Magnetic treatment of water is an effective method for preventing or drastically reducing the formation of scale or corrosion without the use of chemicals. The theory is discussed together with case studies.

Magnetic treatment of water prevents mineral build-up

C. Jack Quinn, Professor Emeritus, Purdue University, Fort Wayne, Ind., **T. Craig Molden**, President, Molden Associates, Inc., Michigan City, Ind., and **Charles H. Sanderson**, Project Engineer—Superior Manufacturing Div., Magnatech Corp., Fort Wayne, Ind.

WITH today's growing demand on natural resources, water treatment has become one of the major problems in industrial applications, power production and water supply. With this increased demand, coupled with today's escalating costs of energy, industry cannot afford to waste energy. An effective water treatment program can provide substantial savings in both production time and costs.

When any heat-transfer surface becomes scaled, this insulating scale reduces the efficiency of the equipment, increases fuel requirements and maintenance. Thus, there is an ever increasing demand for effectively treating water, not only economically, but to insure the minimum environmental pollution attainable.

Water used in industry comes from rivers, lakes, wells and oceans; it always contains dissolved and suspended solids. These solids contribute to water hardness which is classified as temporary and permanent. Temporary hardness is due to dissolved bicarbonates in the water, mainly calcium and magnesium, that can easily be removed by heating to break them down into carbonates which are insoluble and precipitate out. Permanent hardness, which is due to the presence of soluble sulfates and chlorides of calcium and magnesium, cannot be made insoluble by heating.

Suspended particles (which may be separated by physical means such as centrifuging, settling or hydrocycloning), can also cause problems. Suspended solids present in water such as sand, clay, silt and corrosion products are incorporated into scale together with microbiological pollutants and corrosion impurities.

The deposition of scale makes it necessary to shut down water-using equipment at intervals so that the build-up can be removed. Sometimes, this shutdown will be part of a planned maintenance program. Other times, however, the system may become severely or even completely blocked with scale, making it necessary to remove the equipment from service until the blockage is removed.

Scale deposits can also increase corrosion, due to entrapped oxygen, and because the scale itself is sometimes corrosive to the surface with which it is in contact. Also, scale will interfere with the action of inhibitors in the system, keeping them from reacting with the surface below the scale. If the scale is patchy, the differential aeration between the clean surface and the scale surface may cause a corrosion cell to set up.

Different nonchemical methods of water treatment have been introduced to prevent scale formation. Examples of these technologies are those that are based on permanent magnetic, electromagnetic, electric, electrostatic, ultrasonic, radiation, etc. The permanent magnetic conditioning method and its application is the subject of this article.

Theory of magnetic water treatment

The effectiveness of magnetic water treatment in preventing or retarding scale build-up is strongly affected by the chemical properties of the water, strength and configuration of the magnetic field, thermodynamic properties of the water and fluid flow characteristics.

Structure of water and contained minerals — A molecule of water consists of one atom of oxygen and two atoms of hydrogen, H_2O, that are joined by a chemical bond identified as sharing electrons (Fig. 1). This is a tight bond and, because of the two hydrogen atoms sharing electrons on one end of the molecule, the molecule possesses a positive charge on one end and a negative charge on the other, causing it to act like a small bar magnet. This is referred to as the dipole moment of a molecule.

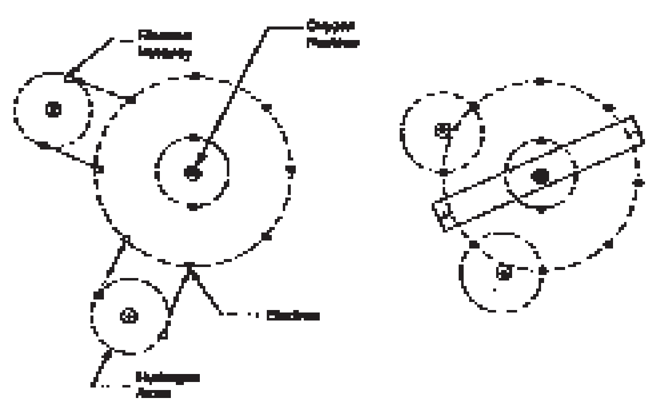


Fig. 1 — Water molecule shown as a polar molecule or a molecule with a dipole moment.

The dipole moment is a vector quantity and is responsible for one of the most important properties of water—its solubility.

Water has been called the universal solvent because it can dissolve, to some extent, almost any inorganic and many organic substances with which it comes in contact. The positive portion of the water molecule attracts negative particles or the negative ends of other polar particles while the negative portion attracts positive particles or the positive end of other polar particles. This effect is illustrated in Fig. 2. As a substance dissolves in water, its particles break away from one another and cling instead to individual molecules.

Fig. 2 — Water molecule with other polar molecule and with neutral particle.

Magnetic field — A magnetic field can be produced by aligning the positives and negatives to opposite ends of any magnetic material. The material used and the type of equipment utilized will determine the strength of the magnetic field and the permanency of the magnet when the magnetic metal has been fully saturated.

Although it was once considered that all magnets could contain only a north and a south pole, this was proven to be erroneous when multipole, multifield single-bar magnets were developed. After considerable controversy, a U.S. patent was granted and issued covering the use of the multifield magnet. It has since been documented that the alternating reversing polarity of a single-bar magnet increases the flux density and utilizes the magnetic lines more effectively than a two-pole magnet. This effect is illustrated by the following example.

The length:diameter ratio, L:D, of most magnetic material is 3.5:1. Therefore, a 3/4 x 8-in. single-bar magnet is most effective when it contains six poles producing three separate high flux density fields.

To produce three fields, based on the former theory, three 3/4 x 2 2/3-in. bar magnets would be required. The disadvantage to this configuration is illustrated in Fig. 3.

Effect of magnetic field — The molecules of a substance may be classified as either polar or nonpolar. A nonpolar molecule is one in which the center of gravity of the positive nuclei and the electrons coincide, while a polar molecule is one in which they do not. Symmetrical molecules, such as H_2, N_2 and O_2, are nonpolar while molecules such as H_2O and N_2O are polar.

Under the influence of a magnetic field, the charges of a nonpolar molecule become displaced (Fig. 4). These molecules become polarized by the magnetic field and are called induced dipoles. When a nonpolar molecule becomes polarized, restoring forces come into play on the displaced charges, pulling them together much as if they were connected by a spring. Under the influence of a given magnetic field, the charges separate until the restoring force is equal and opposite to the force exerted on the charges by the field. These restoring forces vary in magnitude from one kind of molecule to another with proportionate differences in the displacement produced by a given field.

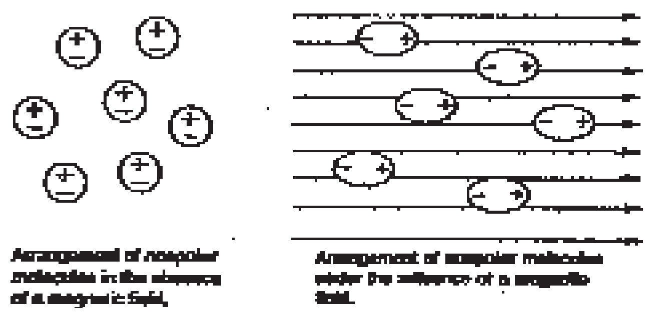


Fig. 4 — Arrangement of nonpolar molecules in absence of and under the influence of a magnetic field.

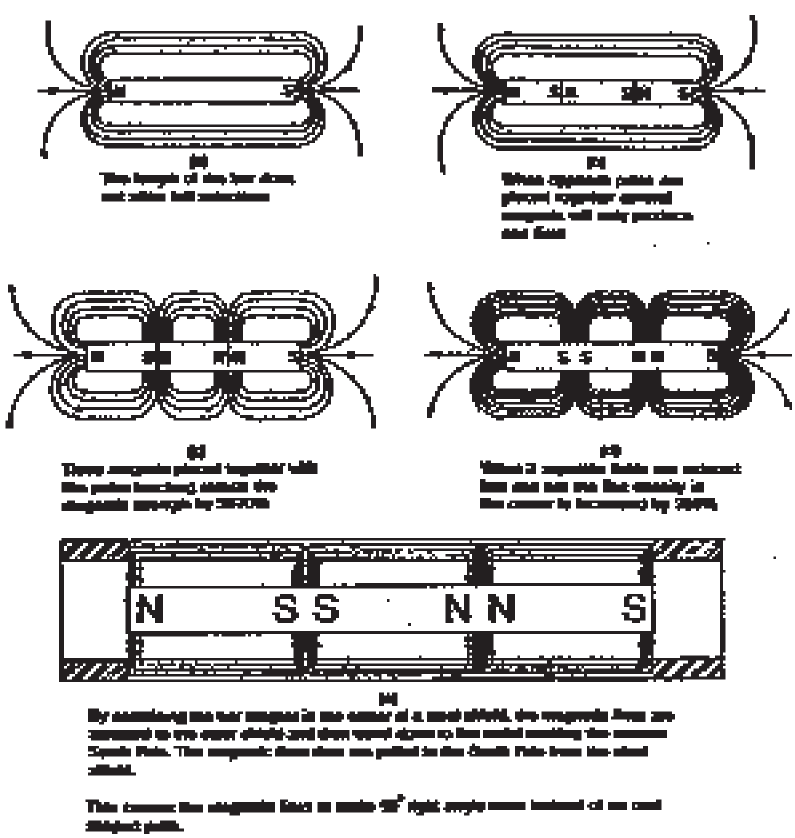


Fig. 3 — Effect of single and multipole magnets on flux density.

Polar molecules oriented at random when no magnetic field is provided are illustrated in Fig. 5 which also shows some degree of orientation when these polar molecules are under the influence of a magnetic field. The stronger the magnetic field, the greater the number of dipoles pointing in the direction of the field.

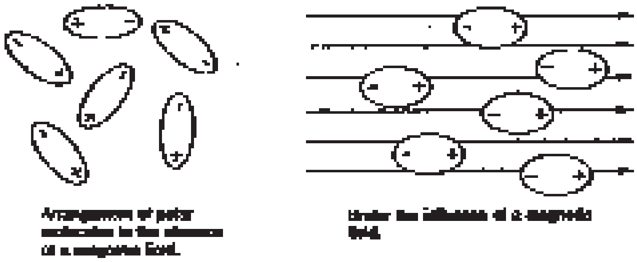


Fig. 5 — Arrangement of polar molecules in the absence of and under influence of a magnetic field.

When water is passed through a magnetic field, several conditions are important in achieving the desired effects:

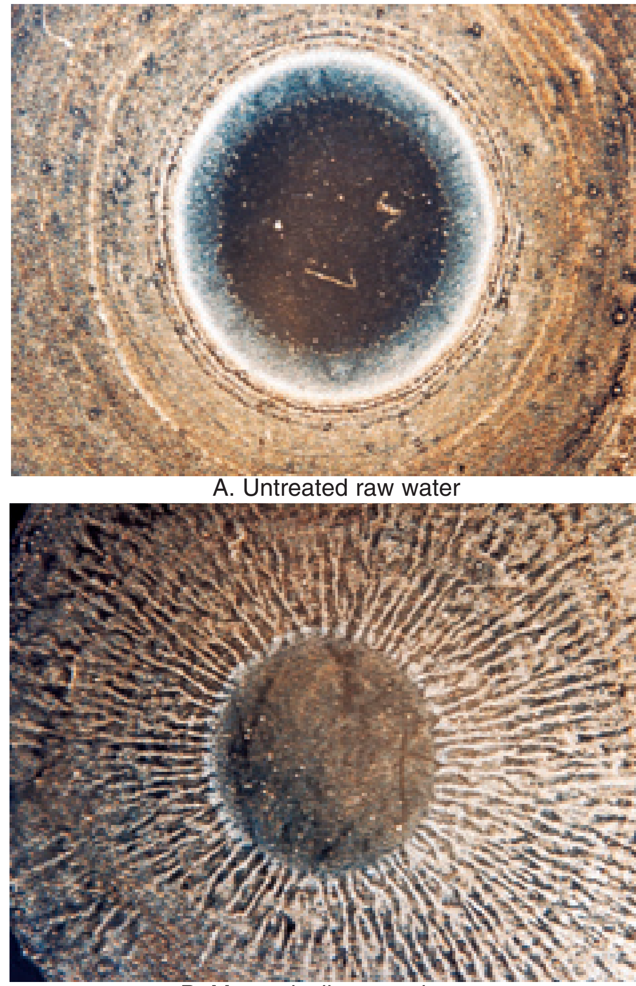
- The water path must be perpendicular to the magnetic lines of force. Cutting the lines at 90° is known as the shear force.
- Water should first cut the south magnetic lines and then proceed to break wider and more dense alternating reversing polarity lines, until exiting the magnetic chamber through the single north pole flux path.
- The capacity of a magnetic conditioner can be determined by the gauss strength, flux density, area surface of the exposure of the number of fields and the distance between alternating poles.
- Water must be under pressure and moving with the least amount of turbulence possible, just before entering and during its travel through the magnetic fields.

Magnetohydrodynamics — Magnetohydrodynamics (MHD) is a branch of mechanics that deals with the motion of an electrically conducting fluid in the presence of a magnetic field. Therefore, the magnetic unit may be considered as a MHD device which is the key for the explanation of its performance under various conditions and applications.

The motion of conducting material across the magnetic lines of force creates potential differences which, in general, cause electric current to flow. The magnetic field associated with these currents modifies the applied (imposed) magnetic field which creates them. In other words, the fluid flow alters the electromagnetic state of the system.

When a conducting fluid passes down an insulating pipe across which a steady magnetic field is applied, a potential gradient (proportional to the flow rate) is created and can be measured by probes embedded in the walls of the pipe.

Magnetochemistry — Disassociated dissolved molecules of $CaCO_3$ in water have a tendency to recombine by forming scale which adheres to the inner walls of the piping system, containers, steam vessels, etc (Fig. 6a). When the water flows through a magnetic field of relatively low intensity, the formation of scale in the treated water is prevented in many instances. Instead, aragonite is formed within the flowing bulk water (aragonite forms dilute slurry in the water, the sediment of which can be easily removed by blow-down or bleed-off). In other words, the magnetic field causes preferentially the recombination of the disassociated $CaCO_3$ molecule into aragonite form (Fig. 6b). It, apparently, takes place by as little energy as needed for spin flopping in the electronic or nuclear energy levels, a process of very low energy of activation.



A. Untreated raw water

B. Magnetically treated water

Fig. 6 — Partially evaporated water (x40 magnification): a. Untreated raw water; and b. Magnetically treated water.

The magnetochemical reaction, is only one of the many cross effect reactions that enable the transformation of calcite to aragonite. Other reactions include: the thermochemical and mechanochemical reaction.

Independent studies — There have been a number of independent studies that illustrate the effect of the magnetic treatment of water on minimizing or eliminating scale formation. Examples of these studies follow:

- The National Aeronautics and Space Administration (NASA) tested magnetically treated water, for corrosion rates of steel corrosion coupons.[1] Corrosion rates of 1 to 50 mils/year were obtained using chemical inhibitors, (4 mils/year considered acceptable), with corrosion rates of 0.0 mils/year obtained for the magnetically treated water. (The authors considered that, although this was documented in the NASA laboratory, we feel it is impossible to never experience some deterioration due to corrosion. Field installations have, however, proven to be very successful in reducing the corrosion rate normally experienced while using chemcials.)

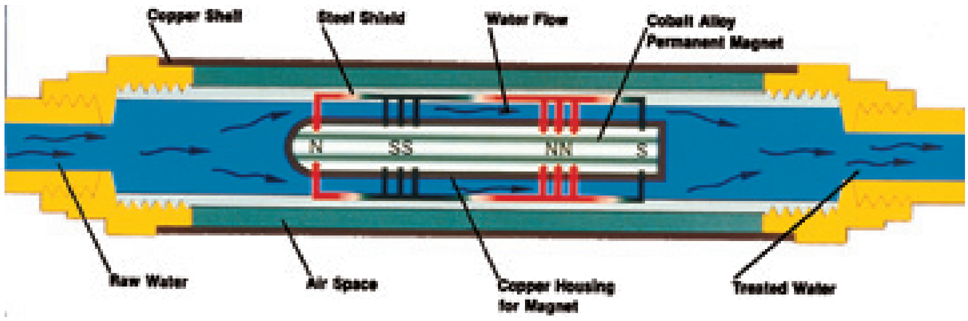


Fig. 7 — Magnetic water treatment unit.

- In the Soviet Union the magnetic treatment of water is used extensively with considerable economic benefits.[2] Marked reductions in scale formation in steam boilers were verified in practice and confirmed in laboratories.
- Rubin reports that the net effects of magnetically treated water is the formation of precipitate in the influent flowing stream which prevented the deposition of scale.[3] The scope of the work performed did not permit a complete investigation of the scale prevention mechanism, but the results supported a crystal growth inhibition mechanism.
- Reimers reported, at a Water Reuse Symposium, that during the past 10 years, researchers have found that magnetic and electrostatic fields have been beneficial in reducing the formation of boiler scale.[4]
- It is concluded, in another Russian study,[5] that the application of an electrode will induce an electromagnetic field which can inhibit crystalline growth and reduce scale adherence to the sides of metallic or other charged surfaces.

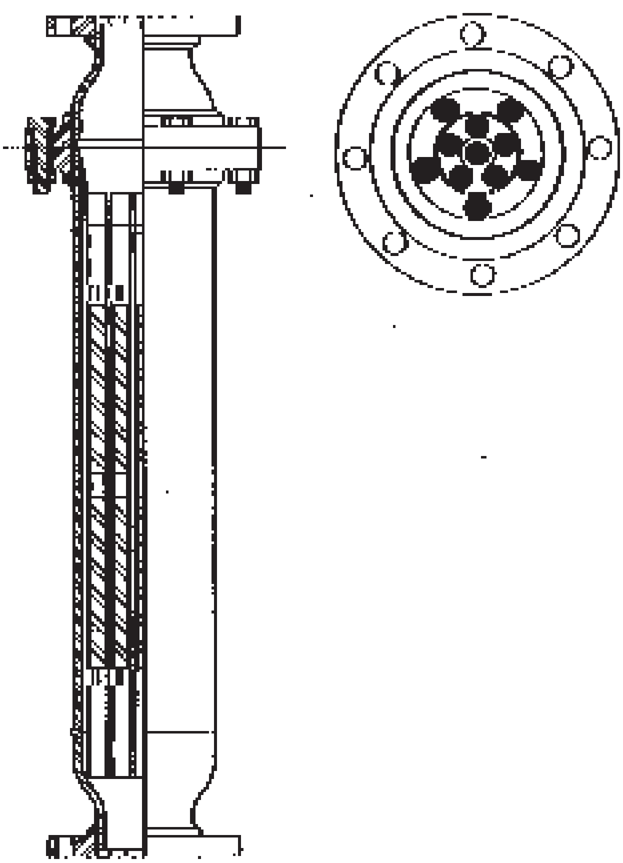


Fig. 8 — Magnetic water treatment unit, 250 gpm.

These studies are in agreement with the results reported in this article.

Magnetic water treatment unit

The construction of a magnetic water treatment unit is illustrated in Fig. 7. In-line magnets are installed inside a section of pipe. Water flows through the pipe around the various magnets. The inside diameter of the pipe containing the magnets is sized to minimize the pressure drop in the system. the unit shown in Fig. 7 has multiple reversing polarities to create a considerable stronger magnetic flux than can be achieved with a standard 2-pole magnet. A cutaway drawing of a 250-gpm unit is shown in Fig. 8.

A refurbished water treatment system (450 gpm) that has been in service for over 10 years, is shown in Fig. 9. A separator (right) removes the suspended solids prior to the magnetic water conditioner to control lime scale and corrosion deposition for a rinse application on a continuous anneal line. The process water used for this application comes from the quench process on the line, with make-up water coming from a recirculated water treatment system in the plant.

A simplified schematic of an installation for the control of lime scale deposition on wringer rolls, and control of

Fig. 9 — Magnetic water conditioning installation.

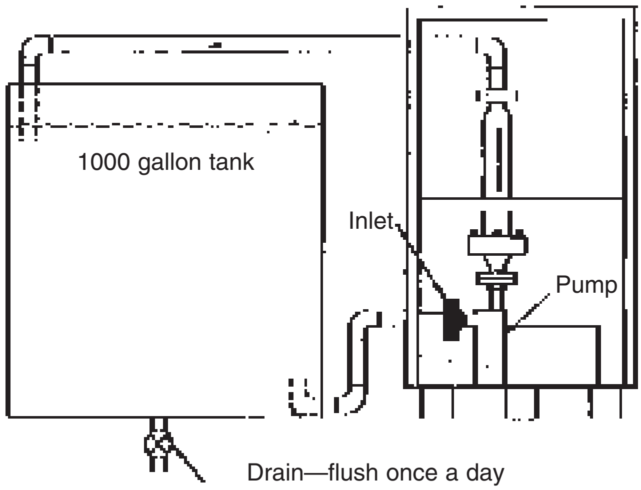


Fig. 10 — Magnetic water conditioning installation.

white rust occurring on strip in a quench tank of a 72-in. hot dip galvanizing line, is shown in Fig. 10.

Applications

Magnetic water conditioning provides the following functions:

- Prevents scale deposition.
- Descaling, recognizing that the descaling process is slow and may take several months to complete.
- Corrosion control.
- White rust control.

Magnetic water conditioners have been employed in over 300,000 applications. Over 700 systems are installed in five major steel plants. Their operation is characterized by:

- Minimum maintenance.
- Slight pressure drop.
- Absence of chemical additions and, therefore, no adverse environmental effects.
- Indefinite service life.
- Easily integrated into existing installations.

The major justifications for installing magnetic water conditioners are energy, product quality, maintenance reduction and increased productivity together with a reduction in downtime. Downtime is especially critical when a continuous annealing, electrolytic cleaning, or galvanizing lines are shutdown due to hard water scale accumulation.

This nonchemical method to control lime scale is not only used to increase quality in the product and reduce production costs, but also as a means to reduce pollution and enhance the image of the industry.

Magnetic water conditioning technology has been employed for over 30 years in the steel industry. It allows closed recirculating systems to convert to once-through cooling systems. High maintenance costs, increased energy consumption and the cost of chemicals that are normally associated with closed recirculating loops can, therefore, be considerably reduced or eliminated when a changeover is made.

Since the nonchemical approach is pollution free, the discharge water can be returned to the source, such as rivers, lakes, or deep wells and meet all regulatory requirements, provided the difference in temperature is within the guidelines of the authorities. A holding pond could be used to adjust the temperature before discharge, if the temperature was a concern.

Cooling tower — Magnetic conditioning of cooling tower water has been particularly successful. It has made the introduction of bleed water (formerly required to control the concentration of dissolved solids) unnecessary, which is then applied as process water for another application.

Sheet finishing line — One of the most important processes in a sheet finishing line is the final rinse section, which is usually supplied with mill service water. In most cases, the original source of the mill service water is a river, lake or sometimes a well. For many years, this particular operation at one plant had been plagued with the plugging of rinse header nozzles with lime scale which adversely affected product quality. The use of chemicals to control the lime scale problem associated in the rinse water process can add to the problem.

The rinse section of a sheet finishing line is an excellent application for the magnetic nonchemical water conditioner, and several mills throughout the world have utilized this process for several years. An additional benefit is that the rinsing and drying of the strip is better and faster because a properly designed unit can reduce the surface tension of the rinse water.

Continuous annealing line — Jet coolers on process lines is another application for this technology. The annual cost of chemicals to treat jet coolers on a continuous annealing line at one plant was approximately $40,000. The service water is taken from a river and is high in total dissolved solids. Even with the use of chemicals, the line experienced thermal problems, especially on heavy gage products, due to scale deposition in the coolers which reduced their cooling capabilities. A situation was reached where the line would have had to be slowed down to achieve proper cooling of the product, which reduced productivity. Motor bearing failures were also experienced on the line which used the same water for bearing cooling.

A nonchemical water conditioner was installed in the jet cooler and motor bearing water supply line in the latter part of 1994. The treatment system was designed to condition 350 to 1150 gpm needed for cooling both light and heavy gage products. The use of chemicals was discontinued to evaluate the system. No thermal problems were experienced on the line during a heavy load period associated with hot summer conditions and there were no motor bearing failures.

Electrical motor room — At another steel plant, a 60-in. hot strip mill was plagued with lengthy electrical delays because of inadequate motor room cooling during the summer months when ambient air and water temperatures were high. Every summer, expensive counter measures had to be used to cool the motor room equipment. The capacity of the heat exchangers and other cooling systems was adequate, but a lime scale build-up occurred that would plug the cooling systems. The mill service water was also taken from a river. A heat exchanger before the installation of the magnetic water conditioner is shown in Fig. 11.

During 1994 and 1995, a total of eight nonchemical magnetic water conditioning units were installed in the motor room. One unit was installed to condition water to the transformer, rectifier and motor generator bearings; and six units were installed on the different motor room cooler heat exchanger systems. Total water capacity of these seven units was 2615 gpm.

Six months after the installation, during one of the hottest summers on record: no mill delays were attributed to motor room cooling. As a result of this performance, the eighth conditioner, rated at 30 gpm, was installed on the mill computer room air conditioning unit, and the supply water to the air conditioner was changed from potable to service water.

After approximately one year of service, the inspection plates were removed from some of the motor room coolers

Fig. 11 — Heat exchanger before installation of magnetic water conditioner.

Fig. 12 — Heat exchanger after one year of service.

and inspected. The tubes were free of hard calcite deposits but there was a build-up of soft mud which was easily removed by flushing the tubes with a water hose. A heat exchanger, after one year of service, is shown in Fig. 12; a heat exchanger washed by a water hose is shown in Fig. 13.

A laboratory analysis was performed on the mud found in the heat exchangers. It showed a low calcium content of 2.9% with the balance of the sample consisting of silica particles and river mud. It was determined that the silica particles had settled in the bottom tubes because of low water velocity in the coolers.

A large manual blow-down valve will be installed at a low point on the exchangers to remove the mud periodically by a manual blow-down.

Fig. 13 — Heat exchanger washed with water hose after one year of service.

Summary

Increased demand for water and especially for water reuse combined with tighter restrictions on environmental pollution has dictated the need for improvement in water treatment. The effective treatment of a water supply to prevent or minimize the formation of scale or corrosion, for example, is complex and any process requiring little or no chemical additions represents an attractive alternative.

Untreated water results in equipment failures, process interruptions and circulating water systems clogged by minerals. These problems are, in many instances, related to scale deposition and corrosion caused by dissolved and suspended solids in the water supply.

Magnetic treatment of water is an effective method of overcoming these problems. The theory, application and case studies involving the use of magnetic treatment are discussed.

REFERENCES

1. Kuivinen, David E., "Comparing Corrosion Rates of Steel Corrosion Coupons in Magnetically Treated Water and in a Water System Utilizing Corrosion Inhibitors," National Aeronautics and Space Administration, Lewis Research Center, Cleveland, 1975.
2. Klassen, V. E., "Magnetic Water: Between Scylla and Carybdis," Institute of Mineral Fuels of the USSR Academy of Sciences, Moscow, 1969, 25-27.
3. Rubin, A. J., "To Determine if Magnetic Water Treatment is Effective in Preventing Scale," Ohio State University, 1973.
4. Reimers, R. S., DeKernion, P. S., and Leftwich, D. B., "Sonics and Electrostatics: An Innovative Approach to Water and Waste Treatment," *Proceedings of Water Reuse Symposium*, Vol. 2, AWWA Research Evaluation, Denver, Colorado, March, 1979, pp 1390-1416.
5. Skorobogator, V. I., "Mechanism of the Action of Ultrasound, Magnetic and Electric Fields on a Scale Liquid," IZV. Vyssh Ucheb Zared, Energy, Vol. 13 (5), 1970, pp 58-62. ▲