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Guidelines for wastewater treatment and reuse in thermal power plants

Lignes directrices pour le traitement et la réutilisation des eaux usées dans les centrales électriques thermiques

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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*.

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

Global water scarcity is becoming increasingly pronounced as a result of the massive demand for water caused by population growth, public life and industrial growth. Due to the increasing cost of water and sewage disposal, wastewater reuse in thermal power plants is being initiated. The number of wastewater recycling projects in thermal power plants is increasing and water treatment and reuse technologies are being developed. Studies have shown that electric power plants account for approximately half the global industrial water withdrawal[1], which means the problem of water shortage will be aggravated with the expansion of thermal power plants.

Although the generation of electricity from renewable sources (e.g. wind, hydro and solar photovoltaic) with almost zero water consumption is growing, the proportion of world gross electricity generated by combustible fuels still accounted for 64,1 % in 2020[2]. In addition, the wastewater from thermal power plants (power plants that generate electricity from combustible fuels) is diverse, with a high volume and complex pollutant components[3], and its discharge poses a threat to the ecology of water environments. Therefore, the reuse of wastewater from thermal power plants has dual benefits of water saving and environmental protection.

The increasing efforts to control water scarcity and water pollution in some countries have made industrial wastewater reuse a valuable means of augmenting the existing water supply and reducing wastewater discharge to the environment. In terms of wastewater treatment and reuse in thermal power plants, the United States[4], China[5], Japan[6] and International Energy Agency (IEA)[7] have all introduced relevant policies to encourage wastewater reuse or even zero discharge in thermal power plants.

However, the reclaimed water quantity of wastewater in thermal power plants is not high, and the different characteristics of wastewater generated from different systems are ignored. Therefore, it is necessary to strengthen the classification and characteristic analysis of wastewater, adopt more reasonable and efficient treatment and reuse technologies in thermal power plants to optimize the reclaimed water quantity of wastewater, to realize zero liquid discharge of wastewater and to improve the benefits of water saving and environmental protection and ultimately achieve the sustainable development goals (see www.un.org/sustainabledevelopment).

Guidelines for wastewater treatment and reuse in thermal power plants

1 Scope

This document specifies guidelines for wastewater treatment and reuse in thermal power plants, including the types and characteristics of wastewater and the technologies of wastewater treatment and reuse.

In this document, thermal power plant drainage systems are divided into fuel supply, chemical water treatment, boiler and auxiliary, recirculating cooling, flue gas processing, gasification scrubber and ash handling. Wastewater from these systems is classified in accordance with its system sources. In addition, technical guidelines for wastewater treatment and reuse are provided according to the water requirements of systems in the thermal power plant. This document is formulated to provide feasible technical guidance for the treatment and reuse of wastewater in thermal power plants.

It is applicable to coal-fired, oil-fired, gas-fired (including gas turbine), biomass-fired, waste incineration and integrated gasification combined cycle (IGCC) thermal power plants.

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, 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 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
advanced treatment for TDS
advanced treatment for total dissolved solids
process of further reducing the salt content in wastewater by using advanced treatment technology after pretreatment to achieve certain reuse water targets

3.1.2
ash handling system
system that includes all the equipment, pipelines and monitoring devices for collecting bottom ash and fly ash from combustion or gasification of fuel in boilers and transferring it out of the power plant

3.1.3
boiler and auxiliary system
system that includes primary production equipment for the combustion or gasification of fuel and other auxiliary machinery

3.1.4
chemical water treatment system
system that treats the raw water to achieve water quality requirements for the different water applications in the power plant

Note 1 to entry: A chemical water treatment system includes the raw water pretreatment, boiler replenishment water treatment, condensate polishing treatment and wastewater treatment

3.1.5
flue gas processing system
system that purifies boiler flue gas and reduces pollutants such as sulfur dioxide, nitrogen oxides, particulate matter and organic gas in flue gas

3.1.6
fuel supply system
system that collects, stores, pre-treats and transports combustible fuels for power generation

3.1.7
gasification scrubber system
system that purifies gaseous fuel after gasification of solid or liquid fuel

3.1.8
recirculating cooling system
system that circularly uses a cooling medium (e.g. water, air) to transfer heat

Note 1 to entry: A recirculating cooling system consists of heat exchange equipment, cooling equipment, treatment facilities, pumps, pipelines and other related facilities.

3.1.9
reclaimed water quantity
amount of water that is directly cascade-utilized or reused after proper treatment in the production process of the thermal power plant

3.1.10
thermal power plant
power plant that converts heat, such as that released by the combustion of carbonaceous fuels, into electricity

Note 1 to entry: Carbonaceous fuels include coal and coal products, oil and oil products, natural gas, biofuels from biomass, industrial waste and municipal waste.

[SOURCE: ISO 27919-1:2018, 3.1.42, modified — Definition revised and note to entry added.]

3.2 Abbreviated terms

A/O	anoxic/oxic
BOD_5	biochemical oxygen demand after 5 days
COD	chemical oxygen demand
EDTA	ethylene diamine tetraacetic acid
FGD	flue gas desulfurization
IGCC	integrated gasification combined cycle
MBR	membrane bioreactor
MVR	mechanical vapor recompression

NF nanofiltration

NTU nephelometric turbidity unit

PAHs polycyclic aromatic hydrocarbons

RO reverse osmosis

TDS total dissolved solids

TP total phosphorus

TSS total suspended solids

UASB upflow anaerobic sludge blanket

UF ultrafiltration

WESP wet electrostatic precipitator

4 General principles

The following principles should be followed for the treatment and reuse of wastewater in thermal power plants.

a) The wastewater should be treated and reused separately if its water quality and reuse target are different.

b) If wastewater has similar water quality and the same reuse target, similar treatment processes can be adopted.

c) Wastewater that meets the water quality requirements of the reuse target can be directly utilized in the target system.

d) The process flow of wastewater treatment and reuse in thermal power plants should be determined taking requirements of the effluent water quantity and quality, influent water quality of reuse targets, site conditions, environmental protection and other factors into account during the technical and economic review.

e) The entire plant water balance should be optimized before designing a water reuse plan. The water withdrawal, consumption and drainage of each system should be considered through a water balance. The water quality requirements of each system should also be considered (see Annex A).

5 Types and characteristics of wastewater in thermal power plants

Wastewater in thermal power plants can be classified based on the following systems: fuel supply, chemical water treatment, boiler and auxiliary, recirculating cooling, flue gas processing, gasification scrubber and ash handling.[8] The types of wastewater in each system are shown in Table 1.

Table 1 — Types of wastewater in thermal power plants

System source	Type	Involved power plants
Fuel supply	Coal wastewater[a]	Coal-fired power plants, IGCC
	Oily wastewater[b]	All power plants
	Leachate[c]	Biomass-fired power plants, waste incineration power plants
Chemical water treatment	RO concentrated water[d]	All power plants
	Membrane washing wastewater[e]	
	Resin reclaimed wastewater[f]	

[a] Coal wastewater has high TSS, COD, chroma and turbidity. The TSS concentration can be between 200 mg/l and 5,000 mg/l. Coal wastewater includes the leakage caused by the spraying and dustproofing in the coal yard, the washing waste water caused by the washing of the coal transporting trestle, the rain water in the coal yard and the effluent water after dust removal in the coal conveying system.

[b] Oily wastewater includes oil slick, disperse oil, emulsified oil and dissolved oil[9]. It can come from the oil storage facilities, the leakage of the oil system in the main plant during the operation of the steam engine and the power generation turning machine bearings, and the oily wastewater generated during the operation, cleaning or overhaul of the equipment.

[c] Leachate has high COD, BOD_5, ammonia nitrogen, TSS and heavy metals, with a pH of 5~7[10]. It comes from the biochemical degradation during the stacking process of biomass or waste. Its quantity and quality are different due to the types of waste generated from various sites, fuel composition and climatic conditions at the power plants.

[d] RO-concentrated water is of high salinity, and its quality is related to the quality of raw water. It is concentrated wastewater generated during the operation of the RO membrane filtration system in the chemical water treatment system of the power plants[11].

[e] Membrane washing wastewater is acidic or alkaline and has a high salinity. It comes from the physical and chemical cleaning of membrane components in chemical water treatment system. Its quantity and quality are related to the quality of raw water and the concentration of chemical cleaning agent.

[f] Resin reclaimed wastewater is the acid or alkali wastewater from the regeneration of ion-exchange resin in the chemical water treatment system. It is of high TDS and TSS. Its quantity and quality are related to resin regeneration time and acid and base dosage.

[g] Boiler blowdown can be divided into boiler continuous blowdown and boiler regular blowdown. The boiler continuous blowdown contains only a small amount of Na^+, PO_4^{3-}, CO_3^{2-}, SiO_3^{2-}, Fe^{2+}, Fe^{3+} and other salts. The iron content in the boiler regular blowdown is high and contains ammonia nitrogen, TSS and COD[12].

[h] Boiler chemical cleaning wastewater has high TDS, COD and TSS. Major pollutants are dependent on the type of acid cleaning agent, such as hydrochloric acid, citric acid, complex acid and EDTA, used in the process of boiler chemical cleaning.

[i] Auxiliary equipment cooling water blowdown contains a small amount of TDS and the water quality is high. It comes from the cooling water system of auxiliary equipment of the power plant.

[j] Cooling tower blowdown has high salinity, which has the largest flow rate in thermal power plants. Its quantity and quality are related to the concentration ratio. The common pollutants include TSS, colloid, organic matter, inorganic salts, microorganisms and algae. These pollutants come mainly from supplemental water and chemicals added to the water cycle, as well as pollutants that grow in the system.

[k] WESP blowdown can be split into WESP continuous blowdown and WESP regular blowdown since the cleaning types of WESP include continuous-flow water cleaning and spray cleaning. The WESP blowdown is acidic wastewater, including TSS, TDS and heavy metal. Its quantity is related to the cleaning type of WESP.

[l] FGD wastewater is acidic, with a pH value between 4 and 6, containing a large number of TSS (e.g. gypsum particles, SiO_2, CaF_2) and a certain amount of COD. TSS is about 10,000 mg/l or more, TDS ranges between 30,000 mg/l to 65,000 mg/l. The hardness is relatively high. The anions in wastewater are mainly Cl^- and sulfate radical ions, and there are many kinds of heavy metal cation, such as mercury, lead, zinc, nickel and arsenic.

[m] Tar-containing wastewater is the organic wastewater with tar as the main pollutant produced by wet gas purification equipment. Tar can be considered a mixture of several acidic, alkaline and neutral compounds. The acidic components include acids and phenols, the basic components include nitrogen-containing compounds and the neutral components include PAHs[12]. In addition, the wastewater also contains ammonia nitrogen, chloride and other inorganic substances.

[n] The quality of ash handling wastewater is determined by the chemical composition of ash. Since the fuel source is not fixed, the water quality of ash handling wastewater is also unstable. In general, ash wastewater is of high pH and TDS. The pH value is generally greater than 9 and sometimes more than 10,5. It contains heavy metal elements and fluoride dissolved from ash residue. The TSS of ash handling wastewater in the slurry concentration pool is higher.

Table 1 *(continued)*

System source	Type	Involved power plants
Boiler and auxiliary	Boiler blowdown[g]	All power plants
	Boiler chemical cleaning wastewater[h]	
	Auxiliary equipment cooling water blowdown[i]	
Recirculating cooling	Cooling tower blowdown[j]	All power plants
Flue gas processing	WESP blowdown[k]	Coal-fired power plants
	FGD wastewater[l]	Coal-fired power plants, oil-fired power plants, biomass-fired power plants, waste incineration power plants

[a] Coal wastewater has high TSS, COD, chroma and turbidity. The TSS concentration can be between 200 mg/l and 5,000 mg/l. Coal wastewater includes the leakage caused by the spraying and dustproofing in the coal yard, the washing waste water caused by the washing of the coal transporting trestle, the rain water in the coal yard and the effluent water after dust removal in the coal conveying system.

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[d] RO-concentrated water is of high salinity, and its quality is related to the quality of raw water. It is concentrated wastewater generated during the operation of the RO membrane filtration system in the chemical water treatment system of the power plants[11].

[e] Membrane washing wastewater is acidic or alkaline and has a high salinity. It comes from the physical and chemical cleaning of membrane components in chemical water treatment system. Its quantity and quality are related to the quality of raw water and the concentration of chemical cleaning agent.

[f] Resin reclaimed wastewater is the acid or alkali wastewater from the regeneration of ion-exchange resin in the chemical water treatment system. It is of high TDS and TSS. Its quantity and quality are related to resin regeneration time and acid and base dosage.

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Table 1 *(continued)*

System source	Type	Involved power plants
Gasification scrubber	Tar-containing wastewater[m]	Biomass gasification power plants, IGCC
Ash handling	Ash handling wastewater[n]	Coal-fired power plants, biomass-fired power plants, waste incineration power plants

[a] Coal wastewater has high TSS, COD, chroma and turbidity. The TSS concentration can be between 200 mg/l and 5,000 mg/l. Coal wastewater includes the leakage caused by the spraying and dustproofing in the coal yard, the washing waste water caused by the washing of the coal transporting trestle, the rain water in the coal yard and the effluent water after dust removal in the coal conveying system.

[b] Oily wastewater includes oil slick, disperse oil, emulsified oil and dissolved oil[9]. It can come from the oil storage facilities, the leakage of the oil system in the main plant during the operation of the steam engine and the power generation turning machine bearings, and the oily wastewater generated during the operation, cleaning or overhaul of the equipment.

[c] Leachate has high COD, BOD_5, ammonia nitrogen, TSS and heavy metals, with a pH of 5~7[10]. It comes from the biochemical degradation during the stacking process of biomass or waste. Its quantity and quality are different due to the types of waste generated from various sites, fuel composition and climatic conditions at the power plants.

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[n] The quality of ash handling wastewater is determined by the chemical composition of ash. Since the fuel source is not fixed, the water quality of ash handling wastewater is also unstable. In general, ash wastewater is of high pH and TDS. The pH value is generally greater than 9 and sometimes more than 10,5. It contains heavy metal elements and fluoride dissolved from ash residue. The TSS of ash handling wastewater in the slurry concentration pool is higher.

6 Wastewater treatment and reuse technologies

6.1 Water quality requirements for reuse water in thermal power plants

To ensure the proper operation of each system, it is recommended that the reuse water quality after treatment meet the requirements of influent water for the given target. The required water quality parameters of various types of industrial reuse water are given in Table 2.

Table 2 — Required water quality parameters of reuse water

No.	Parameter	Fuel supply system		Chemical water treatment system	Boiler and auxiliary system		Recirculating cooling system	Flue gas processing system		Gasification scrubber system	Ash handling system
		Washing water	Dust-suppressing water	Influent water	Boiler make-up water[a]	Cooling water	Cooling water	WESP cleaning water	Process water	Process water	Ash handling water
1	pH (25 °C)	6,5 to 9,0	6,5 to 9,0	C	8,8 to 9,3	7,0 to 9,5	6,5 to 8,5	6,0 to 8,0	6,5 to 9,5	C	6,5 to 9,0
2	TSS (mg/l)	≤ 30	≤ 30	C	C	C	≤ 30	≤ 150	≤ 50	O	≤ 30
3	Turbidity (NTU)	O	O	O	C	C	≤ 5	C	O	O	O
4	Chroma	≤ 30	≤ 30	C	C	C	≤ 30	C	C	C	≤ 30
5	BOD_5 (mg/l)	≤ 30	≤ 30	C	C	C	≤ 10	C	C	C	≤ 30
6	COD (mg/l)	O	O	O	O	C	≤ 60	O	O	O	O
7	Fe (mg/l)	≤ 0,3	≤ 0,3	O	O	C	≤ 0,3	C	C	C	≤ 0,3
8	Mn (mg/l)	≤ 0,1	≤ 0,1	O	C	C	≤ 0,1	C	C	C	≤ 0,1
9	Cl^- (mg/l)	≤ 250	≤ 250	C	O	C	C	≤ 200	≤ 1,000	C	≤ 250
10	SiO_2 (mg/l)	O	O	O	≤ 0,02	C	≤ 50	O	O	O	O
11	Total hardness (mg/l)	≤ 450	≤ 450	C	≤ 0,002	C	≤ 450	≤ 200	≤ 250	C	≤ 450
12	Total alkalinity (mg/l)	≤ 350	≤ 350	C	C	C	≤ 350	C	C	C	≤ 350

NOTE The values in this table refer to References [14] to [21].

[a] The water quality of boiler make-up water in the boiler and auxiliary system should meet the following additional targets: TOC (total organic carbon) ≤ 0,4 mg/l, conductivity (25 °C) ≤ 0,4 μS/cm.

Key

C: The indicator is controlled; the value or range of the indicator is conditional.

O: The indicator is optional.

Table 2 *(continued)*

No.	Parameter	Fuel supply system		Chemical water treatment system	Boiler and auxiliary system		Recirculating cooling system	Flue gas processing system		Gasification scrubber system-Process water	Ash handling system-Ash handling water
		Washing water	Dust-suppressing water	Influent water	Boiler make-up water[a]	Cooling water	Cooling water	WESP cleaning water	Process water		
13	Sulfate (mg/l)	≤ 250	≤ 250	C	C	C	≤ 600	≤ 200	≤ 400	C	≤ 250
14	NH_3-N (mg/l)	O	O	O	C	C	≤ 10	≤ 10	≤ 10	O	O
15	TP (mg/l)	O	O	O	C	C	≤ 1	≤ 5	≤ 5	O	O
16	TDS (mg/l)	≤ 1,000	≤ 1,000	C	≤ 0,1	C	≤ 1,000	C	C	C	≤ 1,000
17	Petroleum (mg/l)	C	O	O	C	C	≤ 5	O	O	C	O

NOTE The values in this table refer to References [14] to [21].

[a] The water quality of boiler make-up water in the boiler and auxiliary system should meet the following additional targets: TOC (total organic carbon) ≤ 0,4 mg/l, conductivity (25 °C) ≤ 0,4 µS/cm.

Key

C: The indicator is controlled; the value or range of the indicator is conditional.

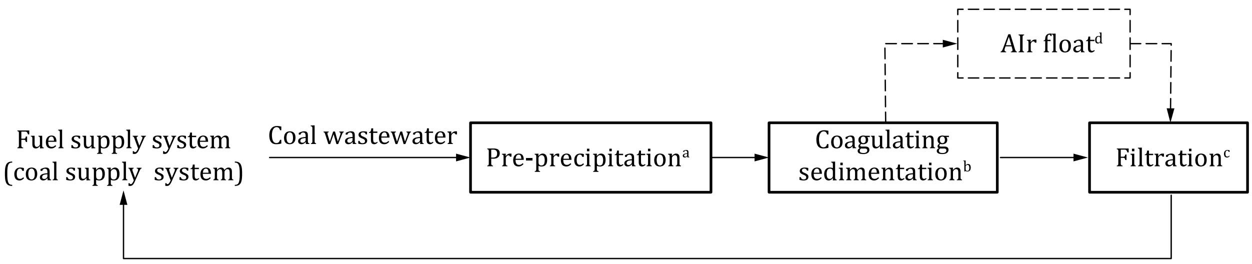
O: The indicator is optional.

6.2 Fuel supply system wastewater treatment and reuse

6.2.1 Coal wastewater

According to the effluent water quality of coal wastewater and the influent water quality requirements for the reuse targets, pre-precipitation, coagulating sedimentation, filtration, etc. or a combination of processes can be adopted to treat the coal wastewater. Options for treatment and reuse processes are shown in Figure 1.

The effluent after pre-precipitation, coagulating sedimentation and filtration treatment can be reused in the coal supply system (washing water for coal conveying facilities, dust-suppressing water for spraying in dry coal yard).



[a] The pre-precipitation of coal wastewater is used to separate large particles of solids from wastewater. Sedimentation by gravity can be used.

b The coagulating sedimentation of coal wastewater is used to remove TSS in wastewater. Chemical flocculation, electronic flocculation, etc. can be used.

c The filtration of coal wastewater is used to separate sludge formed by coagulating sedimentation from wastewater. Mechanical filtration, membrane filtration, etc. can be used.

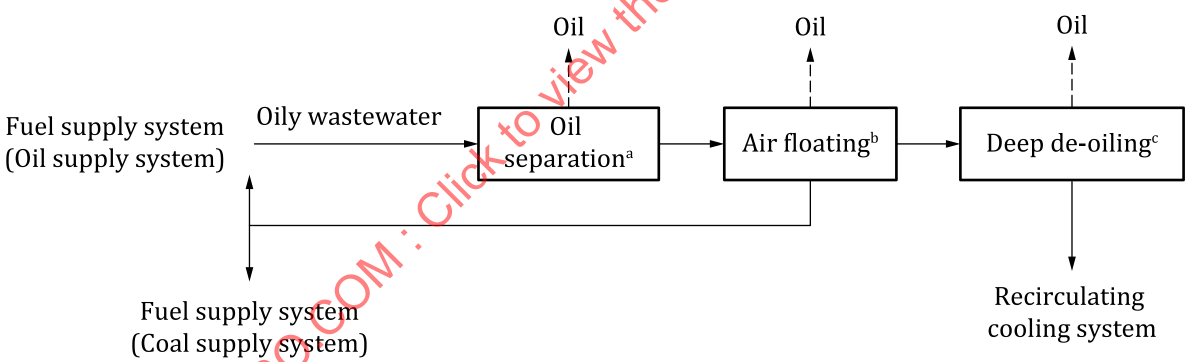
d If there is oil in the coal wastewater, an air float treatment unit can be added after coagulating sedimentation to remove the oil in the wastewater.

Figure 1 — Process flow of coal wastewater treatment and reuse

6.2.2 Oily wastewater

The separation treatment system should be set up for oily wastewater. According to the effluent water quality of oily wastewater and the influent water quality requirements for the reuse targets, oil separation, air floating, deep de-oiling, etc. or a combination of processes can be adopted to treat the oily wastewater. Options for treatment and reuse processes are shown in Figure 2.

The effluent after oil separation and air flotation treatment can be reused in the oil supply system (washing water for oil storage and oil conveying facilities). The effluent after oil separation and air flotation treatment also can be reused in the coal supply system (washing water for coal conveying facilities, dust-suppressing water for spraying in dry coal yard). The effluent after oil separation, air flotation and deep de-oiling treatment can be reused in the recirculating cooling system (recirculating cooling water).



a Oil droplets with larger particle size and suspended oil droplets in wastewater can be removed using oil separation processes such as advection oil traps, inclined plate oil traps or corrugated inclined plate oil traps.

b Dispersed oil droplets with smaller particle size and solid particles in oily wastewater can be removed using air flotation.

c Deep de-oiling of oily wastewater is used to remove dissolved oil droplets from the wastewater using processes such as flocculation precipitation, biological treatment and membrane filtration.

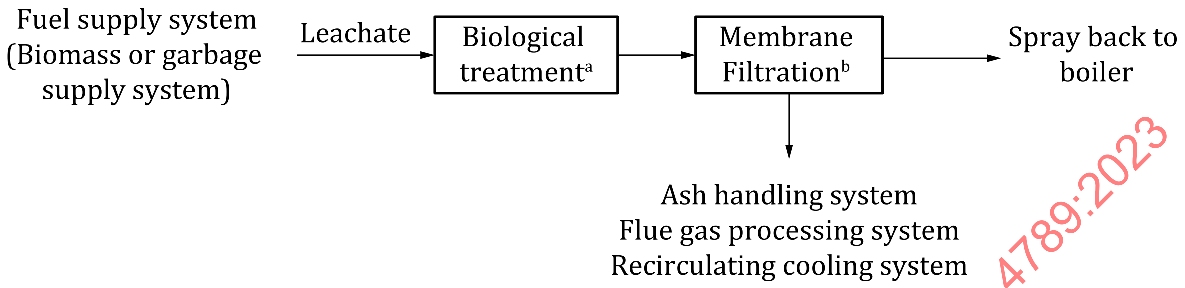
Figure 2 — Process flow of oily wastewater treatment and reuse

6.2.3 Leachate

A separate collection and treatment system should be set up for leachate. According to the effluent water quality of leachate and the influent water quality requirements for the reuse targets, biological treatment, membrane filtration, etc. or a combination of processes can be adopted to treat leachate. Options for treatment and reuse processes are shown in Figure 3. More information about leachate treatment and reuse can be found in ISO 24297 [22].

The effluent after biological treatment and membrane filtration treatment can be reused in the ash handling system (ash handling water, ash field spray water), flue gas processing system (process water) and recirculating cooling system (recirculating cooling water).

The concentrated water after biological treatment and membrane filtration treatment can be sprayed back to the boiler. The concentrated water is regularly sprayed into the boiler in a certain ratio according to the amount and calorific value of the waste, avoiding the generation of excessive crystalline salts by controlling the proportion of concentrated water injected back.



[a] The biological treatment of leachate is used to remove organic matter in wastewater, such as COD, BOD_5 or oil. Anaerobic activated sludge process, A/O, etc. can be used.

[b] The membrane filtration of leachate is used to remove pollutants such as heavy metal ions and small molecules from wastewater. UF, NF, RO, etc. can be used.

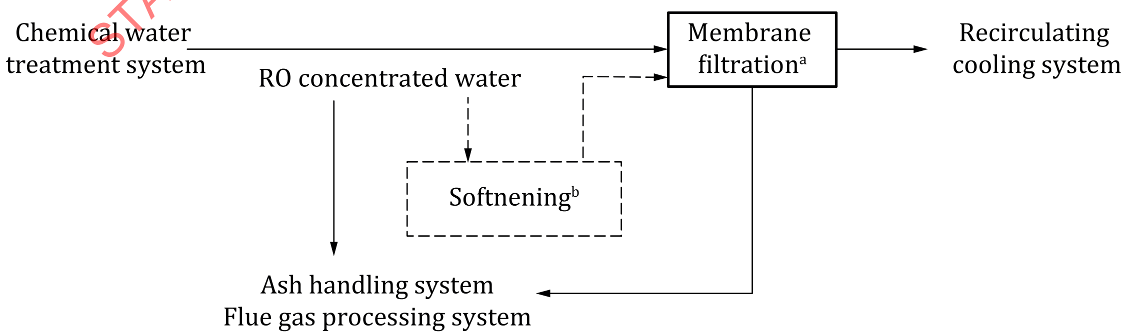
Figure 3 — Process flow of leachate treatment and reuse

6.3 Chemical water treatment system wastewater treatment and reuse

6.3.1 RO concentrated water

According to the effluent water quality of RO concentrated water and the influent water quality requirements for the reuse targets, the membrane filtration processes can be adopted to treat RO concentrated water. Options for treatment and reuse processes are shown in Figure 4.

RO concentrated water can be directly utilized in the ash handling system (ash handling water, ash field spray water) and/or the flue gas processing system (process water). The concentrated water after membrane filtration treatment can be reused in the ash handling system (ash handling water, ash field spray water) and/or the flue gas processing system (process water). The concentration of TDS in the concentrated water needs to be considered to avoid adverse effects on ash reuse and equipment operation. The effluent after membrane filtration treatment can be reused in the recirculating cooling system (recirculating cooling water).



[a] The membrane filtration of RO concentrated water is used to remove salts in wastewater. NF, RO, etc. can be used.

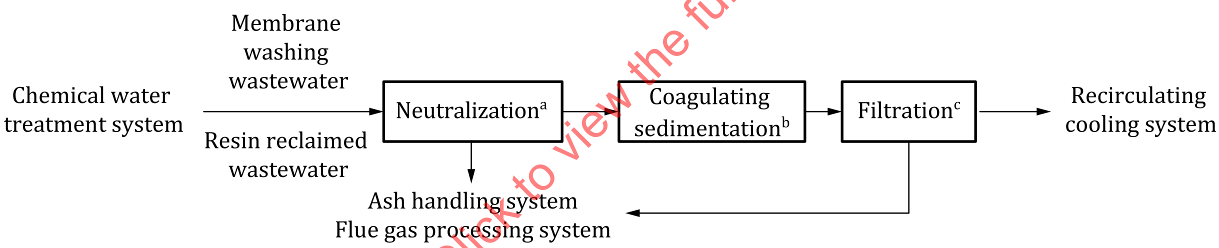
b If the hardness of RO concentrated water is high, a softening treatment unit can be added before membrane filtration to remove hardness. The softening process includes the application of softening agents and ion exchange.

Figure 4 — Process flow of RO concentrated water treatment and reuse

6.3.2 Membrane washing wastewater and resin reclaimed wastewater treatment and reuse

Membrane washing wastewater and resin reclaimed wastewater are similar and have the same reuse targets. According to the effluent water quality of membrane washing wastewater and resin reclaimed wastewater and the influent water quality requirements for the reuse targets, neutralization, coagulating sedimentation, filtration, etc. or a combination of processes can be adopted to treat membrane washing wastewater and resin reclaimed wastewater. Options for treatment and reuse processes are shown in Figure 5.

Membrane washing wastewater and resin reclaimed wastewater can be utilized to the ash handling system (ash handling water, ash field spray water) and/or the flue gas processing system (process water) after neutralization. The concentrated water after neutralization, coagulating sedimentation and filtration treatment can be reused in the ash handling system (ash handling water, ash field spray water) and/or the flue gas processing system (process water). The effluent after neutralization, coagulating sedimentation and filtration treatment can be reused in the recirculating cooling system (recirculating cooling water) if the quantity of TDS is relatively little.



a The neutralization of membrane washing wastewater and resin reclaimed wastewater is used to adjust the pH to neutral by adding acid (or alkali) for subsequent treatment.

b The coagulating sedimentation of membrane washing wastewater and resin reclaimed wastewater is used to remove TSS and some ions from wastewater. The method of adding agents can be used.

c The filtration of membrane washing wastewater and resin reclaimed wastewater, including the mechanical filtration and membrane filtration. Mechanical filtration is used to separate sludge formed by coagulating sedimentation from wastewater and membrane filtration is used to remove salts.

Figure 5 — Process flow of membrane washing wastewater and resin reclaimed wastewater treatment and reuse

6.4 Boiler and auxiliary system wastewater treatment and reuse

6.4.1 Boiler blowdown

The pressure and temperature of boiler blowdown are both very high, so it should be decompressed by the expansion evaporator. After decompressed, boiler blowdown can be directly cascade-utilized in a recirculating cooling system. Options for treatment and reuse processes are shown in Figure 6.

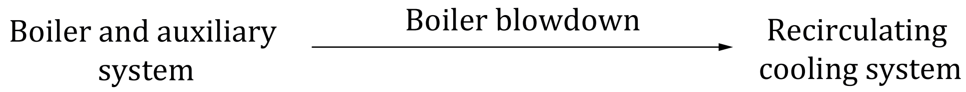
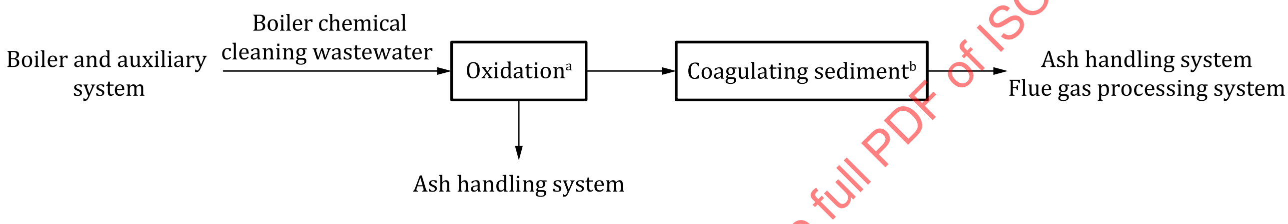


Figure 6 — Process flow of boiler blowdown treatment and reuse

6.4.2 Boiler chemical cleaning wastewater

According to the nature of cleaning agents, the oxidation, coagulating sediment, etc. or a combination of processes can be adopted to treat boiler chemical cleaning wastewater. Options for treatment and reuse processes are shown in Figure 7.

The effluent after oxidation treatment can be reused in the ash handling system (ash handling water, ash field spray water). The effluent after oxidation and coagulating sedimentation treatment can be reused in the ash handling system (ash handling water, ash field spray water) and/or the flue gas processing system (process water). For the power plant without ash handling system and flue gas processing system, the effluent can be further treated to meet discharge requirements.



a The oxidation of boiler chemical cleaning wastewater is used to reduce the COD. At the same time, Fe^{2+} in the wastewater is oxidized into Fe^{3+}, which can be removed in the subsequent coagulating sedimentation. Biological oxidation and chemical oxidation treatment can be used.

b The coagulating sedimentation of boiler chemical cleaning wastewater is used to remove TSS. When the pH of chemical cleaning water does not meet the requirements, it should be neutralized before coagulating sedimentation treatment.

Figure 7 — Process flow of boiler chemical cleaning wastewater treatment and reuse

6.4.3 Auxiliary equipment cooling water blowdown

The water quality of auxiliary equipment cooling water blowdown is good, so it can be directly cascade-utilized in a recirculation cooling system. The options for treatment and reuse processes are shown in Figure 8.

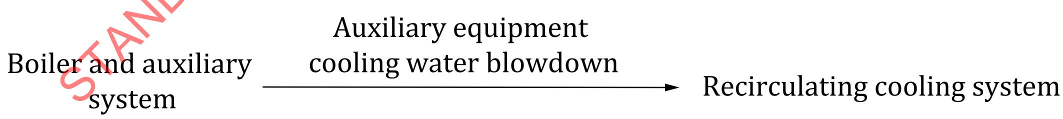


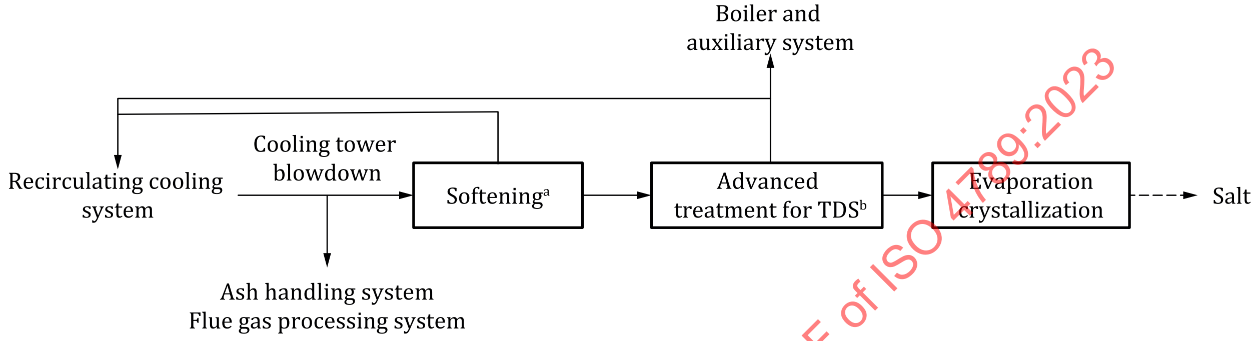
Figure 8 — Process flow of auxiliary equipment cooling water blowdown treatment and reuse

6.5 Recirculating cooling system wastewater treatment and reuse

According to the effluent water quality of cooling tower blowdown and the influent water quality requirements for the reuse targets, softening, membrane filtration, etc. or a combination of processes can be adopted to treat cooling tower blowdown. Options for treatment and reuse processes are shown in Figure 9.

Cooling tower blowdown can be directly utilized to ash handling system (ash handling water, ash field spray water). If TDS meets the requirements of process water for flue gas processing systems, cooling tower blowdown can also be directly utilized in the flue gas processing system (process water). The effluent after softening treatment can be reused in the recirculating cooling system (recirculating cooling water). The effluent after softening and advanced treatment for TDS can be reused in the boiler and auxiliary system (boiler make-up water, equipment cooling water) and/or the recirculating cooling system (recirculating cooling water) (see Annex B).

Hybrid cooling system combined wet and dry cooling towers can reduce the use of water resources and evaporation of circulating cooling water in thermal power plants to a certain extent.[23] Each country can choose to use wet cooling, dry cooling or hybrid cooling systems to save water in thermal power plants, depending on their own circumstances when building or renovating the thermal power plants.



a The softening of cooling tower blowdown is used to soften the water quality by adding alkali and to remove the insoluble salt, TSS, colloid, algae and other pollutants from the water.

b The advanced treatment for TDS of cooling tower blowdown is used to reduce the salt content and obtain higher effluent water quality. NF, RO, etc. or a process combination can be adopted. Mechanical filtration can be adopted before the membrane filtration unit.

c The evaporation crystallization of cooling tower blowdown is the final treatment of the concentrated wastewater after advanced treatment for TDS and is used to obtain the crystallization salt.

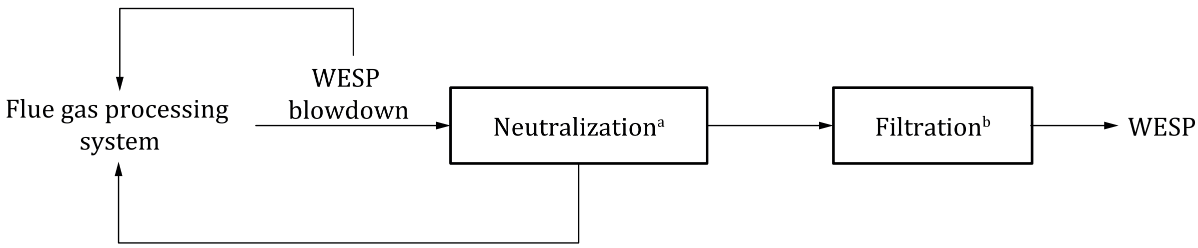
Figure 9 — Process flow of cooling tower blowdown treatment and reuse

6.6 Flue gas processing system wastewater treatment and reuse

6.6.1 WESP blowdown

According to the effluent water quality of WESP blowdown for the reuse targets, neutralization can be adopted to treat WESP blowdown. Options for treatment and reuse processes are shown in Figure 10.

WESP blowdown can be directly utilized to the flue gas processing system (FGD process water). The effluent after neutralization treatment can be reused in the flue gas processing system (FGD process water). The effluent after neutralization and filtration can be reused in the WESP (cleaning water).



a The neutralization of WESP blowdown is used to adjust the pH to neutral by adding alkali for subsequent treatment.

b The filtration of WESP blowdown is the mechanical filtration to separate TSS and sludge formed by neutralization from wastewater.

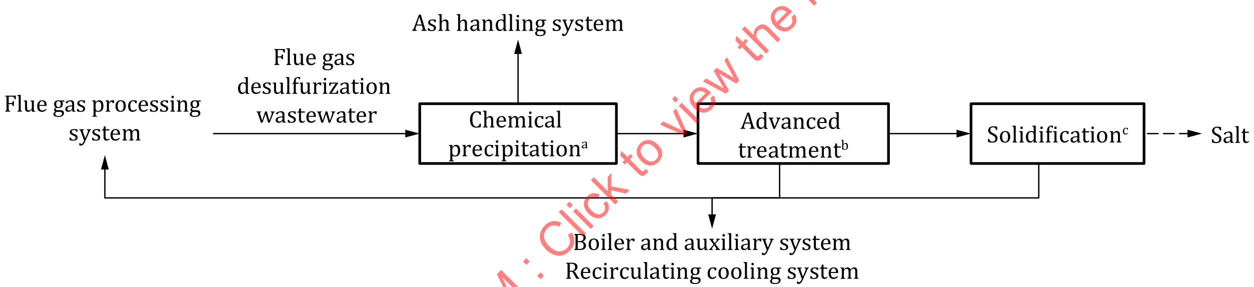
Figure 10 — Process flow of WESP blowdown treatment and reuse

6.6.2 FGD wastewater

According to the effluent water quality of FGD wastewater and the influent water quality requirements for the reuse targets, chemical precipitation, advanced treatment, solidification, etc. or a combination of processes can be adopted to treat FGD wastewater. Options for treatment and reuse processes are shown in Figure 11.

The effluent after chemical precipitation treatment can be reused in the ash handling system (ash handling water, ash field spray water). The effluent after chemical precipitation and advanced treatment can be reused in the flue gas processing system (process water), the boiler and auxiliary system (equipment cooling water) and/or the recirculating cooling system (recirculating cooling water).

The small amount of high-quality effluent after chemical precipitation, solidification or chemical precipitation, advanced treatment and solidification treatment can be reused in the flue gas processing system (process water), the boiler and auxiliary system (boiler make-up water, equipment cooling water) and/or the recirculating cooling system (recirculating cooling water). When the flue gas waste heat evaporation is used for solidification, the condensed water is only reused in the flue gas processing system.



a The chemical precipitation of FGD wastewater is used to remove TSS and heavy metals from the wastewater and also to adjust pH value and soften water quality. Chemical precipitation includes neutralization precipitation, heavy metal precipitation, flocculation precipitation and clarification.

b The advanced treatment of FGD wastewater is used to remove Cl^- that cannot be removed in the process of chemical precipitation and to realize the reduction of high-salinity wastewater and obtain higher effluent quality. NF, RO, etc. or a process combination can be used.

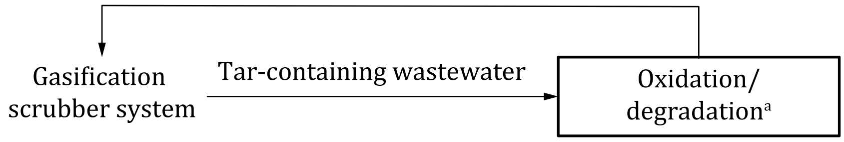
c The solidification of FGD wastewater is the final treatment of the concentrated wastewater after chemical precipitation and advanced treatment. It can be used to solidify pollutants and recover small amounts of clean water. The solidification can be achieved by, for example, flue gas waste heat evaporation[24], evaporation crystallization.

Figure 11 — Process flow of FGD wastewater treatment and reuse

6.7 Gasification scrubber system wastewater treatment and reuse

The main treatment process for tar-containing wastewater is the oxidation/degradation process. Options for treatment and reuse processes are shown in Figure 12.

The tar-containing wastewater can be reused in closed loop after oxidation/degradation treatment.



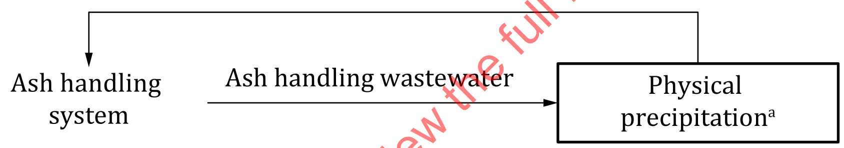
a The oxidation/degradation treatment of tar-containing wastewater is used to eliminate organic matter, such as PAHs, and reduce COD in wastewater. Physical chemistry, advanced oxidation, biodegradation, etc. can be used.

Figure 12 — Process flow of tar-containing wastewater treatment and reuse

6.8 Ash handling system wastewater treatment and reuse

Because the water used in the ash handling system is mostly the blowdown or reclaimed water of each system, the water quality is complex and difficult to use in other systems. The physical precipitation treatment can be used to treat ash handling wastewater for closed-loop circulation. In addition, ash can be divided into bottom ash and fly ash by particle size. Although both can be removed by physical precipitation treatment, there is a difference in difficulty. It is recommended that they are treated separately. The options for treatment and reuse processes are shown in Figure 13.

The ash handling wastewater can be reused in closed loop after physical precipitation treatment.



a The physical precipitation treatment of ash handling wastewater is used to remove TSS. Scale inhibitor should be added in the treatment process to prevent fouling of the backwater pipeline.

Figure 13 — Process flow of ash handling wastewater treatment and reuse

Annex A
(informative)

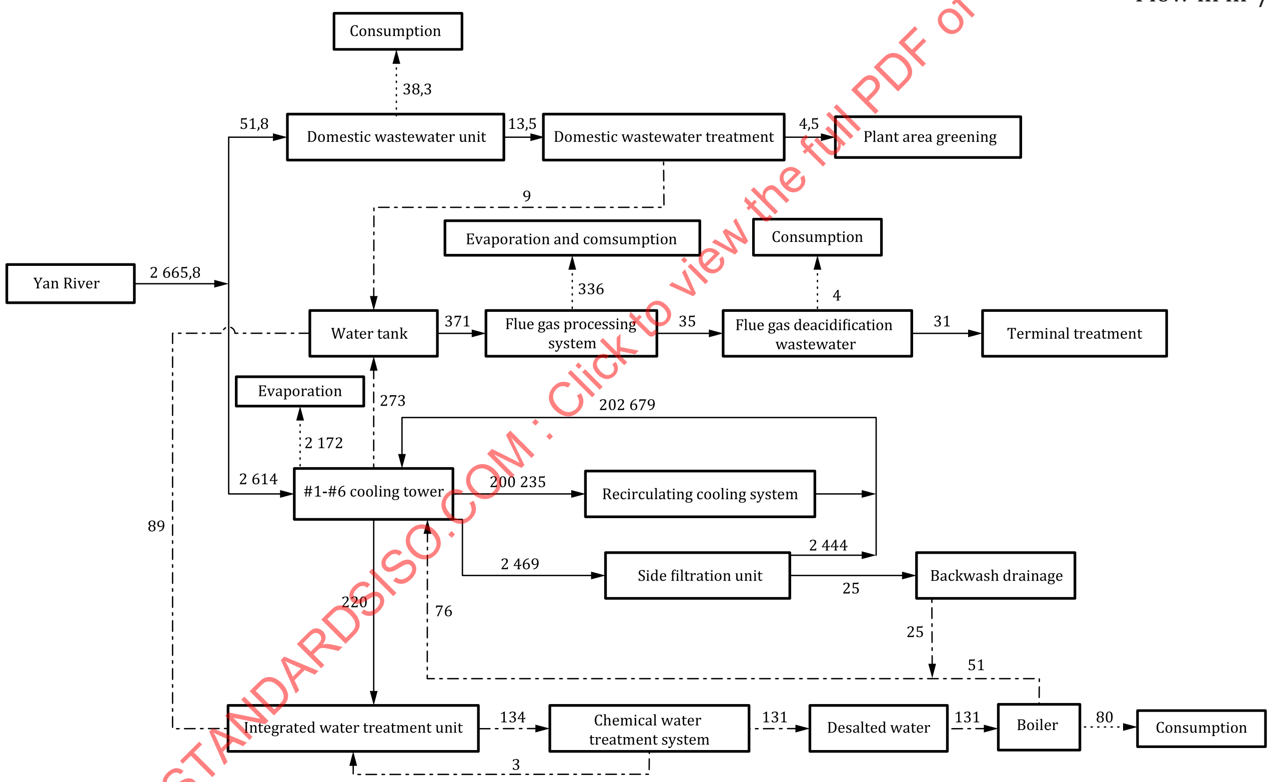
Cases of water balance in thermal power plants

A.1 Coal-fired power plant

A.1.1 General

Figure A.1 shows the water balance scheme of a coal-fired power plant, whose installed capacity is 3 300 MW (6×350 MW+2×600 MW), in which two 600 MW units use air as the cooling medium. The water withdrawal is 2 665,8 m^3/h, taken from the Yan River. The water quality of the Yan River is shown in Table A.1.

Flow in m^3/h



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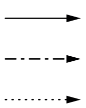


the solid line represents the water supply

the dashed line represents the water reuse path

the dotted line represents the water consumption path

Figure A.1 — Water balance diagram of a coal-fired power plant

Table A.1 — Water quality of Yan River

No.	Parameter	Value	No.	Parameter	Value
1	Turbidity (NTU)	6,95	9	Ca^{2+} (mg/l)	110,4
2	pH	7,09	10	Mg^{2+} (mg/l)	24,4
3	Total alkalinity (mg/l)	3,04	11	Na^{+} (mg/l)	15
4	Conductivity (µs/cm)	663	12	SiO_2 (mg/l)	11,6
5	HCO_3^- (mg/l)	4,32	13	NO_3^- (mg/l)	7,6
6	CO_3^{2-} (mg/l)	0	14	SO_4^{2-} (mg/l)	133
7	Hardness (mg/l)	3,77	15	Cl^- (mg/l)	18,9
8	COD_{Mn} (mg/l)	0,63	16	Total solid content (mg/l)	456
NOTE Hardness and alkalinity are calculated in the form of $CaCO_3$.					

Table A.2 shows water quality requirements of reuse water in a coal-fired power plant.

Table A.2 — Water quality requirements of reuse water in a coal-fired power plant

Number	Parameter	Fuel supply system-Washing water	Boiler and auxiliary system-Boiler make-up	Recirculating cooling system-Cooling water	Flue gas processing system-Process water	Greening unit-Water for Greening
1	pH	6,5 to 9,0	8,8 to 9,3	6,5 to 8,0	6,5 to 8,5	6,5 to 9,0
2	TSS (mg/l)	≤ 30	—	≤ 30	≤ 50	—
3	Turbidity (NTU)	—	—	≤ 5	≤ 5	≤ 5
4	Chroma	≤ 30	—	≤ 30	≤ 30	≤ 30
5	BOD_5 (mg/l)	≤ 30	—	≤ 10	≤ 10	≤ 20
6	COD (mg/l)	—	—	≤ 60	≤ 60	—
7	Fe (mg/l)	≤ 0,3	—	≤ 0,3	≤ 0,3	≤ 1,5
8	Mn (mg/l)	≤ 0,1	—	≤ 0,1	≤ 0,1	≤ 0,3
9	Cl^- (mg/l)	≤ 250	—	≤ 250	≤ 250	—
10	SiO_2 (mg/l)	—	≤ 0,02	≤ 50	≤ 30	—
11	Total hardness (mg/l)	≤ 450	≤ 0,002	≤ 450	≤ 450	—
12	Total alkalinity (mg/l)	≤ 350	—	≤ 350	≤ 350	—
13	Sulfate (mg/l)	≤ 250	—	≤ 250	≤ 250	—
14	NH_3-N (mg/l)	—	—	≤ 10	≤ 10	≤ 20
15	TP (mg/l)	—	—	≤ 1	≤ 1	—
16	TDS (mg/l)	≤ 1,000	≤ 0,1	≤ 1,000	≤ 1,000	≤ 1,000
17	Petroleum (mg/l)	—	0	≤ 5	0	—
NOTE Hardness and alkalinity are calculated in the form of $CaCO_3$.						

Water quality, wastewater treatment and reuse in this power plant are as follows:

A.1.2 FGD wastewater

This power plant uses the wet desulfurization process to remove sulfur dioxide from flue gas. The water quality of FGD wastewater is shown in Table A.3.

Table A.3 — Water quality of FGD wastewater

No.	Parameter	Value	No.	Parameter	Value
1	Total mercury (μg/l)	1,79	10	Ca^{2+} (mg/l)	780,6
2	Total chromium (μg/l)	4,70	11	Mg^{2+} (mg/l)	20,429,35
3	Total cadmium (μg/l)	0,97	12	Na^{+} (mg/l)	803
4	Total lead (μg/l)	4,56	13	TSS (mg/l)	3,231
5	Total zinc (μg/l)	8,86	14	COD_{Cr} (mg/l)	189,59
6	Total arsenic (μg/l)	5,90	15	TDS	14,92 %
7	Total nickel (μg/l)	91,42	16	Cl^{-} (mg/l)	9,499,18
8	Total fluorides(mg/l)	240,5	17	pH	6,63
9	Total sulphides (mg/l)	1,81	18	SO_4^{2-} (mg/l)	56,296

In this power plant, the process of neutralization + flocculation + oxidation is used to remove heavy metals, TSS, fluorides, calcium and magnesium from FGD wastewater. The effluent water goes into the terminal treatment system, using the process of pretreatment + concentration + crystallization to reuse the wastewater.

A.1.3 Resin reclaimed wastewater

The effluent of chemical water treatment system is mainly resin reclaimed wastewater, which is produced during preparation of desalted water. Water quality values are shown in Table A.4.

Table A.4 — Water quality of resin reclaimed wastewater

No.	Parameter	Value	No.	Parameter	Value
1	pH	8,56	9	Cl^{-} (mg/l)	2,150
2	TSS (mg/l)	—	10	Ca^{2+} (mg/l)	124,25
3	Turbidity (NTU)	6	11	Total hardness (mg/l)	7,300
4	Chroma	—	12	Total alkalinity (mg/l)	111,7
5	BOD_5 (mg/l)	—	13	Sulfate (mg/l)	264
6	COD (mg/l)	23,9	14	NH_3-N (mg/l)	—
7	K^{+} (mg/l)	316,71	15	Conductivity (μs/cm)	—
8	Na^{+} (mg/l)	1,304,57	16	TDS (mg/l)	4,606,3
NOTE Hardness and alkalinity are calculated in the form of $CaCO_3$.					

Resin reclaimed wastewater with high salt content is discharged into integrated water treatment unit and treated in combination with cooling tower blowdown by the process of UF + RO. The effluent is reused in flue gas processing systems (reclaimed water quantity: 89 m^3/h) and chemical water treatment systems (reclaimed water quantity: 134 m^3/h).

A.1.4 Boiler blowdown

The pH value of boiler blowdown in this plant is around 9 to 10, with good water quality and high temperature (about 90 °C). It is reused in recirculating cooling systems (reclaimed water quantity: 51 m^3/h) in summer and transported into the heating network to make full use of its heat in winter.

A.1.5 Cooling tower blowdown

The recirculating cooling system is adopted in #1-#6 cooling tower, while an air-cooling system is adopted in #7-#8 cooling tower in this plant. The amount of cooling tower blowdown is huge. Some of the wastewater is directly utilized for flue gas processing (reclaimed water quantity: 273 m^3/h); the remaining wastewater goes into the integrated water treatment unit and is treated in combination with chemical water treatment system wastewater using the UF + RO process. The effluent is used to flue gas processing (reclaimed water quantity: 89 m³/h) and chemical water treatment (reclaimed water quantity:134 m³/h).

A.1.6 Others

Back-wash drainage of the cooling system side filtration unit contains a large number of solid particles. The back-wash drainage is treated by natural sedimentation to remove solid particles, and the treated water can be reused to the recirculating cooling system (reclaimed water quantity:25 m³/h).

The main pollutants of domestic sewage are BOD_5, COD and TSS. These are treated using the biological contact oxidation process. The effluent is reused in the greening unit (reclaimed water quantity: 4,5 m³/h) and flue gas processing system (reclaimed water quantity: 9 m³/h).

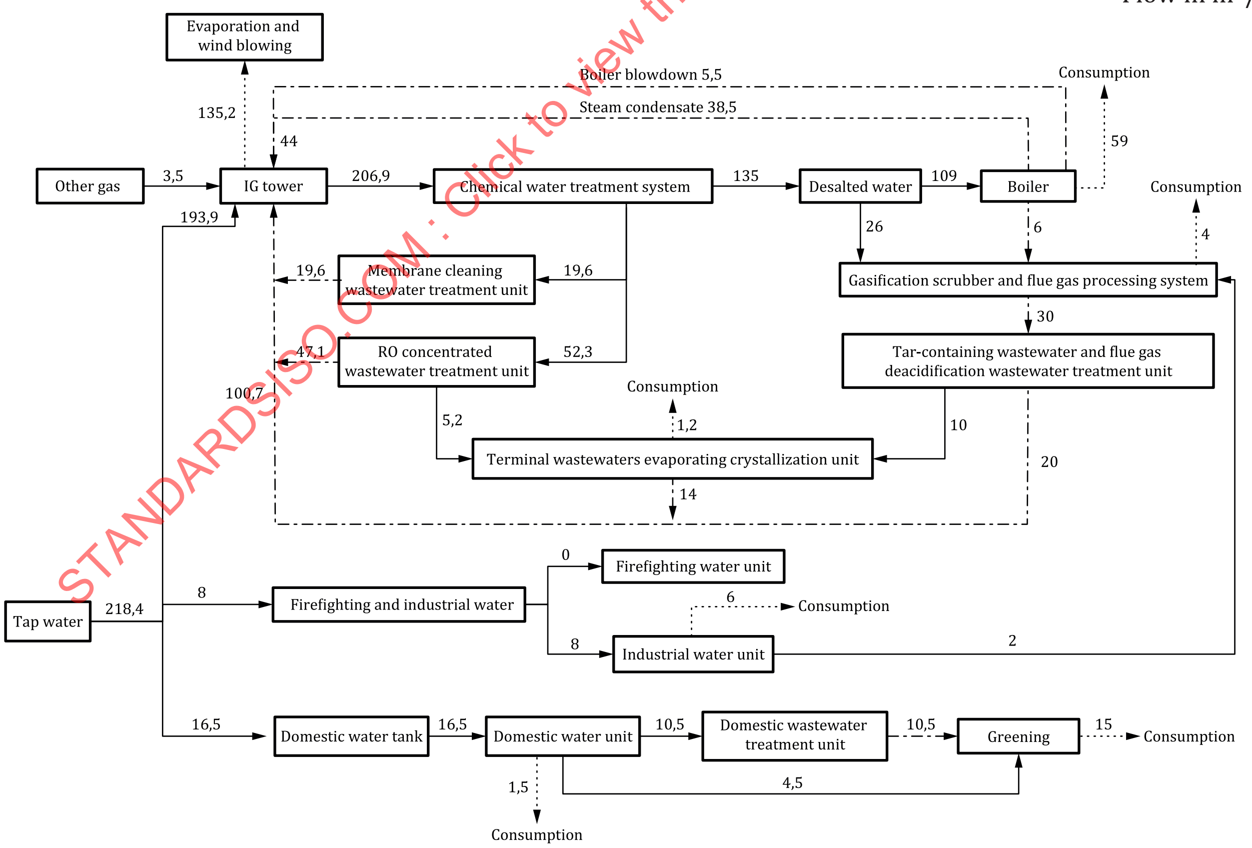
The total amount of water reused in this plant is 597,5 m³/h. Except for evaporation, all the water in the power plant has been reused and the wastewater has achieved zero liquid discharge.

A.2 IGCC power plant

A.2.1 General

Figure A.2 shows the water balance system of an IGCC power plant in China. The installed capacity of the power plant is 265 MW. The water quality requirements of each process system in the power plant are high, except the firefighting water unit and the industrial water unit. The quantity of water intake of the power plant from tap water is 218,4 m³/h [25].

Flow in m³/h



Key

——►	the solid line represents the water supply path
-·-·-►	the dashed line represents the water reuse path
·······►	the dotted line represents the water consumption path

Figure A.2 — Water balance diagram of an IGCC power plant

Table A.5 shows the water quality requirements of reuse water in an IGCC power plant. The water quality parameters of reuse water should not exceed the values in Table A.5.

Table A.5 — Water quality requirements of reuse water in an IGCC power plant

No.	Parameter	Boiler and auxiliary system-Boiler make-up	Recirculating cooling system-Cooling water	Flue gas processing system-Process water
1	pH	8,8 to 9,3	6,5 to 8,0	6,5 to 8,5
2	TSS (mg/l)	—	≤ 30	≤ 50
3	Turbidity (NTU)	—	≤ 5	≤ 5
4	Chroma	—	≤ 30	≤ 30
5	BOD_5 (mg/l)	—	≤ 10	≤ 10
6	COD (mg/l)	—	≤ 60	≤ 60
7	Fe (mg/l)	—	≤ 0,3	≤ 0,3
8	Mn (mg/l)	—	≤ 0,1	≤ 0,1
9	Cl^- (mg/l)	—	≤ 250	≤ 250
10	SiO_2	≤ 0,02	≤ 50	≤ 30
11	Hardness, total (mg/l)	≤ 0,002	≤ 450	≤ 450
12	Alkalinity, total (mg/l)	—	≤ 350	≤ 350
13	Sulfate (mg/l)	—	≤ 250	≤ 250
14	NH_3-N (mg/l)	—	≤ 10	≤ 10
15	TP (mg/l)	—	≤ 1	≤ 1
16	TDS (mg/l)	≤ 0,1	≤ 1,000	≤ 1,000
17	Petroleum (mg/l)	0	≤ 5	0
NOTE	Hardness and alkalinity are calculated in the form of $CaCO_3$.			

The water quality, treatment methods and reuse paths for various types of wastewater are introduced as follows:

A.2.2 Tar-containing wastewater and FGD wastewater

Tar-containing wastewater and FGD wastewater are typical types of wastewater in the IGCC power plant. A mix of the two wastewaters is difficult to treat. The water quality of mixed wastewater is shown in Table A.6.

Table A.6 — Water quality of tar-containing wastewater and FGD wastewater

No.	Parameter	Value
1	pH	8,13
2	Cl^- (mg/l)	855
3	TSS (mg/l)	408
4	NH_3-N (mg/l)	365
5	COD (mg/l)	1,390
6	BOD (mg/l)	390
7	Alkalinity, total (mg/l)	9,69
8	TDS (mg/l)	3,140

The mixed wastewater is sent to the tar-containing wastewater and FGD wastewater treatment unit. COD and TSS in the mixed wastewater are removed by the A/O + coagulation sedimentation + filtration

+ ozone oxidation process. The wastewater is then treated using aerated biological fluid technology to degrade ammonia nitrogen. After being treated by the sand filtration + UF +RO process, the effluent is reused in the IG tower (reclaimed water quantity: 20 m^3/h) and the concentrated water is sent to the terminal wastewater evaporating crystallization unit (reclaimed water quantity: 10 m^3/h). MVR technology is used to separate salt from wastewater in the terminal wastewater evaporating crystallization unit. The effluent is reused in the IG tower (reclaimed water quantity: 14 m^3/h) and the produced salt is transported outside the power plant.

A.2.3 Membrane washing wastewater and RO concentrated water

Membrane washing wastewater and RO concentrated water are the types of drainage water produced by the chemical water treatment system during the preparation of desalted water. The two types of wastewater are collected, treated and reused separately. The water quality of RO concentrated water is shown in Table A.7.

Table A.7 — Water quality of RO concentrated water

No.	Parameter	Value
1	pH	7 to 8
2	Cl^- (mg/l)	150 to 250
3	SO_4^{2-} (mg/l)	19,200 to 28,800
4	NH_3-N (mg/l)	<2
5	COD (mg/l)	20 to 30
6	Hardness, total (mg/l)	600 to 700
7	TDS (mg/l)	1,000 to 1,200

NOTE Hardness and alkalinity are calculated in the form of $CaCO_3$.

Membrane washing wastewater has low salt content and high TSS. It can be reused to IG tower after being treated by coagulation sedimentation and filtration, and the reclaimed water quantity is 19,6 m^3/h.

RO concentrated water has high salt content and hardness and low COD. After being treated by the chemical softening + filtration + UF +RO process, the effluent is reused in the IG tower (reclaimed water quantity: 47,1 m^3/h) and the concentrated water is sent to the terminal wastewater evaporating crystallization unit (reclaimed water quantity: 5,2 m^3/h). MVR technology is used to separate salt from wastewater in the terminal wastewater evaporating crystallization unit. The fresh water is reused in the IG tower (reclaimed water quantity: 14 m^3/h) and the produced salt is transported outside the power plant.

A.2.4 Boiler blowdown

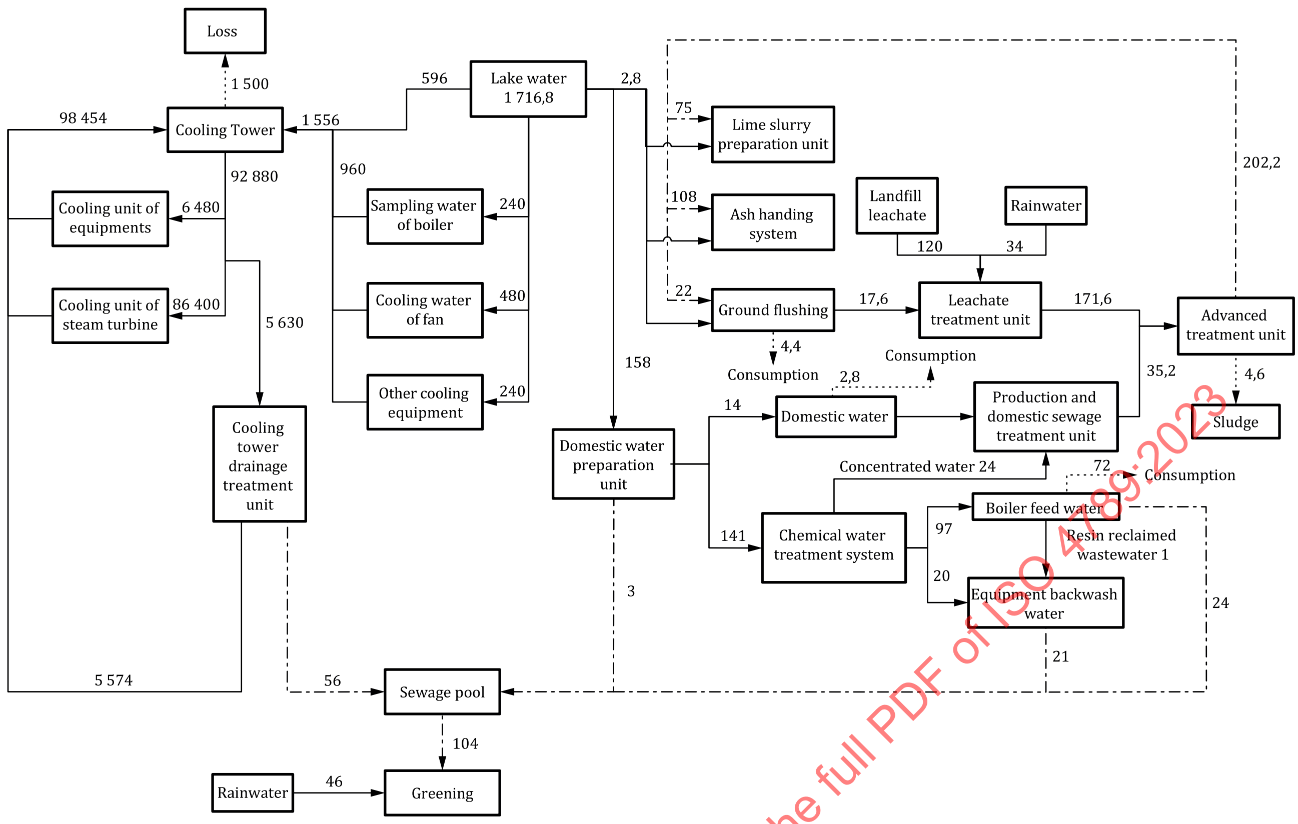
Boiler blowdown in the IGCC power plant has better water quality. It is reused in the IG tower after cooling down (reclaimed water quantity: 5,5 m^3/h). The steam condensate from the boiler is reused in the IG tower directly (reclaimed water quantity: 38,5 m^3/h).

The total quantity of reuse water in the XX IGCC power plant is 161,2 m^3/h. Except for evaporation, all the water in the power plant has been reused and the wastewater has achieved zero liquid discharge.

A.3 Waste incineration plant

A.3.1 General

Figure A.3 shows the water balance system of a waste incineration power plant in China. The installed capacity of the power plant is 12 MW and the daily garbage disposal capacity is 600 tons [26].



Key

the solid line represents the water supply path

the dashed line represents the water reuse path

the dotted line represents the water consumption path

Figure A.3 — Water balance diagram of a waste incineration power plant

The daily water withdrawal of the power plant from Erhai Lake is 1 716,8 m^3. The amount of water consumed in the operation is 79,2 m^3/d, and the total volume of water evaporated in the cooling tower and discharged with the sludge is 1 504,6 m^3/d. Table A.8 shows the pollutants limitations of reuse water in the water supply system of a waste incineration power plant. The quantity of pollutants in reuse water should not exceed the quantity showed in Table A.8.

Table A.8 — Water quality requirements of reuse water in a waste incineration power plant

No.	Parameter	Fuel supply system-Washing water	Boiler and auxiliary system-Boiler make-up water	Recirculating cooling system-Recirculating cooling water	Flue gas processing system-Process water	Greening unit-Water for greening
1	pH	6,5 to 9,0	8,8 to 9,3	6,5 to 8,0	6,5 to 8,5	6,5 to 9,0
2	TSS (mg/l)	≤ 30	—	≤ 30	≤ 50	—
3	Turbidity (NTU)	—	—	≤ 5	≤ 5	≤ 5
4	Chroma	≤ 30	—	≤ 30	≤ 30	≤ 30
5	BOD_5 (mg/l)	≤ 30	—	≤ 10	≤ 10	≤ 20
6	COD (mg/l)	—	—	≤ 60	≤ 60	—
7	Fe (mg/l)	≤ 0,3	—	≤ 0,3	≤ 0,3	≤ 1,5
NOTE Hardness and alkalinity are calculated in the form of $CaCO_3$.						