

Chapter III – Guide to Design of RO System

A complete set of RO system consists of 4 parts: pretreatment; RO section (membrane filtration); post-treatment; system cleaning section. An RO is reasonably designed according to specific feedwater quality and various requirements for product water quality so as to decrease the contamination speed, elongate the cleaning cycle of system, reduce the cleaning frequency, improve the long-term stability of system and decrease the operating costs of system.

The system is designed generally according to the following steps:

1) Completely analyzing the quality of water source

2) Designing a reasonable and efficient pretreatment solution in line with the water sources.

3) Designing a reasonable RO system in accordance with permeate flow and product water quality, etc.

4) Designing the post-treatment section (such as mixed bed or EDI system) to produce the water with higher quality.

5) Designing a reasonable system of chemical cleaning.

6) Determining the designing parameters for pilot test of large-sized system.

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2. 3-1 Design of Pretreatment Section of RO System

3-1.1 Analysis of Type and Quality of Raw Water

3-1.1.1 Type of Raw Water

The type of water is determined by the total dissolved solids (TDS) and the organic content of the raw water:

① RO filtered water, with TDS generally less than 50 mg/L.

(2) Tap water, with TDS generally less than 500 mg/L

③ Brackish water, with TDS generally lower than 5000mg/L, classified as surface water and underground water.

④ Quasi seawater, with TDS generally between 5,000~15,000 mg/L.

⑤ Seawater, with TDS generally at 35,000 mg/L



⁽⁶⁾ Grade-III wastewater (reclaimed water), with organic substance at comparatively high content (high values of TOC and BOD).

Different types of water source require different processes of pretreatment and different models of membrane element. For designing small-sized engineering projects without the conditions for water quality analysis or test, please refer to the pretreatment system of those projects that have been put into operation for similar water sources. Nevertheless, full analysis of water quality must be done for large-scale engineering project.

3-1.1.2 Analysis Items of Water Quality

The water quality of raw water determines the process flow of pretreatment, and the complete parameters of water quality analysis is the important guaranty for designing the reasonable pretreatment system and ensuring the long-term stable operation of RO system. Table 1 shows the items for analysis of water quality of RO system recommended by SHANGYUAN Technology Co., Ltd.



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Project Name		Sampling	g Time	Sa	mpling Position		_
Source of Raw Water		Time of Analysis Analyz		zed by			
pН		Turbidit	y (NTU)		Water Temp. (°C	C)	
SDI		Condu (µS/	ictivity /cm)		ORP(mV)		
Ionic Co	ompositions	ppm	meq/L	Ionic C	Compositions	ppm	meq/L
Calcium	n Ion (Ca^{2+})			Chlori	ne Ion (Cl ⁻)		
Magnesiu	m Ion (Mg^{2+})				$\mathrm{SO_4}^{2-}$		
Sodium	n Ion (Na ⁺)				CO_{3}^{2-}		
Barium	I Ion (Ba^{2+})			I	HCO ₃ ⁻		
Strontium Ion (Sr ²⁺)				PO ₄ ³⁻			
Potassium Ion (K ⁺)				F^{-}			
Ferrous Ion (Fe ²⁺)					NO ₃ ⁻		
Ferric Ion (Fe ³⁺)					SiO ₂		
Aluminu	m Ion (Al^{3+})			OtherIons	(e.g. boron ion)		
Tota	l Cations			Tot	al Anions		
TD	S (ppm)			BC	DD(ppm)		
Total Hardness (CaCO ₃ ppm)				СС	DD(ppm)		
Total Alkalinity (mL)				Numbe (p	r of Microbes er Liter)		
Pheno	lphthalein			Resid	ual chlorine		
Alkali	inity (mL)			Concen	tration (ppm)		

Table 1 – Analysis of Raw Water Quality in RO System

Where Ba^{2+} and Sr^{2+} must be tested to the magnitude of $1\mu g/L(ppb)$ and 1mg/L(ppm).

3-1.1.3 Descriptions of Each Item of Water Quality Analysis and Its Significance

(1) pH Value

The pH value of raw water reflects the acidity/alkalinity of raw water, i.e., to be



neutral with pH at 7, to be acid with pH at $0\sim7$, to be alkaline with pH at $7\sim14$. Since the variation of pH can influence the rejection of ions and cause the variation of rejection rate of system, the optimal pH value of RO system is within $6\sim8$, and pH value is a critical parameter in pretreatment design. In addition, lowering the pH value of feedwater is an effective means to restrict the deposition and separation of calcium carbonate. The pH value has the influence on rejection rate of RO membrane element, as shown in the following figure:



(2) Turbidity

According to ISO, turbidity is defined as the decrease of transparency of liquids caused by the existence of insoluble substances. Based upon the differences in turbidity standard solutions, the turbidity values and measurements obtained may vary from each other. Currently, the solution produced from the reaction of hexamethylenetetramine and hydrazine sulfate is universally used as the turbidity standard solution, and the turbidity measured by using the scattered-light turbidimeter is indicated in NTU. The RO system requires the feedwater with turbidity less than 1 NTU.

(3) Temperature



As a critical parameter in design of RO system, the temperature must be specified. Temperature has direct influence upon the system operating pressure (thus influencing the selection of high-pressure pump), the number of membrane elements and quality of product water as well as the solubility of crystals that may be deposited or separated. In general case, each temperature drop by 3° C will cause a 10% decrease of RO system yield; each temperature drop by 5° C will require a 15% increase of water pump pressure. If the temperature rises, the salt permeation of RO system increases and the conductivity of product water also rises. If the temperature drops, the salt permeation of RO system decreases and the conductivity of product water also rises.

(4) SDI

SDI (silt density inde), also known as fouling index (FI), is an important index representing the feedwater quality of RO system, and is the best way for determining the colloidal and granular contamination in the feedwater of RO system. The standard method for inspecting the SDI is specified in ASTM TEST (D189-82).





Diagram of SDI Tester

Above is the diagram of an SDI Tester.

The test shall be carried out in the following steps:

1. First, take a piece of tested membrane sheet with 47mm diameter and 0.45µm hole diameter and put it into the testing box (pay attention to the correct front and reverse faces of membrane sheet). Tighten and seal the box, and keep it in vertical position.

2. Regulate the feedwater pressure to 2.1bar (30psi) and measure immediately the T_0 , i.e. the time required for 500 (250) ml of water to permeate the filtration membrane. Maintain the pressure consistently at 2.1bar, and continue the filtration for 15 minutes, then measure the T_1 , i.e. the time required for 500 (250) ml of water to permeate the filtration membrane.

3. After obtaining T_0 and T_1 , calculate the SDI of feedwater according the following formula:

$$SDI = [1 - T_0/T_1] * 100/15$$



In practical application, the RO system always requires an SDI value less than 5. When T_1 is equal to 4 times of T_0 , the SDI is 5. With the SDI at 6.7, the water can completely foul the tested membrane and T_1 cannot be obtained, in which case the RO pretreatment system needs to be regulated so as lower the SDI to below 5.0.

Generally, when the feedwater SDI of RO system is less than 3, the membrane system will suffer a much low risk of contamination, and the membrane system can be free from excessively quick contamination during the equipment operation. When the SDI is greater than 5, it represents that serious contamination of membrane may occur during the running of RO system.

(5) Conductivity and Total Dissolved Solids (TDS)

Conductivity is an index representing the electrical conductibility of the ions dissolved in water, and is measured by a conductivity meter and generally shown in μ S/cm. Conductivity is a convenient and effective method for measuring the ion concentration of water, but is unable to accurately reflect the composition of ions. The conductivity rises along with the increase of ionic concentration.

TDS (total dissolved solids) is the inorganic substances remaining after the suspended substances are filtered and the colloids are evaporated. The TDS can be measured directly by using a TDS meter, or can be calculated through the conversion of water conductivity measured. A rough calculation is as follows: For the reference solution of sodium chloride, the conductivity of 2μ S/cm corresponds to the TDS of 1 ppm.

(6) Oxidation-Reduction Potential (ORP)

The oxidation-reduction potential (ORP) is an index representing the amount of oxidative substances and reductive substances, and is indicated generally in millivolt (mV). When the ORP is a positive figure, it represents that there is oxidative substance in the water, while it represents that there is reductive substance in water when the ORP is a negative figure. In general, the RO system requires the ORP of feedwater to be less than 200 mV.

The oxidative substances in water generally include residual chlorine, ozone, etc.



Since compound polyamide membrane has an inferior resistance to oxidation, SHANGYUAN membrane series require the residual chlorine content of feedwater not to exceed 0.1 ppm. For the water sources with high ORP, the oxidative substances must be removed by using the activated carbon adsorption or dosing the reductant.

Sometimes the water in the nature may appear to be negative in ORP, which means that there is H_2S , SO_{2-3} or Fe^{2+} , etc. in the water. The RO system is also sensitive to H_2S and Fe^{2+} , because these two substances may cause colloidal and mocrobic contamination. A number of methods, such as activated carbon adsorption, oxidative deposition, flocculation filtration, ionic exchange, etc., can be adopted to get rid of these substances in pretreatment system.

(7) Composition of Ions

Of the inorganic salts dissolved in water, the hardly or slightly soluble salts formed from the combination of cations and anions may become some soluble at certain temperature, and may foul on the surface of RO membrane when the Feedwater of RO system has been continuously concentrated to exceed the solubility limit. The hardly soluble salts frequently seen include CaCO₃ and CaSO₄, and other compounds that may result in scaling include CaF₂, BaSO₄, SrSO₄ and Ca₃(PO₄)₂. In case it's possible that the cations and anions form the hardly or slightly soluble salts as mentioned above, measures must be taken to control the fouling in pretreatment and to avoid deposition or fouling caused by the situation that the concentration of hardly or slightly soluble salts exceed their solubility. Shangyuan's RODesign or other design software can be utilized to determine whether the hardly or slightly soluble salts can deposit under the designed recovery conditions.

(8) Hardness

Hardness of water means the concentration of calcium and magnesium ions in the water, measured in mg/L as $CaCO_3$. For the water sources with high hardness and alkalinity, special importance should be attached to the prevention of $CaCO_3$ scaling in pretreatment process.

Hardness		
Meq/L	mg/Las CaCO ₃	



Soft	<1	<50
Moderately hard	1~3	50~150
Hard	3~6	150~300
Very hard	>6	>300

(9) Alkalinity

Alkalinity refers to the content of alkaline substances that can react with strong acid (generally the standard HCL solution with 0.1mol/L concentration) in the water. Alkalinity is mainly for representing the content of bicarbonate (HCO₃⁻), carbonate ($CO_3^{2^-}$) and hydroxide ions, and is classified into phenolphthalein alkalinity and total alkalinity. When in titration, the alkalinity measured by using phenolphthalein as indicator (pH = 8.3 at the end point indicated) is called "phenolphthalein alkalinity". The alkalinity measured by using orange methyl orange as indicator (pH = 4.4~4.5 at the end point indicated) is called "methyl-orange alkalinity" or "total alkalinity". Therefore, phenolphthalein alkalinity is simply part of the total alkalinity. The relationship between "phenolphthalein alkalinity" and "total alkalinity" is shown in the following table:

 Table 2 – Relationship between Alkalinity and Part of the Ions Contained in

Relation between	Content of Various Alkalinities of Water			
M and P	HCO ₃ -	CO3 ²⁻	OH.	
M=0,	0	0		
namely A=P	U	0	A	
A>2P,	M	20	0	
Namely M>P	M-P	28	0	
A<2P,	0	214	DM	
Namely M <p< td=""><td>U</td><td>2181</td><td>P−M</td></p<>	U	2181	P−M	

Water



A=2P,	0	А	0
Namely M=P			
P=0,	A=M	0	0
Namely A=M		0	U U

Notes

- 1. The concentration of standard solution HC1 is 0.1 mol/L.
- 2. P is the volume of standard solution consumed where phenolphthalein is used as the indicator; M is the volume of standard solution consumed where methyl orange is used as the indicator subsequently after titration is conducted with phenolphthalein as the indicator.
- 3. A = M + P, i.e. the total consumption of standard solution.

(10) COD, BOD, TOC

In water treatment, three indexes, i.e. chemical oxygen demand (COD), biochemical oxygen demond (BOD) and total organic carbon (TOC) are generally used for representing the content of organic substances in water. There are great varieties of organic substances in the nature, and the organic constituents contained in water mainly consists of humic acid, surfactant, oil, microbes, agricultural chemicals, etc.

1) Chemical oxygen demand (COD) refers to the consumption of oxidant when strong oxidant is used for treating the sampled water under certain conditions. It is an index representing the amount of reductive substances contained in water. Though also containing nitrite, sulphide and ferrous salt, etc., the reductive substances in water consist mainly of organic substances. Therefore, the chemical oxygen demand (COD) is usually used as an index representing the amount of organic substances in water. There are two reagents for determining the COD, i.e. potassium bichromate (CODCr) and acid potassium permanganate (CODMn), of which the former is mostly applied to the test of industrial waste water and the latter is applied to the test of natural water. Since potassium bichromate has a stronger oxidizability than potassium permanganate, the CODCr is generally greater than CODMn.

Biochemical oxygen demand (BOD) is the total amount of oxygen dissolved in



water consumed for the inorganic transformation and gasification of organic substances owing to oxidation and decomposition caused by the biochemical action of microbes. It is indicated in ppm (mg/L). Currently in both domestic and abroad, the amount of oxygen consumed in five days of breeding at temperature of 20°C is used as the index of BOD, called BOD₅.

The biochemical property, i.e. the ratio of BOD_5 to COD_{Cr} , represents the content of organic matters contained in the water that can be biologically decomposed. The higher the ratio is, the better the biochemical capability is, and the lower is the content of organic substances contained in the water produced from biochemical treatment, or vice versa with the lower ratio.

2) Total Organic Carbon (TOC): It is a comprehensive index indicating the total organic matters contained in water body by means of carbon content. The firing method is used for measuring the TOC, which can completely oxidize the organic matters. It can represent the total amount of organic matters in a more direct way than the oxygen consumption can; therefore it is frequently used for evaluating the degree of pollution on the organic matters contained in the water. However, the TOC measuring method is comparatively complicated and has strict requirements for the testing equipment, and moreover, it cannot accurately measure the content of organic substances in the water.

(11) Silicon Dioxide

In most water sources, the content of soluble silicon dioxide (SiO₂) is mainly between $1\sim100$ mg/L. If being excessively saturated, the SiO2 may automatically gather together, and form the insoluble colloidal silicon, thus resulting in the fouling of membrane. The fouling of SiO₂ is one of the serious contaminations in RO membrane elements, and is extremely difficult to be removed once being deposited on membranes. A number of treatment processes are recommended for the water containing SiO₂, such as dosing of anti-scalant, regulating the pH value (SiO₂ has the minimal solubility when the pH value is between 7~7.8), lime-soda softening, decreasing of recovery, increasing of feedwater temperature, etc.



3-1.2 Water Treatment Processes Frquently Used in RO Pretreatment

In most cases, the original water cannot be allowed to enter the RO element, because the impurities contained in water may contaminate the element, which will affect the stable running of system and the service life of membrane element. Pretreatment is a process treating the impurities contained in the raw water according to their properties by using proper technologies so that the requirements of feedwater can be satisfied for the RO membrane elements. It is called pretreatment simply because it occurs in the position prior to the reverse osmosis in the whole technological process of water treatment.

For the RO system, the feedwater is habitually classified as underground water, tap water, surface water, seawater, and wastewater (reclaimed water), etc. Since the water bodies are influenced by various factors, the differences in geographical conditions and seasonal weather can cause the properties of the water bodies and the impurities contained herein to be somewhat different, and therefore the technologies of RO treatment may vary to some extent. The reasonable pretreatment should satisfy the following requirements

- 1. The pretreatment must be capable of removing most of the impurities in the raw water to satisfy the feedwater requirements for membrane elements.
- 2. The variation of water quality (such as seasonal variation in water volume and temperature, etc.) must be taken into consideration in pretreatment so as to prevent the stable operation of the entire system from being influenced by the fluctuation of raw water quality
- 3. The pretreatment process must be able to run stably in high efficiency; besides, it must simplify the processing flow so as to reduce the investment and the operating costs.

The indexes of feedwater quality requirements are as shown in Table 3.



Items		RO Membrane (Spiral Wound Compound Polyamide Membrane)	Type of Possible Contaminations in Over-limit Operation	
1	Chroma (degree)		Contamination of Organic Substances	
2	Turbidity (degree)	<1	Contamination of Silt and Sludge	
3	Silt Density Index (SDI)	<5	Contamination of Silt, Sludge and Colloid	
4	pH Value	3~10	Hydrolization of Membrane Element	
5	Water Temperature (℃)	5~45	Excessively low temperature results in excessively high pressure and therefore in uneconomic operation of system. Excessively high temperature may cause irreversible attenuation of membrane performance.	
6	Hardness (Ca、Mg)(mg/L)		Scaling of Inorganic Salts	
7	Alkalinity (HCO ₃)(mg/L)		Scaling of Carbonate	
8	COD _{Mn} (O ₂ ,mg/L)	<15	Contamination of Organic Substances	
9	TOC(mg/L)	<2	Contamination of Organic Substances	
10	Residual chlorine (mg/L)	Less than 0.1 for regular membrane. No limit for oxidation-resistant membrane.	Oxidation of Membrane Element	
11	Iron (total irons) (mg/L)	<0.05	Contamination of Iron	
12	Manganese (mg/L)	<0.1	Contamination of Manganese	
13	Cations, amphoteric and neutral surfactants	Not detected.	Irreversible attenuation of permeated flow.	
14	Detergent, oil, H ₂ S, etc. (mg/L)	Not detected.	Contamination of organic substances and oil	
15	Precipitates, salts, etc. (mg/L)	No deposition caused by rejected water	Scaling of inorganic salts	

Table 3 – Indexes of Feedwater Quality for RO Membrane

3 -1. 2 . 1 Flocculation and Flucculating Filtration
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Flocculation treatment is for the purpose of treating the suspended granular and colloidal substances. According to the principle of flocculationm, chemical reagents are dosed so as for the impurities in water to form large-granule floccule, deposit under the action of gravity, and then separate from the water. For flocculating filtration, the flocculant is dosed to the water so that the water and the flocculant can repeatedly keep in mutual contact while flowing through the sand filter so as to bring about flocculating reaction between each other, then the produced floc, after growing into specific volume, is retained inside the spaces between sand columns. The retained floc will further adsorb the fine alumen ustum contained in the water flowing by, thus purifying the water quality. Flocculation treatment has also an effect on the colloidal silicon.

Flocculant

There are various flocculants commonly used, among which most are the aluminum-salt flocculant, molysite flocculant or organic flocculant. When the use of simply one flocculant cannot obtain the satisfactorily good effect, the coagulant aids can be added in. The adding of coagulant aids is for two purposes: first, to improve the flocculent structure so as to enlarge its granules, which will be better for precipitation; second, to adjust the pH value of raw water in order to obtain the effect of best flocculation. Table 4 shows the flocculants and coagulant aids commonly available.

Flocculating filtration can be used only in the raw water with turbidity less than 70 degree, which is mostly the tap water or underground water. For the water sources with high turbidity (such as surface water, wastewater, etc.), the combined process with other treatment technologies is required, and only by this means can the feedwater satisfy the requirement of reverse osmosis system.

In order to properly select the flocculant types most suitable for the water body and to determine the most appropriate dosage, certain experiments may be properly carried out. Excessive dosing of flocculant may cause the contamination of membrane element. Especially when using the two flocculants of bivalent molysite and aluminum salt, it is necessary to detect the concentration of Fe^{2+} and Al^{3+} periodically for the purpose of preventing the membrane elements from colloidal



contamination. When using the flocculant of ionic polymer, be sure to prevent the cationic polymer from influencing the regular electronegative membrane elements and prevent the anionic polymer from influencing the electropositive membrane elements. It must be also ensured that the use of flocculant will not react with other chemicals added to the system, such as antiscaling agent, etc. For the specific compatibility, please consult relevant chemical manufacturers.

Conditions of Flocculating Filtration Design and Selection of Equipment

Design Conditions: For the raw water with turbidity less than 70 degrees, multi-media filtration is generally selected, where gravity-type filter or pressure-type filter can be utilized. Different from double filter-material filter chamber commonly used, it requires the filter materials with larger granules, as shown in the following table:

Type of Filtration Material	Granular Diameter (mm)	Non-uniformity Coefficient	Thickness of Filtration Layer (mm)	Filtration Velocity (m/h)
Anthracite Coal	1.2~1.8	1.3	400~600	6~10
Quartz Sand	0.5~1.0	1.5	400~600	6~10

Rinsing intensity of filter chamber: $15-17L/(S \cdot M^2)$

Rinsing Tim: 5—10min

Maximum gravity or filter-chamber head loss: 2.5—3m

Maximum pressure or filter-chamber head loss: 10m, or 5m in general case.

The quartz-sand filter should be put into rinse for 10~15 hours before being used.

Among the filter materials, the anthracite coal is required to be stable in both acidity and alkalinity, while the quartz is required to be acid resistant and slightly dissolved out in alkaline solution. In flocculating filtration, better effect can be obtained by using molysite as the flocculant than using the aluminum salt. The designed water yield of filter should include the water consumption in subsequent



treatment processes and the water consumed by the filter itself, i.e. the water for rinsing.



Table 4: Commonly Used Flocculants and Coagulant Aids and Their Flocculation

Effect

Type of Flocc	ulants	Applicable pH Values	Flocculation Effect
	Aluminum sulphate Al ₂ (SO ₄) ₃ ·18H ₂ O	6~8	At low feedwater temperature, the floccules are light and loose, with considerably inferior treatment results obtained.
Flocculant of inorganic-salt type	Aluminum potassium sulphate (alum) $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$	6~8	The composite salt of aluminum sulphate and potassium sulphate, among which the latter exerts no action on the coagulation, therefore more of this flocculant is added than aluminum sulphate
	Ferrum trichloride FeCl₃·6H₂O	4~11	Obvious effect of coagulation is obtained for treating the raw water with quite high turbidity and quite low water temperature. However, it is moisture-sensitive thus causing corrosion of metal and concrete.
	Ferrous sulphate FeSO₄·7H₂O	4~11	It produces the weighty floccules with quick sedimentation and stable effect, and is little influenced by the water temperature. Yet it can produce $Fe(OH)_2$ of high solubility, which requires to be removed by oxidation.
Inorganic high-molecular coagulant	Alkaline aluminum chloride (PAC) $[Al_2(OH)_nCl_{6-n}]_m$ where n \leq 5, m \leq 10	6~8	It is high adaptable to various kinds of water quality, and enjoys a wide range of pH values. It also has comparatively satisfactory effect on the low-temperature water, where it quickly forms the floccules with large and weighty granules, and causes only little reduction of raw water alkalinity after being added in. Less quantity of it needs to be added in than aluminum sulphate does.
	Polymerized ferric sulphate [Fe ₂ (OH) _n (SO ₄) _{3-n/2}] _m where n<2,m>10	4~11	Enjoying the properties of small consumption, excellent effect (especially the effect of decoloration), low causticity, a wide range of applicable pH values, and small quantity of iron residues.



	Polymerized aluminum sulphate (PAS) $[Al_2(OH)_n(SO_4)_{3-n/2}]_m$ where $1 \le n \le 6$, $m \le 10$	6~8	Having the flocculation characteristics similar to polymerized aluminum chloride, enjoying the comparatively good properties of decoloration, defluorination and turbidity reduction of the high-turbidity water. The water contains small quantity of aluminum residues after PAS treatment, and enjoys powerful filterability.
Organic	Polyacrylamide (PAM)	8 and above; also applicable to water solution with the acidity not so strong	It is the synthetic organic high-molecular flocculant used most extensively. Its hydrolyzability is controlled within 30%~40%, and will get better effect when combinedly used with aluminum salt or molysite.
flocculant	Anionic polymer	6 and above	It owns the excellent flocculation effect but is expensive, and cannot be used in pretreatment of the low-fouling electropositive elements.
	Cationic polymer	6 and above	It owns the excellent flocculation effect but is expensive, and cannot be used in pretreatment of the low-fouling electronegative elements.
	Silicic acids, such as activated silicic-acid clay, etc.	Less than 9	It has high effectiveness as the coagulant aids, but it is not easy to put its preparation under control and owns only a limited service life.
Coagulant aids	PH and alkalinity regulator		Commonly using the muriatic acid, sulphate, lime, and sodium hydroxide, etc.
	Redox catalyst		Used for the oxidation of iron, manganese and ammonia nitrogen, and for the deodorization, etc.

3-2.2.2 Adsorption

Adsorption is a treatment method where porous solid substances are utilized to adsorb certain contaminants in the water onto surfaces of said substances so as to purify the water body. The contaminants that can be removed by adsorption method include organic substance, colloidal substance and residual chlorine, which have the functions of decoloration and deodoration, etc. The adsorbents frequently used



include activated carbon, macroporous adsorbent, etc., classified as powder type and granule type according to their shapes. Currently, gtranular activated carbon is the adsorbent used most frequently.

Activated carbon Adsorption

Activated carbon is a kind of black porous granule made from various black coal, anthracite coal, fruit shell or wood dust, etc. through carbonization and activation treatment. The physical property of activated carbon refers mainly to the structure and distribution of pores. The pores of various shapes and sizes are formed in the course of activation, which creates an enormous specific surface area and a large contacting area with water, thus bringing about a strong adsorbability. The activated carbon can not only adsorb various contaminants in the water, but also adsorb those contaminants such as SO_2 in the waste gases, and therefore owns a wide range of applications in the fields of environmental protection and water treatment, etc.

The high-quality activated carbon generally has a specific surface area of above $1000m^2/g$, the total pore volume as high as $0.6 \sim 1.18 \text{ cm}^3/g$ and the pore diameter of $0.001 \sim 10 \mu \text{m}$. According to their sizes, the pores can be classified as macropore, transitional pore and micropore, which have different adsorbability as shown in the following table. There are many indexes for the active-carbon products, as shown in the following table, which is based upon the national standard of GB/T7701.4-1997 of the People's Republic of China. Please refer to this table for all applications

Design of Activated carbon Column (Filter)

There are various kinds of activated carbon columns, such as pressure type and gravity type, etc. The pressure-type activated carbon column is frequently used in RO pretreatment system, with its shape and structure similar to the mechanical filter.

Activated carbon filter can be shaped simply into active column, or combined with quartz sand to form the quartz-sand active-carbon filtering column, which can not only adsorb the residual chlorine and organic matters but also get rid of the suspended solids.

In a quartz-sand active-carbon filter, a supporting layer and a quartz-sand



filtering material layer with combined thickness of $0.2\sim0.5m$ are loaded on the bottom of filter, and a layer of activated carbon with $1.0\sim1.5m$ thickness is loaded atop. It has a filtration velocity of $6\sim12m/h$, but owing to the small thickness of filling layer, however, it can be used only in the applications of comparatively good water quality and low contents of suspended substances and residual chlorine.

In a simplex active-carbon filter, no quartz sand is placed on the supporting layer but a layer of activated carbon fillings with 2.0~3.0m height, and the filter works at the filtrating velocity of $3\sim10$ m/h and the reverse flushing intensity of $4\sim12$ L/(s×m²).

		Indexes				
Items		Super-grade	First-grade	Acceptable		
		Products	Product	Product		
Pore Volume (c	m ³ /g)	≥0.65				
Specific Surfac	e Area (m ² /g)	≥900				
Flotation Rate ((%)	≤2				
pH value		6~10				
Adsorption Val	ue of Phenol (mg/g)	≥140				
Water content (%)		≤5.0				
Intensity (%)		≥85				
Adsorption Val	ue of Iodine (mg/g)	≥1050	900~1049	800~899		
Adsorption Va Blue (mg/g)	lue of Methylene	≥180	150~179	120~149		
Ash Content (%	ó)	≤10	11~15	_		
Filling Density (g/L)		380~500	450~520	480~560		
	>2.50mm	≤2				
Granularity	1.25~2.50mm	≥83				
(%)	1.00~1.25mm	≤14				
	<1.00mm	≤1				

 Table 5: Technical Indexes of Coal-granule Activated carbon for Water

 Purification



Points for attention when using the activated carbon

- The activated carbon should be soaked in clean water before being filled into the filter in order to get rid of the contaminants. After being filled in the filter, it should be treated for 1~3 times alternately by using the 5% HCl solution and the 4% NaOH solution in the filtrating velocity of 10~21m/h, with the consumption being three times as much as the volume of activated carbon, then the filter should be rinsed for 8~10 hour.
- 2) Before running, the suspended matters and colloidal matters in the water should be removed as much as possible so as to prevent the micropore of activated carbon from being blocked. For general feedwater, it is required that the suspended substances shall be less than 3~5mg/L.
- 3) The adsorption end of activated carbon filter should be determined upon the nature of the substances to be removed. Since the activated carbon in RO treatment is mainly purposed for eliminating the residual chlorine, the residual chlorine content in the permeated water should be limited to less than 0.1mg/L. Once this limit is exceeded, the activated carbon shall be replaced or regenerated immediately.

3-2.2.3 Precision Filter (Safety Filter)

Precision filtration, also known as micropore filtration or safety filtration, utilizes the machine-shaped filtration materials, such as filter fabric, filter paper, filter mesh and filter element, etc. to remove the extremely fine granules.

Ordinary sand filtration can remove the very tiny solid granules, and cause the permeated water to reach the turbidity of approximately 1 degree; nevertheless, the permeated water still contains a great quantity of granules with $1\sim5\mu m$ grain diameter, which cannot be removed by sand filtration. Though being very tiny in diameter, these granules, if directly entering the host machine of RO system, can still cause the contamination of membrane elements with the concentrating action of



RO membrane. In order to get rid of these granules, precision filtration must be adopted.

The precision filter is usually mounted following the pressure filter, or installed at the end of the pretreatment process for the purpose of preventing the broken filtration materials, activated carbon and resin, etc. from entering the RO system, thus preventing as far as possible the granules produced in the preceding process from being conveyed to the next process. The diameter of filtration pore should match the granular phase of the impurities contained in water, and excessively large or small diameter should be avoided.

A pressure gauge should be mounted respectively at the water inlet and outlet of precision filter, and the difference can give judgment on the pollution degree of filter element in the precision filter. In general case, the filter element inside it needs to be replaced when the difference is greater than 15psi (0.1MPa).

Materials	Minimum grain diameter of granules removed (µm)	Materials	Minimum grain diameter of granules removed (μm)
Woven fabrics of natural and synthetical fiber	100~10	Foam plastic	10~1
Ordinary mesh filtration	10000~10	Fiberglass paper	8~0.03
Filter element of woven nylon mesh	75~1	Sintered ceramic (or sintered plastic)	100~1
Fiber paper	30~3	Microporous filtration membrane	5~0.1

 Table 6:
 Filtration Precision of Precise Filtering Materials Frequently Used

3-2.2.4 Oxidation

Oxidation is a kind of chemical treatment method for oxidizing and



decomposing the contaminants in water by utilizing strong oxidant. For RO system pretreatment, oxidation is usually for the purpose of removing the following two kinds of substances

- ① Organic substances
- 2 Iron, manganese

Furthermore, oxidation can also get rid of the color, taste, odor and microorganisms, etc. in the water. The use of oxidation combined with such treating methods as flocculation, filtration and adsorption, etc. can achieve an excellent pretreatment effect. There are two kinds of oxidants frequently used, i.e., chlorine series and oxygen series. Besides, such oxidants as KMnO₄, etc. can also be used.

Chlorine series: Cl₂, ClO₂, NaClO, etc

Oxygen series: O₃, H₂O₂, etc.

1) Removal of Organic Substances

The RO feedwater requires the TOC to be less than 2mg/L, because excessive organic matters will cause the contamination of elements, which must be removed in the pretreatment process. Theoretically, as soon as enough quantity of strong oxidants such as O₃, ClO₂, Cl₂, etc. is added in, most of the organic matters can be thoroughly transferred to inorganic matters through oxidation; however, it requires considerably large quantity of oxidants to be added, long time of reaction and comparatively high cost, and may produce harmful byproducts. Usually in RO pretreatment, only the strong oxidant is required to break the long chain of organic matters, and convert them to micro-molecular organic matters, which shall then be removed by using such processes as adsorption, etc.

2) Removal of Fe²⁺ and Mn²⁺, etc.

Usually in the nature, the water body, especially the underground water, appears in the state of reduction because the water contains such reductive substances as Fe^{2+} , Mn^{2+} and H_2S , etc. Fe^{2+} is one of the reasons that cause the ferric contamination and colloidal contamination to membrane elements. In RO feedwater, ferric contaminant is still possibly caused even if the content of Fe^{2+} is less than



0.1 mg/L. Therefore, when treating this kind of water source, the oxidation method is most frequently adopted to convert Fe^{2+} and Mn^2 into the hardly soluble Fe^{3+} and MnO_2 and then to remove them through filtration. ClO_2 , O_2 and Cl_2 are frequently used for oxidation, with the reaction formula as follows:

$$2ClO_2 + 5Mn^{2+} + 6H_2O = 5MnO_2 + 12H^+ + 2Cl^-$$
$$ClO_2 + 5Fe(HCO_3)_2 + 3H_2O = 5Fe(OH)_3 + 10CO_2 + Cl^- + H^+$$

 ClO_2 has a higher capacity of removing the iron and manganese than Cl_2 does, therefore the utilization of ClO_2 is recommended for treating the water sources with high contents of iron and manganese.

It's necessary to notice that common polyamide composite membrane has an inferior oxidation resistance, and in terms of residual chlorine, the maximum concentration of residual chlorine in feedwater that Shangyuan membrane element can endure is 0.1mg/L, and therefore, relevant process must be set up to eliminate the residual oxidant in the pretreatment where oxidant is added in, in which case the method of active-carbon adsorption and the dosing of reductant (NaHSO₃) are usually adopted.

3-2.2.5 Sterilization and Disinfection

All of the water bodies contain such microorganisms as bacteria, fungus, algae, virus and protozoan, etc. If the water containing microorganisms enters directly the RO element without being treated by sterilization, the microorganisms will, under the RO concentration effect, gather on the surface of membrane, and form a microorganism film, which seriously influence the water permeate and rejection rate of element, cause the increase of pressure difference and result in the telescoping of the elements. Moreover, the rinse of element doesn't always obtain a satisfactorily good effect when it is contaminated with microorganisms, and therefore, the sterilization action must be taken in pretreatment process for the raw water, especially for the surface water, seawater and waste water, which contain microorganisms. For these water sources, we recommend you to select the oxidation-resistant RO membrane element which can simplify the pretreatment and prevent the risk of oxidation of membrane element. The sterilization process



frequently used includes physical sterilization and chemical sterilization.

1) Physical Sterilization – UV Device

The UV with 254-nm wavelength has the best effect of sterilization. When UV irradiates on the bacteria, the energy of UV is absorbed by the nucleic acid of bacteria and thus changes the vitality of bacteria, and the synthesis of protein and enzyme inside the bacteria body becomes obstructed, thus causing the variation or death of microorganisms.

2) Chemical Sterilization – Germicide

Chemical germicide is generally classified as oxidative germicide and non oxidative germicide. The oxidative germicide includes Cl_2 , ClO_2 and O_3 , etc. The non oxidative germicide refers mainly to certain organic matters, such as DBNPA, isothiazolinone, formaldehyde, etc.

When oxidative germicide is used, it must be noticed that common compound membrane has an inferior resistance to oxidation, and the maximum content of residual chlorine in water that Shangyuan elements can endure is 0.1mg/L, and therefore, relevant process must be set up to eliminate the residual oxidant in the pretreatment where oxidant is added in, in which case the method of active-carbon adsorption and the addition of reductant (NaHSO₃) are usually adopted.

3-2.2.6 Prevention of Scaling Caused by Hardly Soluble Salt

The scaling of inorganic salt is a kind of contamination most commonly seen in RO element. Most of the water bodies in the nature contain hardly soluble saturated salts, such as calcium carbonate, etc. If directly entering the element without being treated before, the saturated salts will, upon the concentrating action of RO system, reach the oversaturated concentration, and form crystals that deposit on the membrane surface, thus causing contamination to the elements.

Regarding the scaling of $CaCO_3$, the indexes of LSI or S&DSI can be employed to represent the scaling tendency. For the rejected water with salt concentration less than 10000ppm, LSI is used as the index to indicate the scaling tendency of CaCO₃, while S&DSI is used as the index to indicate the scaling



tendancy of CaCO₃ for the rejected water with salt concentration greater than 10000 ppm. These two indexes are calculated according to the formulas as follows:

LSI=pHc-pHs	TDS≤10000ppm
S&DSI=pHc-pHs	TDS>10000ppm

where pHc refers to the pH value of rejected water, and pHs refers to the pH value of water saturated with calcium carbonate.

When LSI or S&DSI is ≥ 0 , the scaling of CaCO₃ will occur. Unless the antiscaling agent is dosed in the RO system, it must be guaranteed that both of LSI and S&DSI indexes be negative.

For the scaling of sulphates including those hardly soluble substances such as CaSO₄, BaSO₄, SrSO₄, such methods as softening method, dosing of antiscaling agent or reducing of system recover rate is usually used for preventing the scaling. There are mainly three kinds of antiscaling agents, i.e. sodium hexametaphosphate, micromolecular organic phosphate and polyacrylate, with their merits and shortcomings shown in Table 7. Table 8 shows the solubility product constant of hardly soluble compounds.

Ingredients of Antiscaling Agent	Antiscaling Effects	Merits	Shortcomings		
Sodium Hexametaphosphate	Inferior effect. It can ensure that the scaling of CaCO ₃ will not occur only when the LSI is ≤ 0.8	Inexpensive	Limited and unsteady effect of antiscaling; highly hydrolyzable; having the scaling risk caused by calcium phosphate.		
Micro-molecular Organic Phosphate	Good effect. Being free from scaling of calcium carbonate when the LSI is ≤ 2.0 .	Good effect of antiscaling	Comparatively expensive		
Polyacrylate	Good effect. No scaling of calcium carbonate will occur when the LSI is	Good effect of antiscaling	Comparatively expensive		

Table 7: Comparison of Properties of Antiscaling Agents Commonly Used



SHANGYUAN TECHNOLOGY CO., LTD ADD: BLD 2, Tiantongyuan Beiqijia, Changping district, Beijing China

≤2.0.	



SHANGYUAN TECHNOLOGY CO., LTD ADD: BLD 2, Tiantongyuan Beiqijia, Changping district, Beijing China

Descriptions	Molecular Formula	K _{sp}	pK _{sp}	Descriptions	Molecular Formula	K _{sp}	pK _{sp}
Barium Carbonate	BaCO ₃	5.1×10 ⁻⁹	8.29	Nickel carbonate	NiCO ₃	6.6×10 ⁻⁹	8.18
Barium fluoride	BaF ₂	1.0×10 ⁻⁶	6.00	Lead carbonate	PbCO ₃	7.4×10 ⁻¹⁴	13.13
Barium sulphate	BaSO ₄	1.1×10 ⁻¹⁰	9.96	Lead chloride	PbCl ₂	1.6×10 ⁻⁵	4.79
Calcium carbonate	CaCO ₃	2.9×10 ⁻⁹	8.54	Zinc carbonate	ZnCO ₃	1.4×10 ⁻¹¹	10.84
Calcium fluoride	CaF ₂	2.7×10 ⁻¹¹	10.57	Zinc hydroxide	Zn(OH) ₂	1.2×10 ⁻¹⁷	16.92
Calcium phosphate	$Ca_3(PO_4)_2$	2.0×10 ⁻²⁹	28.70	Zinc phosphate	Zn ₃ (PO ₄) ₂	9.1×10 ⁻³³	32.04
Calcium sulphate	CaSO ₄	9.1×10 ⁻⁶	5.04	Zinc sulphide	ZnS	1.2×10 ⁻²³	22.92
Calcium hydroxide	Ca(OH) ₂	1.55×10 ⁻⁶	5.81	Ferrous carbonate FeCO ₃		3.2×10 ⁻¹¹	10.50
Copper hydroxide	Cu(OH) ₂	5.6×10 ⁻²⁰	19.25	Ferrous hydroxide	Fe(OH) ₂	1.6×10 ⁻¹⁴	13.80
Copper sulphide	CuS	8.5×10 ⁻⁴⁵	44.07	Ferrous sulphide	FeS	6.3×10 ⁻¹⁸	17.20
Copper chloride	CuCl ₂	1.2×10 ⁻⁶	5.92	Iron hydroxide	Fe(OH) ₃	1.1×10 ⁻³⁶	35.96
Magnesium carbonate	MgCO ₃	3.5×10 ⁻⁸	7.46	Ferrous phosphate	FePO ₄	1.3×10 ⁻²²	21.89
Magnesium fluoride	MgF ₂	6.4×10 ⁻⁹	8.19	Lead sulphate	PbSO ₄	1.6×10 ⁻⁸	7.80
Magnesium hydroxide	Mg(OH) ₂	1.2×10 ⁻¹¹	10.92	Strontium carbonate	SrCO ₃	1.1×10 ⁻¹⁰	9.96
Ammoniate d magnesium phosphate	MgNH ₄ PO ₄	2.0×10 ⁻¹³	12.70	Strontium sulphate	SrSO ₄	3.2×10 ⁻⁷	6.49
Manganese carbonate	MnCO ₃	1.8×10 ⁻¹¹	10.74	Strontium fluoride	SrF ₂	2.4×10 ⁻⁹	8.61
Manganese hydroxide	Mn(OH) ₂	4.0×10 ⁻¹⁴	13.40	Aluminum hydroxide Al(OH) ₃		2.0×10 ⁻³³	32.70

Table 8:	Solubility Product Constant of Hardly Soluble Salts (291~298K)
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3-2.2.7 Softening



Softening refers to the treatment method where the chemical method is adopted to remove the hardness in the water. It is classified as ion-exchange softening and chemical-reagent softening

Chemical-reagent softening is the process where, based upon the principle of solubility product, the hardness contained in the water is converted into the hardly soluble salts under proper conditions and then removed. In chemical-reagent softening, lime softening technology is usually adopted, which can effectively reduce the concentration of such ions as Ca^{2+} , Mg^{2+} and Ba^{2+} , etc., and which, however, is generally applied to large-scale brackish water system owing to that it needs to use the special-purpose reactor, that the pH value of permeated water may go up and that its operational cost is comparatively high. At present, ion-exchange softening is the softening method frequently used in RO pretreatment.

Ion-exchange softening is a softening treatment where ion exchanging agent is used in order for the hardness compositions of water body such as ions of Ca^{2+} and Mg^{2+} , etc. to react with the effective exchange group (mainly the sodium ion) so that the water quality can be softened. It works as shown in the following formula

Exchange

$$2 \text{ RNa} + \begin{cases} Ca(HCO_3)_2 & 2 \text{ Na}HCO_3 \\ CaCO_3 & = R_2Ca + \\ CaSO_4 & Na_2CO_3 \\ Mg(HCO_3)_2 & 2 \text{ Na}HCO_3 \\ MgCO_3 & = R_2Mg + \\ MgSO_4 & Na_2SO_4 \\ Na_2SO_4 \\ Na_2SO_4 \end{cases}$$

Regeneration

$$R2Ca + 2NaCl = CaCl_2 + 2RNa$$
$$R2Mg + 2NaCl = MgCl_2 + 2RNa$$

Since ion exchange softening requires the regeneration of resin, which will consume the regenerative liquid and produce high-concentrated saline wastewater, it is economically inferior for the high-hardness water, and therefore, its utilization is



restricted by certain conditions. Presently, it is adopted only in the small-scale system, while the middle-scale and large-scale systems generally use the method of dosing the antiscaling agent to prevent the contamination of inorganic-salt scaling.

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J.2.2.0	Effects of Typical I	Tetreatment Trocesses	un various	Containnants

Pretreatment											Organic
Processes	CaCO ₃	$CaSO_4$	$BaSO_4$	SrSO_4	CaF_2	SiO_2	SDI	Fe	Bacteria	Oxidant	Matters
Acidifying the	A							\triangle			
pH value											
Dosing the	\bigtriangleup					\bigtriangleup					
anti-scalant											
Softening with											
ion resin											
Multimedia						\bigtriangleup	\bigtriangleup	\bigtriangleup			
filtration											
Flocculation – Aided						\bigtriangleup		\bigtriangleup			
Coagulation											
MF/ UF								\bigtriangleup	\triangle		
Filtration with						\bigtriangleup	\bigtriangleup	\bigtriangleup	\bigtriangleup		
Precision											
Filtering Element											
Filtration with											
Granular											
Activated carbon											
Dosing of											
Reductant											
Disinfection with											
chlorination /											
oxidation											
Shock									\bigtriangleup		
Disinfection											
Oxidation -							\bigtriangleup				
filtration											
Lime softening	\bigtriangleup	\bigtriangleup	\bigtriangleup	\bigtriangleup	\bigtriangleup	\bigtriangleup	\bigtriangleup	\bigtriangleup			\bigtriangleup
Preventive	Δ					\triangle	\bigtriangleup	\triangle	\triangle		\triangle
cleaning											
Regulation of		\triangle	\triangle	\triangle	\triangle						
operating parameters											
(pH, recovery rate)											

riangle regularly effective

▲ High effective



For the contaminants contained in feedwater, a suitable pretreatment system shall be designed according to the effective pretreatment measures mentioned in the above table.