Designation: D4582 – 10

Standard Practice for
Calculation and Adjustment of the Stiff and Davis Stability Index for Reverse Osmosis[1]

This standard is issued under the fixed designation D4582; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the calculation and adjustment of the Stiff and Davis Stability Index (S & DSI) for the concentrate stream of a reverse osmosis device. This index is used to determine the need for calcium carbonate scale control in the operation and design of reverse osmosis installations. This practice is applicable for concentrate streams containing more than 10 000 mg/L of total dissolved solids. For concentrate streams containing less than 10 000 mg/L of total dissolved solids, refer to Practice D3739.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D511 Test Methods for Calcium and Magnesium In Water
D1067 Test Methods for Acidity or Alkalinity of Water
D1129 Terminology Relating to Water
D1293 Test Methods for pH of Water
D1888 Methods Of Test for Particulate and Dissolved Matter in Water (Withdrawn 1989)[3]
D3739 Practice for Calculation and Adjustment of the Langelier Saturation Index for Reverse Osmosis
D4194 Test Methods for Operating Characteristics of Reverse Osmosis and Nanofiltration Devices
D4195 Guide for Water Analysis for Reverse Osmosis and Nanofiltration Application
D6161 Terminology Used for Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis Membrane Processes

3. Terminology

3.1 *Definitions*—For definitions of terms used in the practice, refer to Terminology D1129 and D6161.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 For description of terms relating to reverse osmosis, refer to Test Methods D4194.

3.2.2 *Stiff and Davis Stability Index (S & DSI)* [4]—an index calculated from total dissolved solids, calcium concentration, total alkalinity, pH, and solution temperature that shows the tendency of a water solution to precipitate or dissolve calcium carbonate.

4. Summary of Practice

4.1 This practice consists of calculating the S & DSI index for a reverse osmosis concentrate stream from the total dissolved solids, calcium ion content, total alkalinity, pH, and temperature of the feed solution and the recovery of the reverse osmosis system.

4.2 This practice also presents techniques to lower the S & DSI by decreasing the recovery; decreasing the calcium and alkalinity concentrations; or by changing the ratio of total alkalinity to free carbon dioxide in the feedwater.

5. Significance and Use

5.1 In the design and operation of reverse osmosis installations, it is important to predict the calcium carbonate scaling properties of the concentrate stream. Because of the increase in total dissolved solids in the concentrate stream and the differences in salt passages for calcium ion, bicarbonate ion, and free CO_2, the calcium carbonate scaling properties of the concentrate stream will generally be quite different from those of the feed solution. This practice permits the calculation of the S & DSI for the concentrate stream from the feed water analyses and the reverse osmosis operating parameters.

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[1] This practice is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.08 on Membranes and Ion Exchange Materials.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Stiff, H. A. and Davis, L. E., "A Method for Predicting the Tendency of Oil Field Waters to Deposit Calcium Carbonate," *Petroleum Transactions*, Vol 195, 1952.

5.2 A positive S & DSI indicates the tendency to form a calcium carbonate scale, which can be damaging to reverse osmosis performance. This practice gives procedures for the adjustment of the S & DSI.

6. Procedure

6.1 Determine the calcium concentration in the feed solution in accordance with Test Methods D511 and express as $CaCO_3$ as demonstrated in section 6.6.

6.2 Determine the total dissolved solids of the feed solution using Test Methods D1888.

6.3 Determine the total alkalinity of the feed solution using Test Methods D1067 and express as $CaCO_3$.

6.4 Measure the pH of the feed solution using Test Methods D1293.

6.5 Measure the temperature of the feed solution.

6.6 Convert feed water alkalinity and calcium as mg/L $CaCO_3$.

$$Ca_f = [Ca^{+2}] \times \frac{100gCaCO_3}{mol} \times \frac{1000mg}{g} \times \frac{1eqCaCO_3}{1eqCa^{+2}} \tag{1}$$

$$Alk_f = [HCO_3^{\ -}] \times \frac{100gCaCO_3}{mol} \times \frac{1000mg}{g} \times \frac{1eqCaCo_3}{2eqHCO_3^{\ -}} \tag{2}$$

where:

Ca_c = calcium concentration in concentrate as $CaCO_3$, mg/L,
Ca_f = calcium concentration in feed as $CaCO_3$, mg/L,
Alk_c = alkalinity in concentrate as $CaCO_3$, mg/L, and
Alk_f = alkalinity in feed as $CaCO_3$, mg/L.

6.7 Measure the concentration of all major ions using the methods cited in Guide D4195. At a minimum, measure the concentration of Mg^{++}, Na^+, K^+, $SO_4^=$, and Cl^-.

7. Calculation

7.1 Calculate the calcium concentration in the concentrate stream from the calcium concentration in the feed solution, the recovery of the reverse osmosis system, and the calcium ion passage as follows:

$$Ca_c = Ca_f \times \left(\frac{1 - Y(SP_{Ca})}{1 - Y} \right) \tag{3}$$

where:

Ca_c = calcium concentration in concentrate as $CaCO_3$, mg/L,
Ca_f = calcium concentration in feed as $CaCO_3$, mg/L,
Y = recovery of the reverse osmosis system, expressed as a decimal, and
SP_{Ca} = calcium ion passage, expressed as a decimal.

NOTE 1—SP_{Ca} can be obtained from the supplier of the specific reverse osmosis system. For most reverse osmosis devices, SP_{Ca} can be considered to be zero, in which case the equation simplifies to:

$$Ca_c = Ca_f \times \left(\frac{1}{1 - y} \right) \tag{4}$$

This assumption will introduce only a small error.

7.2 Calculate the alkalinity in the concentrate stream from the alkalinity in the feed solution, the recovery of the reverse osmosis system, and the passage of alkalinity by:

$$Alk_c = Alk_f \times \frac{1 - y(SP_{Alk})}{1 - y} \tag{5}$$

where:

Alk_c = alkalinity in concentrate as $CaCO_3$, mg/L,
Alk_f = alkalinity in feed as $CaCO_3$, mg/L,
y = recovery of the reverse osmosis system, expressed as a decimal, and
SP_{Alk} = alkalinity passage, expressed as a decimal.

NOTE 2—SP_{Alk} may be dependent on the pH of the feed solution, and its value should be obtained from the supplier of the specific reverse osmosis system.

7.3 Calculate the ionic strength of the feed stream by:

$$I_f = 1/2 \sum m_i z_i^2 \tag{6}$$

where:

I_f = ionic strength of the feed stream,
m_i = molal concentration of ion, i (moles/1000 g of water) in the feed solution, and
z_i = ionic charge of ion, i.

To calculate I_f use at least all major ions: Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, $SO_4^=$, and Cl^-.

7.4 Calculate the ion strength of the concentrate stream from the ionic strength of the feed solution, the recovery, and the total dissolved solids of the feed solution by:

$$I_c = I_f \left[\frac{10^6 - TDS_f}{10^6 - (TDS_f)\left(\frac{1}{1 - y} \right)} \right] \left[\frac{1}{1 - y} \right] \tag{7}$$

where:

I_c = ionic strength of the concentrate stream and
TDS_f = total dissolved solids of the feed solution, mg/L.

7.5 Calculate the pCa and pAlk from Fig. 1 or use Eq. or :

$$pCa = -0.4343 \times Ln(Ca_c) + 5 \tag{8}$$

$$pAlk = -0.45 \times Ln(Alk_c) + 4.8 \tag{9}$$

7.6 Calculate *K*, which is a function of Ionic Strength and Temperature in °C, from Fig. 2 or Eq. :

$$\begin{aligned} K = {} & 3.78342 + 0.16781*LN(I_c) - 0.26411*LN(I_c)\text{^}2 \\ & - 0.1029*LN(I_c)\text{^}3 - \\ & 0.01124*LN(I_c)\text{^}4 - 0.01221*T - 0.0001316*T\text{^}2 \end{aligned} \tag{10}$$

where:

I_c = ionic strength of the concentrate, and
T = temperature in °C.

7.7 Calculate saturation pH according to Eq. :

$$pH_{sc} = pCa_c + pAlk_c + K \tag{11}$$

7.8 Calculate the free carbon dioxide content (C) in the concentrate stream by assuming that the CO_2 concentration in the concentrate is equal to the CO_2 concentration in the feed: $C_c = C_f$. The concentration of free carbon dioxide in the feed solution is obtained from Fig. 2 as a function of the alkalinity and the pH of the feed solution.

7.8.1 Calculate CO_{2f} from the alkalinity (as $CaCO_3$) and the pH_f from Fig. 3 or the following equation:

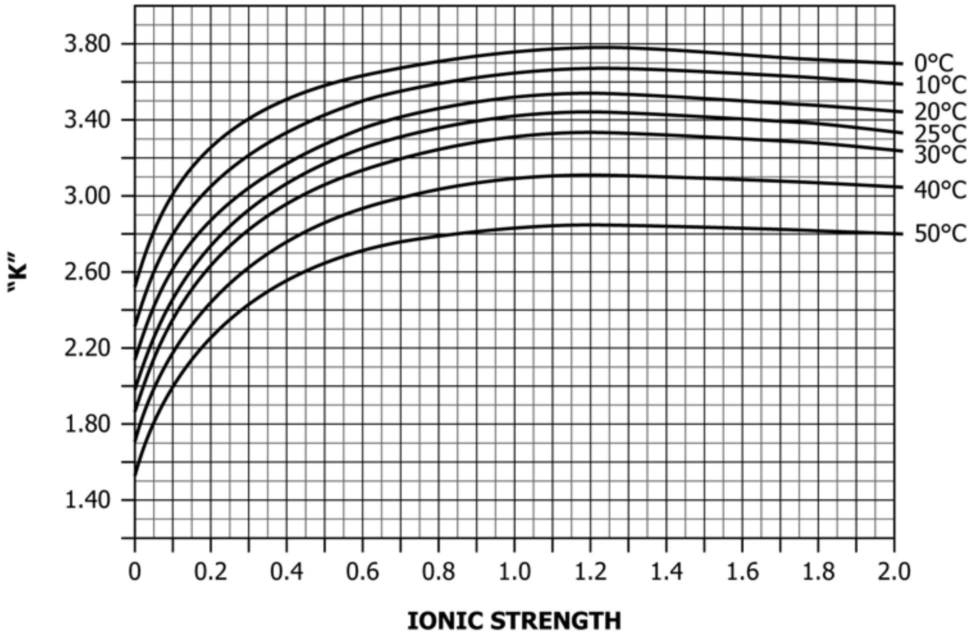

FIG. 1 *K* versus Ionic Strength and Temperature

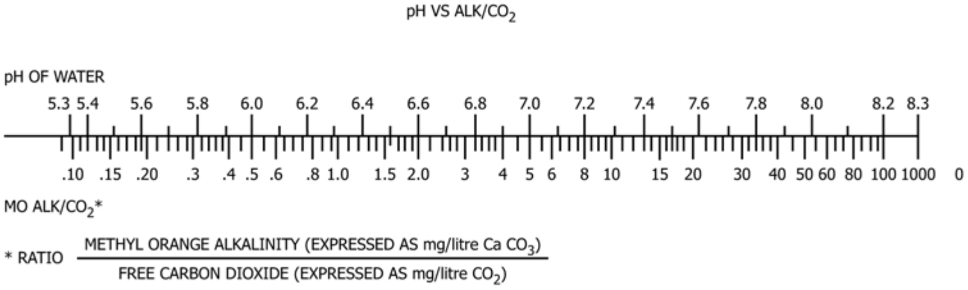

FIG. 2 pH versus Methyl Orange Alkalinity/Free CO_2

$$CO_{2f} = Alk_f \times exp - \left(\frac{pH_f - 6.3022}{0.423}\right) = CO_{2c} \tag{12}$$

Assume that the CO_2 in the concentrate equals that of the feed.

7.9 Calculate the pH of the concentrate stream (pH_c) using the ratio of alkalinity (from 7.2) to free CO_2 in the concentrate (from 7.8), Fig. 3, or .

$$pH_c = 0.423 \times Ln(Alk_c/CO_{2c}) \times 6.2033 \tag{13}$$

NOTE 3—For seawater systems, the calculated pH of the concentrate stream can be 0.1 to 0.2 higher than measured pH values if the feed pH is above 7.0. In these cases, empirical correlations between the feed pH and the concentrate pH as a function of conversion can be used to more accurately calculate the concentrate pH. Check with the supplier of the reverse osmosis (RO) device to determine if empirical correlations should be used.

7.10 Calculate the Stiff and Davis Stability Index of the concentrate (S & DSI_c) as follows:

$$S \ \& \ DSI_c = pH_c - pH_s \tag{14}$$

7.10.1 *Adjustments of S & DSI_c*—If the S & DSI_c is unacceptable based on the supplier's recommendation, adjustments can be made by one of the following means. A new S & DSI_c can then be calculated.

7.10.1.1 The recovery (*y*) can be lowered and the S & DSI_c can be calculated as above by substituting a new value for the recovery.

7.10.1.2 Decreasing the calcium and alkalinity concentrations in the feed solution by means of lime or lime soda ash softening will increase the *p*Ca and *p*Alk and will therefore decrease the pH_s.

7.10.2 Addition of acid (HCl, CO_2, H_2SO_4, etc.) to the feed solution either with or without lime or lime soda ash softening changes the Alk_f, C_f, pH and may change the SP_{Alk}. The slight change in I_f can usually be neglected. Acid addition will decrease the S& DSI_c; however, since many variables change with acidification, trial and error computations are required to determine the amount of acid needed to determine the amount of acid needed to obtain the desired S & DSI_c.

7.10.2.1 For an assumed pH (pH acid), obtained from addition of acid to the feed solution, obtain the ratio of Alk_{Acid}/C_{Acid} from Fig. 2. From this ratio, Alk_f and C_f, calculate the milligrams per litre of acid used (*x*). For example, for H_2SO_4 addition (100 %), calculate as follows:

$$(Alk_{Acid}/C_{Acid}) = (Alk_f - 1.02x)/(C_f + 0.90x) \tag{15}$$

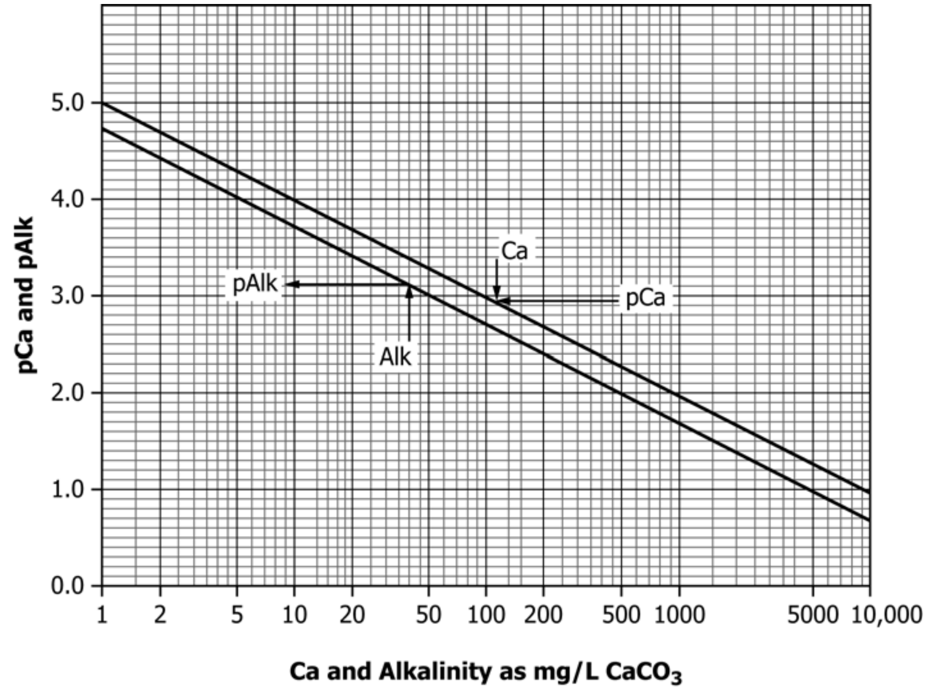

FIG. 3 Conversion of Calcium and Alkalinity to *p*Ca and *p*Alk

7.10.2.2 Calculate the total alkalinity of the acidified feedwater (Alk_{Acid}) and the CO_2 content in the acidified feedwater (C_{Acid}) as follows:

$$Alk_{Acid} = Alk_f - 1.02x \tag{16}$$

$$C_{Acid} = C_f + 0.90x \tag{17}$$

7.10.2.3 Using Alk_{Acid}, C_{Acid}, and the supplier's value for SP_{Alk} for the new pH, calculate the S& DSI_c in accordance with Section 7.

7.10.2.4 If HCl (100 %) is used for acidification, the equation in 7.10.2.1 is as follows:

$$(Alk_{Acid}/C_{Acid}) = (Alk_f - 1.37y)/(C_f + 1.21y) \tag{18}$$

where:

y = HCl, mg/L (100 %).

8. Reverse Osmosis in Operation

8.1 Once a reverse osmosis system is operating, the S & DSI_c can be directly calculated from the analysis of Alk_c, Ca_c, pH_c, and I_c of the concentrate stream and compared with the projected S & DSI_c calculated in Section 7.

9. Keywords

9.1 calcium carbonate; membrane scaling; reverse osmosis (RO); stability index for RO; Stiff and Davis Stability Index (S & DSI)

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