

# Corrosion and Scaling Problems with Process Cooling Water

By

LALIT MOHAN AGARWAL

*Sudbury Laboratory of India, Calcutta*

## INTRODUCTION

Water is the most abundant of our natural resources. Without it, life would perish. Without it, many industrial processes cannot function. Some of its important uses are in Air Conditioning and Refrigeration, Diesel Generating Sets, Air Compressors, Power Plant Condensers, Chemical Plants, Heat Exchangers, Furnaces, Steel Plants, etc. In effect, today the process cooling water in any modern Industry, is as essential as the raw material.

Water is boon to industry but is treacherous to machineries inflicting corrosion, and scale formation, unless made to behave. To treat water is a costly and complicated affair, hence proper understanding of the cooling system and problems is essential before solving the same.

Recently, the owner of a 400 ton air conditioning plant had to change his complete condenser. A check of the job showed that the plant has been in operation for less than 2 seasons. The condenser tubes were coated with a thick layer of calcium scale and were perforated with pitting type corrosion which had developed on the water side beneath the scale deposit.

This would appear to be a paradoxical situation. Why, when a tube is protected with a heavy calcium scale, would fail because of corrosion? What must be done if the new condenser tubes are to give a satisfactory service life? Let us look at the operation of the equipment.

The job consisted of a standard 400 ton air conditioner with evaporative type condensers.

The makeup water was used from the tubewell and a water softening plant was installed for water treatment. It seemed most unusual to the owner that the water even after installing a softening plant could cause all this trouble.

The condenser tubes failed on this job because :

1. Improper chemicals and feeding technique were employed.
2. No bleed off was provided from the evaporative condensers.
3. Because of the above, scaling resulted which permitted dissolved oxygen in the recirculating water to cause serious pitting corrosion under the scale which has formed in varying thickness, thus permitting greater or less oxygen to reach the tube surface in one area as compared to other. The metal under the thickest scale is deficient in oxygen, thus creating an oxygen concentration cell which causes the pit to form.

A better understanding of uses of water and properties of water available will be helpful in clarifying the problem.

## **PROCESS COOLING WATER SYSTEMS**

There are generally following systems in use :

### *(i) Once through system*

This system is applied generally where abundant and cheap source of water is available, e.g., river, sea, etc. Water is used once for cooling and returned to the source or waste. This system may pose either a scaling or corrosion problem depending on the water quality but usually not both. If extremely large quantity of water is used, then sometimes, water conditioning may not be economical, and in such cases it might be advantageous to have the equipment designed in such a way as to have either high scale factor or the corrosion resistant material, as the conditions require.

### *(ii) Closed Recirculating system*

This type is generally used in small systems ,e.g., engine cooling. In large systems it may be also applied by indirect cooling with refrigeration ,e.g., chilled water system. Generally, the problem in such system is corrosion, particularly where multimetal construction is involved.

### *(iii) Open Recirculating System*

This is probably the most widely used system. The water is reused by cooling through a cooling tower or spray pond. Only a small makeup water is required to compensate the loss due to evaporation, windage, spillage, bleed-off, etc. This system has invariably both scaling and corrosion problems. Due to its wide application, water conditioning in open recirculating system is becoming more important.

## **Natural Waters**

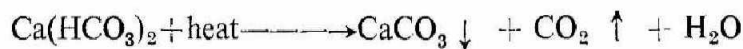
The major source of natural water is the collection of rain and snow in rivers, lakes and underground tables. Rain and snow have their origin in the oceans. The ocean water evaporates and releases pure water to the atmosphere. When atmospheric conditions are right, the pure water vapour is precipitated as rain or snow. At this instant, water which was pure till now, begins to pick up impurities, being the universal solvent.

As rain falls, it absorbs nitrogen, oxygen and carbon dioxide from air. If it rains in an industrial area, it also absorbs acid gases, such as sulphur dioxide. When the rain contacts the ground, it will either be absorbed by the soil or will run off into rivers and lakes. The water which is absorbed in the ground absorbs larger amounts of carbon dioxide derived from the decomposition of organic matter. As it percolates through the ground, it dissolves limestone, gypsum, and other minerals. Finally, it collects in subterranean pools and is available as well-water. Run-off water will not dissolve so much minerals and carbon dioxide. For this reason, well waters usually contain much larger concentrations of minerals and carbon dioxide than river and lake waters. The relationship of concentration of the dissolved minerals and gases determines to a large extent the corrosive or scale forming characteristics of the water. The higher the concentration of dissolved minerals and

the lower the concentration of dissolved gases, the more severe is the scaling tendency of the water. The lower the concentration of dissolved gases, the more severe is the corrosive tendency of the water.

## Scaling

Calcium bicarbonate,  $\text{Ca}(\text{HCO}_3)_2$ , is the dissolved mineral which causes most scaling problems. When its concentration exceeds about 180 parts per million (ppm) as  $\text{CaCO}_3$ , serious scale formation may be expected from recirculating cooling tower water when the water is heated in a condenser. When these conditions prevail, chemical water conditioning is required. Scaling occurs because the calcium bicarbonate changes according to the following reaction.



The above chemical reaction is accelerated by the following factors :

- 1) Increasing the concentration of  $\text{Ca}(\text{HCO}_3)_2$
- 2) Increasing the temperature of the water increases rate of reaction.

Recirculated water used for cooling system is affected by all these factors.

Again concentration of the recirculating water which goes on increasing due to evaporation loss in the cooling tower needs equal attention.

## What Scale does

Scale not only reduces the flow of water, but acts as an insulator and thus heat transfer efficiency is reduced markedly. With low heat transfer, temperature increases. The equipment works harder increasing power costs and causing it to fail to produce the designed capacity. Inefficient heat transfer reduces the life of equipment and may lead to serious damages.

## Reconcentration

When equipment is cooled by cooling tower water, the water in turn is cooled by evaporation through the cooling tower. For example, for each ton of effective refrigeration, the cooling water must remove about 250 BTU per min. including compressor heat. One pound of water evaporated will remove approximately 1000 BTU from the remaining water; therefore, the evaporation of one pound of water per minute is equal to about four tons of refrigeration. Calculating on this, a 150-ton electric motor-driven refrigeration system with shell and tube condenser is supplied with 450 U.S. gallons per minute of cooling tower water with 10° TD. Four and one half U.S. gallons of water must be evaporated from the cooling tower each minute to cool the recirculated water. A well designed cooling tower will have a windage loss—the mechanical loss of water droplets—of about 0.2 percent of the recirculation rate. In this case, drift loss will be about 0.9 gallons per minute and will have a

dissolved mineral concentration equal to that of the recirculated water. This case can be illustrated diagrammatically, assuming a calcium bicarbonate concentration of 75 ppm in the make-up water.

$C_1$  = concentration of make-up water

$C_2$  = concentration of recirculating water

B = gpm bleed plus windage loss with  $C_2$  concentration

$$\frac{B}{E} = \frac{C_1}{C_2 - C_1} = X \text{ ratio}$$

$C_1$  = 75 ppm calcium bicarbonate

$C_2$  = unknown

B = 0.9 gpm from above

E = 4.5 gpm from above

$$C_2 = \frac{75 \times 4.5}{0.9} + 75 = 450 \text{ ppm calcium bicarbonate}$$

For equilibrium this is the condition that should exist in the recirculating water, a concentration of six times. By actual chemical analysis of the make-up and recirculating water, the results were :

	Make-up water	Recirculating water
Ca (HCO <sub>3</sub> ) <sub>2</sub>	75 ppm	332 ppm
NaCl	11	66 ppm

The sodium chloride (NaCl) in the make-up water does not decompose in the recirculating water. It is a good indication of concentration effect. The sodium chloride increased six times in the recirculating water. The calcium bicarbonate increased only 4.4 times. It should have increased six times. Therefore, part of the calcium bicarbonate precipitated as calcium carbonate scale.

This particular failure could probably have been prevented by the simple expedient of arresting the calcium bicarbonate concentration in the recirculating water by providing bleed-off and proper water conditioning. Bleed-off is the continuous removal of a portion of the recirculating water to waste. In this case to maintain a maximum calculated concentration of 180 ppm of Ca (HCO<sub>3</sub>)<sub>2</sub> it would be as follows :

$$B = 4.5 \left\{ \frac{75}{180 - 75} \right\} - 0.9 = 2.31 \text{ gpm}$$

In general the windage loss can be neglected in calculating bleed requirement as it merely provide a reasonable factor of safety.

Bleed-off is the most often overlooked factor in scale control. It is practically always required in order to prevent excessive concentration of minerals in the recirculated water. As a general rule, bleed-off is unavoidable, but may be reduced depending upon the type of water treatment used.

If scaling had been controlled in this installation, the pitting type corrosion would not have occurred. Pitting is a form of electrolytic corrosion usually caused by the formation of concentration

cells. Concentration cells develop when adjacent areas of metal are in contact with different concentrations of a corrosive agent such as oxygen.

Recirculated condensing water from a cooling tower is saturated with dissolved oxygen. The scale, which has formed, varies in thickness and porosity, thus permitting greater amounts of oxygen to reach the tube surface in one area as compared to another. In cases where copper or copper alloy tubes are used, pitting occurs where the oxygen concentration is lower than the adjacent areas. The metal under the scale is deficient in oxygen, thus creating an oxygen concentration cell which causes the pit to form. This pit continues to grow until the tube is perforated. Pitting also develops along the entire length of the tube well where differences in thickness and porosity occur.

In addition to preventing the recurrence of pitting of tubes, scale prevention will also result in lower operating costs and in maintaining full capacity of the equipment.

The importance of continuous bleed-off cannot be over-emphasized. A recent field survey indicated that almost 60 percent of cooling towers have no bleed-off. It must be realized, however, that bleed-off alone will not completely control the scale formation and supplemental chemical treatment will be required. Scale control will be required for any recirculating water system which evaporates water. Closed recirculating water systems, such as chilled water circuits, seldom require scale control but may require corrosion control, if there is any aeration or water is corrosive.

### **Corrosion**

The destructive action of corrosion might be described as opposite to scale. Instead of leaving a deposit on equipment, corrosive water picks up the material and actually carries it away bit by bit. While the control of scale definitely contributes to corrosion control, supplemental corrosion control is required to protect fully, all metals in open and closed recirculating systems. Corrosion is accelerated by low pH and dissolved oxygen content of the water. Low pH is the result of dissolved gases such as carbon dioxide and sulphur dioxide, forming acids.

When untreated waters have values below pH 7, serious corrosion of steel can occur. Whenever dissolved oxygen and acids are present, the corrosion of steel is further accelerated and the corrosion of copper and its alloys occur. Even at values above pH 7, serious corrosion of steel may occur if oxygen is present.

To control corrosion effectively, pH control and corrosion inhibitors must be used at correct concentrations.

It is always profitable to prevent scaling and corrosion than changing the equipment reducing its efficiency.

### **PREVENTION OF CORROSION**

Generally, there are three methods used to fight this menace of corrosion and scaling.

First method is to change the characteristic of water in such a way as to make it harmless. This method depends entirely on the water quality and the end use to which it is put. Sometimes, more than one system is required to produce the desired result and therefore, at times, this process is costly and complicated and may prove uneconomic in the long run.



The common method for changing the characteristic of water is utilised mainly for reducing hardness for the prevention of scaling. The process is called water softening. There are various techniques in water softening but the basic idea is to replace the calcium/magnesium and other scale forming salts with the sodium salt of the exchange medium. This system requires daily or other similar periodic regeneration of the exchange media with common salt, etc.

The basic *disadvantage* of this system is that it normally reduces the scale at the cost of corrosion. When the carbonate balance of the water is disturbed to such degree that the first uniform protective layer of scale is not formed then corrosion is markedly increased. Therefore, when water softening method is employed care should be taken for preventing the corrosion.

The second method is to use costly metals in the equipment through which water is flowing. Apart from increasing the initial capital cost tremendously, it has got two major disadvantages. Firstly, scaling will not be stopped and secondly, if the system is not designed and maintained with extreme care there might be increased electrolytic corrosion due to the use of dissimilar metals, particularly, in acidic water.

The third method is the use of inhibitors to form microscopic thin film on the metal surface which becomes barrier between water and the metal. When metal is not allowed to come in contact with water, there cannot be any corrosion either due to electrolytic action or oxidation. Proper inhibitor will also keep the precipitated scale forming salts suspended by sequestering so that they flow away with water bleed or remain as loose sludge at the bottom of the cooling tower which can be conveniently cleaned periodically.

It is very important that the concentration of corrosion inhibitors be maintained above minimum specified values. If these minimum values are violated, more serious corrosion can occur than would have been experienced had no corrosion inhibitors been used. pH values must also be maintained. It is practically impossible to control corrosion effectively regardless of inhibitor used when pH values are too low.

There are many inhibitors available in the market, but, like in every field, they do not solve all the problems effectively and economically.

The important characteristics which a inhibitor should have :—

- i) Must not affect heat transfer.
- ii) Must not build upon itself, i.e., should be self dissolving and self healing.
- iii) Can be used effectively with all metals normally used in the cooling system.
- iv) Should be effective in all general types of water in use ,e.g., hard, soft, brine, sea water, etc.
- v) Can be used in old or new equipment alike.
- vi) Should not be toxic hence does not create effluent problem and preferably be safe for use in potable water.

vii) should be simple in operation.

viii) Should be economic in installation and maintenance.

ix) Must prevent both internal corrosion and scaling at the usual temperature to which water is affected in the normal cooling system.

x) Readily available in India.

Water conditioning can be successful only if it is properly applied. A recent survey indicated that more than 70 percent of water conditioning programmes were failing because inadequate chemical feeding was employed. A number of programmes which are carried out by dumping chemicals into cooling towers once a day, or even less frequently has resulted in overdosing at certain periods and underdosing at other times. Good automatic proportional feeding devices are required. They maintain a continuous flow of chemicals to the system thus assuring that correct chemical concentration exists at all times.