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Standard Practice for Standardizing Reverse Osmosis Performance Data[1]

This standard is issued under the fixed designation D4516; 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 standardization of permeate flow and salt passage data for reverse osmosis (RO) systems.

1.2 This practice is applicable to waters including brackish waters and seawaters but is not necessarily applicable to waste waters.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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]

D1129 Terminology Relating to Water

D4194 Test Methods for Operating Characteristics of Reverse Osmosis and Nanofiltration Devices

D6161 Terminology Used for Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis Membrane Processes

3. Terminology

3.1 For definitions of terms used in this practice, refer to Terminologies D1129 and D6161.

3.2 For description of terms relating to reverse osmosis, refer to Test Method D4194 and Terminology D6161.

4. Summary of Practice

4.1 This practice consists of calculating the permeate flow and salt passage of RO systems at a standard set of conditions using data obtained at actual operating conditions.

5. Significance and Use

5.1 During the operation of an RO system, system conditions such as pressure, temperature, conversion, and feed concentration can vary, causing permeate flow and salt passage to change. To effectively evaluate system performance, it is necessary to compare permeate flow and salt passage data at the same conditions. Since data may not always be obtained at the same conditions, it is necessary to convert the RO data obtained at actual conditions to a set of selected constant conditions, thereby standardizing the data. This practice gives the procedure to standardize RO data.

5.2 This practice can be used for both spiral wound and hollow fiber systems.

5.3 This practice can be used for a single element or a multi-element system. However, if the RO system is brine staged, that is, the brine from one group of RO devices is the feed to a second group of RO devices, standardize the permeate flow and salt passage for each stage separately.

5.4 This practice is applicable for reverse osmosis systems with high rejections and with no significant leaks between the feed-brine and permeate streams.

6. Procedure

6.1 *Standardization of Permeate Flow:*

6.1.1 Calculate the permeate flow at standard conditions using Eq 1:

$$Q_{ps} = \frac{\left[P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - \pi_{fbs} + \pi_{ps}\right](TCF_s)}{\left[P_{fa} - \frac{\Delta P_{fba}}{2} - P_{pa} - \pi_{fba} + \pi_{pa}\right](TCF_a)}(Q_{pa}) \qquad (1)$$

where:

Q_{ps} = permeate flow at standard conditions,
P_{fs} = feed pressure at standard conditions, kpa,
$\frac{\Delta P_{fbs}}{2}$ = one half device pressure drop at standard conditions, kpa,
P_{ps} = permeate pressure at standard conditions, kpa,
π_{fbs} = feed-brine osmotic pressure at standard conditions, kpa,
π_{ps} = permeate osmotic pressure at standard conditions, kpa,

[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.

TCF_s = temperature correction factor at standard conditions,
Q_{pa} = permeate flow at actual conditions,
P_{fa} = feed pressure at actual conditions, kpa,
$\frac{\Delta P_{fba}}{2}$ = one half device pressure drop at actual conditions, kpa,
P_{pa} = permeate pressure at actual conditions, kpa,
π_{fba} = feed-brine osmotic pressure at actual conditions, kpa,
π_{pa} = permeate osmotic pressure at actual conditions, kpa, and
TCF_a = temperature correction factor at actual conditions.

6.2 *Standardization of Salt Passage:*

6.2.1 Calculate the salt passage at standard conditions using Eq 2:

$$\%SP_s = [EPF_a/EPF_s] \times [STCF_a/STCF_s] \times (C_{fbs}/C_{fba}) \times (C_{fa}/Cfs) \times \%SP_a \quad (2)$$

where:

$\% SP_s$ = percent salt passage normalized to standard (reference) conditions,
$\% SP_a$ = percent salt passage at actual conditions,
EPF_s = average element permeate flow at standard (reference) conditions,
EPF_a = average element permeate flow at actual conditions,
$STCF_s$ = salt transport temperature correction factor at standard (reference) conditions,
$STCF_a$ = salt transport temperature correction factor at actual conditions,
C_{fbs} = feed-brine concentration at standard (reference) conditions, mg/L NaCl,
C_{fba} = feed-brine concentration at actual conditions, mg/L NaCl,
C_{fa} = feed concentration at actual conditions, mg/L NaCl, and
C_{fs} = feed concentration at standard (reference) conditions, mg/L NaCl.

NOTE 1—The average element permeate flow is permeate flow of the RO system divided by the number of membrane elements operating in the system.

NOTE 2—Permeate flow at the standard conditions is the nominal permeate flow of membrane element specified by the membrane manufacturer, or average permeate flow of membrane element at the operating conditions, selected as a reference conditions. The value of EPF_s may be different then the value of Q_{ps} calculated using Eq 1.

NOTE 3—In Eq 2, $STCF_s$ and $STCF_a$ are dependent on the membrane type material and configuration. Obtain equations for $STCF_s$ and $STCF_a$ from supplier of the device. If unavailable use TCF_s and TCF_a respectively (Eq 3 and 4).

6.3 In Eq 1, TCF_s and TCF_a are dependent on the type of device (spiral or hollow fiber) and on the membrane type (cellulose acetate, polyamide, composite). Obtain equations for TCF_s and TCF_a from the supplier of device. If unavailable use Eq 3 and Eq 4.

$$TCF_s = 1.03^{(T_s - 25)} \quad (3)$$

$$TCF_a = 1.03^{(T_a - 25)} \quad (4)$$

where:

T_s = temperature at standard conditions, °C, and
T_a = temperature at actual conditions, °C.

6.4 In Eq 1 and Eq 2, π_{fba} and π_{fbs} are calculated from the concentration of salt (expressed as mg/L NaCl) in the feed and brine streams. See Annex A1 for the procedure to calculate the concentrations of salt in feed stream as mg/L NaCl.

6.4.1 The concentration of salt in the brine stream is calculated using Eq 5:

$$C_b = C_f/(1 - Y) \quad (5)$$

where:

C_b = concentration of salt in the brine, mg/L NaCl,
C_f = concentration of salt in the feed, mg/L NaCl, and
Y = conversion, expressed as a decimal.

6.4.2 The feed-brine concentration for some RO devices is based on an average (Eq 6):

$$C_{fb} = (C_f + C_b)/2 \quad (6)$$

and for other RO devices, the feed-brine concentration is based on a log mean average (Eq 7):

$$C_{fb} = C_f \ln[1/(1\ Y)]/Y \quad (7)$$

Consult supplier of device to determine whether Eq 6 or Eq 7 should be used.

6.4.3 Calculate π_{fb} using Eq 8:

$$\pi_{fb} = 0.2654\ C_{fb}(T + 273.15)/(1000 - C_{fb}/1000) \quad (8)$$

6.5 The value for $\Delta P_{fbs}/2$ in Eq 1 and Eq 2 is a selected and constant value. A realistic value can be obtained from the supplier of the RO device.

6.6 To calculate π_{ps} and π_{pa} in Eq 1 and Eq 2 use Eq 9 for brackish water and Eq 10 for seawater as follows:

$$\pi_p = 0.05\ \pi_{fb} \quad (9)$$

$$\pi_p = 0.01\ \pi_{fb} \quad (10)$$

6.7 To obtain the most accurate standardization, the standard conditions should be set close to the average actual conditions.

6.8 Proper calibration and reading of instrumentation is critical for accurate actual RO data.

6.9 For large differences in pressure between actual and standard conditions, the standardized salt passage can be inaccurate if ions whose passage are independent of pressure are present to a significant extent. Consult supplier of RO device to determine if modification to the salt passage equation is needed.

7. Use of Computers for Standardization

7.1 The calculations in this practice are adaptable to simple computer analysis.

ANNEX

(Mandatory Information)

A1. CALCULATION FOR CONCENTRATION OF SALT IN RO FEED STREAM AS mg/L NaCl

A1.1 First calculate the osmotic pressure of the RO feed (π_f) in kPa using Eq A1.1.

$$\pi_f = 8.308\phi\,(T_f + 273.15)\sum \bar{m}_i \quad (A1.1)$$

where:

ϕ = osmotic coefficient,
T_f = temperature of feed stream, °C, and
$\sum \bar{m}_i$ = summation of molalities of all ionic and non-ionic constituents in the water.

NOTE A1.1—Estimates of osmotic coefficients for brackish and seawater of 0.93 and 0.90, respectively, can be used in Eq A1.1.

A1.2 Calculate the concentration of salt in the RO feed (C_f) as mg/L NaCl using Eq A1.2:

$$C_f = 1000\,\pi_f/[0.2654\,(T_f + 273.15) + \pi_f/1000] \quad (A1.2)$$