Designation: D 4692 – 87 (Reapproved 1996)

Standard Practice for
Calculation and Adjustment of Sulfate Scaling Salts (CaSO$_4$, SrSO$_4$, and BaSO$_4$) for Reverse Osmosis[1]

This standard is issued under the fixed designation D 4692; 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 calcium, strontium, and barium sulfates for the concentrate stream of a reverse osmosis system. The calculations are used to determine the need for scale control in the operation and design of reverse osmosis installations. This practice is applicable for all types of reverse osmosis devices (tubular, spiral wound, and hollow fiber).

1.2 This practice is applicable to both brackish waters and seawaters.

2. Referenced Documents

2.1 *ASTM Standards:*
D 511 Test Methods for Calcium and Magnesium in Water[2]
D 516 Test Method for Sulfate Ion in Water[2]
D 1129 Terminology Relating to Water[2]
D 3352 Test Method for Strontium Ion in Brackish Water, Seawater, and Brines[3]
D 4194 Test Methods for Operating Characteristics of Reverse Osmosis Devices[3]
D 4195 Guide for Water Analysis for Reverse Osmosis Application[3]
D 4382 Test Method for Barium in Water, Atomic Absorption Spectrophotometry, Graphite Furnace[2]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 For definitions of terms relating to reverse osmosis, refer to Test Methods D 4194.

4. Summary of Practices

4.1 This practice consists of calculating the potential for scaling by CaSO$_4$, SrSO$_4$, and BaSO$_4$ in a reverse osmosis concentrate stream from the concentration of Ca^{++}, Sr^{++}, Ba^{++}, and SO$_4^=$ in the feed solution and the recovery of the reverse osmosis system.

4.2 This practice also presents techniques to eliminate scaling by decreasing the recovery, by decreasing the Ca^{++}, Sr^{++}, and Ba^{++} concentrations in the feed water, and by addition of scale inhibitors.

5. Significance and Use

5.1 In the design and operation of reverse osmosis installations, it is important to predict the CaSO$_4$, SrSO$_4$, and BaSO$_4$ scaling properties of the concentrate stream. Because of the increase in total dissolved solids and the increase in concentration of the scaling salts, the scaling properties of the concentrate stream will be quite different from those of the feed solution. This practice permits the calculation of the scaling potential for the concentrate stream from the feed water analyses and the reverse osmosis operating parameters.

5.2 Scaling by CaSO$_4$, SrSO$_4$, and BaSO$_4$ will adversely affect the reverse osmosis performance. This practice gives various procedures for the prevention of scaling.

6. Procedure

6.1 Determine the concentrations of Ca^{++}, Sr^{++}, Ba^{++}, and SO$_4^=$ in the feed stream in accordance with Test Methods D 511, D 3352, D 4382, and D 516, respectively.

NOTE 1—If H$_2$SO$_4$ is used for control of CaCO$_3$ scale, measure the SO$_4^=$ after acid addition.

6.2 Determine the concentration of all major ions using the appropriate methods given in Guide D 4195. At a minimum, the concentrations of Mg^{++}, Na$^+$, HCO$_3^-$, and Cl$^-$ must be determined.

7. Calculation

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

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

where:
Ca$_c$ = calcium ion concentration in concentrate, mg/L,
Ca$_f$ = calcium ion concentration in feed, mg/L,
Y = recovery of the reverse osmosis system, expressed as a decimal, and

[1] This practice is under the jurisdiction of ASTM Committee D-19 on Water and is the direct responsibility of Subcommittee D 19.08 on Membranes and Ion Exchange Materials.
Current edition approved May 29, 1987. Published July 1987.
[2] *Annual Book of ASTM Standards*, Vol 11.01.
[3] *Annual Book of ASTM Standards*, Vol 11.02.

SP_{Ca} = calcium ion passage, expressed as a decimal.

NOTE 2—SP_{Ca} can be obtained from the supplier of the reverse osmosis system. For most reverse osmosis devices, SP_{Ca} can be considered to be zero, in which case the equation simplifies to:

$$Ca_c = Ca_f \times \frac{1}{1-Y}$$

This assumption will introduce only a small error.

7.2 Calculate the $SO_4^=$ concentration in the concentrate stream from the $SO_4^=$ concentration in the feed solution, from the recovery of the reverse osmosis system, and from the sulfate ion passage by using the appropriate substitutions in the equation given in 7.1. The simplified equation can be used.

7.3 Calculate the concentration of the major ions in the concentrate stream using the appropriate substitutions in the equation given in 7.1. The simplified equation can be used.

7.4 Calculate the ionic strength of the concentrate stream as follows:

$$I_c = \frac{1}{2} \Sigma \, \bar{m}_i Z_i^2$$

where:
I_c = ionic strength of concentrate stream,
$\bar{m}_i$ = molal concentration of ion, i (moles/1000 g of water) in the concentrate stream, and
Z_i = ionic charge of ion, i.

NOTE 3—The molal concentration is calculated as follows:

$$m_i = \frac{C_i}{1000 \, MW_i \left[\frac{10^6 - TDS}{10^6} \right]} = \frac{1000 \, C_i}{MW_i \, (10^6 - TDS)}$$

where:
C_i = concentration of ion, i, in concentrate stream, mg/L,
MW_i = molecular weight of ion, i, and
TDS = total dissolved solids in concentrate stream, mg/L.

7.5 Calculate the ion product (IP_c) for CaSO$_4$ in the concentrate stream as follows:

$$IP_c = (^mCa^{++})_c \, (^mSO_4^=)_c$$

where:
$(^mCa^{++})_c$ = M Ca^{++} in concentrate, mol/L and
$(^mSO_4^=)_c$ = M SO$_4^=$ in concentrate, mol/L.

7.6 Compare IP_c for CaSO$_4$ with the solubility product (K_{sp}) of CaSO$_4$ at the ionic strength of the concentrate stream (Fig. 1).[4] If $IP_c > K_{sp}$, CaSO$_4$ scaling will occur and adjustment is required.

NOTE 4—Some suppliers use a safety factor. Check with the supplier of the reverse osmosis device to determine if some fraction of the K_{sp}, for example 0.8 K_{sp}, should be used to compare with IP_c.

7.7 Determine the scaling potential for SrSO$_4$ using the appropriate substitution in steps 7.1 to 7.4. Compare IP_c for SrSO$_4$ with the K_{sp} of SrSO$_4$ at the ionic strength of the concentrate stream (Fig. 2).[5]

7.8 Determine the scaling potential for BaSO$_4$ using the appropriate substitutions in steps 7.1-7.4. Compare IP_c for BaSO$_4$ with the K_{sp} of BaSO$_4$ at the ionic strength of the concentrate stream (Fig. 3).[5]

8. Adjustments for Scale Control

8.1 If the IP_c for CaSO$_4$, SrSO$_4$, and BaSO$_4$ is less than the K_{sp} or the recommended fraction of K_{sp}, a higher recovery can be used with respect to scaling by the various salts. Reiteration

---

[4] Marshall, W. L. and Slusher, R., "Solubility to 200°C of Sulfate and its Hydrates in Sea Water and Saline Water Concentrates and Temperature, Concentration Limits," *Journal of Chemical and Engineering Data*, Vol 13, No. 1, 1968, p. 83.

[5] Davis, J. W. and Collins, A. G., "Solubility of Barium and Strontium Sulfates in Strong Electrolyte Solutions," *Environmental Science and Technology*, Vol 5, No. 10, 1971, p. 1039.
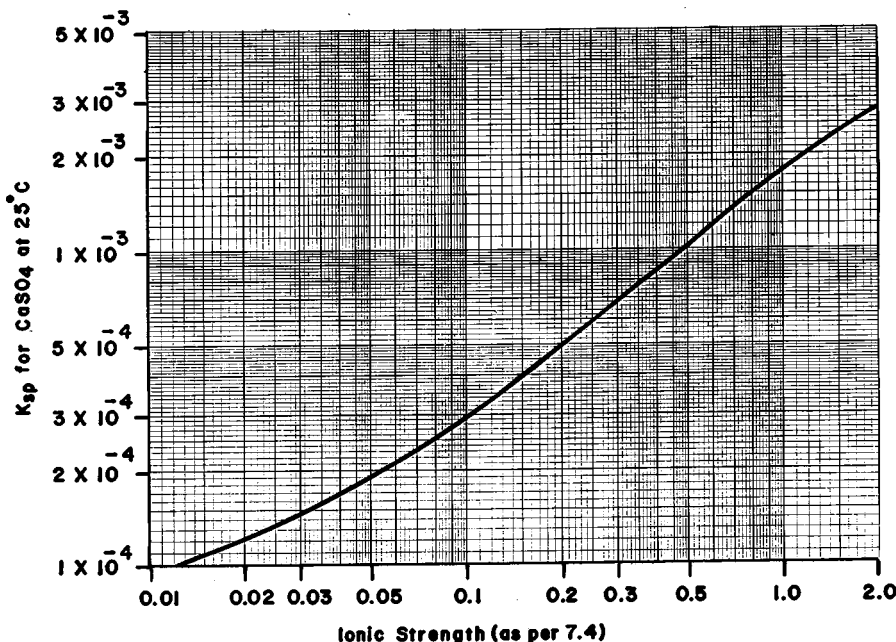

FIG. 1 K_{sp} for CaSO$_4$ versus Ionic Strength