Ballot ID:

Title:	**MODIFICATION OF API 581 CARBONATE CRACKING – Confirmation Ballot**
Purpose:	Modification of the damage factor to include susceptibility chart
Impact:	Changes in the damage factor criteria
Rationale:	To update Part 10 based on the modified susceptibility range. This was derived from NACE chart for pH versus Carbonate ion.
Technical Reference(s):	

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Tracking Status					
Submitted to Task Group		Submitted to SCI		Submitted to Master Editor	
Date	*Resolution*	*Date*	*Resolution*	*Date*	*Added*

Proposed Changes and/or Wording *{attach additional documentation after this point}*

10 SCC Damage Factor – Alkaline Carbonate Stress Corrosion Cracking

10.1 Scope

The DF calculation for components subject to alkaline carbonate stress corrosion cracking (ACSCC) is covered in this section.

10.2 Description of Damage

ACSCC is the common term applied to surface breaking cracks that occur at or near carbon and low alloy steel welds under the combined action of tensile stress and in the presence of alkaline water containing moderate to high concentrations of carbonate ions (CO_3^{2-}).

On a macroscopic level, ACSCC typically propagates parallel to the weld in the adjacent base material, but can also occur in the weld deposit or heat-affected zones.

At times surface inspection results of ACSCC may be mistaken for SSC or SOHIC, but further review will show that ACSCC is usually located further from the toe of the weld into the residual stress field of the base material and can contain multiple parallel cracks. When cracking is in the weld metal, the pattern of cracking observed on the steel surface is sometimes described as a “spider web” of small cracks, which often initiate at or interconnect with weld-related flaws that serve as local stress risers. Finally, from the microscopic perspective the cracking is characterized by predominantly intergranular, oxide-filled cracks similar in appearance to ACSCC found in caustic and amine services.

Historically, ACSCC has been most prevalent in fluid catalytic cracking unit main (FCCU) fractionator overhead condensing and reflux systems, the downstream wet gas compression system, and the sour water systems emanating from these areas. Based upon recent survey results, sour water strippers with side-pump around designs, CO_2 removal facilities for hydrogen manufacturing units and delayed coker light ends units have been added to the list of affected units. There have also been cases of ACSCC in non-refining industries. In all instances, both piping and vessels are affected.

Assuming the presence of an alkaline water phase containing H_2S, three key parameters are used to assess the susceptibility of steel fabrications to ACSCC; pH of the water, carbonate ion concentration of the water, and the residual stress level of the exposed carbon or low alloy steel.

a) pH – Typically pHs are greater than 7.5 and process streams that are lower in H_2S or higher in NH_3 causing higher pHs will be more susceptible to this form of ACSCC. Although H_2S is often present, no threshold level has been established; no evidence exists to indicate cyanides or polysulfides have an impact.
b) Carbonates – Plants that generate more carbonate ions in the water will be more susceptible to ACSCC.
c) Residual Stresses – ACSCC appears to be very susceptible to residual stress levels so that welded structures and cold worked structures will be susceptible.

Studies have concluded that the electrochemical potential of the alkaline water can be used to assess the likelihood of ACSCC.— However, accurate measurement in a field environment is difficult. Therefore, further discussion of the electrochemical potential is outside the scope of this document.

With regard to mitigation techniques, the application of a post fabrication stress-relieving heat treatment (e.g., ~~post weld heat treatment~~PWHT) is the most commonly used method of preventing ACSCC in carbon and low alloy steels. A heat treatment of about 649-663°C (1,200-1,225°F) in accordance with WRC 452 or AWS D1010 is considered effective to minimize residual stresses. The heat treatment requirements apply to all exposed welds as well as any external welds with heat affected zones (HAZ) in contact with the service environment. Other mitigation techniques include: process barriers (either organic or metallic), alloy upgrades (solid or clad 300 series, Alloy 400 or other corrosion resistant alloys), effective water washing and inhibitor injection.

10.3 Screening Criteria

If the component’s material of construction of the component is carbon or low alloy steel and the process environment contains water at pH > 7.5 in any concentration, then the component should be considered for evaluation for susceptibility to ACSCC. Another trigger would be changes in FCCU feed sulfur and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen~~ [7]~~.

10.4 Required Data

The basic component data required for analysis is given in Table 4.1 and the specific data required for determination of the ACSCC DF is provided in Table 10.1.

10.5 Basic Assumptions

The main assumption in determining the DF for ACSCC is that the damage can be characterized by a susceptibility parameter that is designated as high, medium, or low based on process environment, material of construction, and component fabrication variables (i.e. cold work, welding and heat treatment). A severity index is assigned based on the susceptibility parameter.

If cracks are detected in the component during an inspection, the susceptibility is designated as High, and this will result in the maximum value for the Severity Index. Cracks that are found during an inspection should be evaluated using Fitness-For-Service methods in API 579-1/ASME FFS-1 [12~~0~~].

10.6 Determination of the Damage Factor

10.6.1 Overview

A flow chart of the steps required to determine the DF for ACSCC is shown in Figure 10.1. The following sections provide additional information and the calculation procedure.

10.6.2 Inspection Effectiveness

Inspections are ranked according to their expected effectiveness at detecting for ACSCC. Examples of inspection activities that are both intrusive (requires entry into the equipment) and non-intrusive (can be performed externally), are provided in Annex 2.C, Table 2.C.9.4.

If multiple inspections of a lower effectiveness have been conducted during the designated time period, they can be equated to an equivalent higher effectiveness inspection in accordance with Section 3.4.3.

10.6.3 Calculation of the Damage Factor

The following procedure may be used to determine the DF for ACSCC, see Figure 10.1

a) STEP 1 – Determine the susceptibility for cracking using Figure 10.1 and Table 10.2 based on the pH of the water, CO_3^{2-} concentration, and knowledge of whether the component has been ~~PWHT'd~~stress relieved. Note that a HIGH susceptibility should be used if cracking is confirmed to be present.

b) STEP 2 – Based on the susceptibility in STEP 1, determine the severity index, S_{VI}, from Table 10.3.

c) STEP 3 – Determine the time in-service, age, since the last *Level A*, *B* or *C* inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation.

d) STEP 4 – Determine the number of inspections, and the corresponding inspection effectiveness category using Section 10.6.2 for past inspections performed during the in-service time. Combine the inspections to the highest effectiveness performed using Section 3.4.3.

e) STEP 5 – Determine the base DF for ACSCC, D_{fB}^{ACSCC}, using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 4, and the severity index, S_{VI}, from STEP 2.

f) STEP 6 – Calculate the escalation in the DF based on the time in-service since the last inspection using the age from STEP 3 and Equation (2.29). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

$$D_f^{ACSCC} = D_{fb}^{ACSCC} \cdot (\max[age, 1.0])^{1.1} \quad (2.29)$$

10.7 Nomenclature

age is the component in-service time since the last cracking inspection or service start date

D_f^{ACSCC} is the DF for ACSCC

D_{fB}^{ACSCC} is the base value of the DF for ACSCC

S_{VI} is the severity index

10.8 References

1. R. D. Merrick, "Refinery Experiences with Cracking in Wet H_2S Environments," *Materials Performance* 27, 1 (1988), pp. 30–36.
2. J. H. Kmetz and D. J. Truax, "Carbonate Stress Corrosion Cracking of Carbon Steel in Refinery FCC Main Fractionator Overhead Systems," NACE Paper #206, CORROSION/90.
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4. E. Mirabel et al, "Carbonate-type Cracking in a FCC Wet Gas Compressor Station", Materials Performance, July, 1991, pp.41-45.
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8. WRC Bulletin 452, "Recommended Practices for Local Heating of Welds in Pressure Vessels", Welding Research Council (WRC), Shaker Heights, OH.
9. NACE International Publication 8X194, "Materials and Fabrication Practices for New Pressure Vessels Used in Wet H2S Refinery Service", December 2006.
10. NACE International Publication 34108, "Review and Survey of Alkaline Carbonate Stress Corrosion Cracking in Refinery Sour Waters", Appendix D, June 2013.
11. API RP 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*, American Petroleum Institute, 2nd Edition, April 2011.
12. API 579-1/ASME FFS-1 *Fitness-For-Service*, American Petroleum Institute, Washington, D.C., 20005, 2016.

10.9 Tables

Table 10.1 – Data Required for Determination of the Damage Factor – ACSCC

Required Data	Comments
Susceptibility	The susceptibility is determined by expert advice or using

(Low, Medium, High)	the procedures in this section. This type of cracking may be sporadic and may grow rapidly depending on subtle changes in the process conditions. Periodic monitoring of process pH and CO_3^{2-} in FCC alkaline waters should be done to determine cracking susceptibility.
Presence of Water (Yes or No)	Determine whether free water is present in the component. Consider not only normal operating conditions, but also startup, shutdown, process upsets, etc.
pH of Water	Determine the pH of the water phase. If analytical results are not readily available, it should be estimated by a knowledgeable process engineer.
CO_3^{2-} Concentration in water	Determine the carbonate ion concentration of the water phase present in this component. If analytical results are not readily available, it should be estimated by a knowledgeable process engineer.
Age (years)	Use inspection history to determine the time since the last SCC inspection.
Inspection Effectiveness Category	The effectiveness category that has been performed on the component.
Number of inspections	The number of inspections in each effectiveness category that have been performed.

Table 10.2 – Susceptibility to Cracking – ACSCC[2]

pH	Susceptibility to Cracking as a Function of Residual Stress and CO_3^{2-} ~~CO_3^{-2}~~ Concentration in the Water[(1)]				
	Effective PWHT	Unknown or Ineffective PWHT and/or Possible Cold Working			
	CO_3^{2-} ~~CO_3^{2-}~~ ≤ 10,000 ppm[(2)]	CO_3^{2-} ~~CO_3^{2-}~~ < 10 ppm	~~CO_3 <~~ 10 ≤ CO_3^{2-} ~~CO_3^{2-}~~ ≤ 100 ppm	~~CO_3 ≥~~ 100 ≤ CO_3^{2-} ~~CO_3^{2-}~~ ≤ 1,000 ppm	CO_3^{2-} ~~CO_3^{2-}~~ ≥ 1,000 ppm
~~< 7~~ pH ≥ 9.5	None	~~High~~None	~~High~~Low	High	High
9.0 < pH ≤ 9.5	None	~~Medium~~None	~~High~~Low	High	High
8.5 < pH ≤ 9.0	None	~~Low~~None	~~Medium~~Low	High	High
~~≥7.5 to~~ 8.0 < pH ≤ 8.5	None	None	Low	Medium	High
≥7.5 < pH ≤ 8.0 ~~to 9.0~~	None	None	None	Low	Low
~~≥ 9.0~~pH <7.5	None	None	None	None	None

Note 1: Traditional alkalinity titration methods (P,M alkalinity) are not effective for measurement of ~~CO_3~~ CO_3^{2-} in sour water.

Note 2: In refinery processes, the concentration of CO_3^{2-} is typically less than 10,000 ppm

Table 10.3 – Determination of Severity Index – ACSCC

Susceptibility	Severity Index – S_{VI}
High	1,000
Medium	100
Low	10
None	0

10.10 Figure

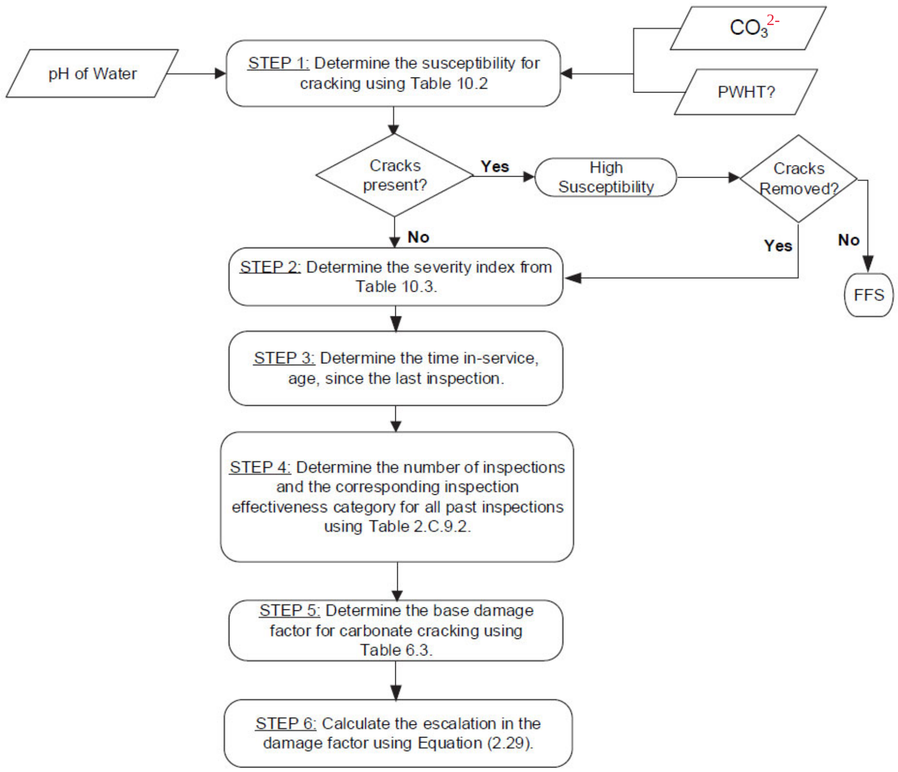

Figure 10.1 – Determination of the ACSCC DF

~~Developed from the following chart:~~