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

## Part 7: Advanced oxidation processes technology

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

*Partie 7: Technologie des processus d'oxydation avancés*

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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

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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.


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# Introduction

Global warming and climate change have become worldwide concerns as many countries suffer from water shortages. There has been global investment to develop alternative water resources and secure water supplies. One of such efforts is water reclamation/reuse since it is readily available. At the same time, the implementation of the water reuse technology raises public and regulatory concerns on potential human health, environmental, and its social impacts. The water reclamation/reuse technology vendors and technology users have increased needs for defining various aspects of water reuse projects, for regulation and for international standardization. Without ISO water reuse standards, many opportunities for sustainable development based on water reuse could be lost.

Standardization of water reuse should include objective specifications, assessments of service level and water reuse system performance dependencies such as safety, environmental protection, resilience, and cost-effectiveness. Therefore, appropriate methods are needed to evaluate the performance of the reuse system.

Varying amounts of persistent organic pollutants (POPs) can be found dependent on the biological activity of the surrounding watershed and the geochemical circulation. POPs are organic compounds that are resistant to degradation. POPs typically are halogenated organic compounds which exhibit high lipid solubility, thus bioaccumulate in fatty tissues. Polyhalogenated organic compounds are of particular concern because of the stability and lipophilicity which are often correlated to their halogen content. Since POPs accumulate and are persistent, they can adversely affect human health and the environment as a result.

The performance of the treatment technology for water reuse should be properly evaluated in order to select the most appropriate technology to achieve the objectives of the water reuse project. Despite considerable research and development on therapeutic techniques, such scientific knowledge is largely depending on the scope of commercial interests. This document establishes a specific performance evaluation method for advanced oxidation processes (AOPs) for water reuse systems based on ISO 20468-1 as a generic standard. To address these issues, this document provides the evaluation of the performance of water reuse systems in many applications by providing methods that most stakeholders can accommodate.

At the ISO TC282/SC3 meeting, a general standard for performance evaluation based on the discussion entitled "Guidelines for Performance Evaluation of Processing Technologies for Water Reuse Systems - Part 1: General" in ISO 20468-1 was discussed. Technology, and combinations, thereof, and descriptions of representative technologies should be included in the individual standards submitted in accordance with ISO 20468-1. In this context, this document establishes a specific performance evaluation method for advanced oxidation processes (AOPs) for water reuse systems based on ISO 20468-1 as a generic standard.

AOP technologies represent a group of treatment processes (e.g., hydrogen peroxide/ozone, hydrogen peroxide/UV, ozone/UV, pH elevated ozonation, etc.) that rely on the production of hydroxyl radicals as a strong oxidant capable of the complete oxidation of most organic compounds.

In water reuse systems, AOP technologies are mainly applied for disinfection and for removing total organic carbon (TOC) including persistent organic pollutants (POPs) that are barely decomposed by conventional oxidation processes, as indicated in Table A.1 (Annex A). For instance, direct oxidation of chlorobenzene by ozone is known to occur very slowly; this reaction's second-order kinetic rate constant is less than 1 $M^{-1}s^{-1}$. On the other hand, the oxidation of chlorobenzene by ·OH is extremely rapid (up to $4 \times 10^9$ $M^{-1}s^{-1}$).

AOPs as an advanced level treatment are generally applied to tertiary treated water, as shown in Figure 1 of ISO 20468-1.

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

# Part 7:
# Advanced oxidation processes technology

## 1 Scope

This document provides a performance evaluation method of treatment technology using advanced oxidation processes (AOPs) for water reuse treatment. It introduces a system of evaluating water quality to validate AOP performance through typical parameters such as the concentration of hydroxyl radicals.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670:2018, *Water reuse — Vocabulary*

## 3 Terms, definitions, and abbreviated terms

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

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

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

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

### 3.1 Terms and definitions

**3.1.1**
**persistent organic pollutant (POP)**
chemical substances that persist in the environment, bio-accumulate through the food web, poses a risk of causing adverse effects to human health and the environment, and can be subject to long range transport away from its original source

Note 1 to entry: Substances are classified as POPs according to either The Protocol to the regional UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) on POPs, opened for signatures in June 1998 and entered into force on 23 October 2003 or the global Stockholm Convention on POP, opened for signatures in May 2001 and entered into force on 17 May 2004.

[SOURCE: ISO 26367-2:2017, 3.8[1]]

**3.1.2**
**advanced oxidation process (AOP)**
process that generates hydroxyl radicals in sufficient quantity to remove organics by oxidation

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**3.1.2.1**
**hydrogen Peroxide/Ozone ($H_2O_2/O_3$)**
combination of $H_2O_2$ and ozone which is able to generate ·OH

Note 1 to entry: When ozone is dissolved in water, it causes a complex chain of reactions that result in the formation of radicals including ·OH and superoxide radicals. The addition of hydrogen peroxide to ozone also generates ·OH radicals. The typical stoichiometry of hydrogen peroxide and ozone based on the mass ratio is from 0,35 to 0,45 because 0,5 moles of $H_2O_2$ are required to every mole of $O_3$ for the complete reaction of ·OH production.

**3.1.2.2**
**hydrogen Peroxide/UV ($H_2O_2$/UV)**
combination of $H_2O_2$ and UV light which is able to generate ·OH through UV photolysis of $H_2O_2$

Note 1 to entry: The oxidation of organics can occur by either direct photolysis or reactions with ·OH in $H_2O_2$/UV system.

**3.1.2.3**
**ozone/UV ($O_3$/UV)**
combination of ozone and UV light which is able to generate ·OH through UV photolysis of ozone

Note 1 to entry: UV photolysis of ozone where $H_2O_2$ is generated as an intermediate, which then decomposes to ·OH. Due to the relatively high molar extinction coefficient of ozone ($\varepsilon_{254\ nm}$ = 3 300 $M^{-1}$ $cm^{-1}$), ozone/UV radiation can generally produce more ·OH than $H_2O_2$/UV radiation.

**3.1.2.4**
**Fenton reaction**
reaction between iron(II) and hydrogen peroxide to yield ·OH

Note 1 to entry: Fenton reaction can occur either in homogeneous systems with dissolved ferrous iron or in heterogeneous systems in the presence of complexed iron. The by-product, ferric iron, in turn reacts with peroxide or superoxide radical to reproduce ferrous iron. The reaction cycle of iron between the ferrous and ferric oxidation states continuous until the $H_2O_2$ is fully consumed, producing ·OH in the process. As in other AOPs, the destruction of organics is primarily due to oxidation reactions initiated by the ·OH. Similar reactions can occur with copper (II) in place of iron (II).

**3.1.2.5**
**hydroxyl radical scavengers**
non-target substances that react to high degree of reactivity of hydroxyl radical

Note 1 to entry: Hydroxyl radical can oxidize a broad range of organic pollutants quickly and non-selectively. A drawback resulting from such a high degree of reactivity is that the hydroxyl radical also reacts with "non-target" materials in solution such as chloride, nitrite, bromide, carbonate, bicarbonate, and NOM, all of which are referred to as radical "scavengers".

Note 2 to entry: see Annex D

**3.1.2.6**
**UV/$TiO_2$**
semiconductor photocatalysts that absorb light and involve the generation of oxidants (e.g., ·OH and $O_2^{\cdot-}$) for the destruction of organic pollutants

Note 1 to entry: When $TiO_2$, a semiconductor photocatalyst, is illuminated by UV light (≤ 400 nm), valence band electrons are excited to the conduction band, resulting in the production of electron and hole pairs. These generated electron and hole pairs are capable of initiating a wide range of chemical reactions (e.g., direct oxidation/reduction, oxidants generation). Among them, ·OH oxidation is the primary mechanism for the destruction of POPs. The production of ·OH can occur via several pathways but, as with many of the other AOPs analysed, is readily formed from hydrogen peroxide.


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**3.1.3**
**hydroxyl radical (·OH)**
neutral form of hydroxide ion (OH-) which possesses an unpaired electron

Note 1 to entry: The unpaired electron makes it a powerful and non-selective chemical oxidant, which acts very rapidly with most organic compounds.

**3.1.4**
**redox potential**
potential of a reversible oxidation-reduction reaction in a given electrolyte recorded on a standard hydrogen electrode scale

[SOURCE: ISO 8044:2020, 6.1.37[2]]

**3.1.5**
**·OH concentration**
molar concentration of ·OH in a unit volume of liquid

**3.1.6**
**·OH monitor**
instrument capable of measuring *·OH concentration* (3.1.5) in samples

**3.1.7**
**electrical energy per order**
electrical energy in kWh which required to degrade a contaminant by one order of magnitude in $1m^3$ of contaminated water

Note 1 to entry: Electrical energy per order as a Figure-of-merit for AOPs has been accepted by the International Union of Pure and Applied Chemistry (IUPAC) in 2001[3].

**3.1.8**
**UV transmittance**
the fraction of photons in the UV spectrum transmitted through a material such as water or quartz. It is preferable that an online UVT sensor be installed and used to verify UVT

Note 1 to entry: The wavelength of the UVT (unit %) should be specified, often using a path-length of 1 cm. The measurement is calibrated compared to ultra-pure water (ISO 3696 grade 1 or equivalent).

Note 2 to entry: UVT is related to the UV absorbance (A) by the following equation (for a 1- cm path length): % UVT = 100 × 10-A.

## 3.2 Abbreviated terms

| | |
|---|---|
| AOP | advanced oxidation process |
| $E_{EO}$ | electrical energy per order |
| LCC | life cycle cost |
| NOM | natural organic matter |
| $O_2^{\cdot -}$ | superoxide anion radical |
| ·OH | hydroxyl radical |
| $OH^-$ | hydroxide ion |
| O&M | operation & maintenance |
| POP | persistent organic pollutant |

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