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**Technical Guidelines for Industrial Wastewater Treatment and Reuse: Membrane-based Processes**

NWIP stage

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Contents

Page

[Foreword iv](#_Toc112097233)

[Introduction v](#_Toc112097234)

[1. Scope of the guideline 6](#_Toc112097235)

[2. Normative references 6](#_Toc112097236)

[3. Terms, definitions and abbreviated terms 6](#_Toc112097237)

[3.1 Terms and definitions 6](#_Toc112097238)

[3.2 Abbreviated terms 8](#_Toc112097239)

[4. General 9](#_Toc112097240)

[5. Technical requirement for membrane-based processes 9](#_Toc112097241)

[5.1 Classification and general requirement of membrane technology 9](#_Toc112097242)

[5.2 Requirements for feed quality 13](#_Toc112097243)

[5.3 Process design 17](#_Toc112097244)

[5.4 Calculation 20](#_Toc112097245)

[6. Operation and maintenance 31](#_Toc112097246)

[6.1 Start-up 31](#_Toc112097247)

[6.2 Commissioning 31](#_Toc112097248)

[6.3 Operation and maintenance 32](#_Toc112097249)

[6.4 Outage 32](#_Toc112097250)

[Annex A (informative) Test Method for Silt Density Index (SDI) 34](#_Toc112097251)

[Annex B (informative) Commonly used membrane-based process for salt fractionation 36](#_Toc112097252)

[Annex C (informative) Membrane fouling and cleaning 38](#_Toc112097253)

[Annex D (informative) Protection during outage period 40](#_Toc112097254)

[Bibliography 42](#_Toc112097255)

# Foreword

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The committee responsible for this document is Technical Committee *[or Project Committee]* ISO/TC *[or ISO/PC]* 282, *[name of committee]*, Subcommittee SC 4, *[name of subcommittee]*.

This second/third/… edition cancels and replaces the first/second/… edition (ISO #####:####), which has been technically revised.

The main changes compared to the previous edition are as follows:

— xxx xxxxxxx xxx xxxx

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

# Introduction

Large consumption of water resource and discharge of industrial wastewater during the industrial production process result in severe water pollution and water resource shortage, especially in the developing countries [1]. Industrial wastewater treatment and reuse is an effective way to reduce wastewater discharge, improve water utilization efficiency and relieve the pressure on the stressed water resources [2].

Recently, membrane-based wastewater treatment technologies have developed rapidly, driven by the increasing demand of wastewater treatment and reuse [3-4]. A variety of membrane technologies, including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), electrodialysis (ED) and electrodeionization (EDI) have been widely applied for industrial wastewater treatment and reuse around the world [5]. However, the absence of an international standard on the membrane-based processes in the field of industrial wastewater treatment and reuse makes it difficult to select and design an appropriate membrane technology for designers, engineers, and enterprises.

Therefore, a universal guideline for industrial wastewater treatment and reuse using membrane-based processes is critically needed, to provide guidance on standardized design, operation and application of membrane-based processes, to meet the requirement of membrane technologies in various countries, and to promote the development and application of membrane technology in the field of industrial wastewater treatment and reuse around the world.

This guideline specifies the classification of membrane technology in the field of industrial wastewater treatment and reuse, and proposes the design guideline and efficacy improvement methods of combined membrane processes, based on the demand of industrial wastewater treatment and reuse. This guideline also specifies the feed water quality, process design, parameter calculation, operation and maintenance requirements of different membrane processes. The complete guideline on the industrial wastewater treatment using membrane processes could provide standardized guidance to enterprises, engineers, operators and other stakeholders involved in the treatment and reuse of industrial wastewater.

Technical Guidelines for Industrial Wastewater Treatment and Reuse: Membrane-based Processes

# 1. Scope of the guideline

This document specifies the guidelines for industrial wastewater treatment and reuse using membrane-based processes, including feed water quality, process design, parameter calculation, operation and maintenance of widely applied membrane technologies and combined membrane processes in the field of industrial wastewater treatment and reuse.

This document is applicable to enterprises, engineers, operators and other stakeholders, who engage in designing or operating industrial wastewater treatment plants, choosing the membrane technologies applied in the industrial wastewater treatment and reuse process, and evaluating the treatment efficacy.

Enterprises include industrial production enterprises, designers, contractors, supervision agencies, and equipment suppliers of membrane modules.

Other stakeholders may include relevant functional departments of government, the management agencies of the industrial estate where the production enterprises are located, industrial wastewater treatment plants, relevant non-governmental organizations, and users that need reclaimed water.

# 2. Normative references

The following documents are referred to in the text partly. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6107, *Water quality — Vocabulary*

ISO 20670, *Water reuse — Vocabulary*

ISO 20468-6, *Guidelines for performance evaluation of treatment technologies for water reuse systems —Part 6: Ion exchange and electrodialysis*

ISO 23044, *Guidelines for softening and desalination of industrial wastewater for reuse*

ISO 22449-1, *Use of reclaimed water in industrial cooling systems—Part 1: Technical guidelines*

# 3. Terms, definitions and abbreviated terms

## 3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1.1**

**electrodeionization**

water treatment technology that utilizes electricity, ion exchange membranes and ion exchange resin in order to desalinate ions from one solution to another solution in a very low concentration

[SOURCE: ISO 20468-6:2021, 3.1.12]

**3.1.2**

**electrodialysis**

water treatment technology that uses ion exchange membranes in order to move ions from one solution to another solution by using electrical potential difference

[SOURCE: ISO 20468-6:2021, 3.1.13]

**3.1.3**

**ion exchange membrane**

polymer sheet that contains negatively or positively charged functional groups in its polymer matrix designed to conduct cations or anions while blocking opposite charged ions

[SOURCE: ISO 20468-6:2021, 3.1.18]

**3.1.4**

**limiting current density**

current density beyond which water dissociation will occur

[SOURCE: ISO 20468-6:2021, 3.1.20]

**3.1.5**

**membrane bioreactor**

type of wastewater treatment technology combining membrane separation process (microfiltration or ultrafiltration) with conventional activated sludge treatment process

**3.1.6**

**microfiltration**

type of physical filtration process by pressure driven where a contaminated liquid is passed through a special pore-sized membrane (0.1-1 μm) to separate microorganisms and suspended particles from process liquid

[SOURCE: ISO 23044, 3.1.8]

**3.1.7**

**multipass**

a kind of membrane module arrangement in which the product water produced by the previous membrane module is used as the feed water of the next membrane module.

**3.1.8**

**multistage**

a kind of membrane module arrangement in which the concentrated water produced by the previous membrane module is used as the feed water of the next membrane module

**3.1.9**

**nanofiltration**

type of membrane separation technology with a filtration accuracy of 0.001-0.01 μm to separate proteins, low molecular organic compounds and multivalent ions

[SOURCE: ISO 23044:2020, 3.1.10, modified]

**3.1.10**

**pre-treatment**

treatment process(es) carried out before the membrane-based processes

**3.1.11**

**reverse osmosis**

flow of water through a membrane from a more concentrated to a less concentrated solution, as a result of applying pressure to the more concentrated solution in excess of the normal osmotic pressure, which is used for removal of ions and organic compounds with molecular weight larger than 150 Da

[SOURCE: ISO 6107:2021, 3.480, modified]

**3.1.12**

**ultrafiltration**

use of microporous membranes with a filtration accuracy of 0.01-0.1 μm for the separation of large molecules or very finely suspended matter from water by filtration, often by means of applied differential pressure

[SOURCE: ISO 6107:2020, 3.595, modified]

## 3.2 Abbreviated terms

BOD5 biochemical oxygen demand after 5 days

COD chemical oxygen demand

ED electrodialysis

EDI electrodeionization

MBR membrane bioreactor

MF microfiltration

MLSS mixed liquid suspended solids

MLVSS mixed liquid volatile suspended solids

NF nanofiltration

NVSS nonvolatile suspended solids

RO reverse osmosis

SDI silt density index

TDS total dissolved solids

TKN total Kjeldahl nitrogen

TN total nitrogen

TOC total organic carbon

TP total phosphorous

TSS total suspended solids

UF ultrafiltration

# 4. General

The industrial wastewater needs to be pretreated in pre-treatment process before being fed into membrane devices.

The selection of pre-treatment process should consider the quality of industrial wastewater, feed water quality requirements for membrane processes, and water treatment requirements (e.g., reuse purposes). Besides, the operation experience of similar projects should be referred, by accounting for local conditions. Finally, users can determine which technology to adopt through technical and economic comparison.

The selection of membrane process for industrial wastewater treatment processes should be determined after technical and economic comparison based on factors such as feed water quality, product quality and quantity requirements, site conditions, and environmental protection requirements.

The product water from industrial wastewater treatment processes is recommended to be reused for urban non-potable water, eco-environmental water, cooling water, as well as pure or ultrapure water for high-quality boiler feed water, process water, rinse water, etc.

Waste liquid (e.g., cleaning liquid of ion exchange membrane, concentrated water of membrane process, etc.) disposed from the membrane treatment processes should be collected separately and treated properly according to the wastewater characteristics.

# 5. Technical requirements for membrane-based processes

## 5.1 Classification and general requirements of membrane technology

**5.1.1 Microfiltration, ultrafiltration, and membrane bioreactor**

**(1) Microfiltration and ultrafiltration**

Microfiltration (MF) is a pressure-driven membrane separation process to remove the particles having diameters of 0.1 and several μm using membranes with a pore size varying between 0.1 and 1 μm. Similar to MF, ultrafiltration (UF) is also a pressure-driven membrane separation process used to remove the particles and solutes having molecular weight of hundreds to millions Dalton using membranes with a pore size varying between 0.01-0.1 μm. Depending on their pore sizes, MF and UF membranes are usually used to remove TSS, turbidity, protozoa, and bacteria from industrial wastewater [7]. The UF membranes can further remove macromolecules, colloidal particles and viruses. The configuration of MF/UF membranes can be classified into inside-out and outside-in types according to the direction of flux, or submerged and pressurized type depending on whether the membrane elements are placed in open basin or pressure vessel.

General technical requirement of MF/UF process:

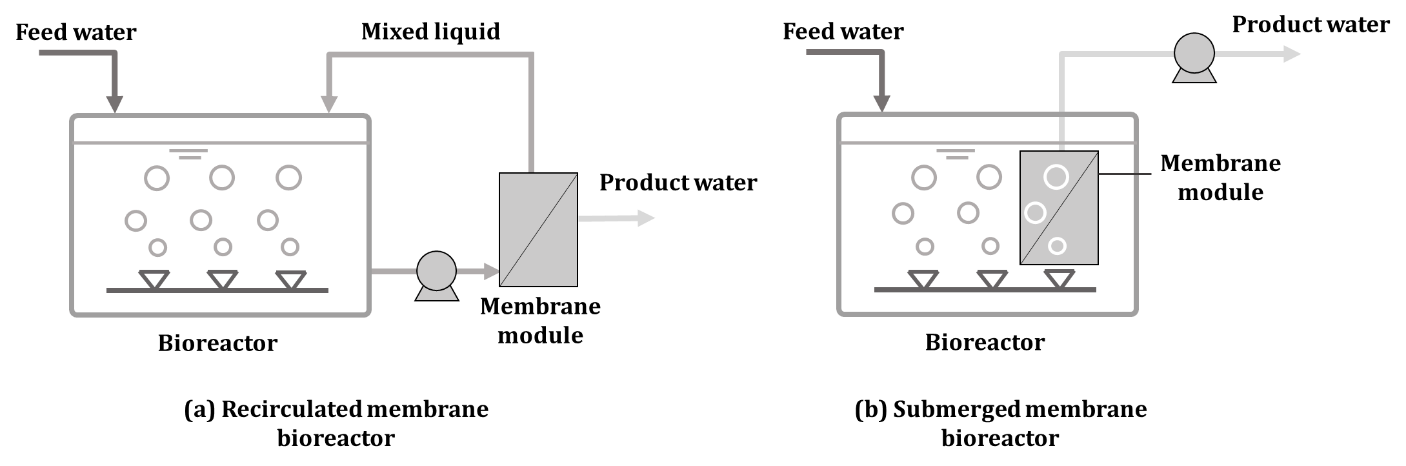
a) MF and UF membranes are usually operated with the pressure under 0.2 MPa and 0.5 MPa, respectively.

b) The MF process usually does not generate concentrate, while the UF process usually generates concentrates which need proper treatment.

c) In combined processes, MF and UF membranes are typically used as pre-treatment processes for NF/RO to ensure that the permeate from MF/UF can meet the feed water quality requirements of NF/RO.

**(2) Membrane bioreactor**

Membrane bioreactor (MBR) refers to a type of wastewater treatment technology combining membrane separation process (microfiltration or ultrafiltration) with conventional activated sludge treatment process. It is used to remove organics, nutrients and particles (including suspended activated sludge flocs). MBR can be classified into recirculated MBR and submerged MBR, and the corresponding designs are shown in Figure 1. For recirculated MBR, the MF/UF membranes are submerged in biological reactor. Submerged MBR has pressurized membrane modules externally coupled to the bioreactor, with the activated sludge recirculated between the membrane modules and the bioreactor by pumping.



**Figure 1 — Typical examples of recirculated and submerged MBR processes**

General technical requirements of MBR process:

a) Adequate aeration is essential for membrane fouling control.

b) The membrane flux is typically maintained within 30~45 L/(m2·h) for recirculated MBR, and 15~25 L/(m2·h) for submerged MBR.

c) The MBRs should be operated at sub-critical flux and intermittent filtration mode. Super-critical flux and continuous filtration mode should not be operated in long term [9].

d) The residual sludge discharged from MBR process needs proper treatment and disposal.

e) In combined processes, MBR can be used as pre-treatment of NF/RO in the treatment of industrial wastewater with high organic concentration.

**5.1.2 Nanofiltration and reverse osmosis**

**(1) Nanofiltration**

Nanofiltration (NF) technology is widely used in desalination and water softening, advanced treatment of domestic sewage, and purification of drinking water. NF is a pressure-driven membrane separation technology between ultrafiltration (UF) and reverse osmosis (RO) membranes [10]. The pore size of NF membranes is in the nanometer range, and the molecular weight cutoff of NF membranes is about 200 to 1000 Da. The active layer of the NF membrane is typically composed of polyamide that is negatively charged at neutral pH, and the rejection rate of the NF membrane for divalent and high-valent ions is higher than that of monovalent ions. Compared with the RO process, the operating pressure of the NF membrane is lower, and it has the advantages of high flux and low energy consumption.

General technical requirements of NF process:

a) In the NF process, the operating pressure is generally in the range of 0.5-3 MPa.

b) At both ends of the pressure vessel, a space of no less than 1.2 times of the membrane module length should be kept.

c) On the low-pressure side of the NF system, pipes made of hard polyvinyl chloride, glass fiber reinforced plastic and high-density polyethylene should be used, and stainless-steel pipes should be used on the high-pressure side.

**(2) Reverse osmosis**

The reverse osmosis (RO) process has been widely used in seawater desalination, pure water preparation, urban wastewater treatment and high-quality reclaimed water production [11]. RO is a separation process where one component of a solution is removed from another component by flowing the feed water stream under pressure across a semipermeable membrane that causes selective movement of solvent against its osmotic pressure difference. The pollutant removal range of RO is wide, which can not only remove dissolved inorganic salts, but also reject various organic compounds with molecular weight larger than 150 Da. It uses hydraulic pressure as the driving force for separation and has high salt removal and water reuse efficiencies. The RO device is easy to operate and maintain.

General technical requirements of RO process:

a) The feed water quality should be strictly controlled to ensure that it meets the requirements of the feed water index.

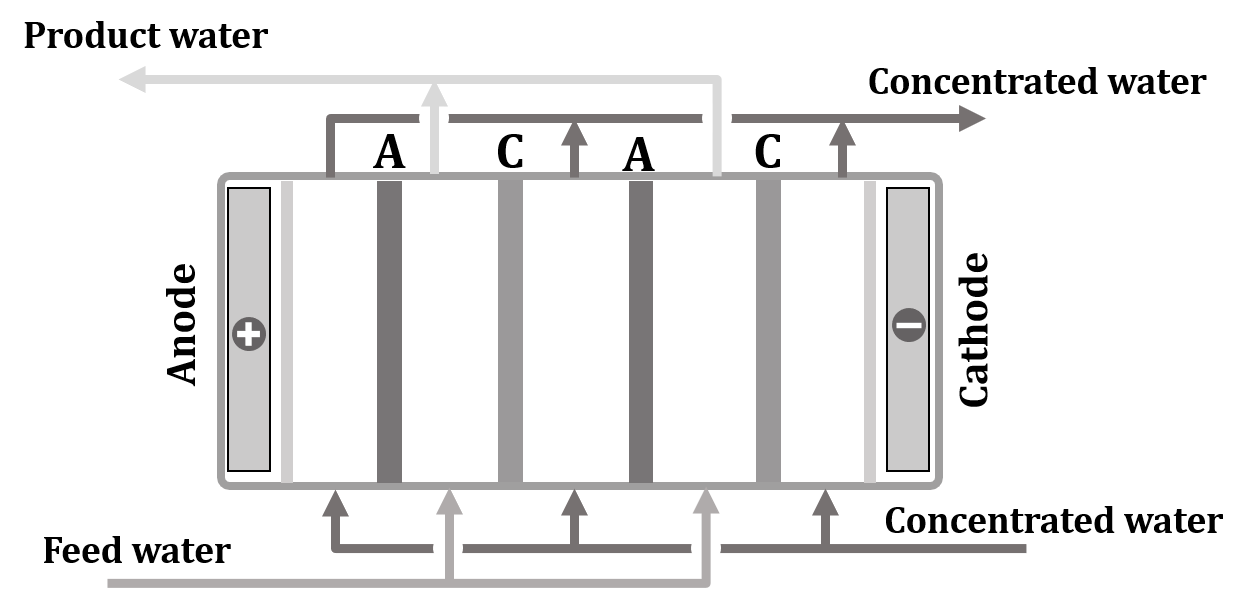
b) Air should be exhausted from the membrane module before operation of the RO module.

c) The applied pressure of RO should be higher than the osmotic pressure difference between the two sides of the membrane to ensure water permeation.

**5.1.3 Electrodialysis and electrodeionization**

**(1) Electrodialysis**

Electrodialysis (ED) is used to transport salt ions from one solution through ion-exchange membranes to another solution under an applied electric potential difference [12]. This is done in a configuration called an electrodialysis cell. The typical cell consists of a feed water (dilute) compartment and a concentrated water (brine) compartment separated by a series of anion exchange membranes and cation exchange membranes placed between two electrodes, as shown in Figure 2. In the process, the ionic substances can be separated from the nonionic substances and the ionic substances can also be selectively separated from each other. The ionic substance can also be desalted, concentrated, refined and recovered. In the combined process, ED is usually used to further concentrate the concentrated water of NF/RO, and ED with bipolar membrane is used to convert the salt in the concentrated water of NF/RO into alkali and acid.



**Key**

A anion exchange membrane

C cation exchange membrane

**Figure 2 — Typical example of ED process**

General technical requirements of ED process:

a) The feed water quality must be well controlled to meet the requirement of influent to avoid scaling and maintain efficiency.

b) The feed water pressure of the ED module must be maintained at a stable and proper level, and a special water supply pump or high-level water tank should be set up.

c) To avoid polarization, the operating current density should be below the limit current density. A value of 70 percent of the limiting current density is usually used as the maximum allowable operating current density to provide a reasonable level of safety in system design.

d) A suitable ED device should be selected according to the feed water flux and product water quality.

**(2) Electrodeionization**

Electrodeionization (EDI) is a water treatment technology that utilizes electricity, ion exchange membranes, and resin to deionize water and separate dissolved ions from water. EDI is usually used as a polishing treatment to RO. EDI technique can produce very high purity water, with a conductivity below 0.1 μS/cm [13]. EDI units are often referred to as continuous electrodeionization (CEDI) since the electric current regenerates the resin continuously. A continuous operational EDI consists of three steps running simultaneously. First, under a continuously applied electric voltage, both cations and anions are directed to those electrodes and captured on the cationic and anionic resins. Second, ions are continuously transported to the concentrated stream through resins and membrane layers. Finally, the continuous regeneration is made by H+ and OH-, which occurs thanks to the dissociation of water. EDI has the advantages of continuous operation, chemical-free regeneration, stable product water quality, low energy consumption and so on. In combination with RO, it can remove up to 99.9% of dissolved ions. In addition, EDI is capable of removing CO2 from feed water.

General technical requirements of EDI process:

a) When designing EDI system, the pressure must be considered based on the whole water treatment system. Each EDI module experiencing a pressure drop across the device should meet the requirements of individual manufacturers.

b) The feed water must meet the requirement of influent to avoid scaling and damaging ion exchange membrane or resin.

c) A suitable EDI module should be selected according to the feed water flux, temperature and product water quality.

## 5.2 Requirements for feed water quality

The feed water quality is of great importance for the design, operation and maintenance of membrane-based industrial wastewater treatment systems. When the water quality cannot meet the requirements, it is easy to cause the membrane process to have problems such as membrane scaling, membrane fouling, and membrane damage, reducing the efficiency of membrane treatment and increasing energy consumption. Typical feed water quality requirements for membrane-based treatment technologies are listed in Table 1-5. The feed water quality can be adjusted by optimizing the pre-treatment process or the previous treatment process.

**Table 1 — Typical feed water quality** **requirements for MF and UF**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Number | Parameter | Unit | Typical value | |
| 1 | Temperature | ℃ | 5~40 | |
| 2 | pH | / | 6~9 | |
| 3 | TSS | mg/L | Inside-out a | ≤30 |
| Outside-in b | ≤100 |
| Submerged c | ≤120 |
| 4 | Turbidity | NTU | Inside-out | ≤20 |
| Outside-in | ≤40 |
| Submerged | ≤50 |
| 5 | COD | mg/L | Inside-out | ≤100 |
| Outside-in | ≤120 |
| Submerged | ≤180 |
| 6 | Animal and vegetable oils | mg/L | ≤3 | |
| 7 | Petroleum | mg/L | ≤3 | |
| 8 | Particle size | μm | Inside-out | ≤5 |
| Outside-in | ≤200 |
| Submerged | / |
| a inside-out refers to the pressurized MF/UF with flux flowing from inside to outside of membrane element.  b outside-in refers to the pressurized MF/UF with flux flowing from outside to inside of membrane element.  c submerged refers to the submerged MF/UF which are always outside-in type. | | | | |

**Table 2 — Typical feed water quality requirements for MBR**

|  |  |  |  |
| --- | --- | --- | --- |
| Number | Parameter | Unit | Typical value |
| 1 | Temperature | ℃ | 10~37 |
| 2 | pH | / | 6~9 |
| 3 | TSS | mg/L | / |
| 4 | Turbidity | NTU | / |
| 5 | BOD5 | mg/L | ≤300 |
| 6 | COD | mg/L | ≤500 |
| 7 | NH3-N | mg/L | ≤50 |
| 8 | Animal and vegetable oils | mg/L | ≤30 |
| 9 | Petroleum | mg/L | ≤3 |

**Table 3 — Typical feed water quality requirements for NF and RO**

|  |  |  |  |
| --- | --- | --- | --- |
| Number | Parameter | Unit | Typical value |
| 1 | Temperature | ℃ | 5~40 |
| 2 | pH | / | 6~9 |
| 3 | TSS | mg/L | ≤2 |
| 4 | Turbidity | NTU | ≤1 |
| 5 | Total hardness (CaCO3) | mg/L | ≤200 |
| 6 | Residual chlorine | mg/L | ≤0.1 |
| 7 | Iron(Ⅲ) | mg/L | ≤0.05 |
| 8 | Iron(Ⅱ) | mg/L | ≤4 |
| 9 | Aluminum | mg/L | ≤0.05 |
| 10 | Manganese | mg/L | ≤0.05 |
| 11 | SDI a | / | ≤5 |
| 12 | Other heavy metals b | mg/L | ≤0.1 |
| 13 | Fluorine | mg/L | ≤0.5 |
| 14 | Silicon | mg/L | ≤5.0 |
| a test method for silt density index (SDI) is provided in Annex A.  b other heavy metals include chromium, cadmium, lead, zinc, copper, mercury, etc. | | | |

**Table 4 — Typical feed water quality requirements for ED**

|  |  |  |  |
| --- | --- | --- | --- |
| Number | Parameter | Unit | Typical value |
| 1 | Temperature | ℃ | 5~40 |
| 2 | pH | / | 2~12 |
| 3 | TSS | mg/L | ≤1 |
| 4 | Turbidity | NTU | ≤1 |
| 5 | SDI | / | ≤5 |
| 6 | Residual chlorine | mg/L | ≤0.1 |
| 7 | Iron | mg/L | ≤0.3 |
| 8 | Manganese | mg/L | ≤0.1 |

**Table 5 — Typical feed water quality requirements for EDI**

|  |  |  |  |
| --- | --- | --- | --- |
| Number | Parameter | Unit | Typical value |
| 1 | Temperature | ℃ | 5~45 |
| 2 | pH | / | 4~11 |
| 3 | Conductivity | S/cm | ≤40 |
| 4 | Total hardness (CaCO3) | mg/L | ≤1 |
| 5 | Residual chlorine | mg/L | ≤0.05 |
| 6 | Iron | mg/L | ≤0.01 |
| 7 | Manganese | mg/L | ≤0.01 |
| 8 | Silica | mg/L | ≤0.5 |
| 9 | TOC | mg/L | ≤0.5 |
| 10 | Sulfide | mg/L | ≤0.01 |

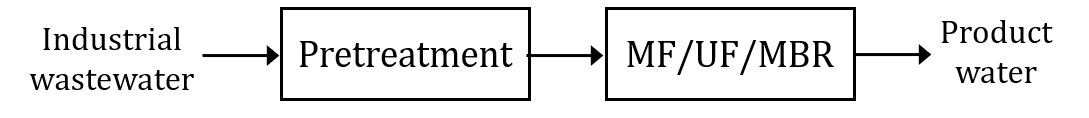
## 5.3 Process design

**5.3.1 Combined process**

There are a large number of membrane-based processes for industrial wastewater treatment and reuse. Among them, there are five typical combined membrane-based processes: MF/UF/MBR, MF/UF/MBR+NF/RO, MF/UF/MBR+NF/RO+EDI, MF/UF/MBR+NF/RO+ED, and MF/UF/MBR+NF+RO+ED.

**(1)** **MF/UF/MBR**

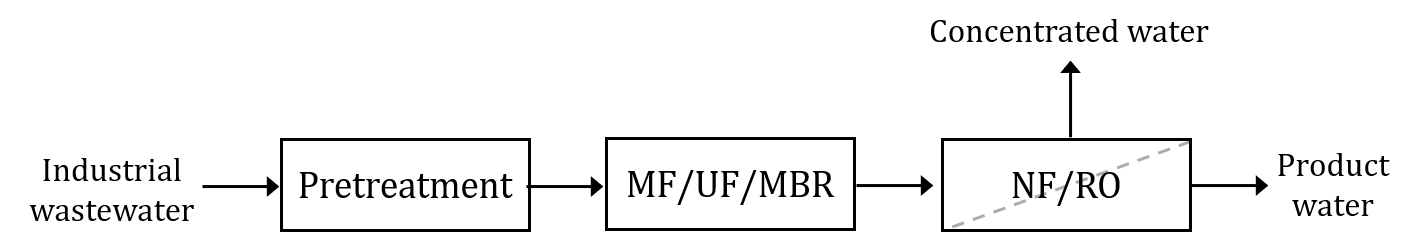
In a typical MF/UF/MBR low-pressure membrane process, as shown in Figure 3, after appropriate pre-treatment, industrial wastewater is treated by one of low-pressure membrane processes including MF, UF and MBR to remove suspended particles. When using MBR, low-pressure membrane process also removes BOD5 and nutrients by the biological degradation. The product water is usually reused for toilet flush, carwash, and other miscellaneous uses after disinfection [14].



**Figure 3 — Typical MF/UF/MBR process**

**(2)** **MF/UF/MBR+NF/RO**

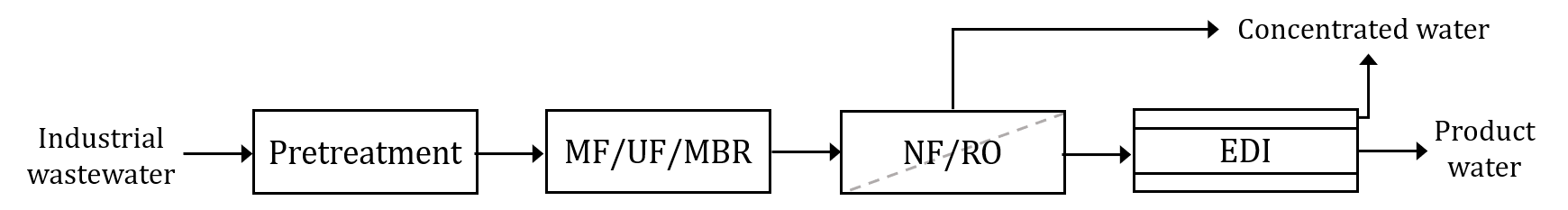
In a typical MF/UF/MBR+NF/RO process, as shown in Figure 4, after appropriate pre-treatment, industrial wastewater is first treated by MF/UF/MBR processes to remove suspended particles, and then treated by NF/RO to remove TDS. The product water is usually reused for cooling water, industrial boilers and other purposes after disinfection.



**Figure 4 — Typical** **MF/UF/MBR+NF/RO process**

**(3)** **MF/UF/MBR+NF/RO+EDI**

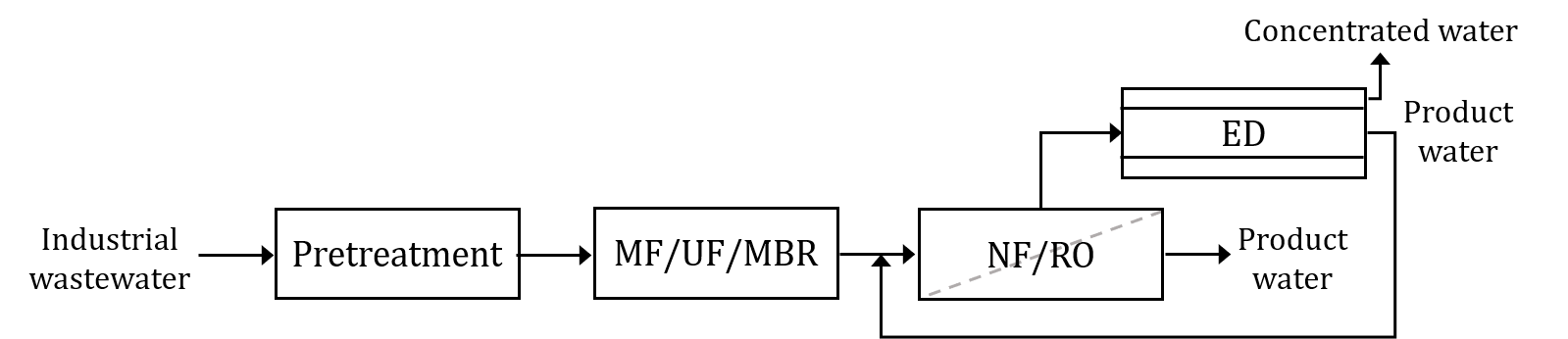
In a typical MF/UF/MBR+NF/RO+EDI process, as shown in Figure 5, after appropriate pre-treatment, industrial wastewater is first treated by MF/UF/MBR processes to remove suspended particles, and then treated by NF/RO to remove TDS. The permeate from NF/RO is further treated by EDI to produce high-quality water. The product water is usually reused for process water, closed recirculating cooling water, industrial boilers and other purposes after disinfection.



**Figure 5 — Typical MF/UF/MBR+NF/RO+EDI process**

**(4) MF/UF/MBR+NF/RO+ED**

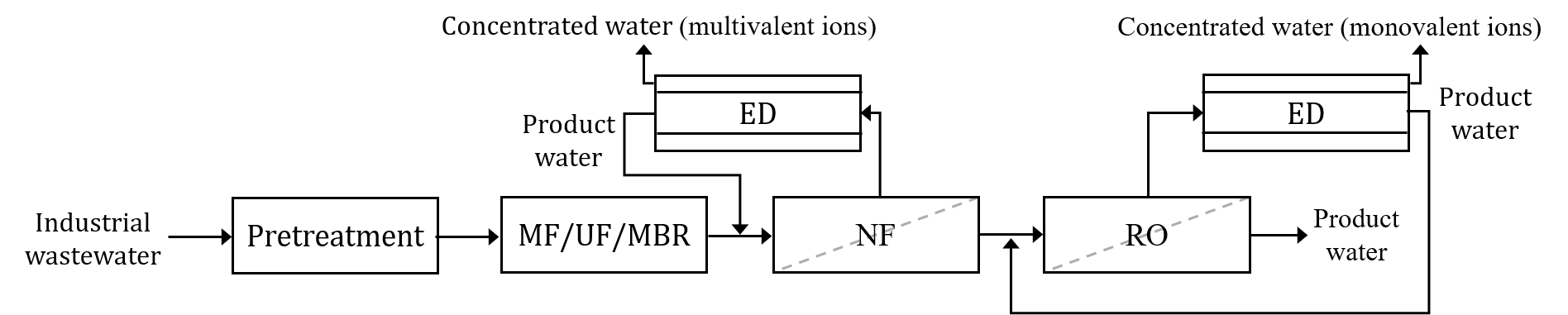
In a typical MF/UF/MBR+NF/RO+ED process, as shown in Figure 6, after appropriate pre-treatment, industrial wastewater is first treated by MF/UF/MBR processes to remove suspended particles, and then treated by NF/RO to remove TDS. The concentrated water from NF/RO is further concentrated using ED to reduce the volume of concentrated water and increase water recovery. The product water from ED is usually recirculated back to NF/RO. The product water from NF/RO is usually reused for cooling water, industrial boilers and other purposes after disinfection.



**Figure 6 — Typical MF/UF/MBR+NF/RO+ED process**

**(5) MF/UF/MBR+NF+RO+ED**

In a typical MF/UF/MBR+NF+RO+ED process for salt fractionation, as shown in Figure 7, after appropriate pre-treatment, industrial wastewater is first treated by MF/UF/MBR processes to remove suspended particles. Other commonly used membrane-based processes for salt fractionation are provided in Annex B. The permeate from MF/UF/MBR processes is treated by NF to remove multivalent ions, and subsequently treated by RO to remove monovalent ions. The concentrated water from NF and RO contains high-concentration multivalent and monovalent ions, respectively. After being further concentrated by ED, the concentrated water can be used for recovery of industrial salts. The product water from ED is usually recirculated back to NF or RO. The product water from RO is usually reused for cooling water, industrial boilers and other purposes after disinfection.

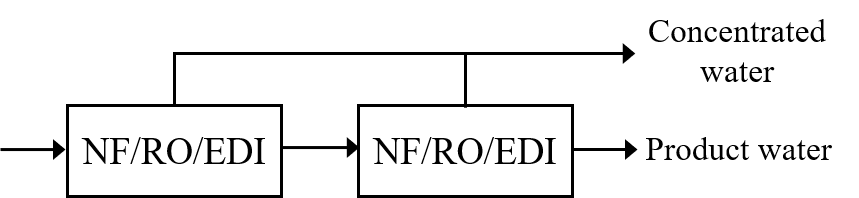


**Figure 7 — Typical MF/UF/MBR+NF+RO+ED process for salt fractionation**

**5.3.2 Multipass and multistage process**

**(1) Multipass**

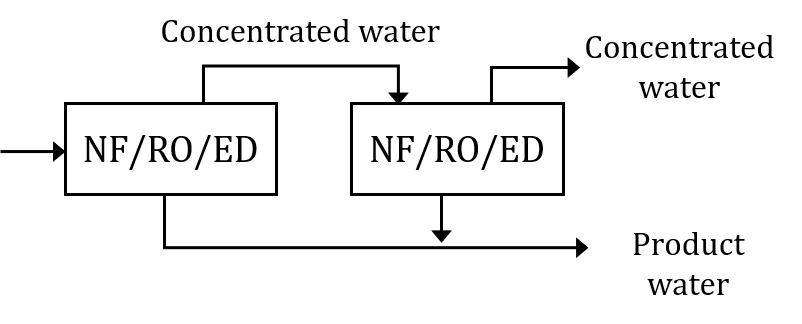
When the water quality of a single NF/RO/EDI membrane cannot meet the requirements, the product water produced by the NF/RO/EDI membrane module can be used as the feed water of the next NF/RO/EDI membrane module to improve the product water quality. The typical multipass membrane module arrangement is shown in Figure 8.



**Figure 8 — Typical multipass membrane module arrangement**

**(2) Multistage**

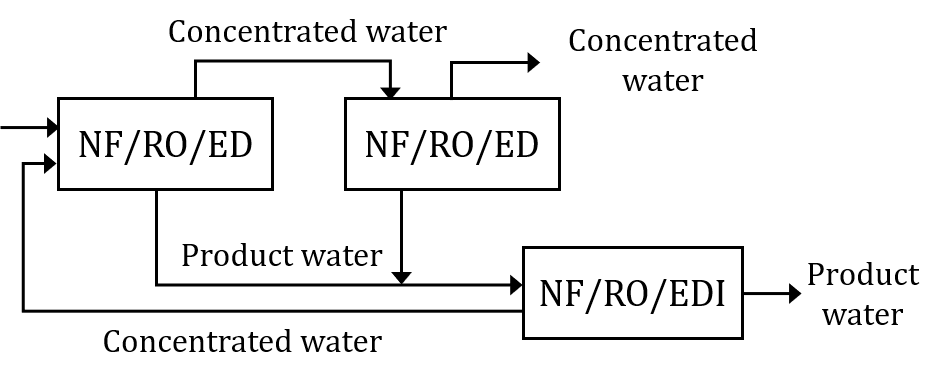
When the water recovery of a single NF/RO/ED membrane cannot meet the requirements, the concentrated water produced by the NF/RO/ED membrane module can be used as the feed water of the next NF/RO/ED membrane module for further concentrating to improve the water recovery. The typical multistage membrane module arrangement is shown in Figure 9.



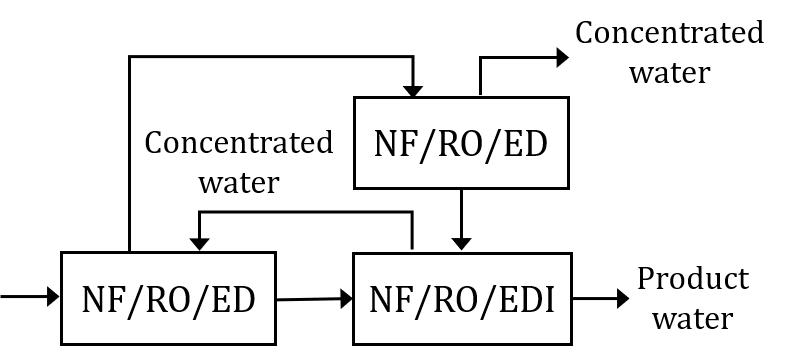
**Figure 9 — Typical multistage membrane module arrangement**

**(3) Combined multistage and multipass**

When it is necessary to improve both water recovery rate and product water quality, multipass and multistage combination can be used. Two typical combined multistage and multipass membrane module arrangements are shown in Figures 10 and 11, respectively.



**Figure 10 — Typical multistage-multipass membrane module arrangement**



**Figure 11 — Typical multipass-multistage membrane module arrangement**

## 5.4 Calculation

**5.4.1 MBR**

Based on wastewater types and the water quality requirements of the product water, different types of MBR can be adopted. For removing organics, Oxic-MBR (O-MBR) can be adopted to remove organics by heterotrophic bacteria. For removing organics and nitrogen, Anoxic/Oxic-MBR (A/O-MBR) can be adopted to remove organics by heterotrophic bacteria and denitrifying bacteria and simultaneously, remove nitrogen by nitrifying and denitrifying bacteria. For removing organics, nitrogen and phosphorous, Anaerobic/Anoxic/Oxic-MBR (A/A/O-MBR) and A/O-MBR coupled with chemical phosphorous removal (when necessary) can be adopted to remove organics by heterotrophic bacteria and denitrifying bacteria, remove nitrogen by nitrifying and denitrifying bacteria, and remove phosphorous by phosphate-accumulating organisms (PAOs) or chemical precipitation. To regulate the design of various MBRs, some basic design parameters are listed in Table 6.

**Table 6 — Design parameters specifications for MBR** [15][16][17]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Number | Design parameter | | Unit | Typical range of values |
| 1 | COD volume loading, *L*COD | | kgCOD/(m3·d) | 1.0~3.0 |
| 2 | BOD5 sludge loading, *L*SBOD | | kgBOD5/(kgMLSS·d) | 0.05~0.15 |
| 3 | Kjeldahl nitrogen volume loading, *L*VN | | kgTKN/(m3·d) | 0.11~0.20 |
| 4 | Total nitrogen sludge loading, *L*STN | | kgTN/(kgMLSS·d) | ≤0.05 |
| 5 | MBR MLSS, *X* | | gMLSS/d | 8~18 |
| 6 | Reflux ratio of the mixed liquid from membrane zone to oxic zone, *R*mo | | % | 100~600 |
| 7 | Reflux ratio of the mixed liquid from oxic zone to anoxic zone, *R*oa | | % | 300~500 |
| 8 | Reflux ratio of the mixed liquid from anoxic zone to anaerobic zone, *R*ap | | % | 100~200 |
| 9 | Average membrane flux | Submerged MBR | L/(m2·h) | 15~25 |
| Recirculated MBR | L/(m2·h) | 30~45 |

**(1) Calculation of oxic zone**

Oxic zone is usually used to realize aerobic degradation of organics, nitrification and phosphorus up-taking. The volume of oxic zone can be determined by using the largest value calculated by Formulas (1)-(3). For O-MBR, the volume of oxic zone can be calculated using Formula (1) alone.

 (1)

where

*V*o is the volume of oxic zone (m3).

*Q*MBR is the average daily flow rate through the MBR process (m3/d).

COD0 is the COD concentration in feed water of the MBR process (mg/L).

CODe is the COD concentration in effluent of the oxic zone (mg/L).

 is the COD concentration (mg/L) removed by the anoxic zone, and it can be considered to be 0 for O-MBR;

*L*VCOD is the COD volume loading (kgCOD/(m3·d)).

 (2)

where

*N*ko is the Kjeldahl nitrogen concentration (mg/L) in feed water of the MBR process. It can also be approximately replaced by total nitrogen concentration.

*N*te is the Kjeldahl nitrogen concentration of effluent of the MBR process (mg/L).

*Y*COD is the sludge yield coefficient (kgMLVSS/kgCOD); it should be determined in accordance with experimental data, otherwise it can be empirically determined from 0.2 to 0.4 when experimental data are not available.

*K*d*T* is the sludge decay coefficient (d-1) at temperature *T*oC.

*θ*c is the design sludge age (d) and its value commonly ranges from 30 to 60 d.

 (3)

where

*L*VN is the Kjeldahl nitrogen volume loading (kgTKN/(m3·d)).

The calculated volume of oxic zone should be checked using Formula (4):

 (4)

where

*S*0 is the BOD5 concentration in feed water of the MBR process (mg/L).

*S*e is the BOD5 concentration in effluent of the MBR process (mg/L).

*X*o is the average MLSS of oxic zone (gMLSS/L).

*V*n is the volume of anoxic zone (m3).

*X*a is the average MLSS of anoxic zone (gMLSS/L).

The amount of residual sludge can be calculated using Formula (5):

 (5)

where

 is the amount of residual sludge (kgMLSS/d).

*SS*0 is the suspended solid concentration in feed of process (mg/L).

*SS*e is the suspended solid concentration in effluent of process (mg/L).

*f*NVSS is the ratio of nonvolatile suspended solids (NVSS) to *SS*0 and its value commonly ranges from 0.17 to 0.28;

The sludge decay coefficient *K*d*T* should be calibrated according to the wastewater temperature of different seasons using Formula (6):

 (6)

where

*K*d*T* is the sludge decay coefficient (d-1), when temperature is *T*oC. *K*d20 commonly ranges from 0.08 to 0.20.

*θT* is the temperature coefficient and its value commonly ranges from 1.02 to 1.06.

*T* is the design temperature (oC).

The average MLSS of the oxic zone can be calculated using Formula (7):

 (7)

where

*X*o is the average MLSS of oxic zone (gMLSS/L). For O-MBR, *X*o is equal to the average MLSS of MBR.

*θ*co is design sludge age (d) of oxic zone and its value commonly ranges from 15 to 30 d. For O-MBR, *θ*co commonly ranges from 30 to 60 d.

Furthermore, the design *θ*co should be larger than the *θ*co calculated using Formulas (8) and (9):

 (8)

 (9)

where

*μ* is the specific growth rate of nitrifying bacteria (d-1).

*μ*max is the maximum specific growth rate of nitrifying bacteria (d-1), when temperature is 20oC, and its value commonly ranges from 0.5 to 1.0.

*F* is the safety coefficient which is related to water temperature, water quality and quantities of feed and effluent, and other factors, and the value of *F* commonly ranges from 1.5 to 3.0.

*N*a is the steady concentration of NH3-N in oxic zone (mg/L).

*K*n is the half-rate constant of NH3-N in nitrification, i.e., the NH3-N concentration when the specific growth rate is half of the maximum specific growth rate of nitrifying bacteria. *K*n is generally taken as 1.

**(2) Calculation of anoxic zone**

Anoxic zone is usually used to realize denitrification. The volume of anoxic zone can be determined using the largest value among those calculated by Formulas (10), (11) and (12).

 (10)

 (11)

where

*V*n is the volume of anoxic zone (m3).

*K*de is the specific denitrification rate, kgNO3-N/(kgMLVSS·d), and it should be determined according to experiments. When experiments are not accessible, it can be empirically determined and its value commonly ranges from 0.03 to 0.06;

*K*de*T* is the specific denitrification rate (kgNO3-N/(kgMLVSS·d)), when temperature is *T*oC.

*X*a is the average MLSS of anoxic zone (gMLSS/L).

 (12)

where

*L*STN is the total nitrogen sludge loading (kgTN/(kgMLSS·d)).

*N*to is the total nitrogen concentration (mg/L) in feed of the MBR process.

The average MLSS of the anoxic zone can be calculated using Formula (13):

 (13)

where

*R*r is the recycle ratio of the mixed liquid from oxic zone to anoxic zone (%).

**(3) Calculation of anaerobic zone and dosage of phosphorus-removing reagents**

Anaerobic zone is usually used to realize phosphorus release and hydrolysis. The volume of anaerobic zone can be calculated using Formula (14).

 (14)

where

*V*p is the volume of anaerobic zone (m3).

*t*p is the hydraulic retention time (h) of anaerobic zone and its value commonly ranges from 1 to 2 h.

The chemical phosphorus removal can be applied with or without anaerobic zone to achieve phosphorus removal. The dosage of phosphorus-removing reagents can be calculated using Formulas (15) and (16).

 (15)

where

*C*p is the total phosphorus concentration that needs to be removed (mg/L).

*TP*0 is the total phosphorus concentration in feed water of the MBR process (mg/L).

*TP*e is the total phosphorus concentration in effluent of the MBR process (mg/L).

*i*p is the mass fraction of phosphorus in mixed liquid (mgTP/gMLVSS), and its value is commonly taken as 0.03.

 (16)

where

*C*M is dosage of coagulant by the concentration of metal elements (mg/L).

*β* is molar ratio of coagulant to total phosphorus, and its value commonly ranges from 1.5 to 3.0.

*M* is the atomic weight of metal elements in coagulant.

P is the atomic weight of P element, P=31.

The amount of chemical sludge can be calculated using Formula (17):

 (17)

where

 is the amount of chemical sludge (kgMLSS/d).

*f* is the conversion coefficient. *f*ch*,* *f*cp*,* *f*mc refer to the ratio of molecular weight of metal hydroxide to metal, metal phosphate to phosphorus and metal to phosphorus, respectively.

The total amount of residual sludge and chemical sludge can be calculated using Formula (18):

 (18)

**5.4.2 MF and UF**

The basic formula for calculating the water production, number of membrane modules and membrane flux of MF and UF processes shall be as follows:

**(1) Water production**

Calculate the water production(*q*s)using Formula (19):

**** (19)

where

*C*m is the assembly factor, the value range is 0.90~0.96.

*S*m is the stability factor, the value range is 0.6~0.8.

*q*0 is the initial water yield of a single membrane module (L/h).

**(2) Number of membrane modules**

Calculate the number of membrane modules (*n*) using Formula (20):

 (20)

where

*Q*UF/MF is the designed initial water yield of a single MF/UF membrane module (L/h).

*q*s is the stable water production with single MF/UF membrane module (L/h).

**(3) Membrane flux**

Calculate the membrane flux ( *J* ) using Formula (21):

 (21)

where

*V* is the sampling volume (L).

*T* is the sampling time (h).

*A* is the membrane effective area (units are m2).

**5.4.3 NF/RO**

The basic formula for calculating the flow balance, mass balance, water recovery rate, concentration factor and desalination rate of NF and RO process shall be as follows:

**(1) Flow balance**

Calculate the flow balance using Formula (22):

 (22)

where

*Q*f is the feed water flow (m3/h).

*Q*p is the product water flow (m3/h).

*Q*r is the concentrated water flow (m3/h).

**(2) Mass balance**

Calculate the mass balance using Formula (23):

 (23)

where

*C*f is the feed water concentration (mg/L).

*C*p is the product water concentration (mg/L).

*C*r is the concentrated water concentration (m3/h).

**(3) Water recovery rate**

Calculate the water recovery rate (*Y*) using Formula (24):

 (24)

**(4) Concentration factor**

Calculate the concentration factor (*CF*) using Formula (25):

 (25)

**(5) Rejection rate**

Calculate the rejection rate (*R*) using Formula (26):

 (26)

**5.4.4 ED**

**(1)** **Limiting current density**

Current density applies to the mobility of individual ions, and the limiting factor is the rate at which ions can freely move in solution. Ions moving through the solution should balance ions moving through the membrane. Current density is a function of fluid velocity in the flow path, fluid temperature, and ionic composition.

As current density increases, ions in a solution migrate through the membrane faster than they move through the solution. The solution becomes depleted of ions while the increase in voltage causes the water to split into hydrogen ions (H+) and hydroxide ions (OH-). This is called a polarization point and occurs in the desalination compartments. When polarization becomes apparent, the pH of the demineralized stream changes. Hydrogen ions and hydroxide ions migrate through cation and anion exchange membranes, respectively. In concentrated streams, OH- tends to combine with ions such as magnesium. The resulting scale limits efficiency and requires frequent cleaning to prevent irreversible fouling in ED systems. The critical current density for concentration polarization is the limiting current density (*i*lim). Therefore, it is essential to limit the operating current density below the limiting current density in ED process.

The limiting current density can be calculated using Formula (27):

 (27)

where

*K* is the hydraulic characteristic coefficient.

*C* is the feed water ion concentration (mg/L).

*V* is the water flow velocity (cm/s).

*m* is the linear velocity index.

Formula (25) is obtained at 25oC. When the temperature is not 25oC, the limiting current water temperature coefficient can be calculated using Formula (28):

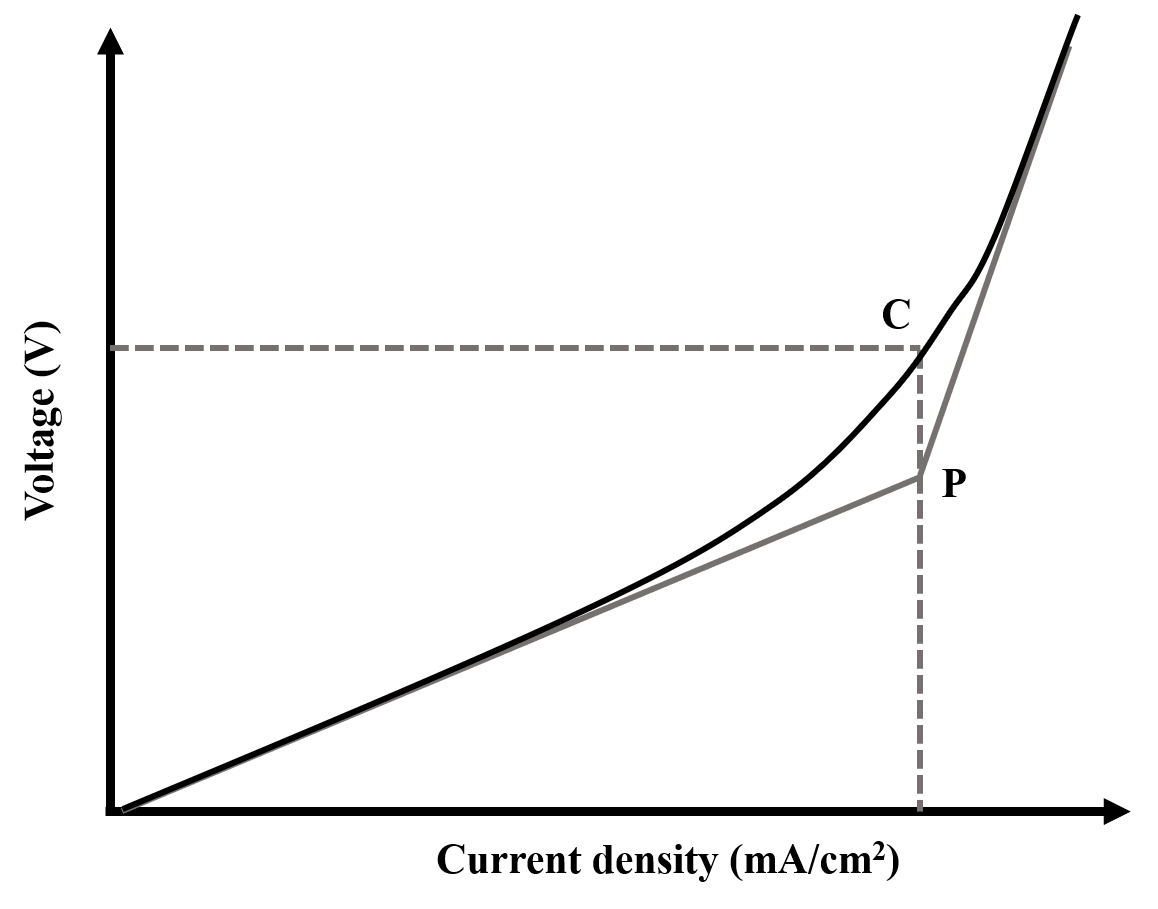
 (28)

where

*T*0 is the standard water temperature (25oC).

*T*1 is the operating water temperature.

In addition to theoretical calculations, the limiting current density can be determined by the voltage-current method [18]. On the premise of stable feed water concentration, keep the flow rate and pressure of waters (i.e., concentrated water, fresh water and polar chamber water), gradually increase the voltage, and measure the corresponding current value after the equipment operation is stable. The voltage-current density diagram of the membrane pair is shown in Figure 5, with the voltage of the membrane pair as the longitudinal coordinate and the current density as the transverse coordinate.



**Figure 5 — Voltage-current density diagram of membrane pair**

When the voltage is small, the current density will increase linearly with the increase of the voltage. However, when the voltage increases to a certain value, the increase of the current density will gradually decrease. Among them, point P is the intersection of the tangent lines at both ends of the curve, and the intersection of the vertical line passing through P and the voltage-current density curve is denoted as C. The current density of C indicates the limiting current density *i*lim.

By changing the water flow velocity *V* of the freshwater separator flow channel, the corresponding limiting current density *i*lim and the feed water ion concentration *C* of the water in the freshwater chamber can be obtained at the flow rate, and the values of *K* and *m* can be obtained by the logarithmic linear relationship corresponding to Formula (27).

**(2) Current efficiency**

The current efficiency *η* for the transfer of salts can be calculated based on an expression of Faraday’s law using Formula (29):

 (29)

where

*Q*p,ED is the product water flow in ED process (m3/h).

*C*f,ED is the feed water concentration in ED process (g/L).

*C*p,ED is the product water concentration in ED process (g/L).

*n* is the number of cell pairs.

*I* is the operation current (A).

**(3) Processing efficiency**

The processing efficiency can be calculated using Formula (30):

 (30)

where

*A* is the effective membrane stack area (m2).

*t* is the operation time (s).

**(4) Energy consumption**

The energy consumption can be calculated using Formula (31):

 (31)

where

*U* is the operation voltage (V).

**5.4.4 EDI**

**(1) Water recovery rate**

The water recovery rate can be calculated using Formula (32):

 (32)

where

*Q*p,EDI is the product water flow in EDI process (m3/h).

*Q*c,EDI is the concentrated water flow in EDI process (m3/h).

*Q*e,EDI is the electrode water flow in EDI process (m3/h).

**(2) Energy consumption**

The water production energy consumption can be calculated using Formula (33):

 (33)

# 6. Operation and maintenance

## 6.1 Start-up

General start-up procedures shall include:

* Ensure the valves, pipelines, devices and instruments can work normally;
* Membrane integrity tests shall be performed to identify membrane modules with breaches;
* Wash the pipelines to remove dirt and protective fluid in the membrane modules;
* Feed water quality shall meet the requirements;
* Open the feed water valves and gradually increase the supply load according to the operating procedure.

In MBR, MF, UF, NF and RO process, start-up shall include exhausting the air in the membrane system [19]. In ED/EDI process, start-up shall include electrical checks of equipment. ED/EDI system shall be powered on after the feed water flow is stable [18].

## 6.2 Commissioning

Operation procedures shall be composed during the first stage of commissioning. Before opening the feed water valves, check the pumps, automatic valves and other devices manually and then set the parameters of the control system with no error. During commissioning process, the control mode shall transfer form manual control to automatic control and the scope shall expand from a single membrane module to the whole membrane system. After the product water quality meet the requirements, the water yield shall be increased to the designed value. The membrane system shall run continuously for no less than 72 h under the designed operating conditions. Operation parameters and water quality of the commissioning process shall be recorded for implementation. If the quality of the product water is not qualified, the integrity test and commissioning operation procedure shall be performed again.

## 6.3 Operation and maintenance

**6.3.1 General**

Standard operational procedures shall be composed according to the system commissioning parameters. Standard operational procedures shall include:

* procedures for operating the system;
* record critical quality parameters and operating conditions;
* schedule for instruments calibration;
* schedule for system check;
* procedures for troubleshooting.

The standard operation procedures shall be reviewed periodically, when membrane modules are replaced, or when the control system is updated.

**6.3.2 Membrane cleaning**

The membranes shall be cleaned regularly to prevent fouling. The cleaning frequency is determined according to feed water quality and system state. Further details of the membrane cleaning are provided in Annex C.

**6.3.3 Maintenance**

Routine preventive maintenance will ensure efficient operation, as well as a long and reliable service lifetime. In daily operation, control settings and operation key factors shall be checked at least once a day and logged on a data sheet recommended by the supplier. Trends of system operation that diverge from normal for the system shall be noted. The abnormal state and troubleshooting methods of the system shall be recorded in detail in the log sheet. The operation settings shall be verified after troubleshooting [18][19][21]. During winter, the operation temperature should be maintained to ensure the water production rate.

## 6.4 Outage

Stopping procedures shall include [17][20]:

* reduce the system pressure to minimum;
* flush the system with pre-treated water or product water;
* close the product and feed water valves. In ED/EDI process, membrane system shall be powered off before closing valves.

Membrane modules shall be protected during outage period. Further details of the membrane protection are provided in Annex D.

1. (informative)  
     
   Test Method for Silt Density Index (SDI)

**A.1 Definition**

Silt density index (SDI) is an index to characterize the concentration of fine suspended solids in water, calculated from the rate of plugging of a 0.45 µm membrane filter.

**A.2 Test Method**

**A.2.1 General**

This standard is suitable for the determination of SDI for feed water of NF/RO with turbidity less than 1.0 NTU.

**A.2.2 Overview of test method**

Water is filtrated through a 0.45 µm membrane filter at a constant applied gage pressure of 207 kPa (30 psi). The particles, colloids, bacteria and other impurities with a diameter greater than 0.45 µm in the water are all trapped on the membrane surface, and the flux of water through the filter is reduced. The SDI value can be calculated from the rate of plugging.

**A.2.3 Procedure**

a) Connect the sample water and set the pressure regulator at 207 kPa (30 psi). Intermittently open and close the sampling valve 3 times, if the pressure gauge always reads in the range of 207 kpa ± 7 kpa (30 ± 1 psi), indicating that the pressure regulator valve works normally.

b) Before installing the membrane filter, flush the apparatus to remove entrained contaminants.

c) Measure the temperature of the water.

d) Open the membrane filter holder and place a 0.45 µm membrane filter (usually 47 mm in diameter) on the support plate of the holder only with dull tweezers to avoid puncturing.

e) Make sure that the O-ring is in good condition and properly placed. Place the top half of the filter holder and close loosely.

f) Bleed out trapped air by cracking the ball valve. Close the valve and close the filter holder tightly.

g) Open the ball valve at 207 kpa according to the indication on pressure gauge. Simultaneously, start measuring the time required for the flow of 500 mL and record the time (*t*0). Leave the valve open for the continued flow.

h) Measure and record the time to collect additional 500 mL of sample. Start the collection at 15 min of total testing time. Measure the water temperature and check the pressure as each sample is collected. The water temperature must remain constant (±1°C) and the pressure must remain at 207 ± 7 kPa (30 ± 1 psi) throughout the test.

i) After completion of the test, take the filter from the holder and check whether the edge of the filter indentation is intact. If there is any damage to the filter, it should be renewed. The used membrane filter may be retained for future reference.

**A.3 Calculation**

The silt density index (SDI*t*) can be calculated using Formula (A.1) [21]:

 (A.1)

where

*t* is the total testing time (min), usually 15 min.

*t*0 is the initial time required to collect 500 mL of sample (s).

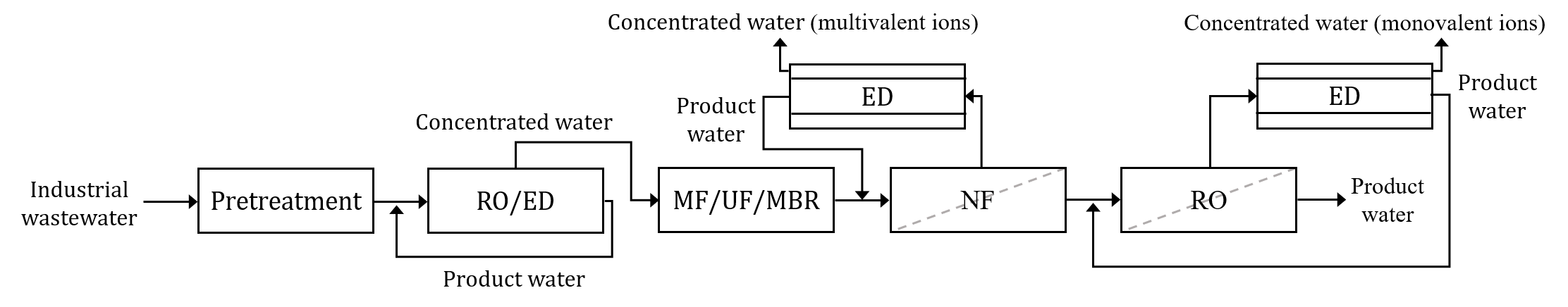
*t*1 is the time required to collect 500 mL of sample after test time *t* (s).

For this test method, if *t*1 > 4*t*0, a shorter time (5 min or 10 min) should be used for *t*. If *t*1 > 4*t*0 even forthe 5-min measurement, other test methods should be used for analysis.

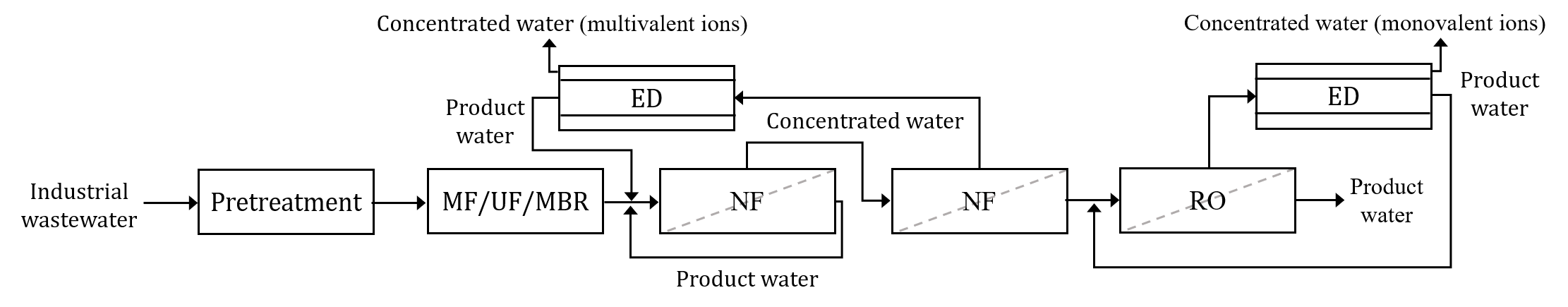
**A.4 Precision**

For the same water source, the standard deviation of SDI value measured by different operators using this method should be less than 0.43.

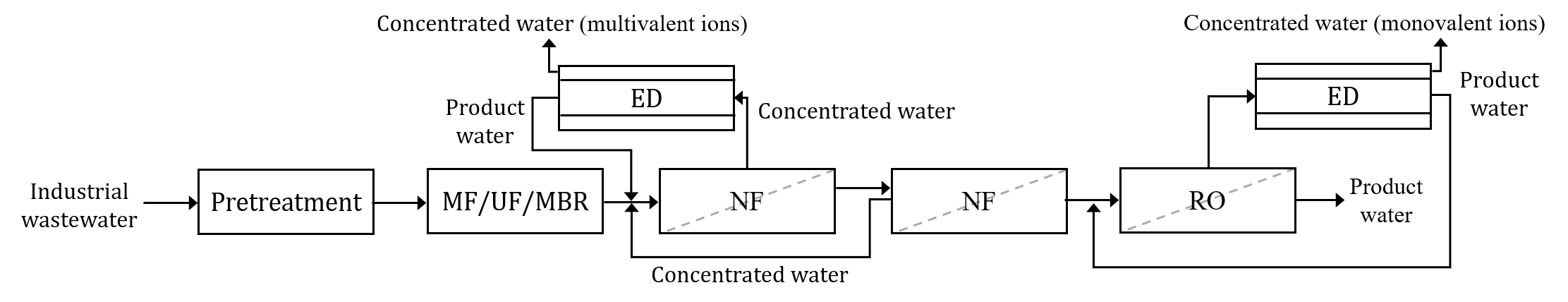
1. (informative)  
     
   Commonly used membrane-based process for salt fractionation

When the salt concentration in the feed water entering the membrane-based salt fractionation system is low, the concentrating treatment such as reverse osmosis and electrodialysis can be carried out first to improve the desalting efficiency and reduce the treatment cost. The process is shown in Figure B.1.

**Figure B.1 — Salt fractionation process for low-salinity feed water**

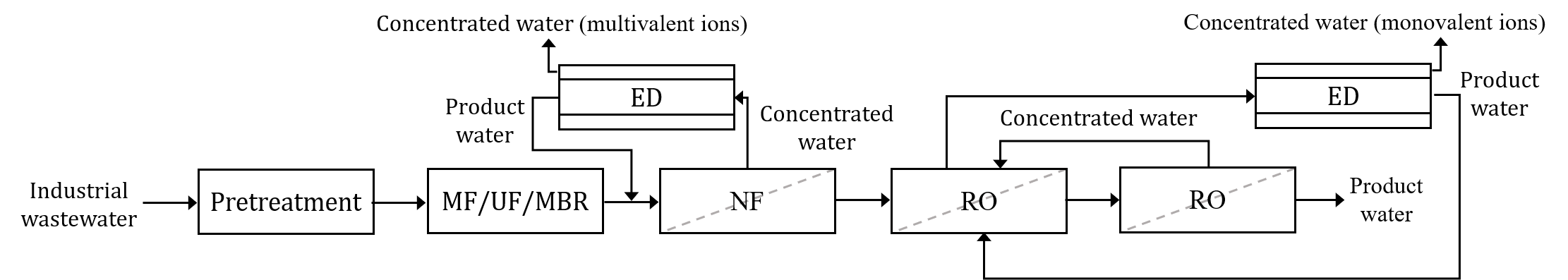
When the multivalent salt quality produced by the crystallization of concentrated water containing multivalent ions is low, the multistage NF treatment can be used to improve the purity of multivalent ions. The process is shown in Figure B.2.

**Figure B.2 — Salt fractionation process for the wastewater with a low multivalent salt quality**

When the monovalent salt quality produced by the crystallization of concentrated water containing monovalent ions is low, the multipass NF treatment can be used to improve the purity of monovalent ions. The process is shown in Figure B.3.

**Figure B.3 — Salt fractionation process for the wastewater with a low monovalent salt quality**

When the product water quality needs to improve, the multipass RO treatment can be used as shown in Figure B.4.

**Figure B.4 — Salt fractionation process for a high product water quality**

1. (informative)  
     
   Membrane fouling and cleaning

**C.1 MBR system**

**C.1.1 On-line cleaning**

On-line cleaning of hollow fibre membrane shall not be less than once a month, and flat membrane shall be once every 2~3 months. Cleaning with a 1~3‰ NaClO solution is the most frequently used method. Other cleaning agents shall be chosen as recommended by the manufacturer. Input the cleaning solution into the membrane modules, soak the membrane for 20 min~30 min, and then drain. The waste cleaning solution is discharged into the waste liquid storage tank or sewage pre-treatment tank [21].

**C.1.2 Off-line cleaning**

Off-line cleaning of MBR system shall be performed once every six months to once a year. A 3~5‰ NaClO+NaOH (weight ratio 1:1) or citric acid solutions are recommended for off-line cleaning. The waste cleaning solution is returned to the sewage pre-treatment tank after treated with activated carbon or reduced by NaHSO3 [21].

**C.2 MF and UF system**

When the feed water pressure exceeds the initial pressure of 0.5 MPa, flush the system with iso-pressure and high-flow water. If normal operation cannot be restored, chemical cleaning should be performed. The selection of cleaning agent depends on the type and degree of fouling, configuration and properties of membrane. Commonly used cleaning agents include: sodium hydroxide, hydrochloric acid, citric acid, enzyme detergent, hydrogen peroxide water solution, sodium tripolyphosphate, sodium hypochlorite solution and etc. [19].

**C.3 NF and RO system**

Chemical cleaning shall be performed when one of the following conditions occurs [23]:

* water yield decreased by 10%;
* pressure drop increased by 15%;
* salt rejection rate decreased by 5%.

The selection of cleaning agent depends on the type and degree of fouling and properties of membrane. Commonly used cleaning agents include: sodium hydroxide, hydrochloric acid, citric acid, Na-EDTA, surfactant, enzyme preparation and etc. Other cleaning agents shall be chosen as recommended by the manufacturer. The maximum temperature of the cleaning solution shall not exceed 45oC in the pH range of 2 to 10, and shall not exceed 35oC in other cases. Sequential cleaning shall be performed by alkaline cleaning and then acid cleaning. After chemical cleaning, water flushing is usually practiced.

**C.4 ED and EDI system**

Cleaning membrane and electrode with acid solution shall be performed at least once a month. The ED/EDI unit shall be disassembled and cleaned every six months or a year. The selection of cleaning agent depends on the type of fouling and the recommendation of the manufacturer. Commonly used cleaning agents include: hydrochloric acid, sodium chloride solution (pH=8.0~10.0) and sodium hypochlorite solution [18].

1. (informative)  
     
   Protection during outage period

**D.1** **MBR system**

**D.1.1 Short-term outage protection**

Short-term outage is usually less than 7 days. Physical cleaning shall be performed before shut down. After physical cleaning, fill the membrane modules and pipelines with water or protective fluid and close the valves. The membrane modules shall be aerated and scrubbed once a day. Add 30 mg/L~100 mg/L NaClO solution to the water or protective fluid to prevent microbial growth and membrane fouling [21].

**D.1.2 Long-term outage protection**

Long-term outage is usually longer than 7 days. The protection procedures in D.1.1 shall be performed first. The membrane shall be stored in wet state after chemical cleaning. Clean, fill and exhaust the membrane modules and pipelines every 5 days according to D.1.1. The disinfectant (NaClO solution) shall be replaced regularly [21].

**D.2 MF, UF, NF and RO system**

**D.2.1 Short-term outage protection**

Short-term outage is usually 5~30 days. Clean the membrane and eliminate the internal gas before shut down. Protect the membrane with 1% NaHSO3 solution. After the membrane modules are fully filled with protective solution, close all valves to keep the protective solution in the pressure vessel. Replace the protective fluid (1% NaHSO3 solution) every 5 days [20].

**D.2.2 Long-term outage protection**

Long-term outage is usually longer than 30 days. When the storage temperature is below 27oC, replace the protective solution once a month. When the storage temperature is above 27oC, replace the protective solution every 5 days. If the protective solution is turbid, it shall be replaced more frequently [20].

**D.3 ED and EDI system**

**D.3.1 Short-term outage protection**

Short-term outage is usually 5~30 days. Clean the membrane before shut down. Wash the membrane stack at low pressure every day to prevent membrane drying. Other protection items shall be performed as recommended by the manufacturer.

**D.3.2 Long-term outage protection**

Long-term outage is usually longer than 30 days. The membrane stacks shall be disassembled in accordance with procedures recommended by the manufacturer. The membrane shall be stored in the recommended protection solution at the required temperature after chemical cleaning.

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