TECH NOTE | Conversion of Electrochemical Measurements to Mass Loss

ACUITY
corrosion technology

ACUITY CORROSION MONITORING PRODUCTS

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TABLE OF CONTENTS

1 OVERVIEW

This document provides instructions for calculating thickness loss and mass loss using galvanic and free corrosion measurements from Acuity LS™ and Acuity CR™ atmospheric corrosion monitoring systems.

Although electrochemical corrosion rate measurements are often reported in terms of electrical current and charge, the use of thickness loss and mass loss can be more informative for assessing corrosion damage. The use of mass loss and thickness loss is consistent with methods used to classify environmental severity according to ISO 9223.

1.1 Limitations

Conversion of corrosion current and charge to penetration depth is not provided in this document for alloys that undergo localized corrosion (pitting and intergranular corrosion). Penetration depth for localized corrosion processes can be significantly deeper than estimates obtained using uniform corrosion assumptions.

For free corrosion measurements, the Stern-Geary equation is used to calculate thickness and mass loss. Alloys that have localized corrosion, such as pitting and intergranular mechanisms, do not satisfy the assumptions for use of the Stern-Geary equation. The Stern-Geary equation should only be applied to alloys with uniform corrosion. The experimental measurements of Tafel slopes to obtain the Stern-Geary coefficient for an alloy are outside the scope of this Tech Note.

2 SUMMARY OF CONVERSION CONSTANTS AND EQUATIONS FOR MASS LOSS AND THICKNESS LOSS

Equations to determine thickness and mass loss are developed in Sections 3 – 5. This summary section provides conversion constants to calculate thickness and mass loss for galvanic and free corrosion measurements. The conversion constants in Table 1 and Table 2 are suitable for use with Luna corrosion measurement systems and sensors fabricated from the alloys identified. The stated output parameters are calculated using the input parameters, conversion constants and an equation of the form:

$$y = n \cdot x$$

Where

y is the desired output

x is the corrosion monitoring device measurement

n is the conversion constant

The units of each of these parameters and constants are given in Table 1 and Table 2.

Table 1. Data conversion constants for determining thickness and mass loss from Acuity LS galvanic corrosion current and charge measurements. These constants are specific to Acuity LS sensing elements and should not be applied to materials or sensors with other electrode areas.

Input (x)		Alloy Conversion Constants (n)					Output (y)	
Parameter	Units	AA7075	AA2024	1008 Stl	Zinc	Units	Parameter	Units
Galv Current	µA	-	-	8.05	10.37	µm/(µA·a)	Thickness loss rate	µm/a
Total Galv Charge	C	-	-	0.255	0.33	µm/C	Total thickness loss	µm
Galv Current	µA	21.67	21.22	63.15	73.92	$g/(\mu A \cdot m^2 \cdot a)$	Corr mass loss rate	$g/(m^2 \cdot a)$
Total Galv Charge	C	0.69	0.67	2.00	2.34	$g/(C \cdot m^2)$	Corr total mass loss	g/m^2

Table 2. Data conversion constants for determining thickness and mass loss from Acuity LS free corrosion current and charge measurements.

Input (X)		Alloy Conversion Constants (n)				Output (Y)	
Parameter	Units	AA7075-T6	AA2024-T3	1008 Stl	Units	Parameter	Units
Free Corr Current	µA	-	-	47.81	µm/(µA·a)	Thickness loss rate	µm/a
Total Free Corr Charge	C	-	-	1.516	µm/C	Total thickness loss	µm
Free Corr Current	µA	-	-	375.15	$g/ (\mu A \cdot m^2 \cdot a)$	Corr mass loss rate	$g/ (m^2 \cdot a)$
Total Free Corr Charge	C	-	-	11.90	$g/(C \cdot m^2)$	Corr total mass loss	g/m^2

3 LUNA MONITORING SYSTEM MEASUREMENTS

The Luna monitoring systems directly measure and report current (I) in units of microamps (µA) and total charge (Q) in coulombs (C).

3.1 Galvanic Corrosion

The Luna monitoring systems measure galvanic current (I_g) and charge (Q_g) using a zero-resistance-ammeter (ZRA). The galvanic current and charge measured can be used directly for corrosion current (I_{corr}) and total corrosion charge (Q), respectively, in the equations for thickness and mass loss given in Section 4 and Section 5.

3.2 Free Corrosion

The Luna monitoring systems measure free corrosion current (I_{rms}) in units of microamps (µA) and total free corrosion charge (Q_f) in coulombs (C). The free corrosion current is measured as a response to a sinewave excitation of 20 mV_{pp} at a frequency of 0.5 Hz. The free corrosion current is reported by the Acuity LS device as the root mean square (RMS) current response to the sinewave voltage excitation. This allows for a free corrosion current measurement that is not specific to an electrode area or alloy used as the sensing element.

The monitoring system free corrosion current and charge must be converted using the Stern-Geary equation before these measurements can be used for determination of thickness and mass loss (Section 4 and Section 5).

3.2.1 Application of the Stern-Equation to Determine Corrosion Current and Total Corrosion Charge

For alloys that undergo uniform corrosion, such as a low alloy steel, polarization resistance may be obtained, and free corrosion rate estimated by means of the Stern-Geary equation (see ISO 17475, ISO/TR 16208, ASTM G59, ASTM G102). There are several assumptions that should be considered when applying the Stern Geary equation to obtain corrosion rate and mass loss (ISO 22858 and ASTM G59).

The polarization resistance (R_p) in mega-ohm square centimeter (MΩ-cm^2) can be calculated using the RMS excitation voltage (V_{rms}) of 0.00707 volts (V), free corrosion current (I_{rms}) in microamps (µA) and area (A) in square centimeters of one side of the interdigitated electrode of the free corrosion sensor (Equation 1).

$$R_p = 0.5 \cdot \frac{V_{rms}}{I_{rms}} \cdot A$$ Equation 1

Using the Stern-Geary coefficient (β) in volts (V) and the polarization resistance, the free corrosion rate (i_f) in microamp per square centimeter (µA/cm^2) can be calculated (Equation 2):

$$i_f = \frac{\beta}{R_p}$$ Equation 2

Where the Stern-Geary coefficient (β) is given by the anodic (β_a) and cathodic (β_c) Tafel slopes in volts (V) (Equation 3):

$$\beta = \frac{\beta_a \cdot \beta_c}{2.303(\beta_a + \beta_c)}$$ Equation 3

The anodic and cathodic Tafel slopes are determined experimentally according ASTM G59 and ASTM G102.

3.2.2 Total Free Corrosion Charge

The total free corrosion charge density (q_f) is calculated using the area (A) of a single electrode of the interdigitated sensor in square centimeters (cm^2) and total free corrosion charge (Q_f) in coulombs (C) output by the Acuity LS device (Equation 4).

$$q_f = \frac{2 \cdot \beta}{V_{rms} \cdot A} \cdot Q_f \quad (C/cm^2)$$ Equation 4

3.2.3 Use of Free Corrosion Current Density and Charge Density for Mass Loss and Thickness Loss

The free corrosion current density (i_f) and charge density (q_f) calculated with the Stern-Geary equation can be used directly for corrosion current density (i_{corr}) and total corrosion charge density (q), respectively, in the equations for thickness and mass loss given in Section 4 and Section 5.

4 THICKNESS LOSS

The corrosion current density (i_{corr}) and corrosion charge density (q) can be used to calculate the thickness loss rate and total thickness loss, respectively.

4.1 Thickness Loss Rate

The corrosion current density (i_{corr}) in units of microamp per square centimeter (µm/cm^2) is calculated using the area (A) in square centimeters (cm^2) of one of the electrodes of the sensor (Equation 5). For a galvanic sensor the area of the anode shall be used (Table 3). Using the methods detailed in ISO 22858 and ASTM G102, the corrosion thickness loss rate (r_t) can be determined from the corrosion current density, alloy density (ρ) and equivalent weight (W_e) of the alloy (Equation 6 and Table 3). For a galvanic sensor, the anode alloy density and equivalent weight shall be used. The thickness loss rate is expressed in units consistent with ISO 9223 (microns per year (µm/a)).

$$i_{corr} = \frac{I_{corr}}{A} \quad (\mu A/cm^2)$$ Equation 5

$$r_t = K_1 \cdot \frac{i_{corr}}{\rho} \cdot W_e$$ Equation 6

r_t is the corrosion thickness loss rate of metal, expressed in microns per year (µm/a);

K_1 is a constant of proportionality equal to 3.270, expressed as micron gram per microamp centimeter year ((µm · g)/(µA · cm · a)).

ρ Is the alloy density in gram per cubic centimeter (g/cm^3) (ASTM G1)

W_e is the atomic weight of the metal divided by the valence of the oxidized metal atom, this is used as a dimensionless quantity (ASTM G102).

Table 3. Material and sensor parameters for determining mass and thickness loss.

Parameter	Material			
	AA7075-T6	AA2024-T3	1008 Steel	Zinc
Equivalent Weight (W_e) (unitless)	9.58	9.38	27.92	32.68
Area (A) (cm^2)	1.445	1.445	1.445	1.445
Density (ρ)	2.81	2.78	7.85	7.13

4.2 Total Thickness Loss

The total corrosion charge density (*q*) in units of coulomb per square centimeter (C/cm^2) is calculated from the total charge (*Q*) in coulombs (C) measured by the Acuity LS device using the area (*A*) in square centimeters (cm^2) of one of the electrodes of the sensor (Equation 7). For a galvanic sensor the area of the anode shall be used. Using the methods detailed in ISO 22858 and ASTM G102, the total corrosion thickness loss (R_t) can be determined from the total corrosion charge density, alloy density (ρ) and equivalent weight (W_e) of the alloy (Equation 8 and Table 3). For a galvanic sensor, the anode alloy density and equivalent weight shall be used. The total thickness loss is expressed in units of microns (µm).

$$q = \frac{Q}{A}\ (C/cm^2)$$ Equation 7

$$R_t = K_3 \cdot \frac{q}{\rho} \cdot W_e$$ Equation 8

R_t is the total corrosion thickness loss of metal, expressed in microns (µm);

K_3 is a constant of proportionality equal to 0.1037, expressed as micron gram per coulomb centimeter ((µm · g)/(C · cm));

5 Mass Loss

The corrosion current density (i_{corr}) and corrosion charge density (*q*) can be used to calculate the mass loss rate and total mass loss, respectively.

5.1 Mass Loss Rate

The corrosion current density (i_{corr}) is calculated using the area (*A*) of one of the electrodes of the sensor (Equation 5). For a galvanic sensor the area of the anode shall be used. Using the methods detailed in ISO 22858 and ASTM G102, the corrosion mass loss rate (r_m) can be determined from the corrosion current density and equivalent weight (W_e) of the alloy (Equation 9 and Table 3). For a galvanic sensor, the anode alloy equivalent weight shall be used. The mass loss rate is expressed in grams per square meter year (g/(m^2·a)).

$$r_{\mathrm{m}} = K_2 \cdot \ i_{\mathrm{corr}} \cdot W_e \qquad \text{Equation 9}$$

r_{m} is the corrosion mass loss rate of metal, expressed in grams per square meter year (g/(m^2 · a));

K_2 is a constant of proportionality equal to 3.268, expressed as gram square centimeter per microamp square meter year ((g · cm^2)/(µA · m^2 · a)).

5.2 Total Mass Loss

The total corrosion charge density (*q*) is calculated from the total corrosion charge (*Q*) in coulombs (C) measured by the Acuity LS device using the area (*A*) of one of the electrodes of the sensor (Equation 7). For a galvanic sensor the area of the anode shall be used. Using the methods detailed in ISO 22858 and ASTM G102, the total corrosion mass loss (R_m) can be determined from the total charge density and equivalent weight (W_e) of the alloy (Equation 10 and Table 3). For a galvanic sensor, the anode alloy equivalent weight shall be used. The total mass loss is expressed in units of grams per square meter (g/m^2).

$$R_{\mathrm{m}} = K_4 \cdot \ q \cdot W_e \qquad \text{Equation 10}$$

R_{m} is the total galvanic corrosion mass loss of metal, expressed in grams per square meter (g/m^2);

K_4 is a constant of proportionality equal to 0.104, expressed as gram square centimeter per coulomb square meter ((g · cm^2)/(C · m^2)).

6 References and Links

ISO 9223:2012, Corrosion of metals and alloys — Corrosivity of atmospheres — Classification, determination and estimation.

ISO 9226:2012, Corrosion of metals and alloys — Corrosivity of atmospheres — Determination of corrosion rate of standard specimens for the evaluation of corrosivity.

ISO 17475:2005, Corrosion of metals and alloys — Electrochemical test methods — Guidelines for conducting potentiostatic and potentiodynamic polarization measurements.

ISO 22858:2020, Corrosion of metals and alloys — Electrochemical measurements — Test method for monitoring atmospheric corrosion.

ISO/TR 16208:2014, Corrosion of metals and alloys — Test method for corrosion of materials by electrochemical impedance measurements.

ASTM G1 - 03(2017)e1, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

ASTM G59-97(2020), Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements, ASTM International, West Conshohocken, PA, 2020, www.astm.org.

ASTM G102-89(2015)e1, Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements, ASTM International, West Conshohocken, PA, 2015, www.astm.org.

7 GLOSSARY

7.1 Abbreviated Terms

Acuity CR™	Acuity Coating and Corrosion Evaluation System
Acuity LS™	Acuity LS Corrosion Management System
ASTM	ASTM International
Corr	Corrosion
Galv	Galvanic
ISO	International Standards Organization
ZRA	Zero-Resistance-Ammeter

7.2 Symbols

ρ	Density
β	Stern-Geary coefficient
β_a	Anodic Tafel slope
β_c	Cathodic Tafel slope
µA	Microamp
A	Area of one electrode of an interdigitated electrode sensor
a	Year
C	Coulomb
cm^2	Square centimeter
Hz	Hertz
I_{corr}	Corrosion current
i_{corr}	Corrosion current density
i_f	Free corrosion current density
I_g	Galvanic current (Acuity LS device output)
I_{rms}	Free corrosion current root mean square (Acuity LS device output)
K_1	Conversion constant for thickness loss rate
K_2	Conversion constant for mass loss rate
K_3	Conversion constant for total thickness loss
K_4	Conversion constant for total mass loss
m^2	Square meter
mV_{pp}	Millivolt peak-to-peak
MΩ	Megaohm
n	Conversion constant
Q	Total corrosion charge
q	Total corrosion charge density
Q_f	Total free corrosion charge (Acuity LS device output)
q_f	Total free corrosion charge density
Q_g	Total galvanic charge (Acuity LS device output)
r_m	Corrosion mass loss rate
R_m	Total corrosion mass loss

R_p Polarization resistance

r_t Corrosion thickness loss rate

R_t Total corrosion thickness loss

V Volt

V_{rms} Free corrosion excitation voltage root mean square

W_e Equivalent weight

x Variable, system measurement

y Variable, parameter being calculated

8 REVISION HISTORY

Revision	Date	Changes
∅	8 June 2021	Original Tech Note
1	1 January 2023	Update company information
2	16 May 2023	Update brand, company, and corrected equation numbering information
3	22 June 2023	Added material parameters - Table 3

The latest version of this document and all application notes can be found at: www.acuitycorrosion.com.

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