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Water reuse in urban areas — Guidelines for water reuse safety evaluation — Stability evaluation of reclaimed water

Recyclage des eaux dans les zones urbaines — Lignes directrices concernant l'évaluation de la sécurité du recyclage de l'eau — Évaluation de la stabilité de l'eau réutilisée

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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

With economic development and population growth, the demand for water resources is steadily increasing. Combined with the exploitation and utilization of water, numerous countries and regions have faced water shortages to different degrees. Increasing efforts has been made to solve the water crisis.

Water reuse has been recognized as a low-cost and effective means to alleviate water resource shortages. Wastewater usually contains a variety of pathogens, chemical pollutants and nutrients. Traditional water treatment cannot remove all pollutants. During the long-term utilization of reclaimed water, residual pollutants will affect human health (e.g. potential health risks to the public and workers handling the reclaimed water), ecological environment (e.g. pollution of receiving water, soil) and production safety (e.g. harmful effects on equipment operation such as corrosion, scaling and fouling). Therefore, water quality stability is a prerequisite to ensure water reuse. It is necessary to monitor and manage the quality of reclaimed water to ensure a safe supply. Chemical stability and biological stability are crucial aspects of water quality stability. Water quality instability usually leads to frequent occurrences of corrosion, scaling and fouling, bacterial regrowth, increasing energy consumption and reduced service life of relevant equipment.

There are limited guidelines or regulations specifically regarding water quality stability for urban purposes of reclaimed water at a global level. For different types of reclaimed water applications, the selection of stability evaluation parameters remains controversial. Stability evaluation and management of water quality are important to ensure safe utilization of reclaimed water. It is necessary to establish a standard for comprehensively evaluating the stability of reclaimed water.

This document aims to provide guidance on water quality stability of reclaimed water and provide stability parameters and methods based on different needs and utilization of reclaimed water. This document includes:

— standard terms and definitions;

— evaluation principles of water quality stability for reclaimed water;

— evaluation parameters of water quality stability for reclaimed water;

— the selection of stability evaluation parameters for pipeline networks and equipment related to reclaimed water;

— evaluation methods of water quality stability for reclaimed water.

Critical values of evaluation parameters for water quality stability are out of the scope of this document. The ranges of different evaluation parameters are provided for reference. The water stability control or management involving the reclamation treatment and/or the distribution system management (e.g. residual disinfectant) are also out of the scope of this document.

This document provides guidance on storage, transportation and application of reclaimed water. The beneficial aspects are reduction of energy consumption, expansion of service life of equipment and reduction of operation costs.

Water reuse in urban areas — Guidelines for water reuse safety evaluation — Stability evaluation of reclaimed water

1 Scope

This document provides parameters and methods for water quality stability evaluation of reclaimed water. This document can be used in various stages of water reclamation projects including storage, transportation, application and post-assessment.

This document considers the needs and utilization of reclaimed water and is applicable to the evaluation and management of water quality stability of reclaimed water from municipal wastewater sources, including chemical stability and biological stability.

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 and definitions

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

ISO and IEC maintain terminology 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

[SOURCE: ISO 23070:2020, 3.1]

3.2
corrosion
physicochemical interaction between a metallic material and its environment that results in changes in the properties of the metal and that can lead to significant impairment of the function of the metal, the environment or the technical system, of which these form a part

[SOURCE: ISO 8044:2020, 3.1, modified — Note 1 to entry removed.]

3.3
critical value
boundaries of acceptable values for evaluation parameters when water quality is stable

3.4
fouling
precipitation of suspended solids, including living organisms (biofouling) and chemical substances (inorganic or organic)

3.5
microbiologically influenced corrosion
MIC
corrosion (3.2) influenced by the action of microorganisms

[SOURCE: ISO 8044:2020, 4.37, modified — Note 1 to entry removed.]

3.6
scaling
crystalline scales caused by the oversaturation of chemical substances on metallic or non-metallic surfaces

4 Abbreviated terms

AI	aggressive index
AOC	assimilable organic carbon
ATP	adenosine triphosphate
BDOC	biodegradable dissolved organic carbon
BFR	biofilm formation rate
BGP	bacterial growth potential
CCPP	calcium carbonate precipitation potential
COD_{Cr}	chemical oxygen demand (dichromate method)
DO	dissolved oxygen
DBP	disinfection by-product
ILR	improved Larson corrosion index
LR	Larson corrosion index
LSI	Langelier saturation index
MAP	microbially available phosphorus
MIC	microbiologically influenced corrosion
MPN	most probable number
RI	Riddick corrosion index
RSI	Ryznar stability index
TDS	total dissolved solids
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids

5 Water quality stability

5.1 General

Water quality stability is the premise of reclaimed water use. The recommended parameters for water reuse safety in ISO 20761 include routine physical and chemical parameters, aesthetic parameters, microbial parameters, stability parameters and toxic and harmful chemicals.[1] Among stability parameters, chemical stability and biological stability are important aspects.

Chemical stability includes corrosion, scaling and fouling. Corrosion can be classified into many types, such as electrochemical corrosion, chemical corrosion, localized corrosion, pitting corrosion and layer corrosion. Detailed information is given in Annex A. Table 1 lists factors influencing the likelihood of corrosion. The main influencing factors include characteristics of equipment and pipelines, characteristics of the reclaimed water and operating conditions. Reclaimed water can be used in many fields for urban areas, such as industrial use, artificial landscape amenity, municipal non-potable use and groundwater recharge. Related equipment includes boilers and heat exchangers, irrigation equipment, air conditioning and toilet flushing devices. Related pipelines include steel and galvanized steel pipelines, concrete and cement pipelines, cement-mortar-lined metal pipelines, plastic pipelines, cast-iron and ductile-cast-iron pipelines and non-ferrous metal pipelines. Operating conditions include temperature, flow conditions and pressure conditions. Scaling is mainly dependent on two situations. One is the decrease in the solubility of ionic components, which lead to crystals precipitation when thermodynamic conditions change. The other is precipitation formed by reactions between different ionic components. Fouling is mainly caused by the precipitation of suspended chemicals. The extent of fouling is affected by hydraulic conditions, the roughness of the contact surfaces and the concentration, size and type of suspended chemicals.

Table 1 — Factors influencing the likelihood of corrosion

Characteristics of equipment and pipelines	Characteristics of the water	Operating conditions
— Chemical composition — Surface conditions — Design and construction	— Physico-chemical composition — Colloidal and particulate matter — Living organisms	— Temperature — Flow conditions, such as flow velocity, turbulence or laminar flow, continuous or intermittent pattern — Pressure conditions

Besides chemical stability, considering the possibility of opportunistic bacterial regrowth in reclaimed water, biological stability is also an important aspect of water quality stability. Biological stability includes MIC and biofouling. MIC is due to microbial activity involving bacteria, archaea and fungi. Within bacteria, sulfate-reducing bacteria, sulfur-oxidising bacteria, iron-oxidising or reducing bacteria, acid-producing bacteria and bacteria that excrete extra-cellular polymeric substances significantly affect corrosion. Among these, some microbes can coexist and their cooperative metabolisms can lead to increasing corrosion rates. Microbes can directly cause MIC by producing acids and they can accelerate the corrosion of pre-existing agents such as O_2 and CO_2 by damaging mineral passivation films on metal surfaces. Moreover, the major mechanisms of MIC include fixing anodic sites, formation of differential aeration or chemical concentration cells and cathodic depolarisation. MIC can cause corrosion to various materials such as carbon steel, stainless steel, aluminium alloy, magnesium, zinc and concrete.[2] Biofouling is caused by the excessive growth of biofilm. Biofilm is the aggregate of microbial cells formed by microorganisms developing layers of polymer-like materials, called extra-cellular polymeric substances, and attached at a surface-liquid interface. Microbial adhesion to surfaces is governed by surface-charge, -free energy and -roughness. Electrostatic, hydrophobic and chemical forces can cause microbial attachment to surfaces. Due to extra-cellular enzymes in the biofilm, microorganisms can utilize complex organic substrates, such as humic acids that are not easily biodegradable by microorganisms in bulk water, which enables the growth of different microorganisms present in bulk water. Biofilm can also protect microorganisms from disinfectants and toxins in the surrounding environment. The formation of biofilm is dependent on various environmental conditions, such as salinity, temperature, conductivity, pH, DO level, BDOC and AOC content and hydrodynamic conditions. In addition, it is not recommended that caustics are used to reduce biofilm formation in pipeline networks, because some bacteria from biofilm can survive under unfavourable conditions (higher pH values).

Water quality stability is affected by many factors, including physical, chemical and biological factors. Examples of related influencing factors on water quality stability are shown in Table 2 and Table 3.

Table 2 — Examples of related influencing factors on chemical stability

Influencing factors	Notes of significance
Calcium and magnesium ions	Calcium and magnesium ions determine water hardness. Low hardness is beneficial for passivation film formation on the inner wall of pipeline networks, which can prevent further corrosion. High hardness can lead to scale formation.
Chloride	High concentration of chloride can increase conductivity of water, accelerate migration rate of ions and electrons in the water and accelerate corrosion. More specifically, high concentration of chloride can cause pitting corrosion, especially for stainless steel.
Sulfate	High concentration of sulfate can increase conductivity of water, accelerate migration rate of ions and electrons in the water and accelerate corrosion. Sulfate can easily cause scale formation when calcium ions exist.
Nitrate	Nitrate can greatly accelerate the general corrosion of iron in acidic solutions but has slight influence on the general corrosion in neutral solutions.[3]
DO	When DO acts on the inner wall of pipeline networks, it can accelerate corrosion. When DO acts on the surface of formed corrosion products, it can promote passivation films formation and prevent further corrosion.
Carbon dioxide	High contents of carbon dioxide can decrease pH value and corrode metals.
Silicon dioxide	Excessive silicon dioxide can form hard scales, especially for heat exchangers.
Iron	Iron can form red iron hydroxide precipitation, causing scale formation. Water containing iron bicarbonate can also cause corrosion.
pH	The increase of pH within specific limits (pH 7,5 to pH 9,5) can reduce the release of iron. Higher pH can increase the oxidation rate of Fe(II) and formed Fe(III) can intensify the physical structure of tubercles, thus inhibiting the release of internal iron.
TSS	TSS are easily disturbed by water flow and can acceleratively scour off corrosion surface layer, thus aggravating erosion of water flow on the inner wall of pipelines. Suspended solids are nuclei of salt crystals. Excessive suspended solids will also promote the formation of scales.

Table 3 — Examples of related influencing factors on biological stability

Influencing factors		Notes of significance
AOC		AOC can provide carbon and energy for heterotrophic bacteria and is generally considered a major limiting factor for the growth of heterotrophic bacteria.
BDOC		BDOC is considered as the hydrolysable pool of carbon available for bacterial growth and biofilm formation in the distribution system. The BDOC can be used to evaluate the reduction in chlorine demand or disinfection by-product (DBP) formation potential through a biological process.
Inorganic nutrients	Nitrogen	Due to bacterial elemental composition (e.g. molar ratio C:N:P is 100:20:1,7), nitrogen is also required for heterotrophic growth, though in considerably smaller amounts than organic carbon. The lack of nitrogen will limit the growth of heterotrophic bacteria. Ammonia can be oxidized to nitrous acid by ammonia-oxidizing bacteria, which simultaneously leads to pH decrease. Under low pH value, pipelines of carbon steel, copper, aluminium and other metals are prone to corrode. Nitrate-reducing bacteria can utilize nitrate and generate nitrogen gas which is not corrosive, which prevents corrosion through competition with sulfate reduction by sulfate-reducing bacteria.
	Phosphorus	Phosphorus is an important limiting factor for bacterial growth, among which phosphate can provide nutrient source for bacteria. Compared with carbon content, phosphorus content required by bacteria is lower. The content of phosphorus in the effluent water depends on the removal efficiency of the treatment process.
	Sulfur	Sulfur-oxidizing bacteria can oxidize elemental sulfur and sulfide, and produce sulfate and corrosive sulfuric acid, which can increase acidity, hydrogen penetration and corrosion rates. The presence of sulfur-oxidizing bacteria can promote the growth of sulfate-reducing bacteria by producing the products necessary for their growth (e.g. sulfate).[4] Sulfate-reducing bacteria can use the oxygen component of sulfate for respiration and generate hydrogen sulfide in the absence of DO or in biofilm. The sulfide will come out of solution at various pH ranges and then convert to sulfuric acid by sulfur-oxidizing bacteria, which will easily lead to corrosion in concrete sewers. Just like sulfate-reducing bacteria, thermophilic sulfate-reducing archaea can also cause corrosion in a similar way.
	Iron	Iron-oxidizing bacteria can oxidize divalent iron Fe(II) to trivalent ion Fe(III) by using DO and produce large amounts of iron oxide precipitates, which can alter the acidity and promote corrosion. In biofilm, aerobic or facultative iron-oxidizing bacteria can provide an oxygen-free local environment for sulfate-reducing bacteria growth, which can lead to more severe corrosion.[4] Iron-reducing bacteria can promote corrosion by altering minerals adhering to alloyed steel, removing passivating layers and increasing the concentration of Fe(II) and ferrous sulfide formed by mixed communities.[4]
DO		The absence of DO can provide suitable conditions for anaerobic bacteria growth, such as sulfate-reducing bacteria and iron-reducing bacteria. Low DO levels can provide suitable conditions for facultative bacteria growth, such as nitrate-reducing bacteria and sulfate-reducing bacteria. High DO levels can provide suitable conditions for aerobic bacteria growth, such as ammonia-oxidizing bacteria, sulfur-oxidizing bacteria and iron-oxidizing bacteria. High pressure and low temperature can increase DO solubility in water and prevent anaerobic conditions in pipelines; high temperature can decrease DO levels. The metabolism of microorganisms in biofilm can lead to concentration gradients of DO and affect microbial community compositions.

Table 3 *(continued)*

Influencing factors		Notes of significance
AOC		AOC can provide carbon and energy for heterotrophic bacteria and is generally considered a major limiting factor for the growth of heterotrophic bacteria.
BDOC		BDOC is considered as the hydrolysable pool of carbon available for bacterial growth and biofilm formation in the distribution system. The BDOC can be used to evaluate the reduction in chlorine demand or disinfection by-product (DBP) formation potential through a biological process.
Operating conditions	Temperature	Increasing temperature can promote bacterial growth. Temperature can also affect bacterial community composition by providing competitive advantages to specific bacterial species in specified temperature ranges.
	Hydraulic conditions	Low flow can lead to low flow velocities and long retention time, providing favourable conditions for bacterial growth. High flow can lead to increasing biofilm detachment and bacterial dispersal.
	Pressure	Operating modes of sewers include gravity modes and pressure modes. Under gravity modes, DO level in sewers is high and dominant microorganisms are aerobic and facultative bacteria. Under pressure modes, sewers are in anaerobic conditions and dominant microorganisms are anaerobic bacteria.
Disinfectants		Dissolved nutrients, extra-cellular polymeric substances, organic and inorganic nutrients adsorbed on biofilm can react with disinfectants, resulting in consumption of disinfectants and promoting bacterial regrowth.
Pipeline materials		The composition of pipeline materials can affect biofilm development, including growth rates, bacterial densities and community compositions. The corrosion of pipes can lead to release of particles and the formation of rough sinks on the pipe surfaces, on which organic and inorganic compounds and bacteria can be adsorbed, and which also protect bacteria from disinfectant residuals. The corrosion of iron pipes is easier than that of plastic pipes as higher bacterial abundance is found on iron pipes than on plastic pipes.

5.2 Evaluation principles of water quality stability

The evaluation of water quality stability should consider the utilization of reclaimed water. Accordingly, evaluation parameters for water quality stability of reclaimed water should be selected based on equipment materials. Evaluation processes should follow the principles of accuracy, comprehensiveness and independence (listed in Table 4).

Table 4 — Evaluation principles of water quality stability of reclaimed water

Principle	Notes
Accuracy	Accurate and objective parameters should be recommended according to utilization, equipment materials and characteristics of reclaimed water.
Comprehensiveness	An appropriate number of evaluation parameters should be selected. The evaluation with multiple parameters is beneficial for accuracy of results. Excessive selection of parameters should be avoided due to the complexity and cost of the evaluation process.
Independence	Independent parameters should be selected. If several parameters describe similar characteristics, one of them should be recommended.

6 Evaluation system of water quality stability

The evaluation of water quality stability can be performed according to the framework depicted in Figure 1. The following points show considerations for establishing a framework for water quality stability evaluation of reclaimed water.

a) Reclaimed water use is a complex process. The evaluation of water quality stability should be based on the specific reuse conditions. Reuse conditions can vary based on applications, equipment and component materials and operating conditions. For example, when characteristics of reclaimed water change, different ionic components can react and form scales. The changes of thermodynamic conditions can lead to reclaimed water instability (e.g. temperature decrease can reduce the solubility of ionic components, thus leading to scaling; increasing temperature can promote bacterial growth). Besides, the extent of fouling is affected by, for example, hydraulic conditions and roughness of the contact surfaces. Water quality stability parameters for reclaimed water are respectively proposed according to chemical stability and biological stability. It is also necessary to supplement or omit some parameters according to the actual situation of different regions. Every parameter has its own characteristics, scopes and limits, and will be discussed in detail in Clause 7. Annex B describes chemical stability evaluation parameters in urban water supply systems of some countries. Annex C and D describe evaluation parameters in water quality standards for boiler water and industrial water, respectively.

b) The tendency of water quality stability for reclaimed water can be evaluated by comparing the determined or calculated values of selected parameters with critical values. The critical values determination usually needs to consider many factors, including social and economic levels and comprehensive utilization benefits of water reuse. It is recommended that generally accepted values are selected as critical values. Moreover, critical values need to be updated with the development of technology.

c) Stability evaluation results for reclaimed water include corrosion, scale formation (including scaling and fouling) and relatively stable. They can be divided into five grades: severe corrosion, slight corrosion, relatively stable, slight scaling or fouling and severe scaling or fouling. Evaluation results should be accurate and comprehensive. The contingency and uncertainty in the evaluation process should be minimized or avoided if possible. Final stability evaluation conclusions for reclaimed water should be drawn based on evaluation results. Suggestions and improvement measures should be proposed.

The framework includes five steps (Figure 1). Specifically, the first step is to determine equipment and pipe materials and to collect given parameters of water quality characteristics for reclaimed water and operating conditions of a specific application. The second step is to select corresponding parameters based on the available information. The third step is to measure or calculate parameters for stability evaluation of reclaimed water. The fourth step is to compare calculated values with critical values. The last step is to analyse evaluation results and draw a conclusion.