Technical Specification

ISO/TS 21152

First edition
2024-12

Guidance on water conservation techniques of circulating cooling water in thermal power plants

Lignes directrices pour les techniques de conservation de l'eau consistant à faire circuler l'eau de refroidissement dans les centrales électriques thermiques

Reference number
ISO/TS 21152:2024(en)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 4, *Industrial water reuse*.

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Introduction

Water plays an important role in transferring energy, cooling and cleaning in the process of thermal power generation. According to the statistics of the International Energy Agency (IEA) and China Water Resources Bulletin, fossil fuel power generation used approximately 189,6 billion cubic metres of freshwater in 2021, accounting for almost 50 % of global energy system freshwater withdrawals and 5 % of total global freshwater withdrawals. In China, water withdrawal for thermal power generation in 2021 accounted for approximately 17,7 % of the industrial water withdrawal, of which cooling water in thermal power plants accounted for approximately 50 %. To save water resources, improve circulating cooling water use efficiency and help thermal power plants to enhance water conservation, work efficiently and orderly, and thus improve the economic and social benefits of thermal power plants, it is important to formulate guidance for the conservation of water used as circulating cooling water in thermal power plants.

The quantity of circulating cooling water used in thermal power plants ranges from tens to hundreds of thousands of cubic metres based on their operating capacity. The reduction of circulating cooling water use should consider the water quality, pipe materials, water treatment, chemicals and other factors. Meanwhile, to achieve water conservation purposes, the use of residual heat of high temperature circulating water to reduce the temperature of circulating water in the cooling tower should be considered. Cycles of concentration is an important index for evaluating water conservation of circulating cooling water, while the amount of make-up water is closely related to the cycles of concentration of circulating cooling water. The higher the concentration, the better water conservation efficiency. However, with higher concentrations, the cost and difficulty of water treatment also increase exponentially.

Circulating cooling water quality control index and water conservation processes differ based on the quality of make-up water. Researchers and engineers should standardize the water conservation process of circulating cooling water in thermal power plants by fully considering the cycles of concentration and other relevant influencing factors, to provide standardized technical guidance for the targeted stake holders (policy makers, managers, technical consultants, designers, operators of water treatment systems, etc.).

Through analysis and research on the circulating cooling water conservation technology in thermal power plants, this document sets up a scientific and objective technical control index, management guidance and implementation methods that are helpful to improve the efficiency of circulating cooling water conservation and the standardization of technical transformation of thermal power plants.

Starting from the perspective of water conservation management and technology, this document provides acceptable operation control specifications for common processes of circulating cooling water conservation for most stakeholders, to improve the operation efficiency and management level of circulating cooling water conservation, which is conducive to guiding the development of specialization, normalization and standardization of circulating cooling water conservation.

This document establishes the technical guidance and recommendations for circulating cooling water conservation technology, provides research direction of circulating cooling water conservation technology, improves the water conservation efficiency, and promotes the transformation of circulating cooling water conservation technology to higher efficiency, lower energy consumption, environment friendly and resource saving, in the end realizing sustainable development.

Guidance on water conservation techniques of circulating cooling water in thermal power plants

1 Scope

This document provides technical and management guidance for water conservation of indirect open recirculating cooling water systems in thermal power plants. It is applicable to circulating cooling systems that use surface water, underground water, reclaimed water, and treated domestic sewage from thermal power plant as the make-up water and use physicochemical treatment methods to increase cycles of concentration, thus realizing water conservation and increasing water use efficiency.

This document is applicable to recirculating cooling in thermal power plants fuelled by coal, oil, natural gas, and biomass.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions 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 Terms and definitions

3.1.1
water conservation of circulating cooling water
process to increase *cycles of concentration* (3.1.2) thus increasing water use efficiency

3.1.2
cycles of concentration
ratio of the concentration of specific ions in the circulating cooling water to the concentration of the same ions in the make-up water

[SOURCE: ISO 16784-2:2006, 3.6]

3.2 Abbreviated terms

BOD_5	biochemical oxygen demand at five days
CFU	colony forming unit
COD	chemical oxygen demand
DO	dissolved oxygen
NH_3-N	ammonia-nitrogen

NTU nephelometric turbidity unit

TDS total dissolved solids

TSS total suspended solids

4 General

The following principles should be followed for water conservation of circulating cooling water in thermal power plants:

— Users should develop efficient circulating cooling water treatment technology, improve the cycles of concentration under the premise of ensuring system safety and energy saving.

— Users should be aware of the requirements of local environment protection regulation.

— Water treatment chemicals with high efficiency, low toxicity and good chemical stability should be used; biodegradable water treatment chemicals should be given priority; toxic and harmful water treatment chemicals should be strictly restricted.

5 Circulating cooling water quality recommendations

5.1 Water quality recommendations of make-up water

When surface water, underground water, seawater, reclaimed water, and treated domestic sewage from thermal power plants are used as make-up water for circulating cooling water system in power plants, the quality of the source water and of the circulating cooling water and the working conditions should be analysed, and technical and economic comparison should be made to select the appropriate cycles of concentration. Table B.1 in Annex B contains water quality recommendations when surface water, underground water is used as make-up water for circulating cooling water system after pre-treatment. Table B.2 in Annex B contains water quality recommendations when reclaimed water is used as make-up water for circulating cooling water system after pre-treatment. When treated domestic sewage from thermal power plant is used as make-up water for circulating cooling water system, the water quality after treatment should not be lower than the recommendations in Table B.2 in Annex B. Table B.3 in Annex B contains water quality recommendations when seawater is used as make-up water of circulating cooling water system.

5.2 Water quality recommendations of circulating cooling water system

The water quality of circulating cooling water systems using surface water, underground water, reclaimed water, and domestic sewage from thermal power plants as make-up water should meet the recommendations of Table 1.

Table 1 — Water quality recommendations of circulating cooling water systems using surface water, underground water, reclaimed water, and domestic sewage from thermal power plants as make-up water

Parameters	Units	Recommended values
pH (25 °C)	—	7,5 to 8,8
TSS	mg/l	≤ 100
$(CO_3^{2-}) + (HCO_3^-)$ [a]	mg/l	400 to 500
SiO_2	mg/l	150 to 200
$(Mg^{2+}) \cdot (SiO_2)$ [a]	mg/l	≤ 60 000
$(Ca^{2+}) \cdot (SO_4^{2-})$ [a]	mg/l	≤ 2,5 × 10^6
$(Ca^{2+} + Mg^{2+}) \cdot (CO_3^{2-})$ [a]	mg/l	2 × 10^6 to 4 × 10^6
Cl^-	mg/l	According to the material of heat exchange
COD_{Cr}	mg/l	≤ 100
NH_3-N	mg/l	≤ 10 (≤ 5 for copper tube condenser)
TDS [b]	mg/l	≤ 5 000
Conductivity [b]	μS/cm	≤ 8 500

[a] Ca^{2+}, Mg^{2+}, HCO_3^- and CO_3^{2-} are calculated by $CaCO_3$(mg/l).

[b] Conductivity and TDS are non-binding parameters, only for reference. Common parameters having great effect on corrosion and scaling in water have been listed in this table. Although other dissolved ions contribute to the conductivity and TDS, they generally have little effect on corrosion and scaling, so these two parameters are only given as reference indicators for water quality.

The water quality of circulating cooling water systems using seawater as make-up water should be determined through the dynamic simulation test of scale and corrosion inhibitor (Annex A), or it should be controlled according to the recommendations of Table 2.

Table 2 — Water quality recommendations of circulating cooling water systems using seawater as make-up water

Parameters	Units	Recommended values
TSS	mg/l	≤ 30
Turbidity	NTU	≤ 20
pH (25 °C)	—	8,0 to 9,0
M alkalinity (calculated by $CaCO_3$)	mg/l	≤ 350
Ca^{2+}	mg/l	≤ 1 000
Mg^{2+}	mg/l	≤ 3 200
Total Fe	mg/l	< 1,0
Cl^-	mg/l	≤ 45 000
SO_4^{2-}	mg/l	≤ 6 000
(Cu^{2+}) [a]	mg/l	≤ 0,1
Oils	mg/l	< 5
Residual chlorine [b]	mg/l	0,1 to 1,0 (or lower, meet environmental requirements)
TDS [c]	mg/l	100 000
Conductivity [c]	mS/cm	≤ 150

[a] The copper ion concentration in seawater circulating cooling water systems containing copper materials should be monitored.

[b] The concentration of free residual chlorine should be controlled when adding oxidizing biocides.

[c] Conductivity and TDS are non-binding parameter, only for reference. Common parameters having great effect on corrosion and scaling in water have been listed in this table. Although other dissolved ions contribute to TDS, they generally have little effect on corrosion and scaling, so these two parameters are only given as reference indicators for water quality.

The total number of heterotrophic bacteria in circulating cooling water should not be more than 1×10^5 CFU/ml, and the amount of biological slime should not be more than 3 ml/m^3.

6 Technical guidance for water conservation of circulating cooling tower

6.1 Basic guidance

6.1.1 The selection of cycles of concentration in circulating cooling water system should comprehensively consider the water source conditions, water quantity and water quality balance, environmental protection requirements, circulating cooling water system material and other factors. Scale and corrosion inhibition test (Annex C) should be performed, and technical and economic comparisons should be made; dynamic simulation test of scale and corrosion inhibitor should be used when necessary. Within the safe range of scale and corrosion inhibition, the cycles of concentration should be increased as much as possible. The calculation of cycles of concentration should refer to Annex D.

6.1.2 A side-stream treatment system should be set up if key indexes such as TSS, NH_3-N and salt content significantly exceed the water quality recommendations of the circulating cooling water system after increasing cycles of concentration, leading to potential risks of system corrosion, blockage and scaling.

6.1.3 The side-stream treatment of circulating cooling water includes side-stream filtration, softening or desalination process. The selection of a side-stream treatment process should be determined by a comprehensive comparison of the circulating cooling water quality, the type and volume of pollutants to be removed and other factors. The calculation of side-stream treatment volume should refer to Annex F.

6.1.4 Side-stream filtration treatment should be set up after technical and economic comparison when there are more than 5 cycles of concentration of circulating cooling water system, or if there is severe seasonal sandstorm.

6.1.5 When reclaimed water is used as make-up water for circulating cooling water, if the water quality does not meet the recommendations of Table B.2 in Annex B, then the treatment process and operation control scheme of circulating cooling water should be determined by scale and corrosion inhibition test and dynamic simulation test of scale and corrosion inhibitor.

6.1.6 When a clarification tank is used to treat circulating cooling water blowdown, the influence of temperature fluctuation on the treatment effect should be taken into account. Automatic temperature regulation device and air separation device should be installed. The influent temperature variations of the clarification tank should not be more than 2 °C/h.

6.2 Guidance for treatment of circulating cooling with water quality stabilizer

6.2.1 General

Water quality stabilization treatment is essential to circulating cooling water treatment, whether it is to adopt natural balance of pH treatment or other treatments such as softening, adding acid, desalting or partial desalting. Water quality stabilization treatments includes scale and corrosion inhibition, microbial control and other technologies.

6.2.2 Scale and corrosion inhibition technology

6.2.2.1 The performance and evaluation of scale and corrosion inhibitor for circulating cooling water should be determined according to the volume of make-up water and the material of circulating cooling water system. The test for selecting and performance evaluation of scale and corrosion inhibitors for circulating cooling water should include the following:

a) The carbonate hardness limit selection test, cycles of concentration limit selection test (Annex E) and scale and corrosion inhibitor concentration selection test (Annex C).

b) The effect of bactericide and its effect on the performance of scale and corrosion inhibitor.

c) Corrosion inhibition performance test (when the material is stainless steel, electrochemical corrosion performance test should be conducted).

d) Analysis items of operation control (chloride ion, hardness, alkalinity, conductivity, pH, etc.) and its control recommendations.

6.2.2.2 The formula of scale and corrosion inhibitor for circulating cooling water should be determined by the dynamic simulation test of scale and corrosion inhibitor and by technical and economic comparison. The following factors should be considered in dynamic simulation test:

a) make-up water quality;

b) thermal resistance value of fouling;

c) corrosion rate;

d) cycles of concentration;

e) material of heat exchange equipment;

f) condenser approach temperature of heat exchange equipment;

g) inlet and outlet water temperature of heat exchanger;

h) water flow rate in heat exchange equipment;

i) the stability of chemicals and their influence on the environment.

6.2.3 Microbial control technology

6.2.3.1 The selection of biocide or other control technology should be based on the type of microorganism, such as heterotrophic bacteria, iron bacteria, sulfate reducing bacteria, nitrifying bacteria etc.

6.2.3.2 The selection of bactericide for circulating cooling water should consider cooling water quantity, water quality conditions, biological species, heat exchange equipment material and other factors.

6.2.3.3 If the proposed microbiological control program is suspected to have a possible positive or negative influence on the effectiveness of the inhibitor program being tested, then the dosing of chemicals for microbiological control should be undertaken in accordance with the manufacturer's instructions or appropriate standards for microbiological growth inhibition.

6.2.3.4 Sodium hypochlorite, liquid chlorine, chlorine ingot, chlorine dioxide and monochloramine should be used as oxidizing bactericides for circulating cooling water. The dosing mode and dosage should meet the following principles:

a) Sodium hypochlorite, solid chlorine tablet, monochloramine or liquid chlorine should be added continuously or by impactor via sequential treatment. For continuous dosing, the residual chlorine in cooling water blow down should be controlled between 0,1 mg/l and 0,5 mg/l; for impact dosing, it should be added one to three times a day, and the residual chlorine in water should be controlled between 0,5 mg/l and 1,0 mg/l and maintained for two to three hours; for solid chlorine tablet, the chemicals can be put into a solid woven bag and hoisted around the cooling pool. The dosage is controlled once every week of every two weeks, and the dosage concentration is 10 mg/l;

b) Chlorine dioxide should be added continuously. When the bacterial concentration is 10^5 CFU/ml to 10^6 CFU/ ml, the amount of chlorine dioxide in circulating cooling water blow down should be controlled at 0,5 mg/l;

c) Monochloramine can be used in sequential treatment in order to reduce the quantities of bactericide used and the chemical discharges while maintaining treatment efficiency.

6.2.3.5 The non-oxidizing biocide should have the properties of high efficiency, low toxicity, broad spectrum, wide range of pH, no mutual interference with scale and corrosion inhibitor, easy degradation and easy stripping of biological slime.

6.2.3.6 The slime removal agent for circulating cooling water should be added regularly to reduce the impact of slime adhering to the metal surface on the heat exchange efficiency. At the same time, it should strengthen the killing effect of sulfate-reducing bacteria, nitrifying bacteria and nitrobacteria. The slime removal agent should be environmentally friendly, have low toxicity for aquatic species and be readily degradable.

6.3 Technical guidance for increasing cycles of concentration

6.3.1 General

When make-up water quality and cycles of concentration meet the recommended values, the pH value natural balance treatment can be used. When the make-up water quality and cycles of concentration do not meet recommended values, make-up water or circulating water side-stream should be treated, and the treatment technology can be lime treatment, weak acid cation resin treatment, membrane treatment, or other treatments.

6.3.2 Lime treatment

6.3.2.1 The selection of lime treatment process should meet the following principles:

a) When the ratio of carbonate hardness is less than 50 % of total hardness, lime-sodium carbonate softening process should be selected based on a technical and economic comparison.

b) When carbonate hardness accounts for not less than 50 % of the total hardness, the lime softening process should be preferred. The carbonate hardness index of treated effluent should be less than 100 mg/l and the turbidity should be less than 3 NTU [alkalinity and hardness are calculated by $CaCO_3$(mg/l)].

c) When the total alkalinity is larger than the total hardness, the lime-gypsum treatment process should be adopted.

6.3.2.2 The water (circulating water side-stream) quality of lime treatment process should meet the following principles:

a) Bicarbonate alkalinity working condition: add a small amount of lime, only $CaCO_3$ will be formed in the precipitation without Mg $(OH)_2$, and the pH value of water should be controlled at approximately 9,5.

b) Hydroxide alkalinity working condition: add excess lime to precipitate $CaCO_3$ and $Mg(OH)_2$, and the pH of water should be controlled at approximately 9,6 to 10,4.

c) Carbonate alkalinity working condition: add excessive lime to reclaimed water with high organic content, the pH value of water should be controlled at approximately 10,5 to 11,3.

6.3.2.3 When lime treatment is combined with scale and corrosion inhibitor, acid should be added before adding scale and corrosion inhibitor to adjust pH.

6.3.2.4 In the lime treatment process, iron coagulant should be selected, and the water temperature should be controlled at 20 °C to 40 °C.

6.3.2.5 The effluent from lime treatment should be filtered with a variable pore particle filter.

6.3.3 Weak acid cation resin treatment

6.3.3.1 Make-up water treatment of circulating cooling water can be processed in whole or in part, and the treatment volume should be determined according to the water quality and treatment process of the circulating cooling water.

6.3.3.2 When the ratio of total hardness to total alkalinity of make-up water is more than 1, the average value of alkalinity of periodic discharge from weak acid cation resin treatment should be controlled at 50 mg/l, and the failure alkalinity should be controlled at 150 mg/l to 300 mg/l. When the ratio of total hardness to total alkalinity of make-up water is not more than 1, the average hardness of periodic effluent of weak acid cation resin should be controlled at 30 mg/l, and the failure hardness should be controlled at 100 mg/l [alkalinity and hardness are calculated by $CaCO_3$(mg/l)].

6.3.3.3 If weak acid cation resin is used to improve the cycles of concentration of circulating cooling water, the priority should be given to the treatment of circulating cooling water side stream.

6.3.4 Membrane treatment

6.3.4.1 When the membrane treatment process is adopted for desalination of circulating cooling water blow down for reuse purpose, the following principles should be met:

a) The pretreatment process should be determined by simulation test according to the influent water quality of reverse osmosis membrane.

b) Before entering the membrane system, the cooling water blow down should be sedimented or acidified.

c) The pretreatment process should be equipped with two-stage filtration treatment based on the water quality of blow down.

d) The electric properties of coagulant and coagulant aids should be consistent with that of reverse osmosis scale inhibitor, and the dosage of coagulant aid should be controlled.

6.3.4.2 Under the operating condition of 25 °C, the first stage reverse osmosis unit should have 96 % to 97 % desalination rate and 60 % to 80 % recovery rate within first 3 years in operation. The second stage reverse osmosis device should have 90 % to 95 % desalination rate and 85 % to 90 % recovery rate. When high pressure reverse osmosis is used, the desalination rate should be 96 % to 97 % and the recovery rate should not be less than 75 % at 25 °C.

6.3.4.3 When ultrafiltration is used as the pretreatment process of circulating cooling water blow down, the influent turbidity of pressure type ultrafiltration membrane should be less than 5 NTU, and the influent turbidity of submerged type ultrafiltration membrane should be subject to the technical parameters of membrane.

6.3.4.4 When pressure type ultrafiltration is used as the pretreatment process for circulating cooling water blow down, cross flow filtration should be adopted.

6.3.4.5 The water consumption rate of the ultrafiltration device should be determined according to the quality of influent and technical parameters of the membrane (see Table 3).

Table 3 — Water consumption rate of different ultrafiltration devices

Membrane type	Water consumption rate (%)
Pressure ultrafiltration/microfiltration membrane	≤ 10
Submerged ultrafiltration/microfiltration membrane	≤ 5

6.4 Technical guidance for reducing water loss

6.4.1 Calculation of drift of circulating cooling water tower. If the circulating water quantity of mechanical draft cooling tower is more than 1 000 m^3/h, the drift rate should not be more than 0,005 %. If the circulating water quantity is 1 000 m^3/h or less, the drift rate should not be more than 0,01 %. The drift rate of natural draft cooling tower should not be more than 0,01 %.

6.4.2 The circulating cooling water drainage pipe should be connected from the downstream of the exchanger, and the regulating valve and flow orifice plate should be installed for regulation and metering. The circulating cooling water make-up point should be set near the inlet of the circulating cooling water pump forebay. The overflow port should be set at the far end of the relative water supply point.

6.4.3 The circulating cooling water tower should be equipped with high efficiency water remover, and the flow field should be optimized by adjusting the water distribution mode, flier type and filler packing mode to enhance the heat transfer effect. A wind baffle should be installed between the bottom of the filler and the water collecting basin, and a return platform should be set around the sump.

6.4.4 In areas with heat sources, heat pump and other waste heat recovery devices can be used in the circulating cooling water system to reduce evaporation loss.

6.4.5 The circulating cooling water quantity should be optimized and adjusted according to source water temperature, climate conditions under different seasonal changes and unit load.

7 Guidance for managing water conservation of circulating cooling water

7.1 Guidance for detection and measurement instrumentation

7.1.1 The online continuous monitoring system should be installed to identify important parameters for monitoring on real time and improving the reliable operation of system. Online conductivity meters, pH meters, etc. should be equipped for make-up water and circulating cooling system water. An online turbidity meter can be set for make-up water and an online total phosphorus meter can be set for system water if necessary. An online residual chlorine meter should be installed in the circulating cooling water of continuous chlorination-type bactericide.

7.1.2 An online total phosphorus meter should be equipped when reclaimed water is used as the make-up water.

7.1.3 The circulating cooling water system should be equipped with an online corrosion and scaling monitoring device and an online detection and control device. By analysing the water quality index, the dosing amount, make-up water and drainage volume can be automatically adjusted.

7.1.4 Scale and corrosion inhibitor should be added continuously and automatically according to the online detection device. For the unit that cannot realize automation detection, calculation of the dosing concentration can refer to Annex G.

7.1.5 The acid adding device of circulating cooling water system should realize automatic adjustment, and acid adding should be continuous and uniform.

7.1.6 The selection of circulating cooling water instrumentation should consider water utility management, the process characteristics, media character, applicable places and functional guidance. Reasonable flow measurement points should be arranged. The make-up water and drainage blow down of circulating cooling water should be equipped with flow meter, and the make-up water valve and blow down valve should be set as regulating valve.

7.2 Water utilities management

7.2.1 Dynamic simulation test of scale and corrosion inhibitor of circulating cooling water should be carried out when make-up water source, water treatment process or water treatment chemicals change significantly. The operation conditions and water quality control index should be rechecked, and the supervision index should be revised according to the changed working conditions and water quality parameters.

7.2.2 During unit maintenance, the surface of the heat exchanger at the water side of the circulating cooling water should be inspected (extraction inspection should be conducted if necessary). According to the scaling and corrosion on the surface of the heat exchanger, the working condition or treatment process should be adjusted.

7.2.3 Continuous operation mode should be adopted for circulating cooling make-up water, and circulating cooling water drainage and water level monitoring should be strengthened.

7.2.4 During the operation, rubber ball cleaning and other technologies should be adopted to keep the surface of the cooling water pipe clean. The operation time of rubber ball system should not be less than 4 hours a day, the ball return rate should not be less than 90 %, and the number of balls put should not be less than 10 % of the number of pipes in one process of the condenser.

7.2.5 The circulating cooling water system should be cleaned or flushed regularly. Sludge of circulating cooling water tower should be regularly cleaned up, and fillers should be washed or replaced to improve the sanitation of the circulating cooling water.

Annex A
(informative)

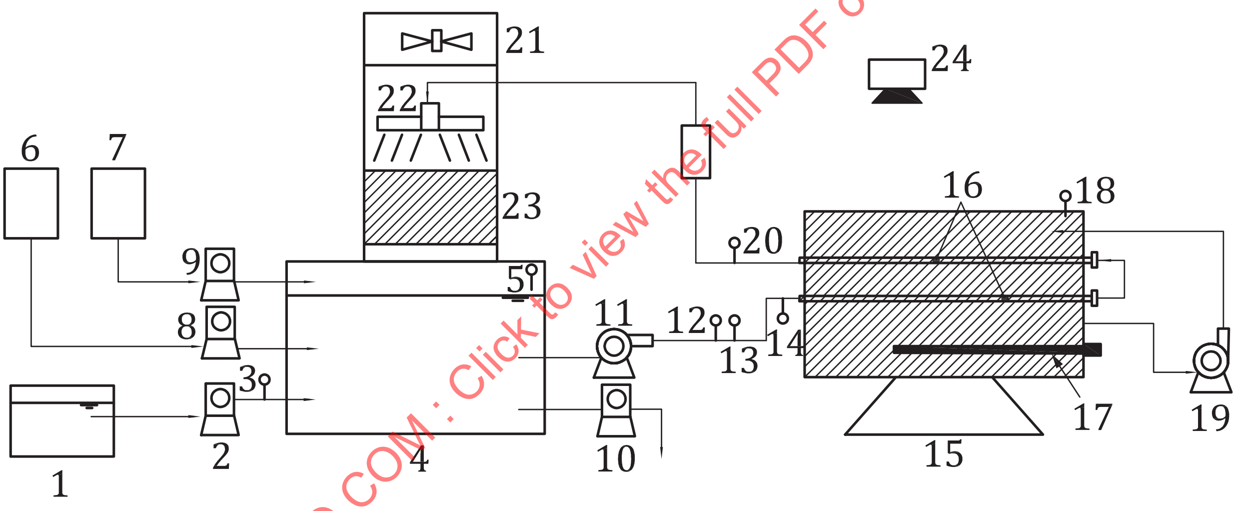
Dynamic simulation test of scale and corrosion inhibitor

A.1 Test method summary

Under the given conditions in the laboratory, thermal media such as normal pressure saturated steam or hot water should be used to heat the simulated heat exchanger. The main process parameters of circulating cooling water field conditions, such as the flow rate, water quality, flow pattern, heat exchange material, heat exchange intensity, inlet and outlet temperature of cooling water, cycles of concentration, pH, electrical conductivity, water treatment agent addition method and concentration, are simulated to evaluate the corrosion and scale inhibition performance of water treatment agents according to the actual needs of users.

A.2 Test equipment

The schematic diagram of the test equipment is shown in Figure A.1.



Key

1	water replenishment tank	2	water replenishment pump	3	replenishment water quality sensor	4	basin
5	liquid level sensor	6	scale and corrosion inhibitor	7	bactericide	8	scale and corrosion inhibitor pump
9	bactericide pump	10	drainage pump	11	main circulating pump	12	circulating water quality sensor
13	flowmeter	14	inlet water temperature sensor	15	simulated condenser	16	heat exchanger
17	electric heater	18	thermal media thermometer	19	thermal media circulating pump	20	outlet thermometer
21	axial flow fan	22	rotating spray	23	packing	24	control system

Figure A.1 — Schematic diagram of the dynamic simulation evaluation device for corrosion and scale inhibition

A.3 Test procedure

In the early stage of the dynamic simulation test, 2 h to 6 h after the operation is stable, the cooling water inlet and outlet temperature and the heat medium temperature can be measured 8 times every 15 min to 30 min. During the measurement, the flow rate, inlet water temperature, and heat medium temperature should be strictly controlled at specified value. Mathematical statistics should be used to discard outliers, then the fouling thermal resistance value of each set of valid data should be calculated according to Formula (A.1), and the arithmetic mean of all valid values should be taken as the clean pipe thermal resistance *r*. Then the above measurement method can be repeated at certain time intervals (2 h to 4 h, if automatic detection can greatly shorten the time interval), and the instantaneous fouling thermal resistance (r_{si}) is calculated according to Formula (A.2). The test period is not less than 15 days, and the thermal resistance value of the fouling is basically stable as the end of the test.

A.4 Calculation and interpretation of the test result

A.4.1 Calculation of fouling thermal resistance

$$r = \frac{0{,}86\pi d_i L}{Q}\left(\frac{T - T'_{\text{in}}}{T'_{\text{out}} - T'_{\text{in}}} - \frac{1}{2}\right) \quad \text{(A.1)}$$

$$r_{si} = \frac{0{,}86\pi d_{\text{i}} L}{Q}\left(\frac{T - T_{\text{in}}}{T_{\text{out}} - T_{\text{in}}} - \frac{1}{2}\right) - r \quad \text{(A.2)}$$

where

r	is the thermal resistance of clean tube, in m²·°C/W;
d_{i}	is the inner diameter of test tube, in m;
L	is the total effective heat transfer length of test tube, in m;
Q	is the flow rate of cooling water, in kg/h;
T	is the temperature of thermal medium, in °C;
T'_{in}	is the temperature of instantaneous inlet of cooling water in clean condition, in °C;
T'_{out}	is the temperature of instantaneous outlet of cooling water in clean condition, in °C;
r_{si}	is the thermal resistance of instantaneous fouling, in m²·°C/W;
T_{in}	is the temperature of instantaneous inlet of cooling water, in °C;
T_{out}	is the temperature of instantaneous outlet of cooling water, in °C.

NOTE The instantaneous fouling thermal resistance r_{si} is measured according to the Formula (A.2), using mathematical statistics to discard the outliers, with r_{si} as the ordinate, and the corresponding time (t) as the abscissa coordinates, drawing the fouling thermal resistance-time curve.

A.4.2 Calculation of corrosion properties

The corrosion rate is calculated according to Formula (A.3):

$$V = \frac{3{,}65 \times 10^3 (G_1 - G_2)}{A \cdot t \cdot \rho} \quad \text{(A.3)}$$

where

V is the corrosion rate, in mm/a;

G_1 is the mass of test tube/test coupons in clean state before test, in g;

G_2 is the mass of test tube/test coupons in clean state after test, in g;

t is the test time, in d;

A is the corrosion area of test tube, in cm^2;

ρ is the metal density, in g/cm^3.

Annex B
(informative)

Make-up water quality recommendations of circulating cooling water

Tables B.1 to B.3 provide recommendations for the quality of make-up water in circulating cooling water systems.

Table B.1 — Water quality recommendations of surface water, underground water used as make-up water for circulating cooling water system

Components	Units	Recommended values
Turbidity	NTU	≤ 3
pH (25 °C)	—	6,0 to 8,5
Total iron	mg/l	≤ 0,3
Cl^-	mg/l	According to the material of heat exchanger
NH_3-N	mg/l	≤ 0,5
Oils	mg/l	≤ 0,3
COD_{Cr}	mg/l	≤ 15

Table B.2 — Water quality recommendations of reclaimed water used as make-up water for circulating cooling water system

Components	Units	Recommended values
pH (25 °C)	—	6,0 to 9,0
Turbidity	NTU	≤ 5,0
BOD_5	mg/l	≤ 10,0
COD_{Cr}	mg/l	≤ 30,0
Fe	mg/l	≤ 0,5
Mn	mg/l	≤ 0,2
NH_3-N	mg/l	≤ 5,0 (when the heat exchanger is copper alloy, then ≤ 1,0)
Total phosphorus (as P)	mg/l	≤ 1,0
Free chlorine	mg/l	End of make-up pipe 0,1 to 0,2
Oils	mg/l	≤ 5,0
Total bacteria	CFU/ml	< 1 000

Table B.3 — Water quality recommendations of seawater used as make-up water for circulating cooling water system

Components	Units	Recommended values
TSS	mg/l	< 10
Turbidity	NTU	< 10
pH	—	6,5 to 8,5
DO	mg/l	> 4
Total Fe	mg/l	< 0,5
Sulfide (calculated in S)	mg/l	< 0,1
Oils	mg/l	< 1,0
COD_{mn}	mg/l	≤ 4,0
Count of aerobic heterotrophic bacteria	CFU/ml	$< 10^3$

Annex C
(informative)

Scale and corrosion inhibition test of water treatment agents (laboratory evaluation test)

C.1 Test method summary

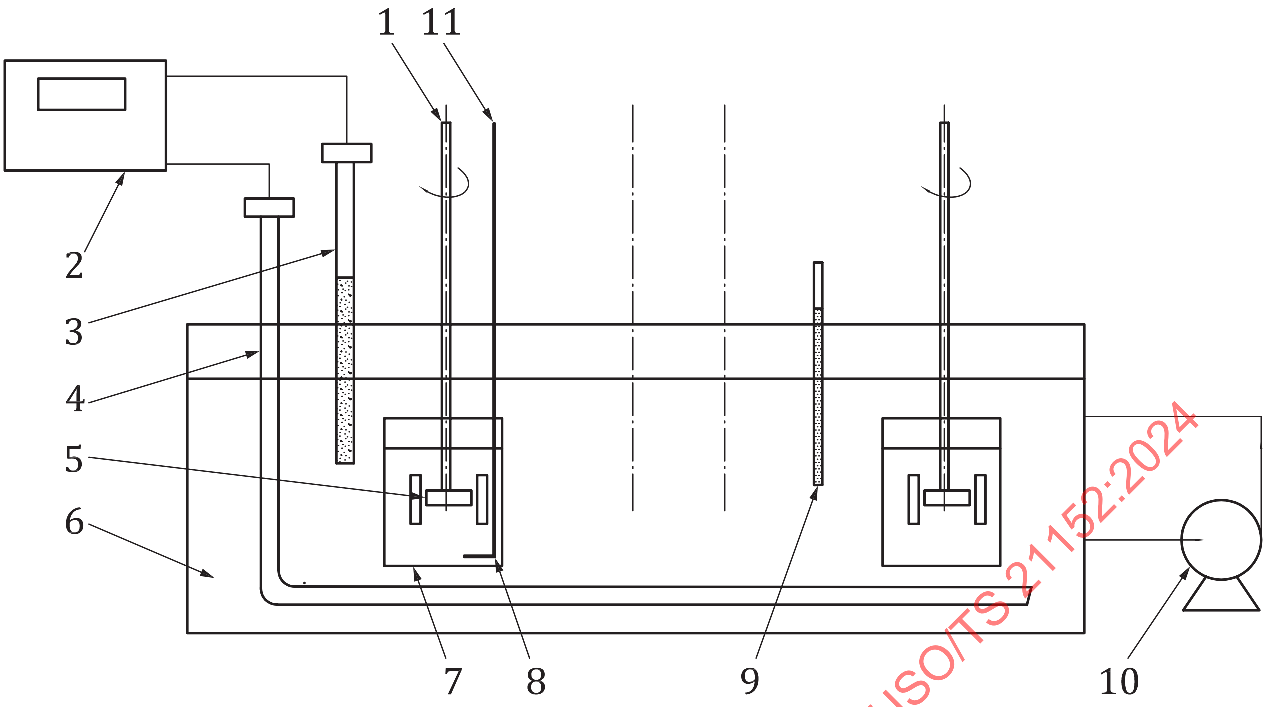
The scale inhibition test uses the calcium carbonate deposition method. The test solution is prepared by preparation water and water treatment agent containing a certain amount of bicarbonate and calcium ions. Under heating conditions, calcium bicarbonate is accelerated to decompose into calcium carbonate. The calcium ion concentration in the test solution is measured after the equilibrium is reached. The scale inhibition performance of the water treatment agent is calculated by the change of the residual calcium ion concentration in the test solution. The higher the concentration of calcium ion, the better the anti-scale performance of the water treatment agent.

Corrosion inhibition test uses rotating hanging plate method. Under the given conditions of the laboratory such as the water sample to be measured, the given temperature and the appropriate rotating speed, the corrosion rate and the corrosion inhibition rate are calculated by the mass loss of the test piece in a certain period of time, to evaluate the corrosion inhibition performance of the water treatment agent.

C.2 Test equipment

The main test equipment in a scale inhibition test includes volumetric bottle, conical bottle, constant temperature water bath, burette.

The main instruments and equipment for the evaluation of corrosion inhibition test are rotary hanging device, 2 l beaker and analytical scale. The schematic diagram of the rotary hanging device is shown in Figure C.1.



Key

1 rotating axis
2 temperature controller
3 measuring slide probe
4 electric heater
5 test piece fixture (can hang 3 test pieces)
6 constant temperature water bath
7 beaker
8 test tablet
9 thermometer
10 water bath circulation pump
11 ventilation tube

Figure C.1 — Test rotating hanging device of corrosion test

C.3 Calculation and interpretation of the test results

The scale inhibition rate is calculated according to Formula (C.1):

$$\eta_1 = \frac{C_2 - C_1}{NC_0 - C_1} \times 100 \quad \text{(C.1)}$$

where

η_1 is the scale inhibition rate, in %;

C_2 is the concentration of calcium ions (Ca^{2+}) in the water sample after adding the water treatment agent, in mg/l;

C_1 is the concentration of calcium ions (Ca^{2+}) in the water sample after the test without adding the water treatment agent (blank test solution), in mg/l;

C_0 is the concentration of calcium ions (Ca^{2+}) in the test solution prepared before the test, in mg/l.

N is the number of cycles, which can be calculated by Formula D.2 in Annex D.

The corrosion rate is calculated according to Formula (C.2):

$$V = \frac{v_0 - v_1}{v_0} \times 100 \quad \text{(C.2)}$$

where

V is the corrosion inhibition rate, in %;

v_0 is the corrosion rate of a blank test of the test piece without water treatment agent, in mm/a;

v_1 is the corrosion rate of the test piece after water treatment agent, in mm/a.

Annex D
(informative)

Calculation of cycles of concentration

The relationship between cycles of concentration and evaporation, blow down and drift loss can be calculated using Formulae (D.1), (D.2) and (D.3):

$$Q_P = \frac{Q_Z + Q_F - N \cdot Q_F}{N - 1} \tag{D.1}$$

$$N = \frac{Q_Z + Q_F + Q_P}{Q_F + Q_P} = \frac{C_X}{C_B} \tag{D.2}$$

$$Q_B = N \times (Q_P + Q_F) \tag{D.3}$$

where

Q_P is the water loss due to blow down, m^3/h;

Q_Z is the water loss by evaporation, m^3/h;

N is the number of the cycles of indirect open recirculate cooling water systems;

Q_F is the water loss due to drift, m^3/h;

C_X is the concentration of a certain ion or salt in circulating cooling water, mg/l;

C_B is the concentration of specific ions or salt in the make-up water, mg/l;

Q_B is the flow rate of make-up water, m^3/h.