equipment has been kept free of any scale deposits for years with only a fraction of the chemical additions which would have been needed without the additional physical water treatment.

2.2.2 Experiment of Wang at all [Wang]:

The experimental set-up is illustrated in Figure 3. The sample solution was kept in a cubic glass cell of dimensions 2 cm x 2 cm x 2 cm. Two disk-shaped rare earth magnets were centered on the outside faces of the squared sample container with unlike poles facing each other (see Figure 3). They rested on the glass by their magnetic attraction. Solutions were stirred with an elbow shaped wire of stainless steel connected to a small motor. It was not necessary to thermally insulate the magnets or sample container as the temperature difference was small. The magnetic field near a single pole-face was measured to be about 0.2 T; meanwhile a small magnetic conductor was placed inside the glass cell to generate a strong gradient of the field. The same results were obtained with two types of magnetic conductors: a piece of mild steel wire (10 mm long and 2 mm in diameter), or a small teflon covered magnetic stirring bar of the same size. The time dependence of turbidity was used to make inferences about the crystallization process.

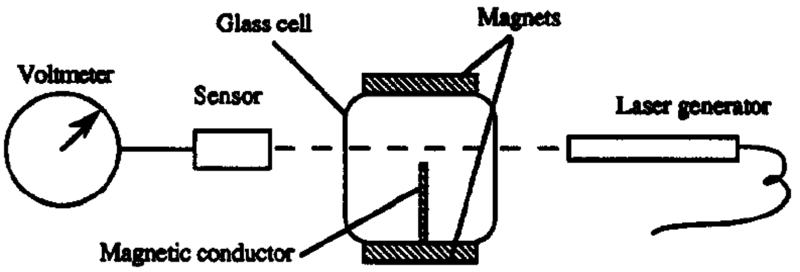


Figure 3. Schematic of laboratory apparatus.

The small grain size is associated with fast nucleation and precipitation, as is clearly demonstrated from the turbidity results. Figure 4 shows a pair of typical turbidity records. The steep increase in turbidity, which indicates the fast nucleation and precipitation, is remarkably repeatable in our tests. The fluctuations near 22 min reflect the agglomeration of tiny crystals; its occurrence was quite random.

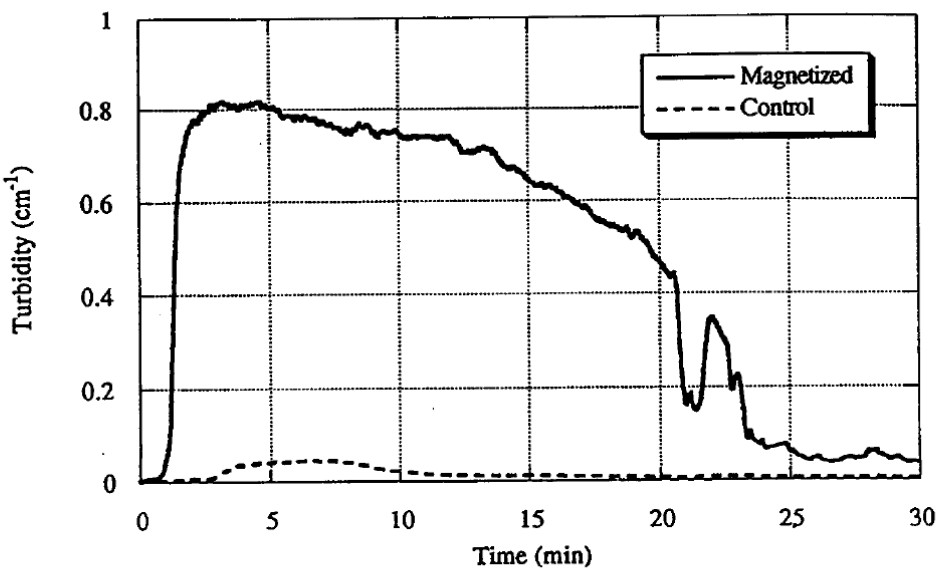


Figure 4. Turbidity recorded as function of time. The magnetic treatment reduces the induction time, and greatly accelerates the nucleation and crystallization process.

Results from parallel tests can be characterized statistically by their means and standard deviation. For six tests with the magnetic device, the rising time is 78.8 ± 10.5 s, and the maximum turbidity is 0.68 ± 0.22 cm^{-1} For the tests without the magnetic device, these parameters are 141.7 ± 40.0 s and 0.012 ± 0.008 cm^{-1}. The difference between these two groups is larger than experimental error.

The purpose of pre-warming was to obtain a stable and repeatable condition. The exact method of stirring was not found to be important. Air bubbling and hand stirring were also tested; similar results were obtained with each technique.

The magnetic conductor inside the cell plays an important role. It generates the magnetic gradient as well as mechanical and magnetic vibrations. The field gradient is difficult to measure and the configuration of the field cannot be described with one parameter. When the conductor is glued to the cell instead of suspended by the magnets, the probability of "burst" is reduced.

Somewhat similar results have been obtained in the former Soviet Union. Tebenihin and Gusev (1968) passed hard water through a constant magnetic field at a fixed speed of 0.1 m/s. Their results show that the number of particles increased with the magnetic field up to 0.8 T; crystal sizes decreased with increase in the magnetic field up to 0.3 T. These observations suggest that the nucleation rate (hence, the number of crystals) is directly related to application of a magnetic field. Our tests using a different method yield results in agreement with theirs.

2.2.3 Experiment of Gabrielli at all [Gabrielli]:

To have reproducible results, carbonically pure water and scaling water made from salts were tested. These artificial scaling waters were often renewed and their stability was checked by monitoring the pH before and after treatment.

The home-made magnetic device is depicted in Figure 6. The water to treat passed through a pipe inserted between the polar pieces in opposition of polarity. In this configuration the magnetic induction was perpendicular to the solution flow. Each polar piece is the assembling of two rectangular permanent magnets (42 x 25 mm^2 and 6 mm thick). The magnetic circuit of each pair of magnets was partially closed by U-shaped pieces of mild steel, to close the magnetic field in the gap. The various pairs were separated by 12 mm. Figure 6(C) shows the induction of the magnetic field, measured using a Hall probe, when the polarity of the pairs of magnets were alternated the magnetic field was highly discontinuous in the gap. Figure 6(D) shows the induction of the magnetic field when the pairs were all in the same direction, here the magnetic field was almost uniform in the gap (mean value 0.16 T). The scaling water to be treated was circulated in a pipe through the gap by means of a centrifugal pump. The water velocity can be changed from a few 0.01 m/s to a few m/s. The pipe, unless specified, was of stainless steel.

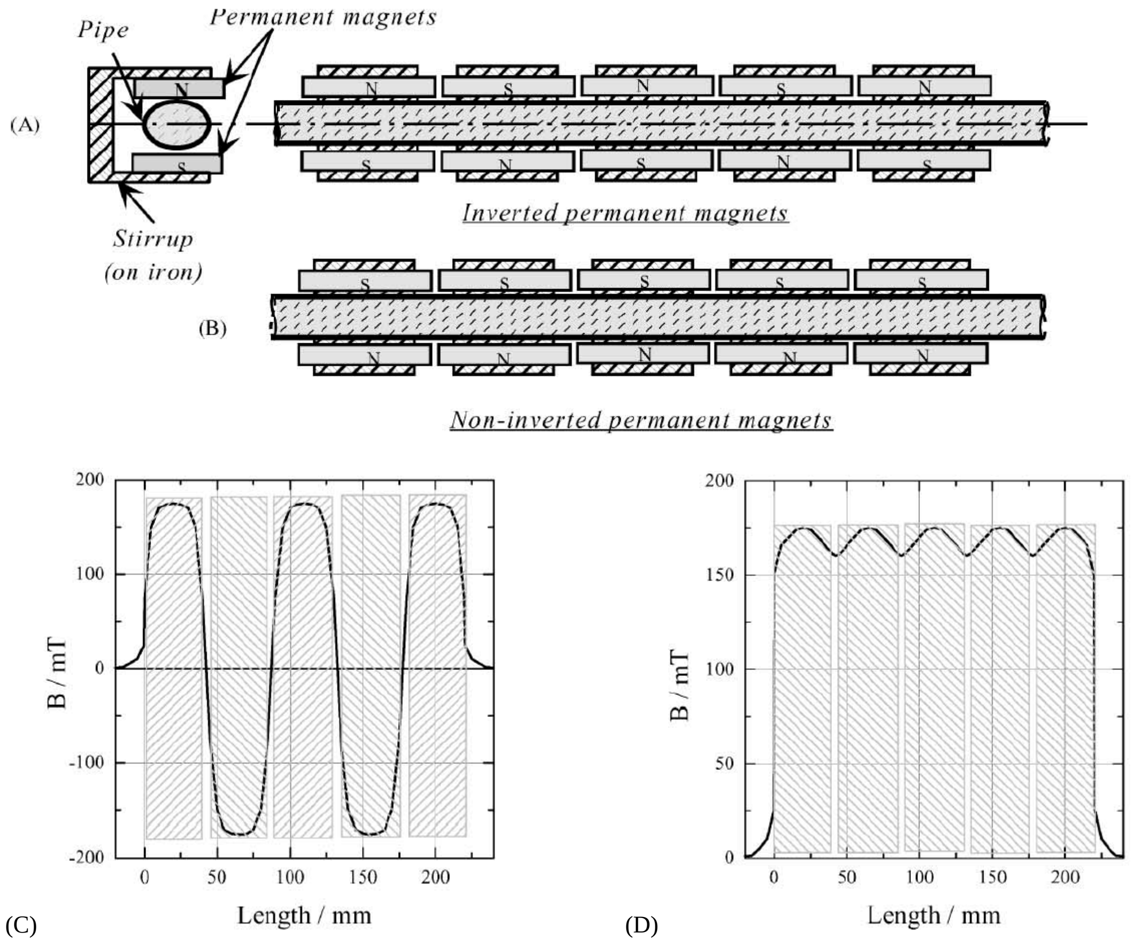


Figure 6. Description of the home-made magnetic device. (A) Scheme of the device with alternated polar pieces, (B) scheme of the device without inversion of the polar pieces, (C) variation of the magnetic induction in the gap for inverted pairs of permanent magnets, (D) variation of the magnetic induction in the gap for non-inverted pairs of permanent magnets.

A neat improvement of the efficiency of the magnetic device was observed when its length was increased.

The inversion of polarity improved the efficiency of the magnetic device. By using 10 pairs of magnets the efficiency decreased from 50 % when the pairs were inverted to 35 % without inversion.

Only a pipe made of stainless steel, which conducted the scaling water to treat across the gap, was used. In addition to stainless steel, copper and two types of polyvinyl chloride (PVC) tubing were used. PVC I was pure PVC, transparent and flexible. PVC II was loaded with calcium carbonate and alumina, grey and rigid, it is the usual tubing used in plumbing.

After five passages in the gap (i.e. 1 min treatment) the concentration of the ionic calcium was reduced by 18 % for a pipe made of PVC II, whereas it was reduced by 28 % for stainless steel and copper. The increase of the treatment time did not increase very much the effect of the device. So, an increase from 5 to 150 passages improved the efficiency by 5 % only. When the pipe was made from PVC I the magnetic treatment was inefficient whatever be the number of passages.

There is an optimum velocity where the magnetic effect is maximum. Therefore, when the flow velocity increases too much, the residence time is too short and the magnetic treatment becomes inefficient. At a constant flow velocity, if the residence time increases too much the ionic calcium concentration decreases up to the point where the backward reaction dissolves the formed particles of calcium carbonate to reach an equilibrium. Therefore, when the length of the device increases, the ionic calcium concentration tends to a limiting value.

Magnetic treatment of scaling waters is efficient by decreasing the ionic calcium content of the solution, even for a single-pass. Decrease in ionic calcium content lead to a decrease of the scaling power of the treated water. The magnetic treatment trapped a part of the ionic calcium, which is then inactive for scaling. Effect is more pronounced for conducting materials than for insulators.

Busch et al. (1986) demonstrated that voltages are produced across the device and localized pH shifts occur inside the pipe, which contains the solution, when a conducting solution is made to flow through a magnetic device. They concluded that currents are generated within the solution and return through the body of the device. This feature supposes that the body is conducting. They found cathodic regions of high alkalinity on the walls of the device. They suggested that dissolved oxygen reduction was responsible for OH^- release, which could force calcium carbonate to precipitate and build seeds, which continue to grow in the bulk. This mechanism supposes conducting walls and above all corrosion of the iron of the wall of the pipe.

The presence of calcium carbonate in the material constituting the tubing may also influence the nucleation rate of the seeds. These seeds seem to be necessary to initiate the magnetic treatment.

It was shown that high gradients of the magnetic induction improve the efficiency of the magnetic treatment. It has to be noticed that even for a quasiuniform induction in the gap, the flowing water was submitted to a positive and a negative gradient of magnetic induction at the input and at the output of the magnetic device. Oshitani et al. (1999) have discussed this point: as water molecules are diamagnetic, a high gradient of magnetic field generates a strong attractive force between ions and water molecules, improving the efficiency of the magnetic treatment.

2.3 Alternating current magnetic field water treatment [Huchler]:

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 to megahertz frequencies) and sometimes in very complex ways. There are a variety of electromagnetic signals used in these types of devices.

Morse patented 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.

Cho, a professor at Drexel University, and others patented two devices allowing switching frequencies to promote better de-scaling and for minimizing corrosion due to carbon dioxide (CO_2) generation during de-scaling.

In a highly detailed lab study, Cho and Choi describe 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- and-frame exchangers. 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 Electronic Anti-fouling Technology (EAF) treatment. As the investigators increased the concentration of calcium from 750 to 1000 parts per million 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.

A product named Scalewatcher Enigma from Environmental Treatment Concepts is a direct application of Cho's work. Clearwater Systems has published two technical papers 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 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.

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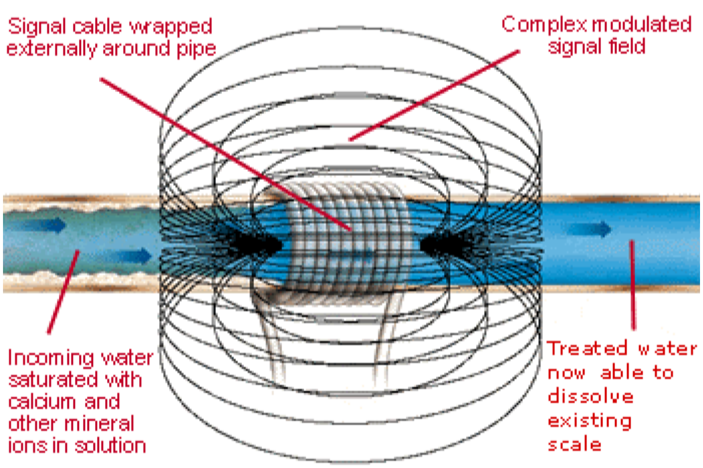

Figure 7. How does scalewatcher work?

2.4 Permanent electric field (electrostatic) water treatment [Huchler]:

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.

One problem noted by Eades 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 biofouling (deposition of particles).

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 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.

Manufacturer claims efficacy against corrosion, scale and microbiological populations with limited explanations of mechanisms.

3 Procedures for evaluation of effects of treatment

3.1 Experimental design of field trials [Huchler]:

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, the Stability Index by Ryznar, and the Practical Scaling Index. Non-chemical water treatment systems (NCWTS) 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.

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

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.

System health monitoring (Table 1) 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 1. Required System Health Monitoring

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

[Kronenberg]:

The reduction of the number of the substrate-bound crystals has been used as a quantitative measure of the magnetic effect.

The water was placed on precleaned glass slides in quantities of 20, 50, and 100 µL and allowed to evaporate. The development of the forming crystals of the mineral content of the water was observed microscopically in polarized light. Significant phases of the solidification processes were recorded photographically. Attention was focussed on the crystals of $CaCO_3$. The calcium carbonate crystals are particularly well identifyable in the polarized light because they are optically active and produce striking contrasts.

Each test slide carried at least one drop of water which had passed the equipment before the magnets were placed. This was for the direct comparison and in order to eliminate possible influences of the slide surface.

The micrographs show a part of the perimeter of a drop because almost all the solidification of the minerals takes place at or close to the outer rim of the drops. This is caused by a vigorous radial convection inside the evaporating drop which transports the heavier minerals towards the drop perimeter.

The effectivity E of the magnetic effect is defined by the reduction of the number of the prismatic crystals, determined by counting these crystals along the perimeters of the treated drop and substracting this number from the one of the untreated drop, expressed in percent.

[Wang]:

Tests were often not repeatable.

Tebenihin and Gusev (1968) passed hard water through a constant magnetic field at a fixed speed of 0.1 m/s. By counting the number of crystals in a certain viewing area and estimating the average sizes with an optical microscope, found the dependence of these two parameters on the strength of the magnetic field.

When crystals are formed in the solution mixture, they will scatter and block an incident laser beam and reduce the photo-energy received by the optical sensor. Strength of the scattering depending on the number of size of particles. Monitoring the laser intensity with time, therefore, indicates the rate and intensity of the crystallization process.

A HeNe laser (wavelength 632.8 nm) and receiving sensor (photomultiplier tube) were used for measuring the turbidity (i.e. transparency) of the fluid. The time dependence of turbidity was then used to make inferences about the crystallization process

4 Reference

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