MARLEY

thermal science

Corrosion Resistant Materials

FOR COOLING TOWERS

Evaporative cooling towers expose materials to a uniquely difficult environment where corrosion poses exceptional challenges. Every cooling tower must endure the combined corrosive effects of uncertain water chemistry, high temperatures, constant saturation and continuous natural aeration. In addition, many cooling towers must also contend with potentially harmful agents in their circulating water as well as a variety of airborne pollutants such as sulfur oxides (SO_X) and acid rain.

Only careful selection of materials can significantly retard or prevent the detrimental effects of corrosion. Effective maintenance and water treatment can help to prolong the life of any cooling tower, but only good choices at the specification and installation stage provide maximum service life.

This report provides an overview of corrosion resistant materials used in modern HVAC cooling towers, including an explanation of the criteria used to select those materials and a brief historical review of their evolution. This discussion and the definition of "normal" conditions which follows will provide a framework to help evaluate the suitability of various materials offered by cooling tower suppliers on various types of installations. Finally, this report includes suggested guidelines for preparing the materials requirements portion of cooling tower specifications.

Corrosion Defined

For purposes of this discussion, corrosion is defined as the chemical or electrolytic reaction of free elements, ions or compounds (either airborne or in aqueous solution) with base materials of construction, causing either loss of base material weight or loss of base material physical properties. By this very general definition, both rust on steel components and chemical attack on poorly selected polymers are considered forms of corrosion.

There exists a wealth of literature describing corrosion mechanisms in a variety of sources. For this reason, no attempt is made here to repeat those explanations.

In the most general terms, corrosion is likely to occur whenever a base material is exposed to a chemically or electrolytically incompatible substance which must be present in sufficient concentration to initiate reaction, over a sufficient time for the reaction to proceed appreciably, and at conditions where the reaction will occur spontaneously—that is, without the addition of an external catalyst or an external heat source. Proper material selection involves a careful review of the specific corrosive agents likely to be present in a given cooling tower, the conditions occurring in the cooling tower, and the chemical and physical properties of the materials being considered.

As an example, the mere presence of a corrosive agent, such as chloride ions, is not sufficient to initiate significant corrosion, even on poorly protected steel components. The chlorides must appear in direct contact with the unprotected steel at a sufficient concentration before measurable degradation of the steel will occur. This distinction will become significant in the discussion of "normal" conditions appearing below.

Material Selection Considerations

Most are quite familiar with the general concepts of galvanized cooling towers, wood cooling towers or fiberglass cooling towers. However, these descriptions apply only to portions of the cooling tower structure itself, while a variety of different materials are used for other components. Let's review the primary materials used in cooling tower construction, and also describe the major considerations which guide cooling tower designers toward those materials.

For this discussion, consider the cooling tower as having three distinct zones, each with a unique operating environment and with its own applied loads. These three areas are the structure, fill (the heat transfer medium) and "other" components, such as water distribution and mechanical components.

Structural materials in common use on cooling towers for HVAC projects include galvanized steel, stainless steel and fiberglass (actually a matrix of fiberglass reinforced polyester, the term "fiberglass" is used throughout this report to describe the composite material — also commonly known as FRP).

Pultruded FRP in a typical field-erected counterflow cooling tower

Cooling towers are actually hybrids using some combination of these materials in various portions of the structure. For example, galvanized cooling towers with stainless steel collection basins are common. Fiberglass exterior casing is used occasionally on galvanized and stainless steel cooling towers. All cooling towers are bolted together with hardware which may be galvanized or plated carbon steel or stainless steel in a variety of alloys.

In selecting appropriate materials, the designer usually considers the imposed loads, the type of exposure to corrosive agents, cost, and manufacturability (which ultimately emerges as product cost). Imposed loads are unique for each part in each cooling tower, so they will be neglected here.

Steel structure and casing in a crossflow design

Exposure for structural components can vary tremendously, depending on the component's location within the cooling tower. Sections of the cooling tower with high water flow velocities, such as the fill region and open hot water distribution basins, receive a nearly constant warm water bath which tends to discourage accumulation of corrosion products. Cold water collection basins, on the other hand, act as reservoirs where flow velocities are extremely low and corrosive agents have ample opportunity to react with the basin material. Cooling tower plenum sections, where air exits the fill region before leaving the cooling tower, tend to alternate between periods of saturation and periods of relatively dry conditions. However, the moisture collecting in the plenum is usually condensate from effluent water vapor which is free from dissolved solids.

Comparing the costs of cooling towers made from these materials is not always easy, because their structural capabilities vary tremendously. For cooling towers of roughly 1500 tons per fan-cell and below, galvanized steel enjoys an inherent cost advantage because it lends itself to the manufacture of factory-assembled units. Typically cooling towers with FRP structures are somewhat more expensive than galvanized steel, while stainless steel is more expensive yet. Wood and pultruded FRP is a practical material only near the top of this range because the field labor required is usually quite costly. For cooling towers over 1500 tons per fan-cell, wood becomes the least expensive alternative, followed by galvanized steel, FRP and stainless steel.

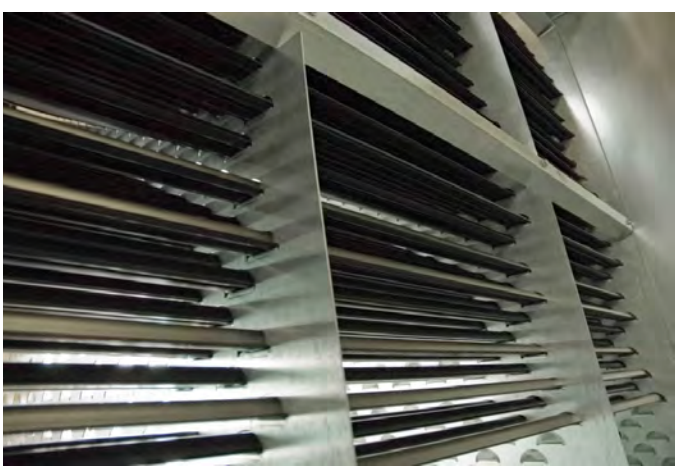
Stainless steel, FRP and PVC make this cooling tower virtually corrosion proof

Hardware selections are usually consistent with structural materials selections. Coated carbon steel is least expensive and suitable for most conditions, assuming that the coating has been properly chosen and applied. Series 300 stainless steels provide additional corrosion resistance at a higher price, while 316 stainless offers even greater resistance at a still higher price.

Typical PVC crossflow film fill

Applications falling into the “normal” category as defined elsewhere in this paper will enjoy long service life with standard, low-cost materials. Selective substitution of components with greater corrosion resistance than standard materials often provides suitable life on marginal applications. Use of stainless steel cold water and/or hot water basins on otherwise galvanized cooling towers is a primary example of this type of selection. FRP structures can withstand all but the most corrosive conditions but may fail to meet the stringent fire codes of some major cities. Stainless steel provides excellent corrosion resistance, but commands an exceptional price.

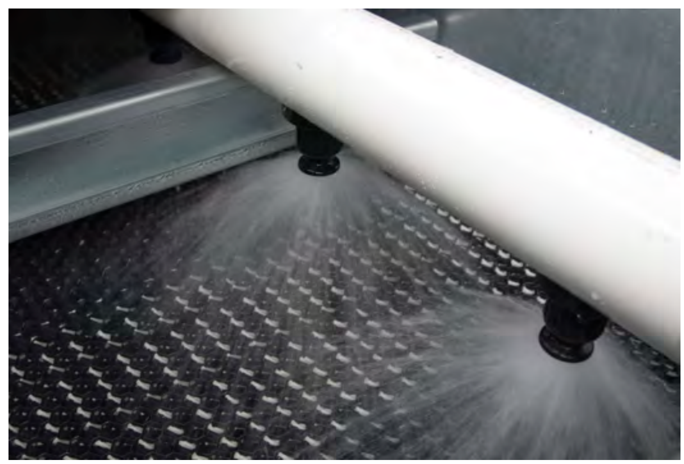
Heat transfer in most modern HVAC cooling towers takes place on film-type fill surfaces which induce the falling water to form a thin film, providing maximum heat transfer surface area. Properly formulated PVC provides excellent manufacturability, outstanding erosion resistance, and stable material properties over a wide range of chemical environments. For most applications, even those involving very corrosive water, PVC is the fill material of choice.



PVC crossflow splash fill is used where suspended solids could cause clogging

If the circulating water may contain suspended solids which are fibrous, greasy, fatty, or tarry, then film-fill should be avoided altogether. These types of foreign substances tend to clog the relatively narrow passages between film-fill sheets, preventing the proper mixing of air and water on the fill sheet surfaces. Splash-type fill provide acceptable service on this unusual type of project. Splash fill may be treated wood, PVC or polypropylene. Again, PVC is usually the material of choice unless some other condition on the individual installation dictates against its use.

Other components make use of specific materials having properties well-suited to their application. For example, water distribution nozzles may be polypropylene, ABS, or glass-filled nylon. These materials serve well in this application because of their inherent resistance to chemical attack and because of their exceptional resistance to erosion. Fan blades, which must withstand extremely high operating loads in a saturated environment, are typically aluminum alloy, fiberglass-reinforced polyester, fiberglass-reinforced epoxy or fiberglass-reinforced vinyl ester. Severe conditions may dictate substitution of stainless steel for some coated carbon steel hardware items and mechanical components. However, minor changes will usually suffice for most of these “other” components, even in the most severe conditions.



PVC distribution system piping with polypropylene nozzles

Brief History of Cooling Tower Materials

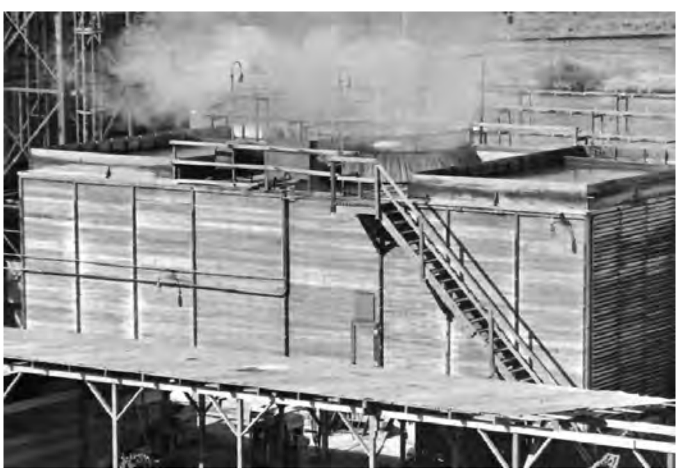
Water cooling towers of today bear little physical resemblance to their technological forebears of the 1920s and 1930s. Those original examples of evaporative cooling design were primarily wood structures, usually untreated redwood, containing a series of brass or bronze spray nozzles which dispersed water into an open plenum over a wood catch basin. A few years later, wood splash fill appeared on the scene to improve heat transfer efficiency. Cooling towers were huge, and, in general, corrosion was a much less significant challenge than was wood decay.

By the late 1940s, the burgeoning market for water-cooled air conditioning systems demanded a less expensive and more standardized product than the old wooden behemoths. Among the dictates of this new market were factory assembly and conformity to the fire codes then becoming more common in many larger cities. Carbon steel became the material of choice to satisfy these demands.

Early designers recognized that corrosion would quickly destroy unprotected carbon steel in a cooling tower atmosphere. Accordingly, they chose to employ a sacrificial type of coating, usually galvanizing, to protect the underlying material. Galvanized steel has since won wide acceptance within the industry as the material of choice for most HVAC cooling towers under "normal" conditions. Major manufacturers have standardized within the last few years on G-235 mill galvanizing. The designation G-235 refers to a coating application rate of 2.35 ounces of zinc coating per square foot of steel as a total for both sides which translates to a nominal coating thickness of 2.0 mils (.002") per side. Occasional suppliers may still offer G-90 galvanizing with a nominal thickness of only 0.8 mils. Comparing only zinc thickness, G-235 galvanizing provides protection 2.6 times as long as G-90 at very little additional cost to the end user.

Stainless steel followed logically as the material for severe exposures, and remains popular today as appropriate materials for suitably sized cooling towers subjected to corrosive atmospheres or potentially harmful water chemistry.

Fiberglass reinforced polyester formulated from isophthalic polyester resins has emerged as a structural material for HVAC cooling towers exposed to all types of environments. The primary challenge of FRP design has always been to keep production costs in line with other materials while attaining suitable section properties. Fill materials have developed through a similar type of evolution. PVC, polypropylene and other polymers have largely replaced wood fill bars in splash-fill cooling towers.



An early wood cooling tower.

A modern cooling tower features construction materials of fiberglass, stainless steel and PVC

Advances in heat transfer technology led to the gradual acceptance of film-fill consisting of parallel sheets of some formed material. Early film-fills were made from a variety of easily formed materials which were later found lacking in one or more properties essential to their effective long-term use in HVAC cooling towers. PVC has gained general acceptance as the industry standard material for film-fill on all types of HVAC projects except a very few high-temperature applications (above 120°-125°F).

Polypropylene, ABS, and fiberglass-filled nylon have largely supplanted the bronze nozzles of early cooling towers. PVC and fiberglass piping have replaced most iron and steel piping inside cooling towers. On larger cooling towers, FRP fan cylinders are used where laminated wood once was common.

These improvements have all provided increased corrosion protection and longer service life while keeping product costs down.

“Normal” Conditions

Water quality and environmental conditions on the vast majority of HVAC and light-to-medium industrial cooling tower applications permit acceptable service life from standard cooling tower construction using the previously described materials. Significant deviation from these “normal” conditions often demands alternate materials choices. For most purposes, the following criteria define “normal” conditions.

Standard cooling tower design assumes a maximum of 120°F hot water to the cooling tower, including system upset conditions. Temperatures over 120°, even for short durations, may impose damaging effects on PVC fill, many thermoplastic components and galvanized steel. Those rare applications demanding hot water in excess of 120°F usually benefit from careful review with the cooling tower manufacturer to assure that appropriate materials changes from the standard configuration are included in the initial purchase specification.

“Normal” circulating water chemistry falls within the following limits (note the distinction below between circulating water and makeup water):

- pH between 6.5 and 8.0, although pH down to 5.0 is acceptable if no galvanized steel is present. Low pH attacks galvanized steel, concrete and cement products, fiberglass, and aluminum. High pH attacks wood, fiberglass, aluminum, and galvanized steel.
- Chlorides (expressed as NaCl) below 750 ppm, 500 ppm for a galvanized steel cooling tower.
- Calcium (as $CaCO_3$) below 1200 ppm—except in arid climates where the critical level for scale formation may be much lower.
- If calcium exceeds 1200 ppm, sulfates should be limited to 800 ppm (less in arid climates) to prevent scale formation. Limit to 250 ppm for a galvanized steel cooling tower.
- Sulfides below 1 ppm.
- Silica (as SiO_2) below 150 ppm.
- Iron below 3 ppm.
- Manganese below 0.1 ppm.
- Langelier saturation index between 0.0 and +1.0—negative LSI indicates corrosion likely; positive indicates $CaCO_3$ scaling likely
- Suspended solids below 150 ppm if solids are abrasive — avoid film-fills if solids are fibrous, greasy, fatty, or tarry (see the discussion on fill materials).
- Total dissolved solids below 5000 ppm, if above may cause thermal performance derate.
- Oil and grease below 10 ppm or loss of thermal performance will occur—avoid film type fill if oil and grease are present.
- No organic solvents.
- No organic nutrients which could promote growth of algae or slime.
- Chlorine (from water treatment) below 1 ppm free residual for intermittent treatment; below 0.4 ppm free residual for continuous chlorination.

These conditions define normal circulating water, including the chemical concentrating effects caused by recirculating the water to some predetermined number of concentrations.

Most of the heat transfer in a cooling tower occurs through evaporation of a portion of the circulating water. The evaporated water leaves the cooling tower as purified vapor, leaving behind a burden of dissolved solids which concentrate in the circulating water. Most operators control the number of concentrations by dumping a calculated fraction of the circulating water into a holding tank or sewer, a process commonly called “blowdown”. Refer to *Cooling Tower Fundamentals* for a thorough explanation and for the formulas used to calculate blowdown amount. It is sufficient here to recognize that makeup water (usually city water supply) will be concentrated on the cooling tower. The net effect is that the cooling tower will be exposed to concentrations of corrosive agents which are multiples of their concentration in the makeup supply. The result of this concentrating effect may lead to conditions which indicate that some materials should be more corrosion-resistant than those used on standard cooling towers.

Deviations from normal water are usually regional, and necessary adjustments are widely known within the area. Similarly, most cooling tower users operate their cooling towers within the range of 3-5 cycles of concentrations. However, regional concerns such as water availability or sewer usage restrictions may dictate unusually high circulating water concentrations. In either case, the engineer unfamiliar with the impact of these conditions on cooling towers will benefit from discussing the specific application with one or more knowledgeable cooling tower suppliers.

Common environmental conditions which may dictate use of nonstandard materials of construction include proximity to bodies of salt water, the presence of corrosive vapors (as in a chemical or steel plant) and the presence of unusually dense air pollution in the form of SOx, hydrogen sulfide (H_2S) or potentially corrosive particulates. Once again, the engineer unfamiliar with these conditions will generally benefit from consulting a Marley sales representative at the specification stage of a project.

Guidelines for Specifiers

As stated earlier, most projects meet the definition of “normal” conditions. Virtually all projects in this category will enjoy long service life with a standard cooling tower using standard materials.

Cooling towers which will operate beyond these limits require greater care at the specification stage.

Solutions for regional concerns such as unusual local water chemistry or proximity to salt water are usually well known. More unusual conditions may demand even greater attention to details in order to assure that the cooling tower will operate successfully over a reasonable service life.

For all these situations, the following guidelines will generally assure that the cooling tower user will receive a cooling tower which provides long corrosion-resistant service at a reasonable price:

- Specify a cooling tower appropriate to the site conditions. If conditions are "normal", a standard cooling tower will serve well. A cooling tower made of other materials may be appropriate to satisfy other design considerations — architectural aesthetics, for example — but corrosion protection is not a determinant in those circumstances. If conditions are more severe, choose materials selectively.

- Specify realistic design conditions. In general, prepare the specification for the most likely case as opposed to the worst possible case. For example, temperature excursions above 120°-125°F for appreciable lengths of time demand extensive and expensive material changes. Don't specify such a condition unless some probable sequence of events could lead to its occurrence. Similar logic applies to potential buildup of corrosive agents in the circulating water supply.

- Define any applicable local fire or building codes. Some codes virtually exclude FRP structures, others impose maximum flame spread ratings, still others impose no restrictions. Thorough definition of those requirements at the specification stage will help to avoid any possible snags in the acceptance process.

- Specify completely. Recognize from the above discussion that a requirement for an "all-fiberglass cooling tower", for example, is virtually meaningless. The specification should define the major material requirements so that no surprises arise when the cooling tower reaches the job site. Typical specification requirements should define structural material requirements, structural hardware material requirements, fill material requirements and any other specific requirements suggested by the engineer's experience with cooling towers on particular types of installations.

- Don't over specify. If research indicates that two or more materials appear to be suitable, allow all appropriate materials in the specification. Let the cooling tower suppliers choose materials which will provide the most economical and effective solution for each particular installation.

- For unusual conditions, request selections based on the conditions. Rather than arbitrarily specifying materials when the best choices are not clear, provide potential suppliers with an enumeration of the site conditions. Include a makeup water analysis, the anticipated number of cycles of concentration, the type of water treatment to be used, design hot and cold water temperatures, and as complete a description as possible of the atmosphere surrounding the cooling tower. Review the materials recommendations carefully, keeping in mind the often opposing goals of economy and service life. Prepare a final specification based on the most reasonable recommendations.

- Stand by the specification. Once the appropriate materials have been defined, demand that the final product selection meet those requirements. If site conditions demand the use of more corrosion-resistant materials, such as an FRP structure, it is reasonable to expect that at least one potential supplier will offer a lower price for a more standard cooling tower. The cooling tower user will usually pay much more in the long run, however, in higher maintenance costs and probable cooling tower replacement costs.

The recent past has produced rapid progress in all areas of cooling tower technology. From the user's standpoint, perhaps the most dramatic improvements have been the introduction of and wide-scale application of the broad range of corrosion resistant materials described throughout this paper. The pace of materials research and water treatment research continues to accelerate.

thermal science

SPX COOLING TECHNOLOGIES, INC.
7401 WEST 129 STREET
OVERLAND PARK, KS 66213 USA
913 664 7400 | spxcooling@spx.com
spxcooling.com

M-008C | ISSUED 10/2016

SPX®