INTERNATIONAL STANDARD

ISO 20468-5

First edition
2021-06

Guidelines for performance evaluation of treatment technologies for water reuse systems —

Part 5: Membrane filtration

Lignes directrices pour l'évaluation des performances des techniques de traitement des systèmes de réutilisation de l'eau —

Partie 5: Filtration sur membrane

Reference number
ISO 20468-5:2021(E)

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Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

A list of all parts in the ISO 20468 series can be found on the ISO website.

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

Guidelines for performance evaluation of water reclamation systems are essential for municipalities, utilities and reclaimed water users to meet water quality requirements without compromising public health. ISO 20468-1, *Guidelines for performance evaluation of treatment technologies for water reuse systems* specifies fundamental requirements for the overall water reuse system, which mainly focuses on the finished water quality. When operating a water reclamation system, performance evaluations at the point of an individual water reclamation process, helps to provide early warnings to enable operator response in avoiding adverse impacts on public health, and to comply with the targets of final water quality. It is particularly important for membrane-based water reclamation processes that are often employed as the most important barriers for the removal of major constituents in wastewater (e.g. particulates, dissolved solids, and pathogens). In addition, guidelines for performance evaluation of individual treatment processes in terms of environmental and economic performances can also assist decisions on the appropriate selection of water reclamation technologies, which is of paramount importance in water reuse. This document is intended to provide stakeholders typical performance evaluation approaches designed for membrane filtration technologies. In addition, this document is expected to assist the development and operation of water reuse projects, in which process designers, plant managers, and operators are involved. Similar to ISO 20468-1, this document is mainly comprised of functional and non-functional requirements for the performance evaluation of membrane filtration technologies.

Guidelines for performance evaluation of treatment technologies for water reuse systems —

Part 5:
Membrane filtration

1 Scope

This document provides guidelines for performance evaluation methods of water reclamation systems using membrane technologies. This document provides guidance in ensuring treated wastewater quality levels at the point of exit from the membrane filtration processes. It also provides potential methods for evaluating the environmental and economic performance of membrane filtration processes in water reuse. This document helps plant designers, operators and end users to effectively design and operate the membrane-based water reclamation systems.

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 20670:2018, *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 terminological databases for use in standardization at the following addresses:

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

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

3.1 Terms and definitions

3.1.1
backwash
reverse flow of water with/without air across a membrane (i.e. from permeate side to feed side)

Note 1 to entry: It is designated to remove the deposited foreign substances (foulants) from the membrane.

3.1.2
bubble point pressure
pressure differential at which bubbles first appear on one surface of an immersed porous membrane, as pressure is applied to the other side

3.1.3
cleaning
operation during which membranes are cleaned using a membrane cleaning system with or without chemical reagents

EXAMPLE backwashing, flushing, chemical cleaning.

[SOURCE: AWWA B110-09]

3.1.4
concentrate
rejected stream exiting a membrane module under a *cross-flow* (3.1.5) mode

Note 1 to entry: Concentrate stream contains increased concentrations of constituents over the feed stream due to the accumulation of rejected constituents by membranes in the feed stream.

3.1.5
cross-flow
flow orientation through a membrane module in which the fluid on the upstream side of the membrane moves parallel to the membrane surface

Note 1 to entry: Fluid on the downstream side of the membrane moves away from the membrane in the direction normal to the membrane surface.

[SOURCE: AWWA B130-13]

3.1.6
dead-end flow
flow through a membrane module in which the only outlet for the upstream fluid is through the membrane

[SOURCE: ASTM D6161-19]

3.1.7
feed
input solution entering the inlet of a membrane module or system

3.1.8
flux
membrane throughput, usually expressed in volume of *permeate* (3.1.17) per unit time per unit membrane surface area such as litre per square meter per hour (l/m^2/hr) at a given temperature or normalized temperature (more often 20 °C)

Note 1 to entry: It can also be expressed in number of moles, volume or mass of a specified component per unit time per unit membrane surface area.

3.1.9
fouling
processes leading to deterioration of membrane flux due to surface or internal blockage of the membrane

[SOURCE: AWWA B130-13]

3.1.10
integrity test
non-destructive physical test that can be correlated to the membrane retention capability of the membrane system to ensure that membrane system is free of physical defect

3.1.11
membrane integrity
relative degree to which a membrane successfully rejects or retains specific target constituents while allowing water to pass through

3.1.12
membrane bioreactor (MBR)
integrated wastewater treatment process combining a suspended growth biological treatment and a membrane filtration system (UF/MF membrane) replacing conventional secondary clarifier

Note 1 to entry: MF or UF membrane is submerged in biological reactor (submerged MBR). Another configuration has pressurized membrane modules externally coupled to the bioreactor, with the biomass recirculated between the membrane modules and the bioreactor by pumping (side-stream MBR).

3.1.13
microfiltration (MF)
pressure driven membrane based separation process designed to remove particles and macromolecules in the approximate range of 0,05 to 2 µm

[SOURCE: ASTM D6161-19]

3.1.14
molecular weight cut-off
rating of a membrane based on the size of uncharged solutes that is typically 90 % retained by a membrane

Note 1 to entry: It is also referred to as nominal molecular weight cut-off (NMWCO).

Note 2 to entry: MWCO is typically expressed in Daltons.

[SOURCE: AWWA B130-13]

3.1.15
nanofiltration (NF)
cross-flow (3.1.5) process with pore sizes designed to remove selected salts and most organics above about 300 Daltons molecular weight range

Note 1 to entry: Nanoflitration (NF) is sometimes referred as loose RO.

Note 2 to entry: Nanofiltration (NF) is a pressure driven separation process in which particles and dissolved molecules smaller than about 2 nm are rejected.

[SOURCE: ASTM D6161-19]

3.1.16
permeate
portion of the feed stream which passes through a membrane

[SOURCE: ASTM D6161-19]

3.1.17
permeability
ability of a membrane barrier to allow the passage or diffusion of a substance (i.e., a gas, a liquid, or solute), also a numerical value used to measure water flow through a MF/UF/NF/RO membrane, usually expressed in volume of *permeate* (3.1.17) per unit membrane surface area per unit time per unit pressure such as litres per square meter per hour per bar (l/m^2/hr/bar) at a given temperature and typically corrected (normalized) to a constant temperature (20 °C or 25 °C)

Note 1 to entry: It is also referred to as specific flux.

[SOURCE: AWWA M53]

3.1.18
pore size
size of the openings in a porous membrane, expressed either in a nominal (average) or absolute (maximum) value, typically measured in µm

3.1.19
reverse osmosis (RO)
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

Note 1 to entry: Reverse Osmosis (RO) removes ions based on electro chemical forces, colloids, and organics down to 150 Daltons molecular weight. May also be called hyperfiltration.

[SOURCE: ASTM D6161-19]

3.1.20
silt density index (SDI)
index for the fouling capacity of water in reverse osmosis systems, measuring the rate at which a 0,45-micrometre filter is plugged when subjected to a constant water pressure of 206,8 kPa (30 psi)

[SOURCE: ASTM D4189-07 (2014)]

3.1.21
transmembrane pressure
hydraulic pressure differential (net driving force) across the membrane

[SOURCE: ASTM D6161-19]

3.1.22
ultrafiltration (UF)
pressure driven process employing semipermeable membrane under hydraulic pressure gradient for the separation components in a solution

Note 1 to entry: The pores of the membrane are of a size smaller than 0,1 µm, which allows passage of the solvent(s) but will retain non-ionic solutes based primarily on physical size, not chemical potential.

[SOURCE: ASTM D6161-19]

3.2 List of abbreviated terms

BOD Biochemical oxygen demand

COD Chemical oxygen demand

LCC Life cycle cost

MBR Membrane bioreactor

MF Microfiltration

MLSS Mixed liquor suspended solids

MWCO Molecular weight cut off

NF Nanofiltration

NTU Nephelometric turbidity units

RO Reverse osmosis

SDI Silt density index

SS Suspended solids

TMP Transmembrane pressure

TOC Total organic carbon

TSS Total suspended solids

UF Ultrafiltration

4 Concepts of membrane filtration technology for water reuse

4.1 General

This clause outlines the fundamentals of membrane filtration technologies in water reuse. Membrane filtration is a viable and recognized technology as physical barrier in water reuse with its high separation performance. Many of recent water reclamation schemes have employed membrane filtration processes in combination with other processes for the removal of multiple constituents in wastewater (see Table 1.)

Table 1 — Membrane types and targeted contaminants

Type	TMP, approximate range (MPa)	Contaminants targeted for removal
MF	< 0,2	0,07 – 1,0 µm diameter particle: TSS, Turbidity, at least 4-log reduction in protozoa, bacteria, but not viruses
UF	0,05 – 0,5	0,008 – 0,05 µm: TSS, turbidity, macromolecules, colloidal particles, at least 4 to 6-log reduction in protozoa, bacteria, and 1 to 6-log reduction in viruses
NF	0,5 - 3	0,001 to 0,02 µm: Pesticides and other macromolecules (high molecular weight) organics, color, colloids, all pathogen groups and polyvalent cations
RO	0,5 - 7	0,0001 to 0,002 µm: dissolved salts, colloids, low molecular weight organics, color, TDS, mono and multi valent ions (e.g. chlorides, sulfates, nitrate, sodium, boron, metals, other ions)

4.2 Membrane type and treatment objectives

Membrane type is typically classified into four categories depending on levels of their pore size for MF and UF membranes and their separation capabilities for NF and RO membranes (see Table 1). Driving force of solution through these membranes is a pressure difference across feed and permeate streams.

MF/UF membrane filtration processes in water reuse are generally used to remove suspended particles including particulates, and colloids. In water reclamation, MF/UF processes effectively work as an alternative process of secondary clarifiers and media filters that are a subsequent process of biological treatment. With their high separation capability for particles, they are often used as a pre-treatment of NF/RO process for fouling mitigation. MF membranes can achieve high removal of suspended solids, large pathogens (i.e. bacteria and protozoa) and some viruses. UF membranes, which have smaller nominal pore size than MF membranes, are in addition capable of removing small constituents in wastewater such as viruses and macromolecules.

MF/UF incorporated with a biological process is referred to as a MBR process.

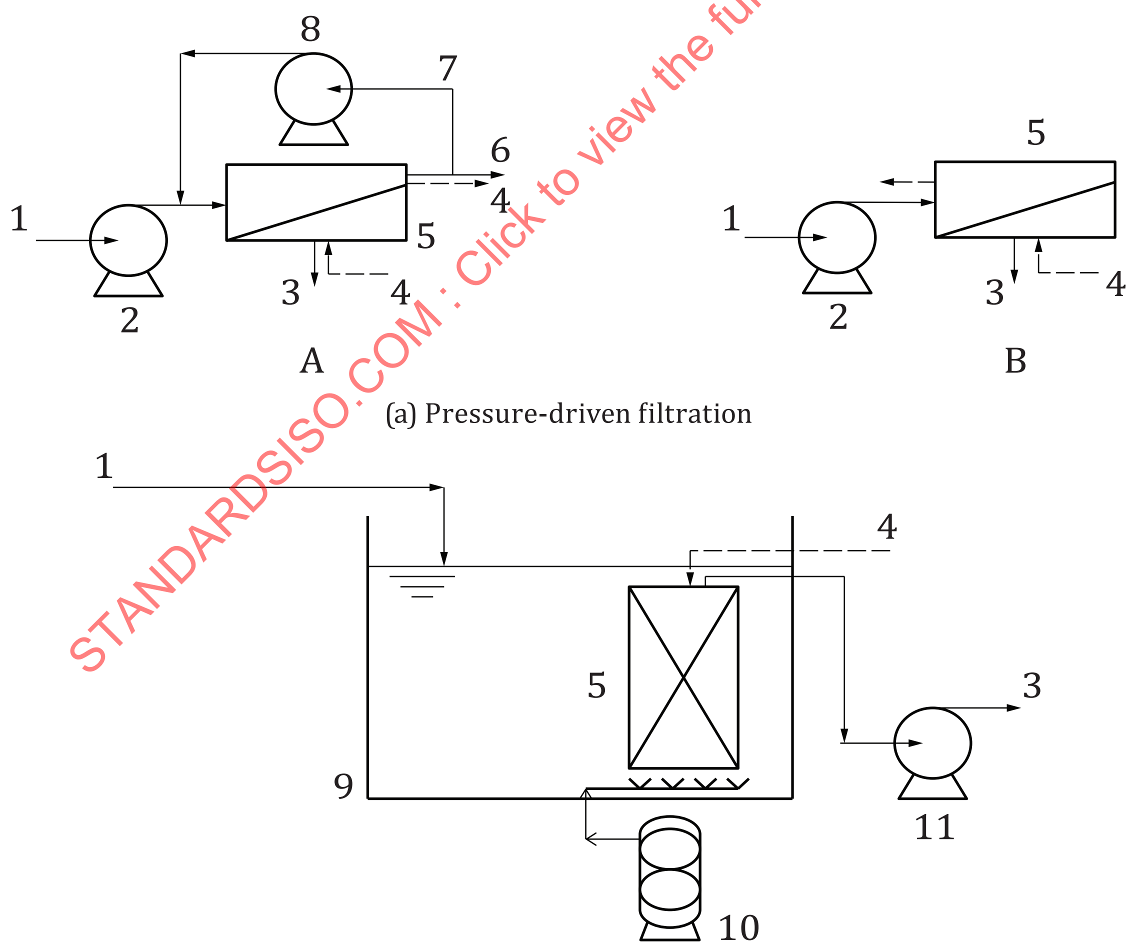
NF/RO membranes have capabilities for producing high-quality reclaimed water which is suitable for many industrial uses and many applications with a high likelihood of human contact. NF membranes can effectively remove multivalent ions including heavy metals and most micropollutants (e.g. >200–300 molecular weight). RO membranes can remove monovalent ions including sodium and chloride ions and low molecular weight micropollutants (e.g. <200–300 molecular weight). NF/RO membrane spiral wound elements are typically housed in a pressure vessel and their processes are usually operated continuously; thus, it is required to undergo sufficient pre-treatment to mitigate membrane fouling (e.g. target SDI in RO feed <3). Downstream to the pressure driven membrane process, disinfection could be required as a safety barrier to ensure the redundancy and the very high reliability of the water treatment.

4.3 Filtration unit process

There are two types of membrane filtration: Pressure driven filtration and Vacuum driven filtration (see Figure 1). In a pressure driven filtration configuration, driving force for filtration is generated by additional pressure generated by a pump installed in the feed stream. In a vacuum driven filtration configuration, driving force for filtration is generated by suction pump installed in the permeate stream.

There are two types of pressure driven filtration modes: cross-flow mode and dead-end mode. In a cross-flow filtration process, most feed flow travels tangentially to the membrane surface for scouring foulants from the membrane surface and minimizing concentration polarization. Because NF/RO processes require high pressure due to the tightness of free-volume holes and the influence of osmotic pressure, almost all NF/RO membranes are housed in pressure vessels and are operated under pressure in a cross-flow orientation. In a dead-end filtration process, no cross-flow occurs, meaning that feed flow rate equals permeate flow rate. For MF/UF, intermittent backwash with permeate and/or air is made to recover the flux decline.

In a vacuum driven filtration process, membrane modules are immersed in an open basin, in which feed water is introduced. In MBR, MF or UF membranes are used in a vacuum driven configuration in an aeration tank and the driving force (i.e. pressure difference) is generated by a vacuum pump in the permeate stream.



(a) Pressure-driven filtration

(b) Vacuum-driven filtration

Key

A cross flow
B dead-end flow
1 feed
2 feed pump
3 permeate
4 (backwash)
5 membrane module(s)
6 concentrate
7 concentrate (recirculate)
8 recirculation pump
9 tank
10 blower
11 suction pump

Figure 1 — Typical Membrane filtration systems

4.4 Membrane filtration process design and pre- and post-shipment tests

Successful system design and constructions of membrane filtration processes for water reuse can be achieved by appropriate membrane selections. It is important for engineers to design membrane filtration systems after verifying the membrane specifications such as pore size, pure water permeability, separation performance, a range of information including membrane configuration, material, operating conditions and cleaning methods. Further details of the membrane specifications are provided in Annex A. Before shipment, during membrane reception on site, and during commissioning, the membrane modules/elements are typically evaluated by confirming the proper storage conditions and whether they meet the product specifications. If required, proper storage conditions of the membrane on site before commissioning shall be anticipated.

5 Principles and general guidelines for performance evaluation

5.1 General

The purpose of performance evaluation for membrane filtration technology is to determine whether membrane filtration processes can consistently meet specified membrane performance requirements. Clause 5 defines two key performance requirements in membrane performance evaluation: functional and non-functional requirements. Performance requirements are evaluated using specified test protocols that include sample collection methods, monitoring methods, ancillary data collection frequency and methods, documentation and valid data analysis procedures, and their details will be described in Clauses 6 and 7.

5.2 Functional requirements for membrane filtration process

Functional requirements for membrane filtration technology address the rejection of constituents in the feed water to produce a highly-treated wastewater that meets the reclaimed water quality requirements. Performance evaluation for functional requirements in membrane filtration process are categorized (1) water quality-based performance evaluation, (2) process based performance evaluation, and (3) integrity testing.

5.3 Non-functional requirements for membrane filtration process

Non-functional requirements involve environmental and economic performance. Environmental performance evaluation for membrane filtration process can be conducted with energy consumption, chemical consumption, and volume of liquid and solid wastes. Economic performance evaluation for membrane filtration technology can be based on LCC, which includes capital cost and operating cost.

6 Performance evaluation for functional requirement

6.1 General

Performance evaluation for water reclamation is primarily conducted through water quality analysis of the finished (reclaimed) water to ensure the compliance for reclaimed water quality requirements that are typically regulated at the end of water treatment trains (or at the exit of the water reclamation plant). However, monitoring water quality at a unit process (e.g. membrane filtration) provides additional confidence and alerts to non-compliance with the water quality requirements. It also acts as an early warning to identify any water quality-related issues that may occur between routine samplings of the finished water.

When a membrane is used for a long period of time, the membrane module may be damaged due to physical defects or chemical deterioration. This can cause a deterioration in membrane separation performance but may not be apparent in monitored water quality. Therefore, the performance evaluation based on the water quality analysis is typically supplemented by other performance evaluation methods that enable to monitor the membrane integrity during the system operation. These methods include direct integrity monitoring and indirect integrity monitoring. Direct integrity monitoring is an accurate and reliable strategy which is able to identify minor deterioration in various applications requiring high-quality water. Indirect integrity monitoring involves surrogate measurement of membrane integrity, which is not as sensitive as direct integrity monitoring but can be readily applied to any types of membrane filtration systems regardless of manufacturer's specifications. It often provides online or real-time indication of membrane integrity.

In order to make the operation of membrane filtration process sustainable, it is important for trouble shooting, to keep the records of design and operation of the membrane system, in order to find potential causes and solutions. Examples of typically frequencies of data collection recommended by the manufactures are provided in Annex B.

6.2 Water quality based performance evaluation

Typical water quality parameters monitored at a membrane filtration process are summarized in Table 2. Turbidity is the water quality parameter that is commonly monitored in the permeate of MF and UF for the assurance of permeate water quality and membrane integrity. Turbidity below 0,1 NTU can be readily achieved by MF or UF. The other common parameters include pH and conductivity, which are frequently adopted for high quality reclaimed water through NF and RO. The pH in RO permeate is generally lower than RO feed due to the permeation of carbon dioxide to the permeate stream. Conductivity monitoring is often employed as a surrogate for the removal of ionic constituents by NF and RO membranes. All of the water quality parameters described in Table 2, except coliform and BOD, can be measured using commercially available online instruments. Manual sample collection and laboratory analyses can also be performed.

Sample collection points for membrane technology could be located at the permeate side of individual membrane units or a combined permeate line in the downstream. In addition to permeate, monitoring and recording the feed water quality is also a common practice, depending on the local jurisdiction and for process performance control.

Table 2 — Examples of water quality parameters monitored at membrane filtration process

<table>
<tr><th>Category</th><th>Parameters</th><th colspan="2">Water Reuse System</th></tr>
<tr><td rowspan="3">Typical monitoring parameters in non-potable water reuse (ISO 20468-1)</td><td>turbidity [a]</td><td colspan="2">x</td></tr>
<tr><td>E. coli [b]</td><td colspan="2">x</td></tr>
<tr><td>BOD</td><td colspan="2">x</td></tr>
<tr><td rowspan="4">Additional parameters in membrane filtration process</td><td></td><th>MF/UF</th><th>NF/RO</th></tr>
<tr><td>pH [a]</td><td>x</td><td>x</td></tr>
<tr><td>electrical conductivity [a]</td><td></td><td>x</td></tr>
<tr><td>TOC [a]</td><td></td><td>x</td></tr>
<tr><td colspan="4">[a] Parameters typically monitored online.
[b] Other microbial indicators may be used according to the local jurisdiction.</td></tr>
</table>

6.3 Process based performance evaluation

In order to achieve a stable operation of a membrane filtration process, membrane operating conditions need to be monitored in order to check the compliance to the design range. The operation condition parameters to be monitored are: TMP, filtration flux, filtration cycle duration, and temperature of effluent.

Membrane fouling and aging which impact membrane hydraulic performance are followed / controlled by the monitoring of the membrane permeability at the operation temperature or at a normalized temperature. The membrane permeability parameters are calculated based on TMP, flux, and temperature.

6.4 Integrity monitoring

6.4.1 Direct Integrity Monitoring

Direct integrity monitoring is conducted through online or offline integrity tests. It can be applied at any phase of scheme development (validation, operation and corrections).

The performance of direct integrity monitoring is governed by three key parameters:

— Resolution;

— Sensitivity;

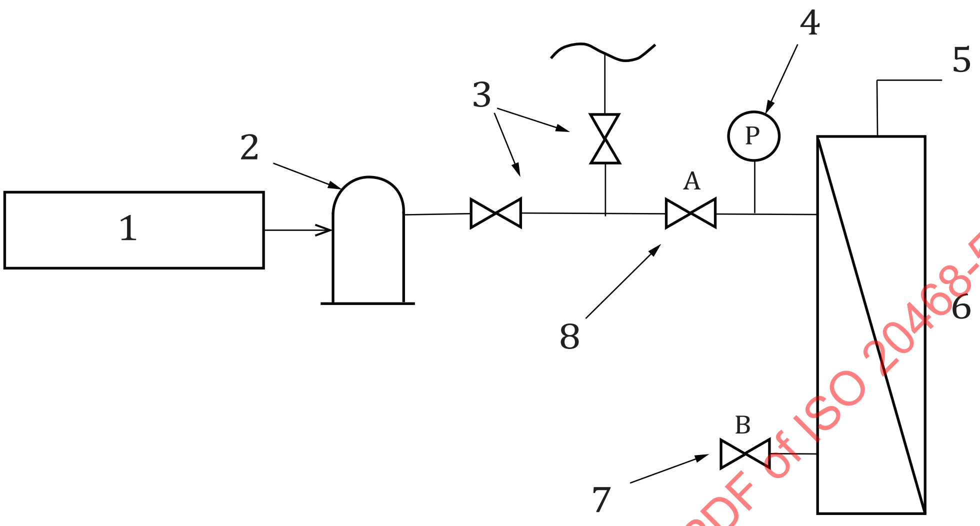
— Frequency.

When any defects or failures are identified that significantly impair the membrane performance and water quality are identified, the damaged membrane module or unit will be isolated from the water reclamation system. The frequency of the integrity test depends on individual condition taking into account the driver and expecting performance of the membrane, the existence and results of indirect integrity monitoring, the risk evaluation of any integrity default on to the reclaimed water quality considering the integrity test sensitivity and the whole treatment line performance. Taking into account all the local constraints, the integrity test could be performed once a day, once a week or less (to be defined case by case).

Three direct integrity tests described below are commonly applied for membrane-based water reclamation systems:

— Pressure decay test

The pressure decay test is based on the measurement of loss in pressure with a typical breach resolution of a few µm. Pressure decay test can be applied to each module element or an entire unit. A typical testing configuration required for pressure decay test is provided in Figure 2. The module or unit targeted is first isolated and the remaining water on one side of the membrane (feed or permeate side) is drained. The drained side is pressurized using compressed air at a pressure lower than the bubble point. Pressure in the pressurized side will be monitored during the test. Any damage on the membrane module can be recognized through the speed of decreasing pressure. Membranes without damage will show negligible loss of the applied pressure over a specific period of time. This test can be implemented both online and offline.



Key

1 compressed air

2 air chamber

3 isolation valves

4 pressure gauge

5 permeate connections (open to atmosphere)

6 membrane module(s)

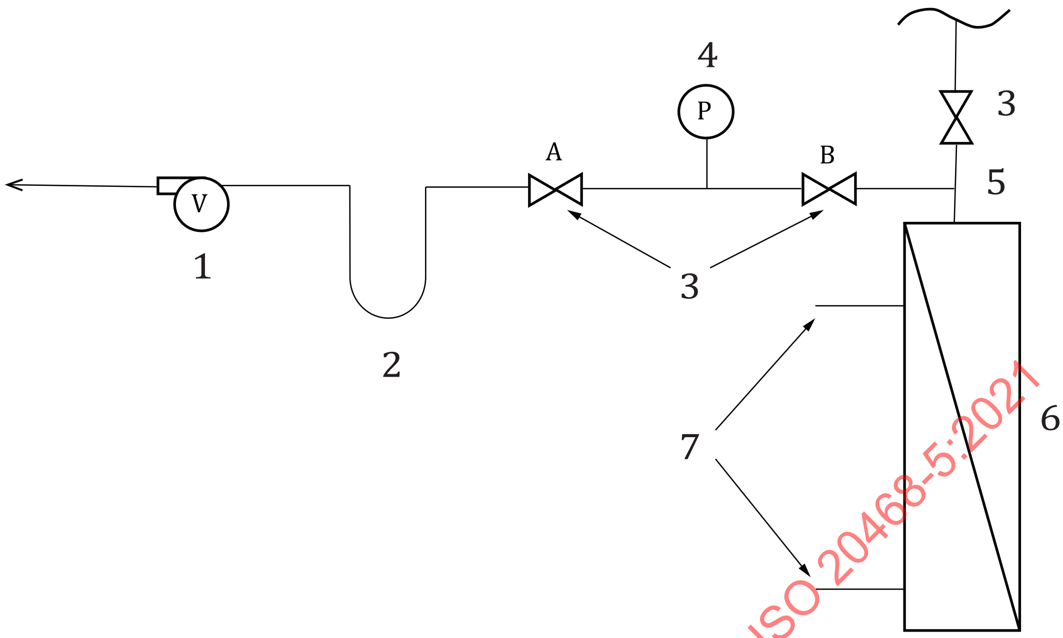
7 concentrate outlet connections (open to be drained, and close to be tested)

8 feed-entry connections (open to be pressured, and close to be tested)

Figure 2 — Schematic configuration of a pressure decay test

— Vacuum decay test

The vacuum decay test is based on the measurement of decay in vacuum with a typical breach resolution of a few µm. A typical testing configuration required for vacuum decay test is provided in Figure 3. A vacuum is generated on one side of the membrane, so that a damage is detected by monitoring a rate of decrease in vacuum pressure. It is often used for pre-shipment inspection of spiral –wound membrane elements.



Key

1 vacuum pump
2 water trap
3 isolation valves
4 vacuum gauge
5 permeate header
6 membrane module(s)
7 feed/concentrate connections (open to atmosphere)

Figure 3 — Schematic configuration of a vacuum decay test

— Bubble testing

The bubble testing is used to identify relatively large leaks, through which the air can go through below the bubble point of membrane. This test is directly related to major membrane integrity breaches, requiring further diagnostic tests or replacement of the membrane module. The applied pressure for the bubble testing is equivalent to the pressure applied to the pressure decay test. The detection of air bubbles can be performed by visual observation or automatic measurement, which utilizes a difference in refractive index of bubbles with a photoelectric tube.

6.4.2 Indirect integrity monitoring

The indirect integrity monitoring is a supplementary method of the direct integrity monitoring. The indirect integrity monitoring is performed by monitoring surrogate parameters; thus, it has a less sensitivity for detecting minor changes in membrane integrity as compared to the direct integrity monitoring. The potential integrity breaches can be identified by detecting changes in the level of water quality in comparison to its baseline. Control limits will be established based on the requirement of reclaimed water quality. When the monitored parameters exceed the control limits, investigations using direct integrity tests and correction measures will be required.

There are a number of different methods and associated devices that may be used for continuous indirect integrity monitoring methods. These include particle counting, turbidity, laser turbidity, and electrical conductivity monitoring. In general, the analytical methods that provide the count of particulate-related constituents in permeate (e.g. number of particles and turbidity) are used for the porous membranes (i.e. MF and UF). Analytical methods measuring dissolved constituents in permeate (e.g. electrical conductivity) would be applicable to NF/RO systems. Any unusual rise in the concentration of the water quality parameters can be a sign of defect occurrence in the membrane filtration system. Subsequently, the direct integrity tests are performed to identify specific membrane modules with membrane breaches. The three most important methods used for indirect integrity monitoring are described as follows:

— Fine particle monitoring

Fine particle monitoring method utilizes a conventional online particle counter consisting of a laser-based light scattering technology for counting the number of particles at specific size ranges. A fine particle counter using laser diode can count and group the number of particles down to 0,05 µm in water.

— Turbidity monitoring

Turbidity monitoring method utilizes a conventional online turbidity meter that shows the intensity of scattered light in the samples. Turbidity is not representative of any countable substances but is relatively proportional to concentrations of particles in water. Thus, turbidity meter is frequently used as the default method for indirect integrity monitoring. Turbidity monitoring is typically conducted using a high precision and non-contact nephelometer according to ISO 7027.

— Electrical Conductivity monitoring

Electrical conductivity or resistivity measurement is the most common indicator of ionic constituents in water. Conductivity probes are generally inserted directly into the main permeate pipes to provide continuous monitoring. Although conductivity in the permeate of NF/RO can vary depending on operating conditions such as pH and temperature, it is still a common practice to identify leak points in modules, O-rings, and seals of NF/RO membrane modules or units.

7 Performance evaluation for non-functional requirements

7.1 General

Non-functional requirements in membrane filtration technology include environmental performance, economic performance and dependability. Key environmental and economic performance parameters include energy consumption, chemical consumption and the amount of liquid and solid wastes. Key economic performance parameter is LCC, which includes capital and operating costs. Operating costs should include expected membrane life duration. Another key non-functional requirement – dependability – is described in ISO 20468-1.

7.2 Energy consumption

The energy consumption of membrane filtration differs according to the type of filtration orientation – pressure driven type or vacuum driven type. The calculation methods for each filtration type are described below:

Energy consumption in membrane filtration system for evaluating the system performance is typically expressed in energy consumption per unit reclaimed water volume (Ev [kWh/m^3]) during a representative time period (e.g. one year) as given in Formula (1):

$$Ev = \frac{E_{\text{mem}}}{V} \tag{1}$$

where

E_{mem} is energy consumption of membrane system (kWh);

V is reclaimed water volume (m^3).

— Pressure driven membrane filtration

Pressure driven membrane filtration system is operated in cross-flow filtration mode or dead-end filtration mode as described in 4.3. The total energy consumption in pressure driven membrane filtration system fundamentally equals to the sum of energy consumed by main power sources (e.g. feed pumps, recirculation pumps for cross-flow filtration, and pumps designated for membrane cleaning). Some other small power sources such as motor valves, air compressors used for air-actuated valves, instrumentations, and control panels may also be included. Major factors of energy consumption in each membrane type are as follows.

— MF/UF: feed/recirculation pump is the major energy consumption item for cartridge system. Backwashing pump and blower should be taken into account.

— NF/RO: high pressure pump is used and its energy consumption is significant. An energy recovery device can be used to recover residual energy of concentrate for high pressure feed pumps. A pressure exchanger (also called isobaric device) contributes to the energy reduction at the feed pump.

— Pressure driven type MBR: Most energy intensive equipment is the feed/recirculation pump of MLSS for cross-flow operation.

— Vacuum driven membrane filtration

The major components of vacuum driven membrane filtration system for energy calculations include blowers for membrane air scouring and suction pumps. Formula (1) also applies. It should be noted that the energy consumption can vary considerably depending on feed water quality and treatment configuration and on the mode of operation, because these factors affect the volume of air supplied to the vacuum driven membrane filtration system.

In vacuum driven MBR process, major factors in energy consumption are blower for membrane air scouring and biological treatment, sludge recirculation pump, the filtration pump. Formula (1) also applies.

7.3 Chemical consumption

Membranes are subject to fouling by substances in wastewater as membrane filtration progresses. Foulants include organic and inorganic substances and microorganisms. Fouling that cannot be removed by periodical physical cleaning, such as backwashing and air scouring, is called irreversible fouling. Accumulation of irreversible fouling causes a deterioration in membrane separation performance and permeability. Therefore, it is important to recover membrane performance by conducting chemical cleaning.

The selection of cleaning chemical reagents will be made based on the type of foulants, the level of fouling, and the handling, toxicity and cost of the chemical reagents. Examples of chemicals typically used for each water reclamation process and objectives are shown in Annex C. Generally, membrane suppliers have their own requirements and/or recommendations for chemical cleaning. It is important to follow their instructions for developing chemical cleaning protocols. The membrane properties (e.g. permeability) right before and after chemical cleaning is recommended to be monitored and recorded, as they can be used to evaluate the cleaning procedure efficiency and the aging level or lifetime of the membrane.

The amount of chemicals used for membrane cleaning will be calculated and evaluated based on the volume (l) or weight (kg) of each chemical per unit reclaimed water volume over a specific time period (e.g. one year).

7.4 Brine water disposal or treatment

Special attention should be paid that in the case NF/RO membranes are used in water reuse, brine water with a high concentration of TDS is produced. The brine water is discharged to sewer or evaporated for minimizing the brine amount or Zero Liquid Discharge (ZLD) system. The brine management depends on local regulation and special local conditions. Attention should be paid to a high TDS when the brine is discharged to sewer. Detailed available scenario in the brine management is described in ISO 23070.

7.5 Solid waste for disposal

Membrane modules/elements are composed of different types of plastic or ceramic materials which are difficult to recycle. As a result, used membrane modules are typically disposed as industrial waste, following local regulations. The amount of the solid waste may be calculated based on the lifetime of membrane modules/elements. For residual chemicals and neutralized liquid wastes generated in cleaning, the final disposal will depend on its biodegradability and toxicity. It may be returned to the biological treatment process, discharged into sewer, or if required to industrial waste collections. The volume/weight of the chemicals will be used for disposal evaluation. Chemical management depends on local regulation and special local conditions.

7.6 Life cycle cost

The LCC of membrane filtration process is composed of capital cost, operating costs, and depreciation. Capital cost for membrane filtration is associated with construction costs and the purchase cost of membrane modules/units, and their associated piping, instrumentation and control systems. Depreciation of capital cost for membrane filtration is usually taken into account as function of inflation rate and project lifetime. In contrast, operating cost equals the cost required for system operation (e.g. chemicals, electricity, membrane replacement, and labours). LCC for membrane filtration can be calculated by the total of these costs. For the fair evaluation, LCCs which are divided by volume of reclaimed water available for reuse at the project lifetime (i.e. the unit is “costs/m^3) should be used.

Membrane lifetime can be calculated based on membrane supplier's recommendations. Their criteria are, but not limited to, the recovery of separation performance after chemical cleaning and membrane integrity. In case the separation performance is considerably deteriorated over time, the membrane elements/modules shall be replaced.

Annex A
(informative)

Examples of parameters on the specification sheet

Table A.1 — Items of specification sheet

Categories	Parameters	MF/UF	NF/RO	MBR
Key membrane performance in water reuse	Membrane pore size, or MWCO	×		×
	Salts Rejection		×	
	TDS in treated water	×	×	×
	TSS in treated water	×	×	×
	Coliforms in treated water	×		×
	Other contaminants in treated water	×	×	×
	Permeate flux	×	×	×
	Applicable pressure	×	×	×
General specifications	Membrane type (hollow-fibre, tubular, flat sheet, spiral-wound, etc.)	×	×	×
	Operation mode (Pressure driven or vacuum driven, cross-flow or dead end filtration)	×	×	×
	Membrane materials	×	×	×
	Membrane surface area	×	×	×
	Dimensions (element/modules and connections)	×	×	×
	Weight	×	×	×
	Pressure drop of element/module	×	×	×
	Transportation/ storage conditions	×	×	×
	Disposal method	×	×	×
Recommended operating conditions and method	Recommended flow scheme	×	×	×
	Recommended cleaning procedure	×	×	×
	Applicable range of Turbidity, BOD, COD	×		×
	Maximum feed water SDI		×	
	Maximum feed water chlorine concentration	×	×	
	Maximum value of other inlet conditions (e.g. oil & grease, heavy metals)	×	×	×
	Operating MLSS range			×
	Operating temperature range	×	×	×
	Operating pH range	×	×	×
	Operating pressure range	×	×	×
	Operating feed flow rate range (Pressure driven)	×	×	×
	Operating product flow rate range (Vacuum driven)	×	×	×

NOTE The list is applicable to all types of membranes: MF/UF, NF/RO, and membranes for MBR.

