ASSOCIATION OF WATER TECHNOLOGIES

Introduction

The Association of Water Technologies (AWT) Cooling Committee's Corrosion Coupon Task Group revised the corrosion coupon guidelines in 2010 and early 2011to better outline acceptable corrosion coupon survey practices and to more properly define corrosion coupon results. The information presented is specific for open recirculating cooling systems and closed chilled water loops (it is not intended as a reference for other system types).

This material was contributed by a number of individuals, thereby providing a consensus of opinion from differing regions, perspectives and operations. The corrosion rates and comparative grading are separated into two general categories: industrial process cooling and comfort cooling (HVAC) applications, so as to provide a more accurate reflection of performance relative to operational challenges.

The document provides "Recommendations and Guidelines" for the water treater. This is not presented, nor is it proposed, as a Standard. It is intended to be used as an aid, in conjunction with other survey methods and data, to determine how well the metallurgies of a system are protected against corrosion and to gauge the impact of changes made to a water treatment program.

This is a "living document" and will be expanded in scope, as more information is forwarded to, and reviewed by, the Coupon Task Group.

Warnings and Disclaimers: This document is designed to provide information regarding the subject matter presented. It is produced with the understanding that neither AWT nor the contributors are rendering legal, medical, engineering or other professional services. Neither AWT nor the contributors shall be liable for damages, in any event, for incidental or consequential damages caused, or alleged to be caused, directly or indirectly, by the use of any information disclosed in this document, including the use of any recommendations, methods, products, services, instructions or ideas.

AWT Recommendations and Guidelines for Corrosion Coupons in Cooling Systems

A corrosion coupon survey should have a defined objective prior to initiating the study. This helps to position the results and pursue any needed corrective action(s).

Corrosion coupons are useful in determining average loss rates over the installation period and can illustrate evidence of localized attack. The results identify trends that reflect acceptable corrosion protection, gains made by changes to the treatment program, equipment or operation of the system or the need for improvements that should be investigated by further survey work.

Coupon studies comprise only one of a number of tools that are available to determine corrosion control. Each result needs to be viewed as a unique value for the operating conditions present during the survey period. This value should be compared against other results to identify improvements in control and protection.

Corrosion coupon results are not an absolute reflection of actual system corrosion rates – existing oxides on older waterside surfaces typically retard corrosion more effectively than the protective surface developed on the corrosion coupon during the survey period. A poor rate does not necessarily reflect a significant problem; however, it does help to identify the need for corrective action.

The values obtained from the gravimetric evaluation of corrosion using coupons, depends upon many factors. These factors include but are not limited to:

1. Type of industry
2. Exposure time in a water system coupon test rack
3. Coupon rack design and coupon placement
4. Orientation of the coupon
5. Flow characteristics passing over the coupon: water velocity, downtime, etc.
6. Temperature of the water passing through the corrosion rack
7. Water chemistry and quality
8. Process contamination: organics, gases, acids, alkalis, metals, etc.
9. Quality and concentration of the water treatment program

1. Acceptable values from an HVAC system (i.e. a cooling tower operating in an institutional or commercial facility) may not be attainable in a refinery, chemical or other industrial manufacturing plant. The same can be said for HVAC systems operating with a stressed water supply (i.e. make-up waters high in total dissolved solids, sulfates and/or chlorides, as examples). Corrosion rates identified in these systems may not match the values used to evaluate protection in unstressed supplies. It might be more appropriate to reference the guidelines identified for industrial cooling tower circuits to gauge corrosion control when operating with these more difficult sources.

2. Corrosion rates measured by corrosion coupons are the result of time averaging the loss of metal from the coupon. However, the rate of loss of metal by corrosion of a clean, unpassivated coupon is not linear. Corrosion rates are much higher in the initial few hours or days of exposure. The higher rate of corrosion occurs during and until the metal surface acquires passivation. Therefore, a recommended and widely accepted exposure time for unpassivated corrosion coupons in a test rack is a minimum of 90 days. Short-term durations (30-days or less) usually will result in higher observed corrosion rates. The higher rates are the result of the short time averaging over the higher corrosion rates present during initial passivation. The short term and resulting higher corrosion rates may be justified when changes to treatment programs, or new treatment programs are being evaluated. With longer term duration, the initial high metal loss from the coupon becomes a smaller percentage of the overall weight loss. Also, as the metal coupon corrodes, the corrosion products can act as a barrier reducing the rate of further attack.

3. The corrosion coupon rack should be constructed of materials which will neither contribute to corrosion nor result in corrosion inhibition. Optimal placement of the rack would be on the return header to the cooling tower, or the return line from a chiller or heat exchanger (i.e. the site offering the warmest recirculating water). The effluent from the rack can flow back to the main water source in free flow to atmospheric pressure where the flow rate can be manually measured or return to the pressurized piping system where a flow meter is first used to monitor and control desired water flow rates.

There is a wide range of opinions concerning preferred and acceptable materials of construction (M.O.C.) used in the manufacture of coupon racks. These vary from the more commonly applied mild steel, to stainless steel, PVC, galvanized and copper metallurgies. While successful applications of each of the common options have been noted there remain a variety of philosophies on the positive and negative aspects of each. Some of these philosophies are shown below.

M.O.C.	**Pros**	**Cons**
Carbon Steel	• Suitable for higher pressure / high temperature • Rugged construction • Components are readily available • Representative of the bulk of the piping metallurgy (typically) • The waterside surface conditions can be used as a qualitative reflection of general protection, conceivably for years	• Under severe operating conditions the waterside surfaces will corrode (but that, in and of itself, would identify poor control) • Ferrous components weigh more than plastic components and may require additional support.
Stainless Steel	• Suitable for higher pressure / high temperature • Rugged construction • Will not corrode readily	• More expensive than other options • Not typically representative of the bulk of the system

	• 316 SS fittings are readily available	piping • Fittings for alloys other than 316 may be not be found easily
PVC	• Easy to construct • Relatively inexpensive • Can be manufactured with transparent segments allowing the coupon surfaces to be visually inspected throughout the survey period • Schedule 80 is available in threaded components	• Limited pressure applications • Limited temperature applications • Not typically representative of the bulk of the system piping
Galvanized	• Suitable for higher pressure / high temperature applications • Rugged construction • Will corrode at a slower rate than will carbon steel (although this may mask an obvious corrosion concern)	• Corrosion of the galvanized surfaces could indirectly improve the corrosion rates of ferrous coupons • Alkaline programs may attack the galvanized pipe.
Copper Tube	• Suitable for higher pressure / higher temperature applications • Sturdy construction	• Corrosion of the coupon rack components could adversely impact the corrosion results of less noble metal coupons (however, corrosion of the copper rack would also imply that corrosion of the system copper metal was occurring).

Construction materials can be ¾” or 1’ inch diameter, schedule 40 or schedule 80 piping. Temperatures of the water and pressure in the system must be considered when selecting the M.O.C. All required valves, strainers and flow restricting devices should be made of similar materials.

Coupon rack designs are often promoted with horizontal sections that are no less than twelve (12) inches in length and vertical section lengths of three (3) inches, or more. When considering that all flows in excess of one (1) gallon per minute will be turbulent, increased horizontal pipe lengths beyond six (6) inches and increased vertical separations of the horizontal sections are unlikely to reduce turbulent effects (see Table 1 below).

Comparative surveys should always be completed in the same coupon rack or coupon rack design as this will limit the variables associated to the differences in loss rates.

It is commonly recommended that coupons should be placed into the corrosion coupon rack following the galvanic series in seawater. This stipulates that the most “active” or least “noble” metal or alloy must be placed in the number one position, which is the first coupon exposed to the flowing water. Other coupons would follow the galvanic series in seawater with the last coupon being the least "active" or most "noble" metal or alloy. The procedure prevents the more "noble" or least "active" metal or alloy from cathodically depositing on the active metal or alloy.

In reality, if an appropriate water treatment program is in place, the actual coupon order will make little or no difference to the results. There is an argument for limiting the number of factors to be considered when analyzing results and if the coupons are installed according to the galvanic series, any high loss rates will not be blamed on, or associated to, galvanic differences (regardless of whether these could, or could not, impact results). As noted previously, working with a standard design and a minimum of variables makes it far easier to assess the potential issues needing redress.

Having a removable carbon steel spool piece as part of the coupon rack is a very useful means of visually monitoring pipe wall conditions over longer-term periods. If these segments are to be utilized, the coupon rack should installed in a location that allows these pieces to be easily inspected (or removed for inspection) without interference. (See example in Figure 2.)

4. Coupons should be placed in the coupon rack such that water flows from the coupon holder to the tip of the coupon. This orientation and direction of flow is promoted as the best means of reducing the potential of erosion at the tip of the coupon. However, at normal flow rates and with no abrasive suspended solids present in the water, erosion is unlikely to be an issue.

Several arguments have been put forward on the ideal direction of flow to limit suspended debris from collecting on one or the other end of the coupon (thereby causing under deposit corrosion). Some suggest that the flow should be from the holder to the coupon tip, others from the coupon end to the holder.

Both concerns can be addressed, at least in part, by utilizing an upstream strainer as part of the rack design (this will help prevent debris from collecting on either the mounting screw or the coupon tip).

Note: where a strainer is incorporated to reduce the impact of any foreign debris, particular attention should be paid to the flow rate during the course of the survey (the trapped material within the strainer may restrict flow and the change in flow rate may impact results). Where practical, the installation of a transparent plastic strainer will indicate whether this might become an issue. (See Parts List Figure 1.)

The coupon should be oriented with the broad face in a vertical position. This reduces the accumulation of debris onto the face of the coupon, which can accelerate corrosion. When removed, the coupon should be inspected to ensure it is still properly oriented and secured on the holder. If not, this information should be included in the analysis report.

The coupon holder should be equipped with a mark identifying the flat edge of the coupon so that the orientation can be confirmed during installation. Coupons should also be electrically isolated from the holder using suitable plastic washers, screws and nuts where the galvanic difference between the coupon and the mounting hardware is felt to be a concern.

Coupon mounting stems 0.5 inches in diameter are recommended. Non-metallic holders are the preferred material of construction but stainless steel is acceptable in alkaline environments.

The holder must position the coupon beyond the Tee fitting that the holder is threaded into. It is generally recommended that the coupon holder stem lengths are no less than three (3) inches in length.

5. Water flow through a coupon test rack should be set to emulate system equipment flow rates. In many systems a constant flow between 3 - 5 feet per second is normal. Higher velocities (i.e. 8 Ft. / Sec. and above) can cause erosion on soft alloys such as copper-based materials. Calculation of the water velocity in a pipe requires three measurements, OD (Outside Diameter), WT (Wall Thickness) and GPM (Gallons per minute flow). These variables are incorporated into the following formula:

Velocity = (0.408 X gpm) / id^2 where id is inches specific to the pipe Schedule and MOC

Lower water velocities can cause particulate matter to settle onto the coupon resulting in under deposit attack; especially if a biofilm is present. A flow meter or other flow control device should be incorporated to maintain a consistent and repeatable flow rate. This practice facilitates accurate comparisons of coupon rates from one time frame to another.

Note: Flow restricting valves usually require a 15 psi drop to operate properly, while flow indicators require roughly a 2 psi differential.

Table 1: Flow Rates and Reynolds numbers for Schedule 80 pipe

Flow GPM	3/4 In Ft/Sec	3/4 In Reynolds #	1 In Ft/Sec	1 In Reynolds #
1	0.742	4258	.446	3298
2	1.484	8517	.892	6596
3	2.226	12776	1.338	9894
4	2.968	17034	1.784	13192
5	3.710	21293	2.230	16490
6	4.452	25551	2.676	19788
7	5.194	29810	3.122	23086
8	5.936	34068	3.569	26384
9	6.678	38327	4.015	29682
10	7.420	42585	4.461	32980
11			4.907	36277
12			5.353	39575
13			5.799	42874
14			6.245	46172
15			6.691	49470

Note: In many cooling systems (both HVAC and process), circulation may be interrupted. Wherever possible, determine the frequency with which this occurs and include it in the evaluation of results (stagnant flow conditions interfere with film formation and maintenance and may result in higher calculated corrosion rates). Incorporation of a check valve to prevent system drainage helps maintain more consistent results.

6. Normally, the corrosion coupon rack is connected to the return riser to the cooling tower, because the water is warmer than the coldwell supply and potentially more aggressive. It should be noted that coupon results do not reflect corrosion rates of heat exchanger watersides, as there is no heat transfer across coupon surfaces.

7. Water chemistry and quality has a strong impact on corrosion. Temperature, pH, conductivity, bacteria and biofilm, dissolved and suspended solids will influence the rate of attack on the coupons.
Uncontrolled microbial populations and/or suspended solids contamination can result in surface accumulations that may harbour sulfate reducing bacteria. This, in turn, can cause localized metal loss resulting in false high corrosion values.

Note: The quality of the water treatment program will impact how well the system metallurgies can be protected from most corrosion mechanisms. Surface passivation and control over microbiological populations (and control over suspended material that might harbour SRB's) will impact results.

8. Process contaminations can accelerate attack. Organics, gases, acids, alkalis and metals can impact corrosion rates. Sour hydrocarbon leaks will increase corrosion due to sulfide attack on copper or carbon steel. Ammonia leaks can decrease attack on carbon steel due to higher pH. However, ammonia will accelerate attack on copper. Acid contamination will accelerate corrosion on steel and copper. Alkali contamination will accelerate attack on copper, brass and zinc galvanized components.

9. The water chemistry and quality of chemical treatment will influence corrosion rates of coupons. Using pre-passivated coupons prior to installation in the rack is not recommended as this process may result in a false, low corrosion rate. Typically, un-passivated coupons are used in a rack with continuous water flow for a 90 day test period with a proper maintenance level of the system's chemical treatment. Using un-passivated coupons for a short test period of only 30 days will yield a higher initial corrosion rate compared to using passivated coupons. For a 90 day test period, un-passivated coupons are successfully used if the chemical treatment is at a level to passivate the system.

Following the above guidelines, acceptable corrosion rates for carbon steel and copper alloys in open recirculating cooling water systems are listed in *Table 2*.

The corrosion rate data and descriptions presented in the Table 2b are not necessarily applicable to all cooling tower systems. It is important to note that some water supplies will present additional challenges to the water treatment professional. Corrosion coupon surveys conducted in these "stressed" waters (i.e. those with high TDS, sulfates and/or chlorides, for example) may need to be evaluated relative to Table 2a or against a hybrid of the Tables 2a and 2b values. Where a make-up water supply is not stressed, the Table 2b values should be considered for HVAC systems. Corrosion rates for closed cooling water systems are listed in *Table 3.*

Table 2a: Quantitative Classification of Corrosion Rates for Open Recirculating Cooling Water Systems – Industrial Cooling Systems and HVAC Systems Operating With High Stress / High TDS Makeup Waters
Corrosion Rates (mpy)

Description	Carbon Steel	Copper Alloys
Excellent	Less than or equal to 1	Less than or equal to 0.1
Very Good	1 to 3	0.1 to 0.25
Good	3 to 5	0.25 to 0.35
Moderate to Fair	5 to 8	0.35 to 0.5
Poor	8 to 10	0.5 to 1
Very Poor to Severe	> 10	> 1

Table 2b: Quantitative Classification of Corrosion Rates for Open Recirculating Cooling Water Systems – HVAC for Institutional and Commercial Facilities.
Corrosion Rates (mpy)

Description	Carbon Steel	Copper Alloys
Excellent	Less 0.5	Less than or equal to 0.1
Very Good	0.5 to 1	0.1 to 0.2
Good	1 to 2	0.2 to 0.3
Moderate to Fair	2 to 3	0.3 to 0.5
Poor	3 to 5	0.5 to 1
Very Poor to Severe	> 5	> 1

Table 3: Quantitative Classification of Corrosion Rates for Closed Recirculating Cooling Water Systems
Corrosion Rates (mpy)

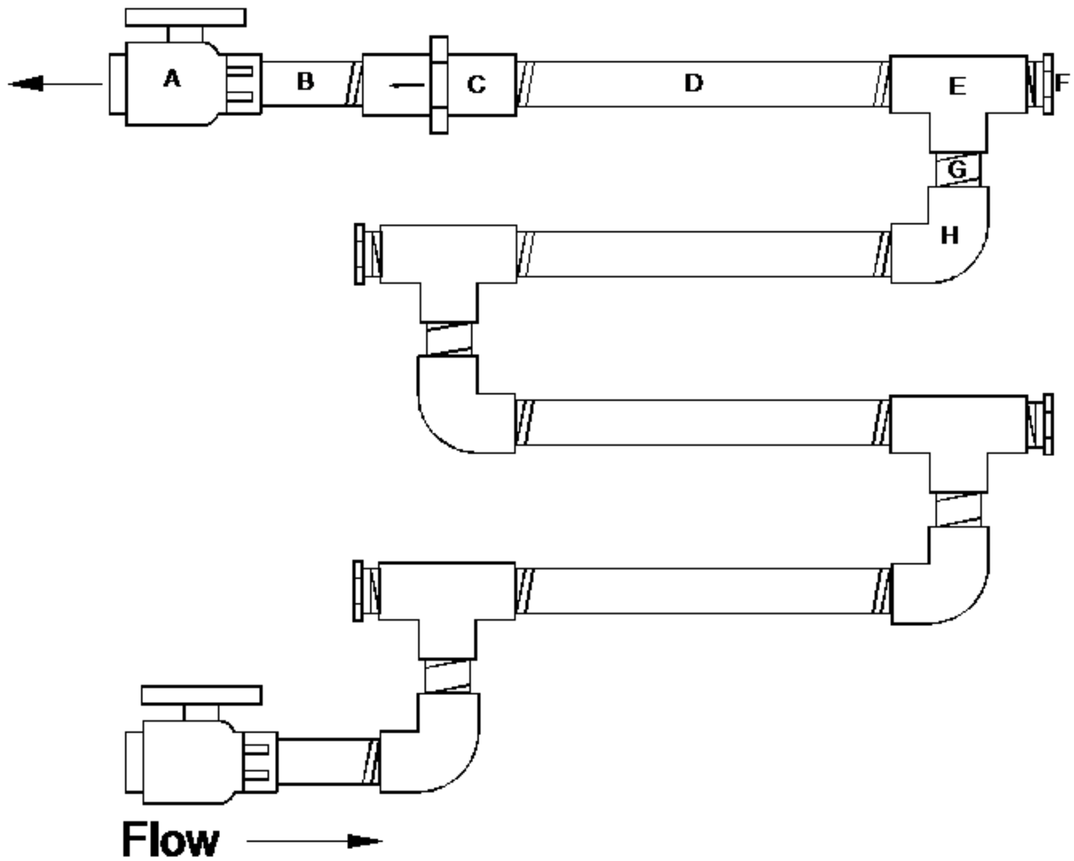
Description	Carbon Steel	Copper Alloys
Excellent	Less than or equal to 0.2	Less than or equal to 0.1
Very Good	0.2 to 0.3	0.10 to 0.15
Good	0.3 to 0.5	0.15 to 0.20
Moderate to Fair	0.5 to 0.8	0.2 to 0.3
Poor	0.8 to 1	0.3 to 0.5
Very Poor to Severe	Greater than or equal to 1	Greater than or equal to 0.5

Notes for Tables 2 and 3:

- These rates assume that the metal loss is uniform with no pitting, localized attack, gouging, etching, microbial or crevice attack evident. These conditions are not acceptable, and if any are noted, the cause should be addressed, near-term, with follow-up surveys to confirm improvement.
- Localized attack at the coupon holder may be ignored if the treatment is unable to interact with the coupon in this area and no other abnormalities are noted.

- Laboratory analysis should express coupon weights to the nearest 0.1 mg, readings are typically reported as mils (or 1/1000ths) of an inch per year.
- Coupons should be stored in suitable corrosion resistant envelopes to prevent corrosion both prior to and following the survey period. To prevent any alteration to the coupon surface before installation, do not touch coupon surface with fingers or contaminate surfaces
- Upon removal, coupons should be gently blotted dry using only a clean paper towel.
- Coupons should be stored in suitable corrosion resistant envelopes to prevent corrosion both prior to and following the survey period.

Figure 1



Parts for Corrosion Coupon Rack
1 Inch Schedule 80 PVC

Letter Designation	Description	Number Required	Spears Number
A	Compact Ball Valve Socket		2122-010
B	Schedule 80 Nipple 6" Trimmed		864-060
C	SS Dole Control Valve 1"X10 GPM	1	DOLE
D_1	Schedule 80 Nipple 18"		884-180
D_2	Schedule 80 Nipple 12"	4	884-120
D_3	Schedule 80 Nipple 9"		884-090
E	TEE Fipt x Fipt x Fipt		805-010
F	Corrosion Coupon Holder	4	MS
	Metal Samples RC13QC010066 3"Teflon		

	Stem		
G	Schedule 80 Nipple 2"		884-020
H	90° ELL Fipt x Fipt		808-010
I	Schedule 80 Nipple 18" Trimmed	1	884-180
J	Schedule 80 PVC Pipe		Pipe Supply
K	TEE Soc x Soc x Soc		810-010
L	Reducing Bushing Spig x Fipt (3/8")	1	838-129
M	Schedule 80 Nipple 3/8" x 1.5"	1	881-015
N	Lab Ball Valve 3/8"	1	1521-003
O	Union Soc X Soc		857-010
P	90° ELL Soc x Soc		806-010
Q	SR Threaded Y-Strainer, Clear		YS31S8-010CLSR

Example of the components used in a 4 position PVC corrosion coupon rack. Note the use of a flow restricting device (item C).

Figure 2

Example of a mild steel corrosion coupon rack showing an upstream mounted strainer, upward flow, a flow indicator, flow from the coupon holder threaded end toward the coupon, union and removable spool piece, dedicated circulation pump and isolation valves. The pump and flow indicator are used to maintain representative flow conditions.

NOTE: This mild steel pipe rack installation utilizes some plastic components – it is mounted in a location where temperature and pressure are not a concern. It is equipped with a 6 inch steel pipe spool in the lower left corner and is equipped with an in-line water booster pump to assure operation with adequate water flow.

Acknowledgements
This document has been produced by the AWT Cooling Subcommittee Corrosion Coupon Monitoring Task Group by the following individuals:

Task Group Chair:
Ken Sansom, CWT – Solutech Water Management, Inc. - Calgary, Alberta, Canada

Task Group Contributors:
Arthur J. Freedman, Ph.D. – Arthur Freedman Associates, Inc. – Naperville, Illinois, USA
Timothy E. Keister, CWT - ProChemTech International, Inc. – Brockway, Pennsylvania, USA
K. Anthony Selby – Water Technology Consultants, Inc. - Evergreen, Colorado, USA
James Scott, CWT – San Joaquin Chemicals – Fresno, California, USA
W. John (Jack) Soost, CWT – Arthur Freedman Associates, Inc. – Lancaster, Pennsylvania, USA