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

Part 6:
Ion exchange and electrodialysis

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Foreword

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This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 3, *Risk and performance evaluation of water reuse 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 resins* (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 resins* (3.1.2) and *cation exchange resins* (3.1.6)

3.1.22
particle size and particle size distribution
diameter of *ion exchange resins* (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 resins* (3.1.19)

3.1.25
regeneration
regeneration of *ion exchange resins* (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 that causes selective movement of solvent against its osmotic pressure difference

Note 1 to entry: Note I 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 D6161-10]

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 electrodialysis in IEM also apply to water reclamation. Annex A shows the main process and typical applications of IER and IEM.

Ion exchange and electrodialysis 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 & Deso-rption	<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.

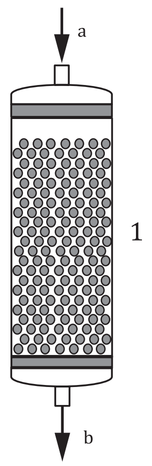
EDI is applied to produce pure water or ultrapure water instead of a resin tower or RO. EDI stacks have an IER or fibre in desalinated chambers to decrease resistivity. As a result, EDI can provide very low conductivity water.

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.



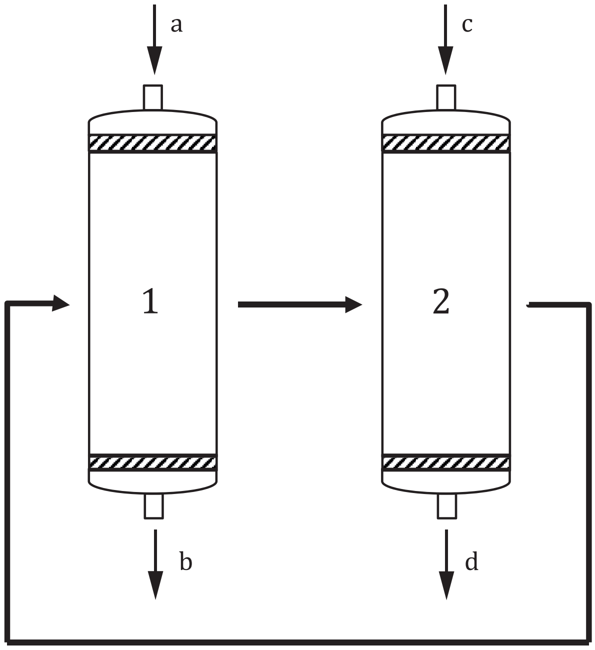
Key

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.

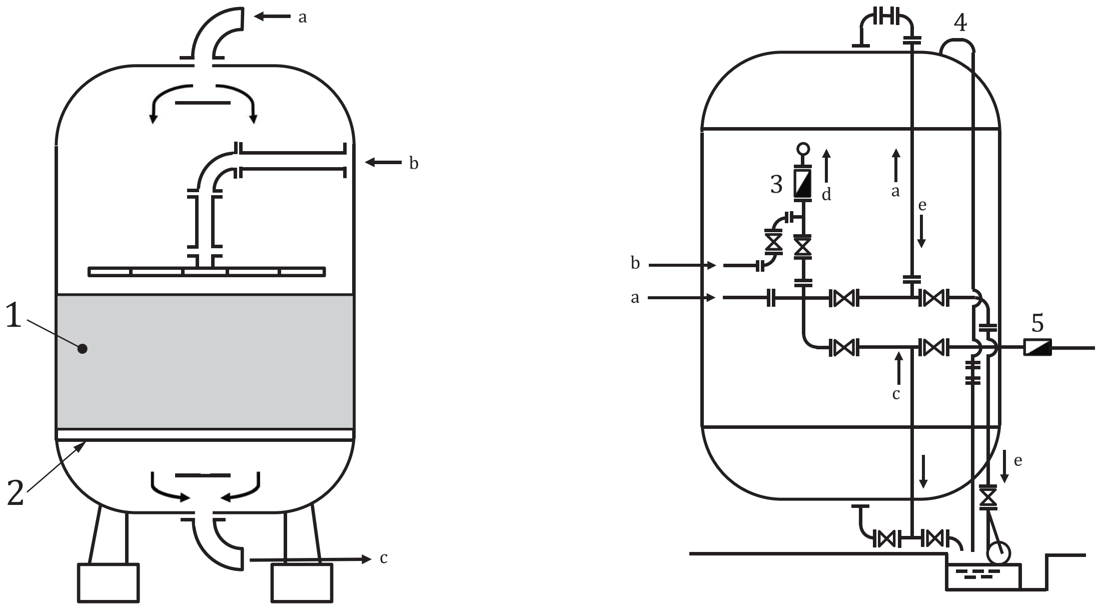
Chelating resins are a type of IER with functional groups that can form chelates with metal ions. Table 3 shows types and groups of CRs.

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 resins 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 process. 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 (Ca2+, Mg2+, 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.

