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Comparision of condenser tubes in a chiller package treated with chemicals (left) and ULF (right).
Photo courtesy of Technova Imaging Systems (P) Ltd.

Managing Water Quality in Chillers

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Hundreds of water-cooled chillers are operating all over India. Even in the current year a majority of the large installations in hotels, hospitals, malls, airports and industry comprise water cooled chillers, inspite of the severe water shortages in all major cities.

Chillers form the heart of an HVAC system. They consume significant amount of energy. It is therefore crucial to maintain them in excellent condition to optimize their performance. The cleanliness of condenser tubes is of paramount importance in water-cooled chillers. The main factors that need control are:

- Scale
- Bio-film
- Corrosion and
- Suspended solids

Scale and bio-film reduce heat transfer efficiency, resulting in loss of energy. Corrosion reduces the life of a pipeline. Corrosion products trapped in bio-film settle in condenser tubes causing reduced heat transfer. Suspended solids such as dust, dirt, and other particles combine with phosphates and other materials to settle in slow moving water in the condenser tubes. They reduce heat transfer and could cause corrosion. We look at each of these issues and how to prevent them.

Is Scale a Problem or Inconvenience?

Quite often one hears a statement "I have no scaling problem." This does not mean there is no scale. In most cases it means the chiller is under an Annual Maintenance Contract and the user does not spend any additional amount for descaling (removing scale using acids and brushing). The condenser tubes may be descaled every few months, depending upon the quality of water. This is similar to one going in for angioplasty every few months, because the costs are covered by insurance. The condenser tube wall thickness is just about 0.8 mm. Every descaling operation reduces the life of these tubes. The chiller is the most expensive investment in an HVAC system. All efforts should be made to make it last as per its designed life span.

A close look at what causes scaling and bio-film will help in taking preventive steps. This will enhance life and performance of the condenser tubes resulting in saving of energy.

Why Does Scale Form?

Let us take a glass of water and add salt to it. We first see the salt as suspended particles. After we stir the water, the salt is dissolved. It is no longer visible. The solid particles of salt dissolved in water are called dissolved solids. Several types of salts such as Calcium and Magnesium are normally dissolved in water. The total of all these is called ***Total***

Dissolved Solids or TDS. The quantity of these salts is measured in ppm or parts per million. Although these dissolved salts are not visible to the naked eye, we can measure them using a TDS or Conductivity Meter.

The Dissolved Solids present in water do not cause any harm to the condenser tubes at room temperature. When the temperature of the water rises inside the tubes, solubility of water reduces. Ions such as Ca and Mg, which are in a dissolved state, combine with other elements and precipitate out as Calcium and Magnesium Carbonates. Some of these precipitates are hard and stick to the condenser tubes. This is called hard scale. There is also hard scale formation inside the pipeline in which the water flows.

Figure 1

How Does Hard Scale Affect The Condenser?

Hard scale affects the condenser:

1. Performance
2. Life

1. Effect of hard scale on performance of condenser tubes

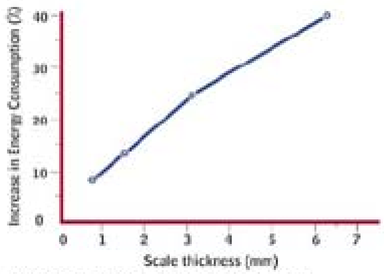
Energy is lost when there is hard scale formation. The loss varies based on thickness and the type of hard scale.

Effect of thickness

Graph 1 indicates the loss of energy with the commonly found Calcium and Magnesium hard scales.

Example of a 400 TR chiller

Let us take the case of a 400 TR water-cooled chiller operating for 12 hours a day, 25 days a month at NPLV of 0.5. It would consume about 7 lac kWh per year. At a power rate of Rs. 5/kWh it would work out to Rs. 35 lacs per year. The % estimated losses worked out as per **Graph 1** for this example are shown in **Table 1**.



Graph 1: Estimated loss of energy.
Source - US Department of Energy

Table 1: Estimated loss of energy for the example.

Thickness of hard scale	Loss of energy per year	
(mm)	%	Rs. Lacs
1.6	13	4.5
3.2	25	8.9

Effect of type of scale

The scale is very hard when the raw water has high Silica. It could cause 3 to 6 times higher energy loss than Calcium scale.

2. Effect on life of condenser tubes

Hard scale is difficult to remove. It is normally removed or descaled using an acid and by mechanical brushing. The condenser tube thickness is about 0.8 mm. When acid and mechanical brushing are used, there is a small erosion in the wall thickness of the tube. It is also extremely difficult to neutralize the acid completely. Quite often traces of acid are left behind unintentionally and this can cause damage to the welds.

Each descaling reduces the life of the condenser tubes. It is estimated that the reduction in life varies from 2- 5% each time it is descaled, depending upon the type of scale and methods used to remove them.

Silica scale

If Silica is present in the water the scale is much harder. It can be removed using very high-pressure water jet or hot acid. The effect of Silica in water is two fold:

- Hard scale forms very rapidly. Sometimes within two weeks.
- Descaling methods mentioned above reduce life drastically.

When such descaling is done frequently, sometimes the condenser tubes have to be replaced within a couple of years.

Although descaling is done without any extra cost to the end user, frequent descaling reduces the life of the condenser tubes and thereby results in re-investment within a few years.

Analysis of raw water in any standard laboratory will help the end user know the Silica content and TDS, apart from several other parameters to be discussed later in this article.

Effect of Recycling Water in Condenser Tubes

The heat absorbed by water in the condenser tubes is taken out in the cooling tower. Some of the water in the cooling tower is lost due to evaporation. When the water evaporates the solids dissolved in the water are left behind. This increases the concentration of the solids in the remaining water. Let us assume 100 mg of solids is dissolved in 1,000 liter of water (this means a TDS of 100 ppm). If 500 liters of this water evaporates, we will now have 100 mg dissolved in 500 liters of water (resulting in a TDS of 200 ppm). The TDS of water would increase from 100 ppm to 200 ppm after evaporation. This process goes on building up the TDS.

The concentration of dissolved solids increases as the number of times the water is recycled. The number of times it is recycled is called *cycle of concentration*. As the concentration of the solids increases (or as the TDS goes up), the chances of hard scale formation increases. Yet water is recycled because of two reasons:

- Shortage of water
- Cost of water

In most cities there is tremendous shortage of water for industrial use. The cost of water over the last few years has shot up dramatically. In Delhi city the cost of municipal water in just one month went up five fold! These constraints force the end user to recycle the water as many times as possible. Quite often the implication of this recycling on the performance and life of the condenser tube is not fully understood.

Recommendations for Water Cooled Chillers

Manufacturers of chillers recommend several parameters for the quality of raw water used in the water-cooled chillers. Some of them (all values in ppm) are shown below:

Table 2 : Recommended parameters

of water for chillers.

Parameter	Recommended limit in:	
	Raw water	Recirculating water
TDS	250	1,200
Total iron Fe	<0.3	<1.0
Total hardness	<80	<100
($CaCO_3$)	<50	<200
Chloride content	<30	<50
Silica (SiO_2)		

The raw water available in most cities does not conform to these limits and end users are constrained to exceed the limits recommended. It is therefore important to address the control of scale and bio-film despite the bad quality of water.

Common Problems in Treating the Cooling Tower Water

The most common method of treating cooling tower water is with chemicals. The emphasis here is on controlling the precipitation of Ca and Mg ions by using chemicals such as phosphates and nitrites. Ca would be kept dissolved in water or sometimes may combine with Phosphate and form Calcium Phosphate. The common problems associated with this technique are:

- Most chemical dosing is manual leading to either an overdose or an underdose.
- Highly corrosive chemicals like Chlorine or Sulphuric acid are often added for disinfection and scale control purpose. They reduce the life of the equipment.
- Phosphates are the most common additives. These are excellent fertilizers and promote growth of algae and bacteria.
- The addition of one set of chemicals to control a particular problem creates side effects. Another set of chemicals is added to counteract these side effects. This is a cyclic phenomenon.
- There are unintended deposits and byproducts due to chemical treatment. These cannot be removed by normal means. One of these is Calcium Phosphate.
- The TDS limit in recycled water in cooling towers recommended by most chemical treatment suppliers is 1,000 to 1,500 ppm. Even at this limit there is often hard scale formation. When this limit reaches 3,000 or 6,000 ppm, the ability to control

hard scale formation is further restricted and this results in faster and thicker scale. It means more energy loss and more frequent descaling.

Figure 2 shows a 7-year-old pipe, with scale three times the thickness of the actual pipe. When these pipes get clogged the flow rate reduces, affecting the basic design parameters of the system.

Figure 2

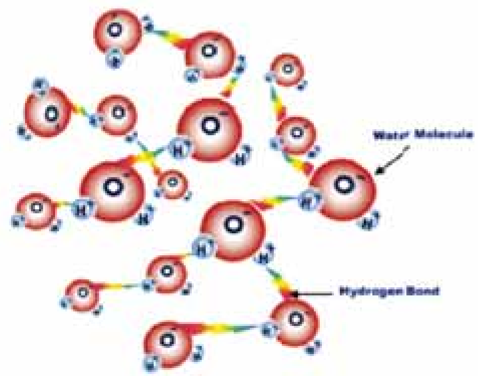


Figure 3

Ultra Low Frequency (ULF) Treatment

Now a technique that helps in controlling hard scale despite bad quality of water is Ultra Low Frequency Wave treatment or the ULF treatment. It has been successfully used for over four years abroad and over a year in India. It is not to be confused with magnetic treatment. In this treatment there is no permanent magnet used, and there is hardly any magnetic field generated. ULF addresses the issue of scale control differently from the traditional chemical treatment. It does not try to remove the Ca and Mg ions. It focuses on controlling the harmful effects of these when the temperatures are high.

Principle of Operation

It is an established fact that energy waves with various amplitudes and frequencies affect molecules differently.

– Gamma and X-rays tend to strike off electrons.

– Ultraviolet rays are used to purify water.

– Microwaves rotate the molecules and generate heat. – At still lower frequencies, **Ultra Low Frequencies**, these waves increase the inter-molecular bond strength.

Calcite Crystals Aragonite Crystals

Figure 4: Crystal structures of Calcite and Aragonite.

When the water intermolecular bond strength increases, the Ca and Mg ions are held tight, and they are less likely to come out and form hard scale. If by chance the Ca ions come out, the crystal structure of the deposit is different. The normal crystal structure is calcite. Calcite is hard and sticks to the surface, causing loss of energy. When water is treated with ULF waves the higher energy level causes Aragonite to form, which is soft and harmless.

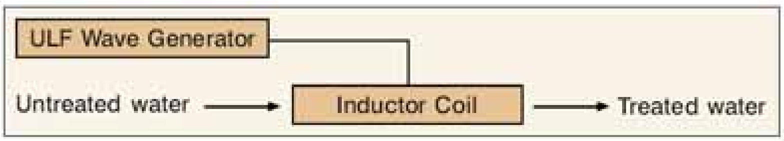


Figure 5: Schematic of a ULF System.

Case Study on Two 220 TR Chillers in India

At Technova Imaging Systems Pvt. Ltd., Taloja (near Mumbai) two chillers of the same international brand and same capacity were used for trial. Each was 220 TR capacity, working continuously 24 hours a day. Although the raw water quality used by them is good (TDS around 100 ppm), the condensers needed descaling every three months. Both chillers were descaled and started on the same day. Cooling tower for one chiller was treated with chemicals and the other with ULF waves. After about three months the chiller whose water was treated with chemicals started giving a problem. Both chillers were opened and photographs, shown on the first page of this article, taken. They found hard scale in the first one and no scale at all in the one treated with ULF waves.

Once again the chiller with scale was descaled and both started. Again after three months the chiller treated with chemicals was opened and descaled. ULF treatment ensured there was no build up of scale in the other chiller. When the valve was opened the water flowing through the condenser was clean.

Success Across the Country

ULF treatment has been implemented in India in different cities with diverse water conditions - Mumbai, Navi Mumbai, Taloja, Pune, Hyderabad, Bangalore, Chennai, Kolkata, New Delhi, Gurgaon, Noida, Vizag and so on. The water TDS ranged from 50 to 1,500 ppm. Water with high Silica too has been successfully treated. The successful applications include commercial buildings, hotels, software parks, hospitals, and process plants.

Old scale breaking up Collected at strainer

Figure 6: Descaling effect of ULF treatment.

Descaling Effect of ULF Treatment

Added benefit of the ULF treatment is descaling of existing scale and chemical deposits in the pipelines. These scales start cracking and slowly break up. They are trapped in the strainers as shown in **Figure 6**. This descaling process is not a replacement for the normal acid descaling. It takes place over a period of time. The ULF treatment also removes the Calcium Phosphates left behind by chemical treatment in the pipelines.

Effect of Bio-film

The effect of bio-film is probably of least concern to most people. Bacteria in cooling tower water produces a bio-film. Bio-film reduces heat transfer. You can see this from the **Table 3**. A lower value of Thermal Conductivity means greater resistance to heat transfer.

Table 3: Thermal Conductivity of different materials

Source: N.E.M Business Solutions (http://www.cip.ukcentre.com/bio.htm)

Substance	Thermal Conductivity (W m-1K-1)
$CaCO_3$	2.60
$CaSO_4$	2.30
$Ca_3(PO_4)$	2.26
Fe_2	2.90
Biofilm	0.60

Bio-films may entrap precipitated calcium salts and corrosion byproducts. These will act as crystal growth sites. An excellent analogy from http://www.cip.ukcentre.com/bio.htm is reproduced below:

A typical bio-film induced mineral deposit that we are all familiar with is the calcium phosphate scale the dental hygienist removes from our teeth. When bio-films grow on tooth surfaces, they are referred to as plaques. If these plaques are not continually removed, they will accumulate calcium salts, mainly calcium phosphate, and form tartar (scale). One could make a comparison between rinsing your mouth twice daily with an antiseptic mouthwash to control plaque, with feeding micro-biocides and bio-dispersants to control bio-film related deposition in heat exchangers. If bio-films in heat exchangers are not controlled, then, like dental plaques, mineral scale may result.

The growth of bacteria and formation of bio-films may also result in another problem, that of corrosion. Microbiological corrosion may be defined as corrosion that is influenced by the growth of microorganisms, either directly or indirectly.

Bio-film reduces the heat transfer several times more than hard scale of the same thickness. It is therefore important to control the bio-film. The traditional method involves treatment with biocides. Biocides are harmful to the environment and are banned in several parts of the world. The bacteria get resistant to biocide and hence often two types are biocides are used alternately. Water treated with biocide cannot be discharged in several cities in India due to norms of pollution control. It means this water has to be once again treated with chemicals before discharge.

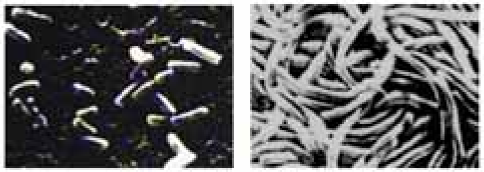
The second component of the ULF treatment has **Copper- Silver ionization**. This is based on the age-old method of treating water in India.

Report from Times of India April 12, 2005

New York Indian wisdom rings true: water from brass vessels fights diseases.

In this article microbiologists say that water stored in brass containers can help combat many water borne diseases. Live bacteria in brass vessels dropped dramatically over time, and after 48 hours they fell to undetectable levels. The key to the result is copper.

The ULF waves weaken the bacteria. This is followed up by Copper-Silver ionization, which prevents the bacteria from multiplying and kills them. **Figure 7** shows this.



Bacteria multiplying

Bacteria getting longer - unable to multiply

Figure 7: Effect of Copper-Silver ionization on bacterial growth

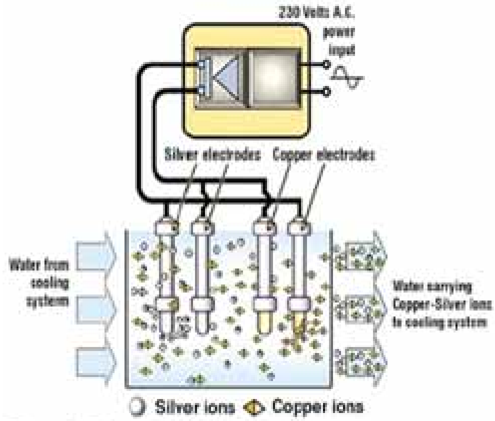


Figure 8 : Process of Cu-Ag ionization.

Principle

In this process a transformer/rectifier brings down the AC 230 V to a low voltage DC current. This current is passed through the electrodes. Once the current leaves the electrode the copper and silver ions are released. They bring down the bacteria level dramatically. In one instance the Total Bacteria Count (TBC) in a cooling tower before ULF treatment was 1,55,00,000 cfu/ml. After the ULF plus Copper- Silver ionization it came down to 300 cfu/ml within about three months. Sometimes the bacteria count may go up initially because of the existing phosphates being removed from the system. The water in the cooling tower becomes clearer and in most cases one can see the bottom of the cooling tower.

With the bacteria count in the cooling water maintained at consistently low levels, slime or biofilm produced by the bacteria becomes almost non-existent. And once the thickness of bio-film is reduced, heat transfer efficiency improves a lot.

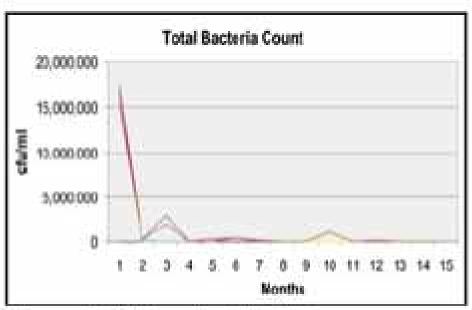


Figure 9: TBC control in Indian installations

Figure 10: Clarity of water

Effect of Copper-Silver ionization.

Corrosion Control

Fe ion content in the cooling tower water is a measure of corrosion state in the system. As per Cooling Technology Institute the maximum control limit is 3 ppm. In the traditional treatment method this parameter is not analyzed. ULF waves promote formation of Magnetite (Fe_3O_4) instead of normal rust (Fe_2O_3). Magnetite does not peel off like normal rust. It is not porous. This helps in controlling the corrosion in the system. In most installations in India the Fe ion is less than 0.1 ppm when treated with ULF waves. **Figure 12** illustrates this.

Magnetite formation in chilled water pipe with ULF treatment is shown in **Figure 12**.

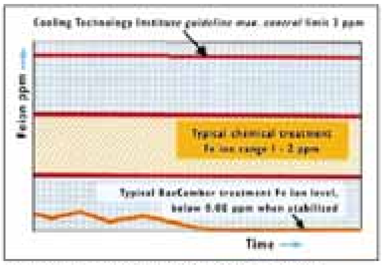


Figure 11 : Recommendations of CTI for Fe ion

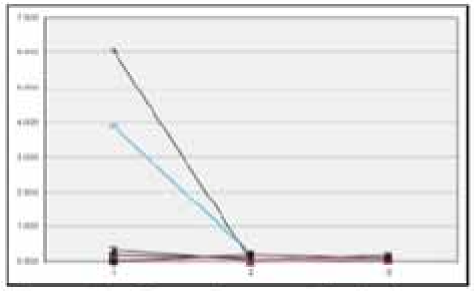


Figure 12 : Corrosion control in Indian installations

> ***Note***
>
> ULF treatment has been successfully applied to control corrosion in chilled water pipeline.
>
> • It has brought down the Fe ion content in a chilled water unit of an aircooled chiller in Mumbai from 160 ppm to 6 ppm within about 3 months. The color of the chilled water changed from coca cola to iced tea within this period.
>
> • It has also been successfully installed in chilled water pipelines exceeding 1.2 km with header size of about 18 inches.

Water Saving

When the TDS of the cooling tower reaches the recommended level, a part of the water is taken out or bled and fresh raw water is added. This brings down the TDS of the recirculating water in the cooling tower.

In most parts of India pollution control norms do not allow the water bled from cooling tower to be put in the drain directly. When cooling tower water is treated with chemicals the water bled has to be treated in an effluent plant before discharging into the municipal system.

Not a drop of chemical is added in the ULF treatment. The water bled need not be re-treated.

This saves the cost of re-treatment. The entire water, which is bled in cooling towers, is reusable when treated with ULF waves. It can be used for washing floors or gardening.

Figure 13: Corrosion protection with Magnetite layer

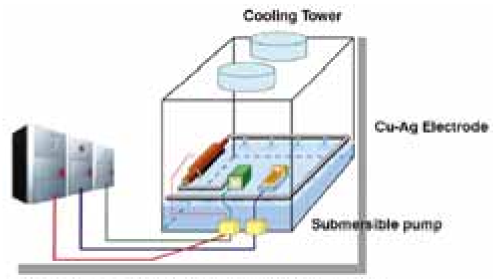


Figure 14: Typical installation in a cooling tower

Typical Installation

The ULF system is installed as per the schematic shown in **Figure 14.** The power consumption of a system for 500 TR cooling tower is about 250 W. The only consumable is the electrode. It is practically maintenance free.

Controlling Suspended Solids

Suspended solids come into the cooling tower water from different sources:

- Atmospheric dust from traffic on road
- Dust storms
- Coal dust from nearby factories
- Small stone particles from nearby quarries or stone cutting factories
- Steel foundries or scrap melting units

These cause erosion of condenser tubes reducing their life. It is now easy to remove these using a side stream filtration unit or Hydrofil filtration system consisting of:

- Cyclone filter
- Bag filter

The bag filter could be traditional material or stainless steel. This unit may be operated for a few hours a day. It could also be connected to more than one cooling tower and the water from these cooling towers may be cleaned by rotation. The bag filters may be chosen depending upon the particle size distribution. It is possible to get very clean water. This would help in controlling the sediments combined with dust in the cooling tower as well as the condenser tubes.

It would naturally increase the heat transfer and control erosion of the thin condenser tubes.

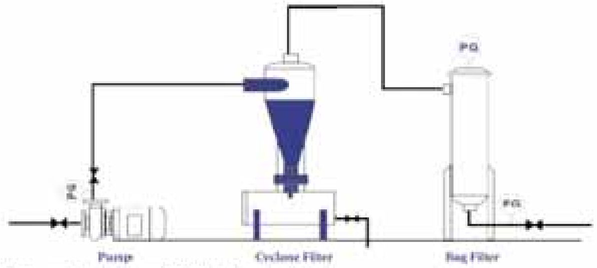


Figure 15 : Hydrofil filtration system.

Conclusion

The water quality 25 years ago was excellent. Almost everyone was using municipal water with low hardness and TDS, with practically no silica. Today borewell and tanker water are the norms. When the end user does not have control over the quality of raw water going into the water cooled chillers, it is extremely important to treat the water in such a way that despite its bad quality it does not harm the most expensive component of the HVAC system - the condenser tubes in the chiller. Keeping the condenser tubes clean will increase not only its life but also save energy. Modern techniques such as ULF treatment, Copper-Silver ionization and Hydrofil filtration systems help in maintaining the condenser tubes in excellent condition with minimum bother. Such techniques are now readily available in India.