Proper Management of Residual Chlorine Concentration in Tap Water for Reduce Chlorine Odor

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Abstract : In Japan, there is a culture of drinking tap water as it is. The Tokyo Metropolitan Government is making daily efforts on water quality control with a quality target which is more demanding than the standards set by the national government.

In particular, for residual chlorine that causes chlorine odor, the target range is set at 0.1 mg/L – 0.4 mg/L for tap water to avoid smelling of disinfectant chlorine while keeping a sufficient disinfection effect.

Throughout the large service area in which water is supplied from multiple water purification plants (WPPs) through a complex water distribution process, various efforts have been taken to control residual chlorine, which decreases over time, within our target range. The main efforts are in such as installation of the advanced water treatment, replacement of aged pipes, and additional chlorine injection at the water supply station. As a result of these efforts, the goal accomplishment ratio has been significantly improved from around 40% in FY2004, when the target was set, to around 90% in FY2015.

Keywords: Chlorine odor, residual chlorine, tap water quality management, suppression of consumption, levelling

Introduction

Japan is one of the few countries where we can “drink the tap water as it is,” thanks to the good water quality in the source and tireless effort of water suppliers, which has made the habit of drinking tap water without any further processing into a kind of Japanese culture.

However, during the period from 1960 to 1970, the era of high economic growth, the quality of the raw water has deteriorated and in spite of meeting the standards, consequently numerous complaints and concerns about the water as beverage, such as the bad smell or taste, were expressed by customers.

According to the customer satisfaction survey conducted in 2003 by Tokyo Waterworks the degree of satisfaction at the tap water as drinking water was 28%.

Accordingly, Tokyo Waterworks has launched the “Safe, Better Tasting Tap Water Project”, aiming for the improvement of customer satisfaction. It has set its own quality target more demanding than the standard set by the national government in the project and various measures have been taken in order to meet the target. “Water quality target for delicious water” defined independently by Tokyo Waterworks is shown in the Table 1.

Among them, management of residual chlorine concentration plays very important role in supplying safe delicious water. It is required to maintain the minimum necessary concentration for hygiene purpose and simultaneously to reduce the concentration in order to supply tasty water with less chlorine odor in the residual chlorine concentration management. Thus, Tokyo Waterworks has set the target concentration with the lower limit of 0.1 mg/L and the upper limit of 0.4 mg/L as the

Table 1 Water quality target for delicious water

	Item		Unit	Objectives		National Water Quality Standard etc
				Target Value	Specifics	
Odor	Chlorine odor	Residual chlorine	mg/L	0.4(MAX) 0.1(MIN)	Most people don't sense the odor of the chlorine used for disinection.	1.0(MAX) 0.1(MIN)
		Trichloramine	mg/L	0	Most people don't sense the chlorine odor.	---
	Threshold odor number (TON)		---	1 (No odor)	People don't sense an offensive taste or odor(other than the chlorine odor).	3(MAX)
	Musty odorant	2-Methylisoborneol	ng/L	0	People don't sense a musty odor.	10(MAX)
		Geosmin	ng/L	0		10(MAX)
Taste	Total organic carbon (TOC)		mg/L	1(MAX)	People don't sense an unpleasant taste.	3(MAX)
Appearance	Color		Color unit	1(MAX)	People don't notice the color and turbidity of the water.	5(MAX)
	Turbidity		Turbity unit	0.1(MAX)		2(MAX)

level which satisfies the free residual chlorine concentration required by the Ordinance for Enforcement of the Water Supply Law and which lets hardly any people feel the smell of the disinfecting chlorine.

As for the measure to manage the residual chlorine concentration, Tokyo Waterworks has been optimizing the residual chlorine level by feed-backing the residual chlorine concentration automatically measured at major sites and ends of the network of the pipeline (Nishino, 2001). However, because the water service areas of Tokyo Waterworks is as large as 1,239 km^2, with water supplied from multiple WPPs through the complex water distribution system, there is a limit to feedback-controlling the chlorine concentration degrading as the time elapses, based on the concentration at hydrants. Therefore the residual chlorine concentration of the tap water is rather high in the neighborhood of the purification plant, while the residual chlorine concentration may become too low at the end of the water service areas if the residual chlorine concentration at the outlet of WPPs is reduced.

Decrease of residual chlorine concentration in the water distribution system is caused by decomposition reaction with the water ingredients (Fuchigami *et al*., 2003; Sohn *et al*., 2004; Vieira *et al*., 2004; Kohka *et al*., 2005), vaporization of chlorine in distribution reservoirs, etc. (Fuchigami *et al.*, 2003), and chlorine decomposition reaction on the inner wall of water pipe (Fuchigami *et al.* 2005; Vasconcolos *et al.*, 1997; Haas *et al.*, 2002). Among them, rate coefficient of residual chlorine concentration decrease caused by the ingredient of the water is the most important in predicting the reduction, because the reduction caused by the ingredient proceeds continuously while the water flows in the distribution pipes. Therefore formulas to estimate the rate coefficient of residual chlorine concentration decrease have been devised, focusing on the initial residual chlorine concentration, water temperature, and total organic carbon (TOC) (Sato et al., 2007; Sato et al., 2008).

Based on the above, Tokyo Waterworks is implementing various measures in order to control the residual chlorine concentration within the target value range. Main countermeasures are: installing advanced water treatment and changing aged pipes according to plans to suppress consumption of chlorine, and preparing additional chlorine injection facility to level the residual chlorine at low concentration throughout the wide-range water supply district, and others. (Hosaka, 2010; Hosaka, 2012). The authors verified the effect of these policies taken by Tokyo Waterworks on the appropriate control of residual chlorine concentration in the hydrant.

Materials and Methods

Measurement of the Residual Chlorine Content of the Tap Water

Since water is supplied through the complicated distribution pipe system from multiple WPPs in Tokyo, residual chlorine and others at hydrants are continuously

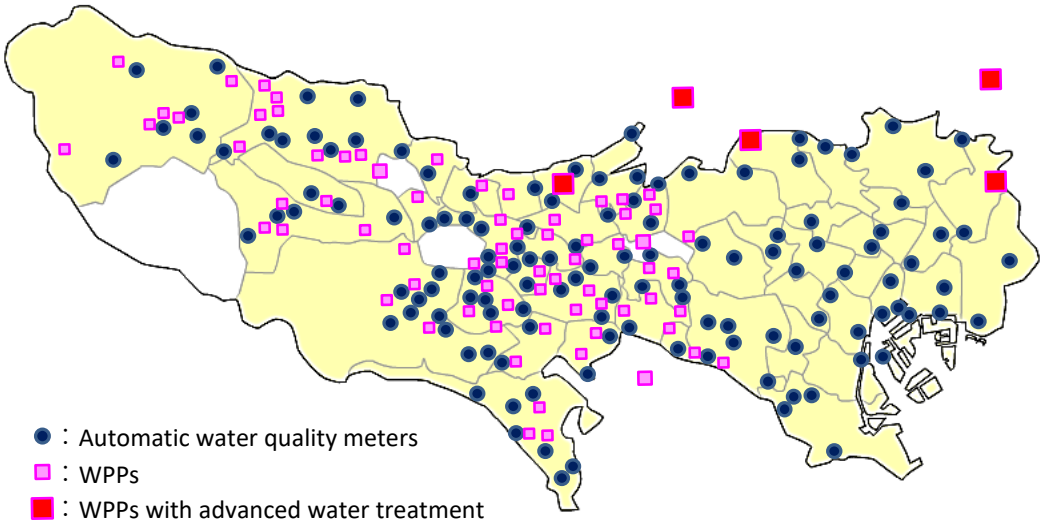


Figure 1 Locations of WPPs and automatic water quality meters

monitored with automatic water quality measurement devices at 131 places in Tokyo. Locations of WPPs and sites where automatic water quality meters are installed are shown in Figure 1. Measuring method of residual chlorine with the automatic water quality measurement devices is polarography.

The result of monitoring residual chlorine with automatic water quality measurement devices was validated by computing daily average in each site and computing its goal accomplishment ratio of residual chlorine based on the formula (1).

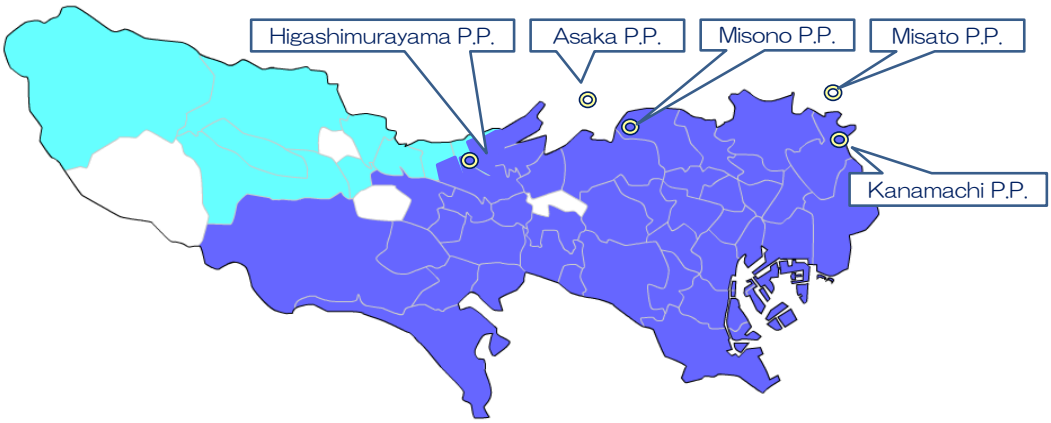
Goal Accomplishment Ratio of the Residual Chlorine
= 100 × (the number of hydrants where the residual chlorine is 0.1-0.4 mg/L) / (the number of hydrants) (%) - (1)

Measures for suppressing the Consumption of Residual Chlorine

Implementation of Advanced Water Treatment. It is known that the residual chlorine is consumed by reaction with organic compounds, and others during the process of water conveyance. It is possible to reduce the content of organic substances by implementing advanced water treatment, the combination of ozonation and biological activated carbon adsorption treatment, and consequently to suppress the consumption of residual chlorine. With this measure, the residual chlorine concentration at the end of the water distribution area becomes to gradually decline than before and consequently it becomes possible to reduce the residual chlorine concentration at the outlets of WPPs.

The locations of WPPs with advanced water treatment installed and their capacity are shown in Figure 2. After Tokyo Waterworks began preparing an advanced water treatment facility in Kanamachi P. P. in 1989, it has been implemented in the five WPPs in the Tone Water System in order, and currently all water has been supplied after treating in advanced method since October 2013.

Changing Aged Pipes. Tokyo Waterworks has constructed about 27,000 km of distribution pipes to supply water to customers. The underground water pipes are always in danger of leaks because of its deterioration over time, earthquakes, ground settlement, and influence of corrosive soil. Therefore Tokyo Waterworks has been actively renewing the pipelines of the cast iron pipes, with low strength without inner lining, aged pipes which was constructed long before, and the early ductile iron pipelines where straight pipes made of ductile cast iron and specials pipes made of high grade cast iron co-exist which has been constructed between around 1960s to



■ : Area where 100% high degree purified water is supplied from the Tone River System (including the one partly supplied).

■ : Area where the quality of raw water is good, with no need of advanced water treatment

□ : Area where water is supplied by other water supply business units than Tokyo Metropolitan Waterworks Bureau

WPPs	Facility capacity		Introduced in
Kanamachi P.P.	1.5 mil. m^3/day	Term Ⅰ 0.26 mil. m^3/day	1992
		Term Ⅱ 0.26 mil. m^3/day	1996
		Term Ⅲ 0.98 mil. m^3/day	2013
Misato P.P.	1.1 mil. m^3/day	Term Ⅰ 0.55 mil. m^3/day	1999
		Term Ⅱ 0.55 mil. m^3/day	2013
Asaka P.P.	1.7 mil. m^3/day	Term Ⅰ 0.85 mil. m^3/day	2004
		Term Ⅱ 0.85 mil. m^3/day	2014
Misono P.P.	0.3 mil. m^3/day		2007
Higashimurayama P.P.	0.88 mil. m^3/day		2010

Figure 2 WPPs with advanced water treatment installed and their capacity

1970s, in order to avoid leak and muddy water and to improve the resistance to earthquakes since old days.

When inner surface of water pipes deteriorates, residual chlorine becomes prone to consumption. Especially, it is reputed that muddy water and reduction of residual chlorine concentration occur many times in aged pipes and early ductile iron pipes, and others. The consumption of residual chlorine is expected to be reduced by eliminating these pipes.

Measures for Leveling the Residual Chlorine Concentration

Preparation of Additional Chlorine Injection Facility in Water Supply Station. Since water service areas of Tokyo Waterworks are extensive, it takes long time to flow from the purification plant to the hydrant in some places, and thus the residual chlorine concentration differed a lot among places, such as high concentration in

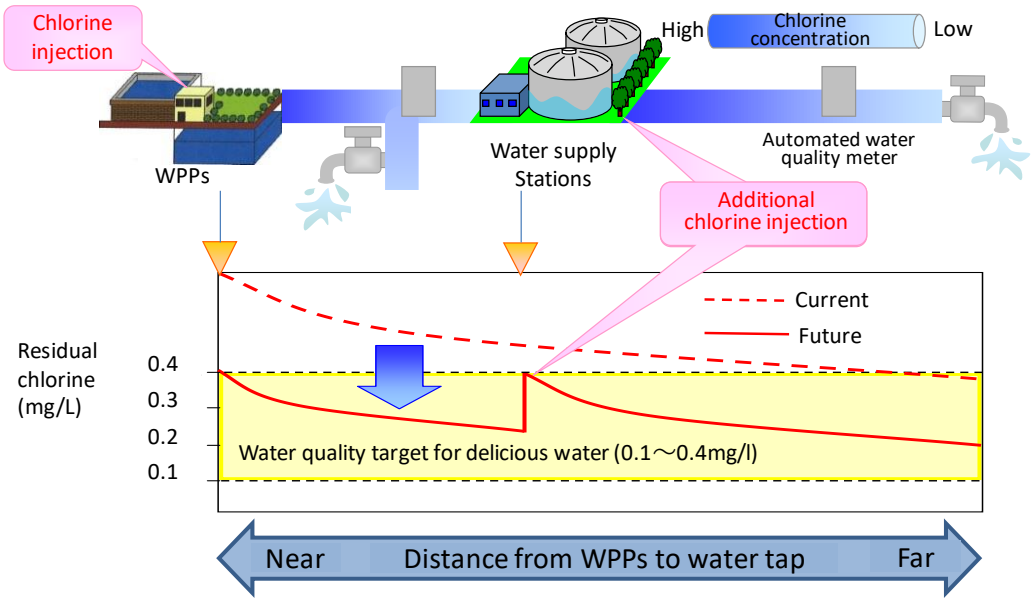


Figure 3 The effect of additional chlorine injection facilities

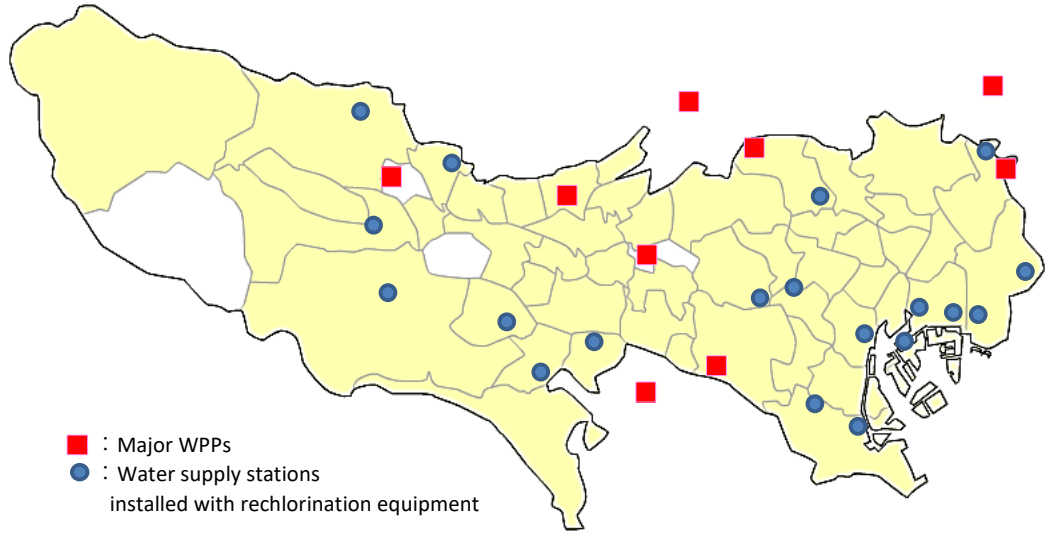


Figure 4 Sites where additional chlorine injection facilities are installed

places close to the WPPs. So we have prepared facilities to inject additional chlorine in water supply stations in the midway of water distribution systems, as shown in Figure 3, in order to reduce the amount of chlorine fed in purification plant and simultaneously level the residual chlorine concentration through the water service areas. 19 additional chlorine injection facilities have been installed in the water service areas of Tokyo Waterworks. Each location is shown in Figure 4.

Results and Discussion

Measures for suppressing the Consumption of Residual Chlorine

Installation of Advanced Water Treatment. Reduction of TOC concentration at outlets has been investigated in WPPs where advanced water treatment is installed. Change of TOC concentration before and after installation of advanced water treatment is shown in Figure 5. The TOC concentration at outlets was reduced by purifying water with advanced water treatment method in every purification plant, and it was confirmed that the concentration was reduced to approximately half after the installation of the advanced water treatment. With this measure, it is possible to reduce the amount of chlorine to inject or sterilization. The relation between TOC concentration at outlets of WPPs and consumption of chlorine per 1 m^3 of water supply is shown in Figure 6. As shown in Figure 6, consumption of residual chlorine is suppressed by reducing the TOC concentration at outlets of WPPs. It was confirmed

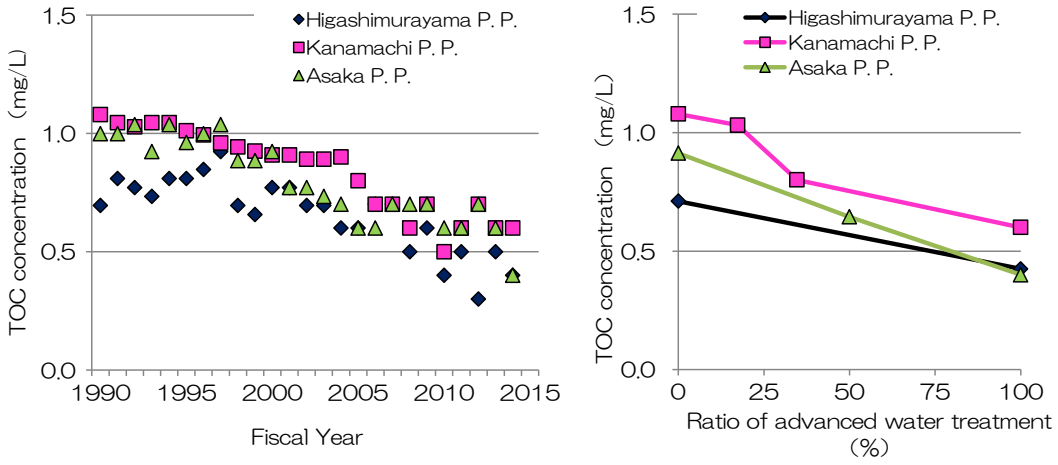


Figure 5 Change of TOC concentration after the implementation of advanced water treatment

that the use of chlorine per 1 m^3 of water supply can be reduced to 2 g/m^3 or less, if TOC concentration at outlets of WPPs is below 0.6 mg/L. Hence, it is expected that the TOC reduction contribute a lot to the reduction of residual chlorine at hydrants.

Replacement of Aged Pipes. The renewal of aged pipes and early ductile iron pipes was verified. Figure 7 illustrates the transition of the elimination rate of aged pipes and early ductile iron pipe. Renewal of aged pipes was completed in 2012. About 3,000 km of early ductile iron pipes which need replace have been constructed. 53% of them have been renewed until 2014, and the renewal is expected to complete in 2021. By renewing aged pipes whose inner surface is supposed to be degraded, we expect that the water leak will be prevented, that the aseismic of pipes will be improved, and that the consumption of residual chlorine during distribution of water will be suppressed.

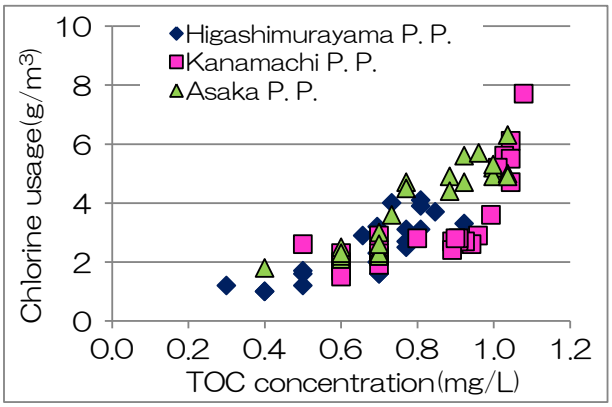


Figure 6 Relation between TOC concentration and chlorine usage

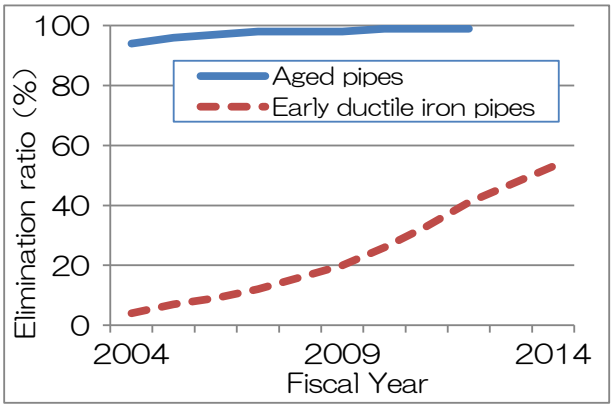


Figure 7 Transition of Elimination Ratio of Aged Pipes and Early Ductile Iron Pipes

Measures for Leveling the Concentration of Residual Chlorine

Installation of Additional Chlorine Injection Facilities in Water Supply Stations. The effect on leveling of residual chlorine concentration was inspected in Kanamachi P. P., where the additional chlorine injection facility were installed. Transition of the residual chlorine concentration before and after the leveling of residual chlorine

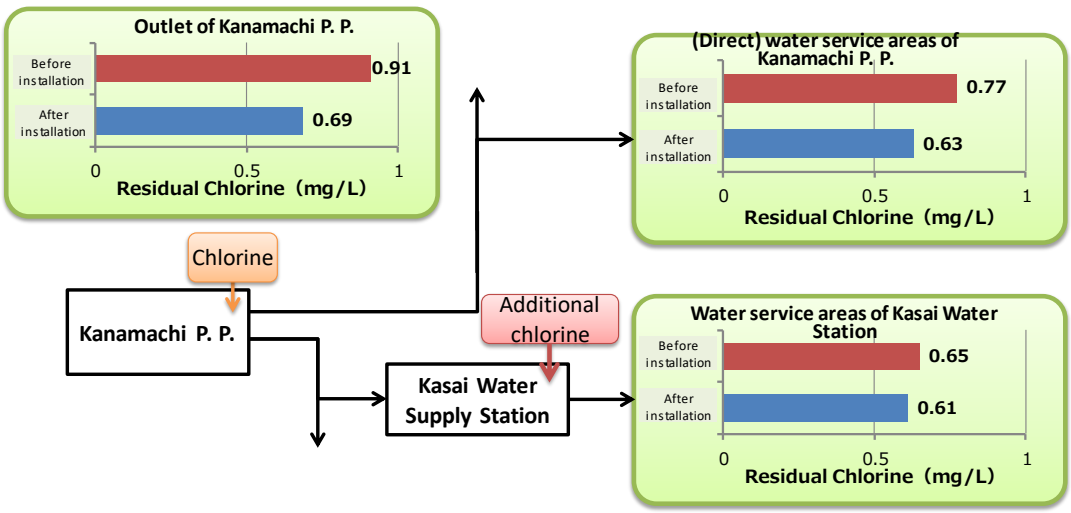


Figure 8 Change of residual chlorine concentration before and after additional chlorine injection in the water supply district of Kanamachi P. P.

concentration is shown in Figure 8. It was necessary to make the residual chlorine concentration at outlet of purification plant 0.9 mg/L in August 2009 with no additional chlorine facilities. But after the installation, it was possible to reduce it to about 0.7 mg/L in August 2011 and it was clarified that the residual chlorine concentration could be leveled at about 0.6 mg/L throughout the water service area.

Ratio of Accomplishing the Goal of Residual Chlorine

Based on the residual chlorine concentration measured with automatic water quality measurement devices installed at 131 sites, accomplishment ratio of the residual chlorine concentration goal was evaluated. Transition of the goal accomplishment ratio of residual chlorine is shown in Figure 9. The goal accomplishment ratio was 37% in FY2004, and it was improved to 60% in FY2005. The ratio has been in upward trend since FY2011 and reached 89% in FY2015. This result is presumed one of the effects of the measures to suppress consumption of residual chlorine including the introduction of advanced water treatment, the measures to level the residual chlorine concentration including preparation of additional chlorine injection facilities, and the delicate management of operating condition of chlorine concentration and additional chlorine injection.

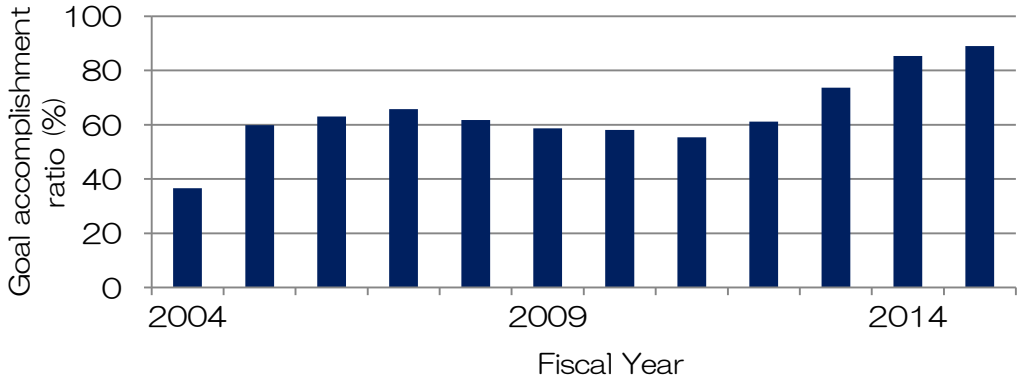


Figure 9 Transition of the goal accomplishment ratio of residual chlorine

Conclusions

We are making several efforts including the installation of advanced water purification system, eliminating aged pipes, preparation of additional chlorine injection facilities in order to level the residual chlorine at about 0.1-0.4 mg/L throughout the whole water distribution area in Tokyo. As a result, ratio of tap water accomplishing the residual chlorine concentration goal has improved from about 40% in FY2004 to about 90% in FY2015. Additionally, the customer satisfaction was improved from 28% in 2003 to 49% in 2014. Moreover, when we asked more than 50,000 customers to compare the taste of the tap water supplied by Tokyo Waterworks with mineral water, the tap water was evaluated no less tasty than mineral water. It is a great result achieved by our measures.

We are going to continue the effort towards the goal accomplishment ratio of 100%.

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