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

Part 6:
Ion exchange and electrodialysis

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

Partie 6: Échange d'ions et électrodialyse

Reference number
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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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).

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

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

“Ion exchange” for purification with ion exchange resin and “Electrodialysis” for desalination and concentration with ion exchange membrane are classified as “Advanced treatment” in ISO 20468-1[4]. Raw water compositions and treated water targets are extremely diverse. Such diversity impedes making world-wide guidelines for ion exchange and electrodialysis.

Ion exchange resin (IER) provides a medium for ion exchange. Target ions in solution are trapped within the medium causing other ions contained within the medium to be released into solution. The most common applications are water softening and water purification.

Electrodialysis (ED) is an ion-separation process that utilizes an electrical potential difference across ion exchange membrane as the driving force for moving ion in a solution. The membrane is selective in that it only permits the passage of either anions or cations but not both and can be used to reject opposite charged ions.

The ISO 20468 series is intended to provide international standards for an objective evaluation of the performance of ion exchange and electrodialysis. It introduces the concepts of “Functional requirements” and “Non-functional requirements,” which are suggested and defined in ISO 20468-1, also used for other water reuse technologies that may be used in combination or alternatively, such as membrane, UV, and ozone disinfection and distillation.

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

Part 6:
Ion exchange and electrodialysis

1 Scope

This document provides guidelines on methods for evaluating the performance of ion exchange and electrodialysis for water reuse including ion exchange resin and ion exchange membrane.

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, *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:

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

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

3.1 Terms and definitions

3.1.1
anion exchange membrane
polymer sheet that contain positively charged functional groups in its polymer matrix designed to conduct anions while blocking other ions

3.1.2
anion exchange resin
polymer beads that contain positively charged functional groups in its polymer matrix capable of undergoing exchange reactions with anions

3.1.3
bed
packed layers of *ion exchange resins* (3.1.19)

3.1.4
block
unit composed of *cell pairs* (3.1.8) and intermediate frame at both ends

Note 1 to entry: Cell-pairs are stacked from several pairs up to thousands of pairs inside an electrodialyser ion exchange.

Note 2 to entry: A large number of cell pairs stacked in series causes problems such as non-uniform hydraulic pressure and increased leak current in an electrodialyser. To prevent such problems, a large electrodialyser is separated with an intermediate frame (Figure 8).

3.1.5
cation exchange membrane
polymer sheet that contain negatively charged functional groups in its polymer matrix designed to conduct cations while blocking other ions

3.1.6
cation exchange resin
polymer beads that contain negatively charged functional groups in its polymer matrix capable of undergoing exchange reactions with cations

3.1.7
cell
thin sheet compartment, through which desalinate (feed water) or concentrate passes

Note 1 to entry: D-cell means a desalinate cell and C-cell means a concentrate cell.

3.1.8
cell pair
series of D-*cell* (3.1.7), *cation exchange membrane* (3.1.5), C-*cell* (3.1.7), and *anion exchange membrane* (3.1.1) that are layered in order to constitute a cell pair

Note 1 to entry: A cell pair is the basic unit for desalination and concentration in electrodialysis.

3.1.9
chelating resin
polymer beads that contain functional groups in its polymer matrix capable of forming chelates with metal ions

3.1.10
current efficiency
ratio of the theoretical to actual current required to transport ions across an *ion exchange membrane* (3.1.18)

3.1.11
direct current
unidirectional flow or movement of electrical charge carriers (which are usually electrons)

3.1.12
electrodeionization
water treatment technology that utilizes electricity, *ion exchange membranes* (3.1.18) and *ion exchange resin* (3.1.19) in order to desalinate ions from one solution to another solution in a very low concentration

3.1.13
electrodialysis
water treatment technology that uses *ion exchange membranes* (3.1.18) in order to move ions from one solution to another solution by using electrical potential difference

3.1.14
electrodialysis reversal
type of *electrodialysis* (3.1.13) process that periodically reverses the electrodes polarity, alternating concentrated and diluted streams, and continuously self-cleaning the scale components

3.1.15
heterogeneous ion exchange membrane
ion exchange membrane (3.1.18) that is obtained by mixing *ion exchange resin* (3.1.19) and thermoplastic resin, and has heterogeneous structure

3.1.16
homogeneous ion exchange membrane
ion exchange membrane (3.1.18) that is uniformly configured except for reinforcement

3.1.17
ion exchange capacity
total quantity of ion exchangeable groups in *ion exchange resin* (3.1.19)

3.1.18
ion exchange membrane
polymer sheet that contain negatively or positively charged functional groups in its polymer matrix designed to conduct cations or anions while blocking opposite charged ions

3.1.19
ion exchange resin
polymer beads that contain charged functional groups in its polymer matrix capable of undergoing exchange reactions with anions or cations

3.1.20
limiting current density
current density beyond which water dissociation will occur

Note 1 to entry: In electrodialysis, ions in a solution migrate from the bulk solution to the surface of an ion exchange membrane and form a boundary layer having a concentration difference. As current density increases, the concentration difference of the boundary layer also increases, and the concentration on the surface of the ion exchange membrane reaches zero. This current density is defined as “Limiting current density (LCD),” and is an important indicator for deciding the operating current of an electrodialyser. Operation beyond LCD causes water to dissociate into hydrogen ions (H^+) and hydroxyl ions (OH^-) at the ion exchange membrane-surface and consumes applied current ineffectually.

3.1.21
mixed bed
mixture of *anion exchange resin* (3.1.2) and *cation exchange resins* (3.1.6)

3.1.22
particle size and particle size distribution
diameter of *ion exchange resin* (3.1.19) beads and its distribution

3.1.23
perfect beads content
non-cracked and non-broken bead content in *ion exchange resin* (3.1.19) beads

3.1.24
reaction rate
ion exchange reaction rate of *ion exchange resin* (3.1.19)

3.1.25
regeneration
regeneration of *ion exchange resin* (3.1.19) is a reversal of the exchange reactions with high concentrations of a regenerate

3.1.26
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 molecular weight. May also be called hyperfiltration.

[SOURCE: ASTM D6161-19]

3.1.27
selectivity coefficient
equilibrium constant for ion exchange reaction in *ion exchange resins* (3.1.19)

3.1.28
stack
entire body of electrodialyser, assembled with multitude of *cell pairs* (3.1.8) or several *blocks* (3.1.4) between anode *cell* (3.1.7) and cathode *cell* (3.1.7), and pair of end plates for tightening

3.1.29
strongly acidic cation exchange resins
resins that have strongly acidic functional groups

3.1.30
strongly basic anion exchange resins
resins that have strongly basic functional groups

3.1.31
transport number
fraction of current carried by a given ion for total current carried by all ions

3.1.32
tower
vessels with packed layers of *ion exchange resins* (3.1.19) and/or degassers

3.1.33
uniform particle size ion exchange resin
ion exchange resin (3.1.19) that has narrow *particle size distribution* (3.1.22)

3.1.34
water extractable residue
water soluble extractable residue from *ion exchange resins* (3.1.19)

3.1.35
water recovery rate
ratio between treated water quantity and feed water quantity to electrodialyser

3.1.36
weakly acidic cation exchange resins
cation exchange resins (3.1.6) that have weakly acidic functional group

3.1.37
weakly basic anion exchange resins
anion exchange resins (3.1.2) that have weakly basic functional group

3.2 List of Abbreviated terms

AC	Alternating current
AEM	Anion exchange membrane
AER	Anion exchange resin
CEM	Cation exchange membrane
CER	Cation exchange resin
CR	Chelating resin
DC	Direct current

EDI	Electrodeionization
ED	Electrodialysis
EDR	Electrodialysis reversal
IE	Ion exchange
IEM	Ion exchange membrane
IER	Ion exchange resin
LSI	Langelier saturation index [7]
LCD	Limiting current density
LCR	Inductance (L), capacitance (C), and resistance (R) of an electronic component
MB	Mixed bed
R	Electrical resistance
RO	Reverse osmosis
SDI	Silt density index
SAC	Strongly acidic cation exchange resins
SBA	Strongly basic anion exchange resins
TDS	Total dissolved solids
WAC	Weakly acidic cation exchange resins
WBA	Weakly basic anion exchange resins

4 Outline of ion exchange and electrodialysis

4.1 General

IER and IEM use ionic functional groups fixed in polymer beads or in polymer sheets. These fixed ionic functional groups exchange ions of an opposite charge or selectively transport ions of an opposite charge. These technologies can be used for many applications including purifying wastewater by passing it through an IER packed tower, or desalinating and concentrating wastewater with an electrodialyser in which IEM are equipped. Among these applications, ion exchange in IER and ED in IEM also apply to water reclamation. Annex A shows the main process and typical applications of IER and IEM.

Ion exchange and ED are one of several technologies (Annex B) that are used for desalination. Table 1 shows typical salinity range of salt removal about IE and ED.

Table 1 — Typical range of salt removal of ion exchange and electrodialysis

Type	Driving Force	Salinity (NaCl) [g/l]		
		Raw Water	Desalinate	Concentrate
ED	Electrical field & Diffusion	0,5~200	>0,2	<240
IE	Adsorption & Desorption	<1	>0,001	-

ED, RO, IE and distillation are widely known as a desalination technology. But each strong point is different. In case of ED, its feature is that both ion concentration and desalination are possible. For example, in the concentration of seawater, it is possible to concentrate salinity up to about 240g/l and on the contrary in the desalination, it can be expected to be desalinated about 0,2g/l. It also can arrange the desalination level. For the desalination purpose, ED is often applicable for brackish water and ground water.

IE is a purification technology for removing target ions. The purification process is performed by an adsorption and desorption mechanism. IE is applicable to raw water under 1g/l-TDS and can produce deionized water and/or ultrapure water. IER is also applicable for decolorizing raw water.

To select an appropriate technology, it is highly recommended to consider the pros and cons of those technologies. In some cases, a combination of those technologies may contribute great benefits to users and stakeholders.

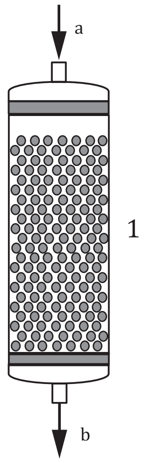
EDI is applied to produce pure water or ultrapure water instead of a resin tower or RO. EDI stacks have an IER or fibre in desalinated chambers to decrease resistivity. As a result, EDI can provide very low conductivity water.

4.2 Principle of Ion exchange[11]-[19]

Typical functional groups of IERs are sulfonic acids and quaternary ammoniums, and such IERs are classified by their functions into CERs, which can exchange cations, and AERs, which can exchange anions. IERs have spherical crosslinked polymer matrix with functional groups, counter ions, and hydrated water. These polymer structures affect the ion exchange capacity, reaction rate, and physical properties of IERs. Annex C shows a structural model of IER.

Ion exchange using IERs depends on a mechanism by which mobile ions from an external solution are exchanged in the opposite direction for an equivalent number of ions that are electrostatically bound to functional groups contained within a solid polymer matrix of IERs. Annex D shows the selectivity and selectivity coefficient of IERs.

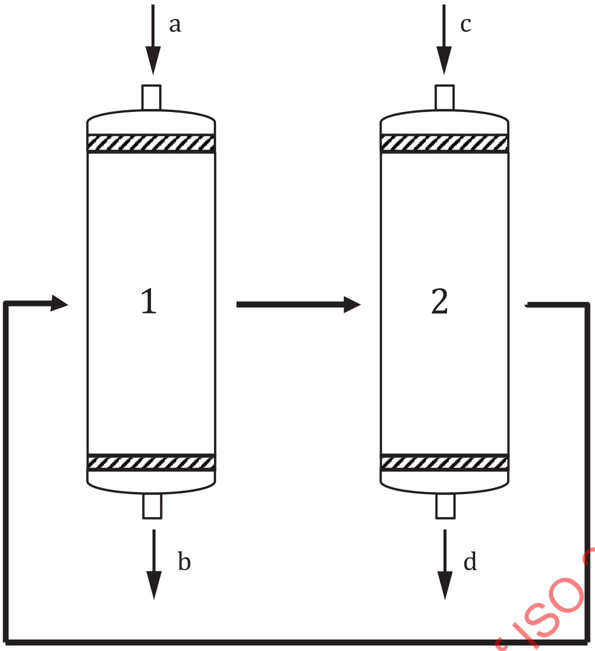
The purification process using IER is most commonly performed in cyclic operations of the column method with an adsorption and desorption mechanism. Each cycle is divided into sorption and regeneration. Figure 1 shows an outline of an IER tower. Figure 2 shows a representation of an ion exchange operation cycle.



Key

1 IERs
a influent
b effluent

Figure 1 — Outline of IER tower[20]



1 sorption

2 regeneration

a feed water

b treated water

c regenerant

d regeneration wastewater

Figure 2 — Schematic representation of an ion exchange operation cycle[20]

4.2.1 System configuration

The most important component of IE is IER and the IER tower that equipped with IER.

4.2.1.1 Ion exchange resins

IERs are categorized by their functional groups and physical structure. Typical functional groups of IERs are sulfonic acids and quaternary ammoniums, and such IERs are classified into CERs and AERs. IERs have two types of physical structure: gel type and macroporous type. Macroporous type IERs have high density of macroporous in the polymer matrixes and much larger specific surface areas of the active surface than gel-type resins.

Table 2 shows types and groups of IERs.

Table 2 — Types and groups of IERs

	Grade	Functional group		Physical structure
1	CER	Strongly acidic	Sulfonic acid	Gel
2				Macroporous
3		Weakly acidic	Carboxylic acid	Macroporous

Table 2 *(continued)*

	Grade	Functional group			Physical structure
4	AER	Strongly basic	Type I	Trimethylammonium	Gel
5					Macroporous
6			Type II	Dimethylethanolammonium	Gel
7					Macroporous
8		Weakly basic		Dimethylamine	Macroporous

In addition, IERs are categorized by particle size distribution into two types: polydispersed particle size IERs and uniform particle size ion exchange resins. Uniform particle size ion exchange resins have narrower particle size distribution than polydispersed particle size IERs.

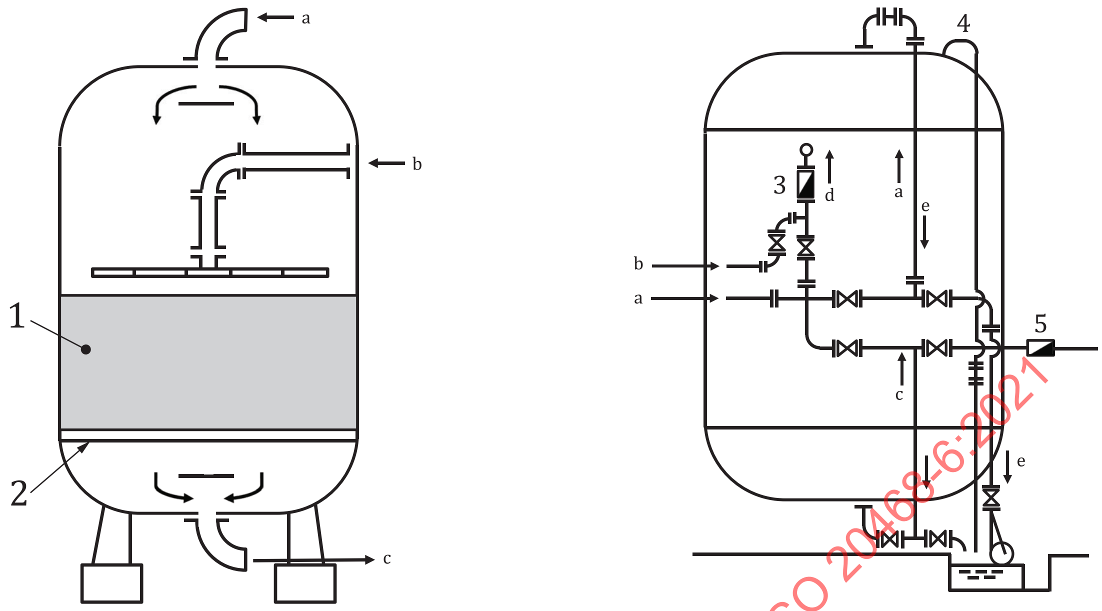
Chelating resins are a type of IER with functional groups that can form chelates with metal ions. Table 3 shows types and groups of CRs.

Table 3 — Types and grouping of CRs

	Grade	Functional group	Physical structure	Target ions
1	CR	Iminodiacetate	Macroporous	Heavy metal ions
2		Polyamine	Macroporous	Heavy metal ions
3		Glucamine	Macroporous	Borate

4.2.1.2 Ion exchange resin tower

IERs are mainly installed in a fixed bed tower. The ion exchange process is composed of IER towers, feeding unit for raw water and regenerants, and tanks for treated water and wastewater. Figure 3 shows an outline of an IER tower.



Outside appearance **Arrangement of pipings**

Key

1	resin bed
2	support plate and strainer
3	flow meter
4	air vent
5	integrating flow meter
a	raw water
b	regenerant
c	treated water
d	wash water
e	backwash waste

Figure 3 — Outline of an IER tower [20]

4.2.2 Process

4.2.2.1 Process design

Purification processes using IER are classified into several types of water treatment processes. The softening process requires a CER tower. The demineralization process requires a CER and an AER tower. The 2-Bed-3-Tower process or 4-Bed 5-Tower process is commonly used for water treatment. Table 4 shows typical water treatment processes.

Table 4 — Typical water treatment processes

Process	Process Flow	Special features
Softening	→ SAC (Na form) →	Hard ions (Ca^{2}+, Mg^{2}+, etc) are exchanged by soft sodium ions with no variance in amounts of salt.
Dealkalization Softening	→ SAC→ Degasser → SAC (Na form)	Both hard ions and bicarbonates are removed.

Table 4 *(continued)*

Process	Process Flow	Special features
2-Bed-3-Tower	→ SAC → Degasser → WBA or SBA	With WBA: Low operation cost, impossible to remove SiO_2. With SBA: most common, Type I and Type II of SBA are both used.
3-Bed-4-Tower	→ SAC → Degasser → WBA → SBA →	Modification to 2-Bed-3-Tower used for raw waters with high concentrations of mineral acids to save NaOH as neutralization. WBA and SBA are sometimes used multi-layered.
4-Bed-5-Tower	→ WAC → SAC → Degasser → WBA→ SBA →	Used for waters with large quantities of salt and temporary-hardness and mineral acids.
	→ SAC → Degasser → SBA → SAC → SBA → → SAC → WBA → Degasser → SAC → SBA →	Used for waters with large quantities of salt to obtain good-quality effluents. SAC and SBA are used at the latter steps as polishers and regeneration wastes are usually recycled to the former steps.
Dual layer 2-Bed-3-Tower	→ WAC/SAC → Degasser → WBA/SBA →	The same as 4-Bed 5-Tower with weakly electrolyte resins.
Mixed bed (MB)	→ SAC/SBA(mixed) →	Superior in demineralization to 2-Bed 3-Tower, in terms of treated water purity, although with lower volume of treated water produced. Usually used as a polisher to get better treated water quality than with 2-Bed 3-Tower or 3-Bed 4-Tower.

4.2.2.2 Ion exchange resin selection

It is important to select the appropriate grade of IERs in order to ensure treated water quality, high-efficiency, and to maintain the design performance. Annex E shows a comparison of various IERs.

Uniform particle size ion exchange resins show higher regeneration efficiency and can decrease the amount of wastewater in the regeneration process. Uniform particle size ion exchange resins are preferable for water treatment processes and are also suitable for chromatographic separation systems.

4.2.2.3 Operation

Operation of the ion exchange process differs depending on the IER process design. Annex F shows the general operation of an IER process.

4.3 Principle of Electrodialysis[11]-[19]

IEMs are selectively permeable to ions and reject ions of the opposite charge. Similar to IERs, the membranes are named after the type of ions which are selectively transported. CEMs have fixed negative charge and selectively transport cations while rejecting anions (Figure 4-1). AEMs have a fixed positive charge and selectively transport anions while rejecting cations (Figure 4-2).

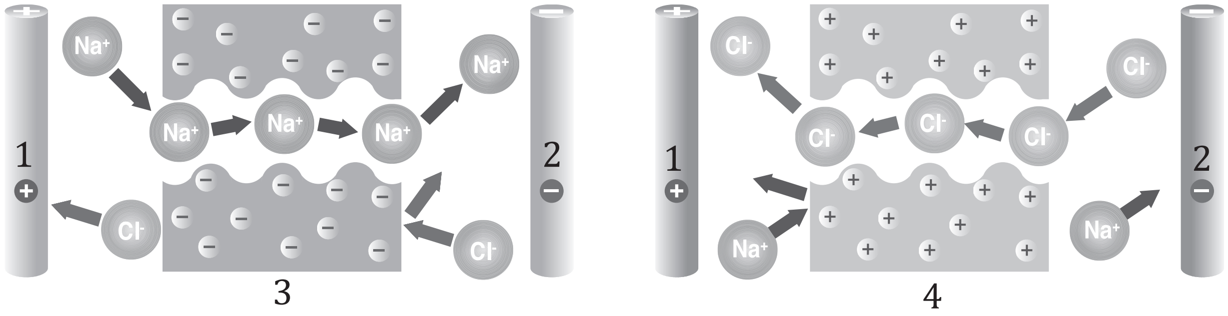


Figure 4-1 Figure 4-2

Key

1 anode
2 cathode
3 cation exchange membrane
4 anion exchange membrane

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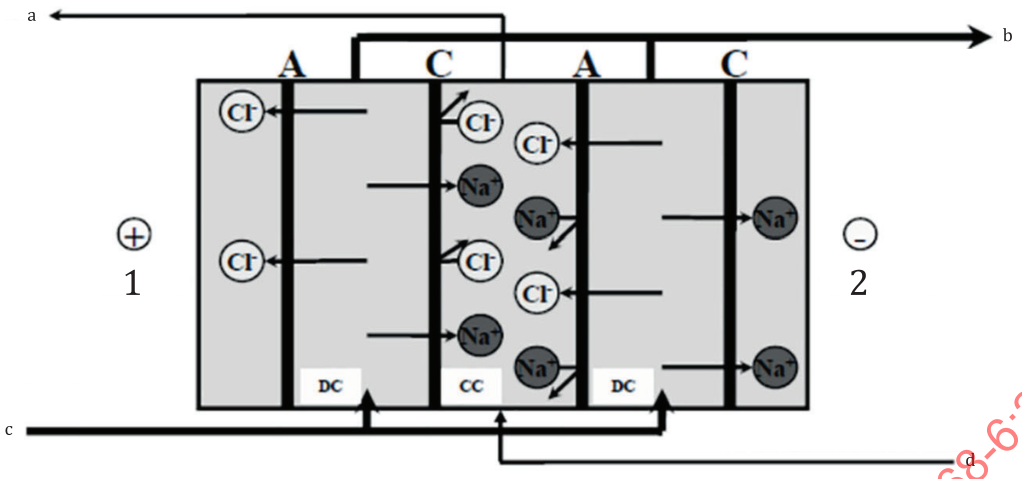
Figure 4 — Electrodialysis principle

In an electrodialyser, a large number of these membranes are arranged alternately between two electrodes and DC is applied to move ions in a solution.

The D-cells and the C-cell are configured alternately (see Figure 5).



Key

1	anode
2	cathode
A	anion exchange membrane
C	cation exchange membrane
CC	concentration compartment
DC	desalination compartment
a	C outlet
b	D outlet
c	Feed solution
d	Concentrated solution

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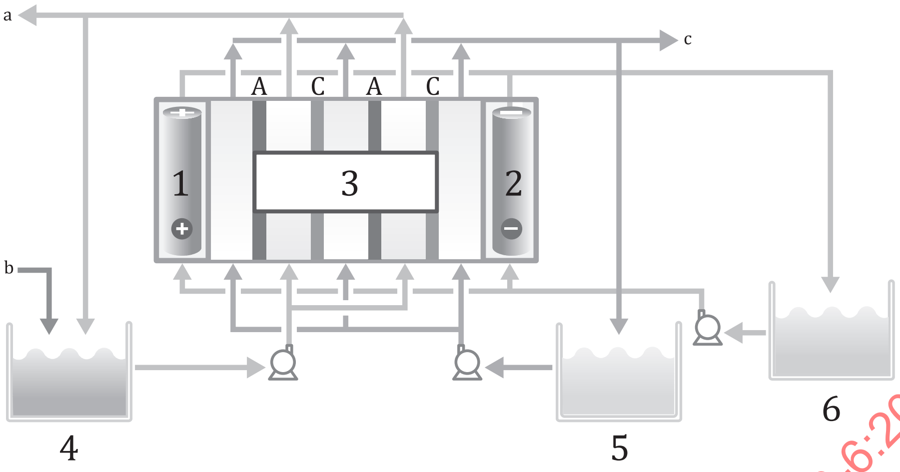
Figure 5 — Electrodialyser stack principle

The feed solution is circulated between the D-cell and the feed solution tank and is desalted (desalinated solution) whereas the concentrated solution is circulated between the C-cell and the concentrated solution tank, and it is concentrated (see Figure 6).

The electrode solution is circulated between the electrode chamber and the electrode solution tank (see Figure 6).



Key

1	anode
2	cathode
3	electrodialyser stack
4	feed solution tank
5	concentrated solution tank
6	electrode solution tank
A	anion exchange membrane
C	cation exchange membrane
[a]	diluted solution
[b]	feed solution
[c]	concentrated solution

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Figure 6 — Typical example of ED process

4.3.1 System configuration

The most important component of ED is IEM and the electrodialyser that is incorporated IEM.

4.3.1.1 Ion exchange membrane

IEM similarly uses ionic functional groups typically attached to a polymer backbone suitable for producing into flat membrane sheets. Poly(Styrene/Divinyl-benzene) type, Poly(Acrylate) type, Poly(Vinyl-alcohol) type and Poly(Olefin) type resin have been used for homogeneous ion exchange membrane and heterogeneous ion exchange membrane. In addition, some other novel membranes have been developed. Typical applications of IEM are shown in Figure A.2.

The IEM is divided into AEM and CEM.

4.3.1.1.1 Classification by ion exchange group

CEM has fixed anionic exchange groups.

AEM has fixed cationic exchange groups.

Typical functional groups of IEMs are negatively charged sulfonic acids used for the transport of cations (CEMs) and positively charged quaternary ammonium for the transport of anions (AEMs). Some kinds of novel functional groups have been developed such as positively charged pyridium group and imidazolium group.

4.3.1.1.2 Classification by structure

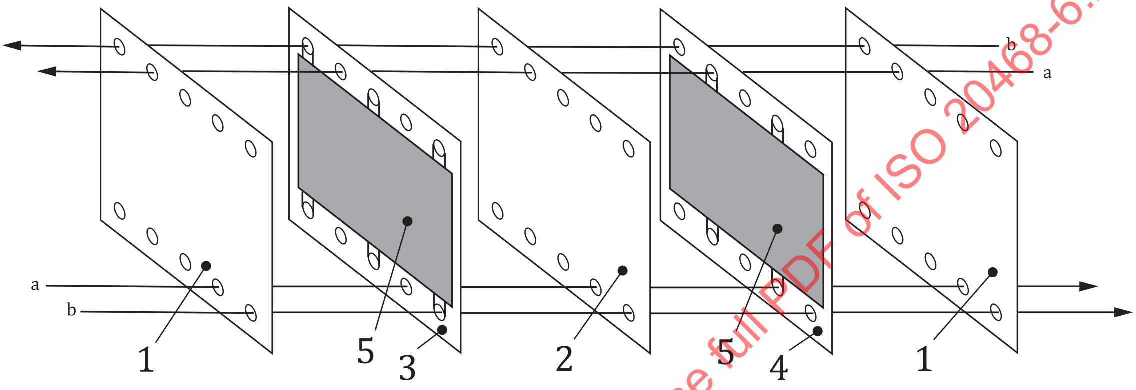
Homogeneous ion exchange membrane is uniformly configured throughout except for reinforcement.

Heterogeneous ion exchange membrane is obtained by mixing IER and thermoplastic resin and has a heterogeneous structure.

Homogeneous ion exchange membrane is superior to heterogeneous ion exchange membrane in electrochemical properties (low electrical resistance, high transport number).

On the other hand, heterogeneous ion exchange membrane is superior to homogeneous ion exchange membrane in mechanical strength and cost.

4.3.1.2 Electrodialyser



Key

1	Anion exchange membrane
2	Cation exchange membrane
3	D-cell
4	C-cell
5	spacer
a	concentrated solution
b	diluted solution

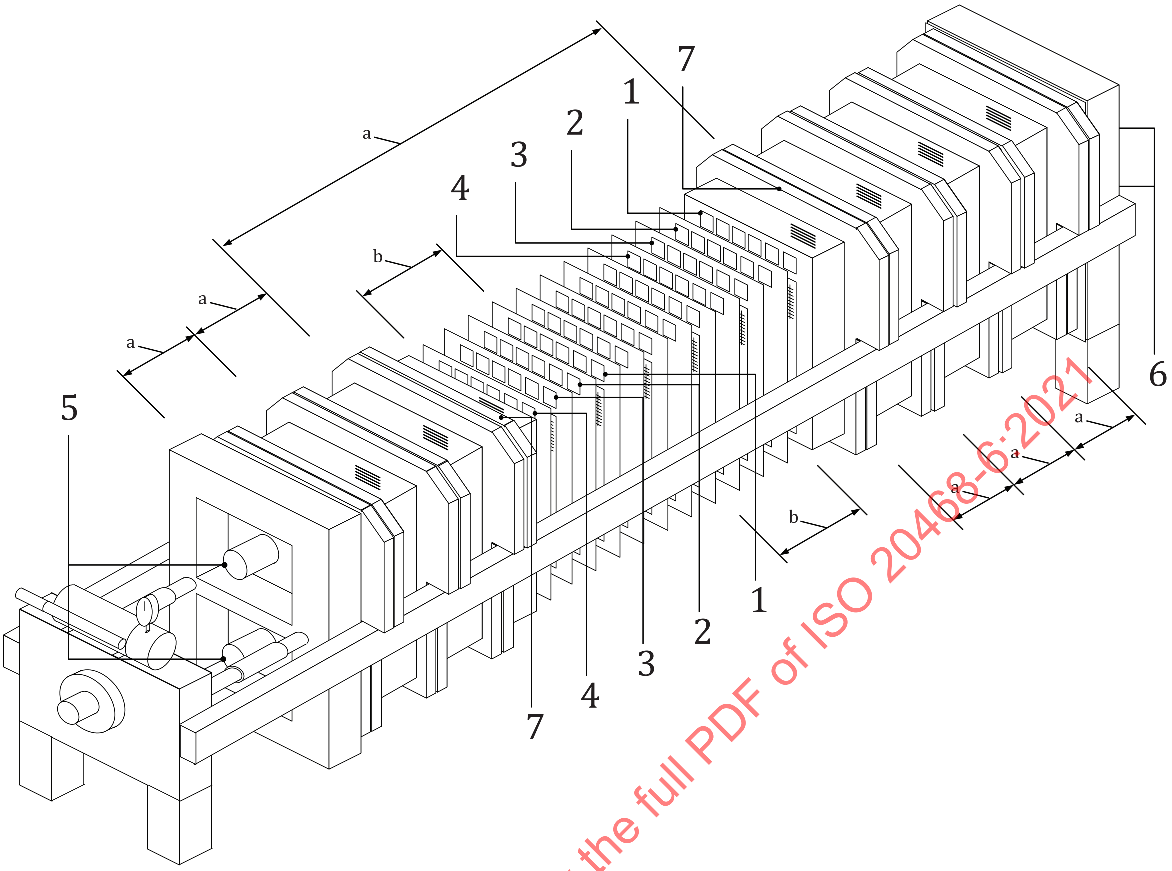
Figure 7 — Cell pairs[20]

Figure 7 shows cell pairs and Figure 8 shows ED unit configuration. The D-cell has holes for supplying and discharging desalination solution at the upper part and the lower part. The D-cell also has a spacer to make space for water flow between two membranes of both sides.

The C-cell has holes for supplying and discharging concentration solution at the upper part and the lower part. The C-cell also has a spacer to make space for water flow between two membranes of both sides.

The IEM has supply and discharge holes at the same position.

The cell pair is stacked in the order of AEM, D-cell, CEM, and C-cell.



Key

1	D-cell
2	anion exchange membrane
3	C-cell
4	cation exchange membrane
5	anode
6	cathode
7	intermediate frame
a	1 block
b	1 cell pair

Figure 8 — Electrodialysis stack configuration[20]

4.3.2 Process

The operation method of ED is chosen using the desalting rate and scale shown in Table 5.

Table 5 — Classification of operation methods

Method		Desalting rate	Scale
Batch		High	Small
Continuous	One pass	Low	Small
	Feed & Bleed	Middle	Middle ~ Large
	Multi-stage	High	Large

4.3.2.1 Batch method

This method circulates raw water between electrodialyser and tank.

The batch method, with replacement of solution but needing work, is used in the case of small-scale, high salt rejection.

4.3.2.2 One-pass method

This method treats raw water with one continuous pass.

This method, because of continuous operation, is easy to control operationally.

Changes in raw water affect the quality of product water.

4.3.2.3 Feed & bleed method

This method continuously supplies raw water to the desalination tank, where it is desalted.

Overflow water from the desalination tank is product water.

Using this method, the tank is small compared to the batch method.

4.3.2.4 Multi-stage method

The desalination rate of the one-pass method and the feed & bleed method increases using the multi-stage method.

4.4 Application examples

4.4.1 Ion exchange

See Figure A.1. Typical IE processes are:

- desalination for boiler feed water;
- desalination for ultra-pure water;
- softening for boiler feed water;
- industrial wastewater treatment and recovery of valuable components;
- desalination in the food-processing industry;
- purification of various chemicals.

4.4.2 Electrodialysis

See Figure A.2. Typical ED applications are:

- table salt production from seawater;
- tap water production from brackish water;
- industrial wastewater reclamation;
- desalination of landfill leachate;
- desalination in the food-processing industry.

NOTE EDR (Electrodialysis Reversal)[8],[9] is one kind of ED process that periodically reverses the electrodes polarity, alternating concentrated and diluted streams, and continuously self-cleaning the scale components.

4.5 Performance evaluation for ion exchange and electrodialysis

Performance evaluation is divided into functional and non-functional requirements. Each requirement is described by the selected key factors, which should be measured and be considered at appropriate points and time intervals.

Performance evaluations goals:

- to ensure treated water quality and quantity;
- to ensure high efficiency;
- to keep designed performance throughout the expected lifetime.

IE and ED are based on the same principle therefore the goals are same; however, these two categories are described in this document as different processes because equipment, devices and requirements are quite different.

5 Performance evaluation guideline for ion exchange resin[14]-[19]

5.1 Performance evaluation

5.1.1 Functional requirements

Functional requirements are performance evaluation of treated water quality and regeneration efficiency.

5.1.1.1 Treated water quality

To achieve the treated water quality, it is necessary to select IERs that have an adequate ion exchange capacity. IERs that have a lower capacity cannot achieve the treated water quality consistently.

Treated water quality is also monitored using electrical conductivity.

5.1.1.2 Regeneration efficiency

In IER technology, increasing wastewater from regeneration process is critical from both economic and environmental aspects. It is necessary to minimize the amount of regenerant in the regeneration process. The selection of IERs is important for this purpose. Uniform particle size ion exchange resins and relatively small particle size IERs are appropriate for minimizing the amount of regenerant. It is also necessary to estimate the particle size and the particle size distribution of IERs.

It is also necessary to estimate the pressure drop and the volume change ratio of IERs to confirm adaptability to the equipment specification of the IER tower.

5.1.2 Non-functional requirements

Non-functional requirements are performance evaluations to ensure treated water quality and to maintain the designed performance throughout the expected IER lifetime.

5.1.2.1 Water extractable residue

To achieve the treated water quality, it is necessary to select IERs that have a lower water extractable residue from IERs. Water extractable residue often causes an increase in the amount of pre-washing water.

5.1.2.2 Ion exchange resin lifetime

It is necessary to prolong the lifetime of an IER. The lifetime of an IER is determined by the physical breaking of an IER and/or organic loading/fouling on the IER surface. The key factors for the physical breaking of an IER are its perfect beads content, physical strength, and osmotic strength. The physical breaking of an IER also causes an increase of pressure drop in the IER tower and it is necessary to monitor pressure drops in the IER tower. The indicator of organic loading/fouling of an IER surface is the reaction rate of an IER.

Table 6 shows a summary of evaluation key factors of IER.

Table 6 — Performance evaluation key factors of IER

Purpose	Target	Key factors	
		Functional requirement	**Non-functional requirement**
Treated water quality	IERs	Ion exchange capacity	Water extractable residue
	Treated water	Electrical conductivity	-
Regeneration efficiency	IERS	Particle size Particle size distribution Pressure drop of IER column Volume change ratio	-
Lifetime of IERs	IERs	-	Perfect beads content Physical strength Osmotic strength Reaction rate
	IER tower	-	Pressure drop

5.1.2.3 Sustainability

Methods for reduction of waste water from an IER tower related to desalination technology can be found in G.1. Concentrated brine generated from desalination systems can have a negative impact on the environment. Figure G.1 shows water treatment system flow diagram and data about IER process.

5.1.3 Timing for evaluating key factors

In terms of timing, the key factors may be evaluated before operation, periodically monitored or continuously monitored (see Table 7).

Table 7 — Timing for evaluating key factors

Target	Key factors	Timing for evaluation
IERs	Ion exchange capacity	Before operation, periodical monitoring
	Water extractable residue	Before operation, periodical monitoring
	Particle size	Before operation
	Particle size distribution	Before operation
	Pressure drop of IER column	Before operation
	Volume change ratio	Before operation
	Perfect beads content	Before operation, periodical monitoring
	Physical strength	Before operation, periodical monitoring
	Osmotic strength	Before operation, periodical monitoring
	Reaction rate	Before operation, periodical monitoring

Table 7 *(continued)*

Target	Key factors	Timing for evaluation
Treated water	Electrical conductivity	Continuous monitoring
IER tower	Pressure drop	Continuous monitoring

5.2 Evaluation method

5.2.1 Ion exchange resin

5.2.1.1 Ion exchange capacity

Ion exchange capacity of IERs is an index for maintaining treated water quality. See ASTM D2187-17 [6] for test methods.

5.2.1.2 Water extractable residue

Water extractable residue is the index to keep the treated water quality. See ASTM D5627-17[10] for test methods.

5.2.1.3 Particle size and particle size distribution

Particle size and particle size distribution is the index of regeneration efficiency of IERs. See ASTM D2187-17[6] for test methods. Image processing methods are available to calculate particle size of each resin beads and measure the particle size distribution for uniform particle size ion exchange resins.

5.2.1.4 Pressure drop of ion exchange resin column

A pressure drop in the IER column is necessary when designing the IER tower. The measurement of the pressure drop in the IER column is evaluated using a laboratory scale column with a pressure gauge.

5.2.1.5 Volume change ratio

The volume change ratio is the volume increase from standard ionic form IERs to regenerated one. The volume of IERs is measured for each type. Ionic forms are;

SACs: Na^+ form to H^+ form

WACs: Na^+ form to H^+ form

SBAs: Cl^- form to OH^- form

WBAs: Cl^- form to free base form

The volume of IERs is measured for each type.

5.2.1.6 Perfect beads content

Perfect beads content is the indicator of physical resistance for industrial use in an IER tower. It is estimated by counting the number of perfect beads with microscope observations.

5.2.1.7 Physical strength

Physical strength is an indicator of physical resistance for industrial use in an IER tower. It is evaluated as the average load required to break IER beads using a breaking strength tester.

5.2.1.8 Osmotic strength

Osmotic strength is an indicator of osmotic resistance for regenerating cycles of IERs. It is evaluated as the decrease of perfect beads content after repeated regenerating cycles.

5.2.1.9 Reaction rate

Reaction rate is the index of surface organic fouling of IERs. It is estimated from the rate of an ion exchange reaction in an ion exchange equilibrium adsorption test.

5.2.2 Treated water quality

5.2.2.1 Electrical conductivity

Electrical conductivity of treated water is monitored to check treated water quality. See ASTM D1125-14[5] for test methods.

5.2.3 Ion exchange resin tower

5.2.3.1 Pressure drop

The pressure drop of IER is evaluated with a pressure gauge, which is incorporated in an IER tower.

5.2.4 Operation and maintenance

Operation and maintenance should be performed in accordance with the technical and/or O&M manuals, as applicable.

Routine preventive maintenance will ensure efficient operation, as well as a long and reliable service lifetime.

In daily operation, control settings and operating key factors should 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 that system should be noted.

Complete the system log sheet and verify that the operating settings are correct.

Examples of items are shown below.

- Electrical conductivity and pH of water (influent, effluent).
- Flow of water.
- Operating temperature.

6 Performance evaluation guideline for electrodialysis [11]-[18]

6.1 Performance evaluation

6.1.1 Functional requirements

Functional requirements are performance evaluation of product water quality and water recovery rate. In order to evaluate them correctly, it is necessary to confirm and maintain some feed water conditions (Table H.1).

6.1.1.1 Product water quality

The factors for the quality of product water is divided into factors about achieving the required water quality and factors about maintaining water quality:

- Achieve required quality of product water;
- Maintain the quality of product water.

It is necessary to select an IEM having suitable selective permeability (see Annex K).

It is necessary to evaluate electrical conductivity and operating electrical current of product water during operation. Electrical conductivity relates to the required water quality and can be monitored continuously. Operating electrical current shows the desalting capacity of ED, and it can be monitored continuously.

6.1.1.2 Water recovery rate

The factors of the water recovery rate are directly related to an environmental impact and this is divided into factors about achieving a high-water recovery rate and factors about maintaining the water recovery rate:

- Achieve a high-water recovery rate;
- Maintain a high-water recovery rate.

To achieve a high-water recovery rate, it is necessary to achieve high concentration water.

It is necessary to evaluate the electrical conductivity of the concentrated water during operation.

6.1.2 Non-functional requirements

Non-functional requirements are performance evaluation of energy consumption and membrane lifetime.

6.1.2.1 Energy consumption

The factors for power consumption are divided into factors for achieving low energy consumption and factors for maintaining low energy consumption:

- Achieve low energy consumption;
- Maintain low energy consumption.

It is necessary to select an IEM having low electrical resistivity and a high transport number.

It is necessary to evaluate electrical voltage, electrical current efficiency, and electrical current leakage from stack during operation.

6.1.2.2 Membrane lifetime

IEM, when handled in use, will gradually have degraded mechanical strength;

- Achieve long membrane lifetime.

It is necessary to select an IEM with high mechanical strength.

Table 8 shows a summary of evaluation key factors of IEM technology.

Table 8 — Performance evaluation key factors of IEM process

Purpose	Target	Key factors	
		Functional requirement	Non-functional requirement
Treated water quality	IEM	Permselectivity	-
	Treated water	Electrical conductivity	-
		Concentration	-
	Stack	Electrical current	-
Water recovery rate (Reduction of concentrated wastewater)	Concentration water	Electrical conductivity	-
Energy consumption	IEM	-	Electrical resistance
		-	Transport number
	Stack	-	Electrical voltage
		-	Electrical current efficiency
		-	Electrical current leakage
Membrane lifetime	IEM	-	Mechanical strength[1],[2]

6.1.2.3 Sustainability

The desalination process involves the generation of concentrated brine, whatever the technique used. However, concentrated brine generated from the ED unit can be expected to have high water recovery therefore this results in higher salt concentrations and lower volume of waste brine. As a result, when the solidification is carried out as the final treatment, it is expected that the high concentration brine will reduce the size of the evaporator and reduce the total amount of energy. As such, ED systems are well suited to evaporation and Zero-Liquid-Discharge (ZLD) technologies, compared to other desalination technologies including RO and IER. An example of such a process is the leachate treatment shown in Figure G.2. The leachate treatment plants without ED discharge, the final concentrated brine to rivers, lakes and sea. Discharge of brine to the natural environment can limit the options for reuse and can also have a negative impact to plants and aquatic organisms. In this point of view, the ED process in leachate treatment can contribute to not only for increasing the possibility of a reuse of desalinated water, but also for reducing the environmental load by reuses of salt generated from concentrated brine.

6.1.3 Timing for evaluating key factors

In terms of timing, the key factors may be evaluated before operation, periodically monitored or continuously monitored (Table 9).

Table 9 — Timing for evaluating key factors

Target	Key factors	Timing for evaluation
IEM	Permselectivity	Before operation, Periodical monitoring
	Electrical resistance	
	Transport number	
	Mechanical strength[1],[2]	
Treated water	Concentration	Periodical monitoring
Stack	Current efficiency	
	Electrical current leakage	

Table 9 *(continued)*

Target	Key factors	Timing for evaluation
Feed water	Electrical conductivity	Continuous monitoring
Treated water		
Concentration water		
Stack	Electrical current	
	Electrical voltage	

6.1.3.1 Indication of initial evaluation

- IEM (permselectivity, electrical resistance, transport number, mechanical strength).

6.1.3.2 Indication of regular evaluation (maintenance, etc.)

- Concentration of each ion in the treated water.
- Stack (leakage, electrical current efficiency).

6.1.3.3 Indication of continuous evaluation (daily or weekly)

- Conductivity (feed water, treated water, concentration water).
- Stack (Electrical voltage, electrical current).

6.2 Evaluation method[5],[7],[8],[9]

6.2.1 Ion exchange membrane

6.2.1.1 Electrical resistance

The electrical resistance of an IEM is related to ED power. When using a low electrical resistance membrane, the electrical energy consumption of ED is low.

Annex I shows how to measure the electrical resistance of an IEM.

6.2.1.2 Transport number

The CEM transmits cations and the AEM transmits anions, and it is difficult for oppositely charged ions to pass. The indicator of this selective permeability is the transport number. Annex J shows the transport number measurement for an IEM.

6.2.1.3 Permselective coefficient

Annex K shows the permselective coefficient of an IEM.

6.2.1.4 Mechanical strength

The mechanical strength of an IEM is related to membrane lifetime.

Annex L shows how to measure the mechanical strength of an IEM.

6.2.2 Stack performance

6.2.2.1 Leak current

A leakage of current decreases the current efficiency of a stack, with a related loss of production.

Annex M shows the leak current calculation for a stack.

- Electrical voltage and electrical current.

Deterioration of a stack and an IEM can be confirmed by evaluating the electrical voltage and electrical current of the stack.

Continuous evaluation of stack electrical voltage and electrical current is required.

6.2.2.2 Electrical current efficiency

Loss of ED can be seen in the evaluation of electrical current efficiency.

The electrical current efficiency *E* for the transfer of salts can be calculated based on an expression of Faraday's law as given in Formula (1):

$$E = \frac{F \times F_\mathrm{d} \times \Delta N \times 100}{I \times N} \tag{1}$$

where

E	is electrical current efficiency
F_d	is Demineralized flow rate (l/h)
F	is Faraday's constant (26.8A·h)
I	is electrical current (A)
N	is Number of cell pairs
ΔN	is Normality (feed water – product water)

6.2.3 Operation and maintenance

Operation and maintenance should be performed in accordance with the technical and/or O&M manuals, as applicable.

Routine preventive maintenance will ensure efficient operation, as well as a long and reliable service life lifetime.

In daily operation, control settings and operating key factors should 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 that system should be noted.

Complete the system log sheet and verify that the operating settings are correct.

Examples of items are shown below:

- Pressure of cartridge filter, pump (feed, circulation, product, concentrate, electrode, chemical, etc.), block;
- Flow of water (feed, circulation, product, concentrate, electrode);
- Electrical conductivity and pH of water (feed, circulation, product, concentrate, electrode);
- Operating electrical voltage and electrical current;
- Operating temperature.

During maintenance, turn off power to the ED Stack.

— Block probing.

Blocks should be probed weekly to monthly, or as required for troubleshooting. This will reduce component damage and replacement costs.

— Inspect all unit piping, pressure instruments, sample tap fittings, and tubing for leaks;

— Inspect stacks in the area around the electrodes for signs of shorting or burning;

— Check that all pressure, differential pressure, and flow-rate instruments are working properly;

— If necessary, also check the pump oil level, electrode waste flows, ground-rod assemblies, etc.

Annex A
(informative)

Main process and typical applications of IER and IEM [20]

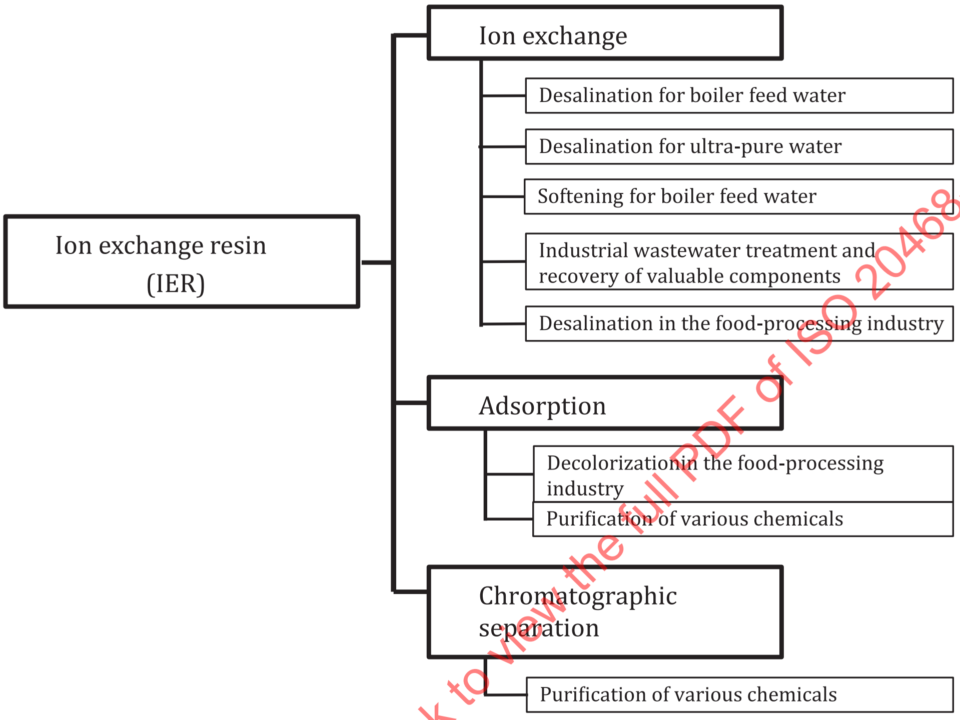


Figure A.1 — Main process and typical applications of IER

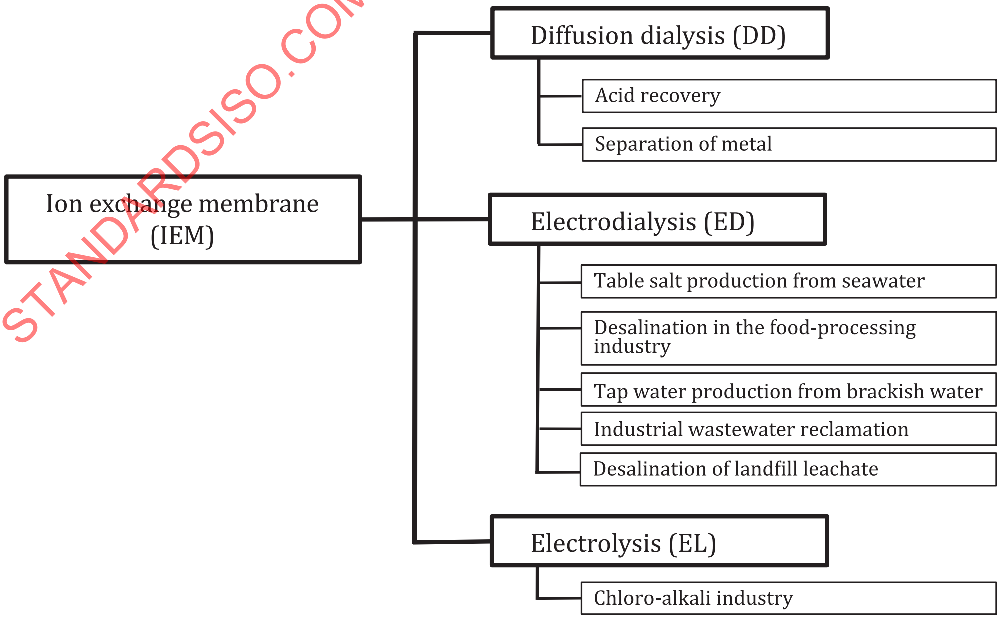


Figure A.2 — Main process and typical applications of IEM

Annex B
(informative)

Main treatment technologies and target constituents for reusing water

Table B.1 indicates main treatment technologies and target constituents after BOD removal for water reuse systems. It is summarized by focusing on typical technologies for advanced treatment and disinfection described in ISO 20468-1 with related functions required for water reuse.

Table B.1 — Main treatment technologies and target constituents/parameters (After BOD removal)

Required functions		Separation	Disinfection			Desalination	Oxidation or others		
Target constituents / Parameters Technologies		Turbidity or TSS	Pathogens			Conductivity or TDS	Colour	Odour	POPs (Persistent organic pollutants)
			Bacteria	Viruses	Protozoa				
Membrane filtration	MF	✔	✔		✔				
	UF	✔	✔	✔	✔				
	NF/RO		✔	✔		✔	✔	✔	✔
Ion exchange	Resin					✔	✔		
	Membrane					✔			
UV			✔	✔	✔				
Ozone			✔	✔	✔		✔	✔	✔
AOPs			✔	✔	✔		✔	✔	✔

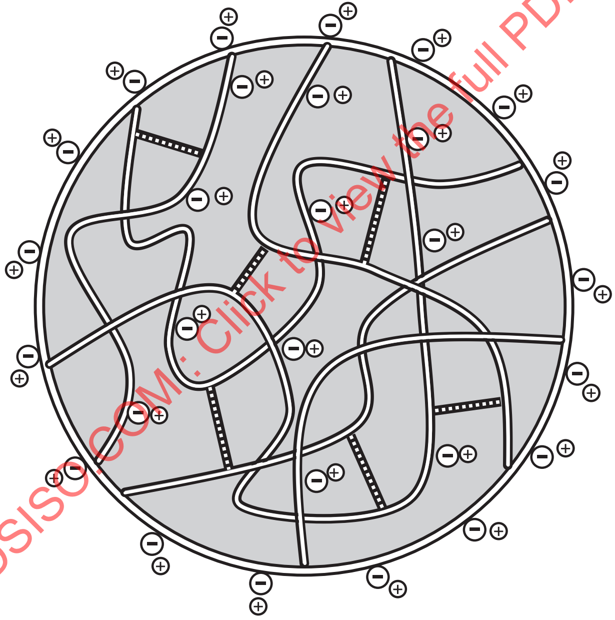
Annex C
(informative)

Structural model of IER

CERs are spherical synthetic resins, which are composed of polymer chain, crosslinker, fixed cation exchange group, counter cation, and hydrated water. Polymer chains and crosslinkers are basic polymer matrix of CERs. Typical polymer chains are polystyrene and typical crosslinkers are divinylbenzene. Typical polymer matrix is a copolymer made from styrene and divinylbenzene, which shows the crosslinked polymer network.

Fixed cation exchange groups such as sulfonic acid are incorporated to these polymer matrix. The ion exchangeable functional groups such as sulfonic acid groups are called “fixed ions” because they are chemically bonded to the polymer matrix. On the contrary, the mobile ions that are electrically neutralized with such fixed ions, H^+ in the case of $-SO_3^-$, are called “counter ions.” CERs adsorb some quantity of hydrated water inside the polymer matrix.

Figure.C1 shows the structural model of CER.



Key

⊖	fixed cation exchange group: SO_3^- etc.
⊕	counter cation: H^+, Na^+ etc.
═	polymer chain of styrene
┅	crosslinking of DVB
▒	hydrated water

Figure C.1 — Structural model of CER[20]

Annex D
(informative)

Selectivity and selectivity coefficient of IERs

When one adds the IER that has ions “B”, its ionic valence of which is D , to the solutions of ions “A” , its ionic valence of which is C , the ion exchange reaction between ions “A” and ions “B” occurs. This ion exchange reaction is written in the equilibrium reaction given in Formula D.1:

$$C\cdot\overline{B}^{D}+D\cdot A^{C}\leftrightarrow D\cdot\overline{A}^{C}+C\cdot B^{D} \tag{D.1}$$

where

A is A ion in the solution

$\overline{A}$ is A ion as a counter ion in the IERs

B is B ion in the solution

$\overline{B}$ is B ion as a counter ion in the IERs

C is ionic valence of A

D is ionic valence of B

The selectivity coefficient is expressed by Formula D.2:

$$K_{B}^{A}=\left(\overline{[A]}^{D}\cdot[B]^{C}\right)/\left(\overline{[B]}^{C}\cdot[A]^{D}\right) \tag{D.2}$$

where

K_{B}^{A} is selectivity coefficient

$[A]$ is concentration of A in the solution

$\overline{[A]}$ is concentration of A as a counter ion in the IERs

$[B]$ is concentration of B in the solution

$\overline{[B]}$ is concentration of B as a counter ion in the IERs

The selectivity coefficient among these three is usually used as a key factor of IERs and representative selectivity coefficients are summarized in Table B.1. The general selectivity trends toward ions are as follows:

i) CERs at low concentrations and normal temperatures are more selective toward high valence ions: e.g. $Na^+ < Ca^{2+} < Al^{3+} < Th^{4+}$.

ii) IERs are more selective toward ions with higher atomic numbers among ions of the same ionic valence: $Li^+ < Na^+ < Rb^+ < Cs^+ < Mg^{2+} < Ca^{2+} < Sr^{2+} < Ba^{2+}$, although such selectivity differences are smaller than those among different ionic valences.

iii) Selectivity differences become smaller when concentrations of ions become higher, and in some cases the order reverses.

iv) The selectivity order of AERs is as follows:

Citrate > SO_4^{2-} > Oxalate > I^- > NO_3^- > CrO_4^{2-} > Br^- > SCN^- > Cl^- > Formate > Acetate > F^-.

Table D.1 — Representative selectivity coefficients compared to Li^+ form SAC[16]

cation	Rational selectivity coefficient	cation	Rational selectivity coefficient
Li^+	1,00	Cu^{2+}	3,85
H^+	1,27	Cd^{2+}	3,88
Na^+	1,98	Ni^{2+}	3,93
NH_4^+	2,55	Ca^{2+}	5,16
K^+	2,90	Sr^{2+}	6,51
Rb^+	3,16	Pb^{2+}	9,91
Cs^+	3,25	Ba^{2+}	11,5
Ag^+	8,51	Mn^{2+}	4,09
Ti^+	12,4	Be^{2+}	3,99
UO_2^{2+}	2,45	Cr^{3+}	7,6
Mg^{2+}	3,29	Ce^{3+}	10,6
Zn^{2+}	3,47	La^{3+}	10,7
Co^{2+}	3,74		

Annex E
(informative)

Comparison of various IERs

E.1 SAC and WAC

Table E.1 provides a comparison of SAC and WAC.

Table E.1 — Comparison of SAC and WAC

SAC	WAC
Insoluble in water, strongly acidic as mineral acids	Insoluble in water, weakly acidic as organic acids
Dissociate in aqueous solutions of all pH range $RSO_3H \rightarrow RSO_3^- + H^+$ (fixed ion) (mobile ion)	Dissociate in neutral ~ alkaline aqueous solutions $RCOOH \rightarrow RCOO^- + H^+$ (fixed ion) (mobile ion)
Exchange cations even with neutral salts $RSO_3H + NaOH \rightarrow RSO_3Na + H_2O$ $2RSO_3H + Ca(HCO_3)_2 \rightarrow (RSO_3)_2Ca + H_2CO_3$ $RSO_3H + NaCl \rightarrow RSO_3Na + HCl$	Exchange cations with bases such as NaOH and with basic salts such as $Ca(HCO_3)_2$, but not with neutral salts in the ordinary conditions $RCOOH + NaOH \rightarrow RCOONa + H_2O$ $2RCOOH + Ca(HCO_3)_2 \rightarrow (RCOO)_2Ca + 2H_2CO_3$
Selectivity for cations in solutions at low concentrations $[Ba^{2+} > Ca^{2+} > Mg^{2+}]$ $[K^+ > NH_4^+ > Na^+ > H^+]$	Almost the same as SACs, but the selectivity of H^+ is higher than that for divalent cations
Selectivity decreases and sometimes reverses in solutions at high concentrations	
The exchanged cation hydrolyzes slightly, a feature that may usually be neglected.	The exchanged cation is easy to hydrolyze $RCOONa + H_2O \rightarrow RCOOH + NaOH$
The exhausted resin can be regenerated with HCl or H_2SO_4 $(RSO_3)_2Ca + 2HCl \rightarrow 2RSO_3H + CaCl_2$	The exhausted resin can be regenerated with HCl or H_2SO_4 $(RCOO)_2Ca + 2HCl \rightarrow 2RCOOH + CaCl_2$
Difficult to regenerate. The amount of regenerant needed far exceeds the theoretical amount.	Easy to regenerate. The amount of regenerant needed slightly exceeds the theoretical amount.
Reaction rate is high.	Reaction rate is slower than for SACs.
Na-form resins, regenerated with NaCl solutions, can be used for softening water. $2RSO_3Na + CaCl_2 \rightarrow (RSO_3)_2Ca + 2NaCl$	Na-form resins can sometimes exchange metal cations. $2RCOONa + CaCl_2 \rightarrow (RCOO)_2Ca + 2NaCl$ Regeneration shall be done with mineral acids and then with NaOH.
The volume of the H^+ form SACs is larger than that of the Na^+ form.	The volume of the Na^+ form WACs is very much larger than that of the H^+ form.

E.2 Comparison of SBA and WBA

Table E.2 provides a comparison of SBA and WBA.

Table E.2 — Comparison of SBA and WBA

SBA	WBA
Insoluble in water, strongly basic as caustic alkali	Insoluble in water, weakly basic as ammonium hydroxide

Table E.2 *(continued)*

SBA	WBA
Dissociate in aqueous solutions of all pH range $R - NOH \rightarrow R - N^+ + OH^-$ (fixed ion) (mobile ion)	Dissociate in neutral ~ acidic aqueous solutions $R - NH_2 + H_2O \rightarrow R\text{-}NH_2 + H^+ OH^-$ (fixed ion) (mobile ion)
Exchange anions even with neutral salts $R - NOH + HCl \rightarrow R - NCl + H_2O$ $R - NOH + H_2CO_3 \rightarrow R - NHCO_3 + H_2$ $R - NOH + NaCl \rightarrow R - NCl + N_aOH$	Exchange anions with mineral acids and with acidic salts as NH_4Cl, but not with neutral acids under normal conditions $R - NH_2 \cdot H^+ OH^- + HCl \rightarrow R - NH_2 \cdot H^+ Cl^- + H_2O$ $R - NH_2 \cdot H^+ OH^- + NH_4Cl \rightarrow R - NH_2 \cdot H^+ Cl^- + NH_4OH$
Selectivity of anions in solutions at low concentrations $SO_4^{2-} > HSO_4^- > NO_3^- > Cl^- > HCO_3^- > OH^-$ The order of the above selectivity reverses in solutions at high concentrations	Selectivity of anions is as follows: $OH^- > SO_4^{2-} > NO_3^- > Cl^-$
The exchanged anion hydrolyzed slightly, a feature that may usually be neglected.	The exchanged anion is easy to hydrolyze $R - NH_2 \cdot H^+ Cl^- + H_2O \rightarrow R - NH_2\text{⍰}H^+ OH^- + HCl$
The exhausted resin can be regenerated with strong bases as NaOH $R - NCl + NaOH \rightarrow R - NOH + NaCl$	The exhausted resin can be regenerated with NaOH, Na_2CO_3, and NH_4OH
Difficult to regenerate. The amount of regenerant needed far exceeds the theoretical amount.	Easy to regenerate. The amount of regenerant needed slightly exceeds the theoretical amount.
Reaction rate is high.	Reaction rate is slower than for SBAs.
The volume of the OH^- form SBAs is larger than that of Cl^- form.	The volume of the OH^- form SBAs is larger than that of free base form.

Table E.3 provides a comparison of Type I and Type II SBA

Table E.3 — Comparison of Type I and Type II SBA

	Type I	Type II
Ion exchange group	$-N^+(CH_3)_3$ trimethylammonium groups	$-N^+(CH_3)_2CH_2CH_2OH$ dimethylethanolammonium groups
Basicity	Strongly basic	Strongly, but slightly weaker than Type I
Regeneration	Difficult to regenerate, and much more regenerant is needed	Not so difficult as Type I, and less regenerant is needed than with Type I
Leakage in exchange with weak acids: i.e. silicic acid	Small leakage	More leakage than Type I
Chemical stability	Stable Operation temperatures: Cl form: up to 80 °C OH form: up to 60 °C	Slightly less stable than Type I Operation temperatures: Cl form: up to 60 °C OH form: up to 40 °C

Annex F

(informative)

General operation of an IER process

General operations of IERs are as follows:

1) Backwashing

Backwashing from the bottom of resin towers washes out suspended solids in raw water that accumulate in resin layers and disentangles pressurized resin layers. The flow rate is appropriate to increase resin volume by 50 ~ 80 %, and sufficient vacant spaces and freeboards are needed.

When suspended solids coagulate to form large lumps, air bubbling in advance of backwashing is sometimes necessary to crush those lumps. Bed expansion during backwashing varies according to temperature, and flow rates are optimized seasonally.

2) Settling

This process keeps the expanded resin layers still. Stop backwashing and just wait until the resin layers become still. The expanded resins settle gradually in order of size; from large to small.

3) Drainage

This process drains the inner water to a level that is a little higher than the top resin layer to prevent regenerant from being diluted with the remaining water above the resin layers. This process is omitted for pure water facilities with inlets for regenerants at the upper parts of the towers.

4) Regeneration

Regenerants flow from the top of towers downward; in counter current regeneration systems, regenerants flow upward from the bottoms of towers. The amounts of regenerant depend on the type of resin, objectives of water treatment, and required specifications of treated waters. The ideal operation has regenerants flow uniformly through resin layers and contact resins for a sufficiently long time and one should avoid letting the regenerant flow stop halfway.

5) Displacement of regenerant

To use the remaining regenerants in resin layers, this extrusion is executed at the following dosage; the flow rate at displacement is the same as that at dosage. The water volume for displacement is around two times the resin volume, and this process should be regarded as an extension of dosage.

6) Rinse (Washing)

This washes out wastewater remaining in the resin layers. The flow rate should be larger than the forwarding processes, and it is usually the same as the raw water flow rate or around 10 beds volume per hour. Rinse water is raw water for cation towers and effluent from anion towers in pure water production. When refining sugar and chemicals, tap water or pure water is used. The end point is when the regenerants disappear.

7) Sweetening on

In water treatments, the operation should continue to the normal deionization process, feeding raw water. On the contrary, this sweetening on is done for other purposes such as treating sugar solutions and reagents: 1) drain excess inner water to avoid dilution of the next treated water; 2) flow raw water downward from the top of the tower. Although the effluent is initially water, the sugar or reagent concentration increases gradually. Discard effluent by the proper end point decided by such concentration. This process is called “sweetening on.”

8) Deionization, exhaustion, or service or loading cycle

Deionization is executed with the downflow of raw water. The flow rate depends on the type of raw water and ion concentrations and is generally higher in standard water treatments. The end point is decided by the leakage of target ions. When the objective ions begin to leak, stop feeding and move to 1) Backwashing. The next 9) Sweetening off should be performed if the remaining raw water is recovered.

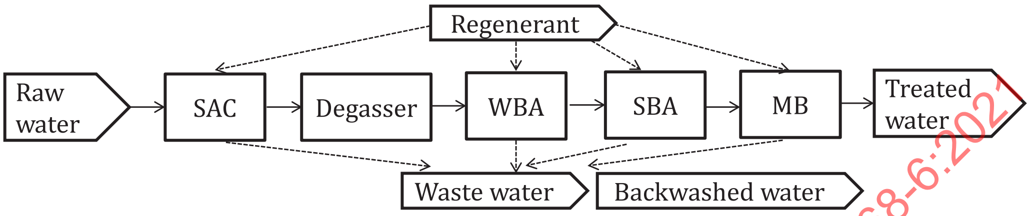
9) Sweetening off

In sugar or reagent solutions, this collects and displaces water remaining in the towers using water. The effluent is collected by the water flow at the same rate as the loading cycle. This procedure is called “Sweetening off.” This is not operated in water treatment.

The IER towers are operated by repeating the procedures mentioned above.

Annex G
(informative)

Flow diagram of IE and ED process [20]



System size: 50m³/h
IER: SAC 2,725L, WBA 1,150L, SBA 1,175L
MB: SAC 575L, SBA 850L
CER Regeneration: Counterflow of H_2SO_4
AER Regeneration: Counterflow of NaOH

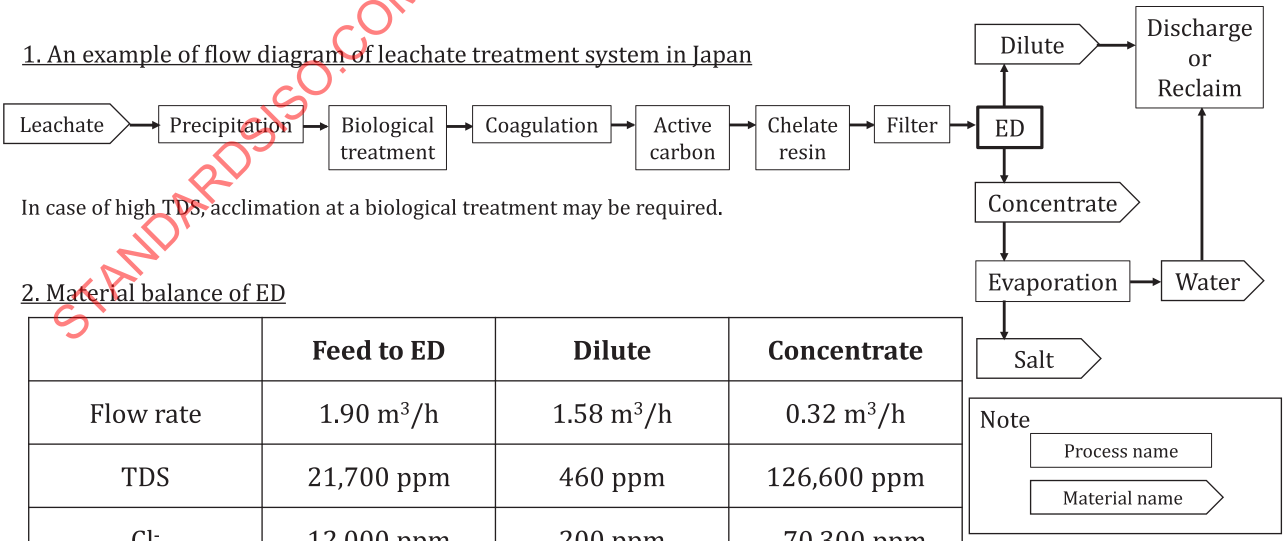
	Raw water	Treated water
Ionic load	1,6 eq/m³	-
TDS	0,08 g/L	<0,00006 g/L
Conductivity	-	<0,1 µS/cm
Na	-	<10 ppb
SiO_2	10 ppm	<10 ppb

Methods for reduction of regenerant and/or waste water
- using uniform particle size IER for SAC and SBA
- counter flow regeneration

Disposal option
- neutralization
- reuse for raw water or another process water

Figure G.1 — An examples of flow diagram and actual data of water treatment system by IER technology

1. An example of flow diagram of leachate treatment system in Japan



In case of high TDS, acclimation at a biological treatment may be required.

2. Material balance of ED

	Feed to ED	**Dilute**	**Concentrate**
Flow rate	1.90 m³/h	1.58 m³/h	0.32 m³/h
TDS	21,700 ppm	460 ppm	126,600 ppm
Cl^-	12,000 ppm	200 ppm	70,300 ppm

Figure G.2 — An examples of flow diagram of leachate treatment system in Japan and actual material balance data of ED

TDS concentrations can affect biodegradation, however, bacteria can adapt to high TDS conditions, as evidenced by bacterial activity in the ocean and ocean sediments. However, bacterial treatment can be severely negatively impacted by variable TDS concentrations.

Annex H
(informative)

Feed water conditions

ED requires certain feed water conditions for proper, long-term operation as listed in Table H.1.

Table H.1 — Feed water conditions for Electrodialysis

Material	Pretreatment	Tolerance
Turbidity	Filtration	<4 (SDI)
Iron	Coagulation settling, Ion exchange	<0.3 mg/l
Manganese	Coagulation settling, Ion exchange	<0.1 mg/l
Carbonate	Acid injection	<=0 (LSI)
Chlorine	Active carbon, Na_2SO_3 or N_2H_4 injection	ND

LSI = pH-pHs

where

pH is measured pH of water

pHs is calculated saturation pH of water