



Designation: D4582 – 23

Standard Practice for Calculation and Adjustment of the Stiff and Davis Stability Index for Reverse Osmosis¹

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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

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 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.3 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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](#)

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.

[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 Terminologies [D1129](#) and [D6161](#).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *alkalinity, n*—the quantitative capacity of aqueous media to react with hydrogen ions; “M” alkalinity is that which will react with acid as the pH of the sample is reduced to the methylorange endpoint of about 4.5; “P” alkalinity is that which reacts with acid as the pH of the sample is reduced to the phenolphthalein end point of 8.3; “M” is the total alkalinity which is the sum of hydroxide, carbonate, and bicarbonate contents and “P” includes all the hydroxyl and half the carbonate content.

3.2.2 *calcium carbonate equivalents (mg/L as CaCO₃), n*—a method for expressing mg/L as ion in terms of calcium carbonate; concentration in calcium carbonate equivalents is calculated by multiplying concentration in mg/L of the ion by the equivalent weight of calcium carbonate (50) and dividing by the equivalent weight of the ion.

3.2.3 *concentrate, n*—the stream exiting a crossflow membrane device which has increased concentration of solutes and particles over the feed stream; portion of the feed stream which does not pass through the membrane; the stream in which dissolved solids or particulates, or both, are concentrated in a membrane separation process.

3.2.4 *feed water, n*—that water entering a device or process.

3.2.5 *ionic strength, n*—measure of the overall electrolytic potential of a solution, the strength of a solution based on both the concentrations and valencies of the ions present.

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

3.2.6 *molarity* ($-mI$), n —moles (gram molecular weight) of solute per 1000 g of solvent.

3.2.7 *pH*, n —negative logarithm of the effective hydrogen-ion activity, approximately $-\log_{10} [H^+]$ where $[H^+]$ is equivalents per litre concentration.

3.2.8 *recovery*— Y (*conversion*), n —the ratio of product quantity (permeate stream flow rate) over the feed quantity (feed stream flow rate), given as fraction or in percent.

3.2.9 *reverse osmosis (RO)*, n —the separation process where one component of a solution is removed from another component by flowing the feed stream under pressure across a semipermeable membrane that causes selective movement of solvent against its osmotic pressure difference; RO removes ions based on electro chemical forces, colloids, and organics down to 150 molecular weight.

3.2.9.1 *Discussion*—May also be called hyperfiltration.

3.2.10 *saturation*, n —the point at which a solution contains enough of a dissolved solid, liquid, or gas so that no more will dissolve into the solution at a given temperature and pressure.

3.2.11 *Stiff & Davis stability index, S & DSI^A*, n —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.

3.2.11.1 *Discussion*—S & DSI is used primarily for seawater RO applications. See Practice D4582 and D3739.

4. Summary of Practice

4.1 This practice consists of calculating the S & DSI 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 CO₂, 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.

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.

^A 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.

6. Procedure

6.1 Determine the calcium concentration in the feed solution in accordance with Test Methods D511 and express as CaCO₃ as demonstrated in 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 CaCO₃.

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 CaCO₃.

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

$$Alk_f = [HCO_3^-] \times \frac{100gCaCO_3}{mol} \times \frac{1000mg}{g} \times \frac{1eqCaCO_3}{2eqHCO_3^-} \quad (2)$$

where:

Ca_f = calcium concentration in feed as CaCO₃, mg/L, and
 Alk_f = alkalinity in feed as CaCO₃, 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⁺, SO₄⁻, 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:

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

where:

Ca_c = calcium concentration in concentrate as CaCO₃, mg/L,

Ca_f = calcium concentration in feed as CaCO₃, mg/L,

Y = recovery of the reverse osmosis system, expressed as a decimal between 0 and 1, 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:

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

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:

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

where:

Alk_c = alkalinity in concentrate as CaCO₃, mg/L,

Alk_f = alkalinity in feed as CaCO₃, mg/L,

Y = recovery of the reverse osmosis system, expressed as a decimal between 0 and 1, 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:

$$I_f = (1/2) \sum m_i z_i^2 \quad (6)$$

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:

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

where:

I_c = ionic strength of the concentrate stream,

I_f = ionic strength of the feed stream,

TDS_f = total dissolved solids of the feed solution, mg/L, and

Y = recovery of the reverse osmosis system, expressed as a decimal between 0 and 1.

7.5 Calculate the pCa and $pAlk$ from Fig. 1 or use Eq 8 or Eq 9:

$$pCa = -0.4343 \times \ln(Ca_c) + 5 \quad (8)$$

$$pAlk = -0.45 \times \ln(Alk_c) + 4.8 \quad (9)$$

where:

pCa = the negative log of the concentration of calcium as mg/L, and

$pAlk$ = the negative log of the concentration of the alkalinity in mg/L.

7.6 Calculate K , which is a function of ionic strength and temperature in °C, from Fig. 2 or Eq 10:

$$K = 3.78342 + 0.16781 \times \ln(I_c) - 0.26411 \times \ln(I_c)^2 - 0.1029 \times \ln(I_c)^3 - 0.01124 \times \ln(I_c)^4 - 0.01221 \times T - 0.0001316 \times T^2 \quad (10)$$

NOTE 3—Eq 10 is not valid if $I_c = 0$.

where:

K = the ionic strength correction factor,

I_c = ionic strength of the concentrate, and

T = temperature in °C.

7.7 Calculate the concentrate saturation pH according to Eq 11:

$$pH_{sc} = pCa_c + pAlk_c + K \quad (11)$$

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. 3 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, Eq 12:

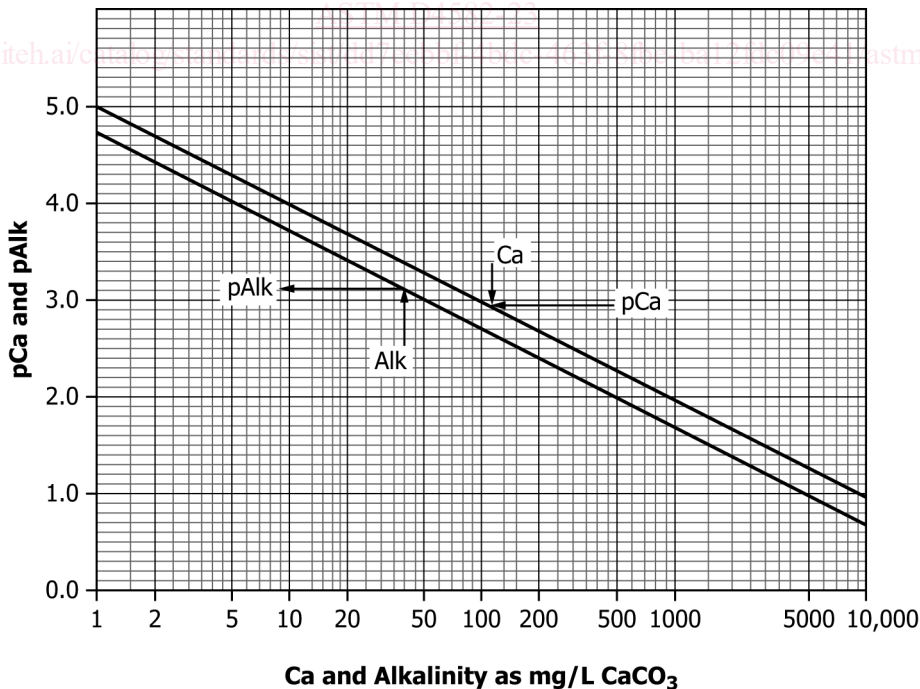


FIG. 1 Conversion of Calcium and Alkalinity to pCa and $pAlk$