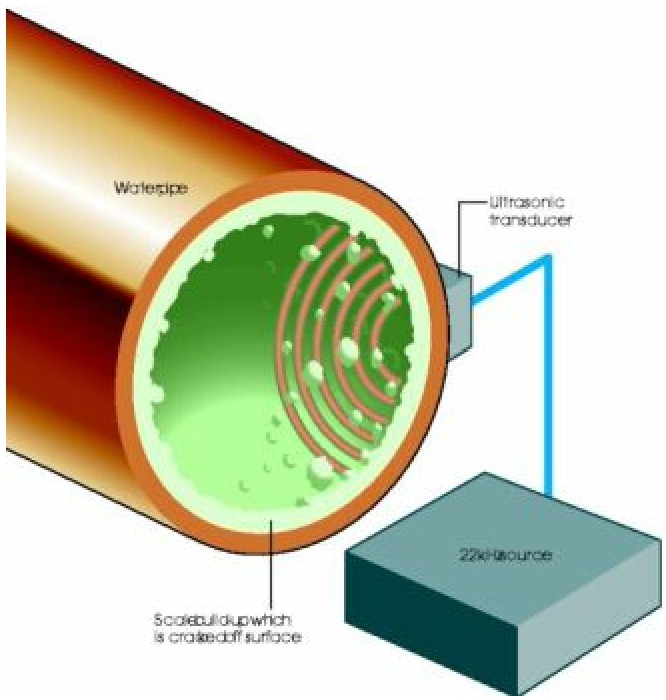
MAY 2002 EUREKA FEATURE STORY

Sound softened water
As well as increasing the fatigue strength of metals, Holopov finds that ultrasound is also a good way of preventing the build-up of scale on the insides of hot water pipes and boiler tubes.



Scale build-up is a hugely expensive problem. A 1mm scale layer, for example, on the inside of a typical heat exchanger can result in an increase in fuel consumption of 2 to 2.5% and a 5mm scale layer requires a fuel increase of 8 to 10%. Overheating and corrosion under the scale layer can also substantially reduce tube life.
The most common way of softening water is to use chemicals to precipitate out lime and other contaminants; ion exchange is another. Both procedures incur significant cost.
There have, however, been persistent reports that various other techniques can cause the precipitation of calcium salts as a fine suspension of apatite crystals, instead of calcite coatings - eliminating harmful effects at much lower cost. We are already aware of the use of permanent magnets and radio frequency magnetic fields but Holopov and his colleagues recommend low levels of ultrasound.
Research into this method apparently began in the USSR in the 1930s, and started to see service in the 1950s and 60s. However, it is only now that the cost of the equipment has dropped to a point where the method is economically attractive.
As well as initiating precipitation within the bulk of the water, ultrasound apparently offers the additional benefit of being able to initiate fractures in - and eventual break-up of - existing scale coatings. Power consumptions in INLAB's commercially available equipment is 30, 70, or 380W, depending on application.

A plethora of potential
Other processes mentioned by the company include: reinforcing of plastic with metal; hole broaching and engraving of ceramic, glass and stone; reduction of residual stresses in welds; dispersion and de-aeration of fluids; metal finish turning, drilling, countersinking, hole reaming and threading; removal of cast ceramic from a casting hollow; and 'impregnation of friction pairs with geomodificators'.
This last is apparently a new process for incorporating naturally occurring mineral ceramic materials into the surfaces of metals, thereby reducing friction and wear. We are told that, in internal combustion engines, it can increase intervals between repairs and servicing by four to six times and reduce fuel consumption by 8 to 15%. For further details, watch this space! (For more information see www.utinlab.ru and contact Tom Shelley in England and Yuri Neshitov in Russia)

Design Pointers

Ultrasonic vibration may be applied to a smoothing tool in a final finishing operation to induce compressive stresses in surface layers, greatly enhancing fatigue life

Ultrasonic vibrations may also be used to prevent and remove scale in pipes carrying hot water and in a host of other applications

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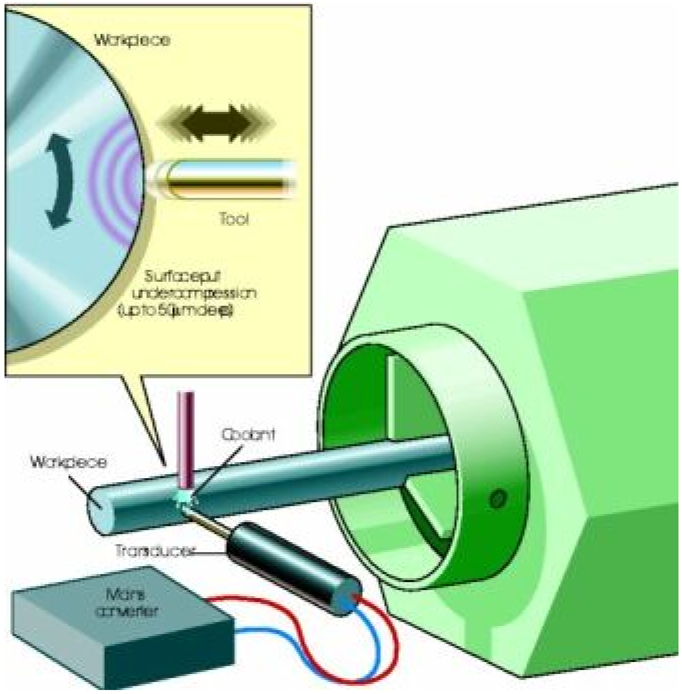
A sound way to strengthen steel

Tom Shelley describes a technique for enhancing fatigue strength using ultrasound that has a surprising number of other uses

Ultrasonic finishing is being used to greatly enhance the fatigue strength of steel and other metal alloy components in a fraction of the time required by alternative techniques and at a much lower cost.



It can be incorporated into a machining process as a separate step, without needing to remove the workpiece, and is already in commercial use in Russia where experience of the process and its capabilities is beginning to build.
Ultrasonic finishing was primarily developed for treating crankshafts and spherical and conical surfaces. However, ultrasonics also appears to work well as a means of eliminating lime scale build-up in hot water and steam systems running on hard water. It also has a host of other uses.
The technology is the result of a lifetime's research work by Professor Yuri Holopov. This has now spun off from St Petersburg State Technical University into the North West Centre of Ultrasonic Technology or INLAB.
The underlying principle is the same as that used in shot peening and vibratory finishing (Eureka, March 2002) and super precession polishing (Eureka, April 2002), which is to put the surface layers of the material into compression to produce a smoothed, polished finish. Both effects are known to be effective, because they remove defects which may act as fatigue crack initiation sites, and close up any that are open.
The underlying technique is to put a tool with an ultrasonically driven hard steel tip into the tool post of a lathe. It does its work as the last stage of a set of machining operations - without requiring removal of the workpiece from the machine.
Ultrasonic finishing can be undertaken in similar timescales as finish machining, Professor Holopov mentioning feed rates of 0.05 to 0.2mm per revolution for crankshaft journal polishing at machining speeds of 500 to 600rpm. Residual tensile stresses of 300 to 400N/mm2 are reversed and turned into compressive stresses of 240 to 700N/mm2. The depth effect is 50 to 500 microns, which is slightly higher than for shot peening. Holopov claims general fatigue strength increases of around 50%, depending on circumstance and fine machined finishes of 1.6 to 3.2μm are turned into mirror finishes of 0.2 to 0.4μm. The fatigue strength enhancement is less than that claimed for shot peening under NC control plus vibratory finishing under best circumstances, but seems

realistic.
If engine crankshafts could be made thinner and lighter, even by a small amount, it has an immediate, fairly dramatic effect on engine acceleration and fuel consumption. Research by most motor manufacturers on improved crankshafts seems to be mainly focussed on using exotic materials, such as metal matrix composites. Shot peening and vibratory finishing has been shown to bring such dramatic benefits to conventional steel gears and gearboxes, but only at motorsport-type prices. Ultrasonic finishing looks to be a lot cheaper than either technique.
The tools are driven using magnetostrictive technology and deliver power outputs of 400 to 600W. They are made in two parts: an acoustic head in contact with the workpiece, which weighs 4 to 6kg; and a separate electronic converter, which turns the normal 220V 50Hz mains supply into 22kHz. The latter weighs 7.5kg.
About 100 sets are currently in service in Russian factories with more on order and a large number of serious enquiries under discussion. The technique has been found to give benefits to mild, construction, tool, cast, alloy and bearing steels; gray cast and wrought iron; and copper, brasses, bronzes and aluminium alloys. It has been successfully applied to shafts, faces, conical and spherical surfaces (external and internal), grooved channels, fillets and the insides of blind holes
Selling price for a complete set is currently $8,000, down from $15,000 a short while ago. The company generally seems to be cutting prices as it gets its production under way and the equipment comes with a two year guarantee.

Ultrasonic units for water scale control

BACK

The water scale settling (of $CaCo_3$, $MgCo_3$, $CaSiO_3$, ferric oxides etc.) is formed on the heat surfaces of heat-engineering equipment (boilers, heat exchangers, evaporators, coolers etc.) at its work.

In this case the heat transfer is deteriorated because the thermal conductivity of the water scale is tens times less than this of metal, the efficiency and the capacity of the equipment are declined because the scale layer of I mm gives rise to fuel overturning of 2-2.5% and at the scale layer of 5 mm it may run up to 8-10%, because of overheating and corrosion of the metal under scale layer, the service life of the tube metal is reduced and damage (flaws, bulges, ruptures) may occur.
Softening of used water requires considerable means for building and servicing of chemical water treatment plants. Water softening through the agency of ion-exchange materials or the use of complexions in open heat supplies systems and at water heating for hot water supply is uneconomical and ecologically harmful.
Ultrasonic method of the water scale prevention is based on studies that have been conducted in the USSR since the late 1930s. The widespread adoption of ultrasonic technologies began at 1950s-1960s, but only is recent years the equipment that combined high effectiveness and reliability and moderate cost has been elaborated.
Under the action of the weak ultrasonic vibration, the multitude of constantly shifting crystallising centres are generated in water, resulting in difficulty of scale crystals growing and settling on heat exchange surfaces of equipment. Microfissures formed in the scale layer under the action of ultrasonic vibration, accumulating, break up existing settling and the unit appears descaled. Slime is removed by water flow or blow-through.
This is the most efficient and universal of the reagents physical method. It is economical, ecologically clean, safe in service for equipment and personnel. It may be combined with the use of complexions and the chemical water treatment.

The North-West Center of Ultrasonic Technologies and INLAB offer the following units for water scale control:	 IL-1M	 IL-1MX	 IL-2
Design:	generator and emitter in common body	generator and emitter are in separate bodies and connected with cable in flexible metal pipe of 6.2 m in length	generator is made in the form of separate two-channel instrument unit with two emitters

Consumed power, W:	30	70	380
Voltage, V 50-60 Hz:	220 ± 10%	220 ± 10%	220 ± 10%
Type of ultrasound emitter:	magnetostrictive		
Mass, no more, kg:	2,5	5	22






BACK

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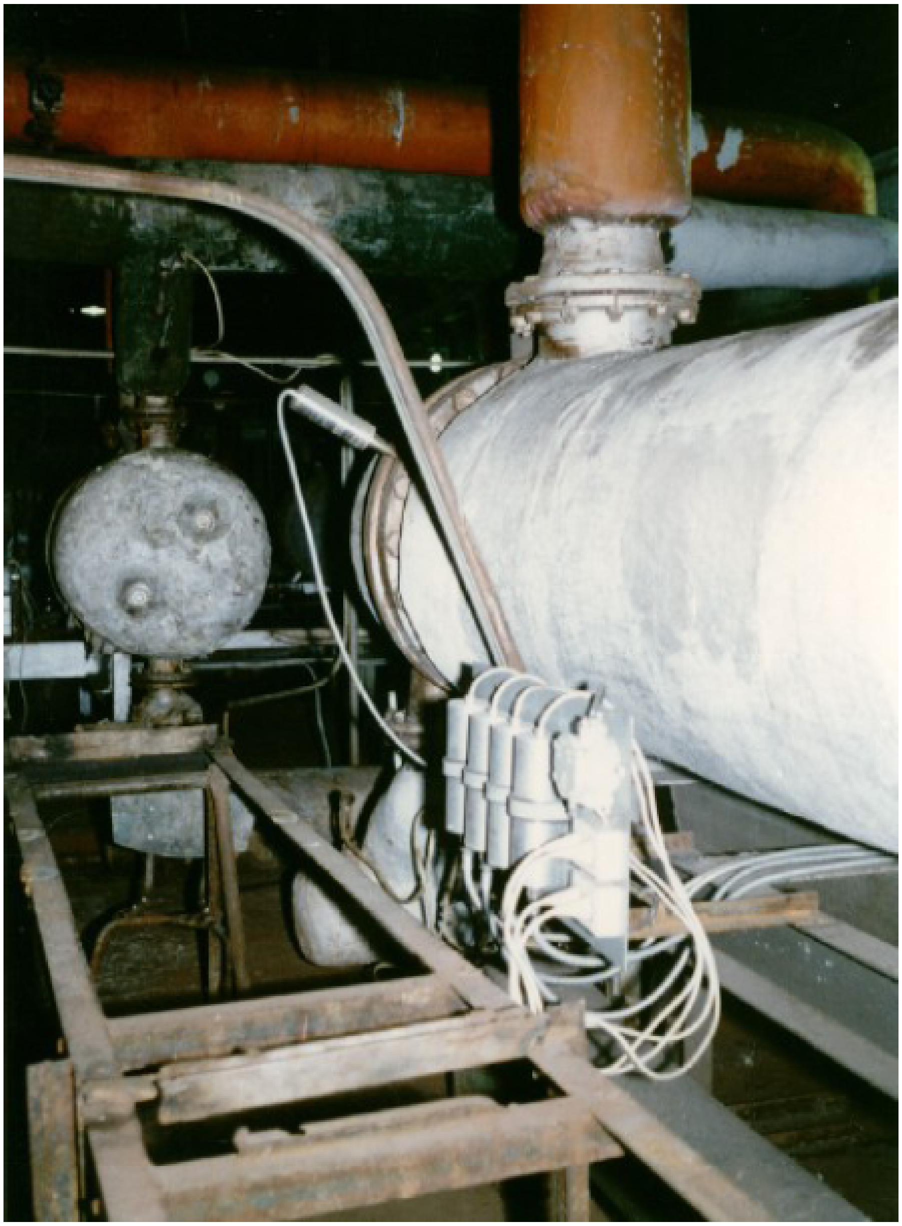

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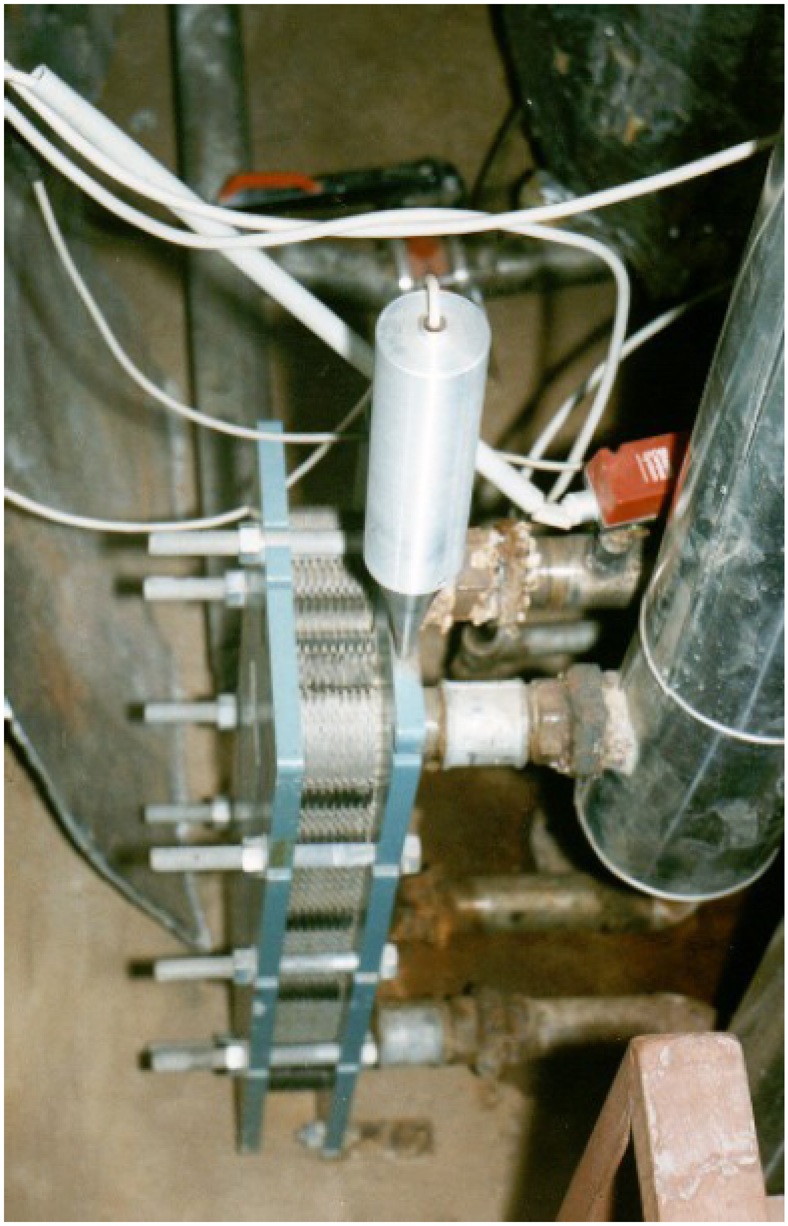

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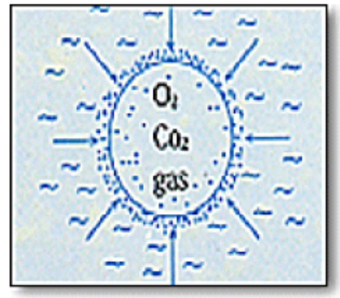
Managers usually don't know the scale problem, but it is the problem of safety, durability of equipment, energy conservation, and environment preservation – that is, in the end, the problem of money.
Water treatment can't solve the problems of scale completely, and sometimes it's impossible or unprofitable to use it.
Water treatment is usually computed for basis regime of equipment's working,
but some times, for example in winter, it is necessary to use peak regimes.
In this case salt's hardness ions can flow through water treatment system and then scale layer is formed.
During cycle time between regeneration, the capacity of ions – exchange decreases.
Sometimes operators are not so attentive. Average leakage of fuel, as a result, is about 4 ~ 20%.
It needs to stop operating the equipment and to make mechanical or chemical cleaning.



SCALE PREVENTION

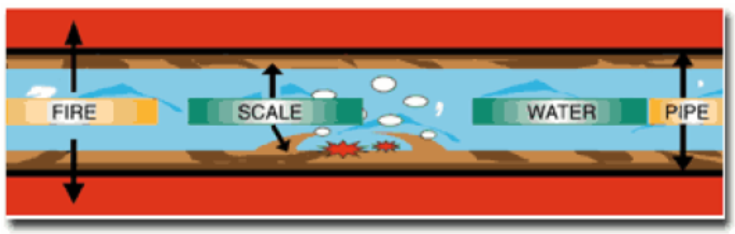
Scale prevention by ultrasonic device makes sure as follows:
– increase the interval stopping of equipment for cleaning, or exclude cleaning work;
– increase the safety factor of equipment;
– decrease the cost of fuel;
– decrease the pollution of chemical substances.
Basic principles of scale preventing and removing are as follows.
It is known that crystals of salts of hardness are forming on the surfaces of heat exchange or on the surfaces of crystal centers.
Volume of scale depends on salts of hardness concentration in water.
Ultrasound can increase number of crystal centers in water and decrease concentration of salts of hardness by influence of cavitation.

CAVITATION

Ultrasonic cavitation is the formation of bubbles (cavities) in liquids at the low–pressure part of wave cycle. The bubbles are filled with gases or vapor coming out of water.
When sizes of bubbles reach a resonance sizes, collapse of bubbles takes place.
The collapse formed extremely high stress shock waves in water. Shock waves are formed in water a lot of crystal centers, and centers became overgrown by crystallization of salts dissolved in water, destroyed by influence of shock wave in

several solid particles – new crystal centers and s.o.
At the same time, decontamination of water takes place. Oxygenium, nitrogenium, CO_2 (CO_2 formed in water like result of disintegration of metastable hydrocarbonates of calcium and magnesium) are removed by the influence of cavitation from water.
Inside bubbles, free chemical radicals are produced.
The processes change chemical data of water, including pH, salts and gases concentration.

Experiments show that the main part of scale in water (not on the heat exchange surfaces) forms like shape of small crystals by influence of cavitation. Its sizes are about 1㎛.
Depend of water speed and designs of equipment, crystals can be removed by water flow or fall down to the bottom like slime and can be removed by blow down.
Scale layers, including what are formed before installation of ultrasonic devices, will be destroyed by influence of cavitation.



MICRO–FLOWS IN WATER

Ultrasound is radiated in water by metallic details of equipment shells, walls of tubes and others. Micro – flows in the water are formed by process of radiation and they are directed from metallic surfaces into the water.
Micro – flows in the water are moving the particles of scale from surfaces of heat – exchange into the water.
In layers of water close to radiated surfaces, the turbulence of water will increase.
Micro – flow and turbulence in the water help scale prevention and increase heat transfer.

- Preventing and removal of scale for boiler
- Improving the efficiency due to preventing and removal of scale for heat exchange
- Improving quality of textile processing, reduction time of processing and decreasing chemicals pollutant chemicals and water pollutant (applying to dyeing machine, weight loss machine, and washing etc.)
- Preventing scale and slime in pipe of cooling water.
- Preventing living of a shellfish inside pipe using sea water.
- Improving oil quality (reduction air pollutant and rising efficiency of combustion due to improvement quality of B-C oil.
- Preventing scale and living of a shellfish of boiler and cooling water pipe in ship preventing scale in boilers and living of shellfish in water pipes of ships.
- Improving efficiency of washing (possibility washing higher temperature than existing ultrasonic washing machine.)
- Pasteurization of bacteria.
- Processing and welding using vibration and etc.

Advantages of USP

- Boiler and heat exchange

  1) Reduction energy consumption due to preventing scale
  2) Preventing environment pollution due to decrease of chemicals using
  3) Extension lifetime of equipment
  4) Reduction cost and time for complete equipment

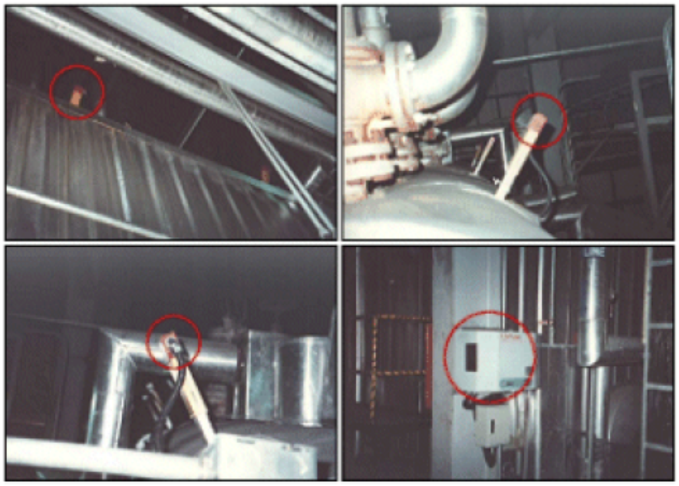
- Equipment of dyeing processing

  1) Improvement quality of goods
  2) Reduction chemical cost
  3) Decreasing rate of badness
  4) Reduction textile processing time
  5) Saving energy
  6) Reduction environment pollutant

- Etc.

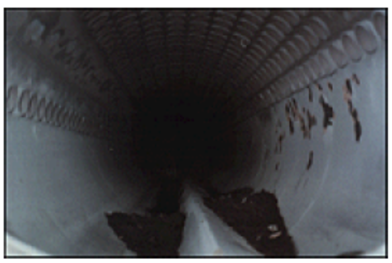
  Improvement efficiency of equipment, reduction processing time, reduction cost for complete equipment.

The form of USP installed to water tube boiler

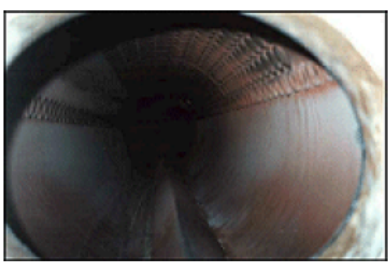


- The form of USP installed to water tube boiler (Hyosung Corp. 5.'98) Transducer were welded and attached to upper and lower drum of 20 t/h water tube boiler. Generator installed aside boiler.

The result after USP installation

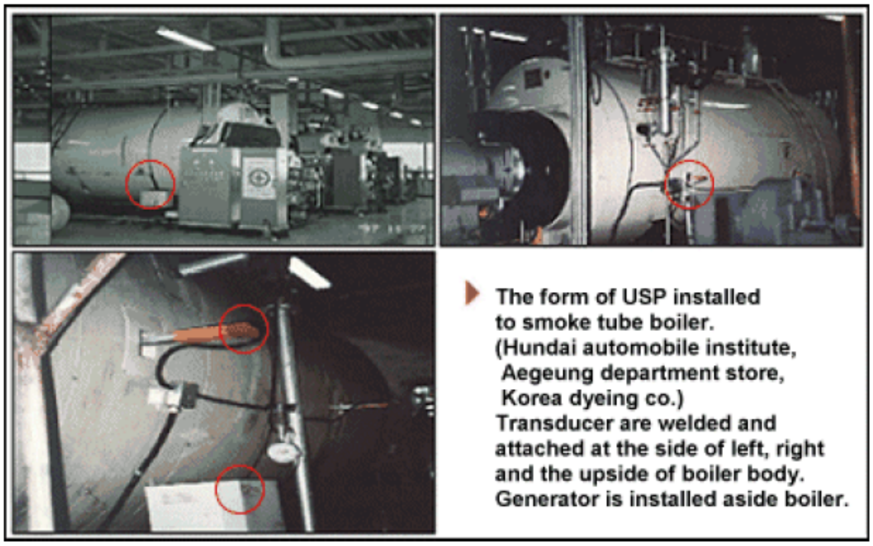


- Inner form of boiler passed 1 month after installation USP to water tube boiler. Being prevent scale and progressing scale removal.



- Inner form of boiler passed 3 months after installation USP to water tube boiler .
Boiler need only washing because all scale fall off inside boiler.

The form of USP installed to smoke tube boiler



- Left upper: before installation USP(passage 2 months after chemical tube cleaning)
- Right upper: inner form of boiler passed 40 days after installation USP. (progressing scale removal)
- Left lower: inner form of boiler passed 54 days after installation USP (after washing)
- Right lower: the picture washing inside boiler 54 days after installation USP

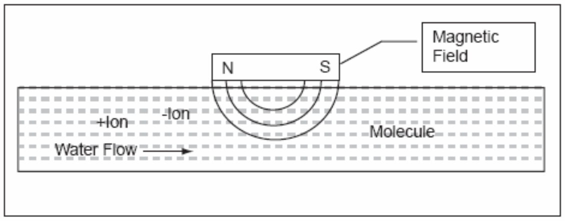


Diagram of magnetic field technology.

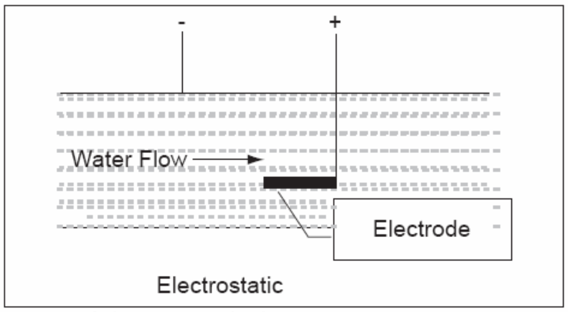


Diagram of electrostatic technology.

contains 'appreciable' concentrations of iron, as in such cases the action of the magnetic field on the hardness–causing ions is very weak. Conversely the action of the magnetic field on the iron ions is very strong and this interferes with the water conditioning process. This results in a variation in the effectiveness of this type of process. Magnetic technology is affected by high voltage (230 volt, and above) power lines which interfere with the unit's operation by imposing a second magnetic field on the water. This is particularly noticeable when such electric power sources are installed within a metre of a magnetic device. This second magnetic field generally will not be aligned with the magnetic field of the device, thus introducing interference and reducing the effectiveness of the treatment.

Electrostatic technology

The availability of ceramic electrodes and other durable dielectric materials have allowed the electrostatic technology to also become more reliable.

With electrostatic units a surface charge is imposed on the ions so that they repel instead of attract each other. Thus the positive and negative ions of a kind needed to form scale are never able to come close enough to initiate the scale-forming reaction.

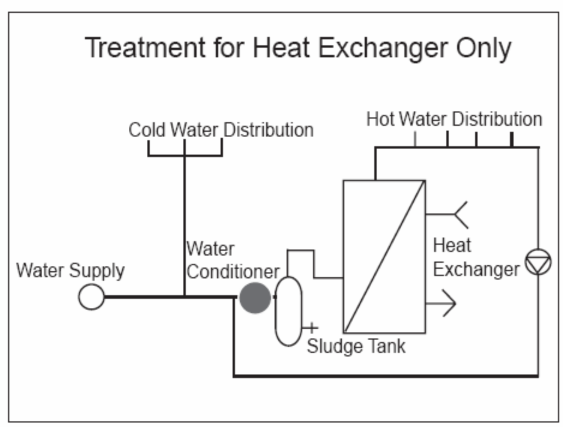
The end result for the user is the same with either technology; scale formation on heat exchange surfaces is greatly reduced or eliminated. When using either technology there are four basic warnings which most manufacturers of such units support:

- Be aware of practical requirements dictated by the effects of the use of these technologies. Additional system filtration will be required to prevent protection filters from blocking up. Iron removal may also be required.
- This technology has been exploited by disreputable manufacturers and/or vendors who have given the technology a bad name. To avoid problems always use products from a reputable manufacturer or vendor who has a verifiable history of success or has the product approved to relevant standards.
- Installation near high voltage electrical equipment or strong magnetic fields is to be avoided since these fields will interfere with the performance of the technology. For 240 volts this means 1 metre distant, for higher voltages it is proportionately more distant. Also the pipeline should be checked to ensure that it is not being used as an electrical ground (earth). Stray electrical current in the pipe will have the same effect as installation near a strong electrical or magnetic field.
- Use only on hard water applications, i.e. where the water hardness is greater than 60mg/litre (or parts per million) as calcium carbonate. A certain amount of deposit on the pipe may be required to protect it from corrosion.

Does the technology work?

Research shows that in many case studies, when the product is properly installed, a decrease in, or elimination of scale formation will be found initially. Analysis of anecdotal evidence states that some devices cease to work after a period of time, but when re-located start to work again. Research has proved that turbulences in most products, rather than magnets, make changes in calcium crystal structure. The dissolving of limescale may give equal results by creating aggressive CO_2 from turbulence forces. The magnetic technologies are not as effective when silica, iron or magnetic minerals are present in the water. There have also been cases recorded where the magnetic field has been applied incorrectly or does not have sufficient strength to affect the reaction. This latter was particularly true when the technology was first used and ferrous based magnets were used. High levels of particulate matter will also adversely affect the efficiency of the technology by reducing the collision frequency of the desirable reactions.

There is now a German DVGW test specification W512 for water conditioners and a number of products have passed the test specification, including the Reliance Protecto Multisafe. Identical test rigs are used so that two tests can be run in parallel, one with no treatment process and one which incorporates the product to be tested. The product is installed in the cold water inlet to the water heater for a period of 21 days. The water is heated to a temperature of 80°C. 130 litres of water is drawn off each day, during a 16 hour period, at a minimum flow rate of 5 l/m. When the test is concluded, the lime adhering to the heating coil and on the sides of the heater is evaluated and



Treatment for Heat Exchanger.

Magnetic Water Conditioners

Electromagnetic water conditioners are a relatively new invention. The idea is that by passing water through a magnetic field, the calcium and magnesium ion's are altered in such a way that they loose their ability to cause scale.

This has a number of benefits; although the water is not technically soft, it has the useful properties of soft water, that is, it won't cause limescale in your pipes thus increasing heating efficiency and lengthening the lifespan of any clothes washed in the conditioned water.

Calcium is an important dietary element, so the fact that conditioned water still retains its calcium content is an added benefit.

While some people are skeptical this method actually works, we have found one manufacturer who has commisioned a scientific analysis by the University of Bath that concludes that their device does indeed stop the build up of limescale.

Go to our REVIEW page to see a comparison of magnetic water conditioners

Magnetic Water Conditioner Comparison

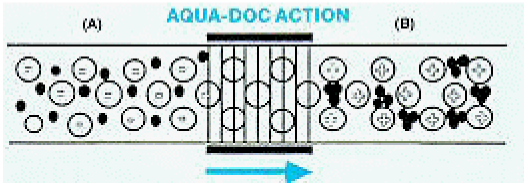
We have searched the web to find you a list of suppliers of electromagnetic and magnetic water conditioners, along with the company name and web site address, we also provide an outline as to their price range, and the guarantee that they state on their site.

There are two types of magnetic water conditioner - electromagnetic (EM) , also known as electronic, and magnetic (M). Both systems work on magnetism, but the later has a finite lifespan and although there is no running cost, it is often more costly intially.

Company Name	Water Imp	Water King	Clearwave	Magnetic Solutions
Based	UK	UK	USA	USA
System	EM	EM	EM	M
Price Guide	from £95 ($140)	from £110 ($160)	from £140 ($200)	from £230 ($330)
Guarantee	190 day Money Back 5 year Manufacturers	100 day Money Back	180 day Money Back 3 year Manufacturers	180 day Money Back

Our recommended supplier is Water Improvements Limited as, in our opinion, they offer the best value, service and guarantee. Their site also supports secure online ordering, and they ship to anywhere in the world for free.

If you are a supplier of electronic / magnetic water conditioners and would like to appear on the site then please email us.



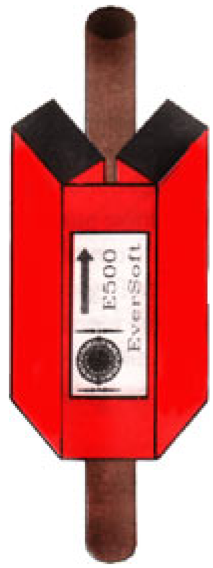
Water is a "carrier vessel" of hard water minerals due to the naturally equal ionic (electric) charge between the minerals and the water. The minerals dissolve in the earth and are transmitted by the water to all parts of the internal surface of the plumbing where they scrape along to re-crystallize and reform the hard rock scale **(A)**. This scaling is naturally progressed at all heating surfaces in the water heater.

When water is magnetically charged, it electrically takes on a greater ionic charge than the minerals which creates a natural magnetic attraction between the two. The magnetization then attracts and locks the dissolved minerals into the water creating healthy and cost free descaling **(B).**

Softening and better taste occurs from an actual reduction in the size of the water molecule. It is similar to a bucketful of rocks the size of pebbles versus the size of sand. The pebbles will bang around like rocks while the sand will pour like water. The small magnetized water molecule has a greater solvency and a magnetic attraction that results in cleaner bathing and washing which cleans and washes like soft water. This saves on soaps, shampoos, and detergents. The smaller molecular size also has less evaporitive surface area which magnetically and dramatically reduces the gases and foul taste of sulfur, chlorine and fluoride, etc.

Acid neutralization occurs from the physical restructuring of the water molecule. The acid taste is reduced while the copper leaching is stopped and the green acid stains eventually and completely wash away.

The **Aqua-Doc** Residential system comes with 4 units: 2 for the hot line & 2 for the cold lines



The EverSoft Solid State Water Conditioner model E500 produces a precise magnetic field when installed on the supply line of your home plumbing system. When water flows through this magnetic field, it is altered in such a way that many of the Benefits obtained by the use of a chemical water softener are achieved. The advantages of smoother hands, more soapsuds for bathing, laundry and cleaning, spot-free glasses and dishes, and softer, more manageable hair, become apparent within a few weeks. Indisputably, these benefits are more pronounced with chemical softeners, however they cost 5 to 10 times the price, add salt to your water, and can be a maintenance nightmare.

The EverSoft Solid State Water Conditioner also reduces staining on toilets, sinks, and shower enclosures. It actually removes scale and lime deposits, which can build up in your water pipes and systems over the years. A 30% to 50% increase in the flow rate through the plumbing system is not uncommon. Easy instructions showing how to measure and document this increase are included with each EverSoft unit.

Once the E500 is installed, clusters of naturally occurring calcium crystals, are broken apart by the magnetic field so they pass through, rather than form scale in the pipe. The formation of lime scale, that can clog plumbing fixtures, faucets, and showerheads, destroy the heating coils in the hot water heater and dishwasher is prevented. Calcium, an important mineral for strong bones, and good health is not removed from the water, and no chemicals or salts which can be harmful to your health are added to the water.

Industrial magnetic water conditioners have been in use for well over 20 years. They are used in factories, commercial building, cooling towers, and oil wells to prevent salt lime scale and paraffin build-up. Thousands of dollars are spent on these commercial units, and with good reason. The savings in maintenance cost on the systems they protect can pay for these units many times over. Unfortunately, these commercial units are too large and too expensive to use in the home.

With the assistance of a sophisticated computer aided design system, an optimum magnetic field has been developed for the pipe sizes and flow rates prevalent in single-family homes and apartments. This has permitted the use of less expensive magnetic materials than those required for commercial units, and allowed the E500 to be manufactured at prices that are affordable for the average family. If someone were to give you a chemical water softener, the costs of the chemicals, salts, and the energy to operate it, could rapidly surpass the price of the EverSoft Solid State Water Conditioner. The E500 has been designed to be installed by practically anyone. No tools, no plumbing, and no adapters are required. It merely clips onto the copper or plastic pipe supplying water to your home. There are no filters to clean, replace, or back flush into the environment. There are no heavy bags of salt to purchase and carry home. There is no maintenance required. The E500 is removed as easily as it is installed, so if you ever move, EverSoft moves with you!

Calcium, the major source of hard water, attaches to the inside wall of the pipes supplying water within the home. It gradually builds up in layers restricting the flow of water. In some cases, it can progress to the point that all of the pipes need replacing. This can be very costly, as it often requires tearing out and replacing portions of walls in order to retrofit the new plumbing. The EverSoft conditioner stops this build up, and over time, removes the calcium from the inside of the pipes, increasing the flow back to the original rate.

Calcium can also build up on the heating coil in the hot water tank. This increases the time required to heat water, and can ultimately cause the coil to burn out. Replacing the coil can be a costly and time-consuming job. The EverSoft conditioner stops the build-up of calcium on the coil, and in time, causes the calcium to flake off the coil, restoring it to like-new condition.

INSTALLATION INSTRUCTIONS

Simply clip the E500 on the water pipe so all the water will be treated before the pipes branch off to the water heater or faucets. It will fit copper or plastic pipe with a diameter of ½" to ¾" nom. Place the unit down line from any turbulence from pumps, filters, or meters, matching the arrow on the E500 label with the direction of water flow in you plumbing system. It is possible to use it with galvanized or iron pipes, but only if it is clipped onto a 2 ft. section of copper or plastic pipe which has been plumbed into the water line.

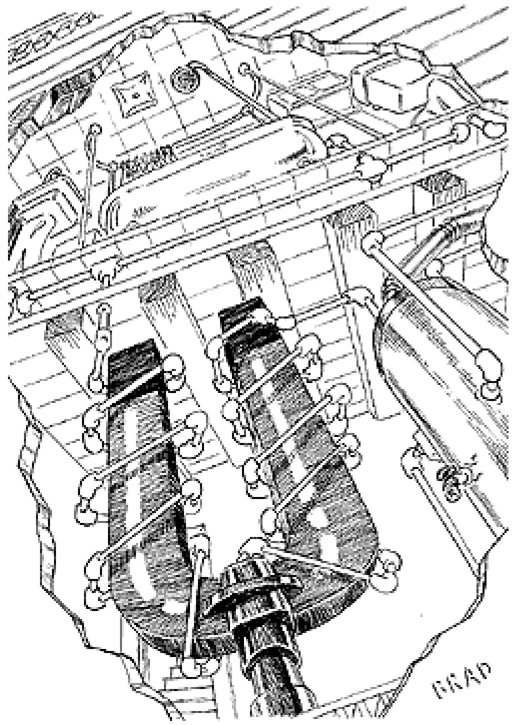
*Water stored in the hot water tank which is not consumed and replenished within 2-3 days, will start to lost it's magnetic polarization. A second unit installed on the hot water line coming from the water heater will insure that all the water you are using will be treated to an optimum level.

EverSoft has been designed to effectively combat the undesirable effects of calcium in your water system. It will not, however, solve other common water problems, caused by iron, bacteria, improper pH, sediments, etc.; nor does it cure unpleasant odors or taste. Caution: be sure to keep unit away from magnetic media such as computer disks, credit cards, or audio and videotapes.

EverSoft Water Conditioner
package of 2 only $149.95

Magnetic and Electronic Water Conditioners:
These products are very controversial in the water softening marketplace. While supporters remind us that these systems have been working in large-scale applications in Europe for decades, skeptics point out a lack of scientific evidence that they actually work.

The concept is fairly simple. An energy field is created and the water is allowed to flow through it. As the water flows through the field, the structures of the hardness agents are altered so that they are not able to precipitate into the limescale that is associated with hard water. Because they cannot precipitate and attach to fixtures, bodies or possessions, they pass harmlessly down the drain.



In a study conducted by Bath University in England, an electronic conditioning device was shown to be effective in cutting down limescale buildup in household copper pipe.

Magnetic Water and Fuel Treatment: Myth, Magic, or Mainstream Science?

Magnetic treatment has been claimed to soften water and improve the combustibility of fuels. A literature review reveals that these claims are not well supported by data.

M I K E R . P O W E L L

Magnets are not just for refrigerators any more. In fact, according to some magnet vendors, magnets can be used to improve blood circulation, cure and prevent diseases, increase automobile mileage, improve plant growth, soften water, prevent tooth decay, and even increase the strength of concrete. Some of these claims are backed by experimental evidence. Many are not. This article focuses specifically on the claimed benefits of magnetically treated fuel and water.

Most magnetic water and fuel treatment systems appear to be marketed through independent distributors who sell out of their homes. An Internet search using the keywords magnetic treatment reveals dozens of independent distributor home pages. Very few such devices are offered by national chain stores or advertised in mail-order catalogs. Possibly, the magnetic-device manufacturers sell through independent distributors to insulate themselves from some of the more exotic claimed benefits of magnetic treatment, or perhaps consumer and wholesaler skepticism has kept magnetic treatment out of mainstream retail. Regardless of the reasons, magnetic water and fuel treatment devices are not usually available at the local hardware or automobile parts supply store. This lack of wide availability has given magnetic water and fuel treatment a sort of fringe-science status in the minds of many consumers. Whether this label is deserved is the subject of this article.

Claimed Benefits and Effects

The claimed benefits of magnetic water treatment vary depending on the manufacturer. Some claim only that magnetic treatment will prevent and eliminate lime scale in pipe and heating elements; others make additional, more extravagant claims. Some of the additional claims include water softening, improved plant growth, and the prevention of some diseases in people who consume magnetically treated water. Magnetic water treatment devices consist of one or more magnets, which are clamped onto or installed inside the incoming residential water supply line. Typical costs for a residential installation range from about $100 to $600 or more.

Magnetic fuel treatment devices are constructed similarly. One or more magnets are clamped around or installed inside an automobile's engine fuel line between the gas tank and the carburetor (or fuel injectors). Claims for these devices include decreased hazardous gas emissions, more complete combustion, improved engine power, longer-lasting engine components, and a 10 percent to 20 percent increase in gas mileage. Prices for automotive fuel treatment magnets range from about $50 to $300.

The distributors of these devices rarely can cite any documented test results that validate these claims. Instead, they rely on numerous testimonials, lists of corporations and municipalities that purportedly use the devices, and scientific-sounding explanations of magnetic water and fuel treatment. However, just because distributors do not cite the literature does not mean that no relevant literature exists. Published test reports and journal articles that investigate magnetic treatment are available. This article reviews the available experimental evidence for magnetic water and fuel treatment.

Magnets and Magnetism

To many people, magnets are a complete mystery. Vendors of magnet-based scams often use this ignorance to their own advantage, so a familiarity with the basics of magnetism can aid in the detection of dubious claims.

Magnetic fields are produced by the motion of charged particles. For example, electrons flowing in a wire will produce a magnetic field surrounding the wire. The magnetic fields generated by moving electrons are used in many household appliances, automobiles, and industrial machines. One basic example is the electromagnet, which is constructed from many coils of wire wrapped around a central iron core. The magnetic field is present only when electrical current is passed through the wire coils.

Permanent magnets do not use an applied electrical current. Instead, the magnetic field of a permanent magnet results from the mutual alignment of the very small magnetic fields produced by each of the atoms in the magnet. These atomic-level magnetic fields result mostly from the spin and orbital movements of electrons. While many substances undergo alignment of the atomic-level fields in response to an applied magnetic field, only ferromagnetic materials retain the atomic-level alignment when the applied field is removed. Thus, all permanent magnets are composed of ferromagnetic materials. The most commonly used ferromagnetic elements are iron, cobalt, and nickel.

The strength of a magnet is given by its magnetic flux density, which is measured in units of gauss. The earth's magnetic field is on the order of 0.5 gauss (Marshall and Skitek 1987). Typical household refrigerator magnets have field strengths of about 1,000 gauss. According to the distributors, the magnets sold for water and fuel treatment have magnetic flux densities in the 2,000 to 4,000 gauss range, which is not unusually strong. Permanent magnets with flux densities in the 8,000 gauss range are readily available. The magnets sold for magnetic fuel and water treatment are nothing special; they are just ordinary magnets.

Water Hardness

The phrase hard water originated when it was observed that water from some sources requires more laundry soap to produce suds than water from other sources. Waters that required more soap were considered "harder" to use for laundering.

Water "hardness" is a measure of dissolved mineral content. As water seeps through soil and aquifers, it often contacts minerals such as limestone and dolomite. Under the right conditions, small amounts of these minerals will dissolve in the ground water and the water will become "hard." Water hardness is quantified by the concentration of dissolved hardness minerals. The most common hardness minerals are carbonates and sulfates of magnesium and calcium. Water with a total hardness mineral concentration of less than about 17 parts per million (ppm) is categorized as "soft" by the Water Quality Association (Harrison 1993). "Moderately hard" water has a concentration of 60 to 120 ppm. "Very hard" water exceeds 180 ppm.

Hard water is often undesirable because the dissolved minerals can form scale. Scale is simply the solid phase of the dissolved minerals. Some hardness minerals become less soluble in water as temperature is increased. These minerals tend to form deposits on the surfaces of water heating elements, bathtubs, and inside hot water pipes. Scale deposits can shorten the useful life of appliances such as dishwashers. Hard water also increases soap consumption and the amount of "soap scum" formed on dishes.

Many homeowners and businesses use water softeners to avoid the problems that result from hard water. Most water softeners remove problematic dissolved magnesium and calcium by passing water through a bed of "ion-exchange" beads. The beads are initially contacted with a concentrated salt (sodium chloride) solution to saturate the bead exchange sites with sodium ions. These ion-exchange sites have a greater affinity for calcium and magnesium, so when hard water is passed through the beads the calcium and magnesium ions are captured and sodium is released. The end result is that the calcium and magnesium ions in the hard water are replaced by sodium ions. Sodium salts do not readily form scale or soap scum, so the problems associated with hard water are avoided.

A 1960 survey of municipal water supplies in one hundred U.S. cities revealed that water hardness ranged from 0 to 738 ppm with a median of 90 ppm (see Singley 1984). Ion-exchange water softeners are capable of reducing the hardness of the incoming water supply to between 0 and 2 ppm, which is well below the levels where scale and soap precipitation are significant.

One of the principal drawbacks of ion-exchange water softeners is the need to periodically recharge the ion exchange beads with sodium ions. Rock salt is added to a reservoir in the softener for this purpose.

Magnetic Water Treatment

A wide variety of magnetic water treatment devices are available, but most consist of one or more permanent magnets affixed either inside or to the exterior surface of the incoming water pipe. The water is exposed to the magnetic field as it flows through the pipe between the magnets. An alternative approach is to use electrical current flowing through coils of wire wrapped around the water pipe to generate the magnetic field.

Purveyors of magnetic water treatment devices claim that exposing water to a magnetic field will decrease the water's "effective" hardness. Typical claims include the elimination of scale deposits, lower water-heating bills, extended life of water heaters and household appliances, and more efficient use of soaps and detergents. Thus, it is claimed, magnetic water treatment gives all the benefits of water softened by ion-exchange without the expense and hassle of rock-salt additions.

Note that only the "effective" or "subjective" hardness is claimed to be reduced through magnetic treatment. No magnesium or calcium is removed from the water by magnetic treatment. Instead, the claim is that the magnetic field decreases the tendency of the dissolved minerals to form scale. Even though the dissolved mineral concentration indicates the water is still hard, magnetically treated water supposedly behaves like soft water.

According to some vendors, magnetically softened water is healthier than water softened by ion exchange. Ion-exchange softeners increase the water's sodium concentration, and this, they claim, is unhealthy for people with high blood pressure. While it is true that ion-exchange softening increases the sodium concentration, the amount of sodium typically found even in softened water is too low to be of significance for the majority of people with high blood pressure. Only those who are on a severely sodium-restricted diet should be concerned about the amount of sodium in water, regardless of whether it is softened (Yarows et al. 1997). Such individuals are often advised to consume demineralized water along with low-salt foods.

There is apparently no consensus among magnet vendors regarding the mechanisms by which magnetic water treatment occurs. A variety of explanations are offered, most of which involve plenty of jargon but little substance. Few vendors, if any, offer reasonable technical explanations of how magnetic water treatment is supposed to work.

The important question here, though, is whether magnetic water treatment works. In an effort to find the answer, I conducted a search for relevant scientific and engineering journal articles. I describe the results of this search below.

More than one hundred relevant articles and reports are available in the open literature, so clearly magnetic water treatment has received some attention from the scientific community (e.g., see reference list in Duffy 1977). The reported effects of magnetic water treatment, however, are varied and often contradictory. In many cases, researchers report finding no significant magnetic treatment effect. In other cases, however, reasonable evidence for an effect is provided.

Liburkin et al. (1986) found that magnetic treatment affected the structure of gypsum (calcium sulfate). Gypsum particles formed in magnetically treated water were found to be larger and "more regularly oriented" than those formed in ordinary water. Similarly, Kronenberg (1985) reported that magnetic treatment changed the mode of calcium carbonate precipitation such that circular disc-shaped particles are formed rather than the dendritic (branching or tree-like) particles observed in nontreated water. Others (e.g., Chechel and Annenkova 1972; Martynova et al. 1967) also have found that magnetic treatment affects the structure of subsequently precipitated solids. Because scale formation involves precipitation and crystallization, these studies imply that magnetic water treatment is likely to have an effect on the formation of scale.

Some researchers hypothesize that magnetic treatment affects the nature of hydrogen bonds between water molecules. They report changes in water properties such as light absorbance, surface tension, and pH (e.g., Joshi and Kamat 1966; Bruns et al. 1966; Klassen 1981). However, these effects have not always been found by later investigators (Mirumyants et al. 1972). Further, the characteristic relaxation time of hydrogen bonds between water molecules is estimated to be much too fast and the applied magnetic field strengths much too small for any such lasting effects, so it is unlikely that magnetic water treatment affects water molecules (Lipus et al. 1994).

Duffy (1977) provides experimental evidence that scale suppression in magnetic water treatment devices is due not to magnetic effects on the fluid, but to the dissolution of small amounts of iron from the magnet or surrounding pipe into the fluid. Iron ions can suppress the rate of scale formation and encourage the growth of a softer scale deposit. Busch et al. (1986) measured the voltages produced by fluids flowing through a commercial magnetic treatment device. Their data support the hypothesis that a chemical reaction driven by the induced electrical currents may be responsible for generating the iron ions shown by Duffy to affect scale formation.

Among those who report some type of direct magnetic-water-treatment effect, a consensus seems to be emerging that the effect results from the interaction of the applied magnetic field with surface charges of suspended particles (Donaldson 1988; Lipus et al. 1994). Krylov et al. (1985) found that the electrical charges on calcium carbonate particles are significantly affected by the application of a magnetic field. Further, the magnitude of the change in particle charge increased as the strength of the applied magnetic field increased.

Gehr et al. (1995) found that magnetic treatment affects the quantity of suspended and dissolved calcium sulfate. A very strong magnetic field (47,500 gauss) generated by a nuclear magnetic resonance spectrometer was used to test identical calcium sulfate suspensions with very high hardness (1,700 ppm on a $CaCO_3$ basis). Two minutes of magnetic treatment decreased the dissolved calcium concentration by about 10 percent. The magnetic field also decreased the average particle charge by about 23 percent. These results, along with those of many others (e.g., Parsons et al. 1997; Higashitani and Oshitani 1997), imply that application of a magnetic field can affect the dissolution and crystallization of at least some compounds.

Whether or not some magnetic water treatment effect actually exists, the further question, and the most important for consumers, is whether the magnetic water treatment devices perform as advertised.

Numerous anecdotal accounts of the successes and failures of magnetic water treatment devices can be found in the literature (Lin and Yotvat 1989; Raisen 1984; Wilkes and Baum 1979; Welder and Partridge 1954). However, because of the varied conditions under which these field trials are conducted it is unclear whether the positive reports are due solely to magnetic treatment or to other conditions that were not controlled during the trial.

Some commercial devices have been subjected to tests under controlled conditions. Unfortunately, the results are mixed. Duffy (1977) tested a commercial device with an internal magnet and found that it had no significant effect on the precipitation of calcium carbonate scale in a heat exchanger. According to Lipus et al. (1994), however, the scale prevention capability of their ELMAG device is proven, although they do not supply much supporting test data.

Busch et al. (1997) measured the scale formed by the distillation of hard water with and without magnetic treatment. Using laboratory-prepared hard water, a 22 percent reduction in scale formation was observed when the magnetic treatment device was used instead of a straight pipe section. However, a 17 percent reduction in scaling was found when an unmagnetized, but otherwise identical, device was installed. Busch et al. (1997) speculate that fluid turbulence inside the device may be the cause of the 17 percent reduction, with the magnetic field effect responsible for the additional 5 percent. River water was subjected to similar tests, but no difference in scale formation was found with and without the magnetic treatment device installed. An explanation for this negative result was not found.

Another study of a commercial magnetic water treatment device was conducted by Hasson and Bramson (1985). Under the technical supervision of the device supplier, they tested the device to determine its ability to prevent the accumulation of calcium carbonate scale in a pipe. Very hard water (300 to 340 ppm) was pumped through a cast-iron pipe, and the rate of scale accumulation inside the pipe was determined by periodically inspecting the pipe's interior. Magnetic exposure was found to have no effect on either the rate of scale accumulation or on the adhesive nature of the scale deposits.

Consumer Reports magazine (Denver 1996) tested a $535 magnetic water treatment device from Descal-A-Matic Corporation. Two electric water heaters were installed in the home of one of the *Consumer Reports* staffers. The hard water (200 ppm) entering one of the heaters was first passed through the magnetic treatment device. The second water heater received untreated water. The water heaters were cut open after more than two years and after more than 10,000 gallons of water were heated by each heater. The tanks were found to contain the same quantity and texture of scale. *Consumer Reports* concluded that the Descal-A-Matic unit was ineffective.

Much of the available laboratory test data imply that magnetic water treatment devices are largely ineffective, yet reports of positive results in industrial settings persist (e.g., Spear 1992; Donaldson 1988). The contradictory reports imply that if a magnetic water treatment effect for scale prevention exists, then it only is effective under some of the conditions encountered in industry. At present, there does not seem to be a defensible guideline for determining when the desired effect can be expected and when it cannot.

One of the claims made for residential magnetic treatment devices is that less soap and detergent will be required for washing. Compared to the claim to suppress scale formation, this claim has received little direct attention in the literature. To decrease soap and detergent consumption, the concentration of dissolved hardness minerals must be decreased. The tests by Gehr et al. (1995), described earlier, demonstrated a decrease in dissolved mineral concentration of about 10 percent. If this fractional decrease in dissolved mineral concentration is representative of that obtained by magnetic treatment, then it is unlikely that soap and detergent use will be significantly reduced. For example, given a water supply with 100 ppm dissolved hardness, magnetic treatment would only be expected to reduce the hardness to 90 ppm, assuming the results of Gehr et al. can be applied at this hardness concentration.

Is there a beneficial effect of magnetic water treatment? Perhaps.

Is there sufficient evidence of a beneficial effect to warrant spending hundreds of dollars on a residential magnetic water treatment unit? Unlikely. The understanding of magnetic water treatment must first be developed to the point where the effects of magnetic treatment can be reliably predicted and shown to be economically attractive.

Does magnetic water treatment perform as well as ion-exchange treatment? Definitely not. At present, the conventional water softening technologies are clearly much more reliable and effective. Further, the initial cost of an ion-exchange water softener (around $500) is comparable to that of many magnetic treatment systems.

Magnetic Fuel Treatment

Magnetic fuel treatment devices installed in automobiles are similar in design to magnetic water treatment devices. Hydrocarbon fuel is pumped through a canister containing one or more magnets or a magnetic device is clamped to the external surface of the fuel line. Magnetic treatment of fuel, it is claimed, results in increased horsepower, increased mileage, reduced hazardous gas emissions, and longer engine life.

Typically, vendors claim that either mileage or horsepower will be improved by about 10 to 20 percent. They also claim that if no improvement in mileage is noted, then the improvement must have come in the form of more horsepower. This, of course, makes it difficult for consumers to determine whether their magnetic fuel treatment devices really are working.

A literature search for magnetic fuel treatment studies revealed that such studies are practically nonexistent. I found a total of three references. Two of these (Daly 1995; McNeely 1994) were anecdotal accounts describing the use of a magnetic treatment device to kill microorganisms in diesel fuel, a fuel treatment application not usually mentioned by magnetic fuel treatment vendors.

The third reference (Tretyakov et al. 1985) describes tests conducted in which the electrical resistance and dielectric properties of a hydrocarbon fuel were found to change in response to an applied magnetic field. This report does not address whether the observed physical property changes might affect fuel performance in an engine, but it references two research reports that may contain performance data (Skripka et al. 1975; Tretyakov et al. 1975). Unfortunately, I could obtain neither report, and both are written in Russian.

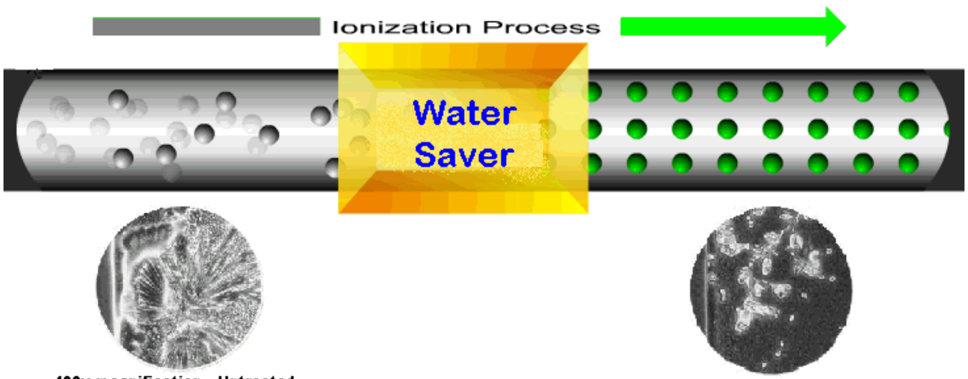
My literature search search found no other credible research reports pertaining to magnetic fuel treatment.

The utter lack of published test data is revealing. According to the vendors, magnetic fuel treatment has been around for at least fifty years. If it actually worked as claimed, it seems likely that it would by now be commonplace. It is not.

Vendors of magnetic fuel treatment sometimes respond to this reasoning with hints that the automobile manufacturers and big oil companies are conspiring to suppress magnetic fuel treatment to maintain demand for gasoline. Such a conspiracy seems quite improbable. This supposed conspiracy has not managed to suppress other fuel-saving innovations such as fuel injection and computerized control.

In summary, I found no test data that support the claims for improved engine performance made by vendors of magnetic fuel treatment devices. Until such data become available, considerable skepticism is justified. At present, it seems quite unlikely that any of the claimed benefits of magnetic fuel treatment are real.

Magnetic Water Softener



400x magnification. Untreated water with hardness of 140ppm

400x magnification. Same water Treated with PKU MFC.

PKU Magnetic Fluid Conditioners

The Effects On Water

*Imparts a charge to the water as it passes through the magnetic field
*Causes calcium to be retained in solution rather than plating on surfaces
*Reduces the odor and taste of sulfur in most cases
*Does not add anything to the water or take anything out
*Eliminates scale buildup
*Reduce the amount of chemicals needed in pools and spas
*WILL SAVE TIME, MONEY AND EFFORT IN MAINTAINING EQUIPMENT

Why is the PKU MFC the best product on the market?
Quality Control, we use the best materials available and the highest grade of magnets. Our research has developed the most effective product sold today and all units are checked prior to packaging to insure Zero defects in the field.

Why do I need multiple units?
There are many factors that are critical to the performance of magnetic water treatment products. One factor is energy imparted to the water. PKU uses the most powerful Neodymium magnets available, not those weak ceramic magnets that always fall off the refrigerator. They focus their energy into the pipe which creates a long field for the water to pass through. This power, coupled with longer contact time of the water to the magnetic energy, equates to the most effective product available on the market.

Will the product remove the minerals from the water?
No. The minerals that are in the water are good for your health. The problem is that they are bad for your plumbing, the PKU MFC will keep the minerals in solution so that they do not accumulate in your plumbing Or on your water heater element.

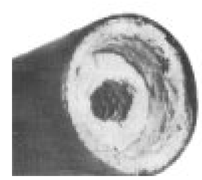
How will the PKU MFC save me money?
The U.S. Bureau of Standards reports that just 3/8" of scale build-up requires 55% more energy. That means an additional $247 more a year for that same hot water.

View Cart

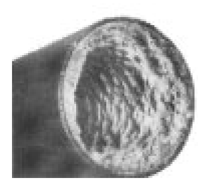
Check This out!!!

Everyone hates that crusty red or white deposit in pipes. It costs Americans Millions of dollars per year in repairs and preventive measures like Softwater treatment tanks and new water heaters.

We offer a device which requires NO salt, NO electricity and NO maintenance!!!



Pipe before PKU device



Pipe during PKU device

I have a water softener. Can the PKU MFC be of any benefit to me?

Absolutely! Install the PKU MFC on the water line before your softener and it will improve the efficiency of your softener by 40% to 60%. This could save hundreds of dollars per year in water cost to back-flush, in addition to the cost of salt. You will not be adding as much sodium to your water or dumping sodium laden water into the waste water system. Thereby doing your part to help conserve the environment.

Pipe after PKU device

What is the difference between a Salt based softener and the PKU MFC?

PKU MFC Device	Salt Based Water Softener
• Compact unit you can install yourself	• Household plumbing needs modification
• Maintenance Free Operation	• Requires Constant Maintenance
• No Salt • No Electricity • No Plumbing • No Back Flushing	• Requires Over 800 Pounds of Salt Each Year, Consumes Electricity, Needs Plumbing Modifications and Will Waste Resources Through Back Flushing
• Controls and Minimizes Hard Water Scale	• Won't Remove Existing Lime and Scale Build-up.
• Will Not Corrode Water Heaters, Pipes and Fixtures.	• Can Corrode Water Heaters, Pipes and Fixtures
• Does Not Harm The Environment or Our Fresh Water Supply.	• Pollutes Waterways, Hinders Septic Systems and Waste Water Treatment Programs.
• Feel Cleaner and Fresher After Bathing.	• Feels Slippery and Unnatural and Can Irritate Sensitive Skin.

Our MFC kit includes everything you need to treat your house water supply. One MFC kit for the cold water line and one MFC kit for the hot water heater inlet. They install over your copper or plastic pipes. This system will not work over iron pipes. The magnetic field cannot pass through the iron pipes.

Cost for 2 MFC kits is only $42.00 with free shipping and handling.
Includes 2 MFC kits for hot and cold water.

You can pay with check, money order, cash or www.paypal.com.

Plans and Kits Unlimited
PO Box 3238
Oceanside, CA 92051

2 Kits Only $42.00

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• Retains Healthful Minerals.	• Eliminates Healthful Minerals.
• Safe For Heart Patients and Those With Hypertension.	• Is Not Safe For Heart Patients and Those With Hypertension.
The PKU System will pay for itself! It is Salt Free!	

Pay with Visa, MC, AMEX, Discover

PK Unlimited	**Fax 760-967-8299**	**E-Mail** ninteach@plans-kits.com

Below is a report done by the U.S. Department of Energy Technology Alert # DOE/EE-0162

FEDERAL TECHNOLOGY ALERTS

Non-Chemical Technologies for Scale and Hardness Control

Technology for improving energy efficiency through the removal or prevention of scale.

Abstract

The magnetic technology has been cited in the literature and investigated since the turn of the 19th century, when lodestones and naturally occurring magnetic mineral formations were used to decrease the formation of scale in cooking and laundry applications. Today, advances in magnetic and electrostatic scale control technologies have led to their becoming reliable energy savers in certain applications.

For example, magnetic or electrostatic scale control technologies can be used as a replacement for most water-softening equipment. Specifically, chemical softening (lime or lime-soda softening), ion exchange, and reverse osmosis, when used for the control of hardness, could potentially be replaced by non-chemical water conditioning technology. This would include applications both to cooling water treatment and boiler water treatment in once-through and recirculating systems.

The primary energy savings from this technology result from decrease in energy consumption in heating or cooling applications. This savings is associated with the prevention or removal of scale build-up on a heat exchange surface, where even a thin film can increase energy consumption by nearly 10%. Secondary energy savings can be attributed to reducing the pump load, or system pressure, required to move the water through a scale-free, unrestricted piping system.

This *Federal Technology Alert* provides information and procedures that a Federal energy manager needs to evaluate the cost-effectiveness of this technology. The process of magnetic

or eletrostatic scale control and its energy savings and other benefits are explained. Guidelines are provided for appropriate application and installation. In addition, a hypothetical case study is presented to give the reader a sense of the actual costs and energy savings. A listing of current manufacturers and technology users is provided along with references for further reading.

About the Technology

The technology addressed in this FTA uses a magnetic or electrostatic field to alter the reaction between scale-forming ions in hard water. Hard water contains high levels of calcium, magnesium, and other divalent cations. When subjected to heating, the divalent ions form insoluble compounds with anions such as carbonate. These insoluble compounds have a much lower heat transfer capability than heat transfer surfaces such as metal. They are insulators. Thus additional fuel consumption would be required to transfer an equivalent amount of energy.

The magnetic technology has been cited in the literature and investigated since the turn of the 19^{th} century, when lodestones or naturally occurring magnetic mineral formations were used to decrease the formation of scale in cooking and laundry applications. However, the availability of high-power, rare-earth element magnets has advanced the magnetic technology to the point where it is more reliable. Similar advances in materials science, such as the availability of ceramic electrodes and other durable dielectric materials, have allowed the electrostatic technology to also become more reliable.

The general operating principle for the magnetic technology is a result of the physics of interaction between a magnetic field and a moving electric charge, in this case in the form of an ion. When ions pass through the magnetic field, a force is exerted on each ion. The forces on ions of opposite charges are in opposite directions. The redirection of the particles tends to increase the frequency with which ions of opposite charge collide and combine to form a mineral precipitate, or insoluble compound. Since this reaction takes place in a low-temperature region of a heat exchange system, the scale formed is non-adherent. At the prevailing temperature conditions, this form is preferred over the adherent form, which attaches to heat exchange surfaces.

The operating principles for the electrostatic units are much different. Instead of causing the dissolved ions to come together and form non-adherent scale, a surface charge is imposed on the ions so that they repel instead of attract each other. Thus the two ions (positive and negative, or cations and anions, respectively) of a kind needed to form scale are never able to come close enough together to initiate the scale-forming reaction. The end result for a user is the same with either technology; scale formation on heat exchange surfaces is greatly reduced or eliminated.

Application Domain

These technologies can be used as a replacement for most water-softening equipment. Specifically, chemical softening (lime or lime-soda softening), ion exchange, and reverse osmosis (RO), when used for the control of hardness, can be replaced by the non-chemical water conditioning technology. This would include applications both to cooling water treatment and boiler water treatment, in once-through and recirculating systems. Other applications mentioned by the manufacturers include use on petroleum pipelines as a means of decreasing fouling caused by wax build-up, and the ability to inhibit biofouling and corrosion.

The magnetic technology is generally not applicable in situations where the hard water contains "appreciable" concentrations of iron. In this FTA, appreciable means a concentration requiring iron treatment or removal prior to use, on the order of parts per million or mg/L. The reason for this precaution is that the action of the magnetic field on the hardness-causing ions is very weak. Conversely, the action of the magnetic field on the iron ions is very strong, which interferes with the water conditioning action.

A search of the Thomas Register™ in conjunction with manufacturer contact yielded eleven manufacturers of magnetic, electromagnetic or electrostatic water conditioning equipment that fell within the scope of this investigation. The defined scope includes commercial or industrial-type magnetic, electromagnetic or electrostatic devices marketed for scale control. Devices intended for home use, as well as other non-chemical means for scale control, such as reverse osmosis, are not within the extended scope of this FTA.

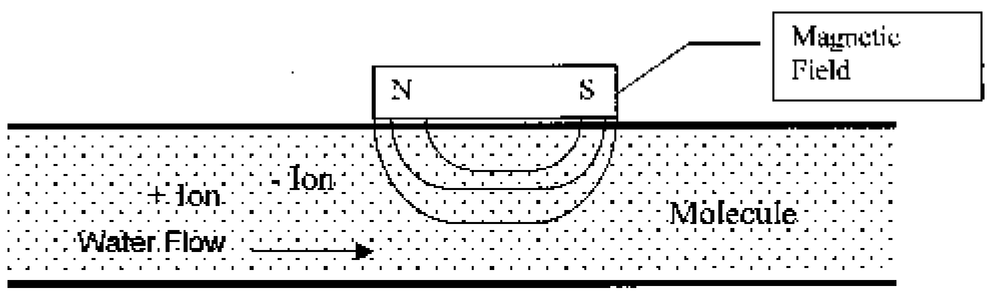

Figure 1. Diagram of General Magnetic Device Construction

Exact numbers of units deployed by these manufacturers are virtually impossible to compile, as some of the manufacturers had been selling the technology for up to 40 years. One manufacturer claims as many as 1,000,000 units (estimated total of all manufacturers represented here) are installed in the field. Where not withheld by the manufacturer because of business sensitivity reasons, customer lists included both Federal and non-Federal installations. Those manufacturers who did withhold the customer list indicated a willingness to disclose customer contacts to legitimate prospective customers.

Literature provided by and discussions with manufacturers described a typical installation for a boiler water treatment scheme as including the device installed upstream of the boiler. Manufacturers vary in their preference of whether the device should be installed close to the water inlet or close to the boiler. Both locations have been documented as providing adequate performance. Generally, the preferred installation location for use with cooling towers or heat exchangers is upstream of the heat exchange location and upstream of the cooling tower. Downstream of the cooling tower but upstream of the heat source was also mentioned as a possible installation location, primarily for the use with chillers or other cooling equipment.

The primary *caveat* on installation of the magnetic technology is that high voltage (230V, 3-phase or above) power lines interfere with operation by imposing a second magnetic field on the water. (This is most noticeable when these electric power sources are installed within three feet of a magnetic device.) This second magnetic field most likely will not be aligned with the magnetic field of the device, thus introducing interference and reducing the effectiveness of the treatment. Installations near high voltage power lines are to be avoided if possible. Where avoidance is not possible, the installation of shielded equipment is recommended to achieve optimum operation. Some manufacturers also have limitations on direction of installation--vertical or horizontal--because of internal mechanical construction.

Energy-Savings Mechanism

The primary energy savings result from a decrease in energy consumption in heating or cooling applications. This savings is associated with the prevention or removal of scale build-up on a heat exchange surface where even a thin film (1/32" or 0.8 mm) can increase energy consumption by nearly 10%. Example savings resulting from the removal of calcium-magnesium scales are shown in Table 1. A secondary energy savings can be attributed to reducing the pump load, or system pressure, required to move the water through a scale-free, unrestricted piping system.

Table 1. Example Increases in Energy Consumption as a Function of Scale Thickness

Scale Thickness (inches)	Increased Energy Consumption (%)
1/32	8.5
1/16	12.4
1/8	25.0
1/4	40.0

As was discussed above, magnetic and electric fields interact with a resultant force generated in a direction perpendicular to the plane formed by the magnetic and electric field vectors. (See Figure 2 for an illustration.) This force acts on the current carrying entity, the ion. Positively charged particles will move in a direction in accord with the Right-hand Rule, where the electric and magnetic fields are represented by the fingers and the force by the thumb. Negatively charged particles will move in the opposite direction. This force is in addition to any mixing in the fluid due to turbulence.

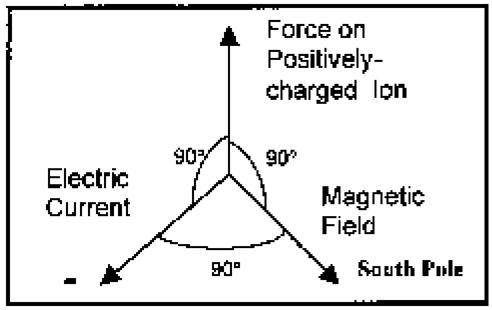

Figure 2. Diagram Showing Positioning of Fields and Force

The result of these forces on the ions is that, in general, positive charged ions (calcium and magnesium, primarily) and negative charged ions (carbonate and sulfate, primarily) are directed toward each other with increased velocity. The increased velocity should result in an increase in the number of collisions between the particles, with the result being formation of insoluble particulate matter. Once a precipitate is formed, it serves as a foundation for further growth of the scale crystal. The treatment efficiency increases with increasing hardness since more ions are present in solution; thus each ion will need to travel a shorter distance before encountering an ion of opposite charge.

A similar reaction occurs at a heat exchange surface but the force on the ions results from the heat input to the water. Heat increases the motion of the water molecules, which in turn increases the motion of the ions, which then collide. In addition, scale exhibits an inverse solubility relationship with temperature, meaning that the solubility of the material decreases as temperature increases. Therefore, at the hottest point in a heat exchanger, the heat exchange surface, the scale is least soluble, and, furthermore due to thermally induced currents, the ions are most likely to collide nearest the surface. As above, the precipitate formed acts as a foundation for further crystal growth.

When the scale-forming reaction takes place within a heat exchanger, the mineral form of the most common scale is called calcite. Calcite is an adherent mineral that causes the build-up of scale on the heat exchange surface. When the reaction between positively charged and negatively charged ions occurs at low temperature, relative to a heat exchange surface, the mineral form is usually aragonite. Aragonite is much less adherent to heat exchange surfaces, and tends to form smaller-grained or softer-scale deposits, as opposed to the monolithic sheets of scale common on heat exchange surfaces.

These smaller-grained or softer-scale deposits are stable upon heating and can be carried throughout a heating or cooling system while causing little or no apparent damage. This transport property allows the mineral to be moved through a system to a place where it is convenient to collect and remove the solid precipitate. This may include removal with the wastewater in a once-through system, with the blowdown in a recirculating system, or from a device such as a filter, water/solids separator, sump or other device specifically introduced into the system to capture the precipitate.

Water savings are also possible in recirculating systems through the reduction in blowdown necessary. Blowdown is used to reduce or balance out the minerals and chemical concentrations within the system. If the chemical consumption for scale control is reduced, it may be possible to reduce blowdown also. However, the management of corrosion inhibitor and/or biocide build-up, and/or residual products or degradation by-products, may become the controlling factor in determining blowdown frequency and volume.

Other Benefits

Aside from the energy savings, other potential areas for savings exist. The first is elimination or significant reduction in the need for scale and hardness control chemicals. In a typical plant, this savings could be on the order of thousands of dollars each year when the cost of chemicals, labor and equipment is factored in. Second, periodic descaling of the heat exchange equipment is virtually eliminated. Thus process downtime, chemical usage, and labor requirements are eliminated. A third potential savings is from reductions in heat exchanger tube replacement due to failure. Failure of tubes due to scale build-up, and the resultant temperature rise across the heat exchange surface, will be eliminated or greatly reduced in proportion to the reduction in scale formation.

Variations

Devices are available in two installation variations and three operational variations. First to be discussed are the two installation variations: invasive and non-invasive. Invasive devices are those which have part or all of the operating equipment within the flow field. Therefore, these devices require the removal of a section of the pipe for insertion of the device. This, of course, necessitates an amount of time for the pipe to be out of service. Non-invasive devices are completely external to the pipe, and thus can be installed while the pipe is in operation. Figure 3 illustrates the two installation variations.

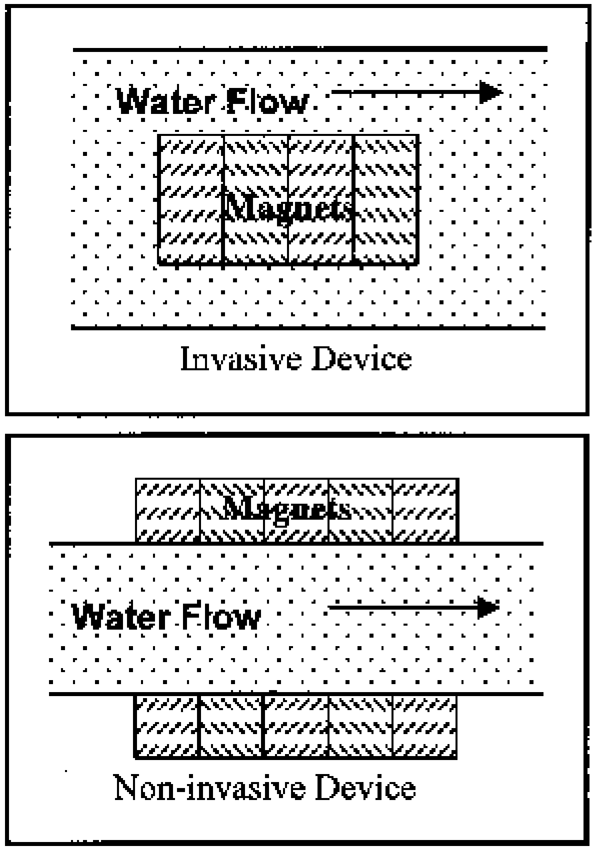

Figure 3. Illustration of Classes of Magnetic Devices by Installation Location

The operational variations have been mentioned above; illustrations of the latter two types are shown Figure 4:

- Magnetic, more correctly a permanent magnet
- Electromagnetic, where the magnetic field is generated via electromagnets
- Electrostatic, where an electric field is imposed on the water flow, which serves to attract or repel the ions and, in addition, generates a magnetic field.

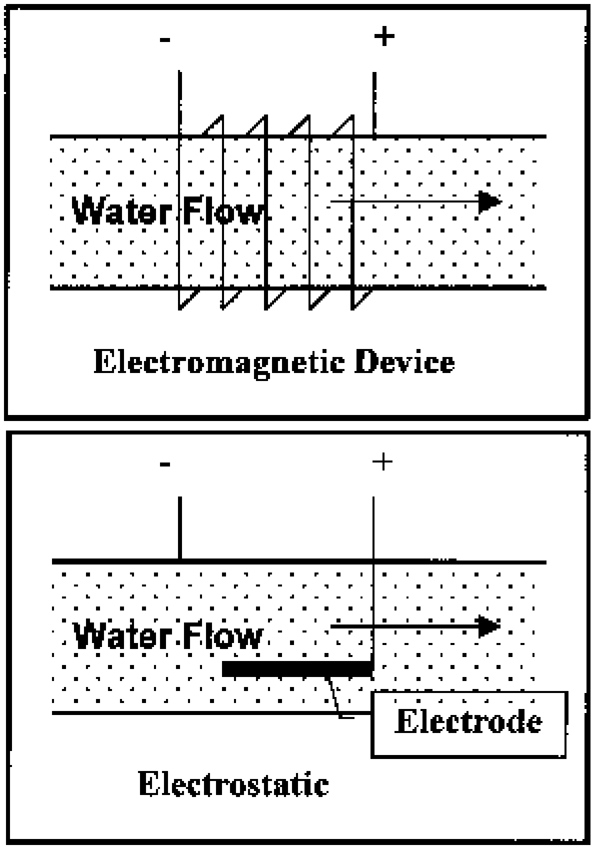

Figure 4. Illustration of Classes of Non-Permanent Magnet Devices

Electrostatic units are always invasive. The other two types can be either invasive or non-invasive. The devices illustrated in Figure 3 are examples of permanent magnet devices.

Installation

Most of the devices are in-line--some invasive, some non-invasive--as opposed to side-stream. The invasive devices require a section of pipe to be removed and replaced with the device. Most of the invasive devices are larger in diameter than the section of pipe they replace. The increased diameter is partially a function of the magnetic or electromagnetic elements, and also a function of the cross sectional flow area. The flow area through the devices is generally equivalent to the flow area of the section of pipe removed.

The non-invasive in-line devices are designed to be wrapped around the pipe. Thus downtime, or line out-of-service time, is minimized or eliminated.

Federal Sector Potential

The potential cost-effective savings achievable by this technology were estimated as part of the technology assessment process of the New Technology Demonstration Program (NTDP).

Technology Screening Process

New technologies were solicited for NTDP participation through advertisements in the *Commerce Business Daily* and trade journals, and, primarily, through direct correspondence. Responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies).

The energy savings and market potentials of each candidate technology were evaluated using a modified version of the Facility Energy Decisions Screening (FEDS) software too (Dirks and Wrench, 1993).

Non-chemical water treatment technologies were judged life-cycle cost-effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings. In addition, significant environmental savings from the use of many of these technologies are likely through reductions in CO_2, NO_x, and SO_x emissions.

Estimated Savings and Market Potential

As part of the NTDP selection process, an initial technology screening activity was performed to estimate the potential market impact in the Federal sector. Two technologies were run through the assessment methodology. The first technology was assessed assuming the technology was applied to the treatment of boiler make-up water. The second technology was assessed assuming the technology was applied to both the treatment of boiler make-up water and cooling tower water treatment. The technology screenings used the economic basis required by 10 CFR 436. The costs of the two technologies were different based on information provided by the manufacturers, thus leading to different results.

The technologies were ranked on a total of ten criteria. Three of these were financial, including net present value (NPV), installed cost, and present value of savings. One criterion was energy-related, annual site energy savings. The remaining criteria were environmental and dealt with reductions in air emissions due to fuel or energy savings and included SO_2, NO_x, CO, CO_2, particulate matter and hydrocarbon emissions.

The ranking results from the screening process for this technology are shown in Table 2. These values represent the maximum benefit achieved by implementation of the technology in every Federal application where it is considered life-cycle cost-effective. The actual benefit will be lower because full market penetration is unlikely to ever be achieved.

Table 2. Screening Criteria Results

Screen Criteria	Results	
	First Screen	Second Screen

Net Present Value ($)	147,518,000.	158,228,000.
Installed Cost ($)	52,819,000.	35,299,000.
Present Value of Savings ($)	200,336,000.	193,527,000.
Annual Site Energy Savings (Mbtu)	4,166,000.	3,761,000.
SO_2 Emissions Reduction (lb/yr)	3,292,000.	427,000.
NO_x Emissions Reduction (lb/yr)	1,028,000.	550,000.
CO Emissions Reduction (lb/yr)	304,000.	128,000.
CO_2 Emissions Reduction (lb/yr)	303,000.	234,000.
Particulate Emissions Reduction (lb/yr)	60,000.	29,000.
Hydrocarbon Emissions Reduction (lb/yr)	7,000.	3,000.
Note: First Screen: Boiler make-up water treatment. Second Screen: Cooling tower water treatment and boiler make-up water treatment.		

Laboratory Perspective

The primary question to be answered is "Does the technology work as advertised?" The history of the technologies, as illustrated through primarily qualitative--but some quantitative--assessment in many case studies, has shown that when properly installed, a decrease in or elimination of scale formation will be found. While the evidence supporting the technologies may be thought of as mainly anecdotal, the fact remains that upon visual inspection after installation of these devices the formation of new scale deposits has been inhibited. In addition, in most cases, scale deposits present within the system at the time of installation have been removed.

The key here is *properly installed*. By this it is meant that a manufacturer or their qualified representative is responsible for equipment integration. Unlike many other technologies where much of the knowledge has been reduced to a quantitative model, the non-chemical water treatment industry still relies largely on experience as the means of providing quality installation, service and, consequently, customer satisfaction.

Of particular interest to the manufacturer would be physical parameters such as water flow rate, and water quality parameters such as hardness, alkalinity, and iron concentration. These parameters will help determine the optimum size and the extent of treatment.

The manufacturer may also want to know whether the installation is for use in conjunction with a boiler or a cooling tower, and for once-through or recirculating water systems. These parameters will help determine the optimum location within the system.

Other factors of interest may include whether the cooling or heating system is sensitive to particulate matter, and if so what particle sizes. The device works by initiating the precipitation of scale, thus particulate matter will be present in the treated water. If the system is sensitive to particulate matter there may be a need for a solid separation device such as a filter, a settling basin, a cyclone, or a sump to collect solids and to allow for their easy removal from the system.

Application

This section addresses the technical aspects of applying the technology. The range of applications and climates in which the technology can be applied are addressed. The advantages, limitations, and benefits in each application are enumerated. Design and integration considerations for the technology are discussed, including equipment and installation costs, installation details, maintenance impacts, and relevant codes and standards. Utility incentives and support are also discussed.

Application Screening

As mentioned previously, the technology can be applied wherever hard water is found to cause scale. Since the technology is a physical process, as opposed to chemical water softening, it is expected to perform best in locations with harder water. In general, only a few locations do not require or would not benefit from some type of hardness control. Hard water is one in which the hardness is greater than 60 mg/L (or ppm) as calcium carbonate. This corresponds to approximately 3.5 grains of hardness per U.S. gallon. The Pacific Northwest states, the North Atlantic coastal states, and the Southeast states, excluding Florida, are locations where naturally occurring soft water is most likely to be found. The balance of the United States could benefit from some type of water treatment to control scale formation, using either one of the traditional technologies such as lime softening or ion exchange, or the non-chemical technology discussed in this FTA.

Where to Apply

Non-chemical scale control technologies can be used for either boiler scale control or cooling tower scale control. Boiler scale control applications are the majority of the installations, but the control of silica scale in cooling water applications is also possible. Experience has been cited with both retrofit installations and in new installations (see References for a brief listing of applicable reports and publications).

Non-chemical scale control technologies are best applied:

- When the use of chemicals for water treatment is to be minimized or eliminated. Lime, salt and acid for cleaning can be reduced or eliminated.
- When space requirements do not allow installation of lime softening equipment or ion exchange equipment. The non-chemical technologies are generally very space efficient.
- When particulate matter in the water can be tolerated by the process; otherwise solids separation is required.
- When frequent system shutdowns are required for descaling even with a diligent chemical scale control program.
- In remote locations where delivery of chemicals and labor cost makes conventional water softening or scale control methods cost prohibitive.

What to Avoid

There are a few precautions to be noted before selecting the technology:

- This technology is littered with disreputable manufacturers or vendors, the actions of whom have given the technology an undesirable history in the eyes of many. Work with a reputable manufacturer (such as those included herein) through their engineering department or their designated installer. These people have much more experience with the technology than the typical water treatment engineering firm.
- Be aware of process water requirements since these requirements may dictate the need to install solids separation equipment or iron removal equipment in order to maximize the performance of the technology.
- Installation near high voltage electrical equipment or strong magnetic fields is to be avoided since these fields will interfere with the performance of the technology. (Near is relative to the voltage; for 208/220/240V it means within 36 inches; for higher voltages it is proportionally more distant.) Also, check the pipeline for its use as an electrical ground. Stray electrical current in the pipe will have the same effect as installation near a strong electrical or magnetic field.

Installation

Installation issues with these devices are few. The first issue is whether a permanent magnet or one of the electronic devices is chosen. The latter needs a suitable supply of electricity.

The second issue is device capacity, which will dictate space requirements and pipe size. The pipe size generally determines the fittings. Smaller devices, up to approximately 2" pipe size, are available with solder or pipe thread fittings. Larger devices may have flange fittings that would necessitate the installation of matching flanges in the current pipe arrangement.

The third issue is the potential for downtime, which needs to be coordinated with other facility activities. However, this should not be a major impediment since downtime for cleaning and maintenance of cooling towers, or boiler inspection is part of the regularly scheduled activities for most installations.

A fourth issue would arise with the corrosion control chemistry, which will likely need some adjustment under a non-chemical scale control technology. In many cases the layer of scale on heat transfer surfaces is beneficial from a corrosion control standpoint. With this layer not present when using a non-chemical technology, the concentration of corrosion control chemicals may need adjustment in order to provide the proper protection. On the reverse side, many users are claiming the presence of a fine powdery film on the surfaces the treated water contacts. This powder has been attributed to serve as a corrosion inhibitor.

The most significant issue may be whether a solids separation device is needed to remove the particulates formed. Filters, hydrocyclones, and settling basins are all compatible with the technology. The choice among these or other solids separation technologies should be made in conjunction with the manufacturer who will have the best idea of particle size distribution, and thus the relative efficiencies of the separation technologies.

Maintenance Impact

There is a significant, positive impact on maintenance. Field applications have shown the technology to be capable of controlling scale for extended periods of time, months or years, eliminating the periodic cleaning or descaling of process equipment that is typical of conventional, chemical-based scale control technologies. The resources--time, chemicals, and equipment--previously devoted to periodic scale removal from heat exchange surfaces will be made available for other tasks. Note, however, the need for periodic inspection of the heat exchange surfaces is not reduced or eliminated.

The electrostatic devices also require periodic inspection of the electrodes. This scheduled maintenance activity can be performed in conjunction with the heat exchange surface inspection and requires less than a person-day to disassemble and inspect the system.

Equipment Warranties

All of the manufacturers offer some type of warranty on their respective device. The range is from 90 days to as much as 10 years. Another perspective is the potential impact upon warranties for installed equipment. No information was uncovered as part of this effort to indicate any instance where a boiler or cooling tower equipment manufacturer voided a warranty for equipment. However, no specific effort was made to contact manufacturers of boilers and cooling tower equipment to assess specific warranty conditions or policies.

Codes and Standards

Only one code or standard specific to the non-chemical technologies was identified in the course of preparing this FTA: API 960, Evaluation of the Principles of Magnetic Water Treatment, 09/1985, 89 pages. Of course, all applicable plumbing, piping, mechanical, and/or electrical codes and standards would still apply.

Costs

Cost information was requested from each manufacturer for three different-size units, based on flow rate: 1 gpm (gallons per minute), 100 gpm and 1,000 gpm. As is typical of process equipment, cost per unit of treatment decreases with increasing capacity. To treat 1 gpm, a typical cost was on the order of $100, or about $100 per gpm. To treat 1,000 gpm a typical cost was on the order of $10,000, or about $10 per gpm.

In general, the electronic units were more costly than the magnetic units for an equivalent flow rate. Costs also ranged considerably with unit size, with the 1-gpm units ranging in cost up to $500. For the 1,000-gpm units the range of costs was considerably greater, from $900 to over $1,000,000.

Installation costs also varied widely, in conjunction with equipment size. The lower flow rate units will mate with 3/4" to 1" pipe sizes with soldered, flanged or threaded (NPT) fittings. Installation time estimates were on the order of one hour, with additional parts costing less than $10. The larger-size units (1,000 gpm) were typically designed to mate with a 12" to 18" pipe using a flange fitting. Estimated installation time ranged from one to four person-days, requiring less than $1,000 in additional materials.

Weight was an important characteristic in the installation estimate because the permanent magnet units may exceed 1,000 pounds. There is a trade-off between installing a heavier permanent magnet unit requiring no outside power versus a lighter electronic unit for which an electrical connection needs to be made, and possibly electrical lines run to the point of installation. The net effect is expected to be neutral with regard to installation time estimates.

Since these units are typically delivered in the sizes quoted off-the-shelf, there is no design cost by the manufacturer. Facilities engineering and design for calculations and updating plant drawings should amount to less than two person-days for the large units, and less than an hour for the small units.

Utility Incentives and Support

Although no specific incentive programs were identified, the Department of Energy and the Advanced Research Projects Agency have funded research in this area. Some utility or trade associations have supported the electronic technologies with funds and exposure. For example, the American Water Works Association sponsored a conference to discuss the non-traditional treatment technologies. In addition, as California municipalities face water shortages, they have turned to a number of measures to lower water consumption and increase water quality. Many have prohibited the use of water softeners and may offer assistance infunding conversion to low/no salt water conditioning technologies.

Additional Considerations

There are additional considerations to be taken into account. Primary among these is the reduction in chemical use at the facility for water softening. The chemical use reduction may lead to reduced safety, training and reporting requirements.

Electricity consumption will also be reduced. The actual reduction is highly dependent upon the technology employed. Permanent magnets use no electricity, so both the on-site electricity used for chemical treatment as well as the off-site energy required to produce and transport the chemicals will be eliminated. For the electronic units, on-site energy requirements may vary from as little as 10% of the chemical-based treatment system energy consumption--typical, to 10 times the energy consumed by the chemical-based treatment system.

Energy consumption reductions will lead directly to reductions in air combustion emissions. There will also be additional indirect reductions due to decreased transportation of fuels and decreased fuel processing. The latter will also lead to reductions in water use, water pollution, and solid wastes from mining and processing operations.

Technology Performance

The information in this section was compiled primarily from case studies, along with selected contact with users and third party researchers. As mentioned previously, the use of magnetic or electric fields to treat water had its origins near the turn of the 19^{th} century. Commercialization of the technology began after World War II, with the largest advances coming in the last 20 years with the development of rare earth magnets and inexpensive electronic controls.

There are records of installation of the technology in the United States from about 1950. Manufacturers claim to have installations operating satisfactorily for as long as 30 years. No good statistics were available on the total number of installations over this period. However, using the estimates of one manufacturer as a basis, there could be upwards of 1,000,000 units installed in the United States in commercial or industrial facilities, inclusive of all units installed by all manufacturers.

Field Experience

As has been alluded to above, user experience has been positive. Two experiences have been common. First, users have noted a dramatic reduction in scale formation to the point where the need for chemical scale control is eliminated. Second, the prior build-up of scale on heat exchange surfaces has been removed over time. This last process has been noted as taking from 30 days to over a year, depending upon the thickness and composition of the scale.

This is not to say there have not been less than successful installations or applications. The non-chemical technologies may not be universally applicable for scale control, just as any technology may not be a universally applicable solution to the problem it was designed to solve.

The magnetic technologies are not as effective when silica is present in the system. Nor do they work as efficiently when iron is present, as was mentioned above, or when other magnetic minerals are present. The history of the technology is also littered with cases where the magnet field was applied incorrectly or did not have sufficient strength to affect the reaction. This latter was especially true early in the life cycle of the technology when ferrous-based magnets were the norm. High levels of particulate matter will also negatively influence the efficiency of the technology by reducing the collision frequency of the desirable reactions.

Energy Savings

Energy savings result from both reductions in pumping energy input to the system and reduction in fuel consumption. The first aspect has not been well quantified by the users or in any of the case studies. It is thought of as a secondary benefit.

Fuel consumption has been lowered in every situation. The exact savings are a result of a number of factors:

- How effective the chemical scale control program may have been relative to the input water hardness
- How often the heat exchange system was taken down for maintenance and cleaning.

On systems that were descaled frequently or had low scale formation, due to low hardness and/or an effective chemical scale control program, the savings in fuel consumption was lower, often from a few percent to as much as 15%. The lower savings were at an installation using ion exchange softening of moderately hard water (less than 150 mg/L as calcium carbonate hardness). On systems where descaling was infrequent or absent altogether, or where the chemical scale control program was not as effective in controlling scale formation, fuel consumption savings ranged up to 30%. This was found to be the case in an installation using very hard water (hardness in excess of 300 mg/L as calcium carbonate), andd a chemical scale control program, with heat exchanger tubes closing due to scale formation after less than one year. In each case the fuel consumption savings was proportional to the thickness of the scale layer removed.

One important note was that fuel consumption savings often trailed installation of the technology by a significant period due to the fact that the savings is driven by the amount of scale on the heat exchange surface. The accumulated scale will erode over time, resulting in fuel consumption reductions. For this reason, many of the manufacturers recommend installing the technology only after the system has been descaled, thus savings in fuel consumption would be immediate.

Maintenance

As mentioned above, maintenance requirements typically are reduced upon implementation of the non-chemical technology. First, periodic maintenance of the water-softening equipment and chemicals is eliminated. Second, the periodic heat exchanger inspection and cleaning cycle is reduced to an inspection cycle. The handling and storage requirements for the chemicals--lime, soda ash, salt and acid--have been eliminated, as has training for their use, storage and handling. The reduction in these periodic activities frees up the previously time allocated for application to other activities.

There are maintenance activities associated with this technology. For the electromagnetic and electrostatic units, a daily check that the power is on is necessary (a "power on" indicator light is included with most, if not all, units). The electrostatic units need to have the electrodes checked periodically, semi-annually, and the electrodes replaced when noticeably worn or damaged, perhaps every five years. The reader should speak to the manufacturer for details which may vary.

When solids or particulates accumulate in the system, they will need to be removed. Automatic blowdown of the system should control the daily accumulation. If the system is not cleaned prior to installation of the non-chemical technology, the scale in the system will detach and its removal will be necessary. Filters, sumps and hydrocyclones are all effective means of capturing the solids, but each will require periodic cleaning.

Environmental Impacts

There are areas where the technology mitigates environmental impacts. The first is air quality due to emissions reduction associated with decreases in fuel consumption. The second is a corresponding decrease in solid wastes, ash and other fuel combustion residues to be disposed. Of course, this will only be applicable in the situation in which an end user combusts fuels on-site for the production of power. A third area is the reduction in release, or potential for release, of water treatment chemicals stored at a facility. Since chemical consumption will decrease, emissions from storage will also decrease. The wastes associated with disposal and management of used chemical containers will also be reduced.

Case Study

For the case study, a hypothetical facility is used and the application of a permanent magnet device is described. The conditions are based on information gathered during the user interviews and reading of published and unpublished case studies. The purpose is to illustrate the types of data required to prepare a site-specific cost analysis, not to illustrate what any particular user might experience in the way of cost savings.

Facility Description

The facility currently uses extremely hard water (hardness of 350 mg/L as calcium carbonate) and employs lime softening. The process water is used in a recirculating boiler water system with flow of 1,000 gpm or 1.4 MGD (million gallons per day). Makeup and blowdown were estimated at 10% of the flow, or 140,000 gallons per day. The water-softening process removes a significant fraction of the hardness, but not all, leading to semiannual inspections and annual cleaning of the heat exchanger. This frequency is thought to be fairly typical.

Cost for the lime used in the process is estimated at $10/ton delivered. Cost for natural gas is $5.80/1000 ft^3. Acetic acid, used for cleaning, costs $2 per gallon.

Existing Technology Description

The current system is a conventional lime softening plant consisting of lime storage facilities, a slaker where the powered lime is mixed with water, a mixing basin for adding controlled amounts of the lime solution to the water, and a settling basin where the precipitated solids are removed. Downstream of the water treatment facilities is a conventional shell-and-tube heat exchanger used to heat the water for both building heat and process water.

Lime consumption for softening is 48 tons/year. In this case, alkalinity is sufficient so as to not require the addition of soda ash during the softening process. Natural gas consumption for process water heating is 400,000 MBtu/year. Electricity consumption for the softening process was estimated at 3,100 kWh per year. Acetic acid is used during cleaning, approximately 100 gallons per cleaning. Production losses due to system downtime are not being included in this analysis.

(If the system had instead used ion exchange softening, the applicable chemical use information would have been the regenerant, typically salt but possibly acid, and the consumption of ion exchange resin. This last item is calculated as the mass replaced divided by the total volume of water treated.)

Data on lime consumption can typically be found in purchasing records, or also in a water treatment system operator's log. The latter would be more accurate since it would more closely reflect lime used for water softening, whereas the former would list only lime purchases including those for water softening, pH adjustment and other uses.

Natural gas consumption, or other fuel consumption data, can be taken from accounting records, if the only use of natural gas is for process water, or from operation data, (e.g., firing rate data), or calculated from an energy balance for a portion of the production system. The firing rate data or other operation data would be the most accurate but might not always be available.

Electricity consumption information can be calculated from nameplate capacity of the mixing and pumping equipment involved. For this report, it was derived from information compiled by the Electric Power Research Institute. In some cases there may be energy or monitoring data available for the process that would be available as part of the water treatment system operator's records.

New Technology Equipment Selection

A magnetic scale control device will be investigated as an alternative to chemical scale control. The first step was consultation with the manufacturer, including submitting water analysis data and a schematic of the current system showing the proposed location of the equipment to facilitate manufacturer selection and equipment sizing. (A magnetic device was chosen because the preferred installation location was remote, with electrical power not readily available.)

For the proposed location and required flow rate, a unit was identified that would fit the current piping configuration without a need for adapters. The unit cost is $10,000 including shipping. The estimate by the in-house facilities engineering staff calls for three days to install the system, one-half day each for set-up and clean-up, one day to remove a section of pipe to make space for the device (including installing flanges), and one day for installation and leak testing. Three people are required, as well as a device capable of lifting 1,000 pounds in order to position the device and facilitate removal of the old section of pipe.

One of the key elements to sizing these devices is the water velocity through the device. Manufacturers recommend, typically, at least a 7 feet per second water velocity. If the water velocity through a section of pipe is too low, it will be necessary to use adapters to decrease the size of the pipe through the device, thus increasing the velocity. Water velocity in feet per second can be calculated as follows, where *Diameter* is in feet:

$$U = \frac{0.535 * GPM}{\pi * Diameter^2}$$

Savings are expected to result from discontinuance of chemical consumption and decreased energy consumption (10% of process energy and all of the water treatment energy). Inspection will still occur.

Savings Potential

Energy savings can result from two areas. First is the reduction in fuel used in generating heat. Methods for calculating the fuel consumption were discussed above in the technology descriptions. The fuel consumption savings is simply the net difference, in this case estimated equal to 10% of the baseline fuel consumption. (This estimated savings was used to illustrate a case where there was a fairly uniform 1/16" thick layer of scale across a heat exchanger surface. Of course, it is realized that the scale layer, and therefore energy consumption, builds over time and is not an instantaneous effect.) This savings is also equal to the loss in heat transfer efficiency due to scale formation on the heat exchange surface.

Second is the energy savings resulting from decreased pressure drop within the heat exchanger. This is not quantified here, but could be quantified if the pressure drop through the current system was known, along with the energy characteristics of the pump so that reductions in pressure could be related to energy consumption.

Cost savings also result from reductions in chemical use. Chemical softening will be reduced, and likely eliminated, by the use of non-chemical treatment technologies. There will also be a corresponding energy decrease from the shutdown of chemical mixing equipment and water treatment equipment used in the softening process. The estimated chemical savings here was 480 tons per year and the corresponding electricity savings was 31,000 kWh per year.

Table 3 illustrates typical consumption data for the baseline and alternative and the potential annual costs savings. Not shown are water consumption and water discharge, which do not change between the alternatives. Capital cost for the alternative treatment system, estimated at $10,000 at the beginning of the 15-year analysis period, is not shown either. Fifteen years was chosen because it was typical of the life of field units.

Table 3. Annual Costs and Savings

Item	Cost $/unit	Baseline Lime Softening		Alternative Magnetic Treatment		Annual Costs Savings
		Annual Consumption	**Annual Cost $/year**	**Annual Consumption**	**Annual Cost $/year**	
Electricity	0.05/kWh	3,100	155	0	0	155
Natural Gas	5.80/MBtu	400,000	2,320,000	360,000	2,088,000	232,000
Chemicals	10/ton	48	480	0	0	480
Total			2,320,635		2,088,000	232,635

Life-Cycle Cost

The full results of the BLCC computations are shown in Appendix B. A discussion of the BLCC software is given in Appendix A. The BLCC Comparative Economic Analysis is shown in Figure 5. Installation cost for the magnetic treatment device is estimated at $10,360, calculated as $10,000 for the device and $360 for design and installation labor. Operating costs for the technology are estimated at $2,088,000 per year versus costs of $2,320,635 per year for the conventional lime-softening technology, both exclusive of water consumption and discharge. Life-cycle costs for each of the technologies as calculated by the BLCC software are $27,524,500 for the magnetic technology versus $30,283,500 for the conventional technology. (This includes the cost of water and wastewater disposal of

$2,605,292.) This represents a life-cycle cost savings of $2,759,000. The Simple Payback from BLCC is less than one year, and the Adjusted Internal Rate of Return is 50.66%.

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* N I S T B L C C: COMPARATIVE ECONOMIC ANALYSIS (ver. 4.4-97) *

****

Project: Non-Chemical Scale Control FTA
Base Case: Lime Soft.
Alternative: Magnetic

Principal Study Parameters:

Analysis Type: Federal Analysis–Energy Conservation Projects
Study Period: 15.00 Years (NOV 1997 through OCT 2012)
Discount Rate: 3.8% Real (exclusive of general inflation)
Base Case LCC File: SOFTEN.LCC
Alternative LCC File: MAGNETIC.LCC

Comparison of Present-Value Costs

	Base Case: Lime Soft.	Alternative: Magnetic	Savings from Alt.
Initial Investment item(s):			
Capital Requirements as of Serv. Date	$0	$10,360	-$10,360
Subtotal	$0	$10,360	-$10,360
Future Cost Items:			
Energy-related Costs	$27,678,200	$24,908,850	$2,769,350
Water Costs	$2,605,292	$2,605,292	$0
Subtotal	$30,283,500	$27,514,140	$2,769,360
Total P.V. Life-Cycle Cost	$30,283,500	$27,524,500	$2,759,000

Net Savings from Alternative 'Magnetic' compared to Base Case 'Lime Soft.'

Net Savings = P.V. of Non-Investment Savings $2,769,360
- Increased Total Investment $10,360
Net savings: $2,759,000

Note: the SIR and AIRR computations include differential initial costs, capital replacement costs, and residual value (if any) as investment costs, per NIST Handbook 135 (Federal and MILCON analyses only).

Savings-to-Investment Ratio (SIR)
For Alternative 'Magnetic' compared to Base Case 'Lime Soft.'

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 267.31$$

Adjusted Internal Rate of Return (AIRR)
For Alternative 'Magnetic' compared to Base Case 'Lime Soft.'
(Reinvestment Rate = 3.80%; Study Period = 15 years)

AIRR = 50.66%

Estimated Years to Payback

Simple Payback occurs in year 1
Discounted Payback occurs in year 1

ENERGY SAVINGS SUMMARY

Energy type	Units	Average Annual Consumption: Base Case	Alternative	Savings	Life-Cycle Savings
Electricity	kWh	3,100.0	0.0	3,100.0	46,500.0
Natural Gas	MBtu	400,000.0	360,000.0	40,000.0	600,000.0

EMISSIONS REDUCTION SUMMARY

Energy type	Average Annual Emissions: Base Case	Alternative	Reduction	Life-Cycle Reduction
Electricity:				
CO2 (Kg):	3,005.0	0.0	3,005.0	45,075.1
SO2 (Kg):	10.9	0.0	10.9	163.6
NOx (Kg):	9.1	0.0	9.1	135.8
Natural Gas:				
CO2 (Mg):	21,125.3	0.0	21,125.3	316,879.9
SO2 (Kg):	84.0	0.0	84.0	1,260.0
NOx (Kg):	16,460.0	0.0	16,460.0	246,900.0
Total:				
CO2 (Mg):	21,128.3	0.0	21,128.3	316,925.0
SO2 (Kg):	94.9	0.0	94.9	1,423.6
NOx (Kg):	16,469.1	0.0	16,469.1	247,035.8

Figure 5. Comparative BLCC Analysis

The Technology in Perspective

The future of non-chemical water treatment technologies is promising. As public awareness of the environmental effects of chemicals increases there will be an increasing demand to deploy alternative, more environmentally beneficial technologies. As a means of reducing energy consumption and stretching the available personnel resources in the days of ever-shrinking budgets, non-chemical technologies make sense as both cost effective and having demonstrated performance.

The Technology's Development

Magnetic and electrical effects on water were first noticed prior to the turn of the 20^{th} century. Considerable research is being conducted on magnetohydrodynamics by the Japanese as a means of propulsion, and similar research has been conducted in the past in the United States and other industrialized countries. This research has been facilitated by the advent of rare earth magnets, solid state electronics, and advanced ceramic or polymeric materials after World War II. Only after these advances has non-chemical water treatment shown promise and come into more widespread use.

Of the manufacturers listed in this FTA most have come into existence since the advent of the environmental movement in the United States in the early 1970s. This can be attributed both to the advent of cost-effective components (e.g., magnets, electronics) and to the public desire for more "green" or environmentally friendly alternatives to chemical treatment.

Relation to Other Technologies

The use of the non-chemical technologies does not prohibit the use of any other technology or equipment. As was mentioned previously, the change from chemical to non-chemical scale control may warrant investigation of other means of corrosion or biofouling control, as these three chemical scale treatment or control strategies or applications are often balanced amongst each other.

An increase in cycles of concentration was also noted by one user as another water saving measure that was employed. The ability to increase the cycles of concentration was attributed to the stability of scale-forming ions or scale particles in suspension. Water consumption was halved in this multi-pass system.

Technology Outlook

There is no basis to assume that the technologies are going to disappear anytime soon. Each has a historical basis of successful installations. Advances in materials science should only serve to improve each of the technologies. More powerful magnets will allow the magnetic devices to become smaller and/or more efficacious. More durable electrodes and dielectric compounds will improve the life of the electrostatic units.

Probably the most significant trend is the move away from chemical treatment technologies. This trend has begun at the consumer level, is becoming apparent at the corporate level, and will continue to grow. Increased availability of information on the technologies, the environment, and human health will only serve to feed this trend.

Manufacturers

The following is a listing of manufacturers of these technologies compiled from the Thomas Register and those who have contacted FEMP directly. It has been limited to U.S. manufacturers; foreign manufacturers or U.S. affiliates of foreign manufacturers were not included. No effort was made to locate and include manufacturers not listed in the Thomas Register. This listing does not purport to be complete, to indicate the right to practice the technology, or to reflect future market conditions.

Advanced Environmental Products
9450 Schulman #113
Dallas, TX 75243
214/340-1435
Fax: 214/344-2134

Aqua-Floe Inc.
Department T-94
6244 Frankford Avenue
Baltimore, MD 21206
800/368-2513
410/485-7600
Fax: 410/488-2030

Aqua Magnetics International, Inc.
915-B Harbor Lake Drive
Safety Harbor, FL 34695
813/447-2575
Fax: 813/726-8888

Conservonics
30555 Southfield Road #420
Southfield, MI 48076
801/540-3634
Fax: 810/716-7508

Descal-A-Matic Corp
4855-T Brookside Ct. Suite A
Norfolk, VA 23502
757-858-5593
Fax: 757/853-3321

Electrostatic Technologies Inc.
2223 Guinotte Avenue
Kansas City, MO 64120
816/842-0616
Fax: 816/842-9756

Enecon Corp.
125 Bayliss Road Suite 190
Mellville, NY 11747-3800
800/854-1374

Enertec Inc.
Department TR
306 Railroad Street
P.O. Box 85
Union City, MI 49094
517/741-5015
Fax: 517/741-3474

Hydrodynamics Corp.
1615 W. Abram Street #110
Arlington, TX 76013
817/277-6700
Fax: 817/277-2197

Magnatech Corp.
Superior Manufacturing Division
2015 S. Calhoun Street
P.O. Box 13543
Fort Wayne, IN 46868
800/692-1123
219/456-3596
Fax: 219/456-3598

Progressive Equipment Corp.
419 East 9th Street
Erie, PA 16503
814/452-4363
800/728-6395
Fax: 814/459-3094

Quantum Magnetic Systems Inc.
5224 Blanche Ave.
Cleveland, OH 44127
216/441-9670
Fax: 216/441-9677

Zeta Hydrometals Corporation
4565 S. Palo Verde Road, Suite 213
Tucson, AZ 85714
520/747-4550
888/785-9660
Fax: 520/747-4454

Who is Using the Technology

Federal Sites

Included here are but a few of the installations provided by the manufacturers. For a full listing the reader is advised to contact a manufacturer directly. Some manufacturers expressed concern about printing customer names in a public list such as this Federal Technology Alert but indicated they could provide such customer references to interested potential buyers. Most manufacturers specify having hundreds to almost 10,000 installations. Not all of these sites were contacted during the course of preparing this FTA.

- GSA, Suitland, MD
- National Aeronautics and Space Administration, multiple locations United States Coast Guard, multiple locations
- United States Air Force, Luke AFB, Phoenix, AZ
- United States Army Corps of Engineers, Sacramento District, Sacramento, CA
- United States Environmental Protection Agency, Andrew W. Breidenbach Environmental Research Center, Cincinnati, OH (Rich Koch and Bob Banner, Cleveland Telecommunications Corporation)
- United States Postal Service, multiple locations

Non-Federal Sites

- Arnold Printing, Cincinnati, OH (Hank Majeushi, 513/533-9600)
- Bethlehem Steel, multiple locations Chrysler, multiple locations
- Ford Motor Company, multiple locations
- General Electric, multiple facilities
- General Motors, multiple facilities
- Getty Center, Los Angeles, CA
- Inland Steel, 200 locations
- House of the Future, Ahwatukee, AZ (Arnold Roy, The Frank Lloyd Wright Foundation, 602/948-6400)
- John Deere, multiple locations
- John Hancock Center, Chicago, IL
- LTV Steel, multiple locations
- Protective Coatings Inc. (Bob Bernadin and Ron Byers, 219/456-3596)
- National Steel, over 100 installations
- USX, multiple locations
- United States Playing Card Company, Cincinnati, OH (Tom Berens, 513/396-5700)

For Further Information

Associations

No trade associations exist that are specific to the non-chemical water treatment technology manufacturers. The following associations are general water quality associations.

American Water Works Association
6666 West Quincy Ave
Denver, CO 80235
303/794-7711

Cooling Tower Institute
P.O. Box 73383
Houston, TX 77273
713/583-4087

Water Quality Association
4151 Naperville Road
Lisle, IL 60532
708/505-0160

Consultants

Robert A. Marth
340 Central Avenue
Sunnyvale, CA 94086
408/746-0964
Fax: 408-737-0291

T. Craig Molden
Water Service Technology/NWI
P.O. Box 545 Michigan City, IN 46361
219/879-8425
Fax: 219/879-8852

User and Third Party Field Test Reports

The following references represent only a small sample of the published work on these technologies. The references here are intended to give the reader an indication of the history of scientific research on the topic as well as the sponsoring agencies and interested audiences.

Alleman, J. 1985. *Quantitative Assessment of the Effectiveness of Permanent Magnet Water Conditioning Devices*. Purdue University. Sponsored by and protocol by Water Quality Association.

American Petroleum Institute. 1985. *Evaluation of the Principles of Magnetic Water Treatment,* Publication 960.

Baker, J.S., and S.J. Judd. 1996. "Magnetic Amelioration of Scale Formation." *Water Research*, 30(2):247-260.

Benson, R.F., B.B. Martin, and D.F. Martin. 1994. "Management of Scale Deposits by Diamagnetism. A Working Hypothesis." *Journal Environmental Science and Health,* A29(8):1553-1564.

Busch, K. W., M. A. Busch, D. H. Parker, R. E. Darling, and J. L. McAtee, Jr. 1986. "Studies of a Water Treatment Device That Uses Magnetic Fields," In *Proceedings Corrosion*/85, Boston MA.

Dirks, J.A., and L.E. Wrench. 1993. "Facility Energy Decision Screening (FEDS) Software System." PNL-SA-22780. In *Proceedings of the Energy and Environmental Congress*. Minneapolis, Minnesota, August 4-5, 1993.

Fryer, L. 1995. "Magnetic Water Treatment A Coming Attraction?" *E-Source*, TU-95-7

Gruber and Carda. 1981. *Performance Analysis of Permanent Magnet Type Water Treatment Devices*. South Dakota School of Mines and Technology. Sponsored by and protocol by Water Quality Association.

Hibben, S.G. 1973. *Magnetic Treatment of Water*. Advanced Research Projects Agency of the Department of Defense.

Marth, R.A. 1997. *A Scientific Definition of the Magnetic Treatment of Water: Its Subsequent Use in Preventing Scale Formation and Removing Scale*. Research Conducted for Descal-A-Matic Corporation.

Parsons, S.A., Bao-Lung Wang, S.J. Judd, and T. Stephenson. 1997. "Magnetic Treatment of Calcium Carbonate Scale -- Effect of pH Control." *Water Research*, 31(2): 339-342.

Quinn, C.J., T.C. Molden, and C.W. Sanderson. 1996. "Nonchemical Approach to Hard Water Scale, Corrosion and White Rust Control." In *Proceedings Iron and Steel Engineer,* Chicago IL, September 30, 1996.

Reimers, R.S., P. S. DeKernion, and D. B. Leftwich. 1979. "Sonics and Electrostatics - An Innovative Approach to Water and Waste Treatment." In *Proceedings Water Reuse Symposium*, Volume 2. American Water Works Research Association Research Evaluation, Denver, CO.

Rubin, A.J. 1973. *To Determine if Magnetic Water Treatment is Effective in Preventing Scale*. The Ohio State University, Columbus, OH.

Schmutzer, M. A., and G. W. Hull. 1969. *Examination to Determine the Physical or Chemical Differences Between Untreated and Magnetically Treated Water*. United States Testing Center, Inc. Hoboken, NJ.

Simpson. L. G. 1980. "Control Scale and Save Energy." The *Coast Guard Engineer's Digest,* Volume 20, Number 205, pp. 32-35.

Design and Installation Guides

Many of the manufacturers have guides for internal use or use by their recommended installer or sales agent. Contained in these guides are listings of customers, design and installation notes, warranty information, and answers to many user questions. Most or all of this information may not be available to customers. However, the manufactures do make available sales brochures and summaries of specific applications or case studies. Also included with the units will be owner's manuals and other end user installation and maintenance documentation.

Appendixes

Appendix A: Federal Life-Cycle Costing Procedures and the BLCC Software

Appendix B: Life-Cycle Cost Analysis Summary

Contacts

General Contacts

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Federal Energy Management Program
U.S. Department of Energy
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Columbus, Ohio 43201

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Disclaimer

- Antiscale Magnetic Treatment - Report on magnetic water conditioning by the School of Water Sciences at Cranfield University (UK). States that the controversial technology has been effective in removing scale in industrial process water systems, but the mechanism of action is not understood.