
Water aggressiveness evaluation and optimized lining choice

*Évaluation de l'agressivité de l'eau et choix optimal des revêtements
intérieurs*

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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 of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 5, *Ferrous metal pipes and metallic fittings*, Subcommittee SC 2, *Cast iron pipes, fittings and their joints*.

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.

Water aggressiveness evaluation and optimized lining choice

1 Scope

This document provides details about the aggressiveness factors, evaluation indicators of raw water, or inlet water of ductile iron pipe system and relevant lining information applicable to ductile iron pipes, fittings and accessories used in water mains and distribution system.

This document is intended to serve as a tool for estimating the properties of certain water and their effect on internal linings of ductile iron pipes, fittings and accessories used in water mains and distribution system which are specified in ISO 2531, ISO 16631 and can be used to decide the most appropriate protective measures to ensure long term durability of pipeline.

It is not always possible to definitively determine the aggressive parameters of certain water, and fully considered by limited test and evaluation. Therefore, the history information of the evaluated water, experiences of local water works can be taken for reference.

The aggressiveness evaluation of water can be carried out before determining the internal lining materials of certain pipeline, and the evaluation and relevant tests can be done by qualified laboratories and engineers.

Water that leads to high-level scaling in the pipeline is believed aggressive.

Drainage and waste water are not in the scope of this document, the internal protection of drainage and waste water can be recommended by pipe suppliers.

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 2531, *Ductile iron pipes, fittings, accessories and their joints for water applications*

ISO 16631, *Ductile iron pipes, fittings, accessories and their joints compatible with plastic (PVC or PE) piping systems, for water applications and for plastic pipeline connections, repair and replacement*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2531 and ISO 16631 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 scaling

dissolvable salts, residues of water pipeline inner surface reaction and other solids deposit on the inner surface of pipeline components, which will reduce the cross-sectional area and increase the head loss

Note 1 to entry: Scaling is sometimes also harmful to water quality and pipeline service life. The scaling process is normally related to the water chemical stability, temperature, flow rate, inner surface roughness of the pipeline component.

3.2 corrosive water

type of water which attacks metal component (pipe, fitting, accessories) without an internal coating

Note 1 to entry: The chemical reactions produce ferrous and then ferric hydroxides, forming nodules and tuberculation, which eventually reduce the component's cross-sectional area and significantly increase head loss, reduce the service life of metal pipeline components.

3.3 water aggressiveness

propensity to react with materials containing calcium such as hydraulic binders

Note 1 to entry: Depending on the chemical analysis, mineral content, pH and temperature of the water, three cases can occur:

- Water in calco-carbonic equilibrium does not attack or deposit calcium carbonate at a given temperature.
- Scaling water tends to deposit calcium salts (carbonates, etc.) on the pipeline components' inner surface.
- Aggressive water can attack certain components of cement mortar containing calcium (lime, calcium silicate and calcium silicoaluminate).

Note 2 to entry: Normally, ductile iron pipe components are supplied with linings, and cement mortar linings are the standard internal protection, so aggressive water and water aggressiveness are mostly used in this document. But the reaction with uncoated metal surface is also considered and described in some parts of this document.

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4 Water aggressiveness evaluation

4.1 Normal internal corrosion mechanics

Internal corrosion mechanics of ferrous pipeline system have been studied for decades, according to the state of art, major pipeline internal corrosion problems can be traced to the stability of calcium magnesium carbonate system and iron system in the water. The status and the change of stability of these systems can lead to the deposition and dissolvment of carbonate and ferrous compound, which is the major reason of lining failure, red water, yellow water, scaling and related secondary corrosion.

The stability of calcium magnesium carbonate system and iron system are complex systemic ion balance problem related to multiple positive and negative ions, and highly related to water temperature. Considering those factors one by one is not a good way to get comprehensive information of the water aggressiveness, those factors are a united system and can be considered systematically.

Many indexes and indicators are concluded to evaluate the aggressiveness or stability of water.

4.2 Internal protection of ductile iron pipe

Ductile iron pipes are normally supplied with internal linings. There can be some special applications without internal linings. Linings are believed an effective way to protect the pipe when they are used appropriately. It is possible to categorize all existing linings as isolation barriers (polymeric linings), active protection (cement mortar lining), or their combination (cement mortar lining+seal coat). Cement mortar linings are standard internal protection of ductile iron pipes, and currently, most of ductile iron pipes are lined by cement mortar lining.

Other linings or internal protections can exist or can be developed as the updating pursue of water quality and pipeline service time.

Suitable lining choice based on water aggressiveness evaluation is beneficial to ensure the durability of lining protection in the long term and reduce the negative effect on water quality.

4.3 Water aggressiveness evaluation for ductile iron pipe system

Ductile iron pipes and fittings are used at any part of the water distribution system. They will influence other pipeline sections by the flowing water and be influenced as well. The interaction of ductile iron pipe and water can be considered based on the stability of calcium magnesium carbonate system and iron system. The interaction of water and cement mortar can also be considered at the same time.

In this document, multiple indicators with comprehensive consideration of aggressive factors based on calcium magnesium carbonate system, iron system, and also the interaction of water and cement mortar material are used to evaluate the aggressiveness of water.

4.4 Main corrosive aggressive factors

4.4.1 The pH value: the pH value of water is a measure of the concentration of the hydrogen ion concentration (H^+ or H_3O^+). The pH scale ranges from 0 to 14. Values less than 7,0 are considered acidic, values greater than 7,0 are considered alkaline, and 7,0 is considered neutral. Drinking water pH values typically range from 6,0 to 10. At higher pH values, there is less of a tendency for metal surfaces in contact with drinking water to dissolve and dissociate, which is why pH adjustment is a common component of an effective corrosion control treatment strategy. Maintaining a consistent target pH throughout the distribution system is always critical to minimizing lead and copper levels at the tap and minimizing discoloured-water complaints, even if other corrosion control methods are employed.

Another important consideration with regard to pH is its impact on other water quality parameters. It plays a significant role in the carbonate balance in that it impacts buffer capacity and dissolved inorganic carbon (DIC) concentrations. It also influences other corrosion-related parameters, such as oxidation-reduction potential (ORP) and corrosion inhibitor effectiveness.

4.4.2 Alkalinity: alkalinity is the capacity of water to neutralize acid. It is the sum of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-) anions and is typically reported as milligrams per litre as calcium carbonate (mg/L as $CaCO_3$). Waters with high alkalinities tend to have high buffering capacities or a strong ability to resist changes in pH. Low-alkalinity waters are less able to neutralize acids or resist changes in pH.

4.4.3 Total dissolved solids/ionic strength: total dissolved solids (TDS) can have an impact on corrosion, though the effect can be less than other corrosion-related parameters. High TDS concentrations are generally associated with high concentrations of ions (e.g. Na^+ , Ca^{2+} , Mg^{2+} , Cl^- , CO_3^{2-} , SO_4^{2-}) that increase the conductivity of the water. Corrosion is an electrochemical reaction in which electrons from the anodic surface are transferred to the cathodic surface. The increased conductivity resulting from high TDS concentrations increases the ability of the water to complete the electrochemical circuit and conduct a corrosive current.

If sulfate and chloride are major anionic contributors to the TDS, the TDS is likely to show increased corrosivity toward iron-based materials. If the TDS is composed primarily of bicarbonate and hardness ions, the water will probably not be corrosive toward iron based or cementitious materials but can probably be highly corrosive toward copper. Low-TDS waters can also be corrosive and increase lead solubility. Low-TDS waters often have a strong tendency to dissolve (corrode) materials with which they are in contact in order to reach electro neutrality. Uniform corrosion is an electrochemical process in which the water solution in contact with the cathode provides the chemicals to accept the electrons donated by the pipe wall. The pipe wall, acting as an anode, then releases the oxidized metal ion to the water. Water has a limited capacity to accept dissolved species. Thus, although high-TDS waters have many electron receptors, low-TDS waters have the ability to accept a large number of anions and cations, resulting in a subsequent dissolution of existing pipe scales and corrosion of pipe surfaces.

TDS is a surrogate for the ionic strength of a solution. The ionic strength is a measure of the force of the electrostatic field caused by the presence of ions in a solution. More simply, the presence of anions and cations in solution increases the conductivity of the solution and can increase corrosion unless offset by passivating layers on the pipe surface. It is possible to determine the ionic strength as shown in [Formula \(1\)](#).

$$I = 2,5 \times 10^{-5} \times TDS \quad (1)$$

where: I = ionic strength; TDS = total dissolved solids concentration, in mg/L.

4.4.4 Dissolved inorganic carbon: DIC is the sum of all DIC-containing species and is one of the most critical parameters for controlling internal corrosion. It includes dissolved aqueous carbon dioxide gas (CO_2 or H_2CO_3), bicarbonate ion (HCO_3^-), and carbonate ion (CO_3^{2-}) in a particular water, and DIC is usually expressed as milligrams per litre of carbon (mg/L as C) or milligrams per litre of calcium carbonate (mg/L as CaCO_3). Although DIC and alkalinity are similar, they are not the same water quality parameter. DIC varies according to water temperature, pH, ionic strength, and alkalinity.

4.4.5 Hardness: hardness is a characteristic that represents the presence of dissolved multi-valence cations, primarily calcium and magnesium, in water and is reported as an equivalent concentration of calcium carbonate (CaCO_3). Hardness can be taken into consideration when corrosion control is selected and implemented because it can create scaling problems within the treatment plant, distribution system infrastructure, and customer plumbing. In this regard, hardness is an important parameter to be considered in developing a corrosion control program and evaluating the amount of pH adjustment that is permissible without causing scale problems.

4.4.6 Dissolved oxygen: dissolved oxygen (DO) can play important roles in both corrosion reactions and metals release. Oxygen can serve as an electron acceptor in the corrosion cell, allowing for metal oxidation at the pipe surface and release of ionized metal species into the water. Thus, new metal surfaces that are exposed to water containing DO will corrode faster compared to anaerobic water.

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4.4.7 Oxidation–reduction potential: ORP, also frequently referred to as redox potential, is a measure of water's capability to oxidize and is reported as electrical potential (volts, V, or millivolts, mV).

4.4.8 Metal ions and anions: it is possible to indicate metals in water as total metal and dissolved metal, dissolved metal ions such as: Ca^{2+} , Mg^{2+} , Fe^{3+} , Mn^{2+} , Al^{3+} . Their dissolution balance affect the water quality and scale formation. Some metal ions are regularly monitored deal to their effect on human health such as lead, they are normally limited in local water quality specifications. Some anions are highly related to the crystallization corrosion of concrete, their mechanisms are introduced in [Annex C](#).

4.5 Water evaluation indicators and their trigger value

Water aggressiveness is evaluated by comprehensive indicators. Normally, two equilibrium systems are considered for ductile iron pipe internal protection: iron equilibrium system and carbonate equilibrium. As ductile iron pipes are normally supplied with cement mortar linings, the aggressiveness of water to cement material can be evaluated.

In this document, five indicators can be used to evaluate the water aggressiveness. Their calculation and trigger value are showed in [4.5.1](#), [4.5.2](#), [4.5.3](#), [4.5.4](#), and [4.5.5](#). Other water evaluation indicators or scaling tendency indicators are possible.

4.5.1 Langelier saturation index (LSI)

$$LSI = pH - pH_s \quad (2)$$

where:

LSI is the Langelier saturation index;

pH is the pH value;

pH_s is the saturation pH (the calculation of pH_s is shown in [Annex A](#)).

The indications for the LSI are based on the following values:

LSI < 0 water is under saturated with respect to calcium carbonate and has a tendency to remove existing calcium carbonate protective coatings in pipelines;

LSI = 0 water is considered to be neutral, neither scale-forming nor scale removing;

LSI > 0 water is supersaturated with respect to calcium carbonate and scale forming can occur.

4.5.2 Ryznar stability index (RSI)

$$RSI = 2pH_s - pH \quad (3)$$

where:

RSI is the Ryznar stability index;

pH is the pH value;

pH_s is the saturation pH (the calculation of pH_s is shown in [Annex A](#)).

RSI is normally used together with LSI; they are based on the same thermodynamic hypothesis.

RSI < 5,0 heavy scale will form;

RSI = 5,0~6,0 light scale;

RSI = 6,0~7,0 little scale or corrosion;

RSI = 7,0~7,5 corrosion significant;

RSI = 7,5~9,0 heavy corrosion;

RSI > 9,0 corrosion intolerable.

4.5.3 Calcium carbonate precipitation potential (CCPP)

The CCPP predicts both tendencies to precipitate or to dissolve $CaCO_3$ and quantity that can be precipitated or dissolved. It is also known as calcium carbonate precipitation capacity (CCPC).

The CCPP is defined as the quantity of $CaCO_3$ that theoretically precipitate from oversaturated waters or dissolved by undersaturated waters during equilibration.

$$CCPP = 100 * ([Ca^{2+}]_i - [Ca^{2+}]_{eq}) \quad (4)$$

Unit: mg- $CaCO_3$ /L.

where:

$[Ca^{2+}]_i$ — $[Ca^{2+}]$ concentration of water sample, in mol/L;

$[Ca^{2+}]_{eq}$ — $[Ca^{2+}]$ concentration of water in $CaCO_3$ equilibrium status.

CCPP = 0~4 no scaling or little scale CCPP = 0~-5 slight corrosion

CCPP = 4~10 light scale CCPP = -5~-10 corrosion

CCPP = 10~15 heavy scale CCPP ≤ -10 heavy corrosion

CCPP ≥ 15 very heavy scale

CCPP is not suitable for hand calculation. It can be calculated by software or determined by experiments.

4.5.4 Larson ratio (LR)

$$LR = \frac{[Cl^-] + [SO_4^{2-}]}{[HCO_3^-]} \quad (5)$$

Unit: mol/L

LR shows the effect of anions in water, which is significantly related to iron-equilibrium and aggressiveness to cement materials.

LR < 0,5 non corrosive water;

LR = 0,5~1 slight corrosion;

LR > 1 corrosive, bigger value, heavier corrosive.

4.5.5 Aggressive index (AI)

$$AI = pH + \lg(Ca \cdot Alk) \quad (6)$$

where:

Ca is the hardness, in mg- $CaCO_3$ /L;

Alk is the total alkali, in mg- $CaCO_3$ /L.

AI shows the aggressiveness to cement material.

AI < 10 heavy aggressive;

AI = 10~12 aggressive;

AI > 12 not aggressive.

4.5.6 Evaluation chart

The following chart can be used to evaluate the aggressiveness of certain water sample. The way to evaluate water stability of certain water sample is shown in [Table 1](#).

Table 1 — Water stability evaluation chart

Evaluation index	Indication	Water sample name	Calculation result	Evaluation conclusion
LSI	LSI <0 water is under saturated with respect to calcium carbonate and has a tendency to remove existing calcium carbonate coatings in pipelines; LSI = 0 water is considered to be neutral, neither scale-forming nor scale removing; LSI >0 water is supersaturated with respect to calcium carbonate and scale forming can occur.			
RSI	RSI <5,0 heavy scale will form; RSI = 5,0~6,0 light scale; RSI = 6,0~7,0 little scale or corrosion; RSI = 7,0~7,5 corrosion significant; RSI = 7,5~9,0 heavy corrosion; RSI >9,0 corrosion intolerable.			
CCPP ^a	CCPP ≤-10 heavy corrosion; CCPP = -10~-5 corrosion; CCPP = -5~0 slight corrosion; CCPP = 0~4 no scaling or little scale; CCPP = 4~10 light scale; CCPP = 10~15 heavy scale; CCPP ≥15 very heavy scale.			
LR	LR <0,5 water is not corrosive; LR = 0,5~1 slight corrosion; LR >1 corrosive, bigger value, heavier corrosive.			
AI	AI <10 heavy aggressive; AI = 10~12 aggressive; AI >12 not aggressive.			
^a If the evaluation results of LSI and RSI are contradictory, CCPP can be considered to get correct indication of the carbonate equilibrium status in certain waters.				

5 Sampling and testing

Water is changing all the time. Natural water source can be affected by seasonal changes or other environmental changes. Those changes can be considered.

Temperature is important for sampling and testing. Water temperature change affects the solubility of salts. The current or estimated pipeline service temperature can be considered during the sampling and testing. Also, the temperature change led by seasonal changes or weather effects can be considered.

If there are more than one water sources used, they can be sampled, tested and evaluated separately and the worse one can be considered for ductile iron pipe internal protection solution.

Relevant ISO standards for water sampling and testing of certain parameters are listed in [Annex B](#).

5.1 Sampling

Representative and adequate water samples are critical to the aggressiveness evaluation. It is possible to follow national water sampling standards, regulations or routine. The water sample can be raw