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Water Reuse in Urban Areas — Guidelines for reclaimed water treatment: Design principles of a RO treatment system of municipal wastewater

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Foreword

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This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 2, *Water reuse in urban areas*.

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

Over the past decade, with an increasing demand of high-quality reclaimed water, reverse osmosis (RO) has been widely applied as an important option for municipal wastewater reclamation. RO is a water purification technology that uses a semipermeable membrane to remove ions and dissolved organic micropollutants from feed water. In reverse osmosis, an applied pressure is used to overcome osmotic pressure, a colligative property that is driven by chemical potential differences of the solvent, a thermodynamic parameter. The automatic operation, small footprint and consistent high permeate quality are the advantages of an RO process, which make it widely recognized. The reclaimed water produced by an RO system could be used as boiler replenishing water, water for industrial production and so on.

Compared with seawater and industrial wastewater, municipal wastewater has its distinctive features. The total dissolved solid (TDS) concentration in seawater is mainly in the range of 30,000 to 45,000 mg/l[1], while the TDS concentration in secondary effluent of municipal wastewater ranges from 100 to 3,000 mg/l[2]. Thus, the RO system of municipal wastewater could achieve higher recovery efficiency with much lower operational pressure compared with that of seawater. However, the dissolved organic matter (DOM) concentration in secondary effluent is in the range of 5 to 20 mg/l as dissolve organic carbon (DOC)[2], which is much higher than that in seawater (<2 mg/l)[1]. Furthermore, the components of the DOM in secondary effluent are much more complicated than those in seawater. Long-term operation of the RO system for municipal wastewater reclamation could lead to serious organic and biological fouling. Therefore, in order to provide the stable operation, the distinctive features of municipal wastewater should be taken into consideration in the design of the RO unit as well as the pre-treatment unit. The design experience of the RO system for other water sources (e.g., seawater and industrial wastewater) could not be applied directly to municipal wastewater.

This document provides guidelines for the planning and design of an RO treatment system for water reuse applications in urban areas. This document is applicable to practitioners and regulatory authorities who intend to implement principles and decisions on water reuse in a safe, reliable and sustainable manner.

This document addresses an RO treatment system in its entirety (e.g. reclaimed water sources, pre-treatment process, RO treatment process, post treatment process, performance of RO system, operation and maintenance and monitoring, usage of reclaimed water).

Water Reuse in Urban Areas — Guidelines for reclaimed water treatment: Design principles of a RO treatment system of municipal wastewater

1 Scope

This document provides guidelines for the planning and design of a reverse osmosis (RO) treatment system of municipal wastewater. This document is applicable to practitioners and authorities who intend to implement principles and decisions on RO treatment of municipal wastewater in a safe, reliable and sustainable manner. This document addresses RO treatment systems of municipal wastewater in their entirety and is applicable to any RO treatment system component.

This document provides:

— standard terms and definitions;

— a description of the system components of an RO treatment system of municipal wastewater;

— design principles of an RO treatment system of municipal wastewater;

— statements on the feed water quality and technical requirements of an RO treatment system;

— guidance for operation and maintenance of an RO treatment system;

— specific aspects for consideration and emergency response.

Design parameters and regulatory values of an RO treatment system of municipal wastewater are out of the scope of this document.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670:2018, *Water reuse — Vocabulary*

3 Terms and definitions

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

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

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

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

3.1
assimilable organic carbon (AOC)
organic carbon which can be used by microorganisms for assimilation

3.2
biodegradable dissolved organic carbon (BDOC)
organic carbon which can be used by microorganisms for assimilation as well as catabolism

3.3
concentrate
rejected stream exiting a membrane module under a cross-flow mode

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

[SOURCE: ASTM D6161-19[3], modified — Note 1 to entry added.]

3.4
feed
input solution entering the inlet of a membrane module or system

[SOURCE: ASTM D6161-19[3]]

3.5
ion exchange
process by which certain anions or cations in water are replaced by other ions by passage through a bed of ion-exchange material

[SOURCE: ISO 6107-1:2004, 46[4]]

3.6
membrane rejection rate
relative measure of how much of the target constituent that was initially in the feed water is separated from the liquid by the membrane

Note 1 to entry: Rejection is generally expressed by 1 - C2/C1, where C1 is feed concentration and C2 is permeate concentration. To make the guideline simple, the word "membrane" is frequently omitted depending on the context.

3.7
microfiltration
pressure driven membrane-based separation process designed to remove particles and macromolecules in the approximate range of 0,05 to 2 µm

[SOURCE: ASTM D6161-10[3]]

3.8
permeate
portion of the feed stream which passes through a membrane

[SOURCE: ASTM D6161-10[3]]

3.9
pressure drop
pressure change of the influent after the treatment by an RO system

3.10
recovery rate
ratio of the permeate volume to the feed volume

3.11
reverse osmosis
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

[SOURCE: ASTM D6161-10[3]]

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

3.12
silt density index (SDI)
index for the fouling capacity of water in reverse osmosis systems, measuring the rate at which a 0,45-micrometre filter is plugged when subjected to a constant water pressure of 206,8 kPa (30 psi)[5]

[SOURCE: ASTM D4189-07 (2014)[5]]

3.13
ultrafiltration
pressure driven process employing semipermeable membrane under hydraulic pressure gradient for the separation of components in a solution

[SOURCE: ASTM D6161-10[3]]

Note 1 to entry: The pores of the membrane are of a size smaller than 0.1 µm, which allows passage of the solvent(s) but will retain non-ionic solutes based primarily on physical size, not chemical potential.

4 Abbreviated terms

AOC	assimilable organic carbon
BDOC	biodegradable dissolved organic carbon
BOD	biochemical oxygen demand
CA	cellulose acetate
COD	chemical oxygen demand
DOC	dissolved organic carbon
DOM	dissolved organic matter
MF	microfiltration
NPF	normalized permeate flow
ORP	oxidation-reduction potential
RO	reverse osmosis
SDI	silt density index
TOC	total organic carbon
TSS	total suspended solids
UF	ultrafiltration

5 Application of RO treatment systems for reclaimed water

5.1 Overview

Over the past decade, with an increasing demand for high-quality reclaimed water, reverse osmosis (RO) among other technologies has been widely applied as an important option for municipal wastewater reclamation. RO technology can achieve high removal efficiency of microbes, colloidal matter, dissolved solids, organics and inorganics from feed water. The advantages of an RO process are automatic operation and high stability of RO permeate and this makes the RO process widely accepted [6-8].

5.2 Design considerations

Generally, permeate flow rate and permeate quality are used to characterize an RO treatment system under certain feed water quality, recovery rate and operational pressure. Therefore, the main objective of designing an RO treatment system is to meet the specific consideration of permeate flow rate and quality with minimal operational pressure and the considerations about the costs of system components. Furthermore, the cleaning process and maintenance should also be taken into consideration to maintain the stable operation of the system.

5.2.1 Safety considerations

In theory, the reverse osmosis process is driven by pressure. In practice, the pressure is provided by the feed pump of the RO process, and a pressure vessel is used to hold the membrane modules and the pressurized feed water. Therefore, the design and operation of a nRO system shall meet the safety consideration for a pressurized system.

5.2.2 Stability considerations

Stability represents the ability of an RO system to provide stable permeate flow rate and water quality under certain operational conditions. In practice, because of membrane fouling, scaling or other factors which could increase the resistance, in order to maintain a stable rate of permeate flow, the operational pressure keeps increasing. When the operational pressure is too high, it is necessary to clean the RO membranes. As for permeate quality, it might deteriorate because of membrane damage, membrane degradation and membrane fouling. Therefore, the permeate quality shall be diligently monitored.

In order to enhance the stability of an RO system, provision for equalization of feed water flow prior to the pre-treatment stage and/or the RO unit may also be considered. The resultant reduced variability in influent flow rate would also allow for more consistent dosing of chemicals such as antiscalants, reductants and non-oxidizing biocides.

5.2.3 Economy considerations

As for the infrastructure cost of an RO system, it is necessary to meet the considerations of permeate flow rate and quality with a minimal cost of system components. As for the operational cost, it is necessary to maintain the operational stability of the whole system with reasonable operational pressure, cleaning and maintenance.

5.3 RO system components

5.3.1 General

An RO system generally consists of six essential components (see Figure 1):

— feed water source;

— pre-treatment;

— RO treatment;

— auxiliary equipment;

— post treatment (optional depending of the reclaimed water usage and quality criteria); and

— monitor.

Each part of the system should be characterized and managed with appropriate strategies. See Annex A for the example of a typical RO treatment system for reclaimed water.

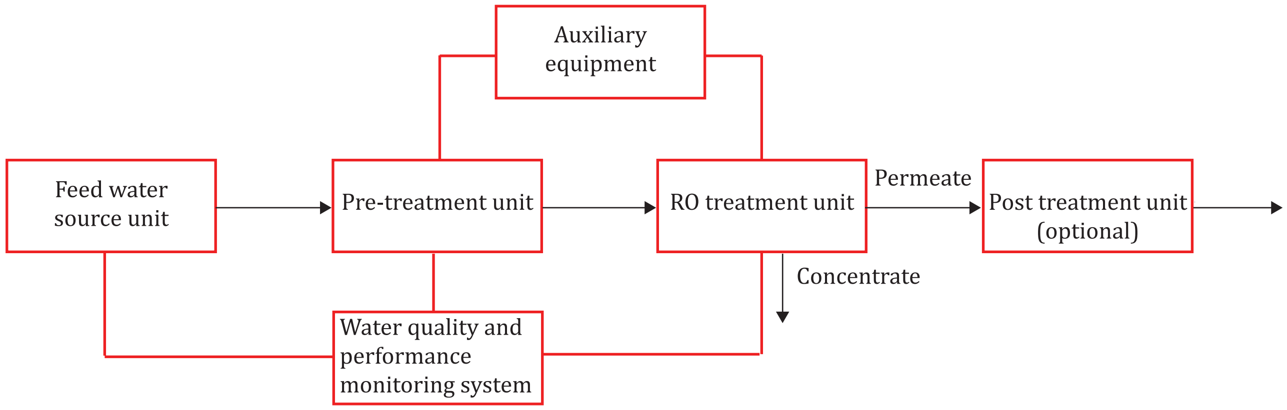

Figure 1 — The essential components of an RO treatment system for reclaimed water

5.3.2 Feed water source

Secondary or tertiary treated municipal wastewater is generally the water source to the RO process stage of the water reclamation plant.

5.3.3 Pre-treatment unit

The pre-treatment unit may include one or more treatment stages such as physico-chemical treatment, oxidation (e.g. ozone/AOPs), media filtration, UF/MF membrane filtration, disinfection.

5.3.4 RO treatment unit

The RO treatment unit generally includes a safety filter, a high-pressure pump, RO equipment and a storage tank for the effluent of RO. It is the key component of the whole RO system.

5.3.5 Auxiliary equipment

The auxiliary equipment may include the dosing and cleaning units. Several kinds of chemicals may be added, including chlorine, cleaning chemicals, antiscalants, reductants and non-oxidizing biocides (Figure 1 and Figure A.1).

5.3.6 Post treatment unit

According to the specific consideration of the end user, one or more stages shall be needed to attain the desired rejection (e.g. secondary RO, ion exchange, electrodialysis reversal). RO concentrate may require treatment. The post treatment unit will be elaborated on in Clause 9.

5.3.7 Water quality and performance monitoring system

In order to maintain the operational stability and safety of the whole system, monitoring equipment should be installed, including temperature meter, pressure gauge, pH meter, flowmeter, conductivity meter, ORP meter and so on.

6 Technical considerations of pre-treatments

6.1 Quality considerations of feed water

6.1.1 General water quality index

General water quality indices of the feed water for an RO system are listed in Table 1.

Table 1 — General water quality for the feed water of an RO system

Category of water quality index	Detailed water quality index
Inorganic index	Metal cations (calcium, magnesium, iron, aluminum, etc.); Silica; Free chlorine residual; Anions (nitrate, phosphate, etc.)
Organic index	COD, BOD, TOC
Other index to be considered	pH, Silt density index (SDI), Turbidity, Oxidation-reduction potential

Metal ions and silica could be of concern for scaling.

Free chlorine residual is of concern for RO membrane oxidizing damage.

The nutrient availability, such as nitrate and phosphate, could be important factors affecting the biofouling of membranes.

Organic index is related to organic fouling and biofouling, which may become the main fouling problems when secondary or tertiary treated municipal wastewater is used as feed water. These indices are elaborated on in 6.1.3.

SDI and turbidity are related to membrane fouling caused by small particles.

6.1.2 Silt density index

Silt density index (SDI) gives the percent drop per minute in the flow rate of the water through the filter, averaged over a period of time such as 15 minutes.

The measurement procedure of silt density index is as follow referring to ASTM D4189-07 (2014)[5]:

The water sample is filtered through a 0.45 µm membrane with a diameter of 47 mm under a constant pressure of 206.8 kPa (30 psi). At the beginning, the time needed to obtain 500 mL filtrate is t_1. After time T (generally, 15 min), the time needed to obtain 500 mL filtrate become t_2. The SDI of the water sample could be calculated with Formula 1:

$$SDI = \frac{\left(1 - \frac{t_1}{t_2}\right)\%}{t_f} = \frac{\%P}{t_f} \qquad (1)$$

where

t_f is the total testing time;

t_1 is the time needed to obtain 500 ml filtrate at the very beginning;

t_2 is the time needed to obtain 500 ml filtrate after the testing time T (generally, 15 min);

$\%P$ is plugging rate if $\%P$ is over 75 %, testing time T should be change to 10, 5 or 2 min.

Feed water with an SDI below 3, is generally considered as adequate feed water.

Other methods or indicators may be used if necessary.

6.1.3 Organic index

Generally, organic indices for an RO system include:

— Total organic carbon (TOC);

— Biochemical oxygen demand (BOD); and

— Chemical oxygen demand (COD).

