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Guidance for performance grading of recovered reverse osmosis (RO) membranes for water reuse

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Foreword

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This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 3, *Risk and performance evaluation of water reuse systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Reverse osmosis (RO) membranes are used in various applications such as seawater desalination, ultrapure water production, wastewater treatment, advanced treatment of secondary treated wastewater for reuse, etc. However, the performance of RO membranes gradually declines due to aging and membrane fouling caused by long-term use. At present, used RO membranes are disposed of as consumable materials after several years of use.[1]

However, used RO membranes, if recovered by an appropriate process such as chemical cleaning, can be reused for various water reclamation and reuse applications, with lower costs than those involved in new membrane production.[2][3] For example, in Japan, disposed RO membranes from Fukuoka seawater desalination plant have been reused for boiler feed water production in the waste water processing centre (sewage plant).

If a used membrane is graded based on its performance, then an appropriate membrane can be selected for each purpose for water reuse. For example, a Grade C1 membrane (lower salt rejection rate and higher flow rate) is suitable for reuse in treating sewage for irrigation usage, while a Grade A1 membrane (higher salt rejection and higher flow rate) is preferable for processing treated sewage for boiler feed water usage.

By reducing membrane disposal, the use of recovered RO membranes can contribute to sustainable development goals (SDGs). Membrane life extension will promote the reduction of old membrane disposal (GOAL12), and less production of new membranes will reduce the carbon footprint (GOAL13). Furthermore, reusing and repurposing RO membranes will also result in an inexpensive and safe water supply to more people (GOAL6).

In order to promote the use of recovered RO membranes, users need information on the membranes, including their performance. This will enable new users to apply the membranes to their intended purpose.

Guidance for performance grading of recovered reverse osmosis (RO) membranes for water reuse

1 Scope

This document provides guidance and requirements for grade classification of performance of recovered reverse osmosis (RO) membranes for water reuse systems.

This standard is applicable to the spiral-wound type of recovered membranes from seawater reverse osmosis (SWRO) and brackish water reverse osmosis (BWRO) systems.

This standard is to ensure consistency in the performance of recovered RO membranes. It does not specify any method or process for the recovery of RO membranes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670:2023, *Water reuse — Vocabulary*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
differential pressure
delta-P
hydraulic pressure drop across the element feed channel that is a differential pressure from the feed water inlet to the concentrate outlet

[SOURCE: AWWA M53]

3.1.2
element
component containing the membrane, generally replaceable, such as a spiral wound cartridge

[SOURCE: ASTM D6161]

3.1.3
flux
membrane throughput

Note 1 to entry: Flux is usually expressed in volume of *permeate* (3.1.6) per unit membrane surface area, for example litre per square metre per hour ($l/m^2 \cdot h$) at a given temperature or normalized temperature (more than 20 °C).

Note 2 to entry: Flux can also be expressed in number of moles, or volume or mass of specified component per unit time per unit membrane surface area.

[SOURCE: ISO 20468-5:2021, 3.1.8, modified — part of the original definition was moved to Note 1 to entry.]

3.1.4
flow rate
mass or volume of fluid passing through the primary device per unit time

[SOURCE: ISO 5167-1:2022, 3.3.1, modified — the admitted term “rate of flow” was removed.]

3.1.5
new membrane manufacturer
company organizations or firms that produce new *reverse osmosis (RO)* (3.1.10) membranes

3.1.6
permeate
portion of the feed stream that passes through a membrane

[SOURCE: ISO 20468-5:2021, 3.1.16]

3.1.7
recovered membrane supplier
company or organization that supplies or sells recovered *reverse osmosis (RO)* (3.1.10) membranes and takes responsibility for quality and performance characteristics of the recovered membranes

3.1.8
recovered RO membrane
used *reverse osmosis (RO)* (3.1.10) membrane that can be reused after *recovery* (3.1.9) process

3.1.9
recovery process
recovery
process to restore performance of a used *reverse osmosis (RO)* (3.1.10) membrane to a certain applicable level by washing, chemical cleaning, reforming, surface coating, etc.

3.1.10
reverse osmosis
RO
separation process in which 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

Note 1 to entry: Reverse osmosis (RO) removes ions based on electrochemical forces, colloids, and organics down to a molecular weight of 150, practically reported in units of Daltons. It can also be called hyperfiltration.

[SOURCE: ISO 20468-5:2021, 3.1.19]

3.1.11
used RO membrane
reverse osmosis (RO) (3.1.10) membrane that has been used for a certain period of time and is in need of replacement

3.1.12
water reuse
use of treated wastewater for beneficial use

Note 1 to entry: Synonymous with water reclamation.

[SOURCE: ISO 20670:2023, 3.109, modified — Note 1 to entry was added.]

3.2 Abbreviated terms

SWRO seawater reverse osmosis

BWRO brackish water reverse osmosis

RO reverse osmosis

4 Concept of grade classification for recovered RO membranes

4.1 General

During a long-term operation period, RO membranes are regularly and repeatedly cleaned with chemicals. When the membranes reach their end-of-life due to deterioration of performance, they are typically disposed as waste.

A used RO membrane that is treated by an appropriate recovery process is regarded as a recovered RO membrane. A recovered RO membrane that conforms to the requirements of this document is a marketable product.

Even if the membrane is reused several times, it may be referred to as a recovered RO membrane as long as it is subjected to an appropriate recovery step.

This document does not require any guarantee or warranty of performance of the recovered RO membrane. Depending on the requirements of users, a guarantee or warranty, or both, can be specified as the responsibility of the supplier.

4.2 Purpose of classifying the grade of recovered RO membranes

Classifying the grade of a recovered RO membrane based on its performance characteristics, as well as verifying that a comprehensive performance test has been performed, can help users choose an appropriate membrane for their applications.

Successful system design and construction or installation of a recovered RO membrane process for water reuse can be achieved by the appropriate grading of the membrane.

Engineers should design the recovered RO membrane process after verifying membrane specifications such as rejection and flow rate.

Clarifying these performance parameters and their expected ranges is a mandatory requirement for the appropriate design of a system, including the feed pump head, piping size and system capacity.

In addition, the design philosophy which is specified in ISO 20468-5 can also be applied to systems with recovered RO membranes.

4.3 Applications of recovered RO membranes

A recovered RO membrane may be applied for water reuse applications, but should not be applied for potable use as per ISO 20469.

There are various possible applications; these include cascade implementations in which RO membranes that are initially used for seawater desalination are subsequently reused for tertiary treatment of sewage or reused in the same process, or both.

4.4 Recommended information for recovered RO membranes

A unique serial number should be provided to each recovered RO membrane. As a minimum, the grade, serial number and recovered membrane supplier name should be displayed on the surface of the membrane element.

The following information, as a minimum, should be recorded for each recovered RO membrane, and can be referenced via URL based on the serial number.

a) Serial number.

b) Grade.

c) Differential pressure.

d) History of the membrane's usage.

e) Recovered membrane supplier information.

f) Performance test information.

These items are summarized in Table 1.

Table 1 — Required information

Items	Contents
Serial no.	A unique serial number is assigned to each recovered RO membrane.
Grade	A grade is provided as a matrix of rejection and flow rate during a performance test, which is the responsibility of the supplier. In addition, an SWRO membrane is classified as "S-", a BWRO membrane is classified as "B-".
History of the membrane's usage	History of the RO membrane is essential information for users to grasp its deterioration level. The history shows the track of usage information [raw water type, application, years of operation, membrane area (m^2)] of the RO membrane.
Recovered membrane supplier information	This includes supplier name, address, contact information, etc.
Performance test information	This describes the performance test's method and conditions (e.g. NaCl concentration, temperature, pH, feed pressure, etc.) and the test result (flow rate, rejection, differential pressure). Refer to Annex A.

If any one of these is missing, the membrane cannot be regarded as conforming to the requirements of this document.

The following is an example of required information recorded for an RO membrane:

a) Serial no.: 1234-567A

b) Grade: S-A1

c) Differential pressure: 5 KPa

d) History: Three years of operation with groundwater treatment at semiconductor factories

e) Recovered membrane supplier:

Name: XYZ company

Address: 1-2-3 A Street B-city, C-state, D-country

Contact: Tel xxxxxx, URL xxxxxx

f) Performance test method: See Annex A

4.5 Displaying of the information

In order to distinguish recovered RO membranes from brand new ones and show their grade, all recovered RO membranes should be marked in a permanent manner with a serial number on the lateral surface of the

membrane element in a human-readable format (e.g. using Arabic numerals and Latin letters). For machine readability, a 2D barcode (e.g. ISO/IEC 18004) or a radio frequency identifier (e.g. ISO/IEC 18000-63) may be attached along with a human-readable format.

In addition, the document containing the data required in 4.4 should be attached to the recovered RO membrane in paper or electronic form. The attached document should be counterfeit-proofed. As a method of counterfeit-proofing, the data, canonicalized and encoded by PKI (public key infrastructure) (ISO/IEC 9594-8 and ITU-T X.509) may be displayed in the document as a 2D barcode (e.g. ISO/IEC 18004) together with the original data.

5 Grade classification

5.1 Method of performance tests

A performance evaluation using the parameters of permeate flow rate and rejection is mandatory in order to classify the grade of a recovered RO membrane. In case of application to a special purpose such as removal of pathogens or organic matter, appropriate parameters can additionally be applied to the performance test.

Performance test methods and conditions should refer to Annex A.

Performance tests should be conducted according to Annex A and refer to the test procedures of ASTM D4194-3 and by typical new membrane manufacturers. The test reagent should be sodium chloride (NaCl).

Each recovered RO membrane should be tested individually according to this document. A random test should not be adopted because of its incompleteness.

The institution that conducts the performance test should perform and report a grade classification for a recovered RO membrane.

5.2 Classification of membrane type

An SWRO membrane is classified as “S-”. A BWRO membrane is classified as “B-”.

The SWRO and BWRO membranes referred to are derived from the respective applications.

5.3 Grade of rejection

Rejection can be obtained using Formula (1):

$$\text{Rejection, \%} = (1 - (K_p/K_f)) \times 100 \quad (1)$$

where

K_p is the electrical conductivity of permeate, in siemens per metre (S/m);

K_f is the conductivity of feed, in siemens per metre (S/m).

A recovered RO membrane can be classified in six rejection performance grades, A to F. This classification system enables a user to select a recovered RO membrane according to the purpose of its reuse.

The grades and the corresponding rejection performance are shown in Table 2.

Grade A membranes will achieve a rejection performance of 99 % or more.

This means that the concentration of the target constituent in the permeate will be less than 1 % of the concentration of that constituent in the feed stream.

Grade B membranes will achieve a rejection performance of between 98 % and 99 %.

This means that the concentration of the target constituent in the permeate stream will not be more than 2 % of the concentration of that constituent in the feed stream.

A Grade B membrane thus allows two times more of the target constituent to enter the permeate than a Grade A membrane.

Each further classification below Grade B generally allows twice as much of the target constituent to enter the permeate compared to the more advanced grade of membrane classification above it, as detailed in Table 2.

Table 2 — Rejection grades and corresponding performance

Grade of rejection	Rejection performance
A	≧ 99,0 %
B	< 99,0 %, ≧ 98,0 %
C	< 98,0 %, ≧ 95,0 %
D	< 95,0 %, ≧ 90,0 %
E	< 90,0 %, ≧ 80,0 %
F	< 80,0 %, ≧ 60,0 %
NQ[a]	< 60,0 %
[a] Not qualified.	

5.4 Grade of flow rate

The flow rate is given by the flux divided by the membrane surface area. Flux is widely used in the water treatment industry.

Based on their flow rate performance, recovered RO membranes can be classified in five grades, 1 to 5.

The grade criteria for permeate flow rate performance of 200 mm (8-inches) membrane elements are shown in Table 3. For other size elements [e.g. 100 mm (4-inch), 400 mm (16-inch)], appropriate parameters can be determined.

Grade 1 membrane elements will achieve a permeate flow of greater than 100 m^3 per day per element.

Grade 2 membranes will achieve a flow rate of between 75 m^3 and 100 m^3 per day per element.

For grade 3 to grade 5 membranes the flow decreases progressively by approximately three-quarters over the classification range.

Table 3 — Flow rate grades and corresponding performance

Grade of flow rate	Flow rate performance	
1	≧ 100 m^3/d	≧ 26,417 US gallons/day
2	< 100,0 ≧ 75,0 m^3/d	< 26,417 ≧ 19,813 US gallons/day
3	< 75,0 ≧ 50,0 m^3/d	< 19,813 ≧ 13,209 US gallons/day
4	< 50,0 ≧ 35,0 m^3/d	< 13,209 ≧ 9,246 US gallons/day
5	< 35,0 ≧ 20,0 m^3/d	< 9,246 ≧ 5,283 US gallons/day
NQ[a]	≦ 20,0 m^3/d	≦ 5,283 US gallons/day
[a] Not qualified.		

5.5 Example of classification

Based on the matrix in Table 4, a recovered SWRO membrane with rejection of 96 % (grade C in Table 2) and flow rate of 68 m^3/d (grade 3 in Table 3) is classified as S-C3. Table 4 shows a matrix of rejection grade and flow rate grade.

Table 4 — Matrix of rejection grade and permeate flow rate grade

Rejections (%)	Flow rate (m^3/d)					
100	NQ[a]	A5	A4	A3	A2	A1
99	NQ	B5	B4	B3	B2	B1
98	NQ	C5	C4	C3	C2	C1
95	NQ	D5	D4	D3	D2	D1
90	NQ	E5	E4	E3	E2	E1
80	NQ	F5	F4	F3	F2	F1
60	NQ	NQ	NQ	NQ	NQ	NQ
	0	20	35	50	75	100

[a] Not qualified.

Annex A
(informative)

Standard test methods and conditions for recovered RO membranes

A.1 Scope

These test methods and conditions should be adopted to determine the grade of the recovered RO membrane from SWRO and BWRO systems.

A.2 Test method

A.2.1 General

Test methods involve non-destructive testing.

A.2.2 Materials and reagents

All test system materials shall be high-quality stainless steel (type 316/degreasing specification) or plastic for all wetted parts to prevent contamination of feed solution by corrosion products. Take care to ensure that no contamination occurs from oil films on new metal piping, fittings, valves, etc., and that contaminants are not released from raw plastic components or from feed solution previously used in the system.

Reagent grade chemicals and water shall be used in all tests.

A.2.3 Apparatus

Feed holding tank equipped with a thermostated heat exchanger system to maintain the feed solution at the desired temperature.

Booster pump (centrifugal type) with feed holding tank for feeding solution to testing device.

Filter can be either a strainer (100 mesh) or a 5-µm filter (based on supplier's recommendation).

High-pressure pump (positive displacement type) for RO membrane testing device.

RO device for testing membrane (SWRO, BWRO).

Valves and accumulator as shown in Table A.1 as a minimum.

Table A.1 — Valves and accumulator list

Instrument	Location	Main purpose	Remarks
Shutoff valve	Suction of booster pump	Preventing excessive pressure drop	
Feed sampling valve	After filter	Sampling	
Back pressure valve	High-pressure pump bypass line	High-pressure pump delivery pressure control	Under no circumstances install throttling valves directly on a positive displacement pump discharge line
Pressure relief valve	High-pressure pump delivery line	High-pressure emergency relief	
Concentrate flow control valve	RO reject concentrate line	Flow control	
Concentrate sampling valve	RO reject concentrate line	Sampling	
Permeate sampling valve	RO permeate line	Sampling	
Accumulator	High-pressure pump delivery line	Minimizing pressure pulsations	Reciprocating position-type positive displacement pump is used

Instrumentations as shown in Table A.2 as a minimum.

Table A.2 — Instrumentation

Instrument	Location	Main purpose	Remarks
Booster pump pressure gauge	Booster pump delivery	Check filter differential pressure	Check by in/out pressure of the filter
High-pressure pump suction pressure gauge	High-pressure pump suction	Prevent high-pressure pump failure	High and low
High-pressure pump delivery pressure gauge	High-pressure pump delivery	Pressure control for RO system and check the differential pressure-1	
High-pressure pump delivery temperature gauge	High-pressure pump delivery	Temperature control for RO system	
RO permeate flow meter	RO permeate line	Flow control for RO system	
RO permeate temperature gauge	RO permeate line	Temperature control for RO system	
RO permeate pressure gauge	RO permeate line	System operation and check the differential pressure-2	Measuring RO pressure drop (ΔP)
RO concentrate line flow meter	RO reject concentrate line	Flow control for RO system	
RO concentrate line pressure gauge	RO reject concentrate line	Flow control for RO system	

A.2.4 Preparation

If the RO device contains any unwanted materials (e.g. sanitizing, agent), flush the device.

Check the installation status of the test device piping, valves and instruments, especially the high-pressure line.

Check the concentration and temperature of the feed solution.

Check the rotation direction of the pumps.

A.2.5 Procedure

A.2.5.1 Start and stabilization

Open the feed circulation line and all valves including the pump by-pass on the positive displacement feed pump throttling valve. Start the booster pump and then the high-pressure pump. Set the feed pressure to a gauge pressure that is in accordance with the specifications of the test membrane. It is possible that the by-pass valve or the throttling valve and the concentrate flow control valve can be adjusted at the same time. Set concentrate flow in accordance with the test membrane specifications by adjusting the concentrate flow control valve.

Recheck and adjust if necessary both the concentrate flow and feed pressure to give the selected values for flow and pressure. Adjust the cooling system in the feed solution to give a permeate temperature of 25 °C ± 1 °C.

A.2.5.2 Measurement

Record each pressure for one hour after the start of testing, record the permeate and concentrate flows and record the permeate temperature and the conductivity of the feed, permeate, and concentrate. Measurement and recording are performed after the stabilization of operation. After that, repeat for 3 consecutive times so that the permeation flow rate (corrected 25 °C) and salt rejection are within 5 %. Average value of the 3 measurements is applied to the test result. The measurement and record are performed based on a 20 min to 30 min test or longer.

A.2.5.3 Stop method

Adjust the bypass valve to reduce pressure and stop the test device. Stop the high-pressure pump and the booster pump, then shut off the feed supply valve. Wait for the pressure to reach zero before disconnecting the RO membrane testing device or carrying out maintenance on the piping system.

A.3 Test conditions of reagents, pH, temperature, feed pressure, and conversion

Test conditions of reagents (NaCl solution), pH, temperature, feed pressure and conversion are shown in Tables A.3 and A.4.

Table A.3 — Test conditions of SWRO membrane

NaCl g/l	pH	Temperature °C	Feed pressure (gauge) MPa	Conversion %
30,0 - 32,0	6,5 - 8,0	25 ± 1	5,5 ± 0,1	8 - 10

Table A.4 — Test conditions of BWRO membrane

NaCl g/l	pH	Temperature °C	Feed pressure (gauge) MPa	Conversion %
1,4 - 1,6	6,5 - 8,0	25 ± 1	1,55 ± 0,1	15 - 17

Conversion is calculated using Formula (A.1):

$$\text{Conversion, \%} = (Q_p/Q_f) \times 100 \quad \text{(A.1)}$$