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Volume 2**

**Design of Thermal Power Facilities
Book 9/12
« Water Treatment Facility »**

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Table of Contents

Chapter-1. Comparison between Technical Regulation and Technical Guideline of feed-water treatment facility	1
Chapter-2. Each Items of Guideline.....	2
Chapter-3. Water Quality Limit of Feed-water, Boiler water, Steam purity.....	59
Chapter-4. Reference International Standards	70
Chapter-5. Reference Japanese Standards	73
Chapter-6. Reference TCVN	74
Chapter-7. Referenced Literature and Materials.....	75

List of Tables

Table- 1: Comparison between Technical Regulation and Technical Guideline of feed-water treatment facility	1
Table- 2: Conversion table of concentration of dissolved gas	4
Table- 3: Conversion table of concentration unit.....	4
Table- 4: Conversion of calcium carbonate	5
Table- 5: Treatment method for feed-water and boiler water	9
Table- 6: Recommended water quality standard by CWT (supercritical once-through boiler)	12
Table- 7: Recommended water tube boiler water limits and associated steam purity.....	16
Table- 8: Boiler water limit (ABMA)	17
Table- 9: ASME guidelines for water quality in modern industrial water tube boilers for reliable continuous operation.....	17
Table- 10: Comparison of steam purity limits JIS with other international standards	19
Table- 11: Steam purity (IEC 61360-2001).....	20
Table- 12: Comparison of various ion exchange water systems	32
Table- 13: Operation pressure of reverse osmosis membrane.....	34
Table- 14: Recommended pH of feed-water	44
Table- 15: Example of chemical injection method.....	50
Table- 16: Frequency of analysis	52
Table- 17: Quality of feed-water and boiler water for cylindrical boiler	60
Table- 18: Quality of feed-water and boiler water for special circulation boiler	61
Table- 19: Quality of feed-water and boiler water for water tube boiler (circulation boiler) (1).....	62
Table- 20: Quality of feed-water and boiler water for water tube boiler (circulation boiler) (2).....	63
Table- 21: Quality of feed-water and boiler water for HRSG.....	65
Table- 22: Quality of feed-water and boiler water for once-through boiler	66
Table- 23: Quality of steam generated by boiler (³⁹).....	66
Table- 24: Quality of water for once-through boiler during start-up (in case of applying volatile treatment).....	67

Table- 25: Quality of water for once-through boiler during start-up (in case of applying oxidization treatment)	67
Table- 26: Boiler Water Limits for Industrial Water Tube Boilers.....	68
Table- 27: Recommended Water Tube Boiler Water Limits and Associated Steam Purity at Steady Load Operation (¹)	69
Table- 28: Reference international technical standards.....	70
Table- 29: Reference Japanese technical standards.....	73
Table- 30: Reference TCVN	74

List of Figures

Fig- 1: Overall configuration of chemical treatment cycle	3
Fig- 2: Change of water treatment for thermal power plant in Japan.....	7
Fig- 3: Classification of boiler water treatment method	10
Fig- 4: Iron and hydrogen potential vs. pH diagram (25°C)	13
Fig- 5: Impact of the electric conductivity for carbon steel corrosion	14
Fig- 6: Dissolved oxygen and corrosion rate (neutral, high purity static water).....	14
Fig- 7: Schematic illustration of scale adhesion status	15
Fig- 8: Relation boiler pressure with silica in the boiler water and steam (excluding in case of AVT).....	21
Fig- 9: Place of impurity penetration, corrosion, scale adhesion of drum boiler (EPRI).....	22
Fig- 10: Typical basic treatment method	23
Fig- 11: Typical construction of pulsating type coagulator	25
Fig- 12: Typical construction of coagulation pressure floating unit	26
Fig- 13: Example of a flow sheet of the coagulation filtration unit	27
Fig- 14: Type of Ion exchange water system.....	28
Fig- 15: Example of up-flow regeneration type.....	29
Fig- 16: Comparison of water quality between counter-current re-generation types.....	29
Fig- 17: Distribution of ions in the resin of counter-current regeneration type and co-current regeneration type.....	30
Fig- 18: Typical flow of counter-current regeneration type with multi-layer-bed.....	31
Fig- 19: Volume of regeneration agent and ion exchange capacity	32
Fig- 20: Osmotic phenomenon.....	34
Fig- 21: Reverse osmosis phenomenon	34
Fig- 22: Typical construction of spiral-shaped membrane module.....	36
Fig- 23: Principle of electric desalination	37
Fig- 24: Typical combination of reverse osmosis and electric desalination unit	38
Fig- 25: Typical construction of precoat-type filter	39
Fig- 26: Filter element of cartridge type filter	39
Fig- 27: Example of flow-sheet of electromagnetic filter	40

Fig- 28: Typical configuration of condensate demineralizer	41
Fig- 29: Example of a change in electric conductivity of NH ₄ -type demineralizing unit.....	43
Fig- 30: Relationship between solubility of magnetite and pH (Hydrogen 25°C at 1 atm saturation).....	45
Fig- 31: Solubility and pH of the copper component.....	46
Fig- 32: Effect of pH on the solubility of iron hydroxide	47
Fig- 33: Effect of the oxygen on the concentration of iron.....	47
Fig- 34: Typical chemical injection point for water treatment (once-through boiler)	49
Fig- 35: Sampling point and monitoring Point (example of once-through boiler)	53
Fig- 36: Sampling equipment flow-sheet (example of once-through boiler).....	54
Fig- 37: Typical configuration of sampling system	57

List of Photos

Photo- 1: Cross-section of hollow fiber membrane in the capillary fiber membrane filter	40
Photo- 2: Condensate demineralizer	41
Photo- 3: Example of ammonia attack of condenser cooling pipe.....	43
Photo- 4: Example of oxygen corrosion of steel pipe for HP feed-water heater.....	44
Photo- 5: Pressure swing absorption equipment	48
Photo- 6: Oxygen gas injection equipment.....	48
Photo- 7: Chemical injection equipment.....	49
Photo- 8: Chemical feed skid.....	49
Photo- 9: Pressure reducing valve (1).....	55
Photo- 10: Pressure reducing valve (2).....	55
Photo- 11: Pressure reducers.....	55
Photo- 12: Example of sampling rack.....	56
Photo- 13: Pressure reducers.....	57
Photo- 14: Sample cooler.....	57
Photo- 15: Thermal shutoff valve	58
Photo- 16: Temperature control unit	58
Photo- 17: Back Pressure regulator relief valve.....	58
Photo- 18: Cation conductivity resin tube.....	58
Photo- 19: Manifold sample valve	58
Photo- 20: Sample sequencer.....	58

List of Acronyms/Abbreviations

ABMA	American Boiler Manufacturers Association
ASME	American Society of Mechanical Engineers
AVT(O)	All Volatile Treatment (without the addition of hydrazine)
AVT(R)	All Volatile Treatment (addition of hydrazine)
CT	Caustic Treatment
CWT	Combined Water Treatment
EPRI	Electric Power Research Institute
FAC	Flow Accelerated Corrosion
HRSG	Heat Recovery Steam Generator
ICP	Inductivity Coupled Plasma
IEC	International Electro-technical Commission
IS	Indian Standard
ISO	International Organization for Standardization
JIS	Japanese Industrial Standard
NWT	Neutral Water Treatment
OT	Oxygen Treatment
PC	Phosphate Treatment
PC(L)	Low pH Coordinated Phosphate Treatment
PC(H)	High pH Coordinated Phosphate Treatment
PSA	Pressure Swing Absorption
PT	Phosphate Treatment
TCVN	Vietnamese National Standard
VGB	VGB PowerTech.

Chapter-1. Comparison between Technical Regulation and Technical Guideline of feed-water treatment facility

The article number of this guideline is shown in Table-1 contrasted technical regulation with technical guideline for easy understanding.

Table- 1: Comparison between Technical Regulation and Technical Guideline of feed-water treatment facility

Technical Regulation		Technical Guideline	
Article 213.	General provision of feed-water treatment facility	Article 213.	General provision
-1.	Water quality of condensate water, feed-water and boiler water	-1.	Water quality of condensate water, feed-water and boiler water
Article 214.	Feed-water treatment facility	Article 214.	Feed-water treatment facility
-1.	Corrosive matters	-1.	Corrosive matters
-2.	Feed water heater	-2.	Feed water heater
-3.	VT and OT	-3.	VT and OT
Article 215.	General provision of chemical injection equipment	Article 215.	General provision of chemical injection equipment
-1.	Chemical injection equipment	-1.	Chemical injection equipment
-2.	pH	-2.	pH
-3.	O ₂ injection for CWT	-3.	O ₂ injection for CWT
Article 216.	Chemical injection equipment	Article 216.	Chemical injection equipment
-1.	Chemical injection	-1.	Chemical injection
-2.	Copper alloy	-2.	Copper alloy
-3.	Chemical injection pump	-3.	Chemical injection pump
-4.	Ammonia injection	-4.	Ammonia injection
-5.	Oxygen injection	-5.	Oxygen injection
Article 217	General provision of sampling rack and water quality monitoring equipment	Article 217	General provision of sampling rack and water quality monitoring equipment
-1.	Sampling equipment	-1.	Sampling equipment
Article 218	Sampling rack and water quality monitoring equipment	Article 218	Sampling rack and water quality monitoring equipment
-1.	Sampling point	-1.	Sampling point
-2.	Depressurizing	-2.	Depressurizing
-3.	Surveillance instrument	-3.	Surveillance instrument
-4.	Automation of sampling equipment	-4.	Automation of sampling equipment
-5.	Structure of sampling equipment	-5.	Structure of sampling equipment

Article 213. General provision of feed-water treatment facility

Article 213-1. Water quality of condensate water, feed-water and boiler water

1. Purpose of feed-water treatment

The purpose of the water quality control (feed-water, boiler water) is to prevent the scale adhesion in the boiler, steam turbine system and other ancillary system due to the water quality of water and steam and corrosion and failure such as a carry-over, and to maintain plant efficiency always best. The thermal power plants for business use, while they have various type, operation temperature, operation pressure and operation circumstances, they are becoming increasingly efficient in recent years such high temperature, high pressure, large capacity, combined cycle and greatly changes in electricity supply and demand situation, Therefore, unless the quality of feed-water, condensate water and boiler water tightly is controlled than ever, it causes the accident which lead to plant shut down due to scale adhesion, corrosion and a failure of carry-over. Therefore, the role of play in maintaining and improving water management of plant reliability is important and always pay close attention, it is necessary to implement water treatment for feed-water.

2. Overview of feed-water treatment

The EPRI (Electric Power Research Institute) organized, consolidated and presented the various water treatment method in the relation of material for feed-water and condensate system and purity (provision of condensate demineralizer, prevention of air leakage of condenser and cooling water cooler) of feed-water and condensate water showing an overview of the chemical cycle as in a conceptual diagram Fig-1. Here, the situation becomes better on water quality and chemical cycle is improved when closing to home direction. In other words, if the purity of feed-water and boiler water is improved, the treatment method can be moved from conventional phosphate treatment (PT) via AVT(R) and AVT (O) reach to CWT. This decreases the amount of chemicals and has also improved the reliability of plant operation and performance, and the rate of operation and thermal efficiency will be improved. As concrete measures to enforce such a direction, the matters listed as follows.

(1) To avoid the use of copper alloys by means of applying iron material for configuration of feed-water and condensate water system:

(2) To prevent mixing of impurity:

1) To reduce mixing impurity from make-up water (suppression of the make-up rate and improvement of purity of make-up water).

2) To install condensate demineralizer. (Including drum type).

(3) To prevent air leakage in the condenser thoroughly (detection and repair of air leak point and repair):

- (4) To keep feed-water, condensate water and boiler water from reducing status to oxidizing status (from base to noble potential).

Currently, the best way is CWT which only ammonia and oxygen are applied as chemical, and the consumption of them is less than conventional AVT and is desirable both economically and environmentally. The AVT (O) is in the next position. This is the treatment of both worlds which has efficacy of a treatment by not using the hydrazine. However, in this case it is mandatory to preserve the water quality of high purity, it is essential to prevent pollution and to remove impurities of the feed-water and condensate system. Of these, the former prevention of pollution of is the basis of the water control; EPRI recommends transition to condensate demineralizer for the drum boiler.

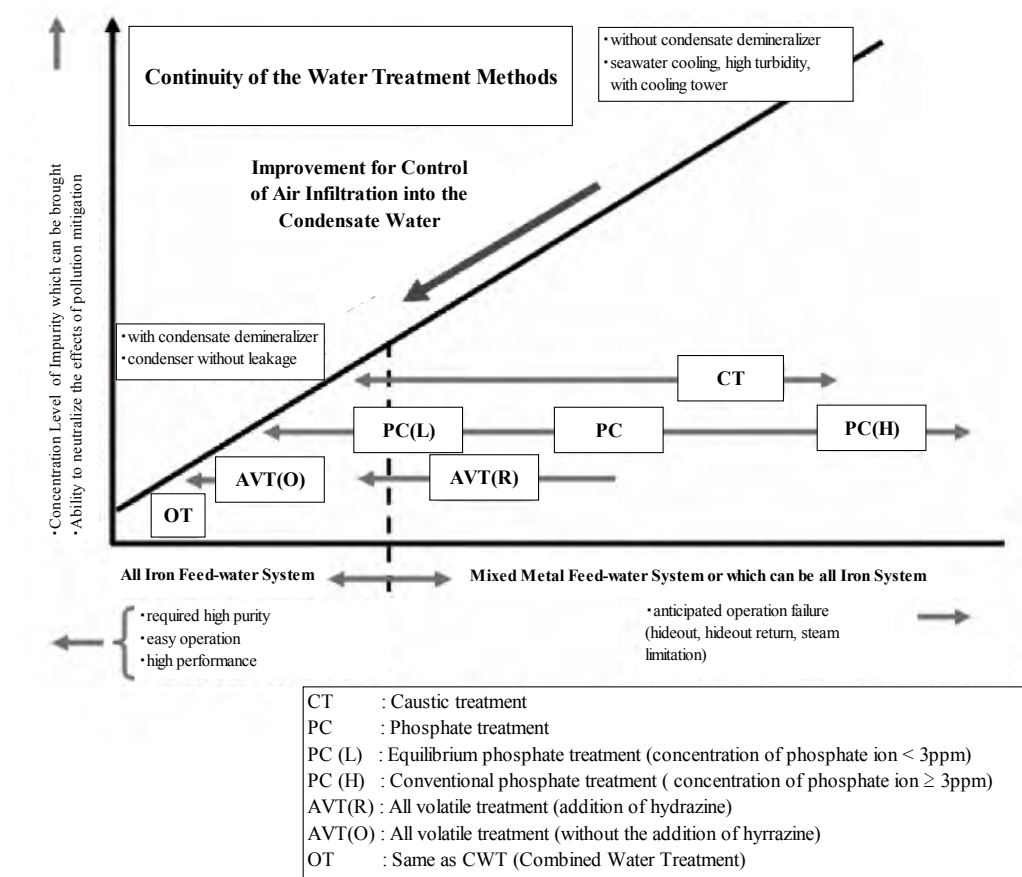


Fig- 1: Overall configuration of chemical treatment cycle

Reference: P-39 Journal (No.614: Nov. /2007): TENPES

3. The basic unit of feed-water treatment and related terms
- 3.1 Unit for concentration

In here, the unit of concentration represents the amount of relatively small amounts which is contained in the feed-water and boiler water is organized.

(1) mg/L, μ g/L (*ppb)

The amount of material contained in 1L of water, represents the number of “mg” or “ μ g”. However, “ppm” means “parts per million” represents the weight fraction of an abbreviation for one million, “ppb” means “parts per billion” represents the weight fraction of an abbreviation for billion.

(2) meq/L (*epm)

The amount of material which is dissolved in 1L of water represents the number of equivalents “mg”. “epm” is the abbreviation of “equivalent per million”.

(3) Unit of concentration gas dissolved in water

There are oxygen (O₂) and carbon dioxide (CO₂) which are dissolved in water. The dissolved concentration of these gases is expressed as the weight of the gas mg/L (ppm) contained in 1L of water. The dissolved gas in volume in the 1L of water may be also expressed in mL/L in terms of normal state (°C: 760mmHg) as shown in Table-2.

Table- 2: Conversion table of concentration of dissolved gas

unit	Dissolved oxygen O ₂		Dissolved carbon dioxide CO ₂		Dissolved nitrogen N ₂	
mg/L (ppm)	1.0	1.43	1.0	1.98	1.0	1.25
mL/L	0.7	1.0	0.51	1.0	0.80	1.0

Reference: P-41 of Journal (No.608: May/2007): TENPES

(4) Equivalent concentration of Calcium Carbonate (CaCO₃)

The concentration of substances that are dissolved in water is expressed in equivalent calcium carbonate (CaCO₃) mg/L (ppm). If applying this expression of concentration, there is advantage which can be compared for each equivalent weight calculation of dissolved substances without epm as shown in Table-3 and Table-4. At present, this is applied to the expression of concentration of alkalinity, hardness and the calculation of the exchange capacity of ion exchange process.

*: The 1L cold water containing low concentrations in room temperature is about 1kg. The unit shown in () is often used for convenience.

Table- 3: Conversion table of concentration unit

mg/L (ppm)	μ g/L (ppb)	meq/L (epm)	grains/gallon (gpg) (USA)
1.0	1000	1/1 equivalent	0.0584
0.001	1.0	0.001/1 equivalent	0.000058
1 equivalent	1000 equivalent	1.0	0.0584 equivalent
17.12	17120	17.12/1 equivalent	1.0

Reference: P-41 of Journal (No.608: May/2007): TENPES

Table- 4: Conversion of calcium carbonate

Substance	Chemical Formula	Molecular weight	CaCO ₃ Conversion factor		Substance	Chemical Formula	Molecular weight	CaCO ₃ Conversion factor	
			A	B				A	B
calcium	Ca ²⁺	40.1	2.50	0.40	Chloride ion (univalent)	Cl ⁻	35.5	1.41	0.71
magnesium	Mg ²⁺	24.3	4.10	0.24	Sulfate ion (bivalent)	SO ₄ ²⁻	96.1	1.04	0.96
Sodium	Na ⁺	23.0	2.18	0.46	Bicarbonate ion (univalent)	HCO ₃ ⁻	61.0	0.82	1.22
Calcium carbonate	CaCO ₃	100.08	1.00	1.00	Silica (univalent*)	SiO ₂	60.1	0.83	1.20

Note-1: The conversion rate of silica to calcium is shown only in conversion value of a univalent because the ion exchange process is carried out in univalent calculation, although there are univalent and bivalent conversion of silica to calcium carbonate.

Note-2: Conversion factor mg/L x A = CaCO₃ mg/L CaCO₃ mg/L x B = mg/L

Reference: P-41 of Journal (No.608: May/2007): TENPES

3.2 Terms for the boiler water

There are many items which indicate the quality such as feed-water, boiler water and condensate water, however in terms of where the key items such as pH, electric conductivity, alkalinity and total hardness are explained briefly.

(1) pH

The pH is the value which indicates concentration of hydrogen ions [H⁺] in the water as shown below, and has been used as an indicator of the strength of the acid or alkaline of water.

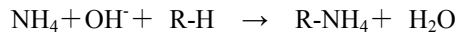
$$\text{pH} = \log 1 / [\text{H}^+] = -\log [\text{H}^+]$$

The ionic product of water (product of [H⁺] and [OH⁻]) is constant when the temperature is constant, which is 10⁻¹⁴ in 25°C. Thus, in case of pure water becomes [H⁺] = 10⁻⁷, [OH⁻] = 10⁻⁷g-ion/L and pH = 7. This is called neutral.

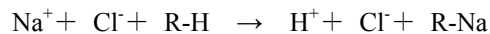
(2) Electric conductivity

The inverse of the solution resistance between the 1m² cross section area and 1m length is called the electric conductivity, and used as a measure of the purity of the water. The value at 25°C is used for water testing and is expressed in mS/m to one thousand of a unit of S/m. However, the boiler feed-water has been injected with ammonia or hydrazine; it would dominate the electric conductivity of this water, so it cannot

be used to measure the purity of the water in this state. Therefore, the method to measure the electric conductivity (acids electric conductivity) after removal of the hydrazine and ammonia through the cation exchange resin to water in advance is applied.



This method is effective for the detection of salts as impurities, it can be got greater measurement sensitivity by means of converting salt into acid which has large electric conductivity by passing through a cation exchange resin.



(3) Alkalinity

The alkalinity is now referred to as “oxygen consumption” in Japanese Industrial Standard (JIS B8224); however, the name of the alkalinity is often used today. Alkalinity refers to the amount of acid required to reach a constant pH, generally corresponding to the amount of acid, calcium carbonate (CaCO_3) to show in terms of mg/L. The alkalinity is divided by pH value at titration end point, and divided into M-alkaline is pH4.8 and P-alkaline is pH8.3.

(4) Hardness

Hardness in this context is the concentration of calcium ions and magnesium ions that are dissolved in water is expressed in equivalent of the corresponding calcium carbonate (CaCO_3) in terms of mg/L.

4. The evolution of water treatment for thermal power plant

The power supply in Japan changed to thermal power in depending on the national economic development in 1955s. The capacity and steam conditions advanced rapidly to high temperature, high pressure and large scale shown in Fig-2, the first supercritical boiler plant has led to running in 1967.

During this advance of the treatment technologies of feed-water and boiler water, the water purification equipment which applying ion exchange resin has been introduced and alkali treatment which applying sodium phosphate and sodium hydroxide (CT: Caustic treatment) in the late 1940s. The sub-critical drum type boiler (17MPa class) was built and was launched operation applying CT in 1959, however, it had to improve water treatment technology of feed-water and boiler water immediately due to frequent trouble with alkaline corrosion of water wall tube in about six months after commercial operation.

Therefore, all volatile treatment (AVT: All Volatile Treatment) which has been developed in Europe and apply ammonia and hydrazine is introduced and applied to sub-critical drum type boiler from 1960. Since the once-through boiler commenced commercial operation in 1961 and good results were obtained by AVT,

AVT is spread rapidly and adopted to the almost advance thermal power plant. The phosphate treatment (PT: Phosphate Treatment) was reviewed according to the survey of scale in evaporating tubes in middle of 1965. The frequency extension effect of chemical cleaning has been demonstrated by means of adopting the low pH phosphate treatment (PC (L): Low pH Coordinated Phosphate Treatment) to the of phosphate ion concentration lower than 3mg/L and to adjust Na/ PO₄ molar ratio of sodium phosphate in 2.5 ~ 2.8 for drum type boiler in order to prevent alkali corrosion and the scale growth rate of tubes is reduced and the stabilization of scale property is measured. Since then, PT is recommended basically and adopted to many boilers as the water treatment for drum type high pressure boiler.

In the application of AVT and PT, the water-related failures have been prevented by means of adjusting pH to alkaline by ammonia, hydrazine and sodium phosphate and inhibiting the corrosion of material in the system and adhesion of scale by reducing maintaining dissolved oxygen as low as possible.

In contrast, the oxygen treatment (CWT: Combined Water Treatment) have been standardized in JIS B8223 in1990, and applied to the mainly supercritical once-through boiler plant by means of using high purity water that containing only the appropriate amount of dissolved oxygen. This water treatment have been focused in terms of suppression of the growth rate of the water wall tube scale, reduction of furnace pressure drop and reduction the scale adhesion to feed-water pump, and have been applied to about 50 once-through supercritical boiler units in Japan up to 2006.

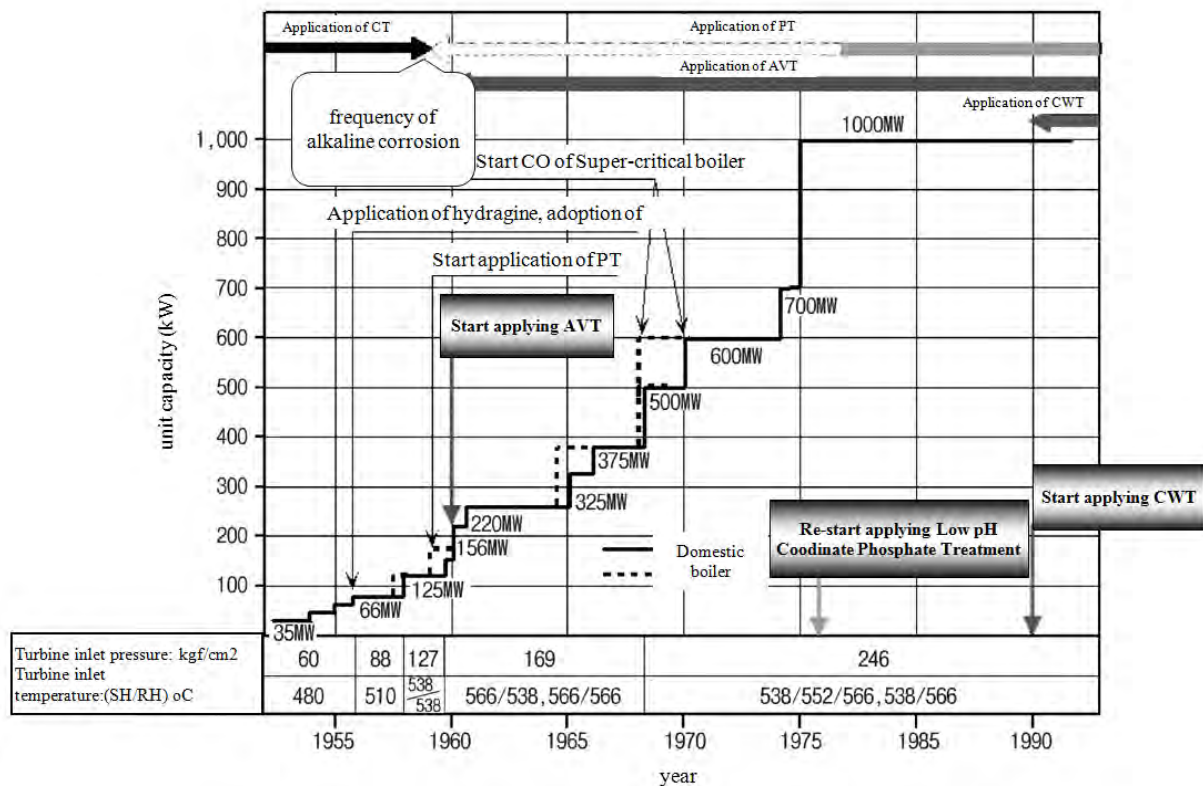


Fig- 2: Change of water treatment for thermal power plant in Japan

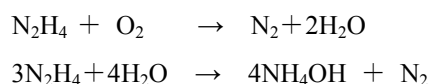
Reference: P-26 of Journal (No. 614: Nov. /2007): TENPES

5. Treatment method of feed-water and condensate water

Nowadays, the main impurities in the feed-water are metal components (corrosive products) which are eluted from material of feed-water and condensate water system because it is possible to obtain high purity make-up water. The main metal ingredients are iron and copper, the behavior of dissolution and sedimentation in the feed-water and condensate water depends on the operation condition, operation history and type of boiler. In either case of sub-critical and supercritical boiler, it has known that the material of system is eluted because that the concentration of metal components increase during passing through the drain system of LP and HP feed-water heater and water side of LP feed-water heater. Some of the iron and copper composition eluted in the feed-water and condensate water will be sediment in the HP feed-water heater, and most of them are brought to boiler and adhered or deposited on such tubes as scale. Therefore, it becomes the main management technology of water quality to minimize the rate of scale formation as possible, to prevent corrosion by excess oxygen. Currently, the two methods are adopted as feed-water and condensate water treatment, the one is volatile treatment which eliminates oxygen as much as possible and the other is oxygen treatment which injecting a small amount of oxygen.

5.1 Volatile treatment

Volatile treatment is commonly used as feed-water and condensate water treatment. This method is intended to reduce the concentration of iron and copper in the feed-water by injecting ammonia or hydrazine in the feed-water. It is effective to maintain alkalinity by means of keeping pH high to prevent corrosion of steel. Therefore, the injection of hydrazine and ammonia into the inlet of feed water heater has been widely adopted along with removal of dissolved oxygen and rising up pH. Particularly with respect to hydrazine, oxygen is removed as soon as the following equation serves to raise the pH to produce ammonia.



This method is based on the principle that the solubility of Fe_3O_4 covering the surface of steel in feed-water and condensate water decrease with increasing pH under the reducing atmosphere as shown in Fig-30.

The minimum solubility points exist as shown in Fig-31 different with iron looking at the effect of pH on solubility although it cannot explain the behavior of the copper component in the feed-water and condensate water in some respects of only solubility. The pH of this point varies with temperature under the condition of feed-water and condensate water exists in the vicinity at pH9 of 25°C. The actual measurement above pH9.1 has shown to tendency to increase with increasing copper concentration as shown in Fig-31. Therefore, in case of sub-critical boiler, the pH is limited in terms of dissolution inhibition because it cannot be raise pH.

5.2 Oxygen treatment

In recent years, the oxygen treatment has been adopted mainly for the supercritical once-through boiler depending on the improvement in purity of make-up water and demineralization technology. This method is to inject ammonia as a pH regulator in the water without using hydrazine by injecting the oxygen of about 100 μ g/L, and reduce the ion concentration in the water. It has the advantage to reduce the amount of iron bringing into boiler compared with volatile treatment because the inner surface of feed-water and condensate water is covered by trivalent iron compound which has low solubility compared with divalent iron compound which is produced by volatile treatment. In addition, trivalent iron compound is very stable at wide pH range, is capable to operate at low pH compared with volatile substances and is capable to reduce chemicals such as ammonia (shown in Fig-32 and Fig-33). On the other hand, it is necessary to apply H-type condensate demineralizer since it is difficult to generate a good protective coating and is required high purity water in case the water quality is low. In addition, most units apply volatile treatment without hydrazine at start-up when the purity of water goes bad.

6. The treatment method for boiler water

Four methods, CT, PT and AVT which adjust pH keeping low dissolved oxygen, and CWT which keep appropriate amount of dissolved oxygen on the condition to use high purity water are prescribed as the treatment of boiler currently operated shown as Table-5. The feed-water is managed to set the optimum pH range of constituent materials of HP and LP feed-water heater shown in Table-5 although the AVT to use ammonia-hydrazine is applied shown as Table-5. That is, the case shown in Table-5 and Table-5 applying copper is set to lower the upper limit of pH. Fig-3 is an organized pH and purity of water. For example, CT which pH is higher is can be applied to low purity water such as softened water, on the other hand, it is required high purity water for NWT (Neutral Water Treatment) or CWT which set pH low. Alkali treatment is not applied to high pressure boiler for business use.

Table- 5: Treatment method for feed-water and boiler water

Treatment method		Water conditioning		application	JIS Standard
		Feed water	Boiler water		
Caustic treatment (CT)		NH ₃ , N ₂ H ₄	NaOH Na ₃ PO ₄	Low and medium pressure drum boiler	
Phosphate treatment (PT)	Phosphate treatment (PT)	NH ₃ , N ₂ H ₄	Na ₃ PO ₄	Medium pressure drum boiler	1966
	Low phosphate Treatment (LPT)	NH ₃ , N ₂ H ₄	NahPO ₄ Na ₃ PO ₄	Medium and high pressure drum boiler	
All Volatile treatment (AVT)		NH ₃ , N ₂ H ₄		High pressure drum boiler Once-through boiler	
Oxygenated treatment (OT)	Natural water treatment (NWT)	O ₂		High pressure drum boiler (with condensate demineralizer) Once-through boiler	1989
	Combined water treatment (CWT)	NH ₃ , O ₂			

Reference: P-28 of Journal (No. 614: Nov. /2007): TENPES

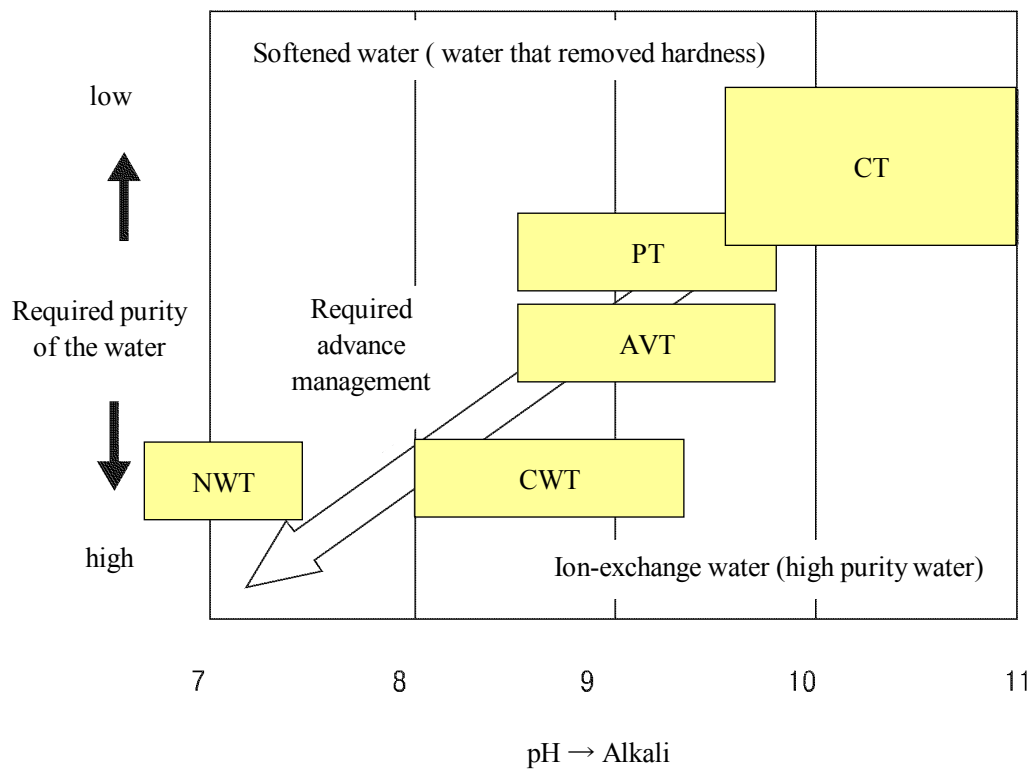


Fig- 3: Classification of boiler water treatment method

Reference: P-28 of Journal (No. 614: Nov. /2007): TENPES

6.1 Caustic treatment: (CT)

CT is the method to adjust the pH of boiler water by adding sodium hydroxide, various phosphate, hydrazine and combination of these. This method is applied to the low pressure boiler (This is not applied to high pressure boiler for business use.) because of the low temperature and pressure condition which is less restrictions on the method of make-up water treatment and water conditioner.

6.2 Phosphate treatment: (PT)

PT is the method to adjust boiler water quality maintaining the relation between concentration of phosphate salt (usually Na_3PO_4) and pH properly without the existence of excess alkaline components in the boiler water, in order to prevent corrosion of boiler evaporator tube by alkali.

The phosphate treatment is the method to maintain concentration of phosphate (usually sodium phosphate) properly and adjust pH of boiler water without the presence of free alkali in the boiler water. It is mainly adopted for middle and high pressure circulation boiler. The advantage of phosphate treatment is an advantage in a large increasing effect on the corrosion protection compared with ammonia. It is capable to increase protection effect against corrosion because the pH is increased by phosphate treatment during

normal operation as well even at start-up when concentration of dissolved oxygen is high. Therefore, many plants apply the phosphate treatment at start-up even when the volatile treatment is applied during normal operation. Also, it is capable to discharge from the system by making sludge and blowing them easily without adhering the hardness such as magnesium and calcium to the tubes. In addition, it is advantageous to the unit which is susceptible to small leakage of the condenser tube because it has a buffer to neutralization effect the acid chloride and magnesium chloride (which produces hydrochloric by hydrolysis in the boiler). Even when emergency measures for sea water leakage, phosphate injection is applied.

On the other hand, it has the advantages mentioned above, the sodium phosphate has disadvantage that it is prone to hideout (precipitation of phosphate on the heat transfer surface). When the hideout occurred, injected Na_3PO_4 produce free alkali, and the alkali corrosion is encouraged by produced NaOH . Therefore, the method to prevent the production of NaOH at hideout is adopted by means of inject mixed Na_3PO_4 and Na_2HPO_4 rather than a single Na_3PO_4 for high pressure boiler. According to the operational experiences in Japan in recent years, the tube bursting accident due to hideout has not experienced.

6.3 All volatile treatment: (AVT)

The AVT is the method to use volatile substances, ammonia (NH_3) and hydrazine (N_2H_4), without using any solid chemicals as boiler water conditioner, and is mainly applied to high pressure boiler. It has no concerns about alkali corrosion and is capable to improve the purity of steam because the concentration of boiler water total dissolved solid is kept as low as possible. The concentration of impurities in the water is limited severely in order to minimize scale formation. The ion exchanged water or equivalent must be used for the make-up water. The oxygen scavenger and pH adjusting agent to keep pH in slightly alkaline are used as pH adjusting agent maintaining the concentration value of dissolved oxygen in the water close to zero. Hydrazine is used as the oxygen scavenger, ammonia which is produced as decomposition product is used as the pH adjuster, and it is customary to inject ammonia into the feed-water (pH is raised by increasing the ammonia). The recommended water quality standard is shown in Table-6. The reference value below $5\mu\text{g/L}$ of iron in the water (at economizer inlet) is set other than standard value. This treatment is characterized by causing the concentration of such alkali components and hideout, this method is adopted to most of the once-through boiler. Moreover, it is adopted to some circulation boiler.

Table- 6: Recommended water quality standard by CWT (supercritical once-through boiler)

classification	Sampling point	item	unit	In case of pressure is more than 20MPa
Feed-water	Economizer inlet	pH (at 25°C)	—	8.0 ~ 9.3 (target: 9.0)
		Electric conductivity (¹)	mS/m	0.02 or less
		Iron	μgFe/L	5 or less (target: 2 or less)
		Copper	μgCu/L	2 or less
		Dissolved oxygen	μgO/L	20 ~ 200 (target: 50)
		Hydrogen	μgN ₂ H ₄ /L	—
		Silica	μgSiO ₂ /L	20 or less
Steam	Main steam	Electric conductivity	mS/m	0.02 or less
		Silica	μgSiO ₂ /L	20 or less

(¹): Measured value after passing the strong acid cation ion exchange resin for hydrogen.

Reference: JIS B8223-2006 “Water conditioning for boiler feed water and boiler water”

The pH increasing effect in the boiler is very small and it may be fewer buffers such as phosphate, because ammonia (hydrazine decomposes to produce ammonia at high temperature) form a small degree of dissociation at high temperature. Therefore, it is considered mandatory conditions of the demineralizer unit to treat in case of once-through boiler, injection phosphate into drum temporarily in case of circulation boiler for the sea water leakage. If there is air leakage in the condenser, the ammonia attacks may be occurred to copper alloys on condenser tubes, because ammonia is easy to form complex ions as nickel and copper components under dissolved oxygen.

6.4 Combined water treatment: (CWT)

CWT is a method to dissolve traces of oxygen in the high purity water, and oxygen as oxidizing agent is injected. There is a track record in Germany and Russia. In Japan, it was begun to be applied to large commercial boiler from 1990, and this method is applied to about 50 units now. There is not much application for the drum type boiler, the JIS standard was revised in 2006 and are set the revised standard for more than 10MPa so that good performance is obtained.

This is the method for managing water quality by means of converting the divalent iron component to the trivalent iron component which has low solubility than the divalent iron component by dissolved oxygen and maintaining it. The dissolved oxygen is the most corrosive substances with undesirable ingredients in the current water treatment. Therefore, that is the basis to prevent corrosion by adjusting pH by means of maintaining the concentration of dissolved oxygen as low as possible. The corrosion inhibition is maintained by a coating on the surface as iron corrosion products. The potential of the iron in the treatment of these treatment and AVT is shown in Fig-4. It can be seen that the stable oxide of iron is magnetite (Fe₃O₄) under the condition of AVT and is hematite (Fe₂O₃) under the condition of oxygen treatment.

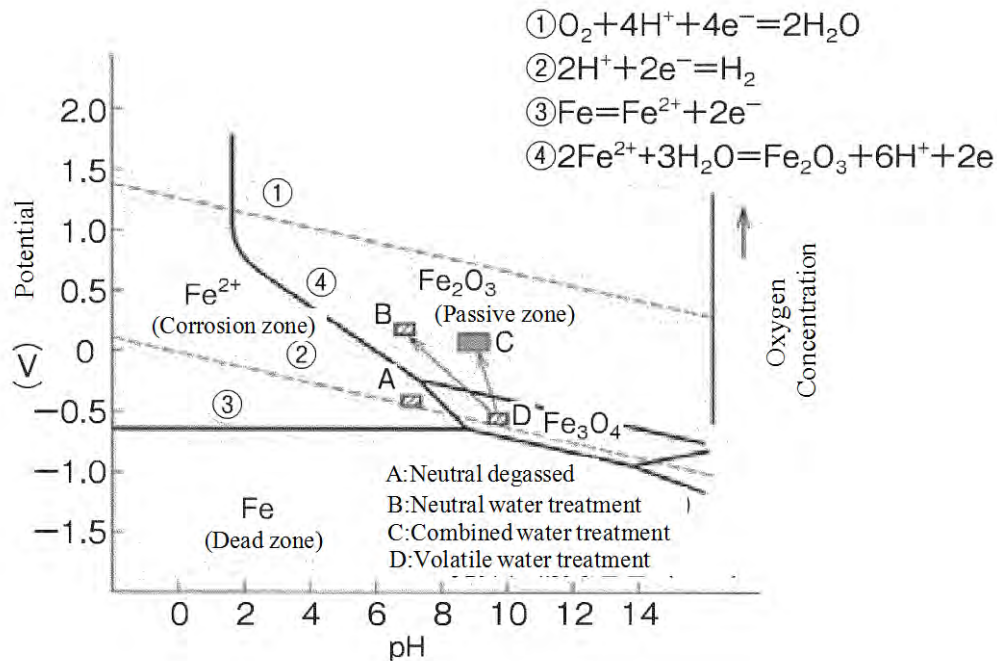


Fig- 4: Iron and hydrogen potential vs. pH diagram (25°C)

Reference: P-32 of Journal (No.616: Jan/2008): TENPES

The relation between electric conductivity and corrosion rate is shown in Fig-5. It is necessary to control electric conductivity strictly in particular in case of CWT, so that it becomes difficult to produce good protection coating in case of low water purity (electric conductivity is high). It is necessary the dissolved oxygen of 0.02~0.2mgO/L for the formation of dense protective coating on the surface of ferrous material, however, the protective coating becomes unstable as shown in Fig-6 when there is 0.2mgO/L and more. The water standard value (recommended value) is shown in Table-6. When applying CWT, since the reduction in iron concentration in the water is observed, the standard of iron have been changed from 10μg/L to 5μg/L or less (target is 2μg/L or less). Also, the target value of dissolved oxygen (control target) is 50μg/L. The following may mentioned the effect of CWT application.

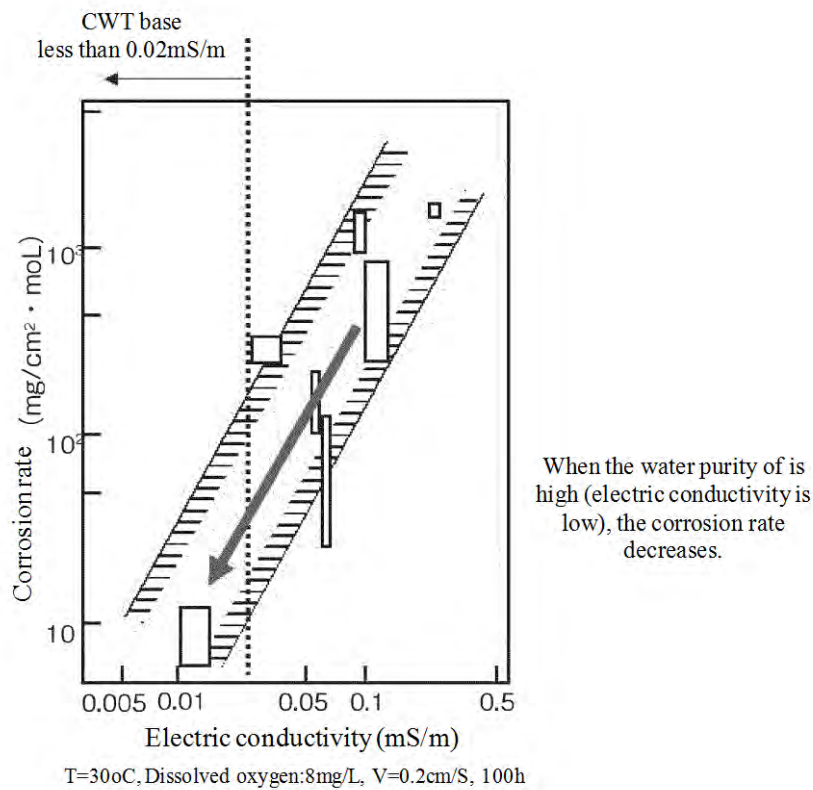


Fig- 5: Impact of the electric conductivity for carbon steel corrosion

Reference: P-32 of Journal (No.616: Jan/2008): TENPES

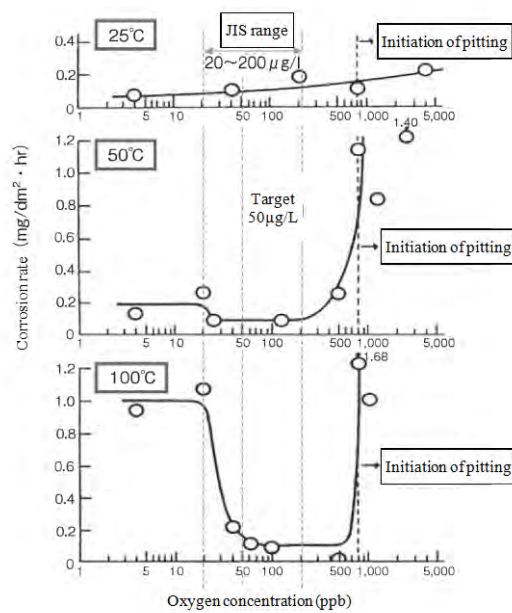


Fig- 6: Dissolved oxygen and corrosion rate (neutral, high purity static water)

Reference: P-32 of Journal (No.616: Jan/2008): TENPES

- 1) Reduction of frequency of chemical cleaning by reducing the rate of scale growth
- 2) Suppression of through-flow resistance of boiler due to wavy scale by reducing scale
- 3) Environmental improvements by reducing the amount of ammonia to use
- 4) Reduction of scaling to the configuring equipment
- 5) Reduction of FAC (Flow Accelerated Corrosion)

The CWT has remarkable effect to reduce differential pressure of boiler by suppression of the formation of wavy scale shown in Fig-7 compared of AVT.

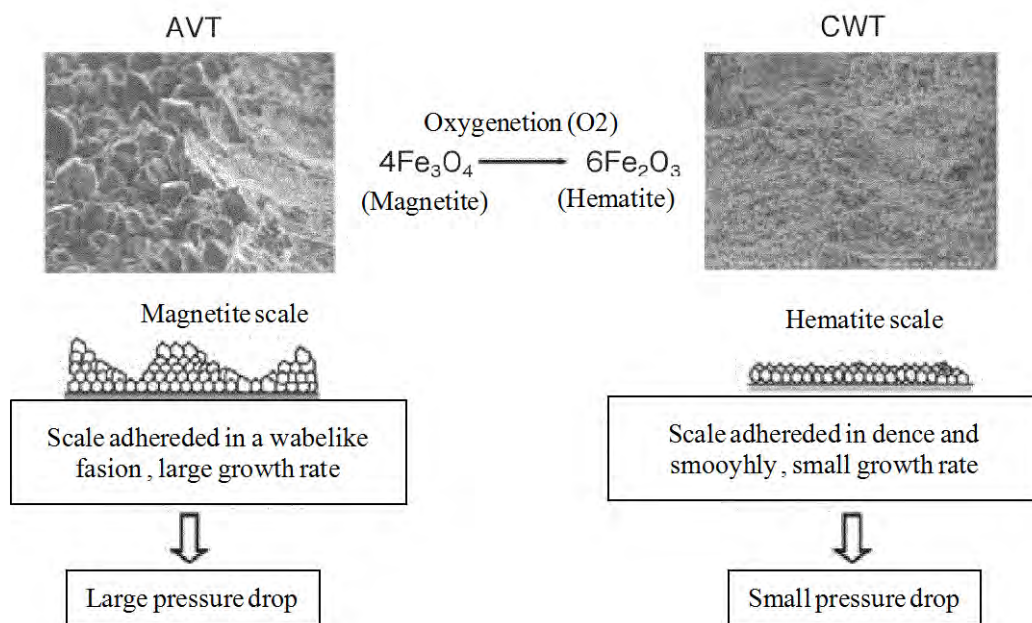


Fig- 7: Schematic illustration of scale adhesion status

Reference: P-32 of Journal (No.616: Jan/2008): TENPES

6.5 Low coordination phosphate treatment: (Low coordination phosphate treatment)

In recent years, the low-phosphate treatment has been used for drum type boiler instead of the caustic treatment, however, the problem of alkaline corrosion is not is not completely abolished.

6.6 Neutral Water Treatment: (NWT)

As the oxygen treatment for re-start of the thermal power plant, there are two methods, one is the NWT (Neutral water treatment) which applying completely pure water and CWT (Combined water treatment) which increasing pH of feed-water to 8.0~9.0 and oxygen simultaneously from the perspective of corrosion inhabitation for copper alloy being used in low pressure feed-water heater and condenser.

7. ABMA- Boiler402: Boiler water quality requirements and associated steam quality for industrial/commercial and institutional boilers

American Boiler Manufacturers Association / 01-Oct-2005 / 74 pages

The new ABMA publication brings together into one, central 70-pages reference book all the information previously contained in two separate documents, updated with the latest information and consensus on the effects of various feed-water and condensate systems on boiler operation, and information on boiler water and steam testing as well as system care and maintenance.

The purpose of this publication is to acquaint engineers, purchasers and operators of industrial, commercial and institutional (ICI) boilers with ABMA's judgment as to the relationship between boiler water quality and boiler performance. This document is published for general guidance as a supplement to detailed operating manuals supplied by the equipment manufacturers. It should also be noted that the information presented is directed to steel boiler designs, as opposed to cast iron sectional or copper finned tube boilers. Furthermore Utility Boilers and Combined Cycle Boilers, which require extremely close control of water quality and steam purity, are not the topic of this document.

This new document combines two previous ABMA Guideline documents, namely "Boiler Water Requirements and Associated Steam Purity for Commercial Boilers" (1998), and "Boiler Water Limits and Achievable Steam Purity for Water-tube Boilers", (1995) as shown in Table-6 and Table-7.

Table- 7: Recommended water tube boiler water limits and associated steam purity
at steady state full load operation ^(a)

Type of boiler	Drum pressure (psig)	Total dissolved solids ^(b) in boiler water (ppm max.)	Total alkalinity ^(c) in boiler water (ppm)	Suspended solid in boiler water (ppm)	Total dissolved solid ^(d) ^(e) in steam (ppm max. expected value)
Drum type	0-300	700-3500	140-700	15	0.2-1.0
	301-450	600-3000	120-600	10	0.2-1.0
	451-600	500-2500	100-500	8	0.2-1.0
	601-750	200-2000	40-400	3	0.1-0.5
	751-900	150-1500	30-300	2	0.1-0.5
	901-1000	125-1250	25-250	1	0.1-0.5
	1001-1800	100	variable	1	0.1
	1801-2350	50	variable	N/A	0.1
	2351-2600	25	variable	N/A	0.05
	2601-2900	15	variable	N/A	0.05
Once-through type	1400 & above	0.05	N/A	N/A	0.05

(a): "Boiler water limits and steam purity for water-tube boilers" American Boiler Manufacturer Association 1992.

(b): Actual values within the range reflect the TDS in the feed-water. High values are for high solids; lower values are for low solids in the feed-water.

(c): Actual values within the range are directly proportional to the actual value of TDC of boiler water lower values are for low solids in the feed-water.

(d): Directed by boiler water treatment.

(e): These values are exclusive of silica.

Table- 8: Boiler water limit (ABMA)

Drum Pressure (psi)	TDS	Alkalinity (ppm CaCO ₃)	Suspended Solid	Conductance (μΩ/cm)	Silica (ppm SiO ₂)
0-300	3500	700	300	7000	125
301-450	3000	600	250	6000	90
451-600	2500	500	150	5000	50
601-750	2000	400	100	4000	35
751-900	1500	300	60	3000	20
901-1000	1250	250	40	2000	8
1001-1500	1000	200	20	150	2.5
1501-2000	750	150	10	100	1
Over 2000	500	100	5		0.5

Note : Based on limiting Silica in stream from 0.02 to 0.03 ppm and also based on SiO₂/Total Anion ratio.

TDS: Total Dissolved Solid

Reference: ABMA

8. ASME guideline for water quality in modern industrial water tube boilers

The recommended water quality limit is stipulated by ASME as shown in Table-9.

**Table- 9: ASME guidelines for water quality in modern industrial water tube boilers
for reliable continuous operation**

UFC3-240-13FN 25 May 2005

Drum Pressure (psi)	Dissolved oxygen (ppm as O ₂)	Total iron (ppm as Fe)	Total copper (ppm as Cu)	Total hardness (ppm as CaCO ₃)	pH at 25°C	Oily Matter (ppm)	Non volatile TOC (ppm as O ₂)
0-300	< 0.007	≤ 0.1	≤ 0.05	≤ 0.03	8.3-10.0	< 1	< 1
301-450	< 0.007	≤ 0.05	≤ 0.025	≤ 0.03	8.3-10.0	< 1	< 1
451-600	< 0.007	≤ 0.03	≤ 0.02	≤ 0.02	8.3-10.0	< 0.5	< 0.5
601-750	< 0.007	≤ 0.025	≤ 0.02	≤ 0.02	8.3-10.0	< 0.5	< 0.5
751-900	< 0.007	≤ 0.02	≤ 0.015	≤ 0.1	8.3-10.0	< 0.5	< 0.5
901-1000	< 0.007	≤ 0.02	≤ 0.01	≤ 0.05	8.3-9.6	< 0.2	< 0.2
1001-1500	< 0.007	≤ 0.01	≤ 0.001	ND	8.3-9.6	< 0.2	< 0.2
1501-2000	< 0.007	≤ 0.01	≤ 0.001	ND	8.3-9.6	< 0.2	< 0.2

Note:

1. Makeup water percentage: Up to 100% of feed water.

2. Assumes existence of deaerator.

3. Conditions: Includes super heater, turbine drives, or process restriction on steam purity.

4. *Saturated steam purity target as shown.*

5. *NS = not specified.*

6. *ND = not detectable.*

7. *VAM = Use only volatile alkaline materials upstream of a temporary water source.*

9. Steam purity

The purpose of managing the quality of the generated steam from the boiler is to prevent corrosion and damage of equipment and piping of steam system and to prevent reduction in turbine efficiency due to the impurities in the steam. The required quality of steam for boiler plant depends on the material constituting the steam system or use of generated steam. Here, in the sense of failure to emphasize prevention of scale adhesion and corrosion damage to steam turbine, it is assumed management items which are relatively easy when the ion exchanged water is applied to feed-water for boiler and steam is supplied to turbine.

The Table-10 is attached to JIS B8223 “Water conditioning for boiler feed water and boiler water” (issued and revised in October 2006) and shows the comparison with the JIS standard for the quality of steam and the other countries and international organizations. The only two items, such as silica and electric conductivity, have been set as the criterion for steam purity in JIS. It has not been reviewed although it seems to be little control items compared to other criteria, because there is no problem in the domestic power plant so far. In addition, when comparing other criteria (EPRI, VGB, and IEC) and JIS, the reference value (silica, electrical conductivity) is slightly higher JIS (high limit) tend to be of normal operation of this. Therefore, the review has not been done so far because that of JIS is managed in very low value. In addition, Na have not been added as a routine administrative items, because in general very low value compared to the reference value (Na, for example 0.001 mg/L or less) although in the case of boiler performance testing of boiler plant (such as steam separation efficiency, steam purity) Na may be measured.

Table- 10: Comparison of steam purity limits JIS with other international standards

item		EPRI (1996)			VGB (1988)	IEC 61370 (2001)	JIS B8223 (2006)
Treatment method ⁽²⁶⁾		OT, AVT, EPT	PT	CT			
Sodium	mgNa/L	0.003	0.005	0.002	< 0.010	≤ 0.005	—
Electric conductivity ⁽²⁴⁾	mS/m	<0.015 ⁽²⁵⁾	<0.03	<0.03	<0.02	≤ 0.02	≤ 0.03
Total iron	mgFe/L	—	—	—	<0.020	≤ 0.020	—
Total copper	mgCu/L	—	—	—	<0.003	≤ 0.003	—
Silica	mgSiO ₂ /L	0.010	0.010	0.010	<0.020	≤ 0.020	≤ 0.020
Chloride ion	mgCl/L	0.003	0.003	0.002	—	—	—
Sulfate ion	mgSO ₄ /L	0.003	0.003	0.002	—	—	—
Total organic carbon (TOC)	mg/L	0.100	0.100	0.100	—	—	—

Note

⁽²⁴⁾ : Conductivity after passing through the strong acid cation exchange resin (hydrogen ion type) layer

⁽²⁵⁾ : Electric conductivity after passing through strong acid cation exchange resin (hydrogen ion type) layer and after removal of dissolved gases such as carbon dioxide

⁽²⁶⁾ : OT: Oxygenated Treatment, AVT: All Volatile Treatment

: EPT: Equilibrium Phosphate Treatment, PT: Phosphate Treatment, CT: Caustic Treatment

Reference: JIS B8223-2006 “Water conditioning for boiler feed water and boiler water”

(1) Electric Conductivity

The problem with impurities in the steam is a carry-over of dissolved salts in the boiler water, silica, iron and copper. The carry-over is facilitated by the rapid changes in operating conditions such as an increase in boiler water impurities. Since most these impurities are electrolyte, the purity of steam is managed as an index to measure the electric conductivity through the layer after strong acid cation exchange resin in the form of hydrogen ions. The typical value of electric conductivity to be managed as pure steam is stipulated below 0.03mS/m (at 25°C) same as the standard value of boiler feed-water considering the circumstances of boiler management.

(2) Silica

Silica has the property to increase solubility in the steam under high temperature and pressure and easy to carry-over to the steam turbine. Therefore, carried-over silica becomes supersaturated over solubility in the low pressure area of low pressure part of turbine a precipitated as silica scale, and cause the turbine efficiency drop. In order to prevent the adhesion of this scale, it is known to be no problem if the silica concentration in steam is kept below 20μgSiO₂/L. In addition, the concentration of silica in the steam related to steam pressure, steam temperature and pH, it is possible to manage silica concentration in the steam below 20μgSiO₂/L during normal operation by adjusting them. The solubility of silica in the super-heated steam is shown in Fig-8. However, the presence of impurities such as salt and sodium in the

steam, it should be aware that they combined with silica and product complicated compound precipitate in the middle or high pressure turbine.

The guideline of the steam purity 2001 of IEC (International Electro-technical Commission) is shown in Table-11. The IEC standard is created with reference to various criteria of and Na, Fe, Cu has been added as the management items compared with JIS. In addition, the normal values and the time limit have been set when deviating from standard value which has shown that a quantitative guideline that assumes the actual plant operation. In operating the real plant, the quantitative guideline may be required to guide from the standpoint of operational management (in overseas plant corresponding to the operating personnel with poor knowledge of chemistry, there are no particular case is required), these standards preferred to respond with reference. As mentioned above, there is a difference in reference value. Thus, not only to apply to gulp down the reference value, the optimal management criteria for plant operation must be grasped according to Table-11 without departing from the reference value.

Table- 11: Steam purity (IEC 61360-2001)

Sampling point	item	Expected value (regular status)	Limit	Allowed time limit for correction		
				Within 1w	Within 24h	Within 1h
Main steam	Electrical conductivity $\mu\text{S/cm}$ (mS/m)	0.06 ~ 0.2 (0.06 ~ 0.02)	≤ 0.2 (≤ 0.02)	0.2 ~ 0.5 (0.02 ~ 0.05)	0.5 ~ 1.0 (0.05 ~ 0.1)	>10 (>0.1)
	Caustic: Na ($\mu\text{g/kg}$)	0 ~ 5	≤ 5	0 ~ 5	—	—
	Silica: SiO_2 ($\mu\text{g/kg}$)	3 ~ 5	≤ 20	—	—	—
	Iron: Fe ($\mu\text{g/kg}$)	2 ~ 5	≤ 20	—	—	—
	Copper: Cu ($\mu\text{g/kg}$)	0 ~ 1	≤ 20	—	—	—

Note: It is necessary to treat within 24 hours, when the colloid ion (Cl) exceeds $20\mu\text{g/kg}$.

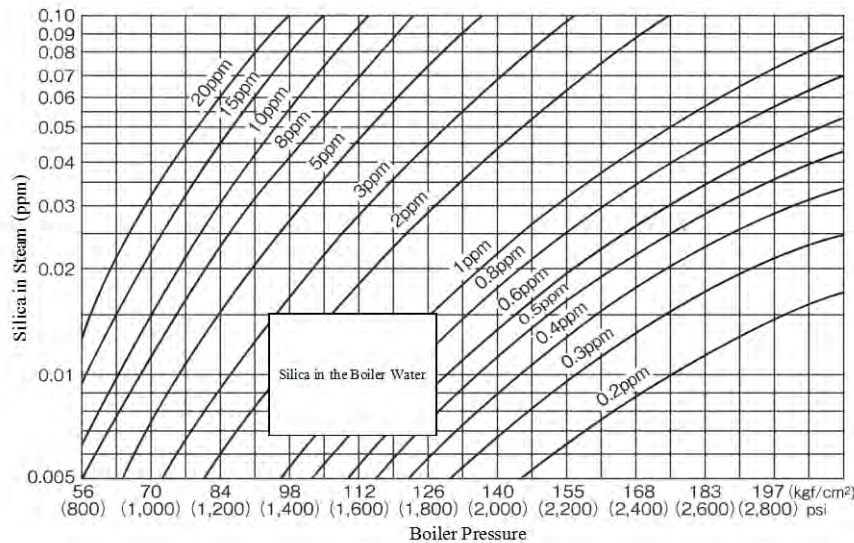


Fig- 8: Relation boiler pressure with silica in the boiler water and steam (excluding in case of AVT)

Reference: P-52 of Journal (No.608: May/2007) TENPES

Article 214 Feed-water treatment facility

Article 214-1. Corrosive matters

1. Where various impurities which can cause damage or reduce efficiency of turbine come from? There are various impurities which aggravates the purity of steam (impurities) as which is focus as is Na, Cl, Cu and the like Si. They rose as to the origin of raw water (such as industrial water), condenser cooling water (sea water), water treatment chemicals involved and plant equipment is considered, and it must be paid to the maintenance of the equipment.
2. Penetration paths of impurity_
 Fig-9 in the “Drum boiler” which is summarized by EPRI in United States indicates the location of the intrusion of impurities, corrosion, and scale. “●” mark shows the path of impurity penetration. In generally, it is believed that Na and Cl is brought into plant with cooling water (sea water, river water and industrial water) to condensate steam from turbine to condensate water via the damaged condenser tube. In addition, it is believed that Na, Cl and Si is brought into plant as hydrochloric acid (HCl), sodium hydroxide (NaOH), resin for ion exchange (particle) and residual silica (SiO₂) which are used as regeneration chemical, although the pure water is supplied as make-up water. It is believed that copper (Cu) is brought into plant due to dissolution by operational pH and dissolved oxygen (O₂) in case the copper is applied to as the material for condenser or heed water heater.
3. The concept of impurity which is introduced into turbine
 The impurity for the turbine is brought in from both strains boiler (carry over) and spray water (feed water fed directly to the steam system for steam temperature control).

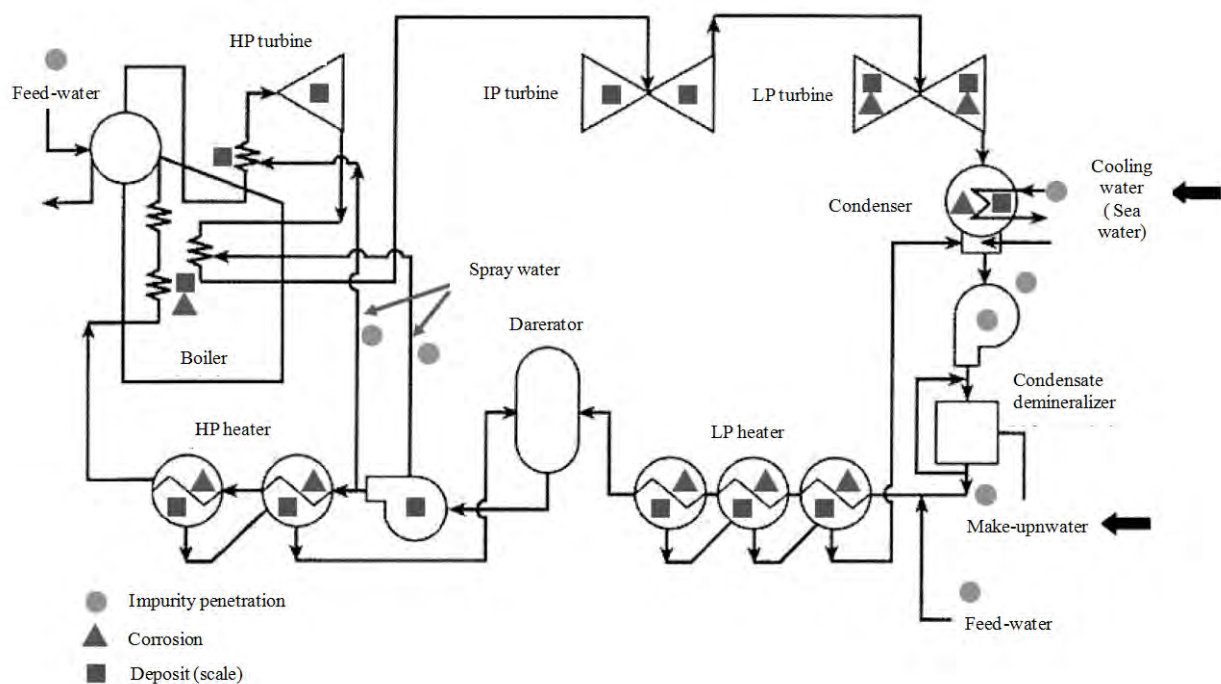


Fig- 9: Place of impurity penetration, corrosion, scale adhesion of drum boiler (EPRI)

Reference: P-50 of Journal (No.614: Nov/2007): TENPES

4. Feed-water treatment Facility

4.1 Make-up water treatment facility

4.1.1 Purpose of make-up water treatment

The purpose of the make-up water treatment is to eliminate impurities such as colloidal matters, suspended matters, dissolved salts and dissolved gases in the boiler feed-water by chemical and physical methods, and prevents failures of boiler and its auxiliary such as corrosion or scale adhesion. The water quality of feed-water and boiler water for boiler is stipulated in JIS B8223 “Water conditioning for boiler feed water and boiler water”. It is necessary to treat most appropriately depending on the construction of boiler, boiler load conditions and presence of the auxiliary equipment according to a standard with respect to these values.

4.1.2 Type of raw water

Natural water such as river water (surface water, subsoil water), lake water (including an artificial lake), ground water (unconfined groundwater, artesian water) or drinking water, industrial water and boiler condensate water which are the water from various water sources are used as raw water is supplied to boiler. The river water and industrial water has high turbidity and the lake water has many algae and organic matters because of accumulation. In addition, it can be obtained water with low turbidity, although the groundwater has relatively high salt concentration.

4.1.3 The basic treatment method

The impurity existing in raw water for boiler make-up water is classified by their size in Fig-10. First, the dissolved gases and electrolytes are present in the low molecular weight area (0.1~1nm), organic matter and organic acids with high molecular weight such as humic acids and colloidal silica are present in the following colloidal area (1~500nm), in addition, suspended matter (such as fine soil component, suspension silica, heavy metal oxide and hydroxides, algae and bacteria) are present in the suspension area (0.5 μ m~1mm). The ion exchange method, reverse osmosis method or deaeration method are applied to the removal of impurities in the low molecular area, the flocculation adsorption, filtration or ultra filtration are applied in the colloidal area, the flocculation adsorption and filtration, cohesive pressure floating and filtration, filtration or sedimentation separation in the suspended solid area.

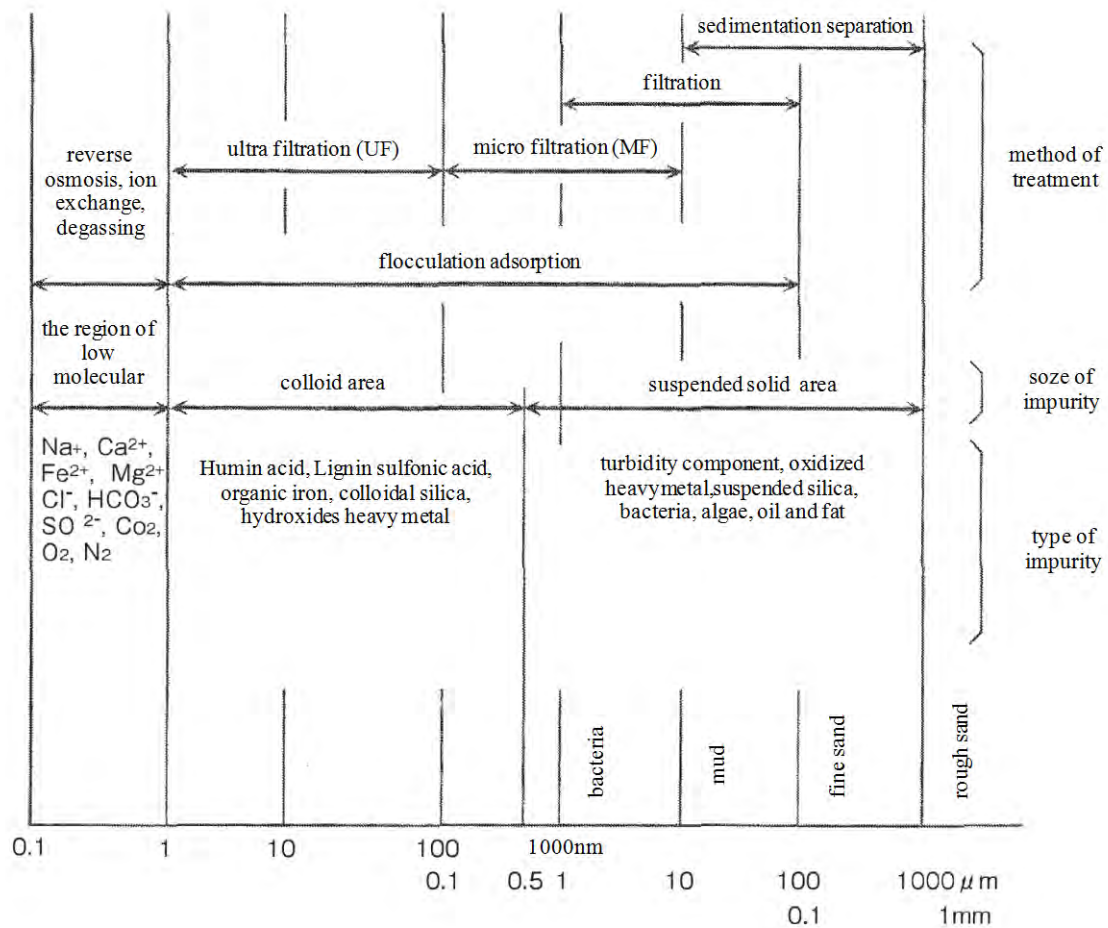


Fig- 10: Typical basic treatment method

Reference: P-66 of Journal (No.608: May/2007): TENPES

4.2 Pretreatment

Pretreatment is the process to remove colloidal matter, suspended solid and organic matters in the raw water by coagulation sedimentation, cohesive pressure floating, filtration adsorption prior to the

desalination treatment such as following ion exchange treatment, reverse osmosis treatment. Thereby, it is possible to prevent the obstruction of reverse osmosis membrane pollution of ion exchange resin. The pretreatment system depends on the type of raw water and coagulation sedimentation, cohesive pressure floating, filtration adsorption is adopted to river water during high suspended solid, industrial water that has high suspended solid and lake water. Various filtration methods (such as microfiltration, rapid filtration) are applied to drinking water or groundwater which has relatively low suspended solid and less variation. In addition, the sodium hypochlorite is injected to lake water which is algae rich for sterilization the carbon filtration method is adopted for raw water which contains organic matters.

4.2.1 Coagulation precipitation

(1) Coagulation

The insoluble fluffy substance which is generated by adding a coagulant to raw water is called flock, and it has coarsened to absorb fine particles in the raw water during generating flock and trend to settle. The coagulation treatment (coagulation precipitation) is the way to remove flock which is easy to settle and catch by the coagulant.

(2) Coagulant and precipitation aids

1) Coagulant: Typical coagulants are aluminum salts and iron salts, being used among vast majority of aluminum salts, When the coagulant generate a hydroxide by hydrolysis in water, they react with bicarbonate and carbonate ions (acid consumption (pH4.8) components) which are the alkaline components in water. For example, when adding the aluminum sulfate in water, it hydrolyze as equation (1.1), react with bicarbonate and carbonate ions and product a precipitation of aluminum hydroxide gel. This precipitation absorbs suspended solids in the water and produces a flock.



2) Coagulation aids: If the turbidity of raw water is low, the flock is likely to emerge due to the low density. In addition, the fine flock will be accounted in treated water because the rate of agglutination becomes slow under low temperature, for example in the winter. To prevent these phenomena, the coagulation aids such as sodium silicate, sodium alginate and organic polymer coagulant with cross-linking action are added. If the turbidity is low, the density of flock is increased to facilitate the setting by means of adding fine particles of clay minerals such as kaolin, bentonite and the concentration of suspended solid in raw water.

(3) Coagulator

The coagulator is consisting by facilities which have three functions, the first function is to stir rapidly after adding a coagulant to the raw water continuously and to neutralize the charge of colloidal substances and fine suspended solid and to aggregates them into a small flock, the second function is to grow up tiny

flock into a large flock colliding with each other by gentle agitation and the third function is to precipitate, enrich and separate flocks at the end. Also, it is common to place a subsequent stage filtration system.

The coagulator is classified in 1) slurry blanket (or sludge blanket) type and 2) slurry circulation type by the sludge blanket or the method of slurry contact. The mixing type of slurry blanket type and pulse type is the equipment to perform mixing by pulsating flow caused a partial strength in the unit in defiance of a mechanical mixture when mixing raw water which is added coagulant with sludge blanket of existing flock. The construction and principle of this equipment is shown in Fig-11. The raw water enters into the vacuum tower b) through raw water inlet pipe a), water is lifted up when the vacuating by vacuum pump, and water drop rapidly when destroy the vacuum. By repeating this operation, the pulsation is transmitted throughout the slurry bed blanket given to the raw water which is discharged from raw water distribution pipe c). The treated water (clarified water) is flowing out from equipment after collected to the catchment ditch j). The increased slurry flow into the concentrator d) and is discharged outside after it has been concentrated in this consolidation. This type of equipment is known as the pulsator. The features of this equipment is said to have good coagulation effects with good effect of contact because the slurry layer is pulsating in the slurry blanket. In case of small size of this type, a pulsating vacuum is generated by a siphon instead of a vacuum pump.

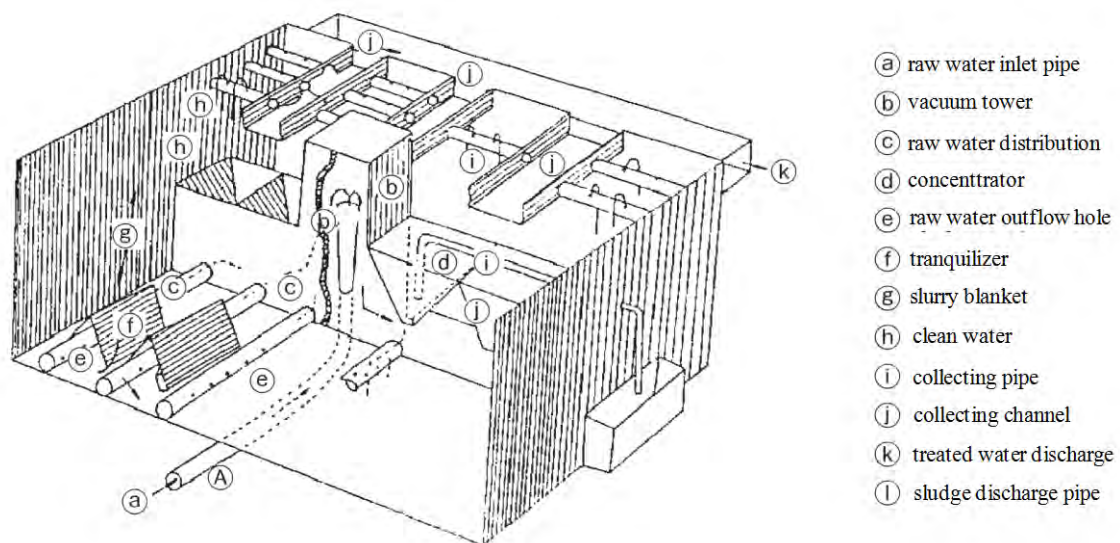


Fig- 11: Typical construction of pulsating type coagulator

Reference: P-67 of Journal (No.608: May/2007): TENPES

4.2.2. Coagulation pressure floating

The solid/liquid separation of the main water treatment of boiler was coagulation and precipitation, and was effective and easy to settle for raw water containing a high concentration of particularly heavy

particles. However, if the raw water is including the low density suspended solid (organic turbidity) or is low turbidity, it was difficult to conduct effective water treatment. On the other hand, the cohesive pressure floating is effective for the suspended solid which is light and easy to emerge due to production algae by eutrophication of lakes because it adheres small bubbles with produced flock and separate them.

- (1) Coagulation pressure floating equipment: The flow sheet and construction of coagulation pressure floating equipment is shown in Fig-12. The pressurized water which is saturated air is injected into raw water which is added the flocculant just before the floating separator 1). The pressurized water is separated from 10~25% of treated water, is pressurized to 400~500kPa and is dissolved air close to saturation. Therefore, dissolved air excessively occur 20~120 μ m fine air bubbles and adhere to the flock in the water when the pressure is close to atmospheric pressure rapidly. And then it is introduced into inner cylinder 2) and changed upward flow. The flock is separated into the water and flock subsequently in the separation layer. Treated water (clarified water) is flowing out from the system by collecting pipe 3). On the other hand, a floating (scum holding a bubble) are layered on top floating in the water and is sent to the scum receiving tank from scum discharge port 5) by skimmer 4). Settled sludge is collected by scraper 6) and is regularly withdrawn from the bottom. The discharged scum will be treated same as the sludge of fast coagulator.

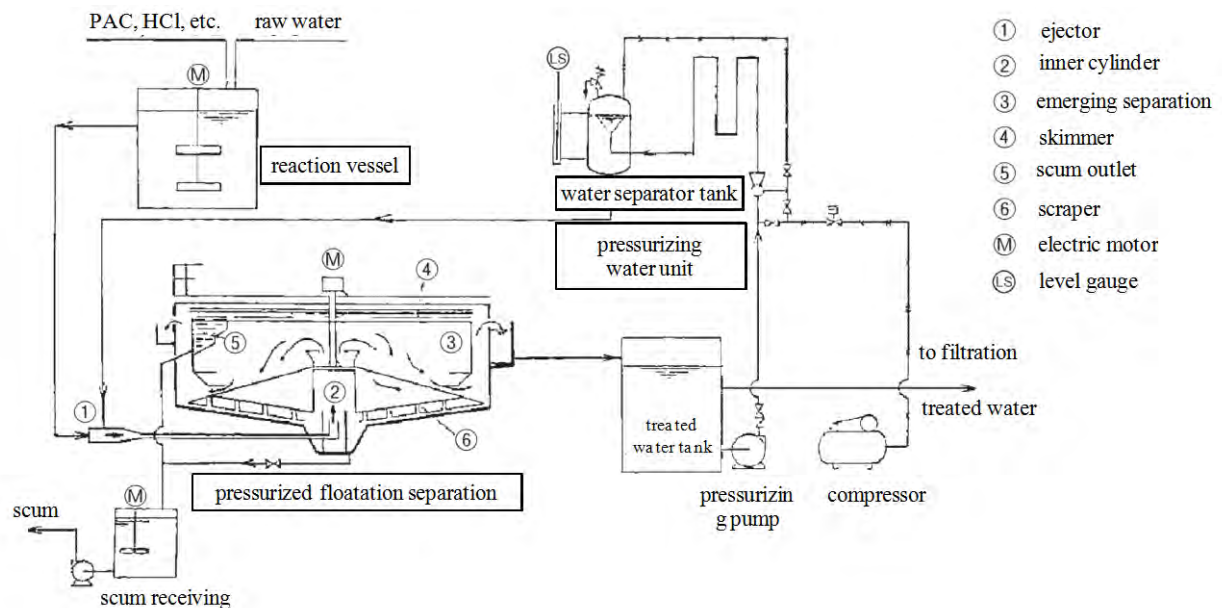


Fig- 12: Typical construction of coagulation pressure floating unit

Reference: P-68 of Journal (No.608: May/2007): TENPES

4.2.3 Coagulation filtration

The coagulation filtration systems is the simple aggregation system that coagulation process (i.e. coagulator) is omitted and is performed immediately filtered after the injection of coagulant into raw water.

In this way, it is necessary to add coagulant to the required minimum coagulation when adding large amount of coagulant, the differential pressure rises faster and operation time is shortened. In particular, the actual raw water turbidity is low, such as industry water, this method is adopted because the required operation hours are obtained.

(1) Configuration of filtration layer

Double glazing (two layers) filtration of sand or anthracite coal (anthracite) is mainly used as the structure of the filtration layer. The multi layer filtration is a way to filtrate overlaid filtration material of two different grain size and density; generally low-density filtration material (i.e. anthracite) on a sand grain is overlapped on the sand. Entire filter layer work well, has good efficiency and enable to have high flow rate (200~800m/d), since this method can be filtered toward the fine from the coarse particle suspensions in the upper large diameter, it is also a fine suspension respectively in the lower layer is removed.

(2) Washing procedure

The method which is combined air-washing and back-washing is effective to discharge effectively the suspended solid which is captured on the boundary layers and inside of filtration material. The flow sheet is shown in Fig-13. Even if it all, if it is required a large amount of coagulants due to high chromaticity, it is preferable for combination method of conventional coagulation and filtration.

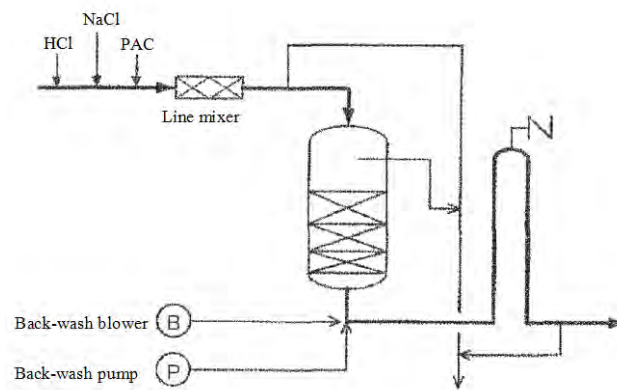


Fig- 13: Example of a flow sheet of the coagulation filtration unit

Reference: P-69 of Journal (No.608: May/2007): TENPES

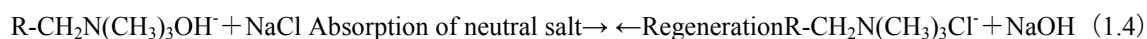
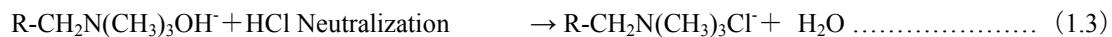
4.3 Ion-exchange process

The ion exchange process is the operation to remove (ion exchange) ionic impurities in the raw water (such as sodium, calcium, chloride ion, sulfate ion and silica) using cation exchange resin for hydrogen ion and anion exchange resin for hydroxide ion. The absorption reaction of sodium chloride and regeneration in the cation ion exchange column and anion ion exchange column is shown in the formula (1.2)~(1.4).

(1) Cation exchange column :



(2) Anion exchange column :



Note: R : Showing the mother of the resin

4.3.1 Type of ion exchange water system

The multi-bed type ion exchange water system is often used for thermal power plant; the regeneration method has been shifted to counter-current regeneration type which intent to improve the purity of treated water and to reduce the amount of chemicals from co-current regeneration type which has been used. In recent years, variety of variant forms which filling strong acidic cation exchange resin with weak acidic cation resin, or strong basic anion ion exchange resin with weak basic anion exchange resin in the same multi-layer, a combination of additional counter-current regeneration method.

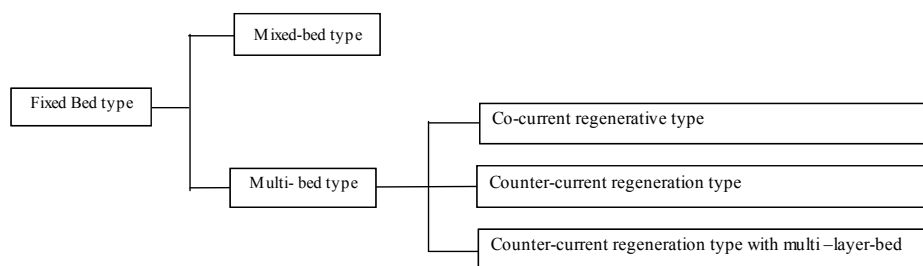


Fig- 14: Type of Ion exchange water system

Reference: P-69 of Journal (No.608: May/2007): TENPES

4.3.2 Counter-current regeneration type

This method shown in Fig-15 intended to reverse the flow direction of water and regeneration agents and has following advantages and has been a number of practical equipments.

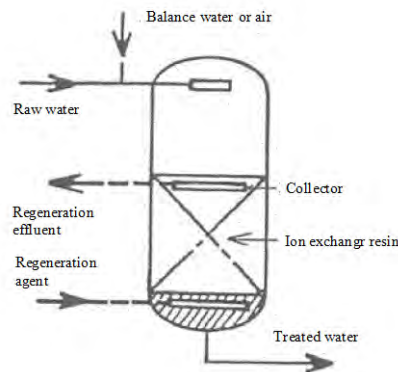


Fig- 15: Example of up-flow regeneration type

Reference: P-69 of Journal (No.608: May/2007): TENPES

- (1) Less regeneration agent is applied and high purity treated water is obtained. It is capable to reduce the amount of regeneration agent 40~65% of co-current regeneration type because the regeneration agent is used effectively in the counter-current regeneration type. In addition, electric conductivity of treated water can be about 0.02mS/m as a minimum because the ion exchange resin layer at the outlet is nearly completely regenerated in counter-current regeneration type. It is capable to keep leakage of silica less than 0.01 mgSiO₂/L.
- (2) As the result of less consumption of regeneration agent, re generation time is shortened approximately 1/2 of conventional. Then, the comparison of water quality of co-current regeneration type with counter-current type is shown in Fig-16.

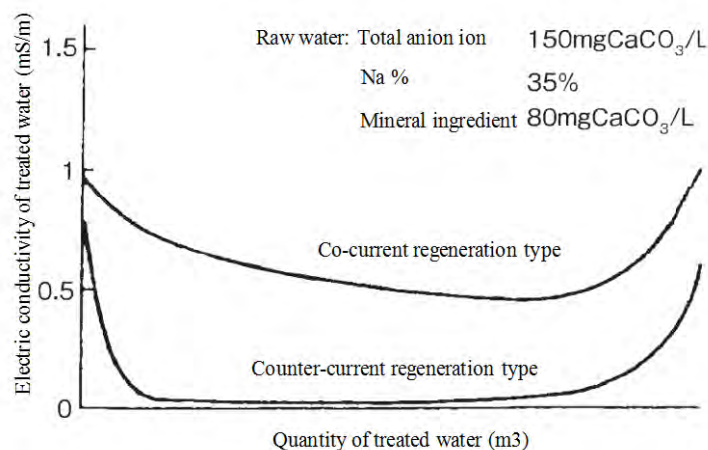


Fig- 16: Comparison of water quality between counter-current re-generation types and co-current regeneration type

Reference: P-70 of Journal (No.608: May/2007): TENPES

The reason for the efficient regeneration of co-current regeneration type is that the hydrogen type exchange

ion is remained at the bottom of cation exchange column as shown in Fig-17(a) when stopping the equipment at breakpoint of the cation exchange unit. This remaining hydrogen type exchange ion is equivalent to 10~20% of total hydrogen exchange ion in the strong acid cation ion exchange resin depending on the quality of raw water. In other words, regeneration will start playing from the presence of hydrogen type exchange ions for the counter-current regeneration type as shown in Fig-17(b). Meanwhile, since the co-current regeneration type flow regeneration agent downward, it is necessary to regenerate cation ions once again which is eluted from top of column is re-absorbed to hydrogen type exchange ion. In other word, despite the hydrogen type exchange ion is remaining, the same amount of regeneration agent same as in case they do not exist is required. In addition, the acid of regeneration agent regenerates sodium type exchange ion which is most easy to regenerate in case of the counter-current regeneration type. The eluted sodium ion elutes the magnesium ion that exchange ion with magnesium type exchange ion in the upper layer, these magnesium ion exchanges with calcium type ion in addition the upper.

The regeneration agent regenerates sodium type exchange ion which is easy to regenerate to regenerate always, because they have a fair of amount of elution and ion exchange in stages before acid contacting with calcium type exchange ion. In other words, the regeneration by sodium chloride is carried out before regenerating with acid and the operation to regenerate by acid naturally. This is one of the reasons to get efficient regeneration. Above have been described in the case of the cation ion exchange tower, this is also true for anion ion exchange tower, the leakage of silica will become extremely small during the water passage when regenerating anion ion exchanger tower by counter-current regeneration type.

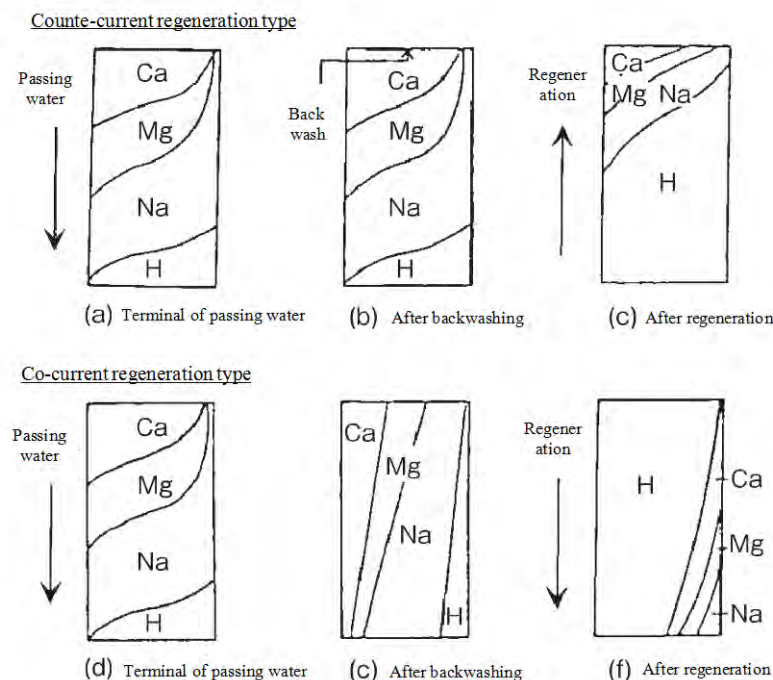


Fig- 17: Distribution of ions in the resin of counter-current regeneration type and
co-current regeneration type

Reference: P-70 of Journal (No.608: May/2007): TENPES

4.3.3 Counter-current regeneration type with multi-layer-bed

This method is composed by cation ion exchange tower packed the strong acidic cation exchange resin and the weak acid cation exchange resin; anion ion exchange tower packed the weakly basic anion exchange resins and strongly basic anion exchange resin, and the deaerator. A basic example of a flow sheet of this equipment is shown in Fig-18. Comparative examples of amount of regeneration agent of weak basic anion exchange resin and strong basic anion exchange resin with ion exchange capacity is shown in Fig-19. The usage is equivalent of roughly ion exchange capacity of weak basic anion exchange resin may be used, because the sodium hydroxide for regeneration of the basic anion exchange resin resin is consumed effectively (regeneration efficiency is too good). This desalination method is characterized by lower regeneration cost, because the largest expense of ion exchange treatment is regeneration agent. This is the ion exchange desalination method which is capable to save amount of regeneration agent than aforementioned counter-current regeneration type which water flow and generation is reverse, because the weak acid cation ion exchange resin which has high regeneration efficiency is regenerated by the regeneration effluent of strong acid cation ion exchange resin or the weak basic anion ion exchange resin which has high regeneration efficiency is regenerated by strong basic anion ion exchange resin. A comprehensive comparison of various ion exchange desalination system is shown in Table-12.

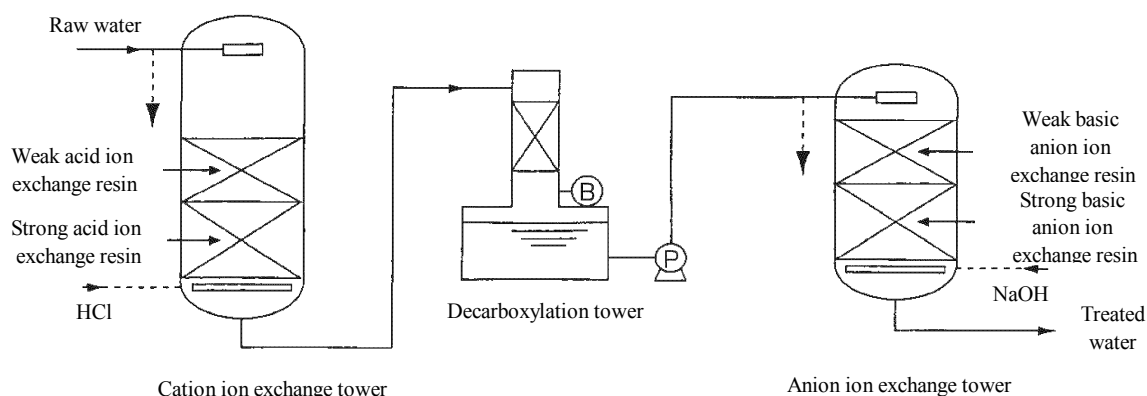


Fig- 18: Typical flow of counter-current regeneration type with multi-layer-bed

Reference: P-70 of Journal (No.608: May/2007): TENPES

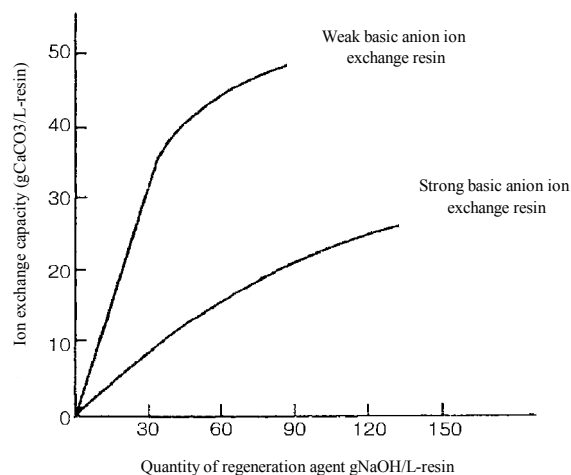


Fig- 19: Volume of regeneration agent and ion exchange capacity

Reference: P-71 of Journal (No.608: May/2007): TENPES

Table- 12: Comparison of various ion exchange water systems

Items / methods		Co-current regeneration type	Counter-current regeneration type	Counter-current regeneration type with multi-layer-bed
Degree of pretreatment (turbidity)		0 ~ 5	0 ~ 1	0 ~ 1
Volume of regeneration chemical		100	50	30
Regeneration time (hr)		3 ~ 4	2	1
Volume of regeneration effluent		100	50	30
Quality of treated water (min value)	Electric conductivity (mS/m)	0.2 ~ 0.5	0.02 ~ 0.1	0.02 ~ 0.1
	Silica (mg/L)	0.05 ~ 0.5	0.01 ~ 0.02	0.01 ~ 0.02

Note: Volume of regeneration chemical and volume of regeneration effluent is 100 of co-current regeneration type.

Reference: P-71 of Journal (No.608: May/2007): TENPES

4.3.4 Ion exchange water system with polisher

Generally, this equipment is combined with double-bed ion exchange water system, and the polisher will be installed in a downstream if it is required the water which is purified by double-bed ion exchange water equipment more high purity. The mixed bed polisher is applied to mixed bed type ion exchange water treatment equipment, the two floor type polisher is applied to double layer type ion exchange water treatment equipment, the silica polisher is applied strong basic anion exchange resin which removes and purify silica, the cartridge polisher is applied to non-generation type ion exchange water treatment equipment. Generally, the mixed bed polisher or two floor polishers is used. It is possible easy to apply the

multi-layer formula-bed up-flow regeneration type (twin strata) to the raw water which is relatively high concentrations of salts and easy to operate because the backwash is carried out always except this special regeneration although the amount of strong acidic cation exchange resin is slightly increase.

4.3.5 De-carbonator and vacuum deaerator

The decarbonator shown in the flow sheet Fig-18 is the system for removing carbon dioxide in water by blowing air into the water that flows down from the top of tower, which reduces the load of carbon dioxide component of the subsequent anion-exchange resin. The vacuum deaerator is the method to separate and remove gases dissolved in water by means of keeping tower inside in vacuum and flow down from the top of tower, and it is employed when it is required deoxygenation and it can be removed carbon dioxide at the same time.

4.3.6 Organic matter for ion exchange resin

Humic (such as humic acid and fulvic acid), wetting agent, oil and fats, industrial effluent, organic matter contained in sewage is absorbed irreversibly in ion exchange resin (mainly anion ion exchange resin), and it would be difficult to disconnect. Such a phenomenon has been termed organic pollution. If the organic pollution is occurred, the rate of ion exchange slow down because ions in the ion exchange resin particles is inhibited the diffusion. Also, the absorbed organic matter is disconnected partly during ion exchange process, causing a deterioration of quality of treated water. The organic pollution is a concern, it is necessary to remove organic matter by sufficient pretreatment such as flocculation, filtration and absorption.

4.4 Membrane process

The membrane technology advances to improve the performance advantage of rapid development and has expanded its scope of application. At present, it has been used mainly in the areas requiring ultra-pure water of electronic industry and the pharmaceutical industry; however, it is applied to demineralization equipment for make-up water equipment for some thermal power plants.

4.4.1 Desalination by reverse osmosis equipment

(1) The principle of reverse osmosis

It is applied the property that the semi-permeable membrane transmits only water. In contrast, when applying pressure above the osmotic behavior, only water move toward low concentration side from high concentration side (salt will be concentrated) as shown in Fig-20 and Fig-21. It is called the reverse osmosis method to separate water aqueous solution.

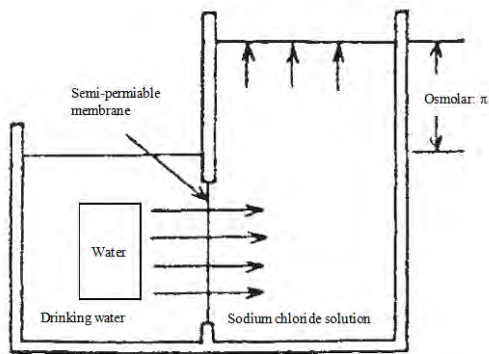


Fig- 20: Osmotic phenomenon

Reference: P-72 of Journal (No.608: May/2007): TENPES

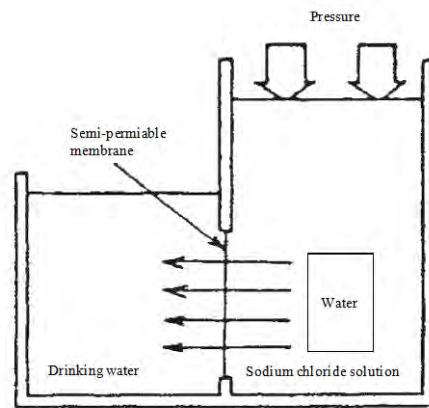


Fig- 21: Reverse osmosis phenomenon

Reference: P-72 of Journal (No.608: May/2007): TENPES

(2) Reverse osmosis membrane

The reverse osmosis membrane which is used as make-up water treatment equipment is classified in operation pressure as follows.

Table- 13: Operation pressure of reverse osmosis membrane

Type		Pressure
1)	High pressure	5 ~ 6 MPa
2)	Medium pressure	2 ~ 4.5 MPa
3)	Low pressure	1 ~ 2 MPa
4)	Very low pressure	~1 MPa

Reference: P-72 of Journal (No.608: May/2007): TENPES

Type and construction of reverse osmosis membrane is as follows. When classifying them in material first, they are divided into following two.

- 1) Cellulose acetate membranes
- 2) Synthetic polymer membranes

What is currently on the market is produced using a polymer compound such as polysulfone for support layer and polyamide for membrane layer. The performance of low pressure type and ultra low pressure type of reverse osmosis membrane in the form of commercially available are shown in appendix-1. In this way, various low pressure type and ultra low pressure type reverse osmosis membranes have been commercialized, which is capable to remove more than 99% of sodium chloride have been developed and started to use in make-up water treatment equipment for boiler.

Appendix-1: Reverse osmosis membrane

Type of membrane	Feature	Use
Cellulose acetate	Most of hypochlorous acid does not pass the membrane and does not come out into transparent water, though it is used while applying the chemicals such as a very small amount of hypochlorous acid to prevent adhesion to the membrane of organic matter and microorganisms in particular.	It is the material which was developed for the reverse osmosis membrane first and it is used primarily in seawater desalination.
Aromatic polyamide	It was commercialized in the 1970s. It has the feature that low operation pressure of membrane, high rejection of salts, less melting of impurities from the membrane. On the other hand, careful pre-processing to remove chemicals such as hypochlorite and impurities in advance is essential due to weak adhesion.	It is an essential material in the manufacturing of pure water and ultra-pure water for industry use. In recent years, the cases application to seawater desalination and home water purifier have been increasing aiming to reduce the energy cost due to the low operating pressure.
Polyvinyl alcohol		The case applying it as a single material is few in recent year. It is used as composite material to prevent aromatic polyamide against the deposition of an impurity exclusively.
Polysulfone	It has low rejection of salts, though it is relatively robust.	It is frequently used for concentration processing such as fruit juice, dairy products or chemicals and water purifier for home use, composite material (material to increase the intensity superposition) of aromatic polyamide membrane support by means of provide large holes.

- (3) Reverse osmosis equipment: The device which is either a reverse osmosis membrane elements is called a membrane element or membrane modules. It is composed membrane and support structure and there are following four basic structures.

- 1) Spiral type
- 2) Capillary type
- 3) Tubular type
- 4) Plate (flat sheet) type

In addition, the membrane module is used spiral shaped ones for water treatment in many case as shown in Fig-22 which is coiled around the collecting pipe like sushi roll and packed in the water-proof pipe as membrane module. When pressurized raw water flow into membrane module, flows through the gap within the spacer, some of the raw water is taken outside the catchment together into a tube inside the bag and pass through the semipermeable membrane.

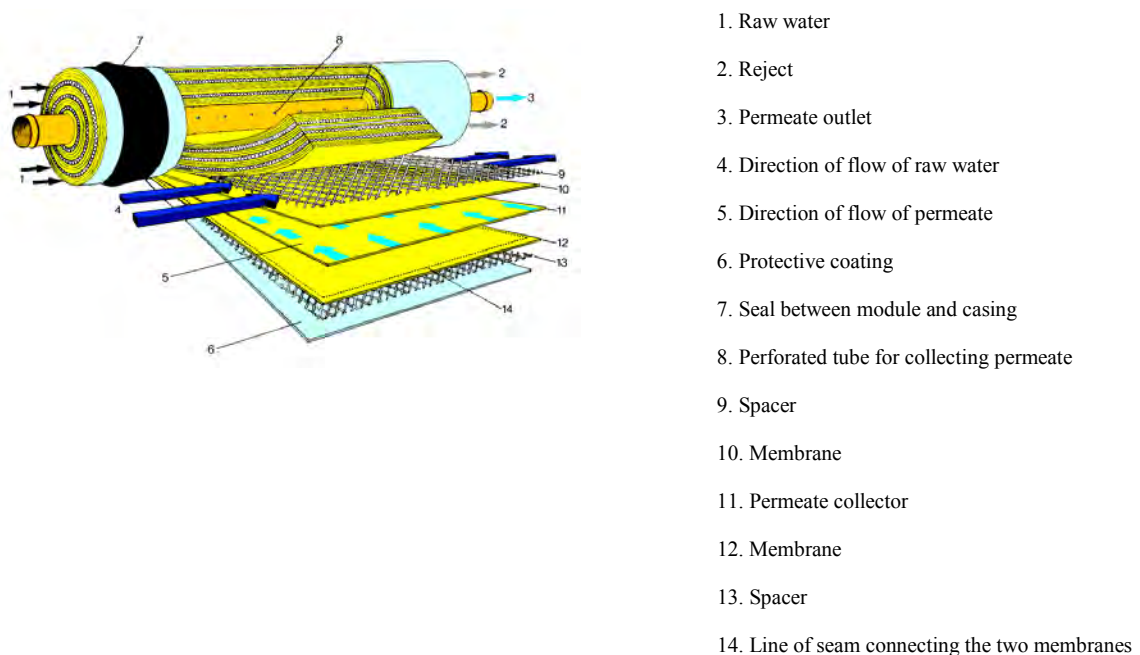


Fig- 22: Typical construction of spiral-shaped membrane module

<http://www.homecents.com/h2o/ro/index.html>

4.4.2 Electric desalination unit

There is a way to obtain high purity water to install an electric desalination unit after the reverse osmosis unit. The electric desalination unit is equipment that combined ion exchange resin, ion exchange membrane and DC power source in order to regenerate the ion exchange resin with deionized and can be operated continuously applying electricity without the need for regeneration agent.

(1) Principle of electric desalination unit

This equipment is composed with the desalination compartment filled with ion exchange resin (or ion exchanger) between the cation ion exchange membrane and the anion ion exchange membrane,

concentrating compartment provided on both side of desalination compartment, combinations of desalination compartment and concentration compartment, and couple of electrode chambers which consists positive electrode and negative electrode shown in Fig-23. Raw water is supplied to the desalination compartment and ion in the raw water is trapped in an ion exchange resin packed in the desalination compartment and then move collected ion to the surface of ion exchange resin and through ion exchange membrane by the direct current and move to the concentrating compartment. During the movement of ions, the cation ion moves in the cation ion exchange membrane, the anion ion moves in the anion exchange membrane selectively and is led to concentrating compartment. At the same time, the movement is hindered by opposite ion exchange membrane. Therefore, because each ion is concentrated in the concentrating compartment, the deionization is carried out continuously by discharging that concentrated water from the system. In addition, DC current generate hydrogen ions (H^+) and hydroxide ions (OH^-) in the part where is high potential gradient. Both ions generated by the process regenerates the ion exchange resin continuously.

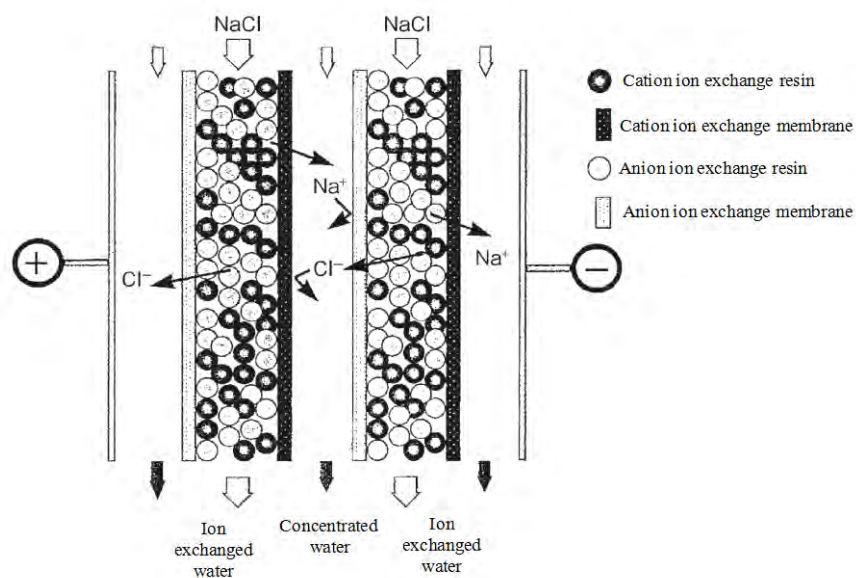


Fig- 23: Principle of electric desalination

Reference: P-73 of Journal (No.608: May/2007) TENPES

(2) Treatment by electric desalination unit

Generally, it is necessary the reverse osmosis treatment as pretreatment in order to operate the electric desalination unit under optimal condition. An example of the flow sheet of the equipment combined with reverse osmosis equipment and electric desalination equipment is shown in Fig-24. 90~95% and more ions in the raw water is removed by reverse osmosis equipment and chlorine in the raw water is removed and filtration is done by charcoal bed. In addition, pre-treatment equipment or post-processing equipment (such as polisher) is provided according to the condition of the raw water or treated water. Currently, the performance of the equipment being marketed, electric conductivity at the outlet of demineralizer is

obtained 0.05~0.1 mS/m (25°C), recovery rate is about 80~95% and treatment capacity is 5~dozens m³/h/Unit if drinking water or industrial water is applied to raw water; it may have been installed in more than one. Electric desalination unit has been adopted as the make-up water treatment equipment; it is expected to be widespread in the future because it is capable to obtain high purity water without the use of regeneration agent.

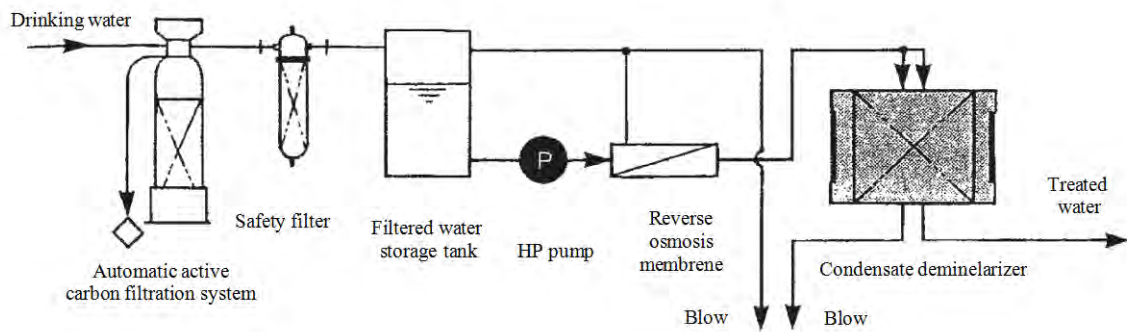


Fig- 24: Typical combination of reverse osmosis and electric desalination unit

Reference: P-73 of Journal (No.608: May/2007): TENPES

4.5 Prefix-filter

Most of the suspended solids in the condensate water is the corrosive product generated from material in the water and steam of power plant system, and they are mostly iron oxides and hydroxides. Especially when the unit starts, the suspended solids increase, and it causes various disorders such as reducing performance of condensate water demineralizer, increasing scale adhesion and increasing differential pressure of feed-water pump strainer. Therefore, the filter is provided in front of the condensate demineralizer to prevent degradation of the resin and improvement of the quality of feed-water if the unit has a lot of starts and stops.

4.5.1 Overview of equipment

There are following types such as precoat-type filter, cartridge type filter, capillary fiber membrane filter and electromagnetic filter. The summary of equipment are as follows.

(1) Precoat-type filter

This is the method to filtrate by very fine pore for filtration by means of coating powder or short fiber on the porous filter. There are two types of filter body, tubular type and leaf type as type shown in Fig-25, the tubular type is made of carbon or ceramic and the leaf type is used wire mesh or filter cloth.

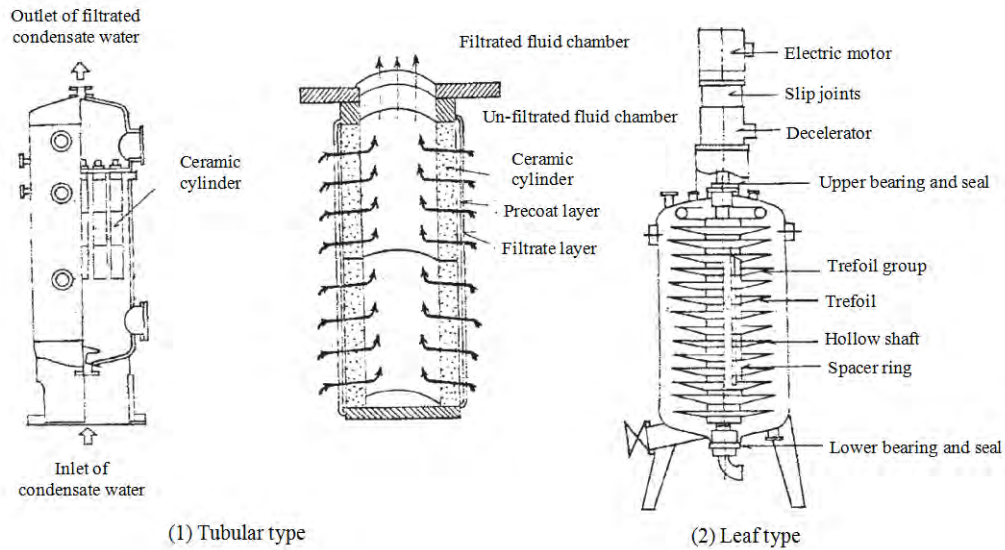


Fig- 25: Typical construction of precoat-type filter

Reference: P-47 of Journal (No.608: May/2007): TENPES

(2) Cartridge type filter

This is the method to filtrate condensate water directly by cartridge type filter packed in the tower. It is capable to start and stop water flow immediately; and it has the advantage that there are no minimum flow restrictions for holding permanent filter aids, no need to regenerate and no need to treat regenerated water and waste water. The cartridge filter is shown in Fig-26.

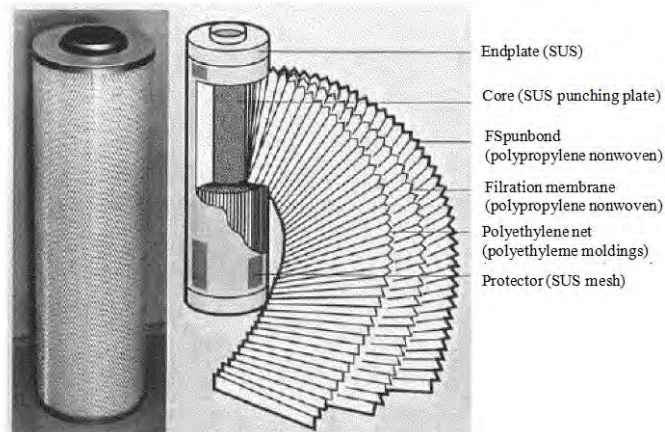


Fig- 26: Filter element of cartridge type filter

Reference: P-47 of Journal (No.608: May/2007): TENPES

(3) Capillary fiber membrane filter

This is the method to filtrate physically by the outer surface of capillary fiber with about $0.1\mu\text{m}$ bore size. The cross sections of capillary membranes are shown in the photo-1. The removal performance is superior

to other types of cleaning, it can be almost completely removed the iron suspension of more than $0.1\mu\text{m}$ diameter. This type filter has the advantages such as the high removal performance of iron suspension, simple configuration of system and low pressure difference at initial and during operation.

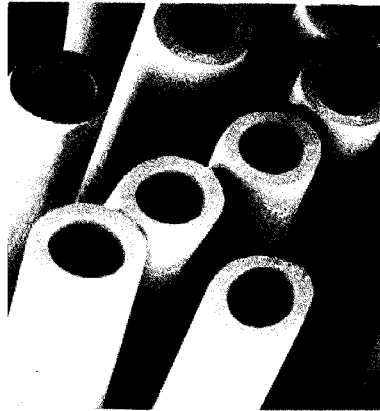


Photo- 1: Cross-section of hollow fiber membrane in the capillary fiber membrane filter

Reference: P-47 of Journal (No.608: May/2007): TENPES

(4) Electromagnetic filter

This is the method to absorb and remove iron in the condensate water by a built-in magnetic material filter (stainless steel) and generated by the exciting coil filter shown in Fig-27. The magnetic filter is generally placed two or three lines, it has an advantage to regenerate by backwash with water and air in a short time.

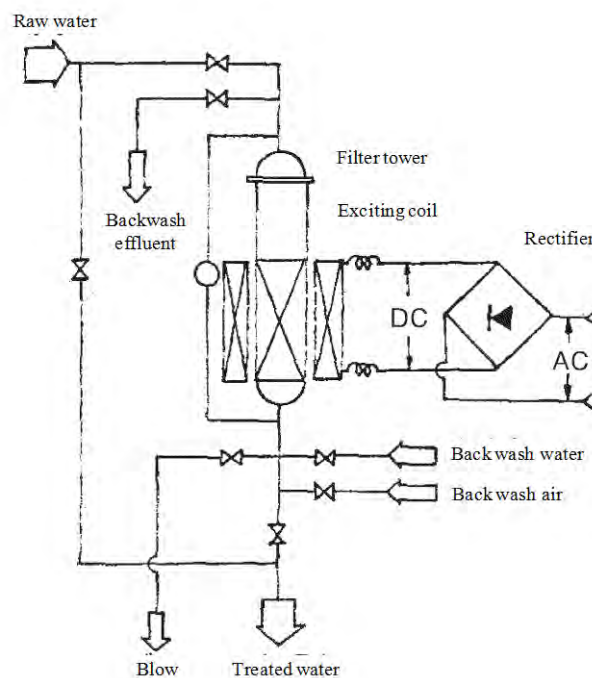


Fig- 27: Example of flow-sheet of electromagnetic filter

Reference: P-47 of Journal (No.608: May/2007): TENPE

4.6 Condensate demineralizer

In case of once-through boiler, it is required the high purity for feed-water because it cannot be adjusted the water quality by such as blowing-off same as the circulation boiler. Therefore, the condensate demineralizer is required and has the function to remove the corrosive suspension such as iron, copper, the ions of these, the trace amount of silica in the condensate water comes from make-up water, the leaked Na^+ , Mg^{2+} and Cl^- from sea water to condensate water through leaked condenser tube.

4.6.1 Configuration

The photo-2 shows the typical construction of 4 demineralizers, the resin regeneration equipment and a resin storage tank.

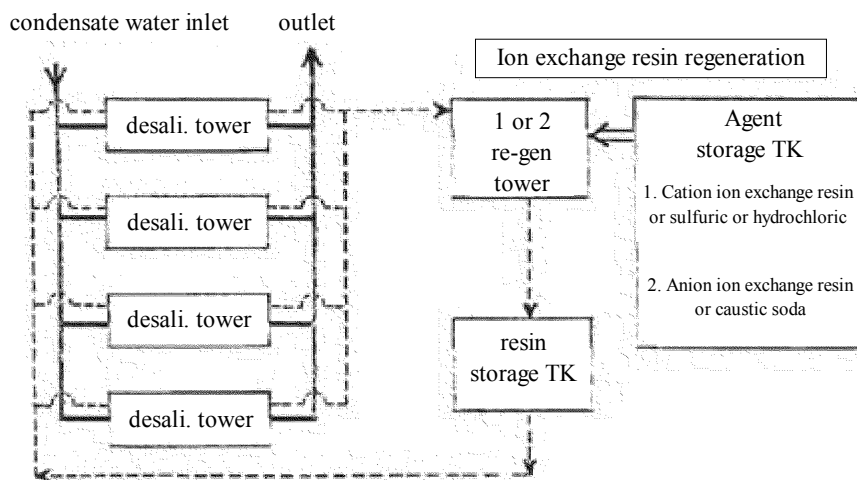


Fig- 28: Typical configuration of condensate demineralizer

Reference: P-48 of Journal (No.608: May/2007): TENPES

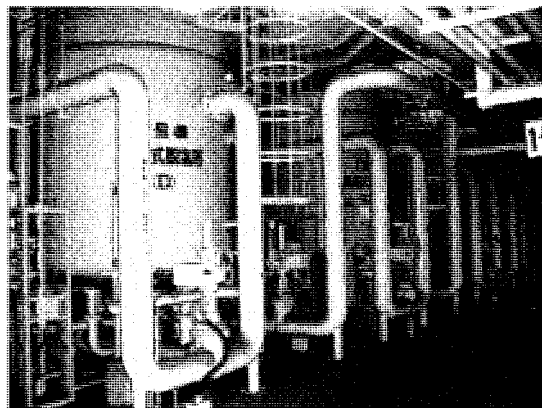


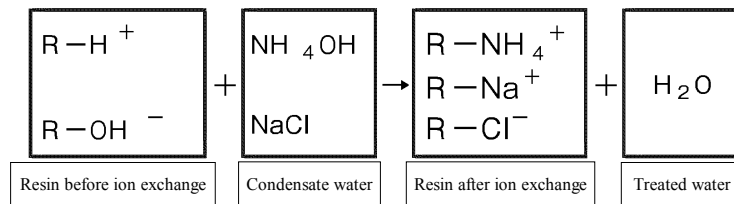
Photo- 2: Condensate demineralizer

Reference: P-48 of Journal (No.608: May/2007): TENPES

4.6.2 The principle of removal of impurities

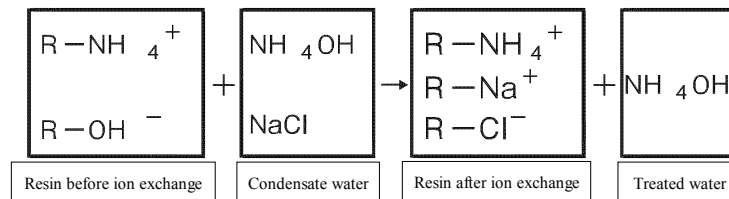
The dissolved impurities are removed by ion exchange reaction using ion exchange resins. For example, if NaCl is included as an impurity in the water for pH adjustment, the reaction depends on as follows. In addition, some effects of the removal of suspended solids are based on the principle of filtration rather than ion exchange reaction.

(1) In case of H-type condensate demineralizer



Reference: P-48 of Journal (No.608: May/2007): TENPES

(2) In case of NH_4 -type condensate demineralizer



Reference: P-48 of Journal (No.608: May/2007): TENPES

4.6.3 Types and features

There are two types of demineralizer, one is the H-type which applying H-type cation exchange resin, the other is the NH_4 -type which applying NH_4 -type exchange resin.

(1) H-type condensate demineralizer

The small amount of cation exchange resin in the anion exchange resin is converted to Na^+ -type resin by anion exchange resin regeneration (injection of caustic soda) because it cannot be completely isolated the anion exchange resin and cation exchange resin during resin regeneration. If the NH_4^+ for pH adjustment is flowed, it absorb impurities and NH_4^+ for pH adjustment, the NH_4^+ start to leaking into outlet condensate water and then the Na^+ which is corrosive factor start to leaking by selectivity of resin. Therefore, it is necessary to stop the water when NH_4^+ begins to leak.

(2) NH_4 -type condensate demineralizer

The NH_4 -type condensate demineralizer is the one which the method of regeneration is improved in order to reduce the formation of Na-type resin during regeneration which is the disadvantage of H-type

condensate demineralizer. This has economical advantage because it has less Na^+ leakage and is possible to pass water after absorption of saturated NH_4^+ long day compared with H-type. There is a way to regenerate the inject ammonia in order to reduce the amount of Na-resin production by chemical injection during anion exchange resin regeneration and to extract mixed part of cation exchange resin and anion exchange resin which including Na-resin and transport to mixed resin storage tank. The change of electric conductivity at the outlet of NH_4 -type condensate demineralizer is shown in Fig-29.

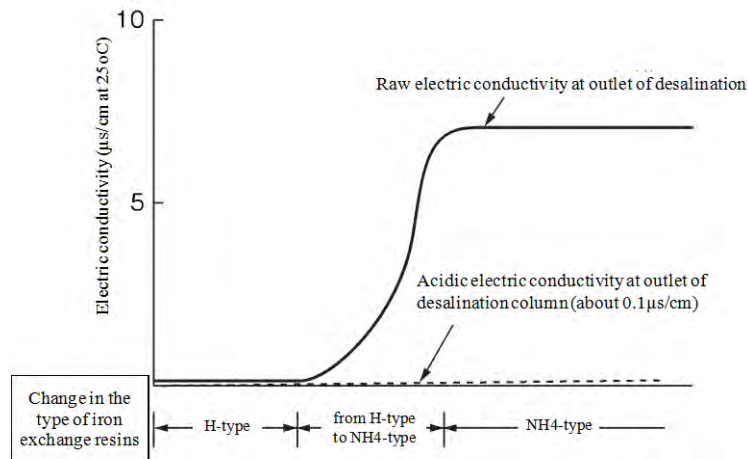


Fig- 29: Example of a change in electric conductivity of NH_4 -type demineralizing unit

Reference: P-48 of Journal (No.608: May/2007): TENPES

Article 214-2. Feed-water heater

1. In case of sub-critical pressure boiler which uses a copper alloy tube for feed water heater, there is massive and layered metal copper other than iron component in the scale and also nickel and zinc is contained. In addition, there is usually no feature because the crystalline form is also diverse.
2. In case of low pressure feed water heater which use s copper alloy and when the steam heating side is operated under negative pressure, non-condensate gas such as leaked air will leak into heater and it is similar to corrode tubes in the vicinity of the extraction area by reaction of oxygen and high concentrations of ammonia gas. The photo-3 shows an example of grove-like erosion in the gap along the circumferential direction in the gas between the plates and the supporting. The measures for this ammonia attack are considered as follows.



Photo- 3: Example of ammonia attack of condenser cooling pipe

Reference: P-59 Journal (No.608: May/2007): TENPES

- 1) To use a material such as copper-nickel alloy (Monel) or titanium tubes having a corrosion resistance for ammonia in which the parts that could be concentrated ammonia
 - 2) To prevent the air leaking into the vessel
 - 3) To maintain pH of steam below 9.3 or less in case of copper alloy for feed-water heater and manage the environment avoiding copper dissolution
3. The following photo-4 shows the situation that the pitting occurred in the context of surface of high pressure feed-water heater, this is caused due to be made to keep wet under atmosphere after blowing water at periodical inspection of plant.

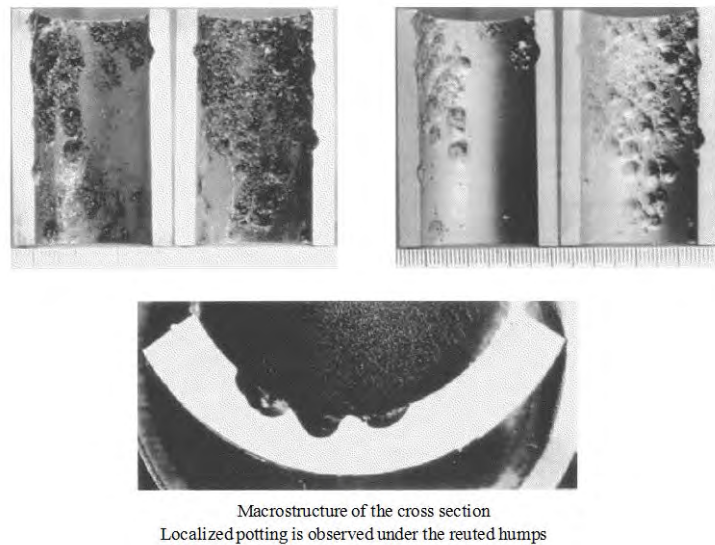


Photo- 4: Example of oxygen corrosion of steel pipe for HP feed-water heater

Reference: P-58 of Journal (No.608: May/2007): TENPES

4. The optimum pH range have set and managed depending on the constituent materials of HP and LP feed-water heater as shown in Fig-13. That is, pH is set to lower limit in case of 1 and 2 in the Table-13 which copper is applied.

Table- 14: Recommended pH of feed-water

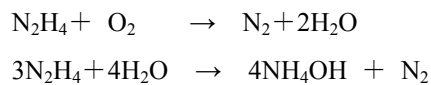
	Material for feed-water heater		Recommended pH of feed-water			
	LP	HP	8	9	10	
1	Copper alloy	Copper alloy		↔		8.5 ~9.0
2	Copper alloy	Steel			↔	9.0 ~9.4
3	Steel	Steel			↔	9.3 ~9.6

Reference: P-28 of Journal (No.614: Nov. /2007): TENPES

Article 214-3. VT and OT

1. AVT

The volatile treatment is one which is commonly used as feed-water and condensate water treatment. This method is to inject ammonia or hydrazine in the feed-water and reduce the concentration of iron or copper in the feed-water. It is effective to keep pH high and maintain alkalinity for the corrosion inhibition of steel. Therefore, the method to raise pH has been widely adopted to raise the pH injecting hydrazine and ammonia at inlet of feed-water heater and removing dissolved oxygen. Particularly with respect to hydrazine, it serves to rise the pH producing ammonia and as soon as removing oxygen the following equation.



This method is depending on the principle that the solubility of Fe_3O_4 which covers the steel surface of feed-water and condensate water system decreases with increasing pH in reducing atmosphere as shown in Fig-30.

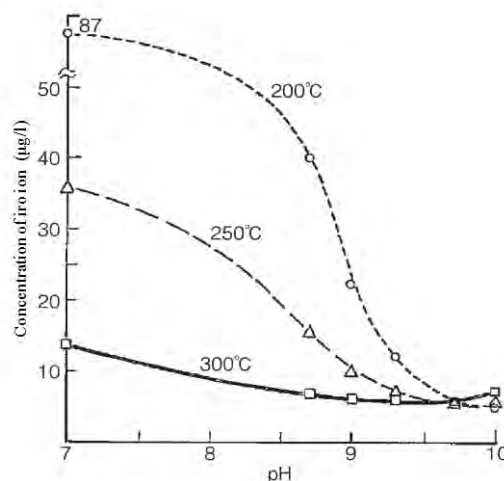


Fig- 30: Relationship between solubility of magnetite and pH (Hydrogen 25°C at 1 atm saturation)

Reference: P-43 of Journal (No.608: May/2007): TENPES

The behavior of the copper component in the feed-water and condensate system cannot be explained in the aspect of a simple solubility, there is the minimum point of solubility shown in Fig-31 unlike the iron component looking at the effect of pH on the solubility. The pH of this point varies with temperature that of the feed-water and condensate water at 25°C is around 9. As shown Fig-31 of the actual measurement, the concentration of copper have trend to increase with increasing pH in the range above pH 9.1. Therefore, it is impossible to raise the pH in case of sub-critical pressure boiler and limited to the pH in terms of dissolution inhibition of copper.

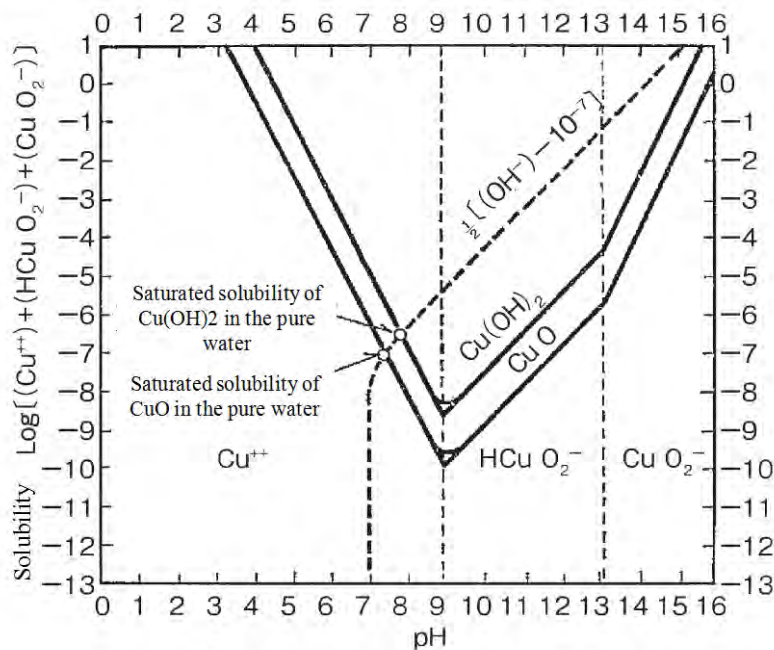


Fig- 31: Solubility and pH of the copper component

Reference: P-43 of Journal (No.608: May/2007): TENPES

2. Oxygen treatment

In recent year, the oxygen treatment is introduced mainly for the supercritical once-through boiler depending on the improvements of the purity of make-up water and condensate demineralization technology. This method is to inject ammonia as a pH regulator in the water and reduce the concentration of iron in the feed-water without using hydrazine by injecting the oxygen of about 100µ g/L. This method has the advantage to reduce amount of iron bringing into boiler because covering the steel surface of the feed-water and condensate system by compound of trivalent iron which has low solubility compared with compound of divalent iron which is produced by volatile treatment. In addition, the trivalent iron compound is stable for a wide pH range and is capable to operate at low pH compared with the volatile treatment, it is capable to reduce the use of chemicals such as ammonia shown in Fig-32 and Fig-33. On the other hand, in case of a low purity of the water, it is necessary to apply the H-type condensate demineralizer because it becomes difficult to generate a good protective coating and is required high purity water than volatile treatment. In addition, almost units apply volatile treatment without hydrazine at start-up when the purity of water goes to bad.

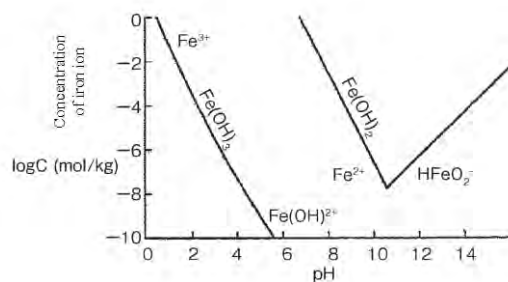


Fig- 32: Effect of pH on the solubility of iron hydroxide

Reference: P-43 of Journal (No.608: May/2007): TENPES

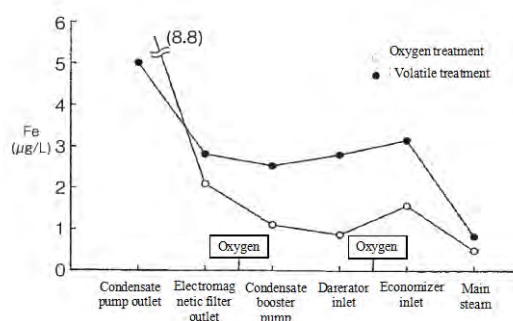


Fig- 33: Effect of the oxygen on the concentration of iron

Reference: P-43 of Journal (No.608: May/2007): TENPES

Article 215 General provision of chemical injection equipment

Article 215-1. Chemical injection equipment

1. Chemical injection equipment

The cause of corrosion and scale formation in pipes due to water quality is broadly the impurities such as pH value, dissolved oxygen, Na, Mg and Cl. The chemical injection equipment is one to inject ammonia, hydrazine for the feed-water treatment, sodium phosphate for boiler water in order to keep appropriate water quality, oxygen for CWT operation in order to leave trace oxygen in the condensate water and feed-water.

Article 215-2. pH

1. The pH is an important item for the purpose of management to prevent corrosion of the feed-water and boiler water system. The corrosion of metallic material is greatly affected by the pH and its proper value depends on such as the material in the system, temperature and pressure. Fig-31 and Fig-32 shows the relation between pH value with solubility of oxides and hydroxides. The pH of the feed-water is set to increase 9.0~9.7 if the steel pipe is used for the feed water heater. On the other hand, the pH is often set slightly lower 8.5~9.0 if the copper pipe is used to consider the corrosion of copper metal. For boiler water, the pH is mainly adjusted by phosphate; however, the upper limit is set because alkaline corrosion by concentration is a concern due to the higher operation pressure. Electric conductivity is a bellwether of the electrolyte concentration in the water, and the point of measurement is also relatively easy, which is mainly used in the boiler water level control and management of water purity. In water management, the bellwether after the removal of ammonia by a strong acidic cation exchange resin in order to detect trace amounts of electrolyte.

Article 215-3. O₂ injection for CWT

1. Oxygen injection system

The oxygen gas for CWT is injected from oxygen cylinder into the condensate water and feed-water by depressurizing. The equipment has been configured with an oxygen cylinder and pressure regulator to control the injection volume proportional to the amount of condensate water flow rate for the condensate water, proportional to the amount of feed-water flow rate and by dissolved oxygen concentration as shown in Photo-6. In addition, PSA equipment which separates oxygen from atmosphere is applied as shown Photo-5.



Photo- 5: Pressure swing absorption equipment

<http://www.sdk-kk.co.jp/prd/gas/O2.html>



Photo- 6: Oxygen gas injection equipment

<http://www.nikkiso.co.jp/products/water/injection.html>

Article 216 Chemical injection equipment

Article 216-1. Chemical injection

1. Chemical injection point and injection procedure

The typical chemical injection points are illustrated in the Fig-34. The typical construction of the chemical injection equipment is shown in Photo-7 and Photo-8. The chemical injection method and its main features are shown in Table-15.

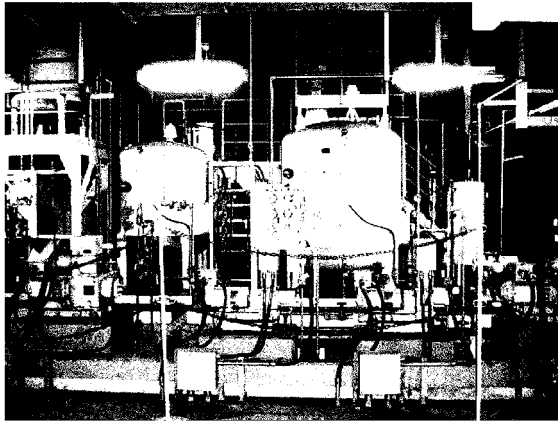


Photo- 7: Chemical injection equipment

Reference: P-46 of Journal (No.608: May/2007): TENPES



Photo- 8: Chemical feed skid

<http://www.poweronline.com/product.mvc/Chemical-Feed-Skids-0001>

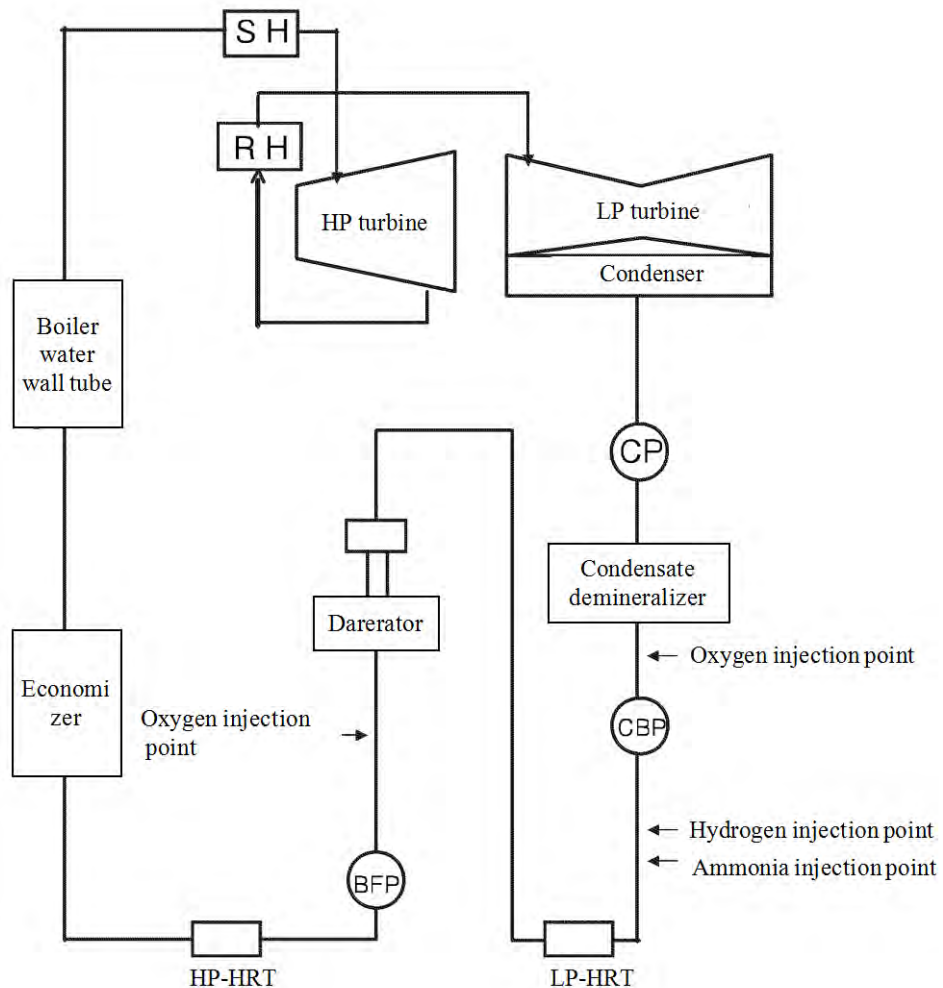


Fig- 34: Typical chemical injection point for water treatment (once-through boiler)

Reference: P-46 of Journal (No.608: May/2007): TENPES

Table- 15: Example of chemical injection method

	Name of chemical	Injection point	Injection method
pH adjuster	O Ammonia (NH ₄ OH 3% liquid)	O Circulation boiler (in case applying steel pipe for feed water heater) Outlet of condensate demineralizer Outlet of deaerator O Once-through boiler Outlet of HP feed water pump	O Continuous injection by a plunger pump O The injection volume control is the proportional corresponding to the condensate water and feed-water flow and electrical conductivity values.
pH adjuster and Oxygen scavenger	O Hydrazine (N ₂ H ₄ • H ₂ O) Starting and stopping: High concentration 10% Normal time: 0.5~2%	O Circulation boiler (in case applying steel pipe for feed water heater) Outlet of condensate demineralizer Outlet of deaerator O Once-through boiler Outlet of HP feed water pump	O Continuous injection by a plunger pump O The injection volume control is the proportional corresponding to the condensate water and feed-water flow and electrical conductivity values.
pH adjuster and agent for hardness removal	O Phosphate Sodium phosphate (Na ₃ PO ₄) Sodium hydrogenphosphate (Na ₂ HPO ₄)	O Circulation boiler Drum	O Intermittent injection by a plunger pump O Use alone or in combination of Na ₃ PO ₄ and Na ₂ HPO ₄
Dissolved oxygen Concentration adjusting agent	O Oxygen	O Once-through boiler Outlet of condensate demineralizer Outlet of deaerator	O Inject depressurized oxygen from vessel O The injection volume control is the proportional corresponding to the condensate water flow for condensate water system and feed-water flow for feed-water flow and dissolved oxygen concentration at economizer inlet.

Reference: P-46 of Journal (No.608: May/2007): TENPES

Article 216-2. Copper alloy

1. Chemical solution to be used

If the high pressure feed-water heater has a copper alloy, the hydrazine treatment is solely applied to process oxygen and pH adjustment in order to control pH value in lower value. In case of steel pipe, the

ammonia water is used for pH control and hydrazine is used as oxygen scavenger in order to keep pH high. In addition, oxygen is injected instead of hydrazine injection in order to leave traces of oxygen in the condensate water and feed water.

Article 216-3. Chemical injection pump

1. Chemical injection pump and injection control

The plunger type high pressure metering pump is used for chemical injection. Chemical is injected in proportional to the amount of water or condensate water and is controlled to eliminate the difference between set value and actual value of electric conductivity of water. In addition, the injection volume is adjusted by adjusting the plunger stroke length and speed.

Article 216-4. Ammonia injection

1. Chemical dissolution

Ammonia has been dissolved ammonia gas automatically detecting tank level and electric conductivity. In addition, the automatic dissolution method is employed to dissolve a certain amount of deionized water to concentrate certain amount of hydrazine, and the solubility has been measured labor saving work.

Article 216-5. Oxygen injection

1. In case of the conventional boiler feed-water system which is applied oxygen treatment, oxygen gas from oxygen cylinder is injected at the injection point of condensate demineralizer outlet through the oxygen gas flow controller. Since the injection point, the oxygen treatment is applied to all system from LP feed-water heater via deaerator, HP feed-water heater, economizer, boiler, turbine to condenser. The adjustment of air vent for deaerator is made to maintain the concentration of dissolved oxygen 20μg/L at sampling point on economizer, and the concentration of dissolved oxygen is made in the range of 20~200μg/L.

Article 217 General provision of sampling rack and water quality monitoring equipment

Article 217-1. Sampling equipment

1. Coordination and management of water quality

1.1 The water quality standard

The water quality standard is stipulated, for example, as Table-17 to Table-24 of JIS B8223, and the adjustment has been made by such as water blow or chemical injection to prevent failure due to the water during boiler operation. Here, it is described an overview of the significance of the reference value and failure.

1.2 Dissolved oxygen

The dissolved oxygen is managed as of upper limit (7ppb or less) under the volatile treatment because it will cause corrosion of metallic material. The deaerator is applied and the oxygen scavenger such as hydrogen is injected a certain amount so as to remain. On the other hand for oxygen treatment, the growth

rate of scale is reduced by produce the hematite film by managing the dissolved oxygen in appropriate concentration (20~200ppb) under more severe conditions (the electric conductivity is 0.02mSm or more).

1.3 Iron and copper

It is necessary sufficient management of the feed-water, if the oxide iron and copper which is corrosive product flow in from pre-boiler system into boiler and the will be scaled in the water wall tube, they cause overheating and punctuation of tubes and dissimilar metal corrosion.

1.4 Silica and phosphate ion, etc.

Silica is dissolved in steam by carrying over or carrying in and attached to super-heater tube, valve and turbine, etc., and it causes obstruction or adversely affects turbine efficiency. In order to prevent such failures, the upper limit of water has set in each pressure category. The upper limit of phosphate ion which is injected as cleaning and pH adjustment is established; however, it is necessary to note the occurrence of Hideout (phosphate precipitation at elevated temperature + pressure). In addition, the reference value stipulated for chloride ions.

2. Analysis items and frequency

The chemical analysis is necessary in order to manage water quality has carried out around the field that cannot be check by water monitoring device or automatic measurement device, the frequency of measurement is shown in Table-16. The water quality testing method has been based on JIS B8224

“Boiler feed water and boiler water - Testing methods” . The conventional analysis was centered on absorption spectrophotometry method; however, recently the ion chromatography method, flame atomic absorption method and ICP emission spectroscopy method have been adopted and utilized in micro-scale materials in the scale.

Table- 16: Frequency of analysis

	Analysis items	Frequency of analysis
Outlet of pure water storage tank	Electric conductivity Silica	Once a week ~ once a month
Outlet of condensate pump Outlet of condensate demineralizer Inlet of deaerator Outlet of deaerator	Electric conductivity Dissolved oxygen Sodium (in case of once-through boiler)	
Inlet of economizer	pH, Electric conductivity Silica Iron, copper Hydrazine	
Boiler water	pH, Electric conductivity Silica Iron, copper Phosphate ion Chloride ion	

Reference: P-51 of Journal (No.608: May/2007): TENPES

Article 218 Sampling rack and water quality monitoring equipment

Article 218-1. Sampling point

1. Sampling rack

The sampling rack is the equipment to extracts water and steam samples from various points of plant system shown in Fig-35 and Fig-36, de-pressurize, cooling, adjusting flow volume and supply specimen for chemical analysis and monitoring devices as shown in Photo-12. The double-pipe corrugated cooler is used for cooling of specimen, and the automatic de-pressurizing mechanism has been adopted to achieve a stable flow rate in response to constantly stop, start and sliding pressure operation. In addition, the automatic sampling equipment is provided for automatic sampling valve and water quality monitoring device which is operated in respond to starting process. The most important thing in the operation of sampling equipment is cleanliness in the sampling system. Especially it is necessary to flush adequately including depressurizing system because of the large contamination due to the high turbidity during start up.

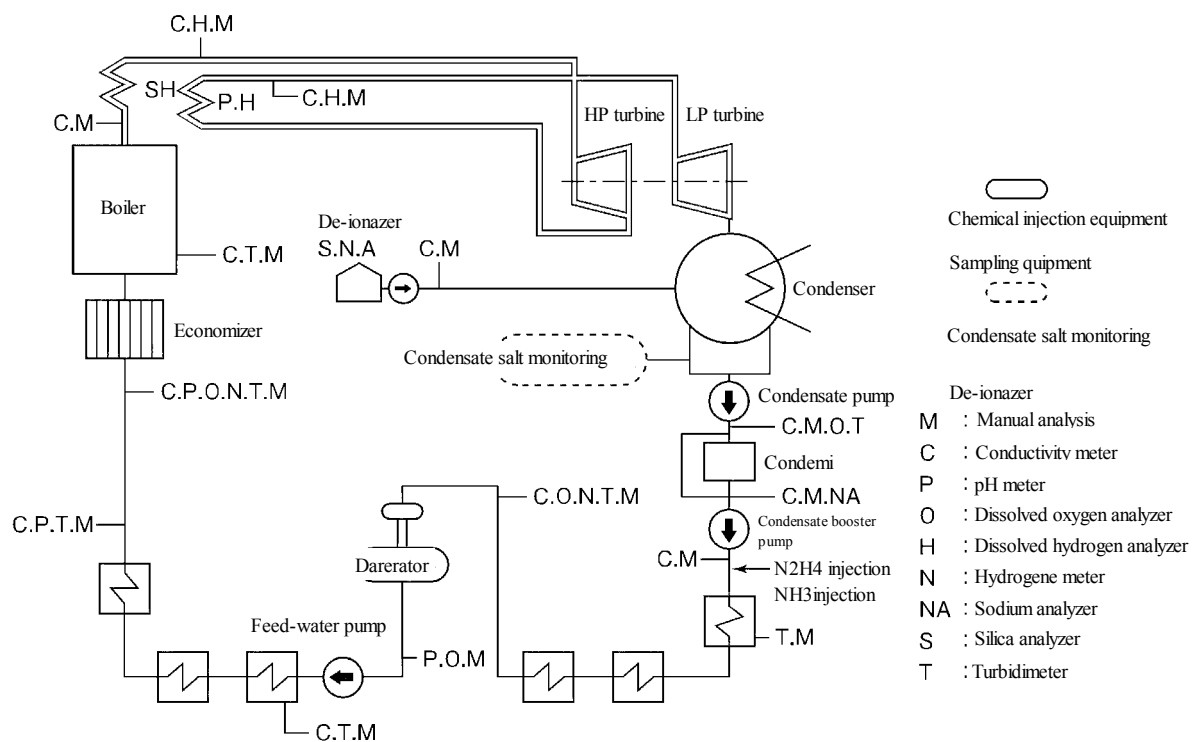


Fig- 35: Sampling point and monitoring Point (example of once-through boiler)

Reference: P-50 of Journal (No.608: May/2007): TENPES

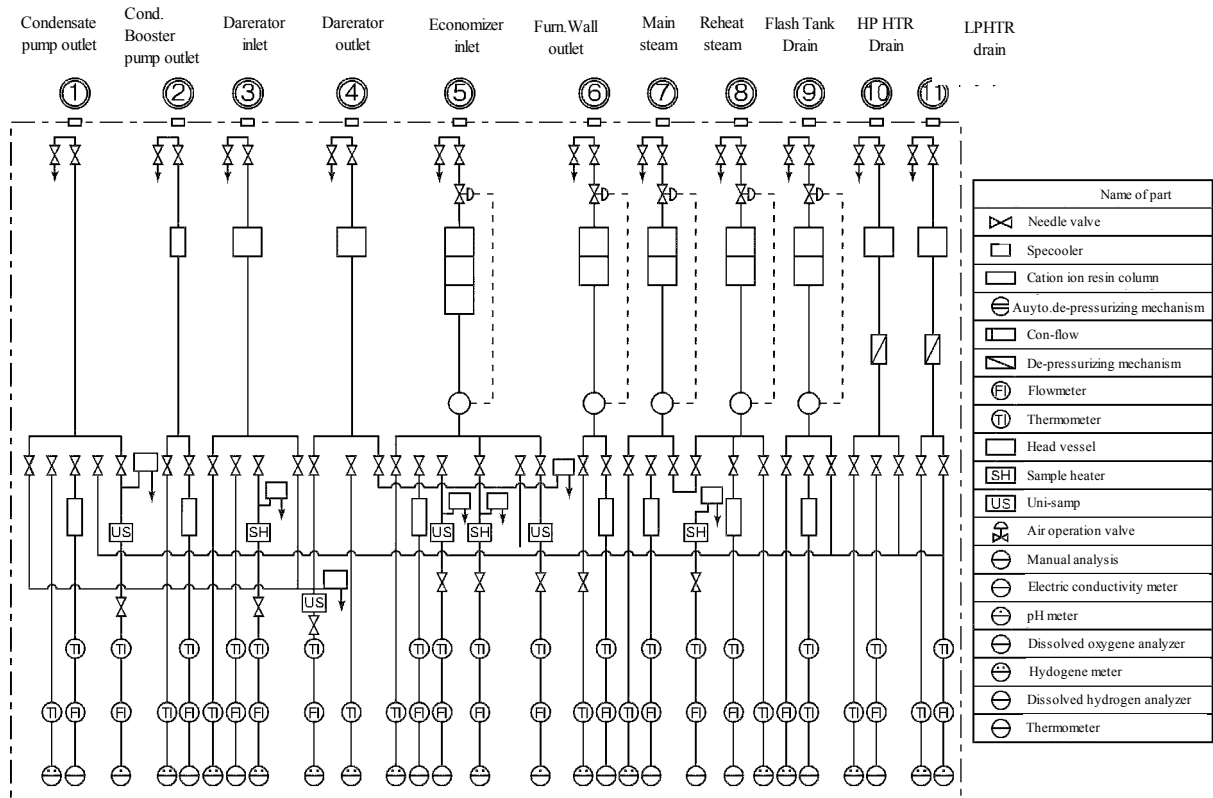


Fig- 36: Sampling equipment flow-sheet (example of once-through boiler)

Reference: P-50 of Journal (No.608: May/2007): TENPES

Article 218-2. Depressurizing

1. Steam and water specimen taken at each sampling point is depressurized and cooled down for chemical analysis as sample water. At this time, the variable flow and pressure type head vessel which is capable to keep the flow and pressure in constant value regardless of fluctuations in flow and pressure of water at sampling point is used as the depressurizing equipment without being constrained the installation position (height).



Photo- 9: Pressure reducing valve (1)

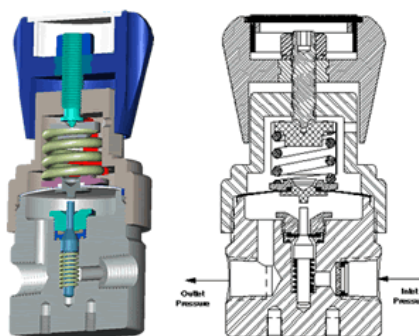


Photo- 10: Pressure reducing valve (2)



Photo- 11: Pressure reducers

Article 218-3. Surveillance instrument

1. Water quality surveillance instrument

The methods of water quality monitoring have been migrated from the chemical analysis to the continuous monitoring by monitoring devices. The instrument are configured as part of the sampling equipment, measurement of each instrument is capable to monitor trends and changes over time trend to be connected to a recorder or data processing equipment. The acid electric conductivity through a cation exchange resin is used as the electric conductivity meter which is applied to monitoring of water quality to measure in order to avoid the effects of ammonia and hydrazine for water treatment when detecting impurities. The pH meter indicates in pH scale which is measured the potential difference between glass electrode and comparison electrode, and it is compensated the change in the force by the temperature compensation electrode. It is necessary to measure and adjust the temperature of sample water by thermostat water tub because the pH value is expressed at 25°C, however, some products has the so-called double temperature compensated function which is capable to compensate water temperature difference. The diaphragm electrode type is applied to the total dissolved oxygen meter which can be measured accurately, the

turbid-meter is applied to monitor suspended iron for supercritical once-through boiler, the Na meter is applied to monitor leak Na from ammonia type demineralizer.

Article 218-4. Automation of sampling equipment

1. In the latest water monitoring of boiler, it is capable to run each monitoring devices sequentially in conjunction with the plant process during the normal operation, normal shut-down and normal start-up of plant. Moreover, by combination of chemical injection equipment, it is possible to automatically adjust the water quality of plant; it is capable to automate even during start and stop the plant that is heavy burden of operating personnel as well as during normal operation.



Photo- 12: Example of sampling rack

Article 218-5. Structure of sampling equipment

1. The typical configuration of the sampling system which has been incorporated into the sampling rack is illustrated as follows. They are composed by the devices to cool-down, depressurize, adjust temperature, adjust flow and select salts, and devices for chemical analysis, water quality monitoring, sample sequencer, etc. The typical configuration and components are shown in the following Fig-37 Photo-13 and ~ Photo-20.

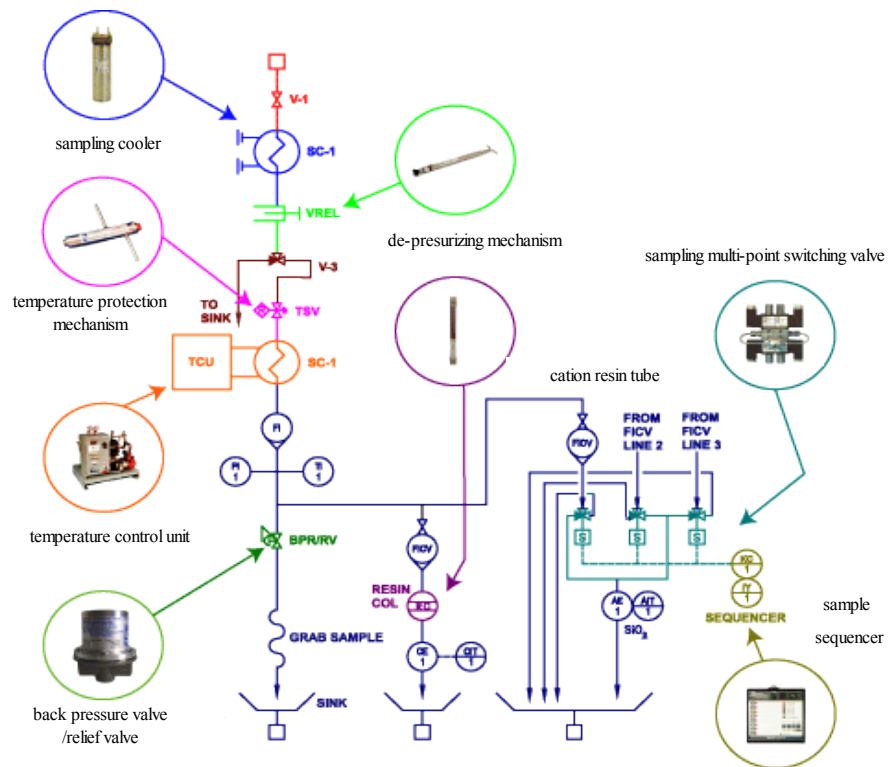


Fig- 37: Typical configuration of sampling system

<http://www.skgr.co.jp/skcpa/sampling/sampindex.htm>



Photo- 13: Pressure reducers



Photo- 14: Sample cooler



Photo- 15: Thermal shutoff valve



Photo- 16: Temperature control unit



Photo- 17: Back Pressure regulator relief valve



Photo- 18: Cation conductivity resin tube

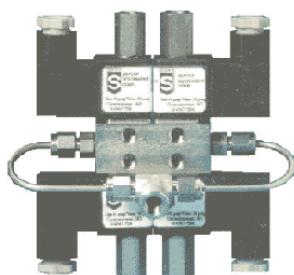


Photo- 19: Manifold sample valve



Photo- 20: Sample sequencer

Chapter-3. Water Quality Limit of Feed-water, Boiler water, Steam purity

The recommended quality standards for boiler feed-water, boiler water and boiler steam corresponding to the type and operation condition are organized as follows.

Table-17	Quality of feed-water and boiler water for round boiler	JIS
Table-18	Quality of feed-water and boiler water for special circulation boiler	JIS
Table-19	Quality of feed-water and boiler water for water tube boiler (circulation boiler) (1)	JIS
Table-20	Quality of feed-water and boiler water for water tube boiler (circulation boiler) (2)	JIS
Table-21	Quality of feed-water and boiler water for HRSG	JIS
Table-22	Quality of feed-water and boiler water for once-through boiler	JIS
Table-23	Quality of steam generated by boiler	JIS
Table-24	Quality of water for once-through boiler during start-up (in case of applying volatile treatment)	JIS
Table-25	Quality of water for once-through boiler during start-up (in case of applying oxidization treatment)	JIS
Table-26	Boiler Water Limits for Industrial Water Tube Boilers	ASME
Table-27	Recommended Water Tube Boiler Water Limits and Associated Steam Purity at Steady Load Operation	ABMA

Table- 17: Quality of feed-water and boiler water for cylindrical boiler

JIS B8223-2006

classification	Pressure of using regularly	MPa	1 ≥ P			2 ≥ P > 1
	Evaporating rate on heating surface	Kg/(m ² h)	30 ≥ R ⁽⁶⁾	60 ≥ R > 30	R > 60	—
	Type of make up water	—	Raw water ⁽⁷⁾	Softened water ⁽⁷⁾		
Feed water	pH (at 25°C)	—	5.8~9.0 ⁽⁸⁾	5.8~9.0 ⁽⁸⁾	5.8~9.0 ⁽⁸⁾	5.8~9.0 ⁽⁸⁾
	Hardness	mgCaCO ₃ /L	60 or less	1 or less	1 or less	1 or less
	Oily matter ⁽⁹⁾	mg/L	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾
	Dissolved oxygen	mg O/L	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾
Boiler water	Method of treatment	—	Caustic treatment			
	pH (at 25°C)	—	11.0~11.8	11.0~11.8	11.0~11.8	11.0~11.8
	Acid consumption (pH4.8)	mgCaCO ₃ /L	100~800	100~800	100~800	600 or less
	Acid consumption (pH8.3)	mgCaCO ₃ /L	80~600	80~600	80~600	500 or less
	Total residue after evaporation	mg/L	4000 or less	3000 or less	2500 or less	2300 or less
	Conductivity (at 25°C)	mS/m	600 or less	450 or less	400 or less	350 or less
	Chloride ion	mgCl/L	600 or less	500 or less	400 or less	350 or less
	Phosphate ion ⁽¹¹⁾	mgPO ₄ ³⁻ /L	20~40	20~40	20~40	20~40
	Sulfite ion ⁽¹²⁾	mgSO ₃ ²⁻ /L	10 and more	10 and more	10 and more	10 and more
	Hydrazine ⁽¹³⁾	mgN ₂ O ₄ /L	0.1~1.0	0.1~1.0	0.1~1.0	0.1~1.0

Note

- ⁽⁶⁾
- : Applied to the case of the cast iron boiler using raw steam and make-up water at all times.
- ⁽⁷⁾
- : City water, industrial water, underground water, river water, lake water, etc. The softened water refers to the raw water treated by water softening equipment (filled with cation exchange resin) or by reverse osmotic treatment.
- ⁽⁸⁾
- : To minimize corrosion in the feed-water system, it is preferred to control the system with the pH value raised 7 or higher.
- ⁽⁹⁾
- : Hexane extract (refer to JIS B8224).
- ⁽¹⁰⁾
- : Preferable to keep at a lower value
- ⁽¹¹⁾
- : Applied when phosphate is added.
- ⁽¹²⁾
- : Applied when sulfite is added for de-oxidation; although the upper limit for the sulfate ion concentration is not specified, it shall be in a range that does not allow the electrical conductivity of boiler water to exceed the specified upper limit.
Preferable to adjust the ion concentration to 10~20 mgSO₃²⁻/L, when a deaerator is used.
- ⁽¹³⁾
- : Applied when hydrazine is added for de-oxidation; however, it is preferable to adjust the concentration to 0.1~0.5mgN₂O₄/L when a deaerator is used.

Remarks

1.
- : In using ion exchange for make-up water of cylindrical boiler, it applies the water quality of table-2 that is de-mineralized water for make-up water of pressure classification of the exceeding 1MPa and 2MPa or less.
2.
- : In using for ships, it applies the water quality of table-2 which is de-mineralized water for make-up of pressure classification of exceeding 1MPa and 2MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher inconsideration of sea water leakage.
3.
- : Either hydrazine or sulfate selected for de-oxidation is added in principle.
4.
- : The sample to test the boiler water shall be taken from the position where the boiler water is most concerned.
5.
- : In case of boiler used in the pressure of the exceeding 2MPa, it applies water quality of the water tube boiler shown as table-2 and same classification.

Table- 18: Quality of feed-water and boiler water for special circulation boiler

JIS B8223-2006

classification	Type of boiler	—	Single tube type		Multi tube type	
	Pressure of using regularly	MPa	1 ≥ P	3 ≥ P >1	1 ≥ P	3 ≥ P >1
	Type of make up water	—	Softened water ⁽⁷⁾		Softened water ⁽⁷⁾	
Feed water	pH (at 25°C)	—	11.0~11.8	10.5~11.0	5.8~9.0 ⁽⁸⁾	5.8~9.0 ⁽⁸⁾
	Hardness	mgCaCO ₃ /L	1 or less ⁽¹⁴⁾	1 or less ⁽¹⁴⁾	1 or less	1 or less
	Oily matter ⁽⁹⁾	mg/L	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾
	Dissolved oxygen	mg O/L	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾
	Total iron	mgFe/L	—	—	—	—
	Total solids	mg/L	3000 or less	2500 or less	0.3 or less	0.3 or less
	Conductivity (at 25°C)	mS/m	450 or less	400 or less	—	—
	Acid consumption (pH4.8)	mgCaCO ₃ /L	300~800	600 or less	—	—
	Acid consumption (pH8.3)	mgCaCO ₃ /L	200~600	500 or less	—	—
	Hydrazine ⁽¹⁵⁾	mgN ₂ O ₄ /L	0.05 and more	0.05 and more	—	—
	Chloride ion	mgCl/L	600 or less	400 or less	—	—
	Phosphate ion ⁽¹¹⁾	mgPO ₄ ³⁻ /L	20~60	20~60	—	—
Boiler water	Method of treatment	—	—	—	Caustic treatment	
	pH (at 25°C)	—	—	—	11.0~11.8	11.0~11.8
	Acid consumption (pH4.8)	mgCaCO ₃ /L	—	—	100~800	600 or less
	Acid consumption (pH8.3)	mgCaCO ₃ /L	—	—	80~600	500 or less
	Total residue after evaporation	mg/L	—	—	2500 or less	2000 or less
	Conductivity (at 25°C)	mS/m	—	—	400 or less	300 or less
	Chloride ion	mgCl/L	—	—	400 or less	300 or less
	Phosphate ion ⁽¹¹⁾	mgPO ₄ ³⁻ /L	—	—	20~40	20~40
	Sulfite ion ⁽¹²⁾	mgSO ₃ ²⁻ /L	—	—	10 and more	10~20
	Hydrazine ⁽¹³⁾	mgN ₂ O ₄ /L	—	—	0.1~1.0	0.1~0.5

Note

- ⁽¹⁴⁾ : Applied to the feed water before the return water is mixed.
⁽¹⁵⁾ : Hydrazine concentration can also be decreased according to the dissolved oxygen concentration at a deaerator exit while the pH does not exceed the maximum.

Remarks

- : In using ion exchange for make-up water of the special circulation boiler, it applies the water quality of table-3 which is de-mineralized water for make-up water of the pressure classification of the exceeding 1MPa and 2MPa or less.
- : In using for ships, it applies the water quality of table-2 which is de-mineralized water for make-up water of the same pressure classification of the exceeding 1MPa and 2MPa or less. However, the concentration of phosphate ion of preferable to be adjusted higher in consideration of sea water leakage. And in case of 1MPa or less, it applies the water quality of table-2 which is de-mineralized water for make-up water of the pressure classification of exceeding 1MPa and 2MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage.
- : The feed-water quality of the single tube boiler is applied to chemicals added to the make-up water or the water composed of the mixture between make-up water and condensate supplied with return water.
- : The feed-water quality of the multi tube boiler is applied to the feed-water before return water is added. The position of sampling is considered 2 points of steam/water separator lower part and body lower part with the structure of boiler marketed now. As it is considered that the former sample is may become non-uniformity during operation, the attention is paid to the location and sampling time for obtaining the sample equalized as much as possible.
- : By remarks: 3 of table-1.

Table- 19: Quality of feed-water and boiler water for water tube boiler (circulation boiler) (1)

JIS B8223-2006

classification	Pressure of using regularly	MPa	1 ≥ P		2 ≥ P >1		3 ≥ P >2		5 ≥ P >3		
	Evaporation rate on heating surface	Kg/(m²h)	50 ≥ R	R >50	—	—	—	—			
	Type of make up water	—	Softened water ⁽⁷⁾			Ion-exchanged water ⁽¹⁶⁾		Ion-exchanged water ⁽¹⁶⁾		Ion-exchanged water ⁽¹⁶⁾	
Feed water	pH (at 25°C)	—	5.8~9.0 ⁽⁸⁾	5.8~9.0 ⁽⁸⁾	5.8~9.0 ⁽⁸⁾	8.5~9.7 ⁽¹⁷⁾		8.5~9.7 ⁽¹⁷⁾		8.5~9.7 ⁽¹⁷⁾	
	Conductivity (at 25°C)	mS/m	—	—	—	—		—		—	
	Hardness	mgCaCO ₃ /L	1 or less	1 or less	1 or less	Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾	
	Oily matter ⁽⁹⁾	mg/L	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾	⁽¹⁰⁾		⁽¹⁰⁾		⁽¹⁰⁾	
	Dissolved oxygen	μg O/L	⁽¹⁰⁾	⁽¹⁰⁾	500 or less	500 or less		100 or less		30 or less	
	Total iron	μgFe/L	—	300 or less	300 or less	100 or less		100 or less		100 or less	
	Total copper	μgCu/L	—	—	—	—		—		50 or less	
	Hydrazine ⁽¹⁵⁾	μgN ₂ O ₄ /L	—	—	—	—		200 and more		60 and more	
Boiler water	Method of treatment	—	Caustic treatment				Phosphate treatment	Caustic treatment	Phosphate treatment	Caustic treatment	Phosphate treatment
	pH (at 25°C)	—	11.0~11.8	11.0~11.8	11.0~11.8	10.5~11.5	9.8~10.8	910.0~11.0	9.4~10.5	9.6~10.8	9.4~10.5
	Acid consumption (pH4.8)	mgCaCO ₃ /L	100~800	100~800	600 or less	250 or less	130 or less	150 or less	100 or less	—	—
	Acid consumption (pH8.3)	mgCaCO ₃ /L	80~600	80~600	500 or less	200 or less	100 or less	120 or less	80 or less	—	—
	Total residue after evaporation	mg/L	3000 or less	2500 or less	2000 or less	—	—	—	—	—	—
	Conductivity (at 25°C)	mS/m	450 or less	400 or less	300 or less	150 or less	120 or less	100 or less	80 or less	80 or less	60 or less
	Chloride ion	mgCl/L	500 or less	400 or less	300 or less	150 or less	150 or less	100 or less	100 or less	80 or less	80 or less
	Phosphate ion ⁽¹¹⁾	mgPO ₄ ³⁻ /L	20~40	20~40	20~40	10~30	10~30	5~15	5~15	5~15	5~15
	Sulfite ion	mgSO ₃ ²⁻ /L	10 and more ⁽¹²⁾	10 and more ⁽¹²⁾	10~20	10~20	10~20	5~10	5~10	5~10	5~10
	Hydrazine ⁽¹³⁾	mgN ₂ O ₄ /L	0.1~1.0	0.1~1.0	0.1~0.5	0.1~0.5	0.1~0.5	—	—	—	—
	Silica	mgSiO ₂ /L	—	—	—	50 or less	50 or less	50 or less	50 or less	20 or less	20 or less

Table- 20: Quality of feed-water and boiler water for water tube boiler (circulation boiler) (2)

JIS B8223-2006

classification	Pressure of using regularly	MPa	7.5 ≥ P >5			10≥ P >7.5		15≥ P >10		20≥ P >15			
	Evaporation rate on heating surface	Kg/(m ² h)	—			—		—		—			
	Type of make up water	—	Ion-exchanged water ⁽¹⁶⁾			Ion-exchanged water ⁽¹⁶⁾		Ion-exchanged water ⁽¹⁶⁾		Ion-exchanged water ⁽¹⁶⁾			
Feed water	Method of treatment	—	—			—		—		Oxygen treatment	—	Oxygen treatment	
	pH (at 25°C)	—	8.5~9.7 ⁽¹⁷⁾			8.5~9.7 ⁽¹⁷⁾		8.5~9.7 ⁽¹⁷⁾		8.0~9.3	8.5~9.7 ⁽¹⁷⁾		8.0~9.3
	Conductivity (at 25°C) ⁽¹⁸⁾	mS/m	—			—		0.05 or less		0.02 or less ⁽¹⁹⁾	0.05 or less		0.02 or less ⁽¹⁹⁾
	Hardness	mgCaCO ₃ /L	Not detected ⁽²⁰⁾			Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾	Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾
	Oily matter ⁽⁹⁾	mg/L	⁽¹⁰⁾			⁽¹⁰⁾		⁽¹⁰⁾		⁽¹⁰⁾	⁽¹⁰⁾		⁽¹⁰⁾
	Dissolved oxygen	μg O/L	7 or less			7 or less		7 or less		20~200	7 or less		20~200
	Total iron	μgFe/L	50 or less			30 or less ⁽²¹⁾		30 or less ⁽²¹⁾		5 or less ⁽²³⁾	20 or less ⁽²²⁾		5 or less ⁽²³⁾
	Total copper	μgCu/L	30 or less			20 or less		10 or less		10 or less	5 or less		10 or less
	Hydrazine ⁽¹⁵⁾	μgN ₂ O ₄ /L	10 or more			10 or more		10 or more		—	10 or more		—
Boiler water	Method of treatment	—	Caustic treatment	Phosphate treatment	All volatile Treatment	Phosphate treatment	All volatile Treatment	Phosphate treatment	All volatile Treatment	— ⁽²⁴⁾	Phosphate treatment	All volatile Treatment	— ⁽²⁴⁾
	pH (at 25°C)	—	9.6~10.5	9.2~10.2	8.5~9.7	9.0~10.0	8.5~9.7	8.5~9.8	8.5~9.7	8.0~9.3 ⁽²⁴⁾	8.5~9.8	8.5~9.7	8.0~9.3 ⁽²⁴⁾
	Acid consumption (pH4.8)	mgCaCO ₃ /L	—	—	—	—	—	—	—	—	—	—	—
	Acid consumption (pH8.3)	mgCaCO ₃ /L	—	—	—	—	—	—	—	—	—	—	—
	Total residue after evaporation	mg/L	—	—	—	—	—	—	—	—	—	—	—
	Conductivity (at 25°C)	mS/m	50 or less	40 or less	—	15 or less	—	6 or less	—	—	6 or less	—	—
	Conductance (at 25°C) ⁽¹⁸⁾	mS/m	—	—	6 or less	—	6 or less	—	2 or less	0.3 or less	—	2 or less	0.3 or less
	Chloride ion	mgCl/L	50 or less	50 or less	2 or less	10 or less	2 or less	2 or less	1 or less	0.05 or less	2 or less	1 or less	0.05 or less ⁽²⁵⁾
	Phosphate ion ⁽¹¹⁾	mgPO ₄ ³⁻ /L	3~10	3~10	⁽²⁶⁾	2~6	⁽²⁶⁾	0.1~3	⁽²⁶⁾	—	0.1~3	⁽²⁶⁾	—
	Sulfite ion ⁽¹²⁾	mgSO ₃ ²⁻ /L	—	—	—	—	—	—	—	—	—	—	—
	Hydrazine ⁽¹³⁾	mgN ₂ O ₄ /L	—	—	—	—	—	—	—	—	—	—	—
	Silica ⁽²⁷⁾	mgSiO ₂ /L	5 or less	5 or less	5 or less	2 or less	2 or less	0.3 or less	0.3 or less	0.3 or less	0.2 or less	0.2 or less	0.2 or less

Note

- ⁽¹⁶⁾ : Water purified by the demineralizer using the strong acidic ion exchanger and strong basic ion exchange resin. It also includes the water (condensed water) refined by the evaporator.
- ⁽¹⁷⁾ : When the pipe material for both low pressure and high pressure feed water heaters is copper alloy, the pH value should be adjusted to pH8.5~9.0; when the low pressure feed water heater is made of copper alloy and the high pressure is made of steel pipe, the pH value should be adjusted to pH9.3~9.7.
- ⁽¹⁸⁾ : Measure the sample by passing it through the column filled with strong acidic cation exchange resin in the form of the hydrogen ion.
- ⁽¹⁹⁾ : Preferable to be 0.01mS/m or less.
- ⁽²⁰⁾ : When hardness is calculated using minimum limit of determination of the applied examination method of the calcium and magnesium of JIS B8224, it is the value lower than that calculated value.
- ⁽²¹⁾ : Preferable to keep 20μgFe/L or less.
- ⁽²²⁾ : Preferable to keep 10μgFe/L or less.

- (²³) : Preferable to keep 2μgFe/L or less.
- (²⁴) : Dissolved oxygen concentration in boiler water becomes low; to adjust pH value, volatile matter (ammonia or volatile amine) is used.
- (²⁵) : The test is carried out according to article5 (chloride ion) and the note(6) of the same article of JIS K0556.
- (²⁶) : If calcium, magnesium and other components that will reduce pH are mixed by sea water leakage to the condenser, add the required phosphate sodium hydroxide corresponding to the entrained amount of these components for corrective actions.
- (²⁷) : Keep the concentration of the silica in the boiler water so that the concentration of silica in steam will be 0.02 mgSiO₂/L or less, from the relationship between the silica concentration in the boiler and in the steam.

Remarks

- 1. : According to remarks 3 of table-1.
- 2. : In using for ships, it applies the water quality of table-3 which is de-mineralized water for make-up water of the same pressure classification. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage. And in case of 1MPa or less, applied the quality of table-3 which is de-mineralized water for make-up water of the pressure classification of exceeding 1MPa and 2MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage.

Table- 21: Quality of feed-water and boiler water for HRSG

JIS B8223-2006

classification	Pressure of using regularly	MPa	10 ≥ P		15 ≥ P >10		20 ≥ P >15	
	Type of make-up water	—	Ion-exchanged water ⁽¹⁶⁾		Ion-exchanged water ⁽¹⁶⁾		Ion-exchanged water ⁽¹⁶⁾	
Feed water	Method of treatment		—		—		—	
	pH (at 25°C) ⁽²⁸⁾	—	8.5~9.7	8.5 and more	8.5~9.7	8.5 and more	8.5~9.7	8.5 and more
	Conductivity (at 25°C) ⁽¹⁸⁾	mS/m	—		0.05 or less		0.05 or less	
	Hardness	mgCaCO ₃ /L	Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾		Not detected ⁽²⁰⁾	
	Oily matter ⁽⁹⁾	mg/L	⁽¹⁰⁾		⁽¹⁰⁾		⁽¹⁰⁾	
	Dissolved oxygen	μg O/L	7 or less		7 or less		7 or less	
	Total iron	μgFe/L	30 or less ⁽²¹⁾		30 or less ⁽²¹⁾		20 or less ⁽²²⁾	
	Total copper	μgCu/L	20 or less		10 or less		5 or less	
	Hydrazine ⁽¹⁵⁾	μgN ₂ O ₄ /L	10 and more		10 and more		10 and more	
Boiler water	Method of treatment ⁽²⁹⁾	—	Phosphate treatment	All volatile treatment ⁽³⁰⁾	Caustic treatment	All volatile treatment ⁽³⁰⁾	Phosphate treatment	All volatile treatment ⁽³⁰⁾
	pH (at 25°C)	—	9.8~10.7	8.5~9.7	9.0~10.0	8.5~9.7	8.5~9.8	8.5~9.7
	Conductivity (at 25°C)	mS/m	40 or less	—	15 or less	—	6 or less	—
	Conductivity (at 25°C) ⁽¹⁸⁾	mS/m	—	6 or less	—	2 or less	—	2 or less
	Chloride ion	mgCl/L	10 or less	2 or less	2 or less	1 or less	2 or less	1 or less
	Phosphate ion ⁽¹¹⁾	mgPO ₄ ³⁻ /L	⁽³¹⁾	—	⁽³²⁾	—	0.1~3.0	—
	Sulfite ion ⁽²⁷⁾	mgSO ₃ ²⁻ /L	2 or less		0.3 or less		0.2 or less	

Note

⁽²⁸⁾ : Preferable to adjust pH 8.5~9.4 in case tube material of condenser is copper, in case steel or titanium, 9.4~9.7. Also when applying the volatiles to the boiler water treatment, pH of feed-water is adjusted to maintain pH of the boiler appropriately.

⁽²⁹⁾ : In case the boiler type which supple feed-water from low pressure boiler to middle and high pressure drum, volatile treatment shall be applied to low pressure drum instead of phosphate treatment.

⁽³⁰⁾ : Adjust pH value of low pressure drum that can be maintained pH of medium water and high pressure boiler water.

⁽³¹⁾ : Adjust to maintain pH of boiler water 9.8~10.7.

⁽³²⁾ : Adjust to maintain pH of boiler water 9.0~10.0.

Table- 22: Quality of feed-water and boiler water for once-through boiler

JIS B8223-2006

classification	Pressure of using regularly	MPa	10 ≥ P >7		15 ≥ P >10		20 ≥ P >15		P >20	
	Type of make-up water	—	All volatile treatment	Oxygen treatment	All volatile treatment	Oxygen treatment	All volatile treatment	Oxygen treatment	All volatile treatment	Oxygen treatment
Feed water	pH (at 25°C) ⁽³³⁾	—	8.5~9.7 ⁽¹⁷⁾	6.5~9.3 ⁽³⁴⁾	8.5~9.7 ⁽¹⁷⁾	6.5~9.3 ⁽³⁴⁾	8.5~9.7 ⁽¹⁷⁾	6.5~9.3 ⁽³⁴⁾	8.5~9.7 ⁽¹⁷⁾	6.5~9.3 ⁽³⁴⁾
	Conductivity (at 25°C) ⁽¹⁸⁾	mS/m	0.03 or less	0.02 or less ⁽¹⁹⁾	0.03 or less	0.02 or less ⁽¹⁹⁾	0.03 or less	0.02 or less ⁽¹⁹⁾	0.025 or less	0.02 or less ⁽¹⁹⁾
	Dissolved oxygen	mg O/L	7 or less	20~200 ⁽³⁵⁾	7 or less	20~200 ⁽³⁵⁾	7 or less	20~200 ⁽³⁵⁾	7 or less	20~200 ⁽³⁵⁾
	Total iron	µgFe/L	30 or less ⁽²¹⁾	20 or less	20 or less ⁽²²⁾	10 or less	20 or less ⁽²²⁾	5 or less ⁽²³⁾	10 or less	5 or less ⁽²³⁾
	Total copper	µgCu/L	10 or less	10 or less	5 or less	10 or less	3 or less	5 or less ⁽³⁶⁾	2 or less	2 or less
	Hydrazine ⁽¹⁵⁾	µgN ₂ O ₄ /L	10 or less	—	10 or less	—	10 or less	—	10 or less	—
	Silica	µgSiO ₂ /L	40 or less ⁽³⁷⁾ 20 or less ⁽³⁸⁾	20 or less	30 or less ⁽³⁷⁾ 20 or less ⁽³⁸⁾	20 or less	20 or less	20 or less	20 or less	20 or less

Note

- ⁽³³⁾ : Add ammonia or volatile amine to adjust pH.
⁽³⁴⁾ : Preferable to adjust to pH8.0~8.5 when copper alloy is used for the system.
⁽³⁵⁾ : It should be made the value suitable to minimize iron and copper concentration of feed-water in this range.
⁽³⁶⁾ : Preferable to keep at 3µgCu/L or less.
⁽³⁷⁾ : Applied to the boiler with super-heater.
⁽³⁸⁾ : Applied to the boiler without super-heater.

Table- 23: Quality of steam generated by boiler ⁽³⁹⁾

Item	Standard value
Conductivity (at 25°C) ⁽¹⁸⁾ (mS/m)	0.03 or less
Silica (µgSiO ₂ /L)	20 or less

Note

- ⁽³⁹⁾ : This applies to the boiler using the ion exchange water as feed-water during the normal operation (except for start-up period) when steam is fed to the turbine.

Table- 24: Quality of water for once-through boiler during start-up (in case of applying volatile treatment)

JIS B8223-2006

classification	Process			Circulation before firing (boiler cold clean up)		Circulation during increased temperature and pressure (boiler hot clean up)		On-load operation ⁽⁴⁴⁾	
	Pressure of using regularly		MPa	20 ≥ P >15	P > 20	20 ≥ P >15	P > 20	20 ≥ P >15	P > 20
Feed water	Economizer inlet	pH (at 25°C) ⁽¹⁷⁾ ⁽³³⁾	—	8.5~9.7	8.5~9.7	8.5~9.7	8.5~9.7	8.5~9.7	8.5~9.7
		Conductivity (at 25°C) ⁽¹⁸⁾	mS/m	0.1 or less	0.1 or less	0.1 or less	0.1 or less	0.1or less	0.1or less
		Dissolved oxygen	µg O/L	40 or less ⁽⁴⁰⁾	20 or less ⁽⁴⁰⁾	10 or less	10 or less	7 or less	7 or less
		Total iron	µgFe/L	200 or less	100 or less	100 or less	50 or less	30 or less	30 or less
		Total copper	µgCu/L	20 or less	20 or less	20 or less	10 or less	5 or less	5 or less
		Hydrazine	µgN ₂ O ₄ /L	20 and more ⁽⁴¹⁾	20 and more ⁽⁴¹⁾	20 and more	20 and more	10 and more	10 and more
		Silica	µgSiO ₂ /L	30 or less	30 or less	30 or less	30 or less	30 or less	30 or less
	Water wall outlet	Conductivity (at 25°C) ⁽¹⁸⁾	mS/m	0.1 or less	0.1 or less	0.1 or less	0.1 or less	—	—
		Total iron	µgFe/L	300 or less	300 or less	200 or less ⁽⁴²⁾	100 or less ⁽⁴³⁾	—	—

Note

- ⁽⁴⁰⁾ : This may be the target for some boiler types.
- ⁽⁴¹⁾ : Preferable to adjust the hydrazine concentration at a higher value to promote formation of the protective film inside the system, when starting after long intervals stopping.
- ⁽⁴²⁾ : The target of iron concentration is 100µgFe/L or less.
- ⁽⁴³⁾ : The target of iron concentration is 50µgFe/L or less.
- ⁽⁴⁴⁾ : Water quality at 50% loading.

Table- 25: Quality of water for once-through boiler during start-up (in case of applying oxidization treatment)

JIS B8223-2006

classification	Process			Circulation before firing (boiler cold clean up)		Circulation during increased temperature and pressure (boiler hot clean up)		On-load operation ⁽⁴⁴⁾	
	Pressure of using regularly		MPa	20 ≥ P >15	P > 20	20 ≥ P >15	P > 20	20 ≥ P >15	P > 20
Feed water	pH (at 25°C) ⁽³³⁾ ⁽³³⁴⁾		—	6.5~9.3	6.5~9.3	6.5~9.3	6.5~9.3	6.5~9.3	6.5~9.3
	Conductivity (at 25°C) ⁽¹⁸⁾		mS/m	0.05 or less	0.05 or less	0.03 or less	0.03 or less	0.02 or less	0.02 or less
	Dissolved oxygen		µg O/L	20~500	20~500	20~500	20~500	20~200	20~200
	Total iron		µgFe/L	100 or less	100 or less	100 or less	50 or less	30 or less	30 or less
	Total copper		µgCu/L	20 or less	20 or less	20 or less	10 or less	10 or less	10 or less
	Silica		µgSiO ₂ /L	30 or less	30 or less	30 or less	30 or less	30 or less	20 or less

Note

- ⁽⁴⁵⁾ : Water quality for a pressure range between 15MPa and 20MPa is applied also to water quality for a pressure range between 10 MPa and 15MPa.

Table- 26: Boiler Water Limits for Industrial Water Tube Boilers

ASME Guideline										
classification	Drum pressure	psig	0-300	301-450	451-600	601-750	751-900	901-1000	1001-1500	1501-2000
Boiler water	pH (at 25°C)	—	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.3-9.6	8.3-9.6	8.3-9.6
	Silica (as SiO ₂)	ppm	≤ 150	≤ 90	≤ 40	≤ 30	≤ 20	≤ 8	≤ 2	≤ 1
	Total alkalinity	ppm	< 350	< 300	< 250	< 200	< 150	< 100	NS	NS
	Conductivity (at 25°C)	μΩ/cm	5400-1100	4600-900	3800-800	1500-300	1200-200	1000-200	≤ 150	≤ 80
	TDS (maximum)	ppm	1.0-0.2	1.0-0.2	1.0-0.2	0.5-0.1	0.5-0.1	0.5-0.1	0.1	0.1
	Dissolved oxygen (as O ₂)	ppm	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007
	Total iron (as Fe)	ppm	≤ 0.1	≤ 0.05	≤ 0.03	≤ 0.025	≤ 0.02	≤ 0.02	≤ 0.01	≤ 0.01
	Total copper (as Cu)	ppm	≤ 0.05	≤ 0.025	≤ 0.02	≤ 0.02	≤ 0.015	≤ 0.01	≤ 0.001	≤ 0.001
	Hardness (as CaCO ₃)	ppm	≤ 0.03	≤ 0.03	≤ 0.02	≤ 0.02	≤ 0.1	≤ 0.05	ND	ND
	Chemicals for pre-boiler system	—	NS	NS	NS	NS	NS	VAM	VAM	VAM
	Non volatile TOC (as O ₂)	ppm	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.2	< 0.2	< 0.2
	Oily matter	ppm	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.2	< 0.2	< 0.2

Note

1.
- : Makeup water percentage: Up to 100% of feed-water.
2.
- : Assumes existence of deaerator.
3.
- : Conditions: Includes super-heater, turbine devices or process restriction on steam purity.
4.
- : Saturated steam purity target as shown.
5.
- : NS=not specified.
6.
- : ND=not detectable.
7.
- : VAM=Use only volatile alkaline materials upstream of a temporary water source.

Table- 27: Recommended Water Tube Boiler Water Limits and Associated Steam Purity at Steady Load Operation ⁽¹⁾

ABMA-Boiler 402

classification	Type of boiler		Drum type											Once-through
	Drum pressure	psig	0-300	301-450	451-600	601-750	751-900	901-1000	1001-1500	1501-2000	1801-2350	2351-2600	2601-2900	1400& above
Boiler water	pH (at 25°C)	—												
	Silica (as SiO ₂)	ppm	125	90	50	35	20	8	2.5	1				
	Total alkalinity ⁽³⁾	ppm	140-700	120-600	100-500	40-400	30-300	25-250	200	150	variable	variable	variable	NA
	Conductivity (at 25°C)	μΩ/cm	7000	6000	5000	4000	3000	2000	150	100				
	TDS ⁽²⁾ in boiler water (max.)	ppm	700-3500	600-3000	500-2500	200-2000	150-1500	125-1250	100		50	25	15	0.05
	Suspended solid	ppm	15	10	8	3	2	1	1	1	NA	NA	NA	NA
	TDS ⁽⁴⁾ ⁽⁵⁾ in steam (max.)	ppm	0.2-1.0	0.2-1.0	0.2-1.0	0.1-0.5	0.1-0.5	0.1-0.5	0.1	0.1	0.1	0.05	0.05	0.05
Boiler feed-water	Total iron (as Fe)	ppm	0.1	0.05	0.03	0.025	0.02	0.02	0.01	0.01				
	Total copper (as Cu)	ppm	0.05	0.025	0.02	0.02	0.015	0.015	0.01	0.01				
	Hardness (as CaCO ₃)	ppm	0.3	0.3	0.2	0.2	0.1	0.05	0.00	0.00				

Note

- ⁽¹⁾ : “Boiler limits and steam purity for water-tube boiler” of American Boiler Manufacturer Association 1992
- ⁽²⁾ : Actual values within the range reflect the TDS in the feed-water. High values are for high solids; lower values are low solids in the feed-water.
- ⁽³⁾ : Actual values within the range are directly proportional to the actual value of TDC of boiler water lower values are for low solids in the feed-water.
- ⁽⁴⁾ : Directed by boiler water treatment.
- ⁽⁵⁾ : These values are exclusive of silica.

Chapter-4. Reference International Standards

The reference international standards for water treatment facility are organized in Table-27.

Table- 28: Reference international technical standards

Number	Rev.	Title	Content
IEC TS 61370	2001	Steam Turbines-Steam Purity	This describes the importance of the chemical characteristics of steam supplied to steam turbines and the need to prevent corrosion and deposition in steam space, in order to minimize the risk of turbine corrosion failures or loss of efficiency or output. Is applicable to turbines of all electrical output rating and any exhaust condition, i.e. condensing or back pressure. It is designed for new plant, but may be adapted for use on existing plant. The limits described in this specification are specifically designed to protect the steam turbine. This specification is applicable to steam turbines driven from any source, except geothermal plants in which the turbine is fed direct from the geothermal sources
EPRI TR-113692	1999	Revised Guideline for Makeup Water Treatment (Electric Power Research Institute)	Because the quality of boiler cycle makeup water is central to ensuring the necessary purity of boiler water, feed-water, and steam, it plays an important role in ensuring component availability and reliability in fossil plants. This EPRI report presents up-to-date guidelines based on proven approaches for the production of makeup water from various raw water supplies.
VGB-R450Le	2004	Guidelines for Feed Water, Boiler Water and Steam Quality for Power Plants Industrial Plants	This guideline supports the operator of steam/water cycles in power plants and related branches in selecting and judging suitable water regimes in respect to a safe and economically sound operation of the power plant for a long period of time. Of course are the showed parameter values no absolute commandment or limit - they are recommendations and represent the bandwidth of water regimes in use. Deviations are always possible if the plant design is specific and/or good operating experience had been made during a long time.
IS 10392	1982	Feed water and boiler water for low and medium pressure boilers	Indian Standard
IS 10496	1983	Feed water , boiler water and condensate for high pressure boilers (Amendment 1)	Indian Standard
IS 12085	1987	Cyclohexylamine for boiler water treatment	Indian Standard
IS 14199		Steam purity—method of sampling and test	Indian Standard
ISO 5667-1	2006	Water quality—Sampling—Part.1: Guidance on the design of sampling programmes and sampling techniques	This sets out the general principles for, and provides guidance on, the design of sampling programmes and sampling techniques for all aspects of sampling of water (including waste waters, sludges, effluents and bottom deposits).

Number	Rev.	Title	Content
ISO 5667-3	2003	Water quality—Sampling—Part.3: Guidance on the preservation and handling of water samplings	This gives general guidelines on the precautions to be taken to preserve and transport all water samples including those for biological analyses but not those intended for microbiological analysis. These guidelines are particularly appropriate when spot or composite samples cannot be analyzed on-site and have to be transported to a laboratory for analysis
ISO 5667-7	1993	Water quality—Sampling—Part.7: Guidance on sampling of water and steam in boiler plants	This recommends procedures and equipment for sampling water and steam in boiler plants including examples of sampling apparatus, to provide samples for physical and chemical analysis that are representative of the main body of water or steam from which they are taken. The procedures for sampling apply to raw water, make-up water, boiler feed water, condensate, boiler water, cooling water. Does not apply to the sampling of water and steam in nuclear power plants.
ABMA Boiler 402	2005	Boiler Water Quality Requirements and Associated Steam Quality for Industrial/Commercial and Institutional Boilers	This new ABMA publication brings together into one, central 70+-page reference book all the information previously contained in two separate documents, updated with the latest information and consensus on the effects of various feed-water and condensate systems on boiler operation, and information on boiler water and steam testing as well as system care and maintenance. The purpose of this publication is to acquaint engineers, purchasers and operators of industrial, commercial and institutional (ICI) boilers with ABMA's judgment as to the relationship between boiler water quality and boiler performance. This document is published for general guidance as a supplement to detailed operating manuals supplied by the equipment manufacturers. It should also be noted that the information presented is directed to steel boiler designs, as opposed to cast iron sectional or copper finned tube boilers. Furthermore Utility Boilers and Combined Cycle Boilers, which require extremely close control of water quality and steam purity, are not the topic of this document. This new document combines two previous ABMA Guideline documents, namely "Boiler Water Requirements and Associated Steam Purity for Commercial Boilers" (1998), and "Boiler Water Limits and Achievable Steam Purity for Water-tube Boilers", (1995).

Number	Rev.	Title	Content
ASME PTC 19.11	2008	Steam and water sampling, conditioning and analysis in the power cycle	The object of this Code is to specify and discuss the methods and instrumentation for testing boiler makeup and feed-water, steam, and condensate in relation to performance testing as may be required in Performance Test Codes in on-time acceptance testing and continuous performance monitoring. This Code also provides guidance to power-plant management, engineers, chemists, and operators in the design and operation of sampling systems for monitoring of cycle chemistry. The methods and equipment recommended herein may be useful for monitoring other influent and effluent streams of the power plant. Contamination of the steam and water cycle must be at or less than the maximum specified for the performance test before a turbine, condenser, or deaerator performance test is made.

Chapter-5. Reference Japanese Standards

The reference Japanese industrial standards for water treatment facility are organized in Table-28.

Table- 29: Reference Japanese technical standards

Number	Rev.	Title	Content
JIS B8223	2006	Water conditioning for boiler feed water and boiler water	This stipulates feed-water and boiler water quality of steam boiler for land and marine boilers based on the reality of recent production and use, and has been enriched and revised the content as follows. 1. The term or definition for HRSG is added and water quality standard of boiler feed-water and boiler water for HRSG is added. 2. The feed-water quality at start-up for once-through boiler (when applying oxygen treatment) is stipulated. 3. Values relation to water quality was reviewed in terms of quality consistency between each other depending on the current results.
JIS B8224	2005	Boiler feed water and boiler water-Testing methods	This stipulates feed-water, boiler water and steam quality of boiler based on the reality of recent production and use, and has been enriched and revised the content as follows. 1. Quoted items from JIS K0101 (Industrial water testing method) is modified to suit JIS K0101. 2. Analysis method for trace amounts of metal an element which is adopted as ICP mass spectrometry determination in JIS K0101 is adopted as high frequency plasma mass spectrometry in the standard. 3. Electric conductivity and dissolved oxygen are stipulated as continuous measuring method by automated measuring instruments. 4. Annex describes a new method and continuous measurement of corrosion potential and redox potential of boiler plant.
JIS K0556	2010	Testing methods for determination of anions in highly purified water	This stipulates testing method of anion ions (fluoride ion, chloride ion, sulfite ion, bromide ion, phosphate ion, nitrate ion and sulfate ion) in the ultra-pure water.
JIS K0410-3-07	2010	Water quality—Sampling —Part7: Guidance on sampling of water and steam in boiler plants	This established without changing the content and format of technical specification of the original standard ISO 5667-7 1993: “Guidance sampling of water and steam in boiler plants”.

Chapter-6. Reference TCVN

The reference Vietnamese national standards for water treatment facility are organized in Table-29.

Table- 30: Reference TCVN

Number	Rev.	Title	Content
TCVN 6663-1	2011	Water quality. Sampling. Part 1: Guidance on the design of sampling programmes	Tiêu chuẩn này trình bày các nguyên tắc chung phải áp dụng khi lập chương trình lấy mẫu nước để kiểm soát chất lượng, xác định chất lượng và phân định nguồn ô nhiễm nước, kể cả cặn đáy và bùn. Hướng dẫn chi tiết về các điều kiện lấy mẫu cụ thể được trình bày trong tiêu chuẩn tiếp sau
TCVN 6663-3	2008	Water quality. Sampling. Part 3: Guidance on the preservation and handling of water samples	Tiêu chuẩn này đưa ra hướng dẫn chung về những điều cần lưu ý trước khi bảo quản và vận chuyển mẫu nước kể cả bảo quản và vận chuyển mẫu để phân tích sinh học nhưng không phải là bảo quản và vận chuyển mẫu để phân tích vi sinh vật.
TCVN 6663-7	2000	Water quality. Sampling. Part 7: Guidance on sampling of water and steam in boiler plants	Tiêu chuẩn này trình bày các quy trình và thiết bị để lấy mẫu nước và mẫu hơi nước từ phân xưởng nồi hơi, kể cả các thí dụ về dụng cụ lấy mẫu, nhằm cung cấp mẫu đại diện để phân tích lý hoá của vùng nước chính hoặc của hơi nước ở nơi lấy mẫu
TCVN 6663-13	2000	Water quality. Sampling. Part 13: Guidance on the sampling of water, wastewater and related sludges	Tiêu chuẩn này hướng dẫn lấy mẫu bùn từ các công trình xử lý nước thải, các công trình xử lý nước cấp và bùn từ các quá trình công nghiệp. Tiêu chuẩn này được áp dụng với tất cả các loại bùn sinh ra từ các công trình này cũng như các loại bùn có đặc tính tương tự, ví dụ như bùn từ bể tự hoại. Tiêu chuẩn này cũng hướng dẫn cách lập chương trình lấy mẫu và phương pháp lấy mẫu
TCVN 7704	2007	Boilers. Technical requirement of design, construction, manufacture, installation, operation, maintenance	Partly the recommended water limit for boiler is stipulated.

Chapter-7. Referenced Literature and Materials

The referenced books, literatures, standards to establishing this guide line are organized as follows.

1. Water management for thermal power plant-water and chemical management in thermal and nuclear power station (Journal No.608: May/2007): TENPES (Thermal and Nuclear Engineering Society of Japan)
2. Up-to-date trend of cycle chemistry: (T.Mizuno: Journal No. 614: Nov/2007): TENPES (Thermal and Nuclear Engineering Society of Japan)
3. Lean from the experts “Cycle chemistry-(1)”: (S. Tsubakizaki: Journal No.614: Dec/2007): TENPES (Thermal and Nuclear Engineering Society of Japan)
4. Lean from the experts “Cycle chemistry-(2)”: (S. Tsubakizaki: Journal No.616: Dec/2007): TENPES (Thermal and Nuclear Engineering Society of Japan)
5. Lean from the experts “Cycle chemistry-(3)”: (S. Tsubakizaki: Journal No.617: Feb/2008): TENPES (Thermal and Nuclear Engineering Society of Japan)
6. Lean from the experts “Cycle chemistry-(4)”: (S. Tsubakizaki: Journal No.621: Jun/2008): TENPES (Thermal and Nuclear Engineering Society of Japan)
7. JIS B8223-2006 “Water conditioning for boiler feed water and boiler water”
8. ASME Guideline “Boiler water limits for industrial water tube boilers”
9. ABMA-Boiler 402 “Recommended water tube boiler water limits and associated steam purity at steady load operation”-1992
10. Spiral-shaped membrane module: <http://www.homecents.com/h2o/ro/index.html>
11. Pressure swing absorption equipment:
12. Oxygen gas injection equipment:
13. Chemical feed skid:
14. Pressure reducing valve:
15. HP of SANKO Controls Co., Ltd.: <http://www.skgr.co.jp/skcpa/sampling/sampindex.htm>