INDUSTRIAL WATER

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Summary

Many industries use water for their production, and this water often requires particular properties such as solubility, transportation potential, or heat exchanging potential. Water in industries is consumed for boiler make-up, processing, product treatment and cleaning, cooling, etc.

The quantity of water consumption differs between the types of industries. The steel, chemical, and pulp and paper industries are major users of large quantities of water per unit price of products because they use fresh water for cooling, cleaning and product processing.

Cooling water comprise the majority of the consumption of industrial water. Due to the huge water consumption in each plant, cooling water is generally reused in order to save the acquisition cost and the water resource. The cooling water reuse may result in impairment by scale, slime, or corrosion caused by the concentration of soluble salts inside the circulation systems due to the evaporation or emission of cooling water. Therefore, the quality control of cooling water is the most important factor in the operation of cooling water systems. There are two ways to control cooling water quality, i.e. the treatment of make-up water and the treatment for circulated cooling water. In order to improve the quality of circulated cooling water, pH control and corrosion inhibiters are applied. In addition, circulated water is partially discharged to prevent excessive concentration of soluble salts.

"Ultra-pure water" is the result of currently available technologies which remove the impurities as much as possible to approach theoretical H_2O. Ultra-pure water removes those impurities such as suspended solid components, dissolved gas components, and microbes as much as possible with state-of-art technologies. Therefore, ultra-pure water cannot be defined chemically but it is a general term that has a certain range of the quality. LSI manufacturing processes require ultra-pure water with very high quality for cleaning not to cause contamination to silicon wafers or computer chips from water.

Industrial water consumption affects the production cost as well as the conservation of limited water resources; therefore, many industrial installations make efforts to reduce their water consumption by introducing in-factory water recycling systems in combination with wastewater treatment systems. The circulated use of water is usually applied to indirect systems, which are easily maintained due to absence of pollution in the systems. In the circulated use of water, soluble salts are concentrated in the system as evaporation proceeds. Thus, the quality of water should be controlled to avoid corrosion, deposition of scale, or generation of slime.

1. Introduction

Many industries use water for their production, and this water often requires particular properties of water such as solubility, transportation potential, or heat exchanging potential. Water in industries is consumed for boiler make-up, processing, product treatment and cleaning, cooling, etc.

Boilers are used to produce hot water, steam, or hyper-thermal water. The required water quality is usually different for each purpose since many types of boilers are used for generating electricity, heating processes or products, providing steam or hot water, etc. Generally speaking, the boiler water must be at least non-corrosive and non-scale forming in the boiler and in the heat exchange piping, or power generating system.

Processing water is used as a raw material or additive in brewery, ice making, beverages, food processing, synthetic fiber processing, and dissociation bath application. The purpose of processing water thus differs between these and the quality must comply with the requirements. The processing water, especially in food related factories, must be clean and pathogen free.

Water for product treatment and cleaning is used for physical processes such as cleaning, swelling, or dissolving raw material, intermediate products and final products. The quality and quantity of water for product treatment and cleaning vary owing to manufacturing process and final product. The quality level required for chemical, food, textile and pulp/paper industry is high. Semiconductor processing water, in particular, requires the highest quality of water, so called ‘ultra-pure water’, because silicon wafers or computer chips need sub-micron precision and no contaminants, regardless of particulate or dissolved forms, are allowed on the surface. Previously, semiconductor factories used organic solvents to clean the products, but this caused serious soil and groundwater contaminations. Ultra-pure water works as the optimal cleaning agent with no contamination or hazard to humans or the environment.

Industrial water consumption affects the production cost as well as the conservation of limited water resources, so many industrial installations make efforts to reduce their water consumption by introducing in-factory water recycling systems in combination with wastewater treatment systems.

2. Industrial water consumption

The quantity of water consumption differs between the types of industries. In order to evaluate water consumption many industries use unit consumption, i.e. the quantity of water needed to produce a product in monetary term, e.g. m^3 day^{-1} to produce one hundred million yen (or one million US$) of industrial product per year. Figure 1 shows the trends of unit consumption in Japan. The average quantity of water consumption is almost steady at 50 m^3 day^{-1} (100 mil. yen $year^{-1})^{-1}$ in total. However, there is a big difference between the type of industries, which depends on the purpose of water utilization. The steel, chemicals, and pulp and paper industries are major industries which uses a large quantity of water per unit price of products because they use fresh water for cooling, cleaning and product processing.

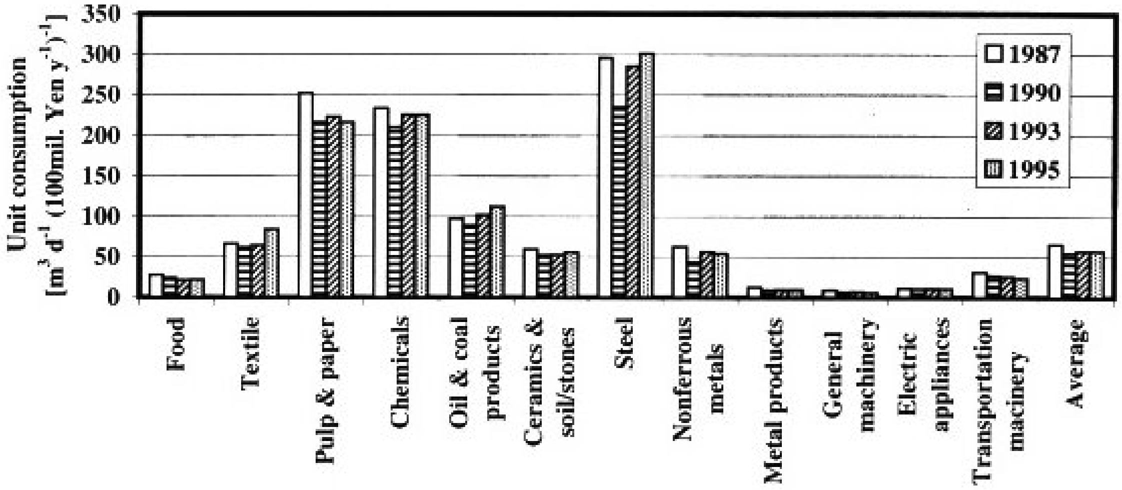

Figure 1. Unit consumption of industrial water in various industries

There is wide difference in unit consumption of water between the types of industry. No clear trend has been observed in these values in the last ten years or so. The total consumption of industrial water increased from 17.9 billion m^3 $year^{-1}$ in 1965 to 54.1 billion m^3 $year^{-1}$ in 1995, as shown in Figure 2.

The source of industrial water is classified into recycled water and make-up water. Recycled water is used repeatedly with or without water treatment in the factory, and make-up water means fresh water either supplied by public water supply sector or treated by the factory itself. As shown in Figure 2, significant amounts of water are recycled year by year. On the other hand, make-up water is almost constant in these years.

There are two major reasons for increasing the recycling rate. Firstly, the exploitation of new water sources, either surface water or groundwater, has become more and more difficult from the viewpoint of water resource conservation and environmental protection.

Increasing the water resource for industry means constructing new facilities such as a reservoir, for more effective utilization of run-off water during heavy rain, because surface water resources in Japan, as in other countries, are fully utilized by traditional and conventional irrigation and public water supply. The development of water resource has been increasingly difficult due to reduced opportunities to acquire appropriate dam sites and high costs of compensation to local residents.

The unit development cost for dams in Japan ranges from 10 to 30 yen m^{-3}. If industrial water is acquired from a reservoir, there will be additional cost for transportation, treatment, and distribution facilities, so newly developed industrial water will cost 50 to 200 yen m^{-3}. Although industrial water is essential for their activities, a limitation is imposed by the additional cost on the price of products.

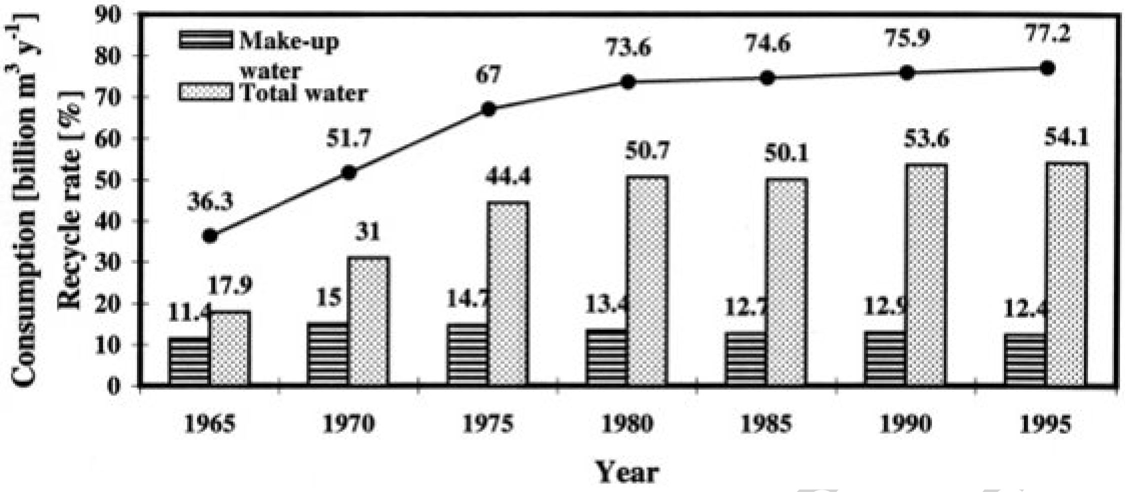

Figure 2. Consumption and recycle rate of industrial water in Japan

Groundwater is the most attractive alternative for industrial water because it only needs a well, a pumping facility and, if necessary, a treatment plant in the factory. Groundwater exploitation has, therefore, been implemented by many industries, but soil subsidence has often occurred as a result of over-exploitation of groundwater. Groundwater has been extracted at a rate much higher than the natural recharge to the aquifer. Soil subsidence has worsened in many urban and industrial areas and caused adverse effects on buildings, roads, bridges and other structures. The use of groundwater for industrial purposes has, therefore, been restricted by the soil subsidence prevention law. As a result, many factories have to reduce their consumption of fresh water and enhance the reuse of wastewater after appropriate treatment.

Another reason to enforce water reuse is the national regulation regarding wastewater discharge to ambient water environment by total mass pollutants. In order to protect water bodies from pollution, wastewater discharge from industries is regulated by very stringent law. Many industries have consequently reduced their fresh water consumption and increased wastewater reuse in the factories.

As shown in Figure 2, the recycling rate of industrial water to total consumption of industrial water increased from 36% in 1965 to 77% in 1995. Table 1 shows the consumption of recycled water and make-up water (fresh water) by industry and the recycling rate of the industrial water.

Many different industries use recycled water, but they have some common applications, i.e. product treatment and cleaning, cooling water, boiler and temperature control. Table 2 shows the consumption of industrial water and the recycling rate in each purpose. Cooling water is largely consumed in every industry so that more efficient use has been devised. As a result, the recycling rate is high. Almost 90% of water is repeatedly used.

Industry	**Make-up water [1000m^3 day^{-1}]**	**Recycled water [1000m^3 day^{-1}]**	**Total [1000m3 day^{-1}]**	**Recycling rate [%]**
Food	3,434	1,607	5,041	31.9

Textile	1,786	383	2,169	17.7
Pulp & paper	8,491	6,747	15,238	44.3
Chemicals	8,506	41,516	50,022	83.0
Oil & coal products	8,74	7442	8,316	89.5
Ceramics & soil/stones	9,98	2483	3,481	71.3
Steel	3,744	34,450	38,194	90.2
Nonferrous metals	733	2,453	3,186	77.0
Metal products	545	498	1,043	47.7
General machinery	544	828	1,372	60.3
Electrical machinery	1,586	4,207	5,793	72.6
Transportation machinery	820	9,589	10,409	92.1
Others	1,635	3,044	4,679	65.1
Total	33,696	115,247	148,943	77.4

Table 1. Consumption of make-up water and recycled water by industry (1996)

	Product treatment and cleaning	**Cooling water**	**Boiler**	**Temperature control**	**Others**
% of total consumption	17	72	1	6	4
Recycling rate (%)	70	89	34	86	36

Table 2. Water consumption and recycling rate

3. Cooling water

3.1. Water quality management of cooling water

Cooling water comprises the largest part of the consumption of industrial water. Due to the huge water consumption in each plant, cooling water is generally reused in order to save the acquisition cost and the water resource. The cooling water reuse may result in impairment by scale, slime, or corrosion caused by the concentration of soluble salts inside the circulation systems, due to evaporation or emission of cooling water. Therefore, quality control of cooling water is a very important factor in the operation of cooling water systems.

The quality standards of cooling water are shown in Table 3. Circulated water is the water that is repeatedly used in cooling water systems. The quality of circulated water should be monitored and controlled since it is in direct contact with cooling equipment and piping. Make-up water is the water that is added to circulation systems to compensate for water loss due to evaporation, emission, or blow down. Concentration ratio is the ratio of the quality of circulated water to that of make-up water as shown in equation (1).

$$\text{Concentration ratio} = \frac{\text{Quality of circulated water}}{\text{Quality of make-up water}} \quad (1)$$

The standards in Table 3 assume a common concentration ratio of 2 to 5 in cooling water systems.

	Item	**Cooling water**		**Consideration**	
		Circulated water	**Make-up water**	**Corrosion**	**Scale generation**
Standards	pH	6.5 - 8.2	6.0 - 8.0	X	X
	Electrolytic conductivity [mS m^{-1}]	80 or less	30 or less	X	X
	Chlorine ion [mgCl L^{-1}]	200 or less	50 or less	X	
	Sulfuric ion [$mgSO_4$ L^{-1}]	200 or less	50 or less	X	
	M alkalinity [$mgCaCO_3$ L^{-1}]	100 or less	50 or less		X
	Total hardness [$mgCaCO_3$ L^{-1}]	200 or less	70 or less		X
	Calcium hardness [$mgCaCO_3$ L^{-1}]	150 or less	50 or less		X
	Ionized silica [$mgSiO_2$ L^{-1}]	50 or less	30 or less		X
References	Iron [mgFe L^{-1}]	1.0 or less	0.3 or less	X	X
	Copper [mgCu L^{-1}]	0.3 or less	0.1 or less	X	
	Sulfuric components [$mgSO_4$ L^{-1}]	Under detection limit	Under detection limit	X	
	Ammonium ion [$mgNH_4$ L^{-1}]	1.0 or less	0.1 or less	X	
	Residue chlorine [mgCl L^{-1}]	0.3 or less	0.3 or less	X	
	Free-radical carbonate [mgC L^{-1}]	4.0 or less	4.0 or less	X	

"StandardS" refers to critical parameters which directly affect the performance of facilities. "References" are recommended values to avoid nuisance by algal growth or water-borne diseases such as legionaire's disease.

Table 3. Quality standards of cooling water

3.1.1 pH

The metal parts used in cooling water systems may suffer from corrosion at lower pH value, while the system will have deposition of scale due to calcium (Ca), magnesium (Mg) and silica (SiO_2) at higher pH value. Thus, the pH value of cooling water should be controlled in a range of 6 to 8. However, the corrosion properties cannot be evaluated by pH values only—the other qualities described below should also be considered.

3.1.2 Electrolytic conductivity

Electrolytic conductivity shows the total amount of soluble salts in water. Soluble salts are a factor of impairment such as corrosion and scale deposition as described above. Water with high electrolytic conductivity is likely to cause such impairment. Make-up water with low electrolytic conductivity increases the concentration ratio of circulated cooling water system and reduces the loss of water because the quality of make-up water is inversely proportional to concentration ratio. The electrolytic conductivity and pH value are easily measured, and thus readily used in routine quality control.

3.1.3 Chloride ion

Chloride ion is an important factor of corrosion. Use of well water or seawater with high concentration of chloride ion, results in corrosion to piping or equipment. Electricity generation plants, which use seawater for cooling are often equipped with anti corrosion piping and equipment.

3.1.4 Sulfuric acid

Sulfuric acid as well as chloride ion causes corrosion. Water with a high concentration of sulfuric acid is not suitable for cooling water. In general, the concentration of sulfate ion is lower than that of chloride ion. If water contains a high concentration of sulfate ion, the water must be aerated to strip sulfur dioxide gas (SO_2) to the air.

3.1.5 Methyl-red alkalinity (acid consumption)

Methyl-red alkalinity is a value that indicates concentration of bicarbonate ion (HCO_3), which, in combination with hardness components such as calcium, could cause impairment by generating calcium carbonate scale.

3.1.6 Hardness

Harness is the sum of calcium and magnesium, which is a component of scale in combination with pH and methyl-red alkalinity. The scale is deposited on the heat exchange conductors in cooling equipment, and thus, causes impairment such as reduced heat conductivity.

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Biographical Sketch

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 a degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. After working for the same university for four years, he moved to the National Institute of Public Health in 1970. He served as the Director of the Institute. From 1984 he worked for the Department of Sanitary Engineering, then the Department of Water Supply Engineering. He 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 of several ministries and agencies including Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. He performs 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.