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# An Innovative Electronic Descaling Technology for Scale Prevention in a Chiller

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## ABSTRACT

*The present study introduces an innovative method called "electronic descaling (ED)," which was developed as a means to prevent precipitation fouling in a heat exchanger. The operating principle of the ED technology is presented using fundamental physics laws. The validity of the ED technology was tested by evaluating the performance of a full-scale chiller over an entire cooling season. The ED technology eliminated scales in the condenser tubes, resulting in the improvement of chiller performance and in energy savings.*

## INTRODUCTION

When hard water is heated in heat transfer equipment, scaling occurs. When scales deposit on a heat exchanger surface, it is traditionally called "fouling." The type of scale differs from industry to industry, depending on the mineral content of the available water. One of the most common forms of scale is calcium carbonate, $CaCO_3$, which is the subject of the present study.

Once scales build up on a heat transfer surface, at least two problems associated with scales occur. The first problem is the degradation in the performance of the heat transfer equipment. Due to the small thermal conductivity of scales, a thin coating of scales on the heat transfer surface will greatly reduce the overall heat transfer performance. The second problem is that a small change in tube diameter decreases the flow rate or increases the pressure drop across the heat transfer equipment.

Various scale-inhibiting chemicals, such as dispersing or chelating agents, are used to prevent scales (Tchobanoglous and Burton 1991). Ion exchange and reverse osmosis are also used to reduce water hardness, alkalinity, and silica level (Tchobanoglous and Burton 1991). However, these methods are expensive at the industrial level and require heavy maintenance for proper operation. Once fouling occurs in a heat exchanger, scales are removed by using acid chemicals, which shorten the life of heat exchanger tubes, thus necessitating premature replacement. When acid cleaning is not desirable, scraping, hydro-blasting, sand blasting, and metal or nylon brushing is used, operations that incur downtime and repair costs.

## APPLICATION OF ED TECHNOLOGY TO CHILLERS

Energy requirements for the operation of a chiller account for a significant amount of total energy requirements in building management. An effective water management program is essential in controlling energy usage. However, even a good water management program does not totally eliminate scaling. Minimum levels of even soft scale accumulation on condenser tubes will greatly reduce the chiller performance and subsequently increase the annual energy expense.

A major cause in the decrease of chiller performance during operation is fouling of condenser tubes. While manufacturers generally indicate chiller efficiency in kW/ton for new clean tubes, these values are not achieved in actual operation because of heat exchanger fouling. This is caused by the deposition of calcium and calcium bicarbonate ions on the condenser tube wall, providing a thin insulating layer, which inhibits heat transfer from the refrigerant to the cooling water.

The origin of the fouling problem lies in the hardness of cooling tower water. Even though soft water is used for makeup water, the cooling tower water quickly becomes hard due to evaporation. When the cycles of concentration in a cooling tower system are maintained at three or four, the electric conductivity of the recirculating water increases to or

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beyond 1,200 µS/cm, making water hard, thus creating precipitation fouling in the condenser tubes. Note that 1 µS/cm is equal to 1 micromho/cm.

Anticipating the fouling problem in the operation of a chiller, most manufacturers apply a fouling factor in a range of 0.00025 - 0.0005 h·°F·ft$_2$/Btu (1 h·°F·ft$^2$/Btu = 0.176 m$^2$·K/W) in the design of the chiller. In an ideal chiller plant with a perfect water treatment and a perfect off-season maintenance program, it may be possible to maintain the manufacturer's design fouling factor during the entire cooling season. However, under a typical water treatment program with normal off-season brush cleaning, the actual fouling factor may be much greater than the fouling factor specified by the manufacturer. Our recent scale removal studies conducted at our laboratory showed that both nylon and brass brushes do not remove scale deposits from condenser tubes at all, once they become hard (Cho 1998). Accordingly, the energy cost for the operation of a chiller may be much greater than what has been designed, if nylon or brass brush punching is used as the normal off-season cleaning. In many plants and institutions, the cost of chiller operation is not separated from the entire electrical bill, so it is not easy to monitor the actual cost of running the chiller.

A method called "electronic descaling (ED)" has been developed at our laboratory. This innovative ED technology will improve chiller performance by preventing new scales in the condenser tubes, translating into substantial energy savings. Furthermore, the ED technology could remove existing scales from condenser tubes, thus correcting the problems caused by condenser fouling. The objective of the present study was to conduct fouling experiments to examine whether or not an electronic descaling technology indeed prevents fouling in a chiller, thus significantly improving the performance of the chiller.

## THE OPERATING PRINCIPLE OF ED TECHNOLOGY

Figure 1 shows a schematic diagram of the operation of an electronic descaling (ED) device. A 14 gauge wire is wrapped 50 times around a feed pipe to a heat exchanger, forming a solenoid. The two ends of the wire are connected to the ED control unit. The ED unit produces a pulsing current to create time-varying magnetic fields inside the pipe. Subsequently, the time-varying magnetic field creates an induced electric field inside the pipe, a phenomenon that can be described by Faraday's law (Serway 1990):

$$\int E \cdot ds = -\frac{d}{dt}\int B \cdot dA \qquad (1)$$

where $E$ is an induced electric field intensity vector (V/m), $s$ is a line vector along the circumferential direction (m), $B$ is a magnetic field strength vector (T or N/A m), and $A$ is the cross-sectional area (m$^2$). In order to maximize the induction, a pulsing current having a square-wave signal is used. The current and frequency of the square-wave signal used in the present study were 5.0 amp and 500 Hz, respectively. More detailed descriptions on the operating principle and applications of the electronic descaling device can be found elsewhere (Fan and Cho 1997; Cho et al. 1997a, 1997b; Cho et al. 1998a, 1998b; Cho and Choi 1998).

The induced electric field, which oscillates with time, provides molecular agitation to charged mineral ions such that dissolved mineral ions such as calcium and bicarbonate collide and precipitate with the help of impurities in water (e.g., iron oxide particles) (Cowan and Weintritt 1976).

$$Ca^{+2} + 2HCO_3^- \text{ ----> } CaCO_3 + H_2CO_3. \qquad (2)$$

As fluid temperature increases inside a heat exchanger, precipitated $CaCO_3$ particles and heat exchanger surface compete for dissolved mineral ions inside the heat exchanger. Since the combined surface area of the $CaCO_3$ particles can be greater than the surface area of the heat exchanger, the fouling at the heat exchanger surface can be mitigated or prevented.

The concept of introducing fine particles to reduce fouling is not new. Troup and Richardson (1978), who reviewed both chemical and physical methods of water treatment used to prevent fouling in heat exchangers, reported that fouling could be reduced by simply feeding fine $CaCO_3$ particles or forming $Al(OH)_3$ particles in solution using aluminum electrodes across which an alternating current was passed.

Note that the precipitation of $CaCO_3$ particles by the electronic descaling technology occurs in water. Cooling tower water has excess dissolved mineral ions well above the saturation limit of each dissolved ion and, hence, the water becomes unstable (Snoeyink and Jenkins 1982). It is this supersaturated and unstable nature of hard water that causes fouling in a heat exchanger in a time period of months. Of course, fouling also occurs with saturated water when it becomes supersaturated inside a heat exchanger. In this case, the fouling takes place slowly, i.e., over a period of years, and the use of either chemical or physical scale prevention method cannot be justified for economic reasons.

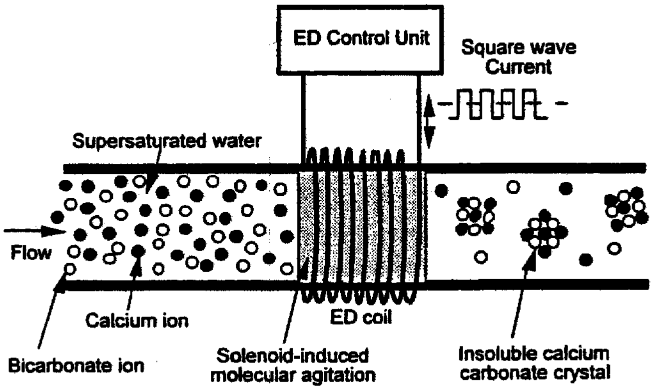

*Figure 1 Sketch of the operating principle of electronic descaling technology.*

## EXPERIMENTAL SETUP

Figure 2 shows a schematic diagram of the chilled water system at a university building. Two 450-ton centrifugal chillers using R-123 were installed in 1996. During the 1997 cooling season, only one chiller was running at any given time, and the chillers were switched every two weeks. The total hours of operation of each chiller in 1997 was 1,500 hours. The efficiency of the chiller is 0.57 kW/ton at full load and 0.52 kW/ton at 50%-80% load (Smit et al. 1996).

Blowdown was carried out using a solenoid valve that was controlled by an electric conductivity meter. The solenoid valve was designed to open when the conductivity meter hit 1,500 µS/cm and to close when the meter read 1,200 µS/cm. Since the electric conductivity of tap water available at the university was 450 µS/cm (approximately 150 ppm hardness), the cycle of concentration at the cooling tower at the building was 3.0 (1,350/450).

Figure 2 also shows the application of an electronic descaling unit, which was installed on a feed pipe into Chiller #2. The ED unit treats water going into the condenser tubes of the chiller at the feed pipe noninvasively.

An automated data acquisition control system was installed in each chiller so that one can download the chiller performance data into a computer every hour. Outside air temperature, chiller motor amp, and supply and return temperatures for both chilled water and condenser water were recorded from chillers #1 and #2 and later transferred to computer files for data reduction.

In order to ensure the accuracy of temperature measurements, all thermistor probes used were calibrated. Each probe was removed from the chiller and immersed in cold water whose temperature ranged from 40°F to 60°F, and the temperature reading was recorded. A calorimeter thermometer was also immersed in the same cold water bath and used as the reference for the thermistor probe calibration. Actual temperature readings were corrected based on the calibration. The error in temperature measurement was ± 0.2°F.

During the entire cooling season of 1997, chillers were operated using a conventional water treatment program. The chillers were turned on May 1, 1997, and the electronic descaling device was turned on July 1, 1997. Hence, the chillers were operated without the electronic descaling device for the first two months but with the conventional water treatment program.

## METHOD TO DETERMINE KW/TON FOR CHILLER EFFICIENCY

The efficiency of a chiller is usually given in terms of kW/ton, which is the electrical consumption required to generate one refrigeration ton. The former is estimated from a motor ampere measured from the chiller using the following equation:

$$\text{kW} = \text{motor amp (A)} \times \text{voltage (V)} \times 1.73 \times \text{power factor} \times 1/1000$$

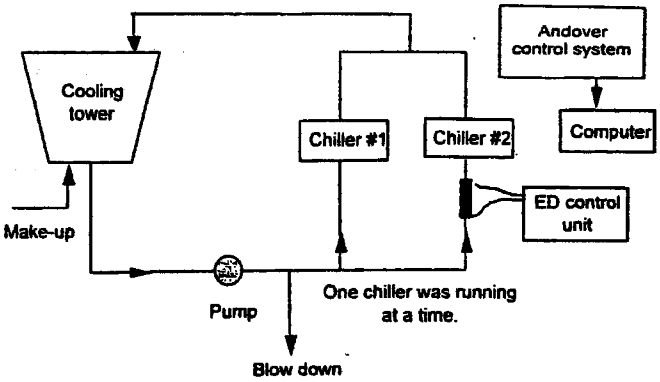

*Figure 2* *Schematic diagram of chiller and cooling tower arrangement. An electronic descaling unit was installed on the feed pipe into the second chiller.*

where motor amp was read directly from the chillers used in the present study, voltage was 480 V for the chillers, 1.73 is the constant applied to three-phase AC, and the power factor was 0.93.

The unit "tons of refrigeration" is often used to represent the cooling capacity of a refrigeration system. In other words, the "ton" means the rate of heat removal from a refrigerated space. The capacity of a refrigeration system that can freeze 1 ton (907.2 kg or 2,000 lb) of liquid water at 0°C (32°F) into ice at 0°C in 24 hours is said to be 1 ton. One ton of refrigeration is equivalent to 211 kJ/min or 12,002 Btu/h (Cengel and Boles 1998).

In normal operation of a chiller, the chilled water split, $\Delta T_{chilled}$, i.e., the temperature difference between chilled water return and chilled water supply, is measured and displayed on a chiller display panel. Hence, if one knows the flow rate of the chilled water, one can estimate the value of "ton" using the following formula:

$$\text{ton} = \text{flow rate (gpm)} \times 60\ \text{min/h} \times 8.33 \times \Delta T_{chilled}\ (^{\circ}\text{F}) \times 1.0\ \text{C(Btu/lb}\cdot{}^{\circ}\text{F)}/12000$$

where 8.33 is to convert gallons to pounds and 12,000 is to convert Btu/h to ton. Once we know the values of kW and ton, one can calculate kW/ton. Note that the chilled water was circulated in the primary loop, thus maintaining a constant flow rate during the entire cooling season, and air handlers were used only in the secondary loop. In other words, the flow rate in the above equation was constant throughout the cooling season.

## RESULTS

Figure 3 shows the efficiency of chiller #2 before and after the electronic descaling treatment in terms of kilowatts per ton at various loads. A dashed line in Figure 3 indicates the design specification, provided for comparison. An upward arrow A indicates the efficiency degradation in chiller #2 prior to the installation of the electronic descaling device. On average, the kW/ton increased from 0.55 to 0.75, a 36% increase

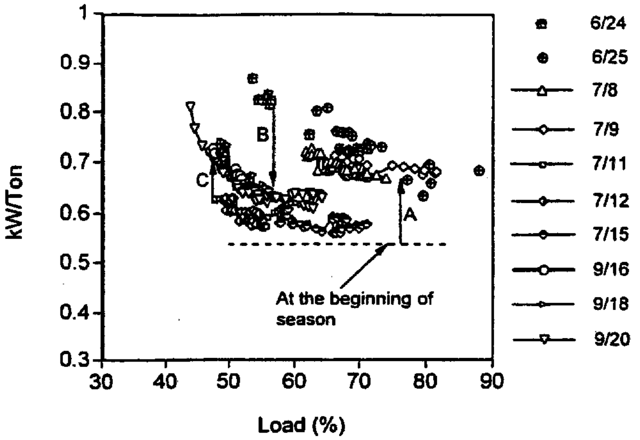

***Figure 3*** *Variation of chiller efficiency (measured in kW/ton) vs. percentage load before and after electronic descaling treatment. ED treatment began on July 1, 1997.*

in energy consumption from the design kW/ton. This efficiency degradation is attributed to mineral fouling in the condenser tubes, which was happening despite a conventional water treatment program.

A downward arrow B indicates the improvement in the efficiency of the chiller after the ED treatment started on July 1, 1997. As soon as the ED treatment started, the value of kW/ton began to drop, reaching 0.58 kW/ton on July 12, 1997. During the next month, the values of kW/ton slightly increased to 0.65 kW/ton, as indicated by an upward arrow C, and stayed at that value for the rest of the season. Since there was no forecast of the level of scaling without the ED treatment during entire season, the decrease in scaling is understated.

Figure 4 shows a typical variation of the efficiency of chiller #2 with time before and after the electronic descaling treatment. The plot was produced using the chiller efficiency data collected in a bin of outside air temperature of 79-81°F. Note that chiller #2 was used every two weeks for two weeks over the entire season. Day 125 represents May 5, 1997,and day 270 represents September 27, 1997. The chiller operated for 50 days (from 125 to 175) without ED treatment. During this period, the value of kW/ton increased from 0.57 kW/ton to 0.82 kW/ton on June 30, 1997, as shown in closed square symbols.

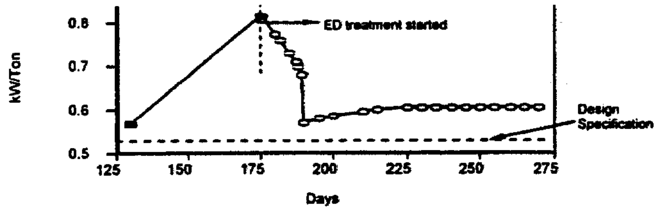

***Figure 4*** *Changes in chiller efficiency (measured in kW/ton) with time before and after electronic descaling treatment. ED treatment began on July 1, 1997 (i.e., 176 days).*

When the ED treatment was installed and turned on (day 176), the performance of the chiller immediately began to dramatically improve, reaching 0.57 kW/ton within two weeks as manifested by open circles. During the next month, the value of kW/ton gradually increased from 0.57 to 0.63 kW/ton and stayed there for the rest of the cooling season. The design specification is also shown in a dashed line for comparison.

Figure 5 shows the condenser split, i.e., the temperature difference between outlet and inlet of the condenser as a function of percent load. The condenser split curve began to shift to the left immediately after the electronic descaling treatment began. For example, at a load of 63%, the condenser split was 5.3°F on June 24, 1997. Within two weeks of the ED treatment, the condenser split at 63% load increased to 6.7°F, indicating that the condenser scales were removed by the ED treatment. During the rest of the cooling season, the condenser splits remained unchanged.

## DISCUSSION

The present study examined the performance of an ED device in controlling the fouling problem in a chiller used in the HVAC industry. The study clearly demonstrated that under a normal industrial condition, chiller efficiency could decrease by 10% - 30% from the design specification due to condenser tube fouling. The electronic descaling device could significantly prevent the performance loss, helping chiller users save substantial energy. In the case being presented, the cost of operation of the chillers would have exceeded $45,000. The actual savings realized using the electronic descaling device was $14,200, a 32% reduction.

One of the questions regarding the data presented in this paper is the mechanism of scale prevention and removal.

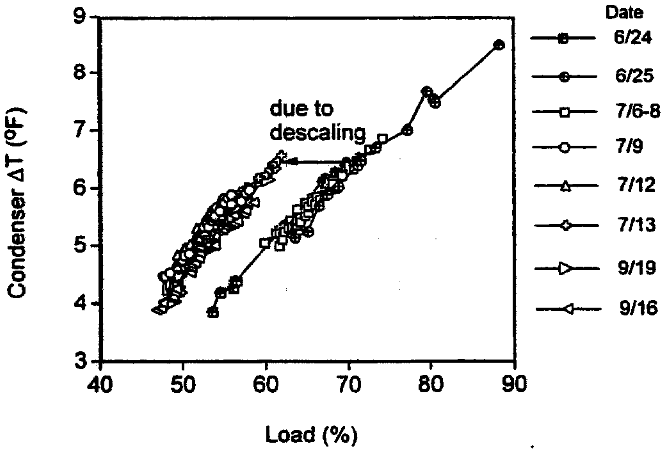

***Figure 5*** *Condenser split (i.e., temperature difference between outlet and inlet of condenser) vs. percent load over entire cooling season with and without ED treatment.*

Since detailed descriptions of the scale prevention mechanism are given earlier, only the mechanism of scale removal will be briefly described below: As demonstrated in Figure 4, the chiller performance dramatically improved once the electronic descaling treatment started, indicating the removal of existing scales. The ED treatment continuously produces insoluble mineral crystals, thus reducing the supersaturation level of recirculating water. As the supersaturation level decreases, the old scale layer from condenser tubes become dislodged in the form of large pieces of several inches, rendering scale-free tubes. Hence, immediately after the ED treatment, the value of kW/ton reaches the peak efficiency. After this brief period, a thin coating of scale is deposited and removed continuously with the help of the electronic descaling treatment. Thus, the value of kW/ton increases slightly from the peak efficiency.

Due to the space limitation, the performance of chiller #1 could not be discussed in detail. Chiller #1 was operated under almost identical conditions in the same recirculating loop but not treated by the electronic descaling device (see a schematic diagram shown in Figure 2). Since the ED treatment was at the feed pipe to chiller #2, chiller #1 did not get the ED treatment. However, the recirculating water was treated for two weeks when chiller #2 was running. Hence, there was some residual effect of the ED treatment in chiller #1, but the benefit was marginal.

## CONCLUSIONS

The present study investigated the performance of an electronic descaling device in controlling fouling in a condenser used in an HVAC chiller. Performance data from two 450-ton chillers were obtained through a data acquisition system over the entire cooling season with and without the electronic descaling unit.

Based on the actual performance data, it is concluded that the ED device helped a chiller to run more efficiently (i.e., about 20% - 30%) even with a normal water treatment program. The ED device not only controlled new scale buildup but removed old scales from the condenser tubes.

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