The Design Criteria for Water Supply Facilities

2012

Ministry of Health, Labour and Welfare
Chapter 5. Water Treatment Facilities

(The excerpt)
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5 Water Treatment Facilities

5.1 General

5.1.1 Principal Matters

Since the water treatment facilities constitute one of mainstays of the water supply system, their function influences the entire water supply system.

The principal function of water treatment facilities is to constantly produce required quality, namely potable, of water in necessary quantity through processes of water treatment. As a reflection of the needs of the society, the provision of facilities with higher level of functions than before is required, which would realize “safe and comfortable water supply”, “more reliable water service with the provision for measures against disasters, accidents etc.”, “necessary steps to protect the environment and prepare for energy issues” and “the provision for encountering emergency events”.

When planning and designing water treatment facilities, the observed should be the articles prescribed in “Ministerial ordinance to establish technical standards for water supply facilities” (23 February 2000 Ministry of Health, Labor and Welfare Ordinance No. 15) and the articles of other related laws and regulations while necessary functions shall be secured in conformity with the technical standards and guidelines established by related academic societies and associations etc. The standards and guidelines related to water treatment facilities are presented in Table 5.1.1 (See 1.3.4 Process of designing and technical standards to be followed).

Table 5.1.1: Standards and guidelines related to structural design

| ・JIS B 8501: Structure of petroleum storage structures (Entirely welded) 1995 (Japanese Standards Association 1996) |
| ・WSP 063-97 Guidelines for design of steel service reservoirs (Water Steel Pipe Association 1997) |
| ・Guidelines for design and construction of pre-stressed concrete tanks for water supply and Interpretation (Japan Water Works Association 1998) |
| ・Guidelines for road earthwork temporary structural work; Guidelines for road earthwork slope work and slope stabilization work; Guidelines for road earthwork retaining wall work (Japan Road Association 1999) |
| ・Guidelines for design of building foundation structures (Architectural Institute of Japan 2001) |
| ・Guidelines for LNG ground surface tank (Japan Gas Association 2002) |
| ・Standard specifications for concrete structures – 2007 “Design” (Japan Society of Civil Engineers 2007) [Note: Download only, from the JSCE Website] |
| ・Guidelines for design of vessel structures – Interpretation (Architectural Institute of Japan 1996) |
| ・Standard specifications for steel and composite structures (Japan Society of Civil Engineers 2008) |
| ・Building Standards Act (1950 Law No. 201; last revision 2008) |
| ・Enforcement order on Building Standards Act (1950 Ordinance No. 338) |
| ・Interpretation book on architectural structure technical standards (Japan Society of Architectural Disaster Prevention – Architecture Center of Japan 2007) |
When planning water treatment facilities, sufficient studies and investigations shall be conducted on the following aspects:

1. **Size of the water treatment facilities**

The size of the water treatment facilities shall be determined in the course of making a master plan for the whole water supply system even considering the prospect of future expansions. It is desirable for a water supply to have certain margin for system capacity so that the design output can be maintained even at the times of system renovation and replacement, and that operational stability of the water supply system is to be strengthened against disasters and accidents, taking a consistency to the master plan into consideration.

2. **Secured water sources**

As for the quantity of water to be secured from water sources, a long-term plan shall be established including water rights to be obtained in future since the capacity of water sources is a direct factor for determining the size of the water treatment facilities.

3. **Raw water quality and the goals for water quality control**

1) **Study on raw water quality**

The raw water quality is one of the most important factors which are related to the selection of the water treatment method. As to water quality items, not only standard water quality items but other items, for which countermeasures are needed, shall be studied. As for raw water quality, its change in future shall be predicted with due attention to not only the analyses of presently available data but also urbanization of the area around the water source, development of an industrial zone, agricultural development etc. which affect the raw water quality; and consideration shall also be given to the possibility of a change in the treatment method or an addition thereto in future.

2) **Goals of water quality control of treated water**

Considering the drinking water quality standards, which shall primarily be observed for the tap water, the water quality control items and their goals shall be set aiming at safe and comfortable water service, for which the water supply utilities are responsible.

4. **Selection of water treatment method and facilities**

1) **Water treatment method**

Water treatment methods include disinfection only, slow sand filtration, rapid sand filtration, membrane filtration, advanced treatment method and combination thereof with other methods. When selecting a treatment method, it is needed to consider to satisfy the goals of treated water quality control with raw water of any quality, the size of the water treatment facilities, and the technical level of their operation and maintenance.

2) **Selection of water treatment facilities**

When selecting the water treatment method, as different facilities may be built even applying the same method depending on the underlying conditions, considered shall be the total cost, including the space of installation of the facilities, construction cost, operating expenses, maintenance cost, reliability and
the ease of operation and maintenance, selection of technologies to reduce the environmental burden and so forth. Depending on the facilities, as treatment efficiency may be largely reduced in relation to water flow, the water treatment method shall be selected with due consideration to the actual flow so as to produce the desired quantity of water in any case.

What is more, a water treatment method and facility, of which operation and maintenance is easy, shall be selected while various methods of water treatment are being developed, and so the treatment facilities become complex and diversified.

5. Location and layout of water treatment facilities

The location of the water treatment plant shall ideally be chosen so that the land is purchasable; that there is difference in the ground elevation between the water treatment plant and the service area, which enables efficient use of the potential energy for water distribution by gravity; that the facilities are not vulnerable to pollution from outside; that sound foundation soil can be obtained, which is safe and reliable even against natural disasters; and that there will be no need of sizeable earthwork to level the site for the water treatment plant.

When laying out the plan of the water treatment facilities, it is important that the respective water treatment processes are laid out so that they can fully perform their functions, and that the facilities shall be so positioned from the hydraulic profile point of view for the difference in elevation as to rationally be utilized. Especially, since the position of the foundation may largely influence the stability of the structures and the construction cost, proper vertical positioning of facilities shall be made in accordance with the result of the preliminary survey. Furthermore, the effective use of land shall be practiced while some space, if required, shall be spared for future improvement, replacement or expansion of the facilities.

6. Environmental concern

Abiding by the laws and regulations related to water supply, the effect of the discharge of wastewater to the public water bodies, odor, noise etc. from the water treatment plant to the surroundings shall be taken into consideration. In addition, as much reduction as possible in the influence of hazards to be caused at the time of construction of the water treatment plant shall also be considered.

7. Safety and reliability against disasters and accidents

It is important to provide water treatment facilities with measures to, as much as possible, lessen the effects, i.e., suspension of service, of natural disasters, accidents etc.; and quickly restore the system. Therefore, it is important to provide means of shutting down the water flow, draining water, regulating water pressure and so on so that damages are prevented beforehand or that augmentation of damages and secondary disasters can be avoided.

Water treatment facilities, as the core facilities of water supply, shall be protected from earthquakes so as to secure sufficient safety. As such, the water treatment plant shall as much as possible be situated on a sound foundation in a location with as much even topography as possible. The work of foundation must carefully be implemented including the improvement of the earth if required and so forth.

To prepare for drought, accidents related to water contamination, salination of the water source caused by tsunami etc., if required, the dispersion of water treatment facilities and water sources, and interconnecting water mains between water treatment plants are useful. What is more, the provision of stand-by units of apparatus against their accidents or failures in required locations, installation of double-circuit power reception or equipping adequate power generators are needed. (See 1.1.4 Risk Management)
8. Improvement and replacement of facilities

Water treatment facilities will be aging over time. Acquisition of land, layout of facilities and margin in system capacity for easy future improvement and replacement shall be considered. At the occasions of improvement and replacement, it is important to secure coordination between the existing facilities and the new ones in terms of changes in system capacity and structures of facilities, conformity of treatment efficiency, hydraulic relationship, and aspects of operation and maintenance. (See 1.1.3 Improvement and replacement of facilities)

5.1.2 Research

For research for planning of water treatment facilities, the following items of aspects shall be included:

1. In the case of new construction or expansion:
   1) Research for planning of water treatment facilities
   2) Research for planning of the site of water treatment facilities
   3) Research for planning of facility construction

2. In the case of improvement and replacement:
   1) Research for planning of improvement and replacement
   2) Research for the implementation of improvement and replacement

[Interpretation]

On the Item 1.1);

The raw water quality shall precisely be understood when planning water treatment facilities. Substances and their concentrations contained in raw water widely vary and possess unique characteristics depending on respective water sources. In addition, in some cases water pollution will advance in future as influenced by the urbanization of the river basin and discharge of wastewater from industrial development. Sufficient study is needed to understand the present status of raw water quality as well as the prediction of future water quality based on the trend of the development of the river basin.

With reference to “5.1.4 Selection of water treatment method and facilities”, research shall be implemented based on the selection of the water treatment method which will enable the achievement of the goals of raw water quality and treated water quality. When planning a water treatment plant, in addition to the grasp of raw water quality, the characteristics of performance of each treatment facility, treatment method, and the method of the treatment of wastewater as well as the type of their operation shall be studied.

(1) Items of water quality survey

When understanding the present water quality, water quality testing shall be carried out at least every month for a year including the times of floods and droughts on the following items (excluding items of disinfection byproducts): all standard water quality items and items for setting water quality control goals as required including free carbon dioxide, ammonium nitrogen, biochemical oxygen demand
(BOD), chemical oxygen demand (COD), ultraviolet absorbance (UV), suspended solids (SS), erosive free carbon dioxide, total nitrogen, disinfection byproducts precursors, organisms etc.

a. In the case of river waters

Water quality of river water tends to be easily affected by the natural and social environment such as atmospheric temperature, water flow, soil of the river basin, wastewater etc.; and its magnitude is different depending on the area and the season. Therefore, the items for study shall be determined based on the condition of respective water sources for their proper locations, items, frequency etc.

At the times of floods, the turbidity shall be studied even as frequently as every hour since its fluctuation tends to be large.

On the other hand, the concentration of dissolved substances becomes high at the times of droughts as the flow decreases; and, in addition, ammonium nitrogen, total organic carbon (TOC), BOD, anionic surface active agents and so forth shall be studied as the water quality is easily affected by the inflow of wastewater.

b. In the case of waters from impounding reservoirs and lakes

In case water is drawn from an existing impounding reservoir, such organisms as plankton, which cause problems of filter trouble, obnoxious odor and taste etc., shall be studied as well as total nitrogen, total phosphates etc. which are precursors for eutrophication. The organisms shall be studied for their species, numbers, chlorophyll a, odor etc. throughout the year since they fluctuate depending on the condition of the reservoir or lake such as the stratified period, turnover period etc.

As iron and manganese elute from the bottom sediment of reservoirs and lakes due to the reduced dissolved oxygen, water temperature, dissolved oxygen (DO), iron, manganese etc. shall be studied by depth. In case water is drawn from a new reservoir, the results of a study on a similar reservoir shall be referred to.

c. In the case of groundwater

The groundwater is classified into two: unconfined groundwater and confined groundwater (artesian groundwater). Although the quality of groundwater is generally good, unconfined groundwater tends to be influenced by surface water; and confined groundwater has indigenous characters originated from the formations surrounding the aquifer in question.

The items of water quality to be tested are water temperature, pH, color, erosive free carbon dioxide, ammonium nitrogen, nitrate nitrogen, iron, manganese, iron bacteria, bacteria etc. and arsenic and fluorides in particular areas.

As there are a number of the incidents of pollution by organic solvents, volatile organic molecules such as 1,1,1-trichloroethane etc. shall be studied in addition to trichloroethylene and tetrachloroethylene.

d. In the case of infiltrated water

Infiltrated water, as river water flowing through a porous formation, contains less turbidity than the river water; its temperature is relatively stable; and it possesses characteristics of water quality in between surface water and groundwater. Testing items of infiltrated water shall be based on those for river water and groundwater.

(2) Analysis of water quality data

Water treatment facilities shall be designed so that sufficient water treatment can be performed even at the times of low raw water quality. Even if abstracted from the same river, the raw water quality varies
depending on the intake location and the season; especially, large fluctuations are observed in turbidity, alkalinity, pH, ammonium nitrogen, TOC, potassium permanganate consumption, bacteria etc. at the occasions of floods, droughts, snow-melting seasons and so on. The water quality characteristics of the water source shall be clarified by analyzing the correlation between the above data and the environment of the river basin, floods, snow-melt runoff, atmospheric temperature, droughts etc. As the deterioration in water quality is remarkable at the times of low river flows in a dry season or unusual drawdown of water level at an impounding reservoir and lake, the use of data obtained at such occasions shall be judged whether or not they are incorporated in statistical analyses with due consideration to the frequency of such occasions.

On the item 1.2);

The following items shall fully be examined for determining the location of a water treatment plant.

(1) The layout of the entire water treatment facilities shall be considered

Since the water treatment facilities perform their function as part of the water supply system together with other facilities from water intake to water distribution, its site shall be chosen taking into account the plan of the entire water supply system and their positions in terms of its hydraulic profile.

(2) Sanitary environment shall be maintained

Since the water treatment plant is a site where drinking water is produced, a location in proximity with a source of pollution shall as much as possible be avoided considering the design of the water treatment facilities. The water treatment plant is vulnerable to not only the discharge of wastewater from factories and other businesses situated upstream but also airborne contaminants since the water treatment plant has large open water surface and so be easily subject to pollution from outside, the environment of the area surrounding the plant shall be studied for sources of contamination including incinerators, aerial spray of agricultural chemicals etc.

(3) Security against disasters

Security measures against disasters must be provided for not only water treatment plants but also water supply systems as a whole. From the viewpoint of the security of water service, it is not desirable to place a water treatment plant at a location where disasters such as collapse and breakage of structures, inundation, damages from salt water etc. are easily caused by earthquakes, heavy rains, typhoons, tsunami etc. When planning the location of a water treatment plant, a location which is safe against such disasters shall be selected with reference to a hazard map and so forth.

In consideration to the earthquake, a place where ground is composed of flexible soil or liquefaction is possible, or in the vicinity of an active fault, which may cause an earthquake with a vertical shock, shall as much as possible be avoided; and a location of strong ground shall be selected. To avoid possible heavy rains and inundation, a location where drainage is easy shall be chosen avoiding a low-lying area.

(4) Provision of land with required space and shape

As for the site for a water treatment plant, the space for the administration building, pipelines, and operation and maintenance works shall be provided in addition to that for the water treatment facilities.

A construction plan of water treatment facilities is often implemented in some phases. It is normal practice to obtain land for all the phases since it is rather difficult to purchase a lot at each phase. Furthermore, the space required for renovation and replacement of facilities must also be prepared at the beginning.
The correlation between the size of water treatment plants and the space for the plant is shown in Figure 5.1.2.

The shape of site for the plant, which is rectangular and not so slender, is preferable.

Even though it is desirable to have as flat land as possible, land with a slope is not necessarily disadvantageous if the water treatment facilities are so positioned as to suit the inclination of the land. For example, wastewater disposal facilities can be situated in low-lying part of the land.

![Figure 5.1.2: Plant output and site space](image)

(5) Location to be selected for the ease of operation and maintenance

The water treatment plant is the main component of a water supply system, so its operation and maintenance constitute a basis of those of the water supply. Thus it is advantageous for the plant to be situated in a location for easy day-to-day operation and maintenance and delivery of chemicals and other materials from outside.

On the item 2.1);

Improvement and replacement of facilities are undertaken for two reasons: (1) restoration or improvement of functions of existing superannuated or outdated facilities; and (2) upgrading of treatment capacity and efficiency for improved treated water quality. In both cases, it is important to study on and evaluate the function and capacity of the existing facilities in advance to find a way to realize effective and efficient improvement and replacement. The examination and evaluation of the functions are primarily carried out on each facility while it is essential to comprehensively evaluate the whole water supply system for the examination for improvement and replacement so that facilities are chosen to bring about the most effective performance. It is necessary to examine and evaluate the functions based on technical problems of the magnitude of wear and deterioration in efficiency, new needs in relation to the enhanced water quality standards, reinforced risk management etc.; and identify the purposes and reasons for improvement and replacement after defining the role and efficiency of the facilities.

On the item 2.2);

As improvement and replacement of water treatment facilities are in general carried out while operating the existing facilities, the influence of such a work to the operation of the existing facilities must be made as little as possible; and sufficient coordination with the existing facilities is required so that the new and existing facilities can function as a unity on the completion of the improvement and replacement work. Therefore, the following items of aspects shall also be studied:
5.1.3 Design water treatment output and the capacity of the plant

The design water treatment output and the capacity of the water treatment facilities are to be set as follows:

1. The design water treatment output is set based on the total of the design maximum daily demand and the consumption for process water in the plant.

2. The water treatment facilities shall be able to properly process the design water treatment flow. It is desirable for the facilities to have spare capacity to strengthen the safety of the water supply system in preparation for a disaster, accident etc. even at the time of improvement and replacement.

[Interpretation]

On the item 1.;

The design water treatment output is set based on the total of the design maximum daily demand and the consumption for process water, water for various utilities, and other losses in the plant. The process water consists of the underflows of sedimentation basins, water for filter washing and washing of sand for slow sand filters, water for dissolution and dilution of chemicals, pressure water for chlorinators, cooling water for machinery, water for water testing and cleaning water for plant facilities; and the water for utilities includes water supply in the plant and water for site cleaning.

On the item 2.;

1) Concept of capacity margin

The water treatment facilities shall possess capacity to be able to treat the design treatment output determined in 1. above, and it is desirable for the facilities to always maintain the capacity even at the time of improvement and replacement. What is more, it shall be considered that the influence of disasters, accidents or failure of machinery to water service is to be minimized; and, therefore, certain spare capacity is desirable to be embodied in the water treatment facilities.

The spare capacity is not for day-to-day small scale failure, cleaning, inspection etc. but for large and long-lasting reduction in the system capacity not including the one necessary for daily operation such as the standby units of filters.

In case dividing water treatment facilities into blocks, the spare capacity of a water treatment plant shall be equivalent to the facilities contained in one of the blocks, and it is the standard practice to set the spare capacity at 25% or so of the design water treatment flow. (See 1.2.1 General)

2) Spare capacity for small scale water treatment plants

In case there are only one or two blocks of water treatment facilities, it must be very difficult to add another block of facilities to the existing one; and the facilities will become too large even if such an
addition can be made. In such a case, as there are in principle more than two sedimentation basins and filters, spare capacity can easily be obtained by means of augmentation of capacity by installing sloping plates in sedimentation basins and dual media in filters. In the case of shutting down a block, it is also possible to use the spare capacity of the remaining block by overloading it within the allowable extent in terms of water quality and hydraulic property.

3) Spare capacity of the water supply system as a whole

In case there are more than two water treatment plants, dynamic water control becomes possible by laying interconnecting water mains between plants. In such a case, it is needed to provide spare capacity mainly in the major plant.

As such the same maximum limit of the spare capacity may not generally apply to all water supplies, but, since it differs according to the situation about provisions of water treatment facilities, the capacity of service reservoirs, the existence of interconnecting raw water mains etc., proper spare capacity shall be determined for the water supply system as a whole.

4) Consideration to the normal water flow and the minimum flow for treatment

When selecting water treatment methods, there are some methods which may bring about an operational trouble when operated in normal output if the facility is designed by the maximum output. In such a case, special consideration is needed.

5.1.4 Selection of water treatment methods and water treatment facilities

The selection of water treatment methods and water treatment facilities shall be carried out in accordance with the following:

1. The water treatment methods shall be capable of reliably producing tap water in conformity with the drinking water quality standards; they shall be selected from the methods of disinfection only, slow sand filtration, rapid sand filtration, or membrane filtration in combination with an advanced water treatment method, if required, in accordance with raw water quality, the management goals for treated water quality and so on. Thereafter, the method shall be chosen taking into account the size of the water treatment plant, the technical level of operation, control and maintenance etc.

[Interpretation]

On the item 1.;

When selecting a water treatment method, the following points shall in general be considered:

1) Water quality standards and management goals of water quality control

Such water treatment method shall be selected as to be able to meet the water quality standards (See Table 5.1.2) stipulated in “Ministry Ordinance on Drinking Water Quality Standards” (20 May 2003 Ministry of Health, Labor and Welfare Ordinance No. 101). Since in addition to the water quality standards, the management goals of water quality control as items to be observed for water quality control have been established, it is desirable to satisfy the management goals set for every item. (See Table 5.1.3) As the water treatment method, a water treatment method, which enables to achieve the above water quality standards and the management goals set by the water supply utility, shall be chosen.
<table>
<thead>
<tr>
<th>Item</th>
<th>Standard (mg/L)</th>
<th>Item</th>
<th>Standard (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard plate count</td>
<td>&lt;100</td>
<td>Total trihalomethanes</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Coliforms</td>
<td>Not to be detected</td>
<td>Trichloroacetic acid</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Cadmium and its compounds</td>
<td>&lt;0.003</td>
<td>Bromodichloromethane</td>
<td>&lt;0.03</td>
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<tr>
<td>Mercury and its compounds</td>
<td>&lt;0.0005</td>
<td>Bromoform</td>
<td>&lt;0.09</td>
</tr>
<tr>
<td>Selenium and its compounds</td>
<td>&lt;0.01</td>
<td>Formaldehyde</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>Lead and its compounds</td>
<td>&lt;0.01</td>
<td>Zinc and its compounds</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Arsenic and its compounds</td>
<td>&lt;0.01</td>
<td>Aluminum and its compounds</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Hexavalent chromium compounds</td>
<td>&lt;0.05</td>
<td>Iron and its compounds</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>Cyan compound ion and cyanogens chloride</td>
<td>&lt;0.01</td>
<td>Copper and its compounds</td>
<td>&lt;1.0</td>
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<tr>
<td>Nitrate nitrogen and nitrite nitrogen</td>
<td>&lt;10</td>
<td>Sodium and its compounds</td>
<td>&lt;200</td>
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<tr>
<td>Fluorine and its compounds</td>
<td>&lt;0.8</td>
<td>Manganese and its compounds</td>
<td>&lt;0.05</td>
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<tr>
<td>Boron and its compounds</td>
<td>&lt;1.0</td>
<td>Chlorides ion</td>
<td>&lt;200</td>
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<td>Carbon tetrachloride</td>
<td>&lt;0.002</td>
<td>Calcium, magnesium etc. (hardness)</td>
<td>&lt;300</td>
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<tr>
<td>1,4-dioxane</td>
<td>&lt;0.05</td>
<td>Total solids</td>
<td>&lt;500</td>
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<td>cis-1, 2-dichloroethylene and trans-1,2-dichloroethylene</td>
<td>&lt;0.04</td>
<td>Anionic surfactants</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>&lt;0.02</td>
<td>Geosmin</td>
<td>&lt;0.00001</td>
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<tr>
<td>Tetrachloroethylene</td>
<td>&lt;0.01</td>
<td>2-methylisoborneol</td>
<td>&lt;0.00001</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>&lt;0.01</td>
<td>Non-ion surfactants</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Benzene</td>
<td>&lt;0.01</td>
<td>Phenols</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Chloric acid</td>
<td>&lt;0.6</td>
<td>Organic matters (Total organic carbon [TOC])</td>
<td>&lt;3</td>
</tr>
<tr>
<td>Chloroacetic acid</td>
<td>&lt;0.02</td>
<td>pH</td>
<td>Higher than 5.8, lower than 8.6</td>
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<tr>
<td>Chloroform</td>
<td>&lt;0.06</td>
<td>Taste</td>
<td>Not to be abnormal</td>
</tr>
<tr>
<td>Dichloroacetic acid</td>
<td>&lt;0.04</td>
<td>Odor</td>
<td>Not to be abnormal</td>
</tr>
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<td>Dibromochloromethane</td>
<td>&lt;0.1</td>
<td>Color</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Bromic acid</td>
<td>&lt;0.01</td>
<td>Turbidity</td>
<td>&lt;2 turbidity units</td>
</tr>
</tbody>
</table>
Table 5.1.3: Items set for water quality control goal

(As of April 2011) Caution: The contents may occasionally be changed.

<table>
<thead>
<tr>
<th>Item</th>
<th>Goal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony and its compounds</td>
<td>&lt;0.015mg/L</td>
</tr>
<tr>
<td>Uranium and its compounds</td>
<td>&lt;0.002mg/L (provisional)</td>
</tr>
<tr>
<td>Nickel and its compounds</td>
<td>&lt;0.01mg/L (provisional)</td>
</tr>
<tr>
<td>Nitrite nitrogen</td>
<td>&lt;0.05mg/L (provisional)</td>
</tr>
<tr>
<td>1,2-dichloroethane</td>
<td>&lt;0.004mg/L</td>
</tr>
<tr>
<td>Toluene</td>
<td>&lt;0.4mg/L</td>
</tr>
<tr>
<td>di-2-ethylhexyl phthalate</td>
<td>&lt;0.1mg/L</td>
</tr>
<tr>
<td>Chlorous acid</td>
<td>&lt;0.6mg/L</td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>&lt;0.6mg/L</td>
</tr>
<tr>
<td>Dichloroacetonitrile</td>
<td>&lt;0.01mg/L (provisional)</td>
</tr>
<tr>
<td>Chloral hydrate</td>
<td>&lt;0.02mg/L (provisional)</td>
</tr>
<tr>
<td>Agricultural chemicals (as total Agricultural chemicals)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Residual chlorine</td>
<td>&lt;1mg/L</td>
</tr>
<tr>
<td>Calcium, magnesium etc. (hardness)</td>
<td>&gt;10mg/L and &lt;100mg/L</td>
</tr>
<tr>
<td>Manganese and its compounds</td>
<td>&lt;0.01mg/L</td>
</tr>
<tr>
<td>Free carbon dioxide</td>
<td>&lt;20mg/L</td>
</tr>
<tr>
<td>1,1,1-trichloroethane</td>
<td>&lt;0.3mg/L</td>
</tr>
<tr>
<td>Methyl-t-butyl ether</td>
<td>&lt;0.02mg/L</td>
</tr>
<tr>
<td>Organic matters (potassium permanganate consumption)</td>
<td>&lt;3mg/L</td>
</tr>
<tr>
<td>Odor (TON)</td>
<td>&lt;3</td>
</tr>
<tr>
<td>Total solids</td>
<td>&gt;30mg/L and &lt;200mg/L</td>
</tr>
<tr>
<td>Turbidity</td>
<td>&lt;1 turbidity unit</td>
</tr>
<tr>
<td>pH</td>
<td>Around 7.5</td>
</tr>
<tr>
<td>Corrosiveness (Langelier’s index)</td>
<td>&gt;around -1, preferably near 0</td>
</tr>
<tr>
<td>Heterotrophic bacteria</td>
<td>&lt;2000p/mL</td>
</tr>
<tr>
<td>1,1-dichloroethylene</td>
<td>&lt;0.1mg/L</td>
</tr>
<tr>
<td>Aluminum and its compounds</td>
<td>&lt;0.1mg/L</td>
</tr>
</tbody>
</table>

2) Selection of water treatment methods

(1) Conditions for selecting water treatment methods

When selecting water treatment methods, the following aspects shall comprehensively be studied with a focus mainly on the condition of raw water quality, the drinking water quality standards and the management goals for treated water quality

(1) Raw water quality

(2) Drinking water quality standards and the management goals for treated water quality
(3) Size of the water treatment facilities

(4) Technical level of operation and control of water treatment facilities and their maintenance

The general steps needed for the selection of water treatment methods are illustrated in Figure 5.1.3 in that starting from (1) apply disinfection by chlorine; (2) determine the management goals for treated water quality, based on the results of water quality analysis; (3) classify the substances in water into dissolved and suspended matters, and determine their management goals for treated water quality control; (4) find suitable combination of methods effective for the treatment of the objective substances. It is needed to make the water treatment flow balanced and efficient with unit treatment processes each sharing rational proportion of the load.

A proper water treatment flow shall be designed synthetically taking into consideration not only treatment efficiency but also the size of the facilities, the technical level of operation and maintenance, construction cost, operating expenses, the space needed for the installation of facilities etc.

What is more, the size of the lot will be one of conditions for the selection of water treatment methods. Since a treatment method such as the slow sand filtration, which requires a large space, cannot be employed where the available space is small, a method, with which efficient use of land is possible, shall be selected.

Figure 5.1.3: General procedures of selecting water treatment method
(2) Selection of the water treatment flow

When selecting a water treatment flow, an appropriate treatment method for suspended solids shall first be chosen; then, if needed, a proper treatment method for dissolved substances must generally be combined with the former. However, in many cases with good water quality of such as groundwater or the like, only disinfection may suffice to achieve the drinking water quality standards. The representative water treatment methods for dissolved matters are the slow sand filtration, rapid sand filtration and membrane filtration. The following are their characteristics:

a. Disinfection only method

Since this method is the simplest one, so, as no wastewater disposal facility is required, operation and maintenance are easy.

b. Slow sand filtration method

This method is usually employed in case the raw water quality is good and stable with low turbidity (less than 10 units). Water is slowly filtered through a layer of relatively fine sand at a rate of 4 to 5 m/day; and suspended solids and dissolved matters are trapped or oxidized or decomposed at the surface of the sand layer and the colonies of organisms (schmutzdecke), which proliferate in the sand.

It is simple and easy to operate and maintain the slow sand filters; and good quality of filtered water is stably produced. Due to the slow rate of filtration, however, large space is required; and labor is needed for regularly scraping the sand surface. Sedimentation basins are or are not provided depending on the raw water quality. A facility, with which chemical dosage can be practiced, is added, if required.

c. Rapid sand filtration method

This method is employed in case the slow sand filtration method cannot deal with the nature of the raw water quality, or the site space is limited.

The method consists of coagulation of such suspended matters as clay and silt, bacteria, algae etc. by a coagulant to form flocs; they are settled and separated in sedimentation basins; and then water is filtered through rapid sand filters. Although this method can deal with highly turbid water, the efficiency of removing dissolved substances is rather low.

Grain of sand for rapid sand filters is coarser than that for slow sand filters. Since the filtration rate is as high as 30 times that of the slow sand filtration, a large quantity of water can be treated on a small space of land.

It is important for the rapid sand filtration to be provided with good coagulation and sedimentation for its good performance, so such a high level of technology as the optimization of coagulant dosage etc. is needed. In addition, a wastewater disposal facility is required. However, since automation and remote control of its operation are possible, it is easy to reduce required manpower.

Furthermore, the employment of the direct filtration method is also possible if raw water turbidity is stable with turbidity of around 10 units or less for a long period of time, which is performed in that water is filtered directly in succession to the coagulation process mainly consisting of rapid mix only without the sedimentation process. (See 5.6.19 Direct filtration)

d. Membrane filtration

This method is employed mainly for the purpose to remove suspended and colloidal matters. Microfiltration membrane (MF) and ultrafiltration membrane (UF) are used, which enable to physically remove suspended matters etc. in accordance with the size of the pores on the membranes.

With this method, chemical cleaning of membranes is needed every several months; and replacement of the membranes is required every several years. However, since there are only a few moving parts;
and its automation and remote control are possible, their operation and maintenance are in general easy.

e. Advanced water treatment

Since dissolved substances cannot fully be removed by the above treatment methods, an advanced method of water treatment shall be employed depending on the type and concentration of the dissolved matters.

The advanced water treatment stands for the removal of the following substances, which cannot be removed by the conventional water treatment method for the removal of suspended solids: odor causing matters (musty odor of 2-methylbornaol, geosmin etc.), precursors of disinfection byproducts such as trihalomethanes, color, ammonium nitrogen, anionic surface active agents, trichloroethylene etc. The advanced water treatment methods include activated carbon adsorption, ozonation, biological treatment and aeration (aeration is a generic name of aeration, volatilization, and stripping).

f. Other water treatment methods

For the removal of such inorganic substances as iron, manganese, erosive free carbon dioxide, fluorides, ammonium nitrogen, nitrate nitrogen, hardness etc., the application of particular removal methods suitable for the respective substances may be needed in some cases. (See 5.17 Removal of iron and manganese, and 5.21 Other water treatment methods) In case there is a trouble caused by algae etc., it is needed to apply a method of removing organisms suitable for respective species of the organisms. (See 5.18 Facilities for removal of organisms)

Treatment method effective to each of these water quality items are summarized in Table 5.1.4.
### Table 5.1.4: Objective substances of treatment and their treatment methods

<table>
<thead>
<tr>
<th>Item of treatment</th>
<th>Objective substance for treatment</th>
<th>Treatment method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insoluble components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>Slow sand filtration, rapid sand filtration (direct filtration), membrane filtration</td>
<td></td>
</tr>
<tr>
<td>Algae</td>
<td>Membrane filtration, micro-strainer, floatation (There are two-step coagulation and mixed media filtration as rapid sand filtration method)</td>
<td></td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Cryptosporidium</td>
<td>Slow sand filtration, rapid sand filtration, membrane filtration, ozonation, UV ray treatment</td>
</tr>
<tr>
<td></td>
<td>Standard plate count bacteria, coliforms</td>
<td>Chlorination, ozonation</td>
</tr>
<tr>
<td><strong>Odor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Musty odor</td>
<td>GAC adsorption, ozonation, biological treatment</td>
<td></td>
</tr>
<tr>
<td>Other odor</td>
<td>GAC adsorption, ozonation, aeration, chlorination</td>
<td></td>
</tr>
<tr>
<td><strong>Disinfection byproducts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precursor of trihalomethanes</td>
<td>Slow sand filtration, rapid sand filtration, membrane filtration, ozonation, GAC adsorption</td>
<td></td>
</tr>
<tr>
<td>Trihalomethanes</td>
<td>GAC adsorption, oxidation, change in the method of disinfection</td>
<td></td>
</tr>
<tr>
<td><strong>Anionic surfactants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GAC adsorption, ozonation, biological treatment</td>
<td></td>
</tr>
<tr>
<td><strong>Trichloroethylene etc. etc.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aeration, GAC adsorption</td>
<td></td>
</tr>
<tr>
<td><strong>Soluble components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inorganic matters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>Pre-chlorination, intermediate chlorination, aeration, utilization of iron bacteria, biological treatment</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>Oxidation (Pre-chlorination, intermediate chlorination, ozonation, potassium permanganate treatment) and filtration, biological treatment</td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrogen</td>
<td>Chlorination (break-point chlorination), biological treatment</td>
<td></td>
</tr>
<tr>
<td>Nitrate nitrogen</td>
<td>Ion exchange, membrane filtration (RO), electrodialysis, biological treatment (denitrification)</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>Chemical sedimentation, activated alumina, bone black, electrolysis</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>Crystallization softening, coagulation precipitation</td>
<td></td>
</tr>
<tr>
<td>Erosive free carbon dioxide</td>
<td>Aeration, alkali agent treatment</td>
<td></td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humic matters</td>
<td>Coagulation and sedimentation, GAC adsorption, ozonation</td>
<td></td>
</tr>
<tr>
<td><strong>Langelier’s index</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkali agent treatment, treatment by carbon dioxide gas and slaked lime combined</td>
<td></td>
</tr>
</tbody>
</table>

---

*1 In case the raw water turbidity is mostly lower than 10 turbidity units and stable. However, to cope with a rise in raw water turbidity, sedimentation or primary filtration can be added before slow sand filtration.

*2 In case the raw water turbidity is mostly lower than 10 turbidity units, the method to apply filtration only with coagulation (direct filtration) can be employed.

*3 In this table, the membrane filtration denotes microfiltration (MF) and ultrafiltration (UF). Pre-treatment is generally needed for treatment of raw water with medium to high turbidity.

*4 This method can be used in case the raw water is other than surface water, and the water quality is not affected by UV ray treatment.

*5 Effective treatment method will depend on the odor causing substances.

*6 Caution: There are such substances as amines with which chlorine generates stronger odor.

*7 Trihalomethane precursors, which can be removed by filtration, are limited to suspended matters.

*8 In this table, change in the disinfection method means the change from pre-chlorination to intermediate chlorination, from pre- or intermediate chlorination to such other means of oxidation as ozonation, or from free residual chlorine to combined residual chlorine.

*9 Treatment efficiency changes depending on the concentration of agricultural chemicals. (See 13. Water quality control, Guidelines for operation and maintenance of water supply facilities)

*10 Although improvement in Langelier’s index is not a direct object of treatment, it is included here and described.
(3) Aspects to be considered when designing the flow of water treatment

Aspects to be considered when designing the flow of water treatment are the following:

(1) Since there are respective properties such as applicable strength of substances as the objectives for removal, when designing the flow of water treatment, efficiency and condition for the respective treatment methods, a rational water treatment flow shall be drawn, which enables efficient water treatment taking into account a proper layout and load distribution in regard to more than two water treatment methods selected based on raw water quality, management goals of treated water quality control etc.

(2) In some cases, depending on the treatment method, treatment efficiency may largely change by the influence of high turbidity; dosage of chemicals such as disinfectants, oxidizers, and pH control agents; and other causes.

(5) It is not recommended to design a water treatment flow with anticipation for the maximum treatment efficiency of the selected treatment method. Rather, proper margin shall be provided for each treatment process and certain flexibility in the water treatment flow as a whole taking into consideration the range of fluctuation in raw water quality etc.

(6) To avoid the spread of a trouble of a treatment process to the entire treatment flow, some bypass conduits or bypass pipe shall be provided in the flow if possible. In such a case, it is cautioned that a change may be needed in the dose of chemicals and so on when the bypass line is used.

5.1.5 Wastewater treatment

The following aspects shall be considered for planning wastewater treatment facilities:

1. The wastewater treatment facility shall possess sufficient functions and capacity to treat and dispose of wastewater generated from the water treatment facilities.

2. A proper method of wastewater treatment shall be selected considering the relationship with the water treatment facilities, raw water quality, quality and volume of wastewater, consistency of sludge, the method of the use or disposal of dewatered cake, operation and maintenance, site area, construction cost, the environment of the surroundings etc.

5.1.6 Layout plan of water treatment facilities

The following aspects shall be considered for laying out water treatment facilities:

1. Water treatment facilities shall be so laid out that each water treatment process can fully work; that harmonization and efficiency of all the facilities are made; and that operation and maintenance, expansion, improvement, or replacement of facilities are easily made.

2. The facilities shall be divided into more than two blocks according to their size as much as possible.

3. The water levels at each facility shall be determined based on the required water head losses by means of hydraulic analyses and experiments.

4. The garbage collection site, cesspits etc. must be so built and located as not to cause pollution.
[Interpretation]

On the item 1.;

1) Principle of layout

The layout of water treatment facilities is primarily restricted by the size and shape of the site. In addition, it shall be determined taking into account the directions for inflow of raw water and transmission of finished water; location of power reception; the sequence of water treatment processes; the space required for plant management; functional arrangement of buildings; locations of the neighboring roads; facilities situated outside the plant such as incinerators which can be sources of pollution; plant facilities which may be sources of such hazards as noise, vibration and odor to the surrounding area. It is also important to incorporate the site space and interconnecting water mains and conduits for future expansion in the layout plan, and draw the layout with due consideration to future improvement and replacement.

The water treatment processes shall in principle be arranged according to the sequence of water treatment. Such an arrangement is also advantageous from the hydraulic and operation and maintenance points of view since it brings about the ease of water flow, and chemical feeding, shorter lengths of communication cables, the ease of switching of incumbent facilities and so forth.

As an example, the aspects to be considered when arranging water treatment facilities of the rapid sand filtration method are shown below for respective facilities:

(1) Receiving well

The receiving well is to be placed so that water is smoothly conducted to the ensuing water treatment processes of coagulation, sedimentation, and rapid sand filtration.

(2) Coagulation chamber (rapid mixer), flocculation basin, and sedimentation basin

Since the coagulation chamber (rapid mixer), flocculation basin, and sedimentation basin are successive water treatment processes, it is not desirable to place them separately. If placed separately, due to the long distance between them, the growth of good flocs is hindered as the travel time is prolonged, or flocs may settle in the conduit. The direction and location of the sedimentation basins shall be determined taking into account the method of desludging and the direction of desludging pipes.

(3) Rapid sand filtration

Since many pipes such as inflow pipe, filtered water pipe, and backwash mains for the rapid sand filters are to be laid in a bunch, a piping gallery shall be provided so that the interconnection of pipes and installation of valves, filtration rate controllers etc. are easily undertaken, and they are accommodated together.

(4) Disinfection

Disinfection is performed by dosing chlorine at a mixing chamber where filtered water is collected. Since it is a rule to contain the filtered water in a closed space to avoid contamination, the mixing chamber is usually placed in part of the filtered water conduit between the filters and the clear water well.

(5) Clear water well

The clear water well is often built underground since it is to be placed at a hydraulically low point. In some cases, the space above the clear water well is utilized for filters as a layered structure.
(6) Layout from the receiving well through the clear water well

Since the facilities are usually connected from the receiving well through the clear water well by a gravity flow, water head losses shall be minimized by making lengths of connecting pipes and conduits between facilities as small as possible. In case facilities cannot be placed closely to each other due to the restriction of the site, mixing chamber (rapid mixer), flocculation basins, and sedimentation basins shall be placed in one block insofar as practicable; and the filters and clear water well may be placed in separate locations parted from each other in some distance.

(7) Transmission pumping station

From the hydraulic point of view it is preferable for the transmission pumping station to be located near the clear water well. If it is placed in conformity with the direction of water transmission, the required lengths of in-plant piping will be small, which will also be convenient to avoid complexity of in-plant piping. Furthermore, since the pumping station is a source of noise, it shall be so located to avert the influence to the surroundings of the plant.

(8) Chemical storage tanks and feeding house

It is convenient to place the chemical storage tanks and the feeding house near the dosing points as well as in the vicinity of the control room of the main operation building. If the dosing points are located near the control room (and also the laboratory), shorter piping is needed for chemical feeding and water sampling, which is also advantageous for facility control and operation and maintenance.

(9) omitted

(10) Wastewater treatment facilities

Wastewater treatment facilities are in some cases situated in a location quite far from the water treatment facilities or in a separate site since they shall not necessarily be directly connected to the water treatment facilities. However, the wastewater transmission main may be clogged if the distance is large. If available, it is beneficial for the wastewater treatment facilities to be situated in a lower point of the plant premises since the wastewater can be led to the point by gravity. The stockyard, the route for carrying out the cake, drying beds etc. shall be located considering the influence of odor from the dewatered cake.

(11) Power substation

Since it is desirable to situate the power substation as close to the facility with high power demand as possible, it shall not necessarily be placed near the water treatment facilities. As such, it is advantageous to make the lengths of power cables between the substation and facilities for loading as short as possible. It is beneficial to place the substation in the proximity of pumping facilities, of which power consumption is large, so as to minimize the voltage drop. Since power is fed to machinery and instrumental facilities by underground cables, it is preferable to lay them so that they do not intersect with pipelines and ducts, taking operation and maintenance into consideration.

(12) Examples of layout

Examples of layout are illustrated in Figure 5.1.4, Figure 5.1.6, and Figure 5.1.8.

2) In the case a single-layered layout cannot be made

(1) Rational layout of facilities

Water treatment facilities shall rationally be laid out in line with the water treatment processes. The layout shall also be made so that the site space is used efficiently. Especially, in case there is an intermediate pumping station in the plant, careful examination is needed when drawing the layout since the entire layout may largely change depending on the location of the pumping station.
Furthermore, Layout shall be so drawn that no cross-connection be made between the flows of finished water and untreated water.

**On the item 2.;**

In case there is only one block of water treatment facilities, the operation of the entire plant must be stopped at the occasions of cleaning, repair, replacement of parts, or unexpected accidents. What is more, considering the need to shut down the operation for improvement or replacement of the facilities for a prolonged period of time, it is needed to provide the plant with more than two blocks of independent facilities as long as possible. Interconnecting mains, gates and valves shall be provided to connect the blocks, which can mutually be used by either one of the two blocks. However, In case there are more than two water treatment plants, the division of facilities into blocks may be made with consideration to the mutual support by the plants.

**On the item 3.;**

Although the head losses of a water treatment plant are designed by means of hydraulic calculations, certain margin is usually provided taking into consideration the increase in the roughness of water conduits due to the aging of facilities.

In the case of the slow sand filtration method, the total head losses from the receiving well through filters is around 1 to 2 m. (See Figure 5.1.5) In the case of the rapid sand filtration method, when it does not employ the advanced treatment facilities, the head losses through the entire facilities, namely, the conventional flocculation, sedimentation, and filtration, is 3.0 to 5.5 m or so. (See Figure 5.1.7)

The major portion of the head losses is the one through the filters. Others consist of the friction losses through the flocculation basins, water mains, conduits and channels, and the ones through the valves and gates for flow control.

Then, the important aspect is how to uniformly divide the flow into each basin or filter. The uniform distribution of flow into filters is maintained by flow controllers set on each filter (Although self-balancing type filters are not equipped with flow controllers, they have a built-in mechanism to maintain the close uniformity of water inlet to the filters.) However, it is difficult to control the flow to each unit of sedimentation basins. The reasons are hydraulic disproportion due to the different lengths of the inlet channels, the reduction in the sectional area of the channels due to the settlement of flocs, inconvenient operation of the inlet gates etc. Given this, inlet pipelines, conduits etc. shall be so designed that the loss of head become equal; and, in some cases, installation of motorized gates is needed so as to finely control the inlet flows.
Figure 5.1.4: Plan of a water treatment plant with a combination of the rapid sand filtration method and the slow sand filtration method (Nabeya water treatment plant of Nagoya City Waterworks and Sewerage Bureau 290,000 m³/day) (Unit in mm)

Figure 5.1.5: Hydraulic profile of a water treatment plant with a combination of the rapid sand filtration method and the slow sand filtration method (Nabeyaeno water treatment plant of Nagoya City Waterworks and Sewerage Bureau 290,000 m³/day) (Unit in mm)
Figure 5.1.6: Plan of water treatment plant of the rapid sand filtration method (Nishiya water treatment plant of Yokohama City Waterworks Bureau 356,000 m³/day) (Unit in mm)
Figure 5.1.7: Hydraulic profile of a water treatment plant with rapid sand filters
(Nishiya water treatment plant of Yokohama Waterworks Bureau, 360,000 m³/day)

- Clear water well
- Receiving well
- Coagulation and sedimentation basins
- Rapid sand filters
- Chlorine mixing basins
- Clear water well
- Transmission pump house

(dry weather level = +59.40)
Figure 5.1.8: Plan of water treatment plant of membrane filtration method (Hinata Wada water treatment plant of Bureau of Waterworks Tokyo Metropolitan Government 3.300 m$^3$/day)

Figure 5.1.9: Hydraulic profile of membrane treatment plant (Hinata Wada water treatment plant of Bureau of Waterworks Tokyo Metropolitan Government 3.300 m$^3$/day)
5.1.7 Water quality control

As for water quality control in water treatment facilities, the following items of aspects shall be taken into account:

1. To control the quality of finished water so as to meet the prerequisite goals of water quality control, a necessary water testing laboratory shall be provided at the water treatment plant. In case water testing is undertaken as required by the Water Supply Law, the laboratory shall be set in a favorable testing environment and be capable of equipping necessary analytical instruments.

2. The effects of chemicals dosed in the water treatment processes and the apparatus and materials contacting, which will come in contact with water, to water quality shall be studied.

[Interpretation]

On the item 1.;

1) Provision of water laboratory

To carry out reliable water quality control, physicochemical, microbiological (bacteriological) and biological examinations of water sampled in every step from the water source through the tap shall be undertaken so that proper operations of the water supply facilities are practiced based on the results of the examinations.

In the water treatment plant, water quality is controlled at every step of water treatment to produce treated water with the quality, which shall meet the management goals of water quality control set with an aim at better water quality.

It is important to make sure that the effect of water treatment is confirmed by examining water quality of raw water, settled water, filtered water, and finished water; and furthermore that the results of the examination is reflected to the dosage of water treatment chemicals, the method of treatment for their improvement and so on. For that purpose, a laboratory needs to be set up based on the condition of raw water quality, the water treatment method, and the size of the facilities.

3) Installation of automatic water quality monitoring apparatus

It is desirable to install automatic water quality monitoring apparatuses in appropriate locations in water treatment facilities, which enable to continuously test the water quality and record its results by automation. The water quality items as the monitoring objectives include water temperature, turbidity, color, pH, alkalinity, odor, ammonium nitrogen, chlorine demand etc. In case there is a risk of contamination of raw water by hazardous matters by unexpected accidents, it is desirable to prepare for early detection of abnormal raw water quality by means of providing an inspection aquarium with fish etc. in it.

5.1.8 Improvement and replacement of facilities

The following aspects shall be considered for improvement and replacement of facilities:

1. An evaluation and assessment of facilities must beforehand be performed for improvement and replacement of facilities. The new or replaced facility shall be able to perform with its full capacity without affecting the capacity, reliability, and consistency of the operation of the existing ones.

2. To supplement the reduction in the capacity of the system in operation during the improvement or replacement work, relief measures shall be provided so that the effect of the work to the existing facilities shall be minimized.
[Interpretation]

On the item 1.;

The work of improvement or replacement will consist either of the following:

(1) To improve or replace the existing water treatment facilities with keeping the exactly same treatment method as the existing one.

(2) To change the existing treatment method with a new water treatment method

(3) To add facilities for a different treatment method from the existing method

Besides them, the work may consist of a replacement or new introduction of wastewater treatment facilities, or electrical, mechanical and instrumental facilities etc.

The following considerations are needed to attain the harmonization between the existing facilities and the new ones:

1) The new facilities shall not interrupt the treatment efficiency of the existing facilities.

It is cautioned that, in some cases, the objective substances for treatment, the efficiency of treatment, the condition for treatment, and the required chemical dosage of the existing facilities may change. (See Table 5.1.6)

2) In case hydraulic changes are brought about, appropriate steps shall be taken.

The problem related to the hydraulic properties is that uniform water distribution to each unit of facilities becomes impossible as a result of improvement and replacement. Even making the shape, inclination etc. of the conduits as identical as the existing ones, and maintaining the conformity of flows theoretically, actual flows may become uneven. To deal with such a problem, flow control gates or valves shall be equipped; and connecting mains and conduits shall be made as short as possible.

In almost all cases, the head losses in the new facilities may be different from those in the existing facilities. The head losses will become larger if the new facilities are inserted between the existing facilities. In such a case, installation of pumps may be required if the applicable head is insufficient.

3) The method of operation and control of the new facilities must be harmonized with the one for the existing facilities.

The introduction of the new method of water treatment will largely alter the ways of operation and maintenance of the facilities. Depending on the size of the facilities, work volume and property of day-to-day operation, repair etc. will be affected by the number and complexity of the apparatus and machinery. Given this, at the time of improvement and replacement, redundant systems or standby units shall be provided so as to ease operation and maintenance work and to enhance the safety of the operation.

In the case of the introduction of a new method of water treatment, if no proper space exists in the water treatment plant, it is needed to provide space by means of the renovation of the existing facilities and the like including the installation of sloping plates in the sedimentation basins, the alteration of slow sand filters to rapid sand filters, or the employment of multi-media rapid sand filters.

In case the introduction of new machinery and apparatus are needed as a result of improvement or employment of a new water treatment method, the capacity of the power substation shall be examined since the power demand may increase.
Table 5.1.6: Examples of concerns and measures for existing facilities to be affected by introduction of advanced water treatment (In case ozonation-granular activated carbon treatment (as biologically activated carbon [BAC]) is added to a water treatment plant where pre-chlorination and return of backwash wastewater are performed.)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Point of concern</th>
<th>Countermeasure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving well</td>
<td>Increase in return water due to backwash waste from BAC filters and more frequent backwash of rapid sand filters</td>
<td>To raise the crown level of the wall of the receiving well; and make return water volume uniform over time</td>
</tr>
<tr>
<td>Rapid mix and flocculation</td>
<td>Decrease in dosage of pH control chemical due to abolition of pre-chlorination</td>
<td>To confirm the formation of flocs</td>
</tr>
<tr>
<td>Sedimentation basins</td>
<td>Algae growth and surfacing (floatation) of sludge due to the abolition of pre-chlorination</td>
<td>To prevent algae growth and sludge surfacing by Minimum pre-chlorination; and putting cover on the sedimentation basins</td>
</tr>
<tr>
<td>Rapid sand filters</td>
<td>Increase in frequency of backwash because of organism growth in sand layer caused by abolition of pre-chlorination; and change in chemical dosage due to the effect of biological treatment</td>
<td>To strengthen the backwash facility for higher rate of backwash etc.; and regularly check the condition of filter media (sand)</td>
</tr>
<tr>
<td>Wastewater treatment</td>
<td>Increase in backwash waste due to more frequent washing of rapid sand filters and granular activated carbon (GAC/BAC) adsorption units; and changes in dewatering nature of sludge as a result of the abolition of pre-chlorination, and consistency of dewatered cake</td>
<td>To increase the capacity of backwash return facilities (return pumps, wastewater tank etc.); uniform return of backwash water (by lowering the peak return flow to the receiving well to ease the chemical dosage control according to the change in water quality as a result of the return); and to strengthen the function of dewatering facility</td>
</tr>
<tr>
<td>Chemical feeding facilities</td>
<td>Decrease in pH control agent due to the abolition of pre-chlorination; change in the location of chlorine dosing (post-chlorination only); and reduced dosage of chlorine because of the introduction of ozonation and GAC(BAC) adsorption</td>
<td>To change or adjust the capacity, the number of units and lines of chemical feeding; and installation of a chlorine contact basin (In case break point treatment is performed to remove ammonium nitrogen)</td>
</tr>
<tr>
<td>Electrical and mechanical facilities</td>
<td>Increase in power consumption due to the ozonation and GAC (BAC) treatment</td>
<td>To augment the capacity of power substation and pumping units</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>Additional instruments for ozonation and GAC(BAC) treatment; and change in instrumentation for chlorine feeding</td>
<td>To change the system of instrumentation</td>
</tr>
<tr>
<td>Others</td>
<td>Increase in head loss due to the addition of ozonation, GAC(BAC) and interconnection mains; and adjustment of the space between the existing and new facilities</td>
<td>To provide a space for new facilities by means of installation of pumps; the improvement of the facilities, or change into multi-level structure etc. as appropriate by case.</td>
</tr>
</tbody>
</table>

On the item 2.;

1) Planned implementation of construction work

Although the work of improvement and replacement will be carried out while the existing facilities are in operation except for the case sufficient margin capacity is available, the reduction in the output cannot be avoided. Thus, the construction work shall be implemented in a low demand season; with support from another water treatment plant, if available; or with sedimentation basins and filters to be overloaded to such an extent as no adverse effects are caused in water quality. However, since the magnitude of the augmentation, which can be made by such a measure as the above, is usually small, careful planning is needed beforehand.
5.1.9 Safety measures

The water treatment facilities must be provided with certain safety measures against natural disasters, accidents of machinery and apparatus, human casualties, and so forth.

[Interpretation]

1. Measures against natural disasters

Safety measures needed to be prepared against natural disasters so that accidents and failures are to be prevented, and that the effect of an accident shall be minimized even if it happens.

1) Safety at the time of an earthquake

Since the acquisition of a land for water treatment facilities is usually very difficult in an urbanized area, they may be obliged to be constructed in an area of unsound soil. In addition, in case enough site space cannot be obtained, the water treatment facilities tend to progressively become complex as, for example, they are accommodated in a multi-story building. As such, there is a great danger for damage of part of facilities to affect the operation of the entire plant. Depending on each element of the water treatment facilities and the condition of the soil, the following measures in general should be considered:

(1) Location where the soil is weak and has tendency to be liquefied: Improvement of the soil and foundation work suitable for the property of the structure and the condition of the soil.

(2) Basin-like structures: An earthquake-resistant design of the basin-like structures including its foundation, measures against dynamic water pressure caused by the rocking of the earthquake (e.g., a confined vessel), and the arrangement of expansion joints.

(3) Buildings: An earthquake-resistant design of the building including its foundation.

(4) Piping in the premises of the water treatment plant: Redundant lines of important water mains, pipe laying to form a loop, interconnecting mains, pipe laying in a common utility conduit, and installation of flexible pipe joints.

(5) Chemical feeding equipment etc.: An earthquake-resistant design of tanks for storage of chemicals, oil etc., and preventive measures against leaks.

(6) Mechanical, electrical and instrumental apparatus: Redundant facilities, and backup units.

(7) Others: Installation of emergency isolation facility, provision for power failure etc.

The points among water treatment facilities, which are easily damaged, are joints separating structures, the interface between pipelines and structures etc. The joints may open as the difference in movements of each block becomes large at the time of an earthquake; or one side of the joints may sink more than the other side leaving a vertical gap. To cope with this, a joint, which can deal with the expected ground displacements, shall be employed so as to design a foundation with sufficient bearing force.

At the interface of structure and pipeline, expansion-flexible joints shall be installed to make the structure capable of resisting the ground displacements, with which concentration of the stress can be avoided.

2) Drainage at the time of heavy rain

To prevent the inundation, the ground level of the water treatment plant needs to be raised one step higher than the surrounding area; a wall is to be built around the plant for the same purpose; and a drainage facility shall be constructed. Provision of a rainwater retaining pond or a drainage pumping station may be useful to mitigate the effect of floods.
3) Preparation for strong winds

4) Measures against salt damage

5) Measures against snow damage

2. Measures against accidents and fire

1) Measures against water quality accidents

As a measure against accidents related to water quality, it is important to avoid the intake of the polluted water into the water treatment plant. An example of such a measure is the installation of a gate, or valve before the receiving well to isolate such water. Oil fences shall be placed before the raw water intake mouth or in the channel against the pollution by oil.

The earlier the detection of a water quality accident, the easier the counter measures to it can be taken. It is desirable to install a water quality monitoring apparatus; and provide a communication network between water treatment plants and managers of rivers situated in the same river basin.

2) Measures against power failure

To be prepared for power failure caused by natural disasters, accidents, fire, and maintenance work of power lines or electrical equipment, the minimum required capacity of power supply need to be secured. Such measures will include the installation of uninterruptible power supply, emergency generator, and power reception from dual sources. The extent (facility capacity) of preparedness for such respective measures and the selection of a measure shall be judged based on the examination of both the expected damage caused by the power failure and the cost of measures against it synthetically taking into account the geographical condition, the importance of the plant, the size of the facilities etc.

3) Measures against failures and accidents of apparatus

Among apparatuses used in water treatment facilities, those, which are prone to failures and accidents, are apparatuses for chemical feeding, water quality measurement instruments, electronic control equipment, parts of submerged machinery subject to attrition etc. To prevent such failures and accidents, it is essential to select apparatus with high reliability. Besides, ones with a simple mechanism and easy maintenance shall be chosen.

4) Measures against leakage of chemicals

Among chemicals used in a water treatment plant, those, for which special attention is needed, are chlorine agents, acidic and alkaline agents, and oxidizing chemicals. Devices for detecting their leakage, neutralizing facilities, safety tools etc. shall be provided for preparation for leakage accidents.

5) Measures against fire

Combustibles stored in a water treatment plant are fuels for generators etc., flammable chemicals, kerosene and gas for heaters, transformer oil, coating materials of cables, building materials etc. Fire-fighting equipment (fire detectors, sprinklers, carbon dioxide fire distinguishers, fire hydrants etc.) shall be installed in accordance with the structure, size etc. of the plant.

6) Workplace safety

In addition to the safety measures for sanitation, sound safety measures shall be practiced for day-to-day operation and maintenance work in a water treatment plant. To this end, abiding by the Labor Safety and Sanitation Law etc., hand-rails and fences to prevent fall from an elevated place, lighting, ventilators, drainage facilities and so on shall be provided.
7) Measures against such illegal acts as terrorism

In Article 17 of “Enforcement order of the Water Supply Law”, it is prescribed that such measures as fences and locks in the water intake station, water treatment plant etc. shall be provided so that easy invasion by human beings and animals into the water supply facilities is prevented.

3. Safety measures as a system

Water treatment facilities consist of unit treatment processes from the receiving well through the clear water well. They must work properly in a unity as well-balanced facilities.

To achieve this, the system must be designed with certain margin in capacity so that remarkable drop in its output can be avoided even if there is a change in the flow through the system or raw water quality. Since certain magnitude of failure of apparatus is unavoidable, and they are not necessarily operated properly, they shall be so designed that a failure of part of apparatus or an error in their operation shall not affect the performance of the entire system. Therefore, the division of water treatment facilities into blocks, duplication of important apparatus, provision of spare units, safety devices against erroneous handling of equipment etc. shall be considered.
5.2 Receiving well

5.2.1 General

1. Function of the receiving well

The receiving well is designed so that the level of raw water arriving from the raw water transmission main is stabilized; that the quantity of raw water is measured; and that the inlet flow is regulated so as for the ensuing water treatment processes of chemical application, sedimentation, filtration etc. to properly and easily be carried out. However, in cases the pressure of raw water is to be utilized, and the conduit receiving raw water is big enough to absorb the water level fluctuation, the receiving well may not be provided.

Furthermore, the receiving well in some cases also perform functions of dosing of chemicals, mixing of waters arriving from different sources, distribution of raw water to respective blocks of treatment trains, receiving return water mainly consisting of backwash waste from filters etc.

2. Facilities equipped at the receiving well

The receiving well shall possess water surface and volume required to stabilize the fluctuation of water level and be equipped with a flow rectification facility, a flow meter, a level meter, a flow control valve, and water quality sensing probes if required.

5.2.2 Structure and volume

The structure of the receiving well shall be formed as follows:

1. The receiving well shall in principle be divided into more than two sections, and equipped with a drainage facility in each of them.

2. An overflow pipe etc. shall be provided in the well keeping lest the water level in the well not to surpasses the high water level.

3. A rubbish remover etc. shall be equipped if required.

4. The retention time of the receiving well shall be more than 1.5 minutes; and its water depth shall be 3.0 m to 5.0 m

[Interpretation]

On the item 1.;

In principle, the receiving well shall be divided into more than two sections with consideration to the need for cleaning, repair of ancillary facilities and so on; and a drainage facility shall be provided. A bypass pipe shall be installed in case the well cannot be divided.

On the item 2.;

The receiving well shall be equipped with an overflow pipe or overflow weir to cope with a sudden change in the water level. The diameter of the overflow pipe and the width of the overflow weir shall be so designed that they can drain 1/5 or more of the inlet flow; and they are placed at the high water level.

On the item 3.;

If trash is brought down through the receiving well, it will adversely affect the ensuing water treatment processes. Such trash removal devices as screens etc. shall be installed in case the raw water contains a lot of it.
On the item 4;

The size of the receiving well shall not be excessively large within the range so that the design maximum treatment flow can safely be handled while considering aspects related to operation and maintenance such as resistance to earthquake, cost effectiveness etc.

5.2.3 Flow meters

A flow meter shall be installed to precisely measure the raw water flow.

[Interpretation]

By measuring the volume of raw water (intake volume), the application of coagulants and chlorine agents and the control of water treatment operations such as sedimentation and filtration can properly be carried out. What is more, the flow meter is to be installed so that the efficiency of water treatment will be confirmed by measuring the water treatment flow.
5.3 Feeding facility of coagulants

5.3.1 General

1. Purpose of coagulation

Even if the raw water turbidity is low, colloidal suspended matters cannot sufficiently be removed simply by rapid sand filtration. In case there is a possibility of contamination of the raw water by cryptosporidiums etc., chemical coagulation is imperative for their reliable removal as the pre-treatment prior to rapid sand filtration.

In the slow sand filtration method as well, if raw water turbidity is higher than 30 turbidity units, as filter bed clogging becomes heavy, it is needed to reduce the turbidity by coagulation and sedimentation.

2. Coagulation chemicals

The chemicals for coagulation are roughly classified into coagulants, pH control agents (acid and alkaline agents), and coagulation aids. The coagulants are used for forming flocs from suspended matters in raw water to make easy the suspended matter to settle, and ready to be trapped in filters. Acid agents are used when pH of the raw water is too high; and alkali agents are applied when alkalinity in it is insufficient. The coagulation aids are used together with a coagulant to strengthen the efficiency of flocculation, sedimentation and filtration. As to chemicals for coagulation, their allowable standard dosages into water are set by “the Ministerial ordinance for setting the technical standards for water supply facilities” depending on respective chemicals etc. for their dosing in treated water or in the water treatment train. The conditions for the selection of coagulation chemicals are full confirmation of their treatment effects, safety, ease of purchase, cost, absence of adverse effects after their dosage, ease of handling etc.

3. Dosage of chemicals

The dosage of chemicals is usually determined by jar tests. There is a method, by which the dosage is automatically computed by automated jar tests, or continuous analyses of turbidity, alkalinity etc. to be obtained by water quality sensing instruments.

4. Storage and feeding equipment

The volume of the storage tank of coagulation chemicals shall properly be determined taking the expected consumption into consideration. The chemical feeding units must have the enough capacity and the number of units, which can precisely measure and control the quantity of the chemical for the range from the minimum to the maximum dosages. The method of feeding shall be chosen from those, which are suitable to such condition for its use as the property of the chemical to be used, its feeding quantity, and the form of feeding, namely, dry or wet feeding, or constant quantity feeding or flow-proportional feeding. As most chemicals have a nature of strong acidity or alkalinity, the feeding equipment shall be built with anti-corrosive materials and structure.

5.3.2 Coagulants

1. The coagulant must be suitable for the raw water quantity, and quality such as turbidity (maximum and hourly changes), the method of filtration and , the type of wastewater treatment and so forth;, and safe in terms of hygiene.

2. The application of coagulant shall be decided with reference to the following:

1) The dosage shall be decided based on testing suitable for the raw water.
2) Careful dosage and handling must be practiced according to its concentration.
3) The quantity of application shall be determined based on the dosage and the quantity of water treatment.

3. The dosing point is in general set at the rapid mixer.

[Interpretation]

On the item 1;
The coagulants used are aluminum sulfate for water supply, polyaluminum chloride (PACl) for water supply, ferric chloride, and polysilicic iron for water supply.

The function of aluminum salts as coagulant is generally explained as follows: The aluminum salts, if diluted in water, are easily hydrolyzed to make aluminum hydroxo complex. On the other hand, as the surface of colloidal matters in aqueous solution are negatively charged, they are kept separated from each other due to the repulsive force they have, and so do not easily settle. If such charges are neutralized by the positive charges of the aluminum hydroxo complex, the repulsive force is reduced. Such minute colloidal particles, if coming close to each other, will gather together, grow larger, trap inorganic and organic matters, and enlarge as flocs.

Aluminum sulfate, also called alum, is produced in forms of solid and solution, and used in solution in most cases because of the ease of handling (JWWA K 155: 2005 [Aluminum sulfate for water supply]). In some cases of the solution, if its concentration is too high, its crystals separate from the solution, and may clog the feeding lines. Therefore, it is needed for the aluminum sulfate to be used in proper strength (8.0 to 8.2% as aluminum oxide) (See 7.3.2 Coagulants of “Operation and maintenance criteria for water supply”). In case water temperature becomes lower than about 10 degrees C., the formation of flocs gets markedly inefficient, and so a coagulant aid will be needed at the time of high turbidity and low water temperature.

Polyaluminum chloride, also called PACl (JWWA K 154: 2005 Polyaluminum chloride), has the coagulation properties in that it has better coagulation efficiency than alum; the suitable pH range is wide; the drop in alkalinity after its application is small; and so on. In many water utilities PACl is used because of the easy water treatment operation with its use and its easy handling. PACl is the most stable when its concentration is from 10.0 to 11.0% as aluminum oxide, and suitable for storage and feeding. However, if diluted, it may become turbid due to suspended matters caused by hydrolysis, and so feeding through piping may be affected.

Iron family coagulants, while they have a wide applicable pH range, and the flocs formed by it settle easier than those by alum, as their acidity and corrosiveness are strong, the materials in contact with their solution are limited. Since treated water is colored because of its residue if they are dosed in an excessive amount, the careful dosage control is important. Their unstable nature while stored or diluted is a demerit.

Polysilicic iron, called PSI (See JWWA K 159: 2010 [Polysilicic iron for water supply]), is only used at water treatment plants, where residual chlorine exists as a result of pre-chlorination or intermediate chlorination for the removal of manganese by sand filtration. Polysilicic iron can form larger and heavier flocs than PACl, and they have superior property of settling; and, as the ratio of the contents of silica to iron becomes high, more solid and larger flocs are formed. However, the quantity of flocs becomes large.

On the item 2.1;
The dosage of the coagulant is set based on the type of the chemical, and the temperature and quality (turbidity, color, pH, alkalinity, organic matters etc.) of the raw water. However, it will not always thus simply be determined since it will also depend on such factors as whether pre-chlorination or powdered carbon treatment is performed, different performance of sedimentation, distribution of
turbidity removal among sedimentation and filtration, the application of direct filtration etc. The
dosage of chemicals as the base for the determination of the capacity of the facility is set by the
following procedure:

Selection of the coagulant and the needs for acid and alkali agents and coagulant aid shall be examined
after jar tests with water samples for a certain period of time with varying water quality such as high
turbidity caused by floods, low turbidity and samples of artificial water containing the highest
turbidity (bottom sediment or clay to be used) expected from the environment of the river. Then the
type of chemical and the range of its dosage (maximum, minimum and average) shall be decided.

[Reference 5.] Jar test

Jar test is a test, using a device with rotating blades, called a jar tester, to decide the proper pH,
chemical dosage etc. for coagulation and sedimentation. Usually a constant dosage-varying pH method
is often used, in which same amount of coagulant is applied to all the beakers and pH is varied, and
then varying amounts of coagulant is applied with the same condition for pH control as the previous
one. In another way, pH is held constant while the dosage of coagulant varies. As the procedure for
testing, following the dosing of coagulant, rapid mixing is applied for 4 to 5 minutes at 150 rpm; and
then slow stirring for 15 to 30 minutes at 40 rpm; being left statically for 15 to 30 minutes; supernatant
is sampled; and residual turbidity, color, pH etc. are measured and evaluated (See Criteria for
operation and maintenance of water supply 2006 [Reference 7.2]).

On the item 2.2):

In many cases, liquid aluminum sulfate is used as the original solution. However, if the dosage is small,
certain dilution is made. Polyaluminum chloride is always used as the original solution since dilution
tends to accelerate its hydrolysis.

On the item 3.:

As the aluminum salts are quickly hydrolyzed in water, the mixing basin generally possesses a rapid
mixer so that the coagulant is instantly mixed after dosing with water to coagulate the turbidity
colloid.

5.3.3 Acid and alkali agents

| 1. The types of acid and alkali agents must be suitable for strengthening the effects of coagulation in
 | accordance with the quality of raw water, and, in addition, not cause adverse effects on hygiene. |
| 2. The following conditions shall be considered for the application of acid and alkali agents: |
| 1) The dosage of acid and alkali agents shall be determined based on the result of experiments with |
 | reference to the alkalinity, pH and the dosage of the coagulant or conversion formula to be made |
 | beforehand. |
| 2) The concentration of the acid and alkali agents shall be set taking into account its dosage and |
 | handling when they are used after dilution. |
| 3) The quantity of feeding shall be computed from the water flow for treatment and dosage of the |
 | agents. |
| 3. The dosing point shall be upstream of the point of coagulant dosing, and where good mixing can |
 | be made. |

[Interpretation]
On the item 1.;

In case the pH of the raw water is constantly or temporarily too high or too low, the pH shall be adjusted by an acid or alkali agent so that it falls in the most optimum range for coagulation.

Following the law of coagulation, aluminum salts react with alkali components (as shown as alkalinity) in water and consume the alkalinity as shown in Table 5.3.2. Hence, the alkalinity that becomes short shall be supplemented according to the alkalinity in the raw water and the dosage of the coagulant. In the case of raw water from an impounding reservoir or lake, the pH may rise as a result of photosynthesis (carbon dioxide assimilation), which lessen the carbon dioxide in water. If water with high pH is introduced in the water treatment plant, coagulation efficiency by a coagulant (aluminum salts) may drop. To cope with this, an acid agent shall be applied.

1) Acid agent

Sulfuric acid, hydrochloric acid and carbon dioxide (gas) are used.

2) Alkali agent

Calcium hydroxide, sodium carbonate and sodium hydroxide are used.

<table>
<thead>
<tr>
<th>Name of agent</th>
<th>Alkalinity</th>
<th>Increase</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium hydroxide (as slaked lime; CaO) (72%)</td>
<td>1.29</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Sodium carbonate (as soda ash; Na₂CO₃) (99%)</td>
<td>0.93</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Liquid sodium hydroxide (45%)</td>
<td>0.56</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>(Liquid caustic soda NaOH) (20%)</td>
<td>0.25</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Aluminum sulfate (as Al₂O₃)</td>
<td>-</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquid (7%)</td>
<td>-</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>Liquid (8%)</td>
<td>-</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>Solid (15%)</td>
<td>-</td>
<td>0.45</td>
</tr>
<tr>
<td>Polyaluminum chloride (as Al₂O₃ [10%] basicity [50%])</td>
<td>-</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Chlorine (Cl₂)</td>
<td>-</td>
<td>1.41</td>
<td></td>
</tr>
</tbody>
</table>

On the item 2.1);

(1) Setting of dosage

The dosage of acid and alkali agents is set in relation to the dosage of the coagulant. Its setting range (maximum, minimum and average) shall also be determined with reference to pH, alkalinity, the dosage of coagulant in the raw water, and the alkalinity of supernatant after a jar test (It is preferable for the alkalinity to remain more than 20 mg/L with due consideration to corrosiveness of water.) if acid or alkali agent is required.

5.3.4 Coagulation aids

The coagulant aid shall be suitable to enhance the efficiency of flocculation, sedimentation and filtration, and not adversely affect the hygiene related to water treatment. Coagulation effects, cost effectiveness and the ease of handling shall be taken into consideration when selecting the coagulation aid.
With a coagulant only or it together with an acid or alkali agent, good flocs may not be formed; the settled water turbidity may rise; and the filtered water turbidity may become high at the time of high raw water turbidity or low water temperature in winter.

In such a case, it is needed to make flocs large and heavy so that their separation from water by sedimentation is easier, and that they are solid enough to be trapped in rapid sand filters. Also in the cases higher efficiency of sedimentation and filtration is also required for the removal of iron, manganese, organisms, and when powdered activated carbon is dosed, a coagulant aid is used. However, in many cases that polyaluminum chloride is used as coagulant, coagulant aids are not applied.

Activated silicic acid is one of coagulant aids. Activated silicic acid is produced by means of activation of sodium silicate by acid (sulfuric acid, hydrochloric acid, carbon dioxide etc.) in the form of high-polymer colloid of salt of silicic acid. Although its function as coagulant aid is very high, it has such demerits as its gelling in the feeding system, rapid built-up of filter head loss, and difficult handling of its activation process.

5.3.5 Facilities for inspection of reception of chemicals

A proper measuring device shall be equipped for the reception inspection of coagulation chemicals.

5.3.6 Storage facilities

1. The storage facilities of respective chemicals shall be so designed that their structural safety is assured, and that the material used are suitable for the types and natures of the chemicals.

2. The capacity of the storage facilities for respective chemicals shall be computed by multiplying the design water treatment flow by the dosage of the respective chemicals; and their standard capacity shall be as follows:

1) More than 30 days of consumption for coagulation chemicals

2) More than 30 days of consumption for alkali agents if they are applied continuously; and more than 10 days in other cases.

3) More than 10 days of consumption for acid agents and coagulation aids

On the item 1.;

As preparation for leakage in a case of emergency, a protective embankment, neutralization equipment, waste liquid storage tank etc. need to be provided. The impounding volume of the protective embankment shall be determined taking into account the risk management and safety measures against the coagulation chemicals to be stored (Example: Volume of the storage tank = the impounding volume of the protective embankment).
5.3.7 Feeding facilities

The chemical feeding facilities shall be designed as follows:

1. The feeding method shall be selected in accordance with the types and natures of chemicals to be used and so that to secure a proper feeding will be performed.

2. The capacity of the feeding facilities shall be so designed as to be able to reliably feed for a dosage range from the minimum to the maximum,

3. Standby units or facilities of the feeding equipment shall be provided. However, such provision will not be needed in case water service can be maintained even if chemical feeding would stop.

[Interpretation]

On the item 1.;

The feeding methods shall be determined after comparing their capacity, control methods, cost-effectiveness etc.

The feeding methods of chemicals are categorized as follows:

(1) Dry or wet feeding depending on the property of the chemical at the time of scaling on its delivery

(2) In the case of dry feeding, the gravimetric scaling or volumetric scaling depending whether the scaling is made by weight or volume

(3) In the case of wet feeding, the measuring pump method or flow meter method depending on the method of flow measurement

(4) Pumping, injector, or gravity flow feeding depending on the way of transportation

(5) Manual or automatic feeding depending on the manner of feeding

(6) Remote or on-site feeding depending on the method of control

The selection among these methods is made considering not only the type of the chemical, treatment efficiency, economic merits, the ease of purchase, safety of operation, the absence of adverse effects after dosing, but also the ease of handling.

In general, as the powdered material tends to be poor in fluidity, a careful design is needed to provide devices to prevent bridging or flashing at the outlet of the storage vessel or the feeding device in the case of dry feeding. (See Figure 5.3.7)

![Flow diagram of an automatic calcium hydroxide dissolution and dosing facility](image-url)
As for wet feeding, there are a constant volume feeding device with an orifice by means of gravity flow, a constant flow pump of centrifugal or volumetric control type, and an injector type device.

Chemical feeding methods generally used are shown in Table 5.3.6.

<table>
<thead>
<tr>
<th>Type of chemical</th>
<th>Method of feeding</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coagulant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid aluminum sulfate</td>
<td>Wet</td>
<td>Used as 6-8% solution as aluminum oxide</td>
</tr>
<tr>
<td>Polyaluminum chloride</td>
<td>Wet</td>
<td>Used as 10-11% solution as aluminum oxide</td>
</tr>
<tr>
<td>Solid aluminum sulfate</td>
<td>Wet</td>
<td>Solid aluminum sulfate used in solution</td>
</tr>
<tr>
<td>Acid agent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>Wet</td>
<td>Sulfuric acid (H₂SO₄) at 98% is diluted 80 to 100 times</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>Wet</td>
<td>Hydrochloric acid (HCl) at 35% is diluted 4 to 5 times</td>
</tr>
<tr>
<td>Carbon dioxide (gas)</td>
<td>Wet</td>
<td>Liquefied gas used through an evaporator</td>
</tr>
<tr>
<td>Alkali agent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid sodium hydroxide (caustic soda)</td>
<td>Wet</td>
<td>Sodium hydroxide (NaOH) in 20-25% solution used</td>
</tr>
<tr>
<td>Calcium hydroxide (slaked lime)</td>
<td>Dry or wet</td>
<td>In a case slaked lime used in powder; in other case, used in lime milk or saturated solution after certain dilution</td>
</tr>
<tr>
<td>Sodium carbonate (soda ash)</td>
<td>Dry or wet</td>
<td>In a case, soda ash used in minute powder in dry form, or in other case, used in certain strength of solution</td>
</tr>
</tbody>
</table>

**On the item 2.;**

Although the feeding quantity of chemicals is set by the multiplying water treatment flow by their dosage (rate), as the dosage depends on raw water quality, it shall be determined with reference to experiments for a certain period of time and the record of actual applications of the chemicals. Since, depending on the types of chemicals, the ratios of the maximum to the minimum dosages fall in such a broad range as several to tens of times, a combination of more than two feeding devices shall be equipped so that feeding for the range of dosage from the minimum to the maximum can be attained at any time.

**On the item 3.;**

Standby units of feeding devices shall be provided so as to cope with the occasions of their failure or inspection and repair. Although it is desirable to provide a standby unit for each block of the facilities, the standby unit can commonly be utilized by more than two blocks depending on the need in case there are a number of blocks.
5.4 Flocculation basins

5.4.1 General

Colloidal particles of diameters of smaller than 10^{-3} mm in raw water hardly settle or cannot be trapped in the filters, while particles of the grain size of 10^{-2} mm or larger can be removed by simple sedimentation. (See Figure 5.4.1) Thus, to efficiently remove suspended matters in sedimentation basins and rapid sand filters, flocculation basins, as a preceding facility, shall be provided so that a coagulant is applied to effectively make the colloidal matters coagulated into flocs.

The function of coagulation is divided into two: in the frontal step, water is rapidly mixed right after chemical dosing so as to coagulate the colloidal matters into minute flocs; and in the rear step, water is gently stirred so as to make the minute flocs to grow further.

The frontal part is called rapid mix and the rear one flocculation. According to these functions, the flocculation basin is composed of the rapid mixer and the flocculation compartments.

Since the processes of coagulant application, rapid mix and flocculation are important for ensuing treatment processes of sedimentation and filtration, and the processes is the determining factor of the achievement of water treatment, the condition of flocculation must accurately be inspected all the time.

In case the raw water with low turbidity is treated, the direct filtration method, in which water is fed to the filters right after the chemical dosing and rapid mix without flocculation and sedimentation, can be employed. (See 5.6.19 Direct filtration [Micro-floc method])

As to the instrumentation for the flocculation basin, see “8.11 Devices and apparatus for instrumentation”, and “8.12.5 Flocculation basins and sedimentation basins”.

<table>
<thead>
<tr>
<th>particle diameter</th>
<th>1 μm</th>
<th>10^{-1} mm</th>
<th>10^{-2} mm</th>
<th>10^{-3} mm</th>
<th>10^{-4} mm</th>
<th>10^{-5} mm</th>
<th>10^{-6} mm</th>
<th>10^{-7} mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>name of particle</td>
<td>clay</td>
<td>silt</td>
<td>sand</td>
<td>gravel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ions/molecules)</td>
<td>suspended</td>
<td>colloidal</td>
<td>solution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(suspended matters/organic matters/heavy metals/hydroxides etc.)</td>
<td>(suspended matters/oxides of heavy metals/bacteria/algae/oils etc.)</td>
<td>Solution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.4.1: Substances present in water and their treatment methods

5.4.2 Mixing basin

The mixing basin shall be designed as follows:

1. A proper mixing device shall be installed so that the coagulant, right after dosing a coagulant, is rapidly mixed uniformly into the raw water.

2. Depending on the intensity of rapid mix, it is the standard practice to set the mixing time for 1 to 5 minutes of the design water treatment flow.

3. The structure of the mixing basin shall be designed so that accompanying rotational movements of water or short-circuiting are not caused.
[Interpretation]

On the item 1.;

As the rate of reaction of the coagulant to be hydrolyzed, be polymerized and react with suspended colloids in water is high, the added coagulant needs to be mixed with water rapidly and uniformly so as to adequately perform the coagulation process. Mixing is carried out by random or eddy currents made by the mechanical energy given from outside, or utilizing the energy of water flow itself.

The types of mixing are as follows:

1) Methods to give mechanical energy from outside

The device generally used is the rapid mixer (See Figure 5.4.2): A wheel with several or tens of blades set around a vertical shaft rotates at a peripheral speed of more than 1.5 m/s, and mixes the water. As a merit, there will be little head loss through the mixer with this type of mechanical mixing method.

![Figure 5.4.2: A rapid mixer (turbine type) (Misono Water Treatment Plant of Bureau of Waterworks Tokyo Metropolitan Government 300,000 m³/day)](image)

2) Methods to utilize the energy of water flow itself

There is a method to apply a random current produced by rapidly turning the direction of water flow by means of placing a baffle plate or plates in the stream. In this method, a velocity of 1.5 m/s or so is needed. In addition, the partial flume or water jump is also used.

Although the method by means of water flow itself has no mechanical components and so its operation and maintenance are easy, the head loss through the device is large. As lacking flexibility, it can be used in a limited range of flow.

On the item 2.;

It is the standard practice to set the mixing time, depending on the intensity of mixing, for 1 to 5 minutes of the design treatment flow. In case sufficient mixing can be made, the mixing time of 1 minute is considered enough.

On the item 3.;

For the mechanical mixing method, a square basin is preferable to a round one so that accompanying currents to the rotation of the mixer blades are prevented. For a round basin, the mixing device is to be set eccentrically, or baffle plates are to be fitted vertically on the wall. The inlet and outlet mouths shall be designed so that short-circuiting currents do not occur in the basin. (See Figure 5.4.4)
5.4.3 Flocculation basin

The flocculation basin shall be designed as follows:

1. The location of the flocculation basins shall be between the mixing basin and the sedimentation basins, and they must be built as an integral structure.

2. The standard shape is rectangular fitted with a mechanical or zigzag flow type stirring device.

3. The standard retention time is 20 to 40 minutes of the design water treatment flow.

4. The intensity of stirring shall be set as follows:
   
   1) The standard peripheral velocity of the stirring device shall be set at 15 to 80 cm/s; and the standard average velocity of the flow with the zigzag type flow method shall be 15 to 30 cm/s.
   
   2) The stirring intensity shall gradually be reduced toward the end of the basin.
   
   3) The intensity of stirring can be adjusted.

5. The structure shall be so designed that no short-circuiting or dead water is caused; and that a facility, by which sludge and scum can be removed, shall be provided.

[Interpretation]

On the item 1;

Flocculation shall be undertaken right after rapid mixing; its location shall be between the mixing basin (rapid mixer) and the sedimentation basins so that the formed flocs shall not be destroyed by excessively turbulent flows, or that they shall not settle; and hence it is desirable that the flocculation basins are built as an integrated structure together with the rapid mixer and the sedimentation basins.

On the item 3;

The retention time of 20 to 40 minutes is considered appropriate. If too short, the effect of flocculation will markedly be reduced even if giving sufficient energy to the water: namely, the shearing force of water will be too strong and so flocs are destroyed.

On the item 4.1);

The flocs, as growing large, become vulnerable to the shearing force of water flow and tend to be broken. Therefore, to form large flocs it is desirable to employ the tapered flocculation, by which strong stirring is given in the initial stage of flocculation when the grain size of flocs is small; and gradually diminishing intensity of stirring is given as the flocs grow. That is, in the case of stirring by the gravity energy of the flow of water itself, the width of the channel shall be widened (or deepened)
to slow down the flow; or in the case of mechanical stirring, the rate of rotation is lowered to lessen the peripheral speed of the stirring device.

[Reference 5.2] Computation of G-Value in the mixing basin

Note 1) Kenji Fujita and Sachio Naito (coauthors), Exercise in Water Supply Engineering (Revised), Gakkensha

1. Rapid mixer type

1) Computation based on the rotating velocity of mixing blades and resistance coefficient

\[ G = \sqrt{\frac{\rho C \sum a_i v_i}{2 \mu V}} \]

Where,
- \( \rho \): density of water (e.g., 1.0 \times 10^3 \text{ kg/m}^3, 20^\circ \text{C})
- \( C \): resistance coefficient of mixing blades
- \( a_i \): area right angle to the direction of movement of mixing blade i (m^2)
- \( v_i \): average velocity of the mixing blade i (m/s)
- \( \mu \): coefficient of viscosity of water (e.g., 1.0 \times 10^{-3} \text{ kg/m} \cdot \text{s}, 20^\circ \text{C})
- \( V \): volume of the mixing basin (m^3)

Note: In the above formula, it is assumed that no accompanying current occurs.

2) Computation based on the shaft power of the driving unit

\[ G = \sqrt{\frac{P}{\mu}} = \sqrt{\frac{W \eta}{V \mu}} \]

Where,
- \( P \): workload per unit time per unit volume
- \( W \): shaft power of the driving equipment [(kg/m^2)/s^3]
- \( \eta \): efficiency of reduction gears

2. Pump dispersion type

\[ G = \sqrt{\frac{\rho v^2 Q}{2 \mu V}} \]

Where,
- \( v \): initial velocity of water spouting from the nozzle (m/s)
- \( Q \): flow spouting from the nozzle (m^3/s)

[Reference 5.3] Computation of G\( \cdot \)T value in a zigzag flow type flocculation basin

\[ G \cdot T = \sqrt{\frac{\rho g h T}{\mu}} \]

Where,
- \( g \): gravitational acceleration (= 9.8 m/s^2)
h: head loss in the flocculation basin (m)
T: retention time in the flocculation basin (s)

The head loss is computed by the following formula.

(1) Up-and-down roundabout type

1) head loss by turning at the bottom h_b (m)

\[ h_b = \frac{f_b}{2} \cdot \frac{v_b^2}{2g} \]

Where,
- \( v_b \): average velocity at the bottom turning corner (m/s)
- \( f_b \): head loss coefficient at the corner 2 to 4.5, average 3.5

2) Friction head loss in a culvert h_c

\[ h_c = \frac{l}{C^2 R} \cdot \frac{v_c^2}{2g} \cdot \frac{1}{n^2} = \frac{1}{R^{1/3}} \]

Where,
- \( v_c \): average velocity in the culvert (m/s)
- \( l \): converted length of the culvert (m)
- \( C \): Chezy’s coefficient (Total length of upward and downward parts of the culvert)
- \( n \): Manning’s roughness coefficient
- \( R \): hydraulic radius (m)

3) Overflow head loss

Assuming that all the velocity head is lost.

\[ h_o = \frac{v_o^2}{2g} \]

Where,
- \( v_o \): average velocity at the overflowing point (m/s)

When computing actually, in case the space between baffle walls is wide, the head loss shall be obtained as the total of 1), 2) and 3); in case the space between baffle walls is narrow, the head loss for both submerged flow and overflow shall be computed by 1), and 2) shall be added to have a figure close to the actual one.

(2) Horizontal zigzag flow type

Perfectly as same as the case of the up-and-down roundabout type, head loss by 180-degree turning h_b and friction head loss as an open conduit can be added up. However, for calculation of h_c, although in the case of up-and-down roundabout type, computation is made by hydraulic radius R as a culvert, in the case of horizontal zigzag flow type, computation is made by hydraulic radius R as an open channel.

[Example of computation – 1] Computation of G•T value based on the shaft power of the driving unit in the rapid mixer
Assuming the shaft power of the driving unit at 2 kW, efficiency of reduction gears at 90%, volume of the mixing chamber at 60 m³, and retention time at 2 min.

[Solution] Formula to give G value

For

\[ G = \sqrt{\frac{P}{\mu}} \]

Where,

\( P \) = work load per unit time per unit volume (= power to be consumed per unit volume of water)

\[ = \frac{2 \times 0.9 \times 10^3}{60} \text{ [kg \cdot m}^2/\text{s}^3/\text{m}^3\text{]}\]

\( \mu = 1 \text{ (cP)} = 10^{-3} \text{ [kg/(m \cdot s)]} \]

And then,

\[ G = \sqrt{\frac{2 \times 0.9 \times 10^3}{60 \times 10^{-3}}} = 173 \text{ [1/s]} \]

\( G \cdot T = 173 \times 120 = 2.08 \times 10^4 [-] \)

[Example of computation – 2] Computation of head loss to compute \( G \cdot T \) value in the up-and-down roundabout type slow mixing basin \( \text{note 2)} \)

Note 2) Example 6-22, (p.171) Kenji Fujita and Sachio Naito (coauthors), Water Supply Engineering - Revised, Gakkensha

Assuming the total length of the slow mixing basin at 156 m, width at 2 m, the number of turning at 104 (bottom opening turning 52, overflow turning 52), both height of the bottom opening and depth of overflow at 1.5 m (the length of each baffle wall contacting with water at 2 m, and the space between baffle walls at 1.5 m). The design treatment flow is assumed at 50,000 m³/day, and water depth at 3.5 m.

(1) Head loss at the bottom turning corner \( h_b \)

\[ h_b = f_b \cdot \frac{v_b^2}{2g} = 3.5 \times \frac{1}{2 \times 9.8} \times \left[ \frac{50000}{86400 \times 2 \times 1.5} \right]^2 \]

\[ \times 52 = 0.345 \text{ (m)} \]

\( f_b: 3.5 \text{ (Turning head loss coefficient)} \)

(2) Friction head loss of the conduit \( h_c \)
\[ h_c = \frac{1}{C^2 R} v_c^2 = \frac{39 \times 4 + 2 \times 104}{3352 \times 2 \times 1.5 / |2 \times (2 + 1.5)|} \]
\[ \times \left[ \frac{50000}{86400 \times 2 \times 1.5} \right]^2 = 0.009 \text{ (m)} \]
\[ C^2 = \frac{1}{n^2} R^{1/3} = \frac{1}{0.015} \times \left[ \frac{2 \times 1.5 / |2 \times (2 + 1.5)|}{1} \right]^{1/3} = 3352 \]
\[ n: 0.015 \text{ (Manning’s roughness coefficient)} \]

(3) Overflow head loss \( h_0 \)
Assuming that all the velocity head loss is lost,
\[ h_0 = \frac{v_0^2}{2g} = \frac{1}{2 \times 9.8} \times \left[ \frac{50000}{86400 \times 2 \times 1.5} \right]^2 \times 52 \]
\[ = 0.099 \text{ (m)} \]

Therefore, the total head loss (hf) becomes 0.453 (m). G value is obtained substituting the total head loss in the following formula:
\[ G = \sqrt{\frac{P}{\mu}} = \sqrt{\frac{\rho g Q h f}{V \mu}} \]

[Reference 5.4] Example of designing an up-and-down roundabout type flocculation basin

Since the head loss computed in accordance with “Example computation- 1 computation of head loss for calculation of G and G•T values in the up-and-down roundabout type flocculation basin” is sometimes different from that in the actual facility, as an actual example, the G•T value set at the time of design cannot be obtained as a result, or the treatment quantity is affected. The following is an example of a study on the computation method based on the head loss in an actual facility.

(An actual example)

As an example of design of an up-and-down roundabout type flocculation basin, using a head loss coefficient set with reference to actual measurement values, a sample of determining the water depth above the overflow weir and the height of the bottom opening at the turning point of the baffle wall is presented. This flocculation basin has a retention time of 30 min with the treatment flow in the actual operation mode, and the basic treatment flow (80 % of the maximum design flow), hydraulic examinations were carried out in accordance with several modes so that a proper tapered flocculation can be secured. As a result, the spacing of baffle walls, the water depth above the overflow weir and the height of the bottom opening at the turning point of the baffle walls were set as shown in Reference Figure 5.4.1.

Maximum flow \( Q_{\text{max}} = 1,940 \text{ m}^3/\text{hr/basin} \)
Basic flow \( Q_{\text{ave}} = 1,650 \text{ m}^3/\text{hr/basin} \)
Minimum flow \( Q_{\text{min}} = 1,100 \text{ m}^3/\text{hr/basin} \)
1. Computation of head loss

1) Head loss at the overflow weir

An estimation formula suitable for the objective facility was made and used.

\[ h_0 = f_0 \cdot \frac{v_0^2}{2g} \]

Where,

- \( h_0 \): head loss at the overflow weir (m)
- \( f_0 \): head loss coefficient at the overflow weir
- \( v_0 \): average velocity at the overflow weir (m/s)

In an actual facility, it is considered that not all the velocity head is lost at the overflow weir and the momentum continues, and there is an effect of the contracting flow as shown in Reference Figure 5.4.2. Based on such findings, the logical formula was reevaluated, and taking into account the measured value of the facility with the same shape, the head loss coefficient at the overflow weir was set at \( f_0 = 2.5 \).

Reference Figure 5.4.1: Cross sections of an up-and-down roundabout type flocculation basin

Reference Figure 5.4.2: Flow velocity distribution in the basin
2) Head loss at the bottom turning point

An estimation formula suitable for the objective facility was made and used for computation of G value and G•T value.

\[ h_b = f_b \cdot \frac{v_0^2}{2g} \]

Where,

- \( h_b \): head loss at the bottom turning point (m)
- \( f_b \): head loss coefficient at the bottom turning point
- \( v_0 \): average velocity at the bottom turning point (m/s)

It was considered that, theoretically, the head loss coefficient at the bottom turning point changes in accordance with the structural condition \( B_1 \) and \( B_2 \). The relationship between \( B_1/B_2 \) estimated through experiments and actual measurements and the head loss coefficient \( f_b \) (Example) is given in Reference Figure 5.4.3.

Here, as \( B_1/B_2 = 1.2 \text{ m}/2.3\text{ m} = 0.52 \), so \( f_b = 2.2 \)

However, since, actually, there is an effect of the contracting flow and so forth, the head loss coefficient \( f_b \) was set at 2.7 also taking the measured value in actual facility with the same shape into consideration.

3) Friction head loss of the conduit

It was determined that the conventional standard formula is to be used.

\[ h_c = \frac{1}{C^2} \frac{v^2}{2g} \cdot C = \frac{1}{n^2} R^{1/3} \]

Where,

- \( h_c \): friction head loss in the conduit portion (m)
- \( l \): converted (equivalent) length of the conduit (m)
- \( C \): Chezy’s coefficient
- \( n \): Manning’s roughness coefficient \( (n=0.015) \)
- \( R \): hydraulic radius (m)

The velocity, head loss, G value, G•T value at the turning points computed at the maximum flow, basic design water treatment flow, minimum flow are presented in Reference Table 5.4.1. As the maximum velocity decreases along the flow from the front stage to the rear stage, which forms tapered flocculation, it shall be confirmed that the G value and G•T value fall within the standard range of the Guideline.
## Reference Table 5.4.1: Computation results of an up-and-down roundabout type flocculation basin

<table>
<thead>
<tr>
<th></th>
<th>stage 1</th>
<th>stage 2</th>
<th>stage 3</th>
<th>stage 4</th>
<th>stage 5</th>
<th>Total</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>maximum flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>overflow velocity cm/s</td>
<td>40.6</td>
<td>31.9</td>
<td>28.1</td>
<td>24.3</td>
<td>18.5</td>
<td>most downstream section 15～30</td>
<td></td>
</tr>
<tr>
<td>velocity at the bottom cm/s</td>
<td>34.6</td>
<td>30</td>
<td>26.5</td>
<td>23.7</td>
<td>20.4</td>
<td>15～30</td>
<td></td>
</tr>
<tr>
<td>head loss m</td>
<td>0.148</td>
<td>0.104</td>
<td>0.086</td>
<td>0.069</td>
<td>0.044</td>
<td>0.451</td>
<td></td>
</tr>
<tr>
<td>G value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>retention time min.</td>
<td>3.9</td>
<td>4.3</td>
<td>4.8</td>
<td>5.3</td>
<td>6</td>
<td>24.4 20～40 min.</td>
<td></td>
</tr>
<tr>
<td>GT value</td>
<td>40.6</td>
<td>31.9</td>
<td></td>
<td></td>
<td></td>
<td>80,387 23,000～210,000</td>
<td></td>
</tr>
<tr>
<td><strong>minimum flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>overflow velocity cm/s</td>
<td>28.7</td>
<td>20.7</td>
<td>17.1</td>
<td>14.2</td>
<td>10.6</td>
<td>most downstream section 15～30</td>
<td></td>
</tr>
<tr>
<td>velocity at the bottom cm/s</td>
<td>19.6</td>
<td>17</td>
<td>15</td>
<td>13.4</td>
<td>11.6</td>
<td>15～30</td>
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</tr>
<tr>
<td>head loss m</td>
<td>0.062</td>
<td>0.039</td>
<td>0.03</td>
<td>0.023</td>
<td>0.014</td>
<td>0.168 15～30</td>
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<tr>
<td>G value</td>
<td></td>
<td></td>
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<td></td>
<td>25.2</td>
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</tr>
<tr>
<td>retention time min.</td>
<td>6.8</td>
<td>7.7</td>
<td>8.5</td>
<td>9.3</td>
<td>10.7</td>
<td>43.1 20～40 min.</td>
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<tr>
<td>GT value</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>23,000～210,000</td>
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<tr>
<td><strong>basic water treatment flow</strong></td>
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</tr>
<tr>
<td>overflow velocity cm/s</td>
<td>37.4</td>
<td>28.6</td>
<td>24.6</td>
<td>20.9</td>
<td>15.8</td>
<td>most downstream section 15～30</td>
<td></td>
</tr>
<tr>
<td>velocity at the bottom cm/s</td>
<td>29.4</td>
<td>255</td>
<td>22.5</td>
<td>20.1</td>
<td>17.4</td>
<td>15～30</td>
<td></td>
</tr>
<tr>
<td>head loss m</td>
<td>0.12</td>
<td>0.082</td>
<td>0.063</td>
<td>0.051</td>
<td>0.031</td>
<td>0.347</td>
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<tr>
<td>G value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44.5</td>
<td></td>
</tr>
<tr>
<td>retention time min.</td>
<td>4.6</td>
<td>5.1</td>
<td>5.7</td>
<td>6.2</td>
<td>7.1</td>
<td>28.7 20～40 min.</td>
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<tr>
<td>GT value</td>
<td>76,446</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>23,000～210,000</td>
<td></td>
</tr>
</tbody>
</table>
5.5 Chemical sedimentation basin

5.5.1 General

The chemical sedimentation basin is provided to settle and remove flocs, which have grown in the flocculation step, by gravity settling, and reduce the load on the ensuing filters. As compared to the chemical sedimentation basin, for which flocculation is needed, among the horizontal flow type sedimentation basins, the one, by which suspended matters are settled without coagulation and flocculation, is called the plain sedimentation basin. (See 5.7 Slow sand filter) The sedimentation basin shall have functions of sedimentation, buffering and desludging; and their properties shall be examined in accordance with the flow of water treatment as a whole.

1. Sedimentation function

The ability of the sedimentation is the function of how efficiently it settles and removes the incoming turbid matters; and its most basic indicator is the overflow rate when considering the efficiency of removal rate in sedimentation. The overflow rate \( V_0 \) is given as the following, assuming \( Q \) as the incoming flow to the sedimentation basin and \( A \) as the water surface area for sedimentation:

\[
V_0 = \frac{Q}{A}
\]

\( V_0 \) has the dimension of mm/min. The overflow rate is defined as the settling velocity of a particle, which enters from the upper end of an ideal sedimentation basin and settles just at the bottom of the end of the basin as illustrated in Figure 5.1.1.

As illustrated in Figure 5.5.1, the removal rate of the particle with the settling velocity of \( V \), which is smaller than the overflow rate \( V_0 \), will be \( V/V_0 \). As shown in Figure 5.5.1, in the case \( V \) is larger than \( V_0 \), the removal rate will be 100%.

![Figure 5.5.1: Horizontal flow sedimentation basin (Ideal sedimentation basin)](image)
Figure 5.5.2: Effects of the double-story sedimentation basin

Therefore, to improve the removal rate, the following three methods may be practiced:

1. To make the sedimentation area A of the basin larger;
2. To increase the settling velocity V of flocs;
3. To decrease the flow Q;

[1] To make the sedimentation area A larger, an intermediate floor may be inserted between the water surface and the bottom floor as illustrated in Figure 5.5.2. The removal rate will be doubled by the intermediate floor. Likewise, it is easily understood that, if two floors are inserted, the removal rate will be tripled. The sedimentation basin based on this concept is the multi-story sedimentation basin. It can attain a large capacity as to the land area occupied by the basin. On the other hand, its structure becomes complex and its operation will be complicated. Example of double-story sedimentation basin is illustrated in Figure 5.5.3.

Figure 5.5.3: Double-story sedimentation basin (Toyono Water Treatment Plant of Osaka City Waterworks Bureau 450,000 m³/day) (Unit: mm)

In this manner, the more floors in the sedimentation basin, the greater the removal rate. If this concept is pursued to the extremity, the system to be obtained is the sloping-plate sedimentation basin and the tube-settler (hereunder called sloping-plate (tube) settler). They have a number of plates or tubes, which are set with a slope so that the sludge settling on the plates or tubes is easily collected on the bottom of the basin. Examples of sedimentation basins fitted with sloping-plate (tube) settlers are illustrated in Figure 5.5.7.
Figure 5.5.7: Chemical sedimentation basin (Kitayama Water Treatment Plant of Fujinomiya City Waterworks Department 16,500 m³/day) (Unit: mm)

2. Buffering property of the sedimentation basin

The quantity and quality of raw water entering the sedimentation basin considerably fluctuate. The sedimentation basin possesses the ability to absorb such fluctuation, and so level off the load on the filters. Such a buffering function is one of important functions of the sedimentation basin.

If the retention time of the sedimentation basin is reduced as a result of a measure to increase its efficiency, its buffering function is lowered. To remedy this shortcoming, the settling property of flocs, the tendency of sludge resurface etc. shall be monitored, and proper chemical dosage shall be performed. In case there is a danger of raw water contamination by cryptosporidiums, it is needed to carry out adequate sedimentation operation with due consideration to its retention time and flow velocity through the basin; and, if higher sedimentation efficiency is required, the installation of sloping-plates and the like shall be considered. In the case of an upward flow type settling tank, careful and reliable settling operation shall be carried out while especially avoiding the effect of density flows.
3. Desludging function

A desludging facility suitable for the structure of the chemical sedimentation basin shall be equipped. It is needed for the mechanism of the desludging facility to have few expected failures, and be able to fully discharge the deposited sludge. It shall be designed also with consideration to its relationship with the ensuing sludge treatment facilities.

The chemical sedimentation basins are classified as shown in Table 5.5.1.

<table>
<thead>
<tr>
<th>Classification of sedimentation basins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal flow sedimentation basin</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sloping-plate type etc</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Suspended solid contact type</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Note) In a case, a settling device such as sloping-plate is fitted in the suspended solid contact type clarifier.

5.5.2 Composition and structure of the horizontal flow type sedimentation basin

The composition and structure of the horizontal flow type sedimentation basin (chemical sedimentation basin) shall be designed as follows:

1. The number of basins shall in principle be more than two.
2. Uniform distribution of inlet flow to each basin shall be considered.
3. The structure of the basin shall be so designed that each unit can be operated independently.
4. The shape of the basin shall be rectangular, and its length shall be 3 to 8 times of its width.
5. The effective depth shall be around 3 to 4 m with more than 30 cm of space for piling of sludge.
6. The standard margin between the high water level and the crown of the basin (freeboard) shall be 30 cm.
7. The basin bottom floor shall be inclined toward the drain hole for the convenience of desludging.
8. A cover on the basin shall be provided if needed.

[Interpretation]

On the item 1.;

It is desirable to build more than two units of sedimentation basins for the convenience for cleaning, inspection, repair etc.

However, for raw water with which water can be led from the rapid mixer to the filters skipping the sedimentation basin for a short period of time, only one sedimentation basin provided with a bypass line to connect the rapid mixer with the filters may be constructed as an exceptional case.
On the item 2.;
When planning the layout of the sedimentation basins, the inlet conduits, gates or valves etc. shall be so designed that the flow is uniformly distributed to the respective basins as much as possible. In addition, certain space for repair work etc. shall be provided.

On the item 3.;
The facilities for inlet, outlet, drain etc. shall be built so that each one of the basins can be used independently and that the work of cleaning, repair and inspection of a basin shall not affect the function of other basins in operation.

On the item 4.;
It is recommended to design the plane figure of the horizontal flow sedimentation basin so shaped as a rectangle to effectively utilize the basin volume as much as possible with a flow from one end to the other while preventing an unbalanced flow. The round or square radial-flow type sedimentation basin with inlet from the center of the basin shall not be employed since it has been confirmed that the flow in the basin tends to be unstable, as the flow direction is non-constant and the flow gets easily affected by such external disturbance as wind etc.

If the width of the rectangular basin is too large in relation to its length, its removal efficiency would be reduced due to uneven flow in the basin which will cause dead water, biased or short-circuit flow in large part of the basin. Therefore, it is important to design a basin in an oblong shape to make the flow stable in a straight streamline. From experiments and experiences, it is said to be a good design to make the length as 3 to 8 times as long as the width. In case an intermediate flow-uniforming wall is introduced, the ratio of the length to the width is usually set at 3 to 5 or so. In case the basin is longitudinally divided for its entire length, this ratio shall apply to each divided section.

For the sloping-plate (tube) type sedimentation basin, as the ratification of flow is made through the sloping-plate device itself, the length of the basin can be less than three times the width.

The width of the basin is often set at 15 m or less with consideration to the convenience for the installation of sludge scrapers.

On the item 5.;
1) Effective depth
In a horizontal flow sedimentation basin, flocs collide each other, become coagulated, grow further, gain higher settling velocity and settle faster. This phenomenon is called coagulation-induced settling, which cannot simply be explained by the concept of overflow rate settling for a single one particle. In other words, the removal rate is also affected by the water depth of the basin, namely, the deeper the water, the higher the removal rate.

However, with a large water depth the construction cost will increase, and there must a limit to the depth also from a stable basin flow point of view. It is empirically set at 3 to 4 m or so. It is not preferable to make the depth too small since the influence of wind, atmospheric temperature etc. become large.

2) Depth of sludge pile
A depth of 30 cm or more shall be provided as the depth of sludge pile in addition to the effective depth of the basin. The depth of sludge pile shall be estimated based on the raw water quality, the frequency of desludging etc. The quantity (volume) of sludge pile is not easily estimated since there are many factors to be considered such as the raw water quality, the type and dosage of coagulant, the consistency of compacted sludge etc. It is desirable to study the experience of other water treatment plants where the water from the same river system is treated with a similar water treatment process.
On the item 6.;

The margin in the freeboard (clearance from the high water level to the crown of the sedimentation basin) is to be set empirically with reference to an analysis of fluctuation in water level based on the open water surface area in the facilities in and around the sedimentation basin, the capacity of the overflow facility, the rise in water level due to wind etc. However, the computed change in water level at the time of an earthquake may exceed 30 cm in some cases. If a dangerous incidence is expected by such fluctuation, special preventive measures shall be provided.

On the item 7.;

The pile of sludge in the sedimentation basin is in general scraped by a mechanical means. It is desirable for the basin floor to have a gradient of 1/200 to 1/300 toward the drain hole since there may be some cases when the sludge is scraped manually.

5.5.3 Design indicators for the horizontal flow sedimentation basin

<table>
<thead>
<tr>
<th>The horizontal flow sedimentation basin shall be designed based on the following:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The standard overflow rate shall be set based on the following:</td>
</tr>
<tr>
<td>1) 15 to 30 mm/min for the single-floored sedimentation basin</td>
</tr>
<tr>
<td>2) 15 to 25 mm/min for the multi-story sedimentation basin</td>
</tr>
<tr>
<td>2. The average velocity of flow through the basin shall be less than 0.4 m/min.</td>
</tr>
</tbody>
</table>

[Interpretation]

On the item 1.;

The overflow rate required for the sedimentation basin will widely vary depending on the raw water quality, effect of coagulation, magnitude of uniformity of flow in the basin, water temperature etc. For the multi-story sedimentation basin, its efficiency may not be proportional to the number of the stories since there may be turbulence in flow due to the deflected flow, or there may be some space where no floors are provided for the convenience for cleaning. Considering these factors, an overflow rate of 15 to 30 mm/min for the single-floored sedimentation basin, and 15 to 25 mm/min for the multi-story sedimentation basin is set as the standard indicator.

5.5.4 Sloping-plate (tube) type sedimentation basin

<table>
<thead>
<tr>
<th>The sloping-plate (tube) type sedimentation basin shall be designed as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The type and form of sloping-plate (tube) settler shall be determined taking the type of the sedimentation basin into account.</td>
</tr>
<tr>
<td>2. An effective measure shall be provided to make the flow to the sloping-plate (tube) settler uniform and prevent short-circuiting.</td>
</tr>
<tr>
<td>3. The standard design factors for the horizontal flow sloping-plate unit shall be the following:</td>
</tr>
<tr>
<td>1) The overflow rate shall be 4 to 9 mm/min.</td>
</tr>
<tr>
<td>2) The angle of slope of the plates shall be 60 degrees.</td>
</tr>
</tbody>
</table>
3) The average velocity in the basin shall be less than 0.6 m/min.

4) The clearance between the lower end of the plates and the basin bottom shall be more than 1.5 m.

5) The space from the inlet wall to the head of the plates, and that from the end of the plates to the outlet wall shall respectively be more than 1.5 m.

4. The standard design factors for the upward flow type sloping-plate settler shall be the following:

1) The overflow rate shall be 7 to 14 mm/min.

2) The number of the layer of the plates shall be one.

3) The angle of slope of the plates shall be 60 degrees.

4) The upward velocity in the basin shall be less than 80 mm/min.

5) The following aspects shall be taken into account so that as much upward flow can pass through the settling device:

   (1) The total area to be occupied by the settling device shall be more than 90 % of the area of the basin with the upward flow. However, in case there are structural restrictions or the like, the area may be more than 80 %. Even in this case, short-circuiting flows shall be prevented by fitting baffle walls etc.

   (2) The space between the basin wall and the settling device shall be less than 100 mm.

6) The following aspects shall be taken into account when setting the upward flow settling device in a rectangular horizontal flow type basin:

   (1) The clearance between the bottom of the settling device and the basin bottom shall be more than 1.5 m.

   (2) The space from the inlet wall and the head of the settling device shall be more than 1.5 m.

   (3) The average velocity of flow at the bottom entrance of the settling device shall be less than 0.7 m/min.

5. The settling device such as the sloping-plate settler shall be provided with a proper facility to prevent damage to be caused by an earthquake etc.

6. In case such a settling device as the sloping-plate settler is introduced in an existing sedimentation basin aiming at improving its removal efficiency, the capacity of the existing facilities shall be taken into consideration.

7. Measures shall be taken against troubles to be caused by the growth of algae

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5.5.6 Flow ratification facility and outlet facility

1. The flow ratification facility in the chemical sedimentation basin has a function to lessen the uneven flow in the basin and raise its efficiency, and shall be designed with consideration to the following:

   1) The inlet mouths shall be so arranged and structured that the inlet flow is as much uniformly as possible distributed over the entire cross section of the basin.

   2) The flow uniforming facilities of the horizontal flow sedimentation basin shall be designed as
follows:

(1) Flow uniforming walls etc. shall be provided so that the flow is introduced and collected uniformly all over the cross section of the basin.

(2) Space of more than 1.5 m shall be placed between the inlet mouths and the flow uniforming wall.

(3) The total standard opening area of holes on the flow uniforming wall shall be 6% of the sectional area of the basin.

(4) A flow training wall and an intermediate flow uniforming wall shall be installed in the basin if required.

2. The settled water collection facilities of the chemical sedimentation basin shall be designed as follows:

1) The collection facilities shall be so designed as not to make the flow in the basin turbulent, and to have a weir loading rate of 500 m³/day-m or less.

2) The collection facility for the upward flow type sedimentation basin fitted with such settling device as the sloping-plate shall be designed as follows:

(1) The space between the bottom of the collection facility and the upper end of the settling device shall be more than 30 cm.

(2) The weir loading rate of the collection facility shall be less than 350 m³/day-m.

Figure 5.5.23: Intermediate flow uniforming wall type sedimentation basin (Higashimurayama water treatment plant of Bureau of Waterworks Tokyo Metropolitan Government 1,265,000 m³/day) (Unit: mm)
5.5.7 Desludging facilities

1. The type of desludging facilities for the horizontal flow type sedimentation basin shall be selected taking into account the structure, operation and maintenance and the property of the sludge.

2. The structure of the desludging facilities for the suspended solid contact clarifier shall be so designed that discharge of margin sludge can fully be made at any time or at constant intervals.

3. The valves on the desludging lines shall be set at the “closed” position at an occasion of power failure etc.

[Interpretation]

On the item 1.;

There are the following methods of desludging:

1) Mechanical scraping method

In this method, hoppers and desludging valves are provided at the basin bottom so that desludging is performed by static water pressure or suction by pumping. In some cases, pressured water spraying device is set around the hoppers.

2) Method to utilize compressed air

In this method, lateral pipes for sucking sludge from the basin bottom, which are connected to a horizontal collection pipe, and trunk discharging pipe to dispose of the sludge to outside, compressed air feeding pipe etc. are installed. Collection and discharge of sludge is carried out by blowing and sucking compressed air into the collection pipe alternately.

3) Method to provide hoppers all over the basin bottom

In some cases, desludging cannot satisfactorily be executed due to a tunneling phenomenon occurring in the sludge pile. Therefore, a pressured water spraying device shall be installed (See Figure 5.5.31), or specially shaped hoppers shall be installed and so forth.

4) Method to desludge after emptying the basin

In case this method is employed, facilities for the use of pressured water are needed to sweep the sludge for its discharge. To this end, pressured water pipelines may be laid in the basin, or a portable motor pump may be provided, with which water from an adjoining basin can be pumped.
5.5.8 Desludging pipe and overflow pipe

The desludging (dewatering) pipe and overflow pipe of the sedimentation basin shall be designed as follows:

1. Proper diameter of desludging pipe shall be determined in accordance with the time required for desludging and the quantity of sludge to be discharged.

2. Desludging shall in principle be performed by gravity.

3. An overflow pipe shall be provided if required.
5.6 Rapid sand filters

5.6.1 General

1. Role of the rapid sand filter

In rapid sand filtration, suspended matters in raw water are coagulated beforehand by a chemical; introduced through granular filter media in a relatively rapid velocity; and removed mainly by the mechanisms of adhesion to the filter media and straining by the filter layer. It is needed for the objective suspended matters to be coagulated beforehand, and formed in flocs, which make adhesion and straining easy.

Even if the raw water turbidity is low, since satisfactory removal of colloidal and suspended matters including cryptosporidiums cannot be expected by plain filtration through the rapid sand filter, water must be treated by a coagulant prior to filtration.

2. Mechanism of the removal of suspended matters

The mechanism of the removal of suspended matters in the filter media is considered to be divided into two stages. In the first stage, the suspended particles are put off the streamline and transported close to the surface of the filter media, when the mechanisms of sieving, straining, and gravity settling are predominant.

In the second stage, the transported particles attach and are trapped to the surface of the media. It is considered that this mechanism depends on the relationship between the suspended particles and the surface of the media grain (the surface of the grain itself at the beginning, and, afterwards, the surface formed by suspended particles trapped).

As such, since the retention on the filter media surface is the main factor of filtration mechanism, the filtration mechanism is more effectively achieved when as much surface area of the media as possible is used for attachment.

1) Surface filtration and deep filtration

The surface area of filter media grains per unit area of the filter is the function of the grain size of the filter media and the depth of the filter layer. Therefore, although the finer the grain size of the media, the higher the straining effect, and suspended matters can be retained even with a thin layer of the media, it is difficult to maintain filter run-time for a long time as the retained matters are densely concentrated on the surface of the filter layer, and cause a large head loss. On the contrary, if a filter layer, which allows flocs to penetrate deep into it, is used so that the entire filter layer can be used to trap suspended matters, it will become possible to retain a lot of suspended matters in the filter layer, and the head loss will also be small.

The former is called surface filtration; and the latter deep filtration (volume filtration) with reference to the manners of loading the filtration mechanism in the direction of the depth of the filter media.

2) Strength of flocs and the quantity of their retention

The condition of retention of flocs in the filter layer is dependent on the physical strength of the flocs. In general, flocs formed with a high dosage of coagulant per suspended matters (a high ALT [aluminum to turbidity] ratio) are weak, and tend to be broken by the shearing force of water and easily leak even if they are once trapped on the grain surface of the filter media. On the other hand, flocs formed with a low ALT ratio of coagulant and receiving intense stirring are strong and do not easily leak.

3. Single medium filtration and dual-media filtration

Since the ordinary filter media have grain distribution of coarse as well as fine sizes, there is a tendency for finer portion of the media remain at the upper position and the coarser portion at the
lower position after backwash as illustrated in Figure 5.6.1 (A). When introducing water to the above filter layer, most of the flocs are removed on or close to its surface showing distribution pattern of retained matters as illustrated in Figure 5.6.1 (A'). As such the head loss at the surface of the layer becomes high, and so filtration operation must be stopped even before the retaining capacity of the body of the filter media is fully used, so a backwash is needed.

To remedy this shortcoming of the single medium filter with sand only, such ideas are practiced as selecting large grain size and narrow size distribution of the medium so as to avoid the concentration of retained matters on the surface only, and making the depth of the layer large to delay the leak.

In the deep filtration, water is filtered in a relatively high velocity so that flocs penetrate deep into the filter layer, and the entire body of filter layer is utilized.

As illustrated in Figure 5.6.1 (B), if a filter layer with the grain size and the porosity gradually become small along with the direction of the water flow can be constructed, a high degree of removal capacity as well as a large volume of retention can be obtained.

To maintain such a filter media composition even after a backwash, the settling velocity of the medium, which forms the lower part of the layer, shall be made higher; and that of the medium for the upper part of the layer lower. To this end, filter medium with high density needs to be used for the lower part of the layer.

As a form of a filter, with which it is aimed for water to be led from a coarse filter medium to a fine filter medium, a multi-media (mixed media) filter is used with different densities of filter media. In many cases, a dual-media filter with an anthracite layer and a sand layer to be laid under the former is employed, which assigns the function of retention of turbidity matters on the anthracite layer as the former has a larger grain size and lower density than sand, and that of polishing on the sand layer. The distribution of grain sizes is illustrated as in Figure 5.6.1 (C). Although the tendency for finer part of medium to stay at the upper position of each filter medium is unavoidable, a composition of layers with a coarse medium on the upper position and finer one at the lower position can be obtained for the filter as a whole. It is considered desirable for a dual-media filter to be designed so as to have a distribution of the retention in the filter layer as shown in Figure 5.6.1 (C').

With the method to filter water upward (upward flow filtration) through the ordinary single medium filter layer (See Figure 5.6.1 (A)), filtration through a filter layer with media grain size gradually decreasing in the direction of flow can be realized. However, there is a demerit that, as the filtration rate becomes high, the filter layer is inflated, the turbidity leaks, and backwash waste tends to remain in the filter media after a backwash.

![Figure 5.6.1: Grain size distribution and retained suspended matters distribution in the filter layer](image)

4. Functions required for the filter

Since the filter, in almost all cases, is used as the final process in the water treatment train for turbidity removal, it shall have such functions as follows:

(1) the function with which such quality of filtered water can be obtained as conforming to the drinking water quality standards and the criteria for the measures against cryptosporidium etc. in water supply
(2) the function of the quantitative retention of turbidity matters
(3) the buffering function against the changes in water quantity and quality
(4) the sufficient function for filter washing

Since the conditions of the retention of suspended matters differ depending on the consistency and property of flocs, the composition of filter layer, filtration rate, filter run-time etc., its washing method shall be designed in accordance with such conditions.

5. Factors to be considered for designing filters

Since the rapid sand filter is part of the rapid sand filtration method, i.e., a synthetic solid-liquid separation system, its design needs to be performed to match the load with turbidity removal and buffering function (absorbance of load fluctuation) assigned to the filter among the system as a whole. In other words, when planning water treatment facilities, it is important to determine how much, or what qualitative and qualitative burden against raw water quality, especially turbidity shall be given to sedimentation and filtration respectively, and the magnitude of margin of safety of filtered water to be ensured by the filter. The filter shall be designed, as a result of the above examination, so that the filter can satisfy the required functions. Considering such functions other than turbidity removal as the removal of manganese to be assigned to the filter, the removal of turbidity shall be assigned to the sedimentation basin as much as possible; and the filter shall not burden too much load, but function as the finishing facility as a treatment process.

The main factors, which can be chosen for the design of the filter, are the grain size of filter media, the composition of the filter layers including its depths, filtration rate and the method of its control, the method of filter bed washing and its frequency etc. Since they are mutually connected, harmonization as a whole system shall be maintained for their selection.

5.6.2 Structure and type

The structure and type of the rapid sand filter shall be in conformity with the following:

1. The type, which can properly perform filtration and the washing can adequately carried out, shall be selected.
2. The standard type shall be gravity filtration

5.6.3 Filter bed area, number of filter units and shape

The bed area, number of units and shape of the rapid sand filters shall be in conformity with the following:

1. The filter bed area shall be computed by dividing the design treatment flow by the filtration rate.
2. The number of filters shall be more than two including the standby unit as the minimum, and one standby filter shall be provided for every 10 units.
3. The filter bed area per filter shall be less than 150 m².
4. The standard shape shall be rectangular.
[Interpretation]

**On the item 4.**;

Since the filter cell shaped as a rectangle has an advantage to circularly or fan-like shaped one in terms of the ease of construction, also as fewer problems related to the operation and maintenance may arise, the standard shape shall be rectangular. Since, if the ratio of the length to the width becomes too large, it is difficult to maintain the uniformity of flow in the filter sell, it shall be less than 1:5 as the standard.

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### 5.6.4 Filtration rate controller

A device to control the flow of filtration shall be installed on the rapid sand filter

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[Interpretation]

Types of filters and methods of filtration rate control

1. **Constant rate filtration method**

1) **Outline of the constant rate filtration method**

As the filter clogging progresses, by either raising the upstream side water level or reducing the resistance (opening the valve) in the outlet rate controller, thus increasing the differential pressure on the filter layer, the constant flow rate can be maintained. This method is called the constant rate filtration, which is widely used.

2) **Control of the constant rate filter**

There are three methods of control of the constant rate filter, namely, flow control method, water level control method and self-balancing method. (See Figure 5.6.4)
(1) **Flow control type**

The flow control type functions with a flow meter and a flow controller on the outlet line, and controls the filter flow by giving a large head loss on the outlet line at the initial stage of filtration; and as the head loss builds up through the filter bed, it reduces the head loss in the outlet line in proportion to the head loss increase in the filter bed so that the constant filter flow is maintained. This type has a merit that the difference in the elevations of the sand surface and the inlet conduit can relatively be small; and, on the other hand, demerits that it requires a relatively complex control device, and that there is a possibility for water quality to get poor due to the occurrence of negative pressure when large head loss occurs in the filter bed.

(2) **Water level control type**

With the water level control type, the water level in the filter cell is detected, and its signal is transmitted to the flow control device so that the constant filter flow is maintained by means of

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**Table:** Methods of flow rate control and types of inlet and outlet of the filter

<table>
<thead>
<tr>
<th>Type of control</th>
<th>Inlet method</th>
<th>Outlet method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>non-cascade</td>
<td>cascade</td>
</tr>
<tr>
<td></td>
<td>cascade</td>
<td>non-cascade</td>
</tr>
<tr>
<td></td>
<td>water level</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cascade</td>
<td></td>
</tr>
<tr>
<td>Water level control type</td>
<td>cascade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>non-cascade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>water level</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cascade</td>
<td></td>
</tr>
<tr>
<td>Self-balancing type</td>
<td>cascade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>non-cascade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>water level</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cascade</td>
<td></td>
</tr>
</tbody>
</table>

Note: The cascade type stands for a type, with which the inlet or outlet water surface is hydraulically separate from the water surface in the filter cell.

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**Figure 5.6.4:** Methods of flow rate control and types of inlet and outlet of the filter
keeping the water level constant. With the water level control type, although the water depth on the sand surface can be made relatively small, a device of a complex mechanism is needed.

(3) Self-balancing type

With the self-balancing type, as the inlet flow is uniformly distributed with a weir to each filter cell with sufficient clearance between the inlet conduit water level and that in the filter cell; and a weir is provided at the end of the outlet conduit at the elevation higher than the sand bed, the water level above the filter bed gradually rises automatically as the clogging of filter layer develops, which prevents the decrease in the filter flow, in other words, maintains the constant flow. In addition, when the incoming flow increases, as the filtration rate changes slowly, it has such an advantage that the filtered water quality is maintained even in the case of a surge in flow. As the filtration operation is stopped and the washing is carried out when the water level above the sand bed reaches a prescribed limit, a long filter run-time can be realized as much as large water depth above the sand bed is set. Although this type possesses such an advantage as the constant flow filtration is possible with no flow control device set on the outlet side, and there is fewer risks of developing vacuum inside the sand bed than other types, and so forth, it also has a disadvantage of the necessity to have a deeper filter cell.

2. Constant pressure filtration type

1) Outline of the constant pressure filtration type

As the filtration rate decreases over time with the constant pressure filtration type, a large head loss through the filter bed, under-drain system, outlet pipeline etc. must be provided to have a long filter run-time. If it is small, the initial filtration rate may be excessively large, or the surge in filtration flow become big as affected by an external turbulence, which may easily cause leak of turbidity. Anyhow, it is difficult to control the flow rate since filtration rate fluctuates. Given this, the upper limit of the filtration rate is generally depressed to a certain threshold by installing a fixed orifice on the outlet line. The declining rate filtration is a typical constant pressure filtration type.

The declining rate filtration can only be employed in case there are many filters. With this type, as the water from the sedimentation basins will be directly filtered without a gap in water levels, the filtration flow diminishes as the resistance through the filter beds develops. Even employing a constant pressure filtration type, the water level in the filter cells automatically rises. When the filtration rate decreases and the water level exceeds a limit, the filters shall be cleaned, and the filtration capacity is regained so that the water level is lowered.

This type has such advantages that its mechanism is simple; that the required head is small; that the risk of turbidity leak is low since the decline in filtration rate is dependent to the development of filter bed clogging, and so forth. However, there are such disadvantages that, in case there are only a small number of filters, the control of the flow rate is difficult due to the diminishing filtration rate, and that large variations in filtration rate and water level are induced by shut-downs and re-runs of the filters.

5.6.5 Filtration rate

| The filtration rate is 120 to 150 m/day in general. |

[Interpretation]

The reason why the filtration rate is set at 120 to 150 m/day is that this magnitude of filtration rate is considered appropriate to obtain filter run-time of 1 to 3 days which is required for good quality of filtered water and the operation and maintenance assuming the condition for coagulation, sedimentation and property of filter sand and composition of the filter as instructed in this design criteria and also referring to the past experience.
In case especially good quality of inlet water to the filter can be obtained as a result of coagulation, sedimentation, advanced water treatment etc., a filtration rate exceeding the above rate can be employed. Actually there are some cases filters are operated at a rate of 300 m/day or so.

5.6.6 Filter sand and its depth

Filter sand and its depth to be used for the rapid sand filtration shall be in conformity with the following:

1. Filter sand shall have such properties as proper grain size distribution, contents of only a small amount of foreign matters, resistance to attrition, and hygienic safety, which enable reliable and effective filtration and washing.

2. The standard depth of the sand bed shall be 60 to 70 cm.

[Interpretation]

On the item 1.;

Silica sand is generally used as filter sand. The quality of the sand shall be as follows:

1) Residual turbidity after washing

Residual turbidity after washing shall be less than 30 turbidity units. It is a yardstick for cleanliness (threshold of pollution) of the sand. However, it does not apply to the manganese-coated sand.

2) Density

The density of sand shall fall in the range of 2.57 to 2.67 g/cm³. Naturally produced sand has a specific gravity of 2.6 or so. Sand with a specific gravity (sp gr) of less than 2.57 may contain organic materials or porous sand in some cases; and that with a sp gr of more than 2.67 may at times contain limestone, ore of heavy metals etc. So it is not suitable as filter sand.

3) Ignition loss

Ignition loss shall be less than 0.75 %. It is desirable for the filter sand to be of good quality with as a small amount of foreign matters as possible. Therefore, the upper limit of contents of such impurities as organic matters, coal grains, limestone, shell etc. shall be determined by an ignition loss test, which can be performed relatively easily.

4) Attrition loss

Attrition loss shall be less than 3.0 %. The attrition loss rate is set so as to prevent that the filter sand is broken and worn out after repeated washing, and that its dust is washed out in wash water waste resulting in the changes in grain size distribution of filter bed and its depth compared with its original design.

5) Solubility to hydrochloric acid

Solubility to hydrochloric acid shall be less than 3.5 %. As same with the above item, the upper limit of the contents of foreign matters is set by the solubility to hydrochloric acid.

6) Appearance

Preferable sand shall be of one without large contents of such impurities as clayey matters, flat or fragile sand etc., with large siliceous components, hard and uniform. Especially, one with only small contents of iron sand is desirable.
7) Effective diameter

Effective diameter of sand shall generally be 0.45 to 0.70 mm. There are various ways to describe the diameter of sand which is a mixture of grains of varying diameters. Hereinafter, it is represented by its effective diameter which has been traditionally used in water supply (sand grain size passing 10 % of the cumulative curve of grain sizes. See Figure 5.6.6).

The smaller the grain size of filter sand, the higher the rate of flocs blocking with more tendency of surface filtration. Although a small grain size of sand has such disadvantages that only small amount of suspended matters can be retained; that mud balls can easily be formed; and that head loss quickly develops and so on, it has such advantages that only low rate of backwash is needed, that a thick sand bed is not necessary etc.

On the contrary, in the case of filter sand with a big grain size, as the tendency of deep filtration is remarkable, a high filtration rate can be attained while maintaining filter run-time long with a thick sand bed with a smaller uniformity coefficient of the sand. In this case, however, it is needed to raise the washing efficiency by employing a higher backwash rate and air-wash together.

In the case of the ordinary rapid sand filters with a sand bed depth of 60 to 70 cm, sand with an effective diameter of 0.6 to 0.7 mm is widely used taking into consideration the blocking efficiency, filter run-time, backwash rate, capability to cope with a wide variety of raw water quality etc.

Figure 5.6.5: Cumulative grain size distribution curve

8) Uniformity coefficient to be less than 1.70

On the cumulative grain size distribution curve of sand (Figure 5.6.5), the ratio of the 60 % passing diameter to the 10 % passing diameter is called the uniformity coefficient, which is an indicator of the magnitude of uniformity of grain diameter distribution.
The uniformity coefficient of sand of natural origin falls in the range of 1.5 to 3.0 or so. In case this sand is used, although the sand at the upper layer and that at the lower layer are mixed when backwashed, coarse sand tends to gather at the lower layer because of faster settling velocity whereas the finer one at the upper layer likewise when backwash stops. As a result, although the rate of turbidity blocking is very high in filtration operation, enough filter run-time cannot be maintained since the filter bed is easily clogged, and so head loss gets too big.

With sand of a large uniformity coefficient, the gradient of grain sizes between the upper layer and the lower layer becomes big, and it has a tendency to get compacted. In order to alleviate clogging at the surface of the sand layer, and give high turbidity retaining capacity in deep portion of the sand layer, it is needed to raise the uniformity of the sand grain size. Hence, the upper limit of the uniformity coefficient was set at 1.70.

As the uniformity coefficient gets as close as 1, the grain sizes become even, and so the porosity of the sand layer become big, which make the turbidity retaining capacity large. However, the smaller the uniformity coefficient, the less the quantity of sand which can be obtained from the original sand. The quantitative yield of usable sand quickly declines as the uniformity coefficient is set about 1.3 or smaller. As such, in case sand of the size of 0.6 to 0.7 mm is used, sand with a uniformity coefficient of 1.3 to 1.6 or so is actually used.

9) The maximum grain size of sand shall not exceed 2.0 mm; and the minimum size shall not be smaller than 0.3 mm. Even in an unavoidable case, the quantity of the larger size than the upper limit or the smaller size than the minimum limit shall not exceed 1 % of the total.

As backwash is repeated, fine sand grains consist of a large portion of the upper layer, and coarse ones comprise that of the lower layer. Since the quantitative distribution of grain size of smaller than the 10 % passing and that larger than 60 % passing diameters on the size distribution curve cannot be prescribed only by the effective size and the uniformity coefficient, the upper and the lower size limits were set to prevent the tendency of classification to get excessively large.

After sand is laid in the filter cell, backwash with a rate, which does not expand the sand bed more than 30 %, is repeated, the fine and light portions of sand, silt etc., which gather within several cm of the surface, are removed. Therefore, it is needed for the filter sand to be placed several cm thicker than the design for provision for scraping the sand bed surface.

On the item 2.;

Since, for the standard type filter used traditionally, the depth of sand layer of 60 to 70 cm is empirically considered appropriate from the economic point of view taking into account the filter run-time, filter efficiency, and the degree of turbidity penetration in the sand layer, this depth was set as the standard.

5.6.7 Filter gravel and its depth

The gravel and its depth used for the rapid sand filter shall be in conformity with the following:

1. The filter gravel shall be of a proper shape and size with only a small amount of foreign matters contained and no hygienic inconvenience, and be able to adequately support the sand layer, with which reliably and efficiently backwash the filter bed.

2. The grain size of the gravel and its depth shall be determined to be properly adapted to the underdrain system.

3. The coarse filter gravel shall be laid at the lower layer, and the fine one at the upper layer, and they shall be laid layer by layer without undulation.
The filter gravel is laid to support the filter sand so that it does not leak during filtration to the filtered water conduit through the underdrain. It also plays a role to uniformly distribute water gushing from the underdrain system when the filter is backwashed.

**On the item 1.;**

The quality of the filter gravel can be judged according to the JWWA standard JWWA A 103: 2006 (Filter gravel for water supply)

1) **Wash water turbidity**
   To be less than 30 degrees of turbidity units.

2) **Density**
   To be higher than 2.50 with its dry surface.

3) **Solubility to hydrochloric acid**
   To be less than 3.5%.

4) **Appearance**
   To be hard and rounded with only a small amount of flat ones, foreign matters, clayey substances, fragile grains etc.

5) **Shape of the gravel**
   The quantity of gravel shaped with the major axis to be as longer than five times the minor axis shall be less than 2%.

6) **Ratio of the weight of gravel by size**
   The total of the ratio of weight of the gravel of smaller size than the design minimum size and that of bigger size than design maximum size to the weight of gravel at each level of the gravel layer shall be less than 15%.

**5.6.8 Underdrain system**

| The underdrain system shall be able to perform uniform and effective filtration and backwash. |

**[Interpretation]**

In the filter, an underdrain system shall be installed with functions of supporting the filter media, collection of filtered water, uniform distribution of backwash water etc.

If washing is unevenly performed over the plane of the filter cell, water in the filtration mode will passes only through the part where washing has been done adequately, and so the filtration rate in such part will be extremely rapid, and local clogging will develop in other parts where washing has be insufficient. The uniformity of washing is important for maintaining the function of the filter.

The head loss of the underdrain is determined by the area of opening (hole), spouting velocity and shape coefficient. (See Figure 5.6.6)

The important elements of a practical underdrain system are described as follows and its Interpretation is added:
Blocks which possess a distribution chamber and a transmission chamber are laid on the filter cell floor. The standard shape and the feature of their installation are illustrated in Figure 5.6.7 and Figure 5.6.8.

With this type of blocks uniform filtration and backwash can be expected by means of double-layered orifices, which enable uniform distribution of water pressure, and a lot of collection holes arranged on the surface of the blocks.

The characteristics of the block are that no props are needed so its installation is easy because of its light weight, that the structure of the filter cell can be made shallow as no pressure conduit is required, that the cell floor can easily be made flat and so forth. Since the larger the cross section of the transmission room, the higher the uniformity of the pressure distribution, even with larger collection holes, the uniformity of water distribution can be maintained resulting in a reduction in head loss in the underdrain.

As the material of the perforated block, ceramics and plastics are used, a collection conduit to collect filtered water from the blocks and distribute backwash water to the blocks is provided either in the center of the filter cell or on its side facing the pipe gallery. The cross section of the conduit shall be more than 1% of the filter bed area (assuming a backwash rate of 0.6 m/min).

The total opening area of the collection holes on the blocks as percent of the total bed area is usually 0.6 to 1.4%.

If the length for connecting the perforated blocks is too large, the imbalance in water pressure will become large over the length. Therefore, the maximum length is considered to be 5 m.

Since upward lifting force works on part of the blocks at the time of backwash, they shall be anchored at a proper interval. The joints between the blocks shall carefully be executed so that water leakage is prevented.
2. Strainer type

The strainer type underdrain has strainers fitted on slabs or pipes laid on the filter cell floor through which backwash water is sent and filtered water is collected. One example of its standard form and the features of its installation are shown in Figure 5.6.9. In case strainers are fit on the pipes, a collection conduit to conduct water from and to the pipes is placed in the center of the filter cell. The material of the pipes shall be durable, and, when they are installed, concrete shall be placed up to the level of the lowest holes on the strainers so that there will be no areas where dead water may occur, and that strainers are soundly fixed without dislodging from the pipes.

The proper interval of the strainers is 10 to 20 cm according to the experience, and they shall be installed at the same elevation. If the total sectional area of the nipples, to which strainers are mounted, is set at 0.25 to 1.0 % of the filter bed area, a uniform flow over the area can be obtained at the time of backwash.
The successful strainer system will be attained by preventing the corrosion and clogging of the strainers. To avoid corrosion, highly anti-corrosive metal or plastics shall be used. To avert clogging, it is useful to block the leak of fine sand providing gravel layers with appropriate grain size and depth suitable to the size of the strainers. What is more, the shape and size of the strainers shall be selected so that they are not clogged even if the filter sand leaks.

3. Perforated pipe type

This type employs perforated pipes with holes facing downward placed on stands at the filter cell floor as an example is shown in Figure 5.6.10. The pipe material shall have sufficient anti-corrosiveness, durability and resistance to pressure; the holes shall have a uniform diameter and be placed in the same angle. The space between the collection pipes shall be less than 30 cm, and its length shall be less than 60 times the pipe diameter. If the length is too long as to the diameter, uniform backwash cannot be attained as the imbalance of pressure in the pipe become too large at the time of backwash.

The perforated pipes need to be firmly fixed on the stands as they easily vibrate at the time of backwash. In some cases the pipes are connected each other at the ends of pipes so as to make the pressure distribution in the pipes as uniform as possible during backwash.
4. Porous plate type

This is a plate formed by agglomerating granular materials of a diameter of several mm into a porous plate. They form an underdrain system set on prop walls covering the filter cell floor, which make pressure chambers. The standard type of the porous plate has a shape as shown in Figure 5.6.11.

As the granular matter, melted alumina with rounded corners (major axis: 3 mm or so) is used.

Although the porous plate has a merits that the gravel layer can be omitted so the filter structure is made shallow, strict construction supervision is required to secure the flatness of the plates and so on. Furthermore, clogging of the plates may occur depending on the raw water quality.

![Figure 5.6.11: A porous plate for the underdrain system](image)

5.6.9 Water depth in the filter cell and its freeboard

<table>
<thead>
<tr>
<th>The water depth in the filter cell and its freeboard (clearance from the water surface to the crown of the filter) shall be in conformity with the following:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The water depth above the sand bed shall be as enough as not to cause negative pressure inside the filter media.</td>
</tr>
<tr>
<td>2. The freeboard shall be 30 cm or so.</td>
</tr>
</tbody>
</table>

[Interpretation]

On the item 1.;

As suspended matters are trapped in the interstices of filter media, and the channels between media grains get clogged, the head loss increases, which causes the gradual drop in water pressure inside the filter media. This phenomenon as to the single filter medium is schematically illustrated in Figure 5.6.12.

Line 1.: Straight line water pressure distribution appears. (before filtration starts)

Line 2.: Water pressure distribution according to the respective resistance of the filter media and the gravel right after the start of filtration.

Line 3.: As filtration goes on, and retention of suspended matters in the filter media progresses, head loss in the filter media becomes big. Since a large amount of suspended matters are retained at the filter media surface, head loss at the surface is bigger than in other parts.

Line 4.: As the total head loss becomes large, and it is reaching the total applicable head loss, it is time to stop the filtration judging from the capacity of filtration. For the actual filters, the total applicable head loss is set at 1 to 2 m or so in many cases.
5.6.10 Type of washing

The standard type of filter media washing is a combination of backwash and surface wash, which can effectively clean the filter media. It may be a combination of backwash and air-scour depending on the needs.

[Interpretation]

Since the performance of filter media washing largely affects the efficiency of filtration, it is important to select a type of washing which can sufficiently clean the entire filter media uniformly.

In case washing is insufficient, such troubles would result as reduced filter run-time, deteriorated filtered water quality, formation of mud balls, cracks on the filter bed, undulated filter bed surface, an opening between the filter wall and the filter bed etc.

The judgment of the performance of filter media washing is usually made by the turbidity of washing waste at the end of cleaning. For removal of cryptosporidiums, as monitoring of the terminal washing waste turbidity is important, the turbidity of less than 2 turbidity units shall be the target. It is desirable for this target to be less than 1 turbidity unit if possible.

The standard type is a combination of surface wash and backwash, with which the deposit of suspended matters on the surface of filter bed is first broken by hydraulic shear of surface wash, followed by the acceleration of backwash up to the state of fluidization of filter bed, tearing-off of dirt stuck on the filter media by the actions of collisions of media grains and shear by water and discharge of dirt from the filter media.

In addition, there is a type of a combination of air-wash and backwash, which dislodges the dirt from the filter media by micro vibration generated by rising air bubbles and discharge it from the media by backwash.

For the types, which makes suspended matters penetrate inside of the filter media, which has deep filter media or of which filter media grain size is big, it is needed for the retained suspended matters to be efficiently removed. For this purpose, air-wash is effective.

1. Surface wash

On the surface of filter media, a lot of suspended matters are deposited, and they will remain there if only backwash is applied, muddy matters will accumulate there, and it will not only reduce the suspended matter retaining capacity but also make mud balls to form. To prevent this problem, surface wash is used together with backwash. The surface wash applies spray of pressured water, breaks the muddy layer by the energy of water, and so the efficiency of washing is enhanced. There are two types of surface wash: the fixed type and the rotating type.
2. Backwash

For backwash, it is needed that a sufficient backwash rate and uniform distribution of backwash water flow are maintained to dislodge suspended matters retained in the filter media, separate them from the media, and transport to the troughs so they are discharged.

The process of backwash is divided into two stages: First stage: The filter media are fluidized by backwash; and the suspended matters stuck on the media are dislodged by collisions and friction between media grains and shear force to be made by short-circuiting currents and small eddies. The detachment of suspended matters stuck on the media and their separation from the media can most effectively be made with a good washing effect when the expansion rate of the filter bed is 20 to 30%.

The second stage: The suspended matters separated from the filter media are quickly discharged, which is affected by the level of the troughs, the interval of troughs etc.

3. Air-wash

With the air-wash type, air is blown from underneath of the filter bed to dislodge the suspended matters stuck on the filter media while backwash is operated at the same time. Surface wash is usually not employed together with air-wash.

5.6.11 Wash water quantity etc.

<table>
<thead>
<tr>
<th>The nature and quantity of washing water etc. for the rapid sand filter shall be in conformity with the following:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Treated water shall be used for washing.</td>
</tr>
<tr>
<td>2. The quantity of water and time of washing shall be as much as required for an adequate effect of washing.</td>
</tr>
</tbody>
</table>

[Interpretation]

On the item 2.;

The backwash rate of about 0.3 m/min will start to fluidize and expand the sand layer with the effective sand grain diameter of 0.6 mm and uniformity coefficient of 1.3 at the water temperature of 20 degrees C. But the rate is insufficient to fully dislodge the suspended matters from the filter media, separate them from the media and discharge them. If increasing the rate up to 0.6 m/min, the rate of expansion will become about 20%, which makes the sand layer properly fluidized, and starts to smoothly perform the detachment of suspended matters and their separation from the filter media by collisions of sand grains, friction between them and the shearing force of water current. It is important to bring the filter layer to such a state as this for high efficiency of washing. To this end, it is needed to set a backwash rate, which enables the sustaining suspension of the filter layer and the transportation of suspended matters separated from the filter media to wash troughs so that they are discharged quickly.

The backwash rate needed to obtain the same expansion ratio becomes high as a bigger grain size of the filter media is used, and it becomes low as the water temperature gets low.
Table 5.6.2: Standard wash water quantity, water pressure and wash time

<table>
<thead>
<tr>
<th>item</th>
<th>wash method</th>
<th>in the case surface wash used jointly</th>
<th>in the case only backwash used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fixed type</td>
<td>rotating type</td>
<td>fixed type</td>
</tr>
<tr>
<td>water pressure of surface wash nozzles</td>
<td>(m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15~20</td>
<td>30~40</td>
<td></td>
</tr>
<tr>
<td>water quantity of surface wash nozzles</td>
<td>[m³/(min • m²)]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.15~0.20</td>
<td>0.05~0.10</td>
<td></td>
</tr>
<tr>
<td>water duration of surface wash nozzles</td>
<td>(min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4~6</td>
<td>4~6</td>
<td></td>
</tr>
<tr>
<td>water pressure of backwash</td>
<td>(m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.6~3.0</td>
<td>1.6~3.0</td>
<td>1.6~3.0</td>
</tr>
<tr>
<td>water quantity of backwash</td>
<td>[m³/(min • m²)]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.6~0.9</td>
<td>0.6~0.9</td>
<td>0.6~0.9</td>
</tr>
<tr>
<td>water duration of backwash</td>
<td>(min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4~6</td>
<td>4~6</td>
<td>4~6</td>
</tr>
</tbody>
</table>

Note) 1 The water pressure of surface wash is the dynamic water pressure at the jetting nozzle.
2 The water pressure of backwash is the dynamic water pressure at the spouting holes of the underdrain system (excluding the underdrain system itself), which is equal to the sum of the head loss of 0.4~0.8m in the filter media and the gravel layer, the standard depth of 1.2~1.6m from the top of the underdrain system to the water surface at the rim of the wash trough and some margin.

5.6.12 Wash water tank, wash pump etc.

The wash tank, wash pump and air-blower for feeding wash water and air shall have necessary output capacities for water and air.

[Interpretation]

For backwash of filters, water is needed to be fed from a wash water tank or pump. To perform washing by directly feeding water from a pump, a relatively large size of pump is needed since a large quantity of water is required to be pumped at one time. However, this method has such an advantage that continuous washing is possible.

On the other hand, in case a wash tank is used, although only a small capacity of pump is needed, the cost of facilities as a whole tends to be high.

It shall be determined which method, direct pumping or wash tank, be selected after synthetically studying the scale, construction cost, power supply capacity, operation and maintenance, environment of the site etc.

1. Wash water tank

The volume of the wash water tank shall be adequate to wash at least one filter; and in case there are more than 20 filters, it is desirable for the tank to have a volume for wash of more than two filters at the same time.

2. Backwash pump

The capacity of the backwash pump for direct feeding shall be adequate to feed a necessary volume of water with reference to Table 5.6.2.

The lift of the wash pump shall be determined based on the total of the head losses in wash water feeding line, valves, flow controller, underdrain system, gravel layer, filter media, the difference in the
elevations of the rim of the wash troughs and the water level in the pump well etc. plus a certain margin.

A standby unit shall be provided for the backwash pump with consideration to breakdown or repair of the facilities. For other aspects, similar consideration with the wash water tank shall apply to the backwash pump.

3. Surface wash pump

Since the quantity of water required for surface wash is small compared with that for backwash, the use of the pressure of water supply in the water treatment plant shall be considered first. If it is unavailable, a pump for the exclusive use shall be installed.

4. Air blower for washing

The standard capacity of the air blower for air wash shall be set with reference to “3. Air wash in 5.6.10 Washing methods”; and its delivery pressure shall be set for the water depth over the air nozzles, friction losses in feeder pipeline and the underdrain system. The blower shall have the capacity required for a filter by one unit provided with a standby facility as provision for a breakdown etc.

5.6.13 Wash drain conduit and wash trough

The wash drain conduit and the wash troughs shall be in conformity with the following:

1. The wash drain conduit and the wash troughs shall be capable to discharge the maximum wash drain water volume with 20% of margin to sustain such a condition that free overflow above the rim of the trough is kept up.

2. Troughs shall be made with sufficiently anti-corrosive and durable material with enough strength, and firmly set level for their rims and at the same elevation.

3. The troughs shall be placed at intervals of less than 1.5 m between their rims lest filter media drain; and their elevation shall be 40 to 70 cm from the sand surface.

[Interpretation]

On the item 1;

The sizes of wash drain conduit and the wash troughs are needed to be set so that they can sufficiently discharge the maximum wash water volume. However, for its design, since the wash water volume may be selected from a certain range as shown in Table 5.6.2, there may be such a case, after the construction of the filter, that the wash rate is needed to be augmented based on actual performance of washing. Given such a situation, if they are designed with very small margin assuming low rate of washing, certain troubles may be encountered. Thus it is appropriate to provide some 20% of margin in the design wash water volume. Besides, as the formulas used for design of troughs, there are Miller’s formula, Camp’s formula, and Nakagawa’s formula.

1) Miller’s formula

\[ Q = 1.05B(h_0 + L \tan i)^{1.5} \]

Where.

- \(Q\): flow in the trough (m\(^3\)/s)
- \(B\): width of the trough (m)
- \(h_0\): water depth upstream of the trough
L: length of the trough  
i: angle of the sole of the trough to the level

2) Camp’s formula (in the case of free fall at the lower end of the trough)

\[ h_0 = \sqrt{2h_e^2 + \left( h_c - \frac{iL}{3} \right)^2} - \frac{2}{3} iL \]

Where,

\[ h_c : \text{critical water depth} = \left( \frac{aQ^2}{gB^2} \right)^{\frac{1}{3}} \]

a: correction coefficient of velocity energy (1.10)  
iL: difference in the heights of the upper end and lower end

3) Nakagawa’s formula

\[ h_0 = h_c \left( x - \frac{iL}{h_c} \right) \]

Where,

x: value to be determined by iL/hc, which is to be found in Figure 5.6.24.

Figure 5.6.24: Computation diagram of the water depth upstream of the trough
5.6.14 Piping (conduits) and valves of rapid sand filters

Piping (conduits) and valves of rapid sand filters shall be in conformity with the following:

1. The diameter of pipes and the cross section of conduits shall properly be determined with consideration to the flow velocity and head loss in them.

2. The pipes and valves shall be firmly fixed with the structure, which allows their dismantlement at the time of repair. Expansion joints shall be provided at joints of not only structures but also pipes.

3. Valves shall be so designed that the changeover from the filtration mode to the wash mode vice versa can reliably be made.

4. Valves shall function on the safety side at the time of emergency.

5. The structure shall be so designed that there will be no risk of contamination of the filtered water by wash waste etc.

[Interpretation]

On the item 1.;

The standard flow velocities in respective pipes and conduits are shown in Table 5.6.3.

On the item 3.;

Since a lot of valves are needed for rapid sand filters, and they are operated in a short period of time, they shall be equipped with such actuators as motorized ones.

<table>
<thead>
<tr>
<th>name</th>
<th>Velocity (m/s)</th>
<th>N.B.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>range</td>
</tr>
<tr>
<td>inlet pipe</td>
<td>0.6</td>
<td>0.50 ~ 1.00</td>
</tr>
<tr>
<td>outlet pipe</td>
<td>1.00</td>
<td>0.60 ~ 1.50</td>
</tr>
<tr>
<td>trunk main wash water pipe</td>
<td>2.00</td>
<td>1.50 ~ 3.00</td>
</tr>
<tr>
<td>lateral main</td>
<td>2.50</td>
<td>2.00 ~ 3.50</td>
</tr>
<tr>
<td>Filter wash drain pipe</td>
<td>2.00</td>
<td>1.50 ~ 3.00</td>
</tr>
</tbody>
</table>

Its diameter is determined by the standard flow of the flow controller.

The wash pressures on respective filters are set as uniform as possible.

For those with pressured water chambers, wash water is to be distributed as uniformly as possible.

To be large enough for rapid discharge.

5.6.15 Piping gallery and operation gallery

The piping gallery and operation gallery of rapid sand filters shall be in conformity with the following:

1. The piping gallery shall be structured so that the delivery and movement of machinery and equipment are easy, that good ventilation is provided, and that careful drainage and dehumidification are accommodated.
2. In case an operation gallery is provided, it shall be so structured that all the filters can be watched.

5.6.16 Multi-media filter

The multi-media filter shall be in conformity with the following:

1. The quality of the materials for the multi-media filter shall be capable of maintaining sufficient filtration and the composition of the filter media, and be hygienic.

2. The total standard depth of the multi-media is 60 to 80 cm in general.

3. The composition of the filter layer shall be able to achieve adequate filtration effects, and maintain vertical separation of respective media and their proper expansion at the time of washing.

4. The supporting layer of the multi-media shall conform to “5.6.7 Filter gravel and its depth”. However, in case a filter medium of fine grain size is used, measures to prevent the leak of the medium shall be provided.

5. The standard filtration rate is less than 240 m/day.

6. The method of washing shall be one that can effectively remove the suspended matters retained on the boundaries and inside of the media.

7. When the single medium filter is reformed as a dual media filter, such a decision shall be made after fully studying the existing facilities.

[Interpretation]

The multi-media filter is composed of more than two filter layers of different densities and grain sizes laid in reverse order from coarse to fine in the direction of flow. It is aimed that they can more effectively utilize the function of the filter than the single medium filter by means of using the entire depth of the filter media. The filter is called the dual media filter in case two kinds of filter media are used; and it is called the triple media filter in case three kinds of media are used. These filters, for which more than two media are employed, are generically named the multi-media (mixed media) filter.

The multi-media filter has the following characteristics compared with the single medium sand filter:

(1) Its filtration efficiency is high since it shows the tendency of deep filtration, and a large amount of suspended matters can be retained.

(2) Its filter run-time is long since the head loss is small with respect to the quantity of retained suspended matters.

(3) A high filtration rate can be applied.

(4) The ratio of wash water to filtered water is small.

(5) The total filter bed area can be made small with a high rate of filtration

(6) Filter clogging is not easily caused by such algae as synedra, melosira, microcystis etc., which are difficult to remove by sedimentation.
5.6.19 Direct filtration (Microfloc filtration)

The following shall be taken into account in case the direct filtration method is implemented.

1. The raw water turbidity is low and stable for a long time.
2. Coagulation and filtration are properly operated, and monitoring of water quality is adequate.
3. In case raw water turbidity is high, there shall be facilities which can treat water by the ordinary coagulation, sedimentation and filtration.

[Interpretation]

With the direct filtration method, of which objective is to filter low temperature and low turbidity water, raw water is dosed with a small amount of coagulant, rapid-mixed, and filtered without sedimentation.

In case raw water turbidity is low, if the removal by sedimentation is expected, high dose of coagulant with respect to the concentration of suspended matters is needed to form big flocs. As a result, the density of flocs tends to become small, and they become fragile resulting in the leak of turbidity from the filter. What is more, it is difficult to treat the sludge deposited in the sedimentation basin since its properties of concentration and dewatering are poor. To deal with these problems, direct filtration is implemented with low turbidity water in some cases.
5.7 Slow sand filtration

5.7.1 General

1. Mechanism of slow sand filtration

Slow sand filtration is a water treatment method, in which suspended matters and dissolved substances are removed by trapping and decomposition by oxidation, which are brought about by colonies of organisms (schmutzdecke) grown on the surface and inside of the sand layer. This method is suitable to be applied to raw water of relatively good quality such as infiltrated water, and can remove suspended matters, bacteria etc. unless the function of the organisms (schmutzdecke) is obstructed. In addition, such dissolved substances as ammonium nitrogen, iron, manganese, odor, detergents, phenols etc., if their contents are within a certain limit.

The treatment mechanism of slow sand filtration is expressed as that, while water slowly passes through the sand layer, suspended matters in water is trapped on the surface of the sand bed by the mechanical functions of sieving and adhesion of fine particles on sand grain surface. Humic substances and nutritious salts adhere to the retained matters, on which algae and microorganisms grow, a lot of bacteria propagate and decompose such matters, and form an organic filter membrane.

After the formation of the organic filter membrane, the blocking rate of suspended matters on the sand bed surface becomes high, and organic substances are mineralized within the membrane. Furthermore, bacteria and their metabolites stick on the surface of sand grains forming a gelatinous membrane, which accomplishes the function to oxidize and stabilize ammonia etc. in water.

Since the retaining function for suspended matters in slow sand filtration concentrates on the surface of the sand bed, large head loss develops in that area. As the head loss increases, the filtration rate is maintained by lowering the water level of the outlet side. When the filtration rate cannot be maintained, filtration is terminated, and some 10 mm of the sand surface is scraped evenly and flatly so as to restore the filtration function.

Since the feature of slow sand filtration is to treat water without the application of water treatment chemicals unlike rapid sand filtration, the above-stated treatment function can steadily be obtained. On the other hand, it is noted that it requires a large site area, and labor for scraping and refilling sand (resanding). When designing slow sand filters, these aspects shall be taken into consideration.

Although there are such cases as plain sedimentation basins are built to reduce the load on the slow sand filters, adequate attention shall be paid for designing the shape of the basins, inlet and outlet structures, flow-uniforming facilities etc.

2. Restrictions related to raw water quality

There are following restrictions in the application of the plain sedimentation basin:

(1) In case the annual maximum raw water turbidity is higher than 30 turbidity units, facilities, with which coagulation treatment can be carried out, shall be provided. Besides, in the case of raw water with less than 10 units of turbidity such as raw water abstracted from an impounding reservoir or groundwater, the plain sedimentation basin can be omitted.

(2) In case a lot of plankton algae are contained in the raw water, in general pH becomes high due to the growth of plankton algae, water gets colored green to dark red, and it smells in some cases. In such a case, facilities, with which chlorination can be applied, shall be provided. However, it must be carried out carefully so that it will not adversely affect the organic filter membrane of the ensuing slow sand filters.

The function of slow sand filter has the following restrictions regarding raw water quality:

1) As the slow sand filter blocks suspended matters on the surface of the sand bed, water with high turbidity or an abnormally large amount of plankton algae will raise head loss in a short period of time,
makes the filter run-time short and so is unsuitable for slow sand filtration. The turbidity of inlet water to the slow sand filter shall be less than 10 turbidity units or so (See 5.1.4 Selection of water treatment methods and facilities).

2) In case only two weeks or so of filter run-time can be achieved, it is desirable to carry out a pre-treatment to remove part of turbidity and plankton algae contents. Sedimentation and primary filtration can be applied for removing turbidity; and, for the removal of plankton, treatment in the reservoir, adjustment of the water level for drawing water, micro-straining, primary filtration, coagulation and sedimentation etc. are applicable. See “5.5 Chemical sedimentation” for raw water turbidity and application of sedimentation.

3) While color caused by iron and manganese in raw water can be removed by the slow sand filter to some extent, color caused by such a stable natural compound as humic acids etc. can hardly be removed.

4) Since the treatment by slow sand filtration depends on organic activities, water polluted by substances, which impede normal organic activities, is unsuitable for slow sand filtration.

5) It is needed to always keep the inside of filter bed in aerobic state. If dissolved oxygen runs short, aerobic bacteria, which perform the decomposition of organic matters and oxidation of nitrogen, will not function, and, furthermore, iron and manganese accumulated in the sand bed will elute. Thus, water with low dissolved oxygen is not directly applicable for slow sand filtration.

5.7.2 Structure and shape

1. The plain sedimentation basin shall be in conformity with the following:

   1) The structure and shape shall be in conformity with “5.5.2 Composition and structure of horizontal flow sedimentation basin”.

   2) The standard overflow rate shall be 5 to 10 mm/min.

   3) The standard average flow velocity in the basin shall be less than 0.3 m/min.

2. The structure and shape of the slow sand filter shall in conformity with the following:

   1) The depth shall be 2.5 m to 3.5 m, which is the total of the height of underdrain, depths of gravel layer and sand layer, water depth above sand bed, and an margin.

   2) The standard shape shall be a rectangle.

   3) The layout shall be in one row or two of basins placed side by side; and space shall be provided in circumference of the facilities as it is needed for operation and maintenance.

   4) The elevation of the crown of the basin walls shall be 15 cm higher than the ground level.

[Interpretation]

On the item 1.2):

The overflow rate shall be determined based on the distribution of raw water turbidity and the actual test data on the settling velocities of the suspended matters.

Assuming the overflow rate at 5 to 10 mm/min and setting its structure in conformity with “5.5.2 Composition and structure of horizontal sedimentation basin”, the retention time of the sedimentation basin will be about eight hours, which is considered to be sufficient even at the time of high turbidity of raw water as judged from experience.
On the item 1.3);
Since it may hinder settling of suspended matters and stir up the settled sludge, if the flow velocity is too high, the standard average flow velocity in the basin was empirically set at 0.3 m/min.

5.7.3 Filtration rate

The standard filtration rate shall be set at 4.0 to 5.0 m/day.

[Interpretation]
Since the slow sand filtration is in principle surface filtration; and the filter layer is renewed by scraping the sand surface, it shall be avoided as much as possible to allow the suspended matters to penetrate into the filter bed. Since a high filtration rate will result in early deterioration of the entire filter layer, leak of turbidity, short filter run-time due to quick rise in head loss etc., it is not advantageous from the viewpoints of water quality and operation and maintenance. Considering these points, the standard filtration rate was set at 4.0 to 5.0 m/day for ordinary surface water. However, the rate can be raised within such a range as slow sand filtration can work in the case of good quality raw water. Even in this case, the maximum rate shall not exceed 8.0 m/day.

After scraping the sand surface, the organic membrane is formed while water is filtered at a low rate and wasted; and such preparatory operation shall be continued until filtered water turbidity becomes less than 0.1 turbidity units; and then the rate shall be slowly raised. It will take some one day in summer and seven days in winter until the filtration function gets ready.

5.7.4 Filter basin floor area and the number of basins

The filter basin floor area and the number of basins of the slow sand filter shall be in conformity with the following:

1. The filter bed area shall be obtained dividing the design water treatment flow by the filtration rate.

2. The number of filter basins shall be more than two, and at least one standby unit shall be provided for every ten or less filters.

[Interpretation]

On the item 1.;
The operation of filters consists of filtration, suspension, sand scraping, resanding etc., and, in addition, the area of a basin shall be determined taking into consideration the size of the water treatment plant, construction cost, ease of operation and maintenance etc. As for actual examples, a large one has an area of 4,000 to 5,000 m²/basin, and small one 50 to 100 m²/basin.

On the item 2.;
Although the necessary number of standby basins depends on run-days of filtration, time required for sand scraping, time in days required for resanding, it shall be provided at least one per every 10 units. The run-days of filtration will mainly depend on raw water quality and the filtration rate; and the time required for sand scraping and resanding will depend on the efficiency of their work and the filter bed area.
5.7.5 Filter sand and depth of sand layer

The filter sand and the depth of sand layer used for slow sand filtration shall be in conformity with the following:

1. The quality of filter sand shall be so specified as its size distribution is proper; the amount of foreign matters is small; it is resistant to attrition; it will not cause any hygienic problems; and it can reliably and efficiently perform filtration.

2. The standard depth of the filter layer shall be 70 to 90 cm.

[Interpretation]

On the item 1;

As to the quality of the filter sand, the following points need to be considered:

1) The effective diameter of sand shall be 0.30 to 0.45 mm. Although the efficiency of filtration is higher with finer grain size, the layer with fine sand is easily subject to clogging, the number of sand scraping increases, and so it is not economical. Hence the effective size of 0.30 to 0.45 mm is often used for slow sand filtration taking the ease of work and the economy into account.

2) The uniformity coefficient shall be less than 2.0. Since slow sand filtration is a type of surface filtration, and unlike in rapid sand filtration, backwash, which causes vertical distribution of coarse and fine sand grains, is not applied, the upper limit of uniformity coefficient is bigger than the rapid sand filter. Notwithstanding, if the uniformity coefficient is too large, while fine filter medium will form a dense filter layer, which will demonstrate a high blocking efficiency, it will develop a large head loss. In addition, the effective diameter will increase as a result of washing of the dirty sand in the long run because the fine part of sand will be washed away causing a change in grain size distribution.

3) The maximum grain size shall be smaller than 2.0 mm, and the minimum size be larger than 0.18 mm.

4) The appearance, wash waste turbidity, ignition loss, specific gravity, attrition loss, and hydrochloric acid solubility shall be in conformity with “5.6.6 Filter sand and its depth”.

On the item 2;

Although slow sand filtration is surface filtration from the turbidity removal point of view, certain depth of filter layer is needed to provide the safety of the filtered water since the sand layer also performs the function of removing dissolved substances. In case the sand surface is scraped repeatedly, the depth of filter sand, which will not cause deterioration in water quality, will depend on the raw water quality, filtration rate, degree of dirtiness of sand, size of sand grain etc, 40 cm or so shall be the minimum limit based on the distribution of organic function in the filter layer and actual experience in operation.

When the terminal depth of 40 cm is reached after repeated scraping, resanding shall be undertaken (See Figure 5.7.5). If the number of scraping required for restoring the filter function is set at 30 times or so, the appropriate initial depth and that after resanding of sand layer shall be 70 to 90 cm.

It will take two to four weeks to restore the filter function after resanding. Since there are few organisms on the sand surface after resanding, a small amount of the scraped sand (without washing) is laid over the new sand so that the supplement and distribution of organisms are aimed and that the restoration of filter function is accelerated. However, it will take one month in summer to two months in winter or so to restore the filter function in case all the sand is replaced.
5.7.6 Filter gravel and depth of gravel layer

The filter gravel and the depth of the gravel layer used for the slow sand filter shall be in conformity with the following:

1. The quality of filter gravel shall be of a proper shape and size with only a small amount of foreign matters contained and no hygienic inconveniences, and be able to adequately support the sand layer.

2. The grain size of the gravel and its depth shall be determined to be properly adapted to the underdrain system. Besides, the coarse filter gravel shall be laid at the lower layer, and the fine one at the upper layer, and they shall be laid layer by layer without undulation.

5.7.7 Underdrain system

The underdrain system shall be in conformity with the following:

1. The underdrain system shall have such a structure and layout that uniform filtration can be performed by the entire area of the filter.

2. The collection conduits and the basin floor shall be sloped for the convenience for dewatering.

5.7.8 Water depth and freeboard

The water depth and the freeboard (clearance from water level to the crown of the basin wall) of the slow sand filter shall be in conformity with the following:

1. The standard water depth over the sand surface shall be 90 to 120 cm.

2. The freeboard shall be 30 cm or so.

[Interpretation]
On the item 1.;

Although the head needed to make water to pass the filter layer, the underdrain system etc. overcoming their friction loss (Reference “H” in Figure 5.7.1) is the filter head, the allowable limit of the filter head is to be set up to the depth of water above sand surface. In other words, the outlet water level shall not be lower than that of the sand surface. The reason is that, if the head loss becomes larger than that, negative pressure will be brought about; air dissolved in water is isolated; and it accumulates inside the sand layer causing “air-binding”, which interrupts filtration. To increase the filter head, it is needed to make the water depth large beforehand.

Since wind will affect the operation of the filter if water depth is shallow, the standard water depth above the sand surface shall be set at 90 to 120 cm. The water level in the filter shall be maintained as constant during filtration so as not to bring flow surge in the filter layer. To this end, gates and valves to control the inlet water (settled water) volume, overflow facilities etc. shall be installed in appropriate locations to effectively adjust the water level.

5.7.9 Regulating device

The regulating device of the slow sand filter shall be in conformity with the following:

1. A regulating device shall be provided at each filter.

2. The regulating device shall be equipped with a flow controller, a head loss meter, indicators for filtration rate and filtered water volume, and pipe and valves if required.

3. The flow controller shall be such as it will not cause negative pressure inside the filter layer.
5.7.10 Water reversing facilities

Water reversing facilities shall be provided in the slow sand filter.

[Interpretation]

After the operation of scraping dirty sand, filtered water is to be introduced backward to the filter from the other filter(s) (Treated water may be used instead of the filtered water). The purpose of this operation is to slowly drive out the air in the sand layer so that it does not cause a trouble for filtration. Water reversing shall be stopped when the water depth reaches 10 cm above the sand surface, and the raw water is slowly introduced. For reversing water, a connecting pipe etc. shall be provided in case the filtered water from the other filters is used by gravity. A pump and water reversing pipe shall be provided in case water is sent by pressure.

5.7.11 Water inlet facilities, overflow pipe and drain pipe

The inlet facilities, overflow pipe and drain pipe (above and under the sand surface) shall be in conformity with the following:

1. The main inlet pipe (conduit) shall be installed close to the filter, and gates or gate valves shall be equipped on the inlet lateral pipes to be connected to the main pipe.
2. One to two inlet lateral pipes shall be provided in accordance with the size of the filter; and its diameter shall be determined based on the average velocity of 50 cm/s or so.
3. A facility to protect the surface of the sand shall be provided around the inlet mouth.
4. The overflow pipe shall be in conformity with “1. of 5.5.8 Desludging pipe and overflow pipe”.
5. The diameter of the drain pipes above the sand surface shall be so set that the time needed for dewatering the filter is 3 to 4.5 hours. Likewise, the diameter of the drain pipes under the sand layer shall be set for 1 to 1.5 hours.
6. The outfall of the drain pipes shall be set at the location where dewatering is always possible and there is no risk of backwater flow of wastewater.

[Interpretation]

On the item 1.;

The main inlet main (conduit) shall be installed close to the filter. Then, at the branching points for the lateral pipes, gates or gate valves shall be equipped for the suspension of the filter, the operation of sand scraping, and control of the inlet flow.

On the item 2.;

Although one or two lateral inlet pipes are provided according to the size of the filter, if the velocity of the inlet flow is large, the filter sand in the vicinity of the inlet mouth is disturbed causing uneven filtration. Thus, the diameter of the inlet pipes shall be as large as possible so that water gently flows into the filter. So the velocity of inlet flow is to be set at 50 cm/s on average or so. It is often set at 30 to 60 cm/s in actual installations (See Figure 5.7.9)
5.7.12 Sand washing facilities

The sand washing facilities for the slow sand filter shall be in conformity with the following:

1. It is desirable for the sand washing facilities to be provided at the location where delivery and moving of sand can easily be made. Besides, boxes for storing washed sand for resanding, scraped sand and unneeded (fine) sand separately.

2. In case sand is washed in the plant site, necessary facilities such as a water source with required quantity and pressure, a settling pit for wastewater of sand wash etc. in addition to the sand wash facilities shall be provided.
5.8 Membrane filtration facilities

5.8.1 General

The membrane filtration is a filtration method by which water is filtered through a membrane as the filter medium to separate and remove impurities in raw water and obtain clean filtered water.

The membranes mainly used for water treatment are the microfiltration and ultrafiltration, and the objective substances for removal are chiefly composed of suspended and other insoluble matters. However, since the raw water often contains dissolved substances, pre-treatment and post-treatment are added to the treatment train in accordance with the substances to be removed. The dissolved substances are classified into the soluble inorganic matters (soluble iron, manganese etc.) and soluble organic matters (odor causing matters, agricultural chemicals, precursors of trihalomethanes etc.)

Although, as a membrane filtration to remove dissolved substances, there is nanofiltration, examples of its actual installation are few to date.

1. Microfiltration (MF)

Using the microfiltration (MF) membrane which has minute holes (pores), visible under a microscope, particles in water are separated by its sieving principle. The particle size range of larger than 0.01 µm or so is the object of separation, of which efficiency is represented by the separable diameter. Since the pore size of membrane commonly used in water treatment is in general 0.01 to 2.0 µm or so, it is used to remove such particles larger than this pore size as colloid, suspended matters and bacteria. A membrane with pores as big as 2.0 µm or so is used to remove cryptosporidiums in some cases.

2. Ultrafiltration (UF)

The ultrafiltration (UF) is a filtration method to use a UF membrane for separation by molecular size by the sieving principle. The UF membrane is defined by the pore size smaller than 0.01 µm, and its separation efficiency is represented by cutoff molecular weight. The range of 1,000 to 300,000 Da of molecular weight is the objective for separation.

3. Nanofiltration (NF)

The nanofiltration (NF) is a membrane filtration to remove molecules of the size of 1 nm or so, which is also called the low pressure reverse osmosis method. It is situated between the UF and the reverse osmosis (RO), and uses a nanofiltration membrane.

The separation methods with the application of these membranes are shown in Table 5.8.1.

The reverse osmosis method used for desalination of sea water is also a type of membrane filtration. In Section 5.8 Membrane filtration facilities, the MF and the UF, many of which have been employed in Japan, are described.
#### Table 5.8.1: Classification of membrane filtration

<table>
<thead>
<tr>
<th>Type of membrane</th>
<th>Separation particle diameter; cutoff molecular weight</th>
<th>Nominal pore size</th>
<th>Principle</th>
<th>Object of removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microfiltration membrane (MF membrane)</td>
<td>Particle size: larger than 0.01µm</td>
<td>0.01 to 0.3µm; membrane with pores of 1 to 2 µm also used for removal of cryptosporidiums etc.</td>
<td>Sieving</td>
<td>Suspended matters, colloid, bacteria, algae, cryptosporidiums etc.</td>
</tr>
<tr>
<td>Ultrafiltration membrane (UF membrane)</td>
<td>Molecular weight: 1,000 to 300,000 Da</td>
<td>Smaller than 0.01µm</td>
<td>Sieving</td>
<td>Suspended matters, colloid, bacteria, algae, virus, cryptosporidiums etc.</td>
</tr>
<tr>
<td>Nanofiltration membrane (NF membrane)</td>
<td>Molecular weight: 200 to 1,000 Da</td>
<td></td>
<td>Sieving; ion removal by surface electric charge</td>
<td>Humic acid, fulvic acid, disinfection byproduct precursors, agricultural chemicals, anionic surfactants, odor causing substances, hardness components such as calcium, total solids etc.</td>
</tr>
</tbody>
</table>

### 4. Reason for employing membrane filtration

The main reasons why the membrane filtration is employed are as follows: (see Figure 5.8.1)

1) It can remove impurities in raw water bigger than a certain size such as suspended matters, colloid, bacteria, cryptosporidiums etc. in accordance with the property of membranes.

2) Although regular inspection, chemical cleaning, replacement etc. of the membrane are needed, its automation is easy, so more saving in labor cost for day-to-day operation and maintenance is possible compared with other treatment methods.

3) Coagulant is not needed, or needed only a little.

4) Only a smaller lot will suffice for its installation than other treatment methods, and the time required for its construction is also short.

5) Since, even if its scale is large, the entire facilities can often be accommodated in a house, and restriction of entrance and exit of visitors and remote video inspection will become easier, the security will be improved against risks (terrorism) compared with other treatment methods.

Since the membrane filtration performs a reliable and high removal rate for bigger substances than a certain size, it is suitable for raw water which does not contain much amount of dissolved substances. Small scale water supplies in general use water source such as clean river water etc., in other words, they often have water sources appropriate for membrane filtration.

![Figure 5.8.1: Reasons for employing the membrane filtration method](image)

As a measure against cryptosporidiums
- Innovation for efficient operation and maintenance
- As a measure to cope with the restricted site space
- Detection of coliform bacteria
- Automation
- As a measure against turbidity at the time of rain and a change in water quality
- Reduction in the operation and maintenance cost
- As a measure against expected deterioration in raw water quality in future

Number of water treatment plants

---

90
5.8.2 Membrane filtration facilities

The membrane filtration facilities shall be in conformity with the following:

1. Appropriate pre- and post-treatment facilities shall be provided so that the water quality goals of treatment can be achieved for the given raw water quality.

2. The number of membrane filtration treatment trains shall be more than two taking into consideration operation and maintenance and suspension of the facilities due to accidents etc.

3. The capacity of facilities shall meet the design water treatment flow, and can also cope with the occasions of the improvement, accidents and so forth.

4. In case the difference of water levels is utilized for membrane filtration, facilities shall be laid out so that the necessary differential pressure on the membrane can be provided.

5. Adequate measures for safety and environmental protection shall be provided.

5.8.3 Pre-treatment facilities

Appropriate pre-treatment facilities of membrane filtration shall be selected from ones such as the following considering the raw water quality, water quality goals of treatment etc. according to the need.

1. Facilities to remove foreign matters
2. Coagulant feeding facilities
3. Sodium hypochlorite feeding facilities and so forth

5.8.4 Membrane and membrane module

The membrane and its module shall be in conformity with the following:

1. The membrane and its module shall be selected taking their treatment efficiency, durability etc. into account.

2. The type of water injection to the module shall be selected with consideration to the nature of the objective water for treatment, the method of cleaning and the characteristics of the membrane.

3. The membrane module, of which inspection and replacement are easy, shall be chosen.

[Intepretation]

On the item 1.;

1) Treatment efficiency

The treatment efficiency of the MF membrane or the UF membrane will depend on the type and pore distribution of the membrane, the nature of the suspended matters in raw water etc. The pores of the MF membrane are 0.01 µm in size if small, and 0.01 to 0.9 µm in general, of which objective substances are solidly shaped particles or microorganisms. In contrast with this, the pore size of the UF membrane is several nm to dozens of nm, with which polymers (molecular weight of 1,000 to 300,000 Da or so), colloid, molecules of protein etc. can be separated. Therefore, the membrane
module etc. is synthetically selected with reference to actual installations and data from experiments. However, if no decision can be made in such a manner, it is needed to implement actual testing before the selection (See Table 5.8.3).

Table 5.8.3: Characteristics of membranes for water supply
(Classification based on “the standards for membrane modules for water supply”)

<table>
<thead>
<tr>
<th>Type of membrane</th>
<th>Membrane with large pores</th>
<th>MF membrane</th>
<th>UF membrane</th>
<th>NF membrane</th>
<th>Reverse osmosis membrane (RO)</th>
<th>RO membrane for desalination of seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>AMST-004</td>
<td>AMST-001</td>
<td>AMST-001</td>
<td>AMST-002</td>
<td>AMST-002</td>
<td>AMST-003</td>
</tr>
<tr>
<td>Nominal pore size</td>
<td>2 µm or so</td>
<td>&gt;0.01µm</td>
<td>&lt;0.01µm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutoff molecular weight</td>
<td>1,000 to 300,000 Da or so</td>
<td>200 to 1,000 Da</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium chloride removal rate (Salt rejection rate)</td>
<td>&lt;5 to 93% *1</td>
<td>&gt;93% *2</td>
<td>&gt;90% on average concentration standard; &gt;98.5% on artificial concentration standard *3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Membrane structure</td>
<td>Asymmetry etc.</td>
<td>Symmetry, asymmetry</td>
<td>Symmetry, asymmetry</td>
<td>Asymmetry, combined type</td>
<td>Asymmetry, combined type</td>
<td>Asymmetry, combined type</td>
</tr>
<tr>
<td>Membrane material</td>
<td>PS, PVDF, CE etc.</td>
<td>CE, PAN, PE, PP, PS, PVA, PVDF, PTFE etc.</td>
<td>C, CA, E, PAN, PES, PS, PVDF etc.</td>
<td>CA, PA etc.</td>
<td>CA, PA etc.</td>
<td>CA, PA etc.</td>
</tr>
<tr>
<td>Manufacture method</td>
<td>Phase transition method etc.</td>
<td>Phase transition method, drawing method, sintering method</td>
<td>Phase transition method, interface polymerization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Module</td>
<td>Hollow fiber type etc.</td>
<td>Hollow fiber type, spiral and tube type, film type, monolith type</td>
<td>Hollow fiber type, spiral type, film type etc.</td>
<td>Hollow fiber type, spiral type, film type etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: *1 Evaluation condition NaCl conc. 500-2,000mg/L, applied pressure 0.3 – 1.5 MPa
*2 Evaluation condition NaCl conc. 500-2,000mg/L, applied pressure 0.3 – 3.0 MPa
*3 Evaluation condition NaCl conc. Or TDS conc. 3.0×10^4 – 6.0×10^4 mg/L

Symbols for membrane materials are the following:
Inorganic membrane CE: ceramics

2) Durability etc.
(1) Selection of the membrane and its module

(i) The membrane and its module shall possess enough durability to stand such mechanical changes as the positive and negative pressure during filtration, repeated stress by aeration at the time of cleaning, deformation by thermodynamic changes during prolonged use and chemical changes caused by cleaning chemicals. Furthermore, shocks by water hammers on the membrane and its module shall be avoided as much as possible.

(ii) Since there is a risk that the membrane and its module can permanently be damaged by freeze, they shall be selected after carefully studying their low temperature resistance.
(iii) Since various chemicals such as alkali or acid, oxidizing agents, organic acid, detergents etc., the chemical resistance of the membrane shall sufficiently be studied beforehand.

(2) Membrane material

The material of the membrane shall be selected so as to be suitable to the nature of the objective water and the cleaning method fully taking into account the property of the membrane as follows:

(i) The organic membranes are divided into the hydrophilic type and hydrophobic type by its material, and they possess different thermal and chemical resistance. Since the membrane with a cellulose family material has a risk of erosion by microorganisms, control of microorganisms by chlorination is needed.

(ii) The inorganic membrane has higher thermal and chemical resistance than the organic membrane, but it is vulnerable to impacts although it has high physical strength. However, it is a must for the membrane to be provided with coagulant dosing. On the other hand, it is noted that the dose of coagulant is not suitable for the inner pressure type membrane in some cases.

Since there are considerable differences in life and price of the membrane depending on its material, synthetic examination including an economic analysis is needed.

3) Deterioration and fouling of membrane

Over the time in operation, deterioration and fouling of the membrane occur.

(1) Deterioration of membrane

The deterioration of the membrane includes physical changes such as deformation as creep and damage by pressure, chemical changes such as hydrolysis, oxidization etc., biological deterioration (bio-fouling) by digestion (consumed as nutrient) by microorganisms, which is an irreversible qualitative change of the membrane itself, and its recovery is said to be impossible.

(2) Fouling

It is not a change in membrane itself, but a phenomenon that the function of the membrane decreases as a result of the progress of clogging and the formation of an absorbing layer on the membrane as solute in the feed water is checked by the membrane. Such a change in membrane efficiency can be recovered by cleaning depending on the cause. On cleaning, reference “5.8.6 Cleaning of membrane and treatment of cleaning wastewater”.

The classification and definition of deterioration, fouling and their contents of the membrane module are presented in Table 5.8.4.
Table 5.8.4: Deterioration and fouling of membrane module

<table>
<thead>
<tr>
<th>Classification</th>
<th>Definition</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterioration</td>
<td>Irreversible decrease in efficiency caused by qualitative change in the membrane itself</td>
<td>Physical degradation, Degradation by consolidation, Damage, Dehydration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compaction of membrane structure due to long-time pressure load (creep transformation), Wounds and attrition on membrane surface caused by solids in raw water or vibration; Irreversible change in membrane structure caused by rupture, dehydration and contraction</td>
</tr>
<tr>
<td></td>
<td>Chemical degradation, Hydrolysis Aging</td>
<td>Decomposition of membrane by the function of pH, temperature etc.; Qualitative change in membrane by oxidizing agents</td>
</tr>
<tr>
<td>Fouling</td>
<td>Decrease in efficiency of membrane caused not by qualitative change in membrane itself but external factors</td>
<td>Adhesion layer Cake layer Gel layer Scale layer Adsorption layer</td>
</tr>
<tr>
<td></td>
<td>Clogging</td>
<td>Solid: Clogging by adhesion, separation, trapping etc. at pores of membrane Liquid: Permutation of hydrophobic porous region of membrane by gaseous body</td>
</tr>
<tr>
<td></td>
<td>Clogging of stream channels</td>
<td>Phenomenon of impeded flow due to clogging of inlet channel or outlet channel by solids</td>
</tr>
</tbody>
</table>

[Reference 5.11] JWRC Specification for membrane modules for water supply

On the membrane module of MF membranes and UF membranes for water supply used in water treatment, the JWRC specification for membrane modules for water supply issued by the Japan Water Research Center is presented mainly aiming at interchangeability of dimensions (Reference Figure 5.11.1). The JWRC specification prescribes the vertical integrated casing type (Type 1-A, 1-B), the horizontal casing storage type (Type 2-A), the vertical casing storage type (Type 3-A, B, C) (For detailed dimensions, see “JWRC Module Specification for water supply” issued by the Japan Water Research Center).

Reference figure 5.11.1: Schematics of membrane modules for water supply in conformity with JWRC specification
On the item 2.;

There are two type of feeding the membrane module with water: the external pressure type, which feeds the objective water from outside of the membrane, and the internal pressure type, which feeds water from inside. For their selection, such a module shall be selected that the structure of the membrane and its module is suitable for the characteristics of the objective water, the method of cleaning, the property of the membrane etc. The following are the types of membrane modules.

1) Hollow fiber type membrane module

It is a bunch of filamentous hollow fibers of 0.5 mm to 3.0 mm or so of outside diameter, with which the apparatus is more compact than other types since no support is needed for the membranes, and so the membranes can in general be densely packed. An example of the hollow fiber type membrane module is shown in Figure 5.8.8.

![Figure 5.8.8: Hollow fiber type module](image)

An example of tank submerged type membrane module

2) Flat sheet type membrane module

Figure 5.8.9 shows an example of the flat sheet type membrane module. The rotating flat sheet type module is of an external pressure type, and has discs fit on a rotating axis cum collecting pipe. Submerged sucking flat sheet type module has membrane elements composed of the perforated support discs with membranes stuck on their both sides, which make collection chambers.

![Figure 5.8.9: Flat sheet type module](image)
3) Spiral wound type module

It is a module consisting of a pressure vessel and sheet membranes, which are molded in an envelope-like bag, and are wound together with spacers to form a column and encapsulated in a vessel (pressure container). The module has membranes densely packed in it, and the head loss though it is small. An example of the spiral wound type module is presented in Figure 5.8.10.

4) Tubular type module

The tubular type module is a perforated pipe module fit with cylindrically molded membrane with a diameter of 3 to 15 mm on either outer or inner side of a perforated pipe. There are two methods of filtration with it: the external pressure method, and the interior pressure method. For the interior pressure module, although its packing density is small, it can be cleaned with a sponge ball, whereas the external pressure type module has small head loss, and its cleaning is easy. Figure 5.8.11 shows examples of the tubular type modules.

5) Monolith type module

It is also called a multi-lumen membrane or a multi-channel membrane since flow channels are bored in a support body molded as a pillar; dense layer is formed on the surface of the channels; and it looks like a stone pillar (monolith). The material of the monolith membrane is in general ceramics. It is naturally designed as an internal pressure type as restricted by the form of the membrane. An example of the monolith type module is presented in Figure 5.8.12.
5.8.5 Membrane filtration facilities

The membrane filtration facilities shall be in conformity with the following:

1. The recovery rate shall be set by synthetically examining the efficiency, cost etc. taking the condition of water intake, quality of feed water, wastewater treatment and so on into account.

2. The flux and area of the membrane shall be set on the following factors:

   1) The flux of membrane filtration set at an appropriate value by synthetically examining the following conditions, cost and the ease of maintenance:
      1. Type of membrane
      2. Quality and the lowest temperature of the feed water
      3. With or without the pre-treatment facilities and their method
      4. The surroundings and the site space

   2) The area of membrane shall be determined by the following formula based on the flow of filtration and the flux.

   \[
   \text{Area of membrane (m}^2\text{)} = \frac{\text{Flow of filtration (m}^3\text{/day})}{\text{Flux of membrane filtration (m}^3\text{/m}^2\text{*day})}
   \]

3. The type of membrane filtration and its operation control shall be so designed as follows:

   1) The most proper type of membrane filtration shall be selected taking the quality of feed water, the type of the membrane etc. into account.

   2) The most suitable type of pressure driving and its operation control shall be chosen considering the driving pressure, the type of membrane, conditions for drainage etc.

   3) The operation of membrane filtration shall in principle be of automation.

   4) A detection mechanism shall be installed for the damage of membranes.
5.8.6 Cleaning of membrane and wastewater treatment

1. The physical washing and chemical cleaning for the recovery of performance of membrane shall be in conformity with the following:

   1) The method of physical washing shall be selected for its suitability for the membrane material and structure, module, type of filtration, type of operation control etc.

   2) As to chemical cleaning, a type effective to the nature and degree of fouling matters shall be selected.

   3) The chemicals used for cleaning shall not cause any hygienic troubles.

2. For membrane filtration facilities, facilities necessary for treatment of waste etc. from physical washing and chemical cleaning (in the case chemical cleaning is performed in the water treatment plant) shall be installed.

5.8.7 Mechanical and electric facilities

In addition to the provisions in “8. Mechanical, electrical and instrumental facilities”, the mechanical and electric facilities for membrane filtration facilities shall be in conformity with the following:

1. Pumps shall meet the following requirements:

   1) Proper types, capacity and the number of units of pumps shall be selected.

   2) Standby units of pumps shall in principle be provided. However, in case they are installed in each block, their needs shall be examined taking the treatment capacity of the block etc. into account.

   3) The lift of the feed pump of membrane filtration (raw water or circulation pump) shall be determined adequately studying the pressure-resistance of the membrane and its module.

2. The air source facilities (for operation and cleaning) shall meet the following requirements:

   1) Proper type, capacity and number of units of compressors (including blowers) shall be selected taking the method of operation and the method of cleaning into consideration,

   2) Standby units shall in principle be provided for compressors and blowers.

   3) The air source tanks shall have capacity with consideration to operation in an emergency.

3. The electric facilities shall be in conformity with the following:

   1) In case remote control devices etc. for which uninterruptible power supply is needed, an uninterruptible power source shall be provided.

   2) The main power source, power source for instrument etc. shall be divided for each block and independently provided for the regular use and emergency use.
5.8.8 Ancillary facilities

The ancillary facilities such as the raw water tank, the wash waste tank etc. shall meet the following requirements:

1. The raw water tank shall be as follows:
   1) A raw water tank shall in principle be provided in membrane filtration facilities.
   2) It is desirable to divide the raw water tank into more than two units with consideration to operation and maintenance.
   3) In case chemicals are dosed in the raw water tank, its structure shall be so designed that the chemical is fully mixed, or a mixing device shall be installed.

2. The tanks for washing, water supply in the plant etc. shall meet the following requirements:
   1) The tanks for washing shall be installed taking the membrane material, method of cleaning etc. into account.
   2) The tanks for washing shall be hygienically safe and possess necessary capacity.

3. The chemical tanks shall be in conformity with the following:
   1) For the chemical tanks, materials durable against the chemicals to be stored shall be used, and its earthquake-resistance shall be considered.
   2) More than two units of chemical tanks used for water treatment shall in principle be installed.

4. Piping and valves shall meet the following requirements:
   1) For piping, its material and structure shall be selected so that they can endure the use for a long time considering operating pressure, environment of laying etc.
   2) For valves used for switching etc. in the automation regime, ones with proper type and driving method shall be selected taking their reliability, the ease of maintenance etc. into account.
   3) Valves shall be installed at the proper locations adequately considering operation and maintenance.
   4) Freeze proofing measures shall be provided at necessary locations in cold districts.
5.9 Clear water well

5.9.1 General

1. Role of the clear water well

The clear water well is the terminal facility in the water treatment facilities, which alleviates the imbalance between the filtration flow and the transmission flow during the operation of the water treatment plant; stores finished water in provision for a change in water quality caused by abnormal raw water quality, an accident, inspection of facilities, maintenance work etc. In case there are service reservoirs in the plant premises, the service reservoir may function as the clear water well, and play a role of an emergency water service point at the time of earthquake disaster etc.

2. Disinfection operation

In case a clear water well is newly built, reporting to the authority and its inspection shall be made prior to its commencement in accordance with Article 13 of the Water Supply Law. The details on the disinfection operation refers to “Clear water well” of the “Criteria on the operation and maintenance of water supply facilities 20067.8”.

The general matters on concrete structures of the clear water well and the service reservoir will be described in this chapter.

5.9.2 Structure

The structure of the clear water well shall be in conformity with the following:

1. The structure shall have sufficient earthquake-resistance and durability, hygienic safety, and water-tightness.
2. The number of units of the wells shall be more than two.
3. A freeboard of 30 cm or so from the high water level to the upper slab shall be provided.
4. The level of the floor slab shall be 15 cm lower than the low water level.
5. The floor slab shall be sloped for the convenience of dewatering if needed.
6. Measures to prevent subsidence or rise etc. of the structure shall be provided in case the clear water wells are constructed where the groundwater level is high, on sandy soil, in reclaimed land etc.
7. In case there is a need to maintain the water temperature in a cold district, necessary measures shall be made.

5.9.3 Water level

The water level in the clear water well shall be in conformity with the following:

1. The standard water depth shall be 3 to 6 m.
2. The high water level shall be determined based on the hydraulic condition in the treatment facilities as a whole.
### 5.9.4 Capacity

The effective capacity of the clear water well shall be equivalent to more than one hour of the design daily water treatment flow.

### 5.9.5 Inlet pipe, outlet pipe and bypass pipe

1. The inlet pipe and the outlet pipe shall be as the following:
   1) Their locations and the number shall be selected so that no dead water occurs in the well taking the structure of the well into consideration.
   2) The elevation of the pipe center of the outlet pipe shall be twice the pipe diameter lower than the low water level.
   3) Water tightness shall be provided at the points on the structure through which pipes are laid. In addition, flexible joints shall be fit on pipes close to the outside of the wall of the well if required.
   4) Stop valves shall be installed on the inlet and outlet pipes.
   5) Emergency stop valves shall be installed on the outlet pipes if required.

2. The bypass pipes shall be as the following:
   1) Bypass pipes shall be provided so that water can directly be transmitted or distributed bypassing the clear water well.
   2) A stop valve shall be installed on the bypass pipe.

### 5.9.6 Overflow and drainage facilities

1. The overflow facilities shall be as the following:
   1) The overflow shall be made at the high water level, and the form of its head is to be a bell mouth or a weir.
   2) The capacity of overflow shall be determined based on the surface area of the well, freeboard and the quantity of incoming flow.
   3) The highest elevation of the water level at the outfall of the overflow facilities shall be lower than the level of the overflow mouth (weir).

2. The drainage facilities shall be as the following:
   1) A drain pipe shall be placed at the lowest point in the well, and a stop valve shall be fit on it.
   2) The diameter of the drainage pipe shall be set based on the quantity of water stored lower than the low water level in the well and time required to empty the well.
   3) The high water level at the outfall of the drain pipe shall be lower than the lowest point of the well. In case the entire water cannot be drained by gravity, a drainage pit shall be provided so that water can be pumped out.
5.10 Disinfection facilities

5.10.1 General

1. The need for disinfection

The tap water shall be hygienically safe without contamination with pathogenic organisms. Since it is impossible to perfectly remove pathogenic organisms by sedimentation and filtration, filtered water shall always be disinfected without fail so as to ensure the hygienic safety in the water distribution system. To this end, disinfection facilities shall always be provided in water treatment facilities irrespective of the size of the facilities or the method of water treatment.

2. Method of disinfection

Since the residual chlorine concentration to be present in tap water is prescribed by the enforcement regulations of the water supply law, and it is also stipulated in the notice of the Ministry of Health, Labor and Welfare in that “The disinfection of drinking water shall be undertaken by chlorination”, no other means of disinfection than chlorination is permitted. The merits of chlorination are that the effect of disinfection is high, that a large quantity of water can easily be disinfected, that the effect of disinfection remains, and so forth. The goal of upper limit of residual chlorine is prescribed as one of setting items for water quality control goals.

Chlorine produces such chlorinated organic molecules as trihalomethanes, enhances odor by reacting with particular substances, and possesses the nature for its disinfection efficiency to be weakened by the reaction with ammonium nitrogen in water. With chlorine dosage as small as possible at the water treatment facilities, and additionally dosing chlorine at various points in the service area, safe and palatable water can be served while keeping the residual chlorine concentration low.

On the other hand, it has been found that the disinfection of cryptosporidiums etc., which are chlorine resistant pathogenic organisms, by chlorine agents is not complete. In case raw water is contaminated by cryptosporidiums etc., although it was a norm to conduct the treatment by filtration etc., the disinfection by ultraviolet ray treatment became possible since April, 2007 (See 5.19 ultraviolet ray treatment facilities).

3. Chlorine agents

Since the dosage of chlorine will depend on water quality, the chlorine agent and the capacity of its feeding facilities shall be determined based on the adequate examination of the dosage, the size of the facilities, the ease of handling etc.

Of chlorine agents, sodium hypochlorite has a drawback of reduction in the effective chlorine components due to decomposition and increase in chloric acid. Since liquid chlorine is regulated for its handling by such laws as the High-pressure gas safety law, the Labor safety and health law etc. and related standards, the structure, earthquake-resistance, quality of material of the structure, and the aspects of its maintenance shall be suitable to fully meet the requirements of the laws and regulations. Besides, in case liquid chlorine has been used, it is needed to study the merit of changing over to the safer sodium hypochlorite to prevent the secondary disaster caused by an earthquake etc.

4. Storage facilities

The storage facility of the chlorine agent shall have appropriate capacity based on its consumption; and its feeding facilities can precisely measure and dose quantity from the maximum to the minimum flows, and shall have sufficient capacity and number of units including the standby units. In addition, in case more than two types of disinfection agents are used, operation can be maintained by switching the disinfection agent even at the time of failure of the feeding facility etc. The feeding method shall be selected from the constant flow feeding method or the flow proportional feeding method suitable for the operational condition based on the type of chlorine agent, amount of water to be treated etc.
The neutralization facilities shall have sufficient capacity lest the leakage of chlorine gas leads to a serious disaster.

In case facilities are replaced or the chlorine agent is changed, provision of the temporary facilities, their operation, the method of changeover etc. shall be examined.

### 5.10.2 Types of chlorine agents, dosage and points of dosage

1. A proper type of chlorine agent shall be selected taking the quantity of treated water, the ease of handling, safety etc. into consideration.

2. The dosing of chlorine agent shall be consistent with the following:
   1) The chlorine dosage shall be so determined that the chlorine residue becomes the prescribed concentration at the tap after consideration for chlorine consumption, its demand, its consumption in the water treatment process, and its consumption after the departure from the water treatment plant.
   2) The concentration of the chlorine agent shall be set taking its dosage, the ease of its handling etc. into account.
   3) The dosing quantity shall be computed from the treatment water flow and the dosage.
   4) The point of chlorine application shall be at the receiving well, chlorine mixing chamber, the entrance to the clear water well etc. where mixing is effective.

3. In case there is a need to control chlorine residue even outside of the water treatment plant, additional chlorine feeding facilities shall be provided at a service reservoir etc.

[Interpretation]

**On the item 1.;**

As the chlorine agents, sodium hypochlorite, liquid chlorine and calcium hypochlorite (containing high-test hypochlorite) are available. In addition, there is a method to produce sodium hypochlorite by a homemade (in situ) method of electrolysis.

1) **Types of chlorine agents**

1. **Sodium hypochlorite**

   In general it is a light yellowish liquid containing more than 12 % of effective chlorine, and shows strong alkalinity. The higher the initial effective chlorine contents, the faster the reduction in the effective chlorine during storage. The sodium hypochlorite contains chloric acid as impurity, which is one of the standard water quality items. Since chloric acid is a product of the decomposition of sodium hypochlorite, which contains the effective chlorine, the one with more reduction in the effective chlorine contains more chloric acid. Even though it is safer and easier to handle than the liquid chlorine, it decomposes while releasing oxygen during storage, and its bubbles accumulate in the pipeline or inside the pump, which may block the flow of the liquid. See 8.5.2 Chemical feeding facilities for more details.

Under the Japan Water Works Association standards, sodium hypochlorite is classified into four classes by the contents in it of chloric acid, bromic acid, sodium chloride etc.: special grade, 1st class, 2nd class, and 3rd class. Since, if the concentration of sodium chloride is very high, its separation occurs and adversely affects pumps and piping, it is desirable for sodium hypochlorite to contain less than 4 % of sodium chloride.
Since the concentration of effective chlorine in sodium hypochlorite to be produced by the in situ apparatus is as thin as 1 to 6 %, although it causes fewer trouble of bubbles than the sodium hypochlorite to be supplied from the market, more complex facilities are required.

(2) Liquid chlorine

It is liquefied chlorine gas filled in a container. Since the chlorine gas is heavier than air, irritating, and highly toxic, adequate attention shall be paid for its handling abiding by the law. Since the effective chlorine in liquid chlorine is almost 100 %, the volume of storage can be small, and its quality is reliable. Neutralization facilities for it are needed due to the nature of the chlorine gas.

(3) Calcium hypochlorite

It is available in powder, granular or tablet form, its effective chlorine is more than 60 %, and has good storability.

2) Selection of chlorine agent

The ease of operation and maintenance and safety at the time of disaster of the facilities shall be taken into consideration together with such properties etc. of each type of chlorine agents as stated above. With respect to these aspects, it is desirable to use sodium hypochlorite purchased from the market or produced by the in situ apparatus. Sodium hypochlorite purchased from the market is popularly used in most water supplies of late. Furthermore, sodium hypochlorite produced by the in situ apparatus is sometimes used for the prevention of a secondary disaster of an accident during transportation of sodium hypochlorite.

For stocking the chlorine agent as preparation for an emergency use at the time of a disaster, the calcium hypochlorite is recommended for the ease of its handling and stability.

The quality standards of chlorine agents are shown in Table 5.10.11.

<table>
<thead>
<tr>
<th>Item</th>
<th>Type</th>
<th>Liquid chlorine</th>
<th>Sodium hypochlorite for water supply</th>
<th>high-test hypochlorite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>JSIA 05-1998</td>
<td>JWWA K 120: 2008</td>
<td>JIS K 1425</td>
<td></td>
</tr>
<tr>
<td>Special grade</td>
<td>1st class</td>
<td>2nd class</td>
<td>3rd class</td>
<td>No. 1</td>
</tr>
<tr>
<td>Effective chlorine (%)</td>
<td>99.4</td>
<td>More than 12.0</td>
<td>&gt;70</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Appearance</td>
<td>Light yellowish transparent liquid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Density (sp gr)</td>
<td>&lt;1.16</td>
<td>&lt;1.16</td>
<td>&lt;1.16</td>
<td>-</td>
</tr>
<tr>
<td>Free alkali (%)</td>
<td>Less than 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bromic acid (mg/L)</td>
<td>Less than 10</td>
<td>Less than 50</td>
<td>Less than 100</td>
<td>Less than 100</td>
</tr>
<tr>
<td>Chloric acid (mg/L)</td>
<td>Less than 2000</td>
<td>Less than 4000</td>
<td>Less than 10000</td>
<td>Less than 10000</td>
</tr>
<tr>
<td>Sodium chloride (%)</td>
<td>Less than 2.0</td>
<td>Less than 4.0</td>
<td>Less than 4.0</td>
<td>Less than 12.5</td>
</tr>
</tbody>
</table>

On the item 2.;

On the item 2.1):

Since the concentration of residual chlorine at the tap is prescribed by the law, the dosage of chlorine to maintain the prescribed concentration shall be determined with reference to the following:

(1) Concentration of free or combined residual chlorine to be maintained at the tap

The residual chlorine concentration to be maintained at the tap shall be sufficient to sterilize such pathogenic organisms as dysentery bacillus, typhoid bacillus etc. and its concentration shall be more
than 0.1 mg/L for free residual chlorine or 0.4 mg/L for combined residual chlorine in an ordinary
time; and 0.2 mg/L and 1.5 mg/L respectively in the occasions when a gastrointestinal infectious
disease is prevalent or water service is resumed after its suspension in a large area.

(2) Amount of chlorine to be consumed between the exit of the water treatment plant and the
consumer’s tap

There are the amount of chlorine, which is consumed when it comes to contact with such facilities as
the service reservoir, transmission and distribution mains, service pipes, pump, water meter etc., and
that which is consumed by oxidizable substances. The former is almost constant depending on the
facilities whereas the latter fluctuates depending on the amount of oxidizable substances and time for
water to travel from the exit of the water treatment plant to the consumer’s tap.

(3) Chlorine demand or consumption by water

Since chlorine is consumed by such oxidizable substances as organic matters, iron, manganese,
ammonium nitrogen etc. in water, chlorine demand or consumption of raw water shall be measured for
a period including the season of fluctuating water quality. At the same time, based on this result, it
shall be determined which chlorination method is to be employed, namely, by free residual chlorine or
combined residual chlorine.

The dosage (maximum, minimum and average) range is determined as the total of above (1) and (2)
with consideration to the value of (3). The maximum dosage shall be determined based on the
expected future trend of ammonium nitrogen in raw water (Chlorine of about 10 times the amount of
ammonium nitrogen is said to be required depending on the water quality).

[Reference 5.13] Basic matters on chlorine agents

1. Effects of disinfection

Sodium hypochlorite and liquid chlorine, if dosed in water, will yield hypochlorous acid and
hypochlorous acid ion.

In the case of sodium hypochlorite:

\[ \text{NaClO} + \text{H}_2\text{O} \rightarrow \text{HClO} + \text{NaOH} \]

\[ \text{HClO} \rightarrow \text{ClO}^- + \text{H}^+ \]

In the case of liquid chlorine:

\[ \text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HClO} + \text{HCl} \]

\[ \text{HClO} \rightarrow \text{ClO}^- + \text{H}^+ \]

Although the hypochlorous acid (HClO) and hypochlorous acid ion (ClO\(^-\)) are the same effective
chlorine, their disinfection abilities are different from each other, and the hypochlorous acid has
stronger disinfection ability than hypochlorous acid ion.

Since the ratio of hypochlorous acid to hypochlorous acid ion becomes high (more the former than the
latter) as pH gets low, the lower the pH, the higher the disinfection effect (See Reference Figure
5.13.1).
2. Effective chlorine

The effectiveness of sodium hypochlorite (NaClO) is equivalent to that of liquid chlorine (Cl₂).

\[ \text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Cl}^- + 2\text{OH}^- \]

3. Free residual chlorine and combined residual chlorine

Chlorine, if dissolved in water, reacts with water and becomes hypochlorous acid (HClO) and hydrochloric acid, and part of hypochlorous acid will dissociate into hypochlorous acid ion (ClO⁻) and hydrogen ion.

This reaction is reversible, and will change by pH and water temperature. Hypochlorous acid and hypochlorous acid ion are called free chlorine or free residual chlorine.

On the other hand, if ammonium nitrogen exists in water, chlorine will react with it and yield chloramines. Chloramines include monochloramine (NH₂Cl), dichloramine (NHCl₂) and trichloramine (NCl₃); and different chloramines are yielded in relation to the existence ratios of ammonium nitrogen and chlorine. Monochloramine and dichloramine are called combined chlorine or combined residual chlorine.

Since the disinfection ability of free residual chlorine is higher than that of combined residual chlorine, it is needed to make the concentration of combined residual chlorine high so as to obtain the same disinfection ability with free residual chlorine.

4. CT value

CT value stands for a product of the concentration of disinfection agent C (mg/L), which is needed to get to a certain sterilizing rate or inactivation rate, and the contact time T (min). See Reference Table 5.13.1.
Reference Table 5.13.1: CT values for disinfection agents against microorganisms

<table>
<thead>
<tr>
<th>Microorganism species</th>
<th>Disinfection agent</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free chlorine</td>
<td>Chloramine</td>
<td>Chlorine dioxide</td>
<td>Ozon</td>
</tr>
<tr>
<td></td>
<td>pH 6 – 7</td>
<td>pH 8 – 9</td>
<td>pH 6 – 7</td>
<td>pH 6 – 7</td>
</tr>
<tr>
<td>E. Coli</td>
<td>0.034-0.05</td>
<td>95-180</td>
<td>0.4-0.75</td>
<td>0.02</td>
</tr>
<tr>
<td>G. lamblia cysts</td>
<td>47-&gt;150</td>
<td>2,200 (a)</td>
<td>26 (a)</td>
<td>0.5-0.6</td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>7,200 (b)</td>
<td>7,200 (c)</td>
<td>78 (c)</td>
<td>5-10 (b)</td>
</tr>
</tbody>
</table>

Note: CT value is the value needed for 99% inactivation at 5 degrees C (excluding the following exceptions)

Unit: mg-L-min

(a) The value for 99.9% inactivation at pH6-9, temperature 25 degrees C
(b) The value for 99% inactivation at pH7, temperature 25 degrees C
(c) The value for 90% inactivation at pH7, temperature 25 degrees C

Source: Disinfection by ozon, Shin-ichiro Ogaki, Jour. JWWA Vol. 64, No. 10 (Serial No. 733, p16, October, 1995)

5. Chlorine demand and chlorine consumption

In the case of chlorination by free residual chlorine, the dosage shall be determined based on the chlorine demand; and in the case of chlorination by combined residual chlorine, the dosage shall be determined by the chlorine consumption. In general, there is no difference between the chlorine demand and chlorine consumption with water of good quality. However, the difference becomes large if water contains a large amount of ammonium nitrogen etc.

Reference Figure 5.13.2 indicates the relationship between chlorine dosage and the concentration of residual chlorine; Type I, II or III will be yielded depending on the water quality.

The Type I will be yielded if water contains perfectly no organic matters or oxidizable substances; such water does not exist. The Type II occurs with water which possesses a certain amount of chlorine demand, and free residual chlorine is detected in proportion to the increase in chlorine dosage. The Type III occurs in the case water contains ammonium nitrogen, combined residual chlorine is yielded if chlorine is dosed in such water, and its concentration increases in relation to the chlorine dosage. However, after the dosage reaches a certain level, the residual chlorine decreases despite the increase in chlorine dosage, and it decreases nearly down to zero or zero (Excessive chlorine decomposes chloramines). As chlorine dosage further increases, free residual chlorine increases in proportion to the increase in chlorine dosage.

In the Type II, the chlorine dosage up to “Point a” is chlorine demand, and also chlorine consumption. In the Type III, the dosage up to “Point b” is chlorine consumption; and that up to “Point c” is chlorine demand.

Figure 5.13.2: Relationship between chlorine dosage and residual chlorine concentration
6. Break point chlorination

It is a method of chlorination, in which disinfection is performed by residual chlorine in case ammonium nitrogen is present in water. The point “c” in the curve Type III in Reference Figure 5.13.2 is called a break point. The method, if chlorine is dosed beyond this point, is called the break point chlorination so that residual chlorine is detected. Since the free residual chlorine possesses strong ability of oxidation and sterilization, it can sufficiently treat dissolved manganese, and perform disinfection. However, attention shall be paid to such disinfection byproducts as trihalomethanes etc.

7. Combined chlorine treatment

In case few bacteria and a large amount of ammonium nitrogen are present in such water as groundwater, disinfection can also be performed by combined residual chlorine. For water quality with ammonium nitrogen due to pollution, disinfection shall be carried out by break point chlorination lest disinfection is insufficient. However, in case the residual chlorine needs to be sustained for a long time or combined chlorine treatment is performed to prevent the increase in color, occurrence of odor etc., after ammonium nitrogen and chloramines are decomposed by chlorine, ammonia and chlorine are dosed as much as to yield combined residual chlorine. Ammonia as ammonium chloride can be fed by an apparatus similar to the one for feeding of chlorine.

In the case of treatment by combined chlorination, enough contact time shall be given by the time of service. What is more, in case the water treated by combined chlorine in the service reservoir and that which is treated by break point chlorination are mixed, there is a risk that the residual chlorine may disappear, so such mixing shall be avoided.

5.10.3 Storage facilities

1. Storage of chlorine agents shall be for more than 10 days of daily average feeding quantity.

2. The storage facilities for sodium hypochlorite to be supplied from the market shall be in conformity with the following:
   1) The chlorine agent shall be stored in more than two tanks or vessels.
   2) The tanks or vessels shall be set in a shade with good ventilation and in a place safe from the earthquake and fire.
   3) A barrier fence or pit against leak of the liquid surrounding the tanks shall be provided.
   4) The material of the tanks or vessels, which comes to contact with sodium hypochlorite, shall be corrosion resistant.
   5) A ventilator or an air-conditioner shall be installed at the storage room.
   6) The floor of the room shall be sloped, and applied with corrosion resistant mortar etc.

3. The storage facilities of salt as the raw material of sodium hypochlorite produced in situ shall be as follows:
   1) The salt shall be stored in more than two tanks.
   2) The tank shall be so structured that the salt is not exposed to rain or direct sunlight, and it shall be earthquake resistant and fireproof.
   3) A barrier fence or pit shall be provided surrounding the tanks.

4. The storage facilities of liquid chlorine by a container shall be in conformity with the following:
1) The container shall be of 50 kg or 1 t contents, which has passed the tests stipulated in the law, and is put a number seal.

2) The container shall be stored in the temperature of lower than 40 degrees C.

3) A stand to fix the container shall be provided. In case 1 t containers are used, an apparatus for moving-in and –out shall be provided for the containers.

5. The storage facilities for liquid chlorine shall be in conformity with the following:

1) Air source facilities for receiving liquid chlorine to the storage tank shall be provided.

2) The containers shall be the one that has passed the tests stipulated in the law.

3) The containers shall not be provided with heat insulating materials and provided with a control desk for the operation of valves etc.

4) More than two containers shall be installed, one of which shall be a standby unit.

6. The room for the storage of liquid chlorine shall be in conformity with the following:

1) The room shall be so structured that the room temperature is always maintained at 10 to 35 degrees C.

2) It shall be earthquake resistant and fireproof, and constructed in a safe place.

3) As its location, a humid place shall be avoided; the room can be shut tight; and it shall have two doors on the different sides.

4) The entrance to the room, where the chlorine containers are stored, shall be air-tight and fitted with a double-door.

5) A barrier fence or a pit shall be provided so that the diffusion of leaked liquid chlorine can be prevented.

6) The room shall be separated from the room for the feeding apparatus, and situated in a place convenient for delivery and moving of the containers and in a location where its inspection is easy.

7. The storage of chlorine agents shall be in conformity with 2. above.

[Interpretation]

On the item 2.3):

Sodium hypochlorite erodes almost everything due to its strong alkalinity and oxidizing action. Besides, since it produces chlorine gas reacting with such acidic chemicals as sulfuric acid, hydrochloric acid, coagulant etc., its mixing with these chemicals shall absolutely be avoided. In addition, to prevent the diffusion of leaked sodium hypochlorite, a barrier fence or a pit shall be provided together with a system of water supply for cleaning in its vicinity.

The volume of the barrier fence or the pit shall be more than the whole storage quantity of one tank.

The mouth on the tank for receiving sodium hypochlorite shall be fitted with a nameplate to be distinguished from other chemicals, especially be placed well apart from that of acidic chemicals.
5.10.4 Feeding facilities

1. The feeding facilities of the chlorine agent shall be in conformity with the following:

1) Their capacity shall be able to reliably cover from the maximum to the minimum dosage with precision, and provided with standby units.

2) The facilities shall be highly corrosion and attrition resistant, and have structure, of which repair is easy.

3) Their layout shall make upkeep and inspection of facilities easy.

2. The feeding facilities of sodium hypochlorite shall be in conformity with the following:

1) The facilities shall be situated as close to the dosing point as possible, and shall be installed in a house.

2) They shall be able to apply pressure needed for feeding.

3. The feeding facilities of liquid chlorine shall be in conformity with the following:

1) The facility with a capacity of more than 20 kg/hr shall in principle be equipped with an evaporator.

2) A location, which is underground or poor with ventilation, shall be avoided for their installation, but a location close to the dosing point and at a higher elevation inside the house than the water level at the dosing point shall be chosen.

3) The room, where the facilities are accommodated, shall be earthquake resistant and fireproof, and have a ventilation opening, concrete floor; and an indirect heating device shall be provided so that the room temperature always be maintained between 15 to 20 degrees C even in a cold season.

4) The room shall have sufficient inside space for uninterrupted feeding operation.

[Interpretation]

On the item 1.2);

(1) Feeding types of sodium hypochlorite

As feeding types, there are the injector type, pumping type etc. For any type, feeding can reliably be performed if sodium hypochlorite with low salt contents (less than 4 % of sodium chloride) is used, which yields only a little bubble and does not cause crystallization (See 8.5.2 Chemical feeding facilities).

Since the effective chlorine contents in sodium hypochlorite supplied from the market is 12 % in general, and the higher the effective chlorine contents, the more likely the yield of bubbles and scaling inside the pipeline. Therefore, it is needed to install a degassing device and regularly replace pipelines etc. In case the quantity of feeding is small, bubbling can be lessened with the use of diluted sodium hypochlorite. What is more, the chlorine concentration can be reduced if as small amount of sodium hypochlorite as possible is dosed in the water treatment plant, and it is applied again at the service reservoir right before service.

(2) Feeding types of sodium hypochlorite

The manufacturing equipment of sodium hypochlorite applies an electrolytic process to produce sodium hydroxide and chlorine gas by electrolyzing salt solution, and make them to react. In this method, hydrogen gas is produced as a byproduct of electrolysis. As the hydrogen gas, a flammable
gas, may explode, the manufacturing equipment shall be provided with a fan to discharge the gas outside. A device to prevent the entrainment of hydrogen gas shall be added to the piping for the transfer of sodium hypochlorite produced in situ to the storage tank. The equipment may be restricted under the law of high-pressure gas safety depending on its size in case the quantity of produced hydrogen gas exceeds a certain limit. Such an aspect needs to be inquired to the related authority (the Labor Standards Inspection Office etc.).

As the electrolytic process, there are the diaphragm process and the diaphragm-less process. The former is advantageous for a small installation; and the latter for a large one.

**a. Diaphragm-less process**

An anode plate and a cathode plate are placed in an electrolysis cell without a diaphragm. The supplied salt solution is electrolyzed; chlorine is generated on the anode whereas hydrogen on the cathode; and hydroxide ion is generated. On the cathode, sodium ion and hydroxide ion react to generate sodium hydroxide; and chlorine generated on the anode reacts with sodium hydroxide to produce sodium hypochlorite (NaClO). A schematic of the principle is shown in Figure 5.10.5.

![Figure 5.10.5: Principle of the diaphragm-less process](image)

The concentration of effective chlorine of the produced sodium hypochlorite is 1.0 % or so, which is lower than that supplied from the market. Since some salt, which has not reacted, remains in the product solution, the ratio of sodium chloride to the effective chlorine is higher than that of sodium hypochlorite supplied from the market. Sodium hypochlorite produced by the diaphragm-less process is weak alkali (about pH9), yields less bubbles and scaling than the one supplied from the market, so causes fewer occurrence of clogging in pipeline.

Examples of the production equipment and the flow diagram of the feeding facility are shown in Figure 5.10.6 and Figure 5.10.7.
Figure 5.10.6: An example of the flow diagram of production of sodium hypochlorite by the diaphragm-less process
Figure 5.10.7: An example of the flow diagram of a feeder of sodium hypochlorite produced by the diaphragm-less process (Fukuoka Water Treatment Plant of Sendai City Water Works Bureau 60,000 m³/day)
b. Diaphragm process

An ion exchange diaphragm (membrane) is set between the anode and cathode in the electrolysis tank; salt solution is put in the anode side and water in the cathode side; chlorine is generated in the anode side; and sodium ion moves to the cathode side permeating through the diaphragm. Hydrogen is generated on the cathode side; and hydroxide ion is yielded. Then, sodium hydroxide is produced in the cathode side by the reaction of the chlorine, which permeates from the anode side, with sodium hydroxide, which is generated on the cathode side. Furthermore, chlorine generated on the anode side and sodium hydroxide react at the outlet of electrolysis tank and produce sodium hypochlorite (NaClO). A schematic of the principle is presented in Figure 5.10.8.

![Diagram of diaphragm process](image)

**Figure 5.10.8: Principle of the diaphragm process**

The concentration (6 % or so) of effective chlorine in the produced sodium hypochlorite solution is higher than that produced by the diaphragm-less method. An example of its manufacturing facilities is shown in Figure 5.10.9.

![Diagram of sodium hypochlorite manufacturing facilities](image)

**Figure 5.10.9: An example of sodium hypochlorite manufacturing facilities by the diaphragm process**

(3) Feeding type of liquid chlorine

The chlorinator is equipment to safely and precisely measure and feed chlorine gas which is continuously fed from its container or evaporator.

The outline mechanism of the chlorinator is that vacuum pressure is generated by an injector and a pressure regulator; chlorine gas is measured and placed under vacuum, the gas is mixed with water in the injector to make chlorine solution, and it is conveyed to the dosing point. The chlorinator possesses a function to automatically stop the chlorine flow in case the pressure inside the equipment becomes

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positive as the water pressure for the injector drops. A typical chlorinator is presented in Figure 5.10.10.

The water quantity required for the injector is different depending on the capacity of the equipment. The water pressure required for the injector shall be determined by the pressure needed for the operation of the injector and the head loss from the injector to the dosing point.

![Figure 5.10.10: Dry gauging (wet feeding) vacuum type chlorinator](image)

**5.10.5 Control of chlorine feeding**

As control of chlorine feeding, there are the manual control, flow pacing control, feedback control, feedforward control etc. Proper type of control shall be selected taking into consideration water flow, change in water quality, the size of the facilities, operation and maintenance etc.

**5.10.6 Storage location of safety tools**

1. In case sodium hypochlorite is handled, since proper protectors are used as required, a store for their storage shall be secured.
2. In case liquid chlorine is handled, protectors needed for operation and maintenance shall always be prepared, and a safe place for their storage shall be secured near the chlorine feeding equipment and storage room.

[Interpretation]

On the item 2.;

There are such protectors as follows:
1) Protectors
Gas mask (diaphragm type, small type by direct connection), air-respirator or air-feed mask, standby air containers, safety clothing (rubber), protective gloves and boots (rubber), crash helmet, protective goggles etc.

2) Emergency tools
Safety cap for preventing leakage, box nuts and gaskets, lead plugs or wooden plugs, flange lids, annealed steel wire and mending tapes, temporary repair tools etc.

3) Others
Ammonia solution for detection of leak (concentration: more than 28%), mouthwash, acid resistant paint etc.

5.10.7 Neutralizing equipment

The neutralizing equipment for the chlorine gas shall be selected taking the following into consideration:

1. For a facility with storage quantity of less than 1,000 kg, chemical for neutralizing and absorption of chlorine gas shall always be prepared. In addition, leak detection tools for the gas shall be provided.

2. For a facility with storage quantity of more than 1,000 kg, in preparation for the leak of the gas, leak detection tools for the gas, neutralization equipment with a neutralization reactor tower, a neutralizing chemical storage tank, exhausters etc. shall be installed.

3. The neutralization equipment shall have enough capacity to fully neutralize the leaked chlorine gas.

5.10.8 Piping etc.

1. For piping for sodium hypochlorite and chlorine (liquid chlorine, and chlorine solution), pipe material with pressure-resistance, and chemical resistance shall be used; and the piping shall be so structured that their inspection is easy.

2. Corrosion resistant materials shall be used for hardware of electric fixtures etc. to be installed in the storage room and the room for feeders.
5.11 Chlorine treatment facilities

5.11.1 General

Chlorine agents are in general dosed after filtration for the purpose of disinfection. Since they have strong sterilizing and algicidal ability and oxidizability, they are dosed in water prior to chemical sedimentation, and in between the sedimentation basin and the filter as a treatment process for water with a progressed state of pollution. The former is called pre-chlorination; and the latter, intermediate chlorination. They are performed for the purposes of the following:

1. Treatment of organisms

For raw water containing a lot of algae, small animals, iron bacteria etc., it is needed to kill them or prevent their proliferation in water treatment facilities.

Especially, against such diatoms as aulacoseira, synedra etc., sufficient pre-chlorination shall be applied to kill the algae prior to coagulation and sedimentation. However, it is known that microcystises, which are present as colony, will be broken by pre-chlorination into cells, and it is difficult to remove them. In such a case, pre-chlorination shall not be applied; but they shall be removed in the coagulation and sedimentation processes, and then intermediate chlorination shall be performed.

2. Treatment of iron and manganese

In case, with raw water containing iron and manganese, chlorination may increase turbidity and color, they shall beforehand be removed after making them as insoluble oxides. However, since chlorination and manganese ion will only react at higher pH than 9, manganese coated sand shall be used as filter sand in case they are treated at the pH of 7 or so. (See Figure 5.17.3 Manganese removal facilities)

3. Treatment of ammonium nitrogen, organic matters etc.

Ammonium nitrogen, nitrite nitrogen, hydrogen sulfide, organic matters etc. shall be oxidized by chlorination.

4. Treatment of odor

Chlorination is effective for the removal of phenols, hydrogen sulfide odor, sewage odor, algae odor etc. However, since chlorination may, depending on the odor causing substances, enhance the odor, or generate new odor, powdered activated carbon shall be applied together with chlorination.

5. Treatment of bacteria

In case, with raw water containing a large amount of bacteria, in a facility where enough contact time after dosing of chlorine cannot be provided, the safety shall be secured by reducing bacteria prior to filtration; and the inside of sedimentation basins and filters shall be maintained hygienically safe.

In the slow sand filtration method, pre- and intermediate-chlorination are not applied since the chlorine gives an adverse effect on the organic filter membrane.

Since pre- and intermediate-chlorination are performed for the above purposes, the effects of chlorination shall be confirmed for their application because enough effects may not be obtained depending on the condition of the raw water.

Since disinfection byproducts such as trihalomethanes may be generated if raw water with contents of such organic matters as humic substances is chlorinated, intermediate chlorination is preferred to pre-chlorination to reduce the disinfection byproducts.
5.11.2 Pre-chlorination

Pre-chlorination shall be performed as follows:

1. The dosing point of chlorine agent shall be at the receiving well, mixing chamber etc. where good mixing is made.

2. The dosage of chlorine agent shall be determined based on the chlorine demand required for the respective treatment purposes, the chlorine demand of raw water etc.

3. The type of chlorine agent, feeding quantity, storage, feeding equipment, neutralization facilities etc. shall be in conformity with 5.10 Disinfection facilities.

[Interpretation]

On the item 2.;

The dosage of pre-chlorination shall be determined with consideration to the following:

1) The chlorine demand required for the respective treatment purposes

For example, 0.63 mg/L of chlorine will theoretically be required to oxidize 1 mg/L of ferrous ion; likewise, 1.29 mg/L for manganese ion; and 7.6 mg/L for ammonium nitrogen.

2) Residual chlorine concentration to be maintained at specific locations

For example, the residual chlorine concentration to be maintained in the filtered water shall be 0.1 to 0.2 mg/L or so for the purpose of disinfecting bacteria; and 0.5 mg/L or so in the case of manganese treatment.

3) Quantity of chlorine consumed at the sedimentation basin etc.

As decomposition of the chlorine in water is accelerated under the direct sunlight, its consumption will depend on the season, weather, day or night, existence of sloping plates, type of the sedimentation basin etc. In case powdered activated carbon treatment is undertaken at the same time, activated carbon also stimulates the decomposition of chlorine. Taking the above aspects etc. into account, the quantity of chlorine to be consumed in such facilities as coagulation basin, sedimentation basin etc. shall be estimated.

4) Chlorine demand of raw water

Since pre-chlorination treatment is usually carried out for raw water containing ammonium nitrogen, the break-point chlorination is suitable. Accordingly, the chlorine demand of raw water shall be tested for a period including the time of change in raw water quality (See 5.10 Disinfection facilities [Reference 5.13]).

In general, the chlorine dosage is to be ten times the quantity of ammonium nitrogen in raw water; and 0.5 mg/L of free residual chlorine, as a yardstick, shall be maintained in filtered water. However, since the required dosage depends on raw water quality and the purpose of treatment, the range of dosage (maximum, minimum and average) shall be determined with reference to above 1) to 4). It is noted that over-dosage shall be avoided for pre-chlorination.
5.11.3 Intermediate chlorination

Intermediate chlorination shall be performed as follows:

1. The dosing point of chlorine agent shall be in between the sedimentation basin and the filter, where good mixing is made.

2. The dosage of the chlorine agent shall be in conformity with “2.1 of 5.11.2 Pre-chlorination”.

3. The type of chlorine agent, feeding quantity, storage, feeding equipment, neutralization facilities etc. shall be in conformity with “5.10 Disinfection facilities”.

[Interpretation]

On the item 1.;

Intermediate chlorination is a chlorination method to dose the chlorine agent in between the sedimentation basin and the filter. This method is mainly undertaken aiming at reducing trihalomethane precursors and the generation of musty odor by removing, as much as possible, by chemical sedimentation such blue-green algae as anabaena, phormidium etc., of which chlorination generates causative agents of musty odor to be released in water, and such blue-green algae as microcystis etc., of which colonies may be broken into cells by pre-chlorination and leak through the filter, and then applying chlorination. In case the removal of anabaena and phormidium cannot be made, treatment by pre-chlorination combined with powdered activated carbon treatment shall be undertaken (See 5.13 Powdered activated carbon adsorption facilities).

Although it is desirable to set the dosing point at the mixing chamber, in case a mixing basin cannot newly be provided, a point, where the chlorine agent is sufficiently mixed with water, shall be selected.

What is more, in cases troubles by the growth of algae etc. on such ancillary facilities as sloping plates and the collection system in the sedimentation basin are apprehended, or a filter trouble of coming-off algae after their growth in the basin, facilities for intermittently applying pre-chlorination to kill algae are sometimes attached. Otherwise, it is desirable to provide water washing equipment.

In case intermediate chlorination is employed as the basic system, if dissolved manganese in more concentration than a certain limit is present in raw water, it cannot be removed only by contact oxidation by manganese sand, a trouble by color may be brought about. In such a case, intermediate chlorination needs to be replaced by pre-chlorination.
5.12 Aeration facilities

5.12.1 General

Aeration is used to expel gaseous substances contained in water by making water to fully contact with air, or accelerate the oxidation of substances in water, which is easily oxidized, by means of taking air into water.

1. Effects of aeration

1) If applied to water with low pH, aeration raises its pH by removing free carbonate,

2) It removes volatile organic chlorine molecules (trichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane etc.).

3) It feeds oxygen of the air into water, and accelerates the oxidization of iron dissolved in water. For example, the ferrous hydrogen carbonate dissolved in water yields ferrous carbonate by aeration in the following way:

\[
\text{Fe(HCO}_3\text{)}_2 \rightarrow \text{FeCO}_3 + \text{CO}_2 + \text{H}_2\text{O}
\]

The ferrous carbonate yields ferrous hydroxide by hydrolysis.

\[
\text{FeCO}_3 + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_2 + \text{CO}_2
\]

If this ferrous hydroxide is further oxidized, it yields insoluble ferric hydroxide.

\[
2\text{Fe(OH)}_2 + \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow 2\text{Fe(OH)}_3
\]

However, depending on the state of iron, it cannot perfectly be oxidized in some cases (See 5.17 Removal facilities of iron and manganese)

4) It removes such obnoxious odor as hydrogen sulfide etc.

2. Types of aeration

As types of aeration, there are the fountain type, the filling tower type etc. (See Figure 5.12.1)

1) Fountain type

There is a type to spouting water as mist by fixed or rotating nozzles. Although its structure is simple, it has such demerits as it needs a considerable amount of power for spouting water, and as water scatters together with air.

2) Filling tower type

The general structure of this type is a vertical cylindrical tower with fillings inside the tower. There are fillings of various shapes and materials, of which efficiency of air-water contact is excellent,

3) Other types

As other types of aeration, there are the storied tower type, which contains shelves of perforated plates; a system of blowing air into water; and a cascade type, with which water falls from the height of 5 to 10 m.
5.12.2 Types of aeration

1. Fountain type aeration shall be in conformity with the following:
   1) Nozzles shall be so designed that the mist of water contacts with air as efficiently as possible.
   2) Nozzles shall be so arranged that water uniformly sprayed.
   3) Aeration rooms shall be so structured that scatter of water spray is prevented. In addition, there shall be more than two rooms.

2. Filling tower type aeration facility shall be in conformity with the following:
   1) The structure of the filling tower shall be a vertical cylinder, and its material shall be corrosion resistant.
   2) Fillings shall have a large porosity ratio and low friction loss of air flow; and shall be corrosion resistant, and mechanically strong.
   3) The diameter of the tower shall be determined by the air flow velocity; and its height shall be decided by the capacity coefficient etc.
   4) The ratio of air to water shall be determined by experiments.
   5) The air blower shall be installed on the air intake side of the filling tower; and its required power shall be determined by air flow, fillings, the pressure head loss through the duct etc.
   6) In case the removal of such substances as trichloroethylene etc., of which handling is regulated by the law, granular activated carbon treatment facilities shall be equipped for the treatment of discharge gas.
5.13 Powdered activated carbon adsorption facilities

5.13.1 General

Activated carbon is classified into two in accordance with its form: powdered activated carbon (PAC) and granular activated carbon (GAC). Although PAC and GAC are sorted out by their form of use, their property, mechanism of adsorption etc. as activated carbon are the same, so they are altogether described in this chapter.

1. Objects of treatment

The activated carbon treatment is applied to remove odor and taste causing matters (2-methylisoborneol: 2-MIB, geosmin etc.), anionic surfactants, phenols, trihalomethanes and their precursors, low boiling point chlorinated organic molecules such as trichloroethylene, such micro hazardous matter as agricultural chemicals, which cannot be removed by ordinary water treatment processes of coagulation, sedimentation and filtration, chemicals, which temporarily contaminate water in a water source area, and other organic matters.

2. Property

Activated carbon is manufactured by carbonization and activation of its raw materials of wood (coconut shell and saw dust), coal etc., and a porous and carbonaceous matter, and has property of absorbing micro organic substances in gas and liquid.

There are two ways of activation: (1) the steam activation method in that the raw material is activated by high temperature steam of 900 degrees C or so; and (2) the chemical activation method in that the wood materials are dipped in the solution of zinc chloride, sulfuric acid etc. and carbonized. Since the activated carbon manufactured by chemical activation elutes such a chemical as zinc, it is not used for water treatment. Thus, the activated carbon manufactured by the steam activation method is mainly used in water supply (See Table 5.13.1).

The activated carbon is a carbonaceous material with a highly porous structure, and its absorbing properties are different depending on its material and the methods of carbonization and activation. Inside the activated carbon, micropores of $10^{-5}$ to $10^{-7}$ m (10 µm to 100 nm) in diameter run three-dimensionally. In addition, micro holes of 10 nm to 0.1 nm or so are arranged on the wall of the micropores. The inside surface area of the micropores is as remarkably large as 700 m$^2$ to 1,400 m$^2$/g, which is the reason for its high absorbing capacity. In water treatment, such ability of adsorption is utilized for the removal of the above substances. The physical properties of activated carbon are represented by its porosity, specific surface area, volume of the pores, pore distribution etc.

Since activated carbon gradually absorbs oxygen in air, oxygen in such an air-tight container as a storage tank etc. has a risk of lacking oxygen, so due attention shall be paid at the time of maintenance and inspection.

<table>
<thead>
<tr>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
</tr>
<tr>
<td>Wood</td>
</tr>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Activation method</td>
</tr>
<tr>
<td>Chemical activation</td>
</tr>
<tr>
<td>Gas activation</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Form</td>
</tr>
<tr>
<td>Powdered activated carbon</td>
</tr>
<tr>
<td>Granular activated carbon</td>
</tr>
</tbody>
</table>
3. Characteristics

The characteristics of the activated carbon are its large capacity to remove soluble organic matters in water, and such merit of its process that it does not leave any reaction product in treated water unlike chemical treatment.

When implementing activated carbon treatment, sufficient studies including experiments are needed beforehand on the property, actual status, effects of treatment etc. of substances to be removed. It is desirable that, in addition to the understanding of the present status, the future trend of the substances for removal shall be forecast, and then the size and type of the facilities shall properly be determined.

4. Types of activated carbon and characteristics of its treatment

PAC dominantly possesses micropores of 1 to 20 nm in diameter whereas GAC possesses those of smaller than 10 nm. Among GAC, coconut shell carbon (woody material) predominantly has micropores of smaller than 3 nm of diameter, and fewer pores of larger than 30 nm. Therefore, substances of low molecule are more easily removed. On the other hand, coal family activated carbon possesses a broad size range of pores from 3 nm to pretty large ones. As such substances of larger molecules tend to easily be removed. GAC has micropores of 0.1 µm to several µm, which become the channels for matters to be diffused into the grains.

In general, the stronger the hydrophobic nature and the larger the molecular weight of a substance, the easier its adsorption to activated carbon. On the other hand, substances, which have greater hydrophilic nature and small molecular weight, tend to be difficult to be absorbed by activated carbon. Agricultural chemicals, which are insoluble in water, are easily absorbed by activated carbon, but such substances as humic matters, which, even though its molecular weight is large, has a property to easily dissolve in water, are not easy to be absorbed by activated carbon. As such, the tendency of substances to dissolve in water and the distribution of pores of activated carbon influence the treatability by activated carbon.

5. Types of activated carbon treatment

In the case of emergency or a short period of use, PAC treatment is suitable; and in the case of continuous use during the year or a relatively long period of use, it is said for GAC to be more economically advantageous. As the adsorption characteristics are different depending on its type, a type suitable to the purpose of use shall be selected.

PAC and GAC are different from each other in terms of their nature of operation and maintenance depending on their purpose of use and the period of treatment by them. Their merits and demerits are described in Table 5.13.2.
### Table 5.13.2: Merits and demerits of PAC treatment and GAC treatment

<table>
<thead>
<tr>
<th>Item</th>
<th>PAC</th>
<th>GAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Treatment facility</td>
<td>○ Treatment is possible using the existing facilities</td>
<td>△ Filters need to be built.</td>
</tr>
<tr>
<td>(2) In the case of a short period</td>
<td>○ Economical since as much quantity as needed shall be purchased.</td>
<td>△ Uneconomical</td>
</tr>
<tr>
<td>(3) In the case of a long period</td>
<td>△ Uneconomical, cannot be reused</td>
<td>○ GAC layer can be made thick Economic as it can be reused</td>
</tr>
<tr>
<td>(4) Growth of organisms</td>
<td>○ No growth of organism since it is disposed of each time.</td>
<td>△ A risk of growth of protozoa</td>
</tr>
<tr>
<td>(5) Disposal</td>
<td>△ Black sludge containing PAC is a source of public nuisance.</td>
<td>○ As reused, it is not disposed of.</td>
</tr>
<tr>
<td>(6) Trouble due to its breakthrough</td>
<td>△ Tends to occur in winter</td>
<td>○ Almost no such a risk</td>
</tr>
<tr>
<td>(7) Operation and management</td>
<td>△ Dosing work is needed</td>
<td>○ Particularly, no such problem</td>
</tr>
</tbody>
</table>

*Note*) ○ merit; △ demerit

#### 5.14 Granular activated carbon adsorption facilities

##### 5.14.1 General

The granular activated carbon (GAC) adsorption facility is a system to introduce the objective water through GAC medium filled in a tank (basin) and remove objective substances in the water mainly by adsorption.

##### 1. Method of GAC treatment

There are two types of GAC treatment, namely, the one that mainly aims at adsorption effect, and the other one, the biological activated carbon (BAC) adsorption method, which, in addition to its adsorption function, lengthens the life of adsorption capacity of GAC by means of decomposition of organic matters by biological activities of organisms that grow in the GAC medium.
5.15 Ozonation facilities

5.15.1 General

The purpose of ozonation is to remove odor and taste and reduce disinfection byproducts by oxidation function of ozone which is more powerful than chlorine.

Since ozonation generates various byproducts, ozonation shall not be used independently and so GAC treatment shall be employed together.

On the other hand, ozonation will leave dissolved ozone in the treated water, and ozone, which has not been absorbed in water, will be emitted into the atmosphere. Excessive residual ozone in the treatment processes will accelerate the consumption of ensuing GAC by its strong oxidizing effect. Since, if exhaust ozone is emitted into the atmosphere, there is a risk to bring about problems in labor safety and on environment, it shall be treated to get sufficiently low concentration prior to its release.

The superior points of ozonation as a unit process to other processes are the following:

1. Advantages of ozonation

1) It has an excellent effect on the removal of taste, odor and color.

It is effective to remove the odor caused by geosmin and 2-MIB, color caused by humic matters, and phenols, of which odor is enhanced by chlorination.

2) It increases the biological decomposition ability of organic matters.

It raises biological decomposability of organic substances of low decomposability, and improves the removal function of organic matters in combination with the ensuing GAC (BAC) treatment.

3) It decreases chlorine demand

If ozone is dosed prior to chlorination, since it oxidizes iron, manganese, nitrites, organic matters etc., it reduces the consumption of chlorine.

4) It possesses powerful inactivation ability of microorganisms

With its powerful oxidizing ability, ozone has stronger inactivation capability than chlorine to destroy or give damage to cell components of microorganisms. However, since it has poor tendency to residue in water, it cannot be used in water supply as a disinfectant instead of chlorine.

2. Points to note about ozonation

Points to note about ozonation are as follows:

1) A contact tank (basin), in which ozone is sufficiently diluted in water, is needed.

2) An exhaust ozone treatment facility is required.

3) Ozonation byproducts will be generated as ozone reacts with organic matters and bromides.

4) When water temperature is high, the dissolving quantity of ozone reduces and its decomposition gets accelerated.

5) The materials used for ozonation facilities shall be highly corrosion resistant.
5.16 Biological treatment facilities

5.16.1 General

Biological treatment facility is a treatment method to purify raw water by oxidation and decomposition of ammonium nitrogen, algae, musty odor, iron, manganese, turbidity matters, anionic surfactants etc. by the function of microorganisms.

It is a process to artificially simulate the natural purifying function of organisms in a basin with great efficiency. To this end, setting fillings or discs etc. in a water basin in order that the surface area is remarkably expanded for attachment of microorganisms, a biological membrane is formed to provide more chances for it to contact with water.

Usually it is performed as a preceding process before the water treatment processes of coagulation, sedimentation, filtration etc.

Types of biological treatment are the submerged filter bed with aggregates of small plastic tubes fixed in water (honeycomb type); rotating discs (rotating disc type); the biological contact filter with granular filter media etc.

Although the purification of water is performed by decomposition or assimilation of organic matters, nitrogen, phosphorus etc. in water by microorganisms in the biological membrane, it is difficult to control the biochemical reactions of organisms in the membrane; the biological treatment has such characteristics as it is difficult to completely remove the objective substances, its function is affected by water temperature and so forth. Therefore, even if the incoming load of objective substances on the facility is the same, the effect of treatment largely changes depending on the season of year, raw water quality etc.
5.17 Iron and manganese removal facilities

5.17.1 General

1. Iron

Iron is sometimes detected in relation to contamination by wastewater from mining, factory etc. and iron of pipe material, and it causes obnoxious taste and odor, coloring laundries and flush toilet apparatuses in brown if contained in high concentration.

In the water quality standards, the maximum limit of iron contents is set at 0.3 mg/L. Even in case the iron contents is higher than the standard, since it is removed to a certain extent by the sedimentation and filtration processes, it shall be determined whether or not a special iron removal facility is to be installed based on a specific study on the contents of iron, its status, the condition of the water supply facilities in question etc.

2. Manganese

Manganese is often contained in groundwater abstracted from a granite area, a basin, gas-containing region etc. in a large quantity. It is also contained at times in river water under the influence of mining waste, factory waste, sewage etc.

In lakes and impounding reservoirs, manganese and iron sometimes elute into water from the bottom sediment as the bottom water becomes anaerobic when thermal stratification is formed in summer.

If manganese is contained even in a minuscule amount, water is colored 300 to 400 times the amount of manganese by free residual chlorine, or separated minute black oxides of manganese stick on the wall of distribution mains or service pipe, which causes black water. What is more, in case iron and manganese are intermingled in water, water is colored blackish brown.

Since manganese can hardly be removed by the ordinary water treatment processes, a manganese removal facility with reliable performance is needed in case a trouble is expected to occur.

In the water quality standards, the maximum limit of manganese contents is set at 0.05 mg/L; and although in the water quality control goal items the allowable contents of manganese are set at less than 0.01 mg/L, it is desirable to reduce its contents as much as possible.

Since in many cases, manganese is coexistent with iron in water containing a large amount of iron, the need for a manganese removal facility shall be considered when the iron removal facility is examined.

5.17.2 Iron removal facilities

As the iron removal facilities, a pre-treatment facility of aeration and or chlorination combined or independently applied and filters shall be provided.

[Interpretation]

Iron is contained in groundwater in the form of ferric hydrogencarbonate (II) [Fe(HCO3)2] in many cases, and it is present as colloidal organic compound (colloid iron) combined with humic acid etc. in the peat area.

In river water, iron in many cases forms as oxidized insoluble iron salt (III), and iron in the form of ferrous (II) ion is relatively less common. However, ferrous sulfate is sometimes present in the case of contamination with wastewater from hot springs, mining, factory etc.
For its removal, the ferrous ion, which is dissolved in water, ionized or colloidal iron are oxidized by aeration or pre-chlorination, separated as ferric salt, and removed by chemical sedimentation and filtration or only filtration.

pH control is combined with the above methods; the filtration is altered into contact filtration; and in addition, iron bacteria method is also used independently.

Aeration is useful for removal of iron in case iron is dissolved in the form of ferrous hydrogencarbonate (II); iron is oxidized to form insoluble ferric hydroxide (III) [Fe(OH)3] and settles; and at the same time free carbonate and hydrogen sulfide are also removed. In case more than 30 mg/L of soluble silicic acid is contained, iron becomes minute colloidal particles combined with silicic acid; since its treatment by chemical sedimentation and filtration becomes difficult, such other method of treatment as oxidation by chlorine etc. is employed.

By pre-chlorination, ferrous (II) ion is oxidized to form ferric iron (III), settles and then filtered. By this method, even in the case of low pH, iron can easily be oxidized, and it is also useful for the removal of colloidal iron. To make the soluble ferrous (II) ion insoluble ferric iron (III), although 0.635 mg/L of chlorine is theoretically needed per 1 mg/L of iron, as much chlorine as to detect free residual chlorine in settled water needs to be dosed since chlorine is also consumed by organic matters and other reducible substances.

In case pH control is combined with other methods, iron other than ferrous hydrogencarbonate (II) is oxidized by dissolved oxygen in water, and separates as ferric hydroxide (III) if pH is raised higher than 9. To accelerate the oxidation of soluble iron by aeration, pH shall be made at 8.5 or so.

5.17.3 Manganese removal facilities

1. For a manganese removal facility, pretreatment in combination with chemical oxidation treatment, pH control treatment, chemical sedimentation etc. or with a single one of them, and filters are installed.

2. The chemical oxidation treatment is performed by pre-chlorination, intermediate chlorination, ozonation or potassium permanganate treatment.

[Interpretation]

On the item 1.;

As the manganese removal methods, there are the method to perform oxidation by chlorine, ozone or potassium permanganate prior to chemical sedimentation followed by filtration; method of contact filtration with manganese sand as filter medium; method to utilize iron bacteria and so forth.

In the case of such water as groundwater, which has no turbidity but contains manganese, contact filtration with manganese sand is suitable since chemical sedimentation is not necessary. In this case, filtration is performed right after pre-chlorination. As an actual example, the depth of manganese sand bed is 600 to 2,000 mm, and the filtration rate is 120 to 600 m/day or so.

When chlorine is used as the oxidizer, manganese, in theory, can hardly be oxidized if the pH is lower than 9. Hence, pH shall be raised higher than 9 by an alkali agent. However, in case such manganese oxide as manganese sand is in water, oxidation of manganese is accelerated by the manganese oxide as catalyst even if pH is around 7.

On the item 2.;

In case chlorine is used as an oxidizer, after chlorine dosing, chemical sedimentation and filtration are carried out, or only filtration is performed. It is known that the removal effect is improved if pH is
slightly in the alkaline side. The dosage of chlorine shall be so set as for the residual free residual chlorine to be maintained in filtered water at the prescribed level. Although, theoretically, chlorine dosage of 1.29 mg/L matches 1 mg/L of manganese, attention shall be paid to the fact that chlorine is also consumed by organic matters and other reducible substances.

If manganese removal treatment by chlorine as the oxidizing agent is performed for a long time, the filter sand becomes colored black coated with oxide of manganese, and it shows as same effect as manganese sand. In such a condition, manganese can be removed even without pH control. In a water treatment plant where chemical sedimentation and filtration are performed after pre-chlorination, the filter sand will become manganese sand within several months, and manganese removal treatment can reliably be made.

In case ozone is used as oxidizer, “5.15.2 Characteristics of ozonation” shall be referred to. If potassium permanganate is used as oxidizer, as its oxidizing effect is strong, manganese can be oxidized in a short period of time even at a neutral pH range.
5.21 Other treatment methods

5.21.2 Control of pH

In case pH is low, pH is adjusted by dosing an alkali agent after flocculation.

5.21.4 Removal of fluoride

In case a large amount of fluoride is contained in water, chemical sedimentation, activated alumina, bone black, electrolysis etc. are applied for its reduction.

5.21.5 Removal of arsenic

In case a large amount of arsenic is contained in water, adsorption treatment is performed using either one of coagulation or activated alumina, cerium hydroxide, and manganese dioxide to reduce it.
5.23 In-plant piping and conduits

5.23.3 Average flow velocity

| The standard average flow velocity of pipes and conduits interconnecting the flocculation basin, chemical sedimentation basin, and rapid sand filter shall be 15 to 80 cm/s; and for other ones, the standard average flow velocity shall be 50 to 150 cm/s. |