DESIGN OF WATER TREATMENT FACILITIES

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Summary

When designing water treatment facilities, the main factors to be considered are (1) type of water source, (2) finished water quality, (3) skill of facility operators and (4) available size of funds. If the water source is clean, the water treatment process is simple. Otherwise rather a complex treatment process may be needed. If the source is clean groundwater, simple disinfection will suffice. For surface water, the slow sand filtration process is recommended if the quality of raw water is good, and if cheap land and labor are available. The rapid sand filtration process will be required if the water is somewhat polluted, including high turbidity. If high quality finished water is desired, not only a conventional water treatment process but also additional processes such as ozonation and GAC adsorption will be needed. Owing to its high quality finished water

and the ease of operation, membrane filtration, which has been designed for small installations, is a promising treatment process for the future, and probably for medium and large-scale applications as its cost is being reduced. To cope with inexperienced operators, even if a rapid sand filtration process is a must, a treatment plant can be designed without complex mechanical facilities: e.g. a zigzag flow flocculation basin in place of mechanical flocculators; and automatic flow control filters instead of ones with flow regulators and backwash pumps. With regard to the finance available, slow sand filtration facilities can be designed, even if only high turbidity water is available, with a large pond to be constructed as the settling basin to reduce the turbidity loading prior to filtration. Likewise, iron removal can be achieved with the provision of a simple shallow tank filled with coarse granular material coated with iron or manganese dioxide for removal of iron from groundwater.

1. Introduction

In designing water treatment facilities, there are many factors to be considered. If a good water source is available, the process of water treatment can be very simple. Conversely, if the raw water is organically or inorganically polluted to a considerable extent, the water treatment facility must have a complex process train. Sophistication of water treatment processes requires skilled operators. Unless skilled labor is available, excessively sophisticated treatment processes should be avoided. Major factors to be considered are: (1) type of the water source, (2) desired finished water quality, (3) skill of facility operators, and (4) the relative size of available funds.

2. Water source

The type of water source and the magnitude of its pollution are the first factors to be considered when selecting the method of water treatment.

Type of water source		**Alternatives of water treatment method**	**Notes**
Groundwater	i. With no pollution and excessive contents of minerals	a. Chlorination only	
	ii. With no organic pollution, but with high manganese and iron contents	b. Iron and manganese removal + chlorination	
	iii. With pollution	c. Abandon the source and obtain another unpolluted one d. Coagulation (+ settling) + filtration + chlorination	
Surface water	i. With almost no pollution with invariably low turbidity	e. Slow sand filtration + chlorination d. Coagulation + settling + filtration +	The slow sand filtration requires large land.

		chlorination f. Membrane filtration + chlorination	
	ii. With mediocre level of pollution	g. Pre-chlorination + Coagulation + settling + filtration + chlorination h. Membrane filtration + chlorination	
	iii. With high level of pollution	c. Abandon the source and obtain another unpolluted one i. Coagulation + settling + sand filtration + ozonation + GAC filtration + chlorination	Sand filtration can be placed after GAC filtration.
Groundwater or surface water	i. With high hardness	j. Softening with (1) a soda ash/lime reactor and a filter; or (2) ion exchange resin	

Table 1. Type of water source

Depending on the distance and the available funds for the transportation, the cleanest water sources available should be chosen so that sophisticated and high cost water treatment can be avoided. Groundwater often contains considerable amount of iron and manganese even though its appearance is clear and clean. Iron and manganese (especially manganese) badly discolor water in the distribution system as a result of disinfection with chlorine. Polluted surface water with organic substances very often contains ammonium nitrogen, too. Therefore, pre-chlorination is required if sophisticated biological processes are to be avoided. Otherwise, normal dosage level of chlorine will soon be depleted by the ammonium nitrogen and no free chlorine will remain to guarantee the water safety to every tap. A high dose of chlorine, of course, risks excessive formation of trihalomethanes, with organically polluted water. Hardness of drinking water is a general problem to its consumers since excessive level of hardness causes a nasty taste and inconvenience when using it for laundry.

3. Desired finished water quality

If the consumers wish to have high quality drinking water, or legislation requires high standards of drinking water quality, water suppliers must employ sophisticated, often expensive water treatment processes unless they can use very clean water sources. In many countries, even including some industrialized countries, surface water is supplied without filtration since their drinking water quality standards are not high enough to prohibit the direct supply of surface water insofar as turbidity, color, pH etc. are within the standard values. In some countries including USA, where direct supply of surface water has recently been banned, water utilities are busy designing and constructing water treatment facilities, including sand filters.

Prior to the recent revisions of WHO's drinking water quality guidelines and national standards of many industrialized countries, in which new water quality items such as trihalomethanes were introduced, water from most surface sources could be supplied just with filtration (e.g. sand filtration with chemical coagulation). After the upgrading of drinking water quality standards and the introduction of the surface water treatment rule, no water suppliers will be allowed to supply surface water without filtration. Further, after the revisions, simple filtration may not be sufficient, so additional processes such as ozonation and granular activated carbon adsorption (GAC) may be required in many cases.

Consumers may complain about the taste and odor of their drinking water, even if the quality of water conforms to the standards. The water suppliers should apply a temporary process such as powdered activated carbon to their water treatment train, or granular activated carbon filtration for the time period of low quality of source water.

4. Skill of facility operators

When designing a water treatment facility with slightly polluted surface water, the facility should be based on slow sand filtration unless skilled operators are available. Slow sand filtration facilities can be run by less trained operators. The disadvantages associated with the slow sand filtration method are the large land requirement for the facility, and sizeable labor needed for skimming, washing and refilling of filter sand. Well-trained and skilled operators are needed for the operation of the rapid sand filtration process since sophisticated handling is required for chemical application optimization and the operation of flocculation basins, sedimentation basins and rapid sand filters. The operation of Ozone-GAC (granular activated carbon) facilities is so complicated that highly experienced operators and chemists are needed for their proper operation.

The selection of unit processes is also important. Even for the conventional rapid filtration facilities, certain complex unit processes may not be suitable for a community where plant operators are rather inexperienced. For example, sloping-tube settlers as a settling device installed in some water treatment plants in Indonesia were abandoned only in less than a year after their commissioning. The operators failed to desludge the settling tank as frequently as required, so the device was completely clogged. In this case, the magnitude of turbidity in the raw water was originally too high for the device.

The operation of membrane filtration systems is so simple that there are very few chances of operational errors. Membrane filtration can be an attractive alternative if financial resources for capital investment as well as operation and maintenance are available.

5. Design criteria

The following are the basic criteria for the design of water treatment facilities using the above methods.

5.1. Slow sand filtration process

5.1.1 Prerequisite conditions

Slow sand filtration process is only suitable where the water source is rather clean river or lake water, or water infiltrated from a riverbed. The source water must be free from extensive pollution with low turbidity and ammonium nitrogen all year around. The average turbidity is preferably lower than 10 NTU; BOD must be less than 2 mg L^{-1}; and ammonium nitrogen must be less than 0.5 (preferably 0.1) mg L^{-1}.

5.1.2 Water treatment process train

The typical treatment process train of a slow sand filtration system is shown in Figure 1.

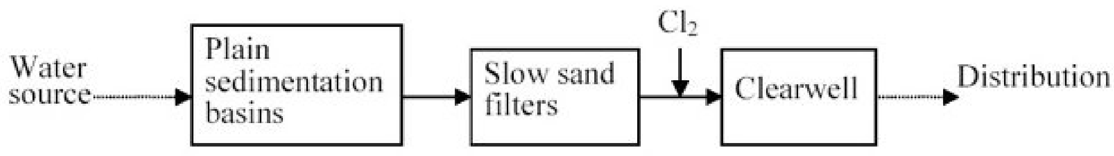

Figure 1. Typical treatment process train of a slow sand filtration system

5.1.3 Design criteria

- Overflow rate of the plain sedimentation basin: 3 - 6 m day^{-1} (m^3 m^{-2} day^{-1}). NB: water surface area of the basin = treatment flow (m^3 day^{-1})/overflow rate.
- Water depth of sedimentation basin: 3 - 4 m. (This and the above make the retention period of the sedimentation basin 12 to 32 hours.)
- Filtration rate of slow sand filters: 4 - 5 m day^{-1} (m^3 m^{-2} day^{-1}). NB: the bed area of the filter = treatment flow (m^3 day^{-1})/filtration rate.
- Depth of sand bed: 0.7 - 1.2 m.
- Filter medium grain size: 0.25 - 0.45 mm.
- Water depth above sand layer: 0.9-1.2 m.

The filters should be facilitated with an inlet device, under-drains and a flow control device at the filter outlet.

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Bibliography

APHA, ASCE, AWWA, and APCF. (1981). Glossary, Water and wastewater control Engineerng, third edition. American Public Health Association, Washington, American Society of Civil Engineering, New York, American Water Works Association, Denver, Water Pollution Control Federation, Washington, USA. 441 pp. [A glossary of terms on water and wastewater control engineering.]

Béchaux J. (1979). Water treatment handbook, fifth edition. Degrémont, Rueil-Malmaison, France. 1186 pp. [Part I of this book is a general survey of water and its action on the materials with which it comes into contact. Part II describes the processes and the treatment plant. Part III covers treatment of various kind of water according to type and ultimate use. And part IV deals with the chemistry of water and reagents used in water treatment, methods of analysis, and the biology of water.]

DeZuane J. (1997). *Handbook of drinking water quality*, second edition. John Wiley & Sons, New York, USA. 575 pp. [This handbook is an essential volume for engineers, water supply and treatment personnel, environmental scientists, public health officials, or anyone responsible for assuring the safety of drinking water.]

Kawamura, S. (1991), *Integrated Design of Water Treatment Facilities*, John Wiley & Sons, Inc, New York, USA. 658 pp. [This was the first book to describe not only basic design criteria for each process but also to show how to design each process in order to maximize overall process efficiency while minimizing operation and maintenance costs.]

McGhee T. J. (1991). *Water supply and sewerage*, sixth edition. McGraw-Hill, New York, USA. 602 pp. [This textbook is intended to introduce the design of water and wastewater treatment systems to the undergraduate student in civil engineering. It may be used in a comprehensive course covering all aspects of water and wastewater treatment, or in separate courses dealing with design of hydraulic networks and design of treatment systems.]

National Research Council. (1997). *Safe water from every tap*, Improving water service to small communities. National Academy Press, Washington, USA. 218 pp. [This book reviews the risks of violating drinking water standards and discusses options for improving water services in small communities.]

Biographical Sketches

Katsuyoshi Tomono is Senior Engineering Adviser of Environmental Planning Institute, Tokyo Engineering Consultants, Co., Ltd., where he has worked since 1999. He graduated from Hokkaido University and received the degree of Bachelor of Engineering in Sanitary Engineering in 1961. After graduation, he worked for Nihon Suido Consultants, Co., Ltd. from 1961 to 1980. He served as Manager of Design Division with responsibilities for planning, design and construction, and supervision of water supply and sewer system projects in Japan and abroad, and studies on water treatment engineering and economic evaluation on projects. He then spent seven years as Project Engineer at Infrastructure Department, Asian Development Bank until 1987. He was responsible for appraisal and evaluation of bank-financed loan projects in the water supply, sewerage and sanitation sectors. From 1987 to 1999, he worked for Japan Water Works Association as Senior Researcher for several fields, which include development studies on advanced water treatment, high-pressure water service, risk management, etc.
He has authored or co-authored many research articles for the Japan Water Works Association and American Water Works Association for more than 20 years. His subject of study includes the art of water treatment in Japan, the costs and benefits of risk management in water supply, the economies of scale in water supply, etc.

Yasumoto Magara is Professor of Engineering at Hokkaido University, where he has been on faculty since 1997. He was admitted to Hokkaido University in 1960 and received the degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. After working for the same university for 4 years, he moved to National Institute of Public Health in 1970. He served as the Director of the Institute since 1984 for Department of Sanitary Engineering, then Department of Water Supply Engineering. He also obtained a Ph.D. in Engineering from Hokkaido University in 1979 and was conferred an Honorary Doctoral Degree in Engineering from Chiangmai University in 1994. Since 1964, his research subjects have been in environmental engineering and have included advanced water purification for drinking water, control of hazardous chemicals in drinking water, planning and treatment of domestic waste including human excreta, management of ambient water quality, and mechanisms of biological wastewater treatment system performance. He has also been a member of governmental deliberation councils for several ministries and agencies including Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. He meanwhile performs the international activities with JICA (Japan International Cooperation Agency) and World Health Organization. As for academic fields, he plays a pivotal role in many associations and societies, and has been Chairman of Japan Society on Water Environment.

Professor Magara has written and edited books on analysis and assessment of drinking water. He has been the author or co-author of more than 100 research articles.