Importance of the Concept of Self Cleaning Networks in a Depopulation Society

Sadahiko Itoh
Department of Environmental Engineering, Graduate School of Engineering, Kyoto University, C-1 Kyotodaigaku-katsura, Nishikyo-ku, Kyoto 615-8540, Japan, itoh@urban.env.kyoto-u.ac.jp

BACKGROUND

Redesigning water distribution system in a depopulation society is needed in some developed countries like Japan in the future. The decrease of water demand in a supply area will cause the decrease of water velocity in distribution networks and longer retention time in relatively old distribution pipes. As a result, drinking water quality including concentrations of residual chlorine can be deteriorated. Thus, control of the quality inside distribution pipes should be emphasized in the future. **Photo 1** shows an example of remote area in Japan.

This paper describes research themes of our project from a viewpoint of controlling the conditions inside pipes, and shows some obtained results. In addition, an ultimate goal of the project is explained. Finally, the importance of the concept of Self Cleaning Networks in a depopulation society is emphasized.

Photo 1. An example of remote area.
Shin-Onsen Town in Hyogo Prefecture of Japan. Service population: About 10 persons.

RESEARCH THEMES

Based on the above background, we have organized a collaborative research team with water supply utilities and private companies. **Table 1** summarizes the research themes of our project (Itoh *et al.*, 2018).

Table 1. Research themes of the project.

Theme No.	Theme	Contents and notes
Theme 1	Quantification of weight of particles flowing into distribution network.	Quantification of weight in kg/day of solid (fine particles, insoluble manganese and others) flowing into distribution network from a water treatment plant. Quantification of weight in g/m^2 and g/m of accumulated matters on the surface of pipes.
Theme 2	Adhesion of particles on pipe surface.	Adhesion characteristics of fine particles, manganese and bacteria on test pieces of ductile cast iron pipes and plastic pipes. The preferable quality of pipe material when renewing pipes could be suggested.
Theme 3	Water treatment process contributing to maintain the inside surface of distribution pipes clean.	In the future, water treatment processes should be responsible for the conditions inside distribution pipes.
Theme 4	Modeling of developing the inside condition and proposing critical control points.	Numerical simulation of accumulated matters in a supply area. Control of the inside condition by redesigning the network could be discussed.
Theme 5	Redesigning of water distribution system towards a depopulation society.	A balance among self-cleaning function and earthquake disaster resilience and fire protection function should be discussed.

RESULTS AND DISCUSSION

Quantifying weight flowing into distribution network

Table 2 shows the results obtained at the A-Plant in Hyogo Prefecture and the B-Plant in Osaka Prefecture. The performances of these plants are fairly good, since turbidity of the treated waters are very low. We calculated the weight in kg/day based on a concentration of particles in the treated water (mg/m^3) and an average water volume produced. **Table 2** demonstrates that 2.2 kg/day from the A-Plant and 16.4 kg/day from the B-Plant enter into distribution network for a long time such as a few decades. As a matter of fact, B-Plant has a plan to change the treatment steps that set rapid sand filtration after activated carbon adsorption. It was found that this change can decrease the weight from 16.4 kg/day to 14 kg/day.

Table 2. Estimated weight of particles flowing into distribution network.

	Turbidity of treated water	Concentration of particles in treated water (mg/m^3)	Average water volume produced (× 10^3 m^3/day)	Weight flowing into distribution network (kg/day)
A Plant	**0.004**	**4.6**	**470**	**2.2**
B Plant	**0.023**	**14.5**	**1,130**	**16.4**

Quantifying weight of accumulated matters

We have conducted field surveys in Kobe City collecting water samples when the pipes are cleaned. Conventional flushing (see **Photo 2**) is conducted with an increased velocity ranged from 0.3 m/sec to 0.8 m/sec to remove accumulated matters. Flushed water was collected to analyze suspended solid,

Photo 2. Pipe cleaning by conventional flushing.

heavy metals and so on. The results show that weight of accumulated matters on the inside surface of pipes is approximately 1.0 to 3.0 g/m^2 (excluding iron) (Kishomoto *et al.*, 2017).

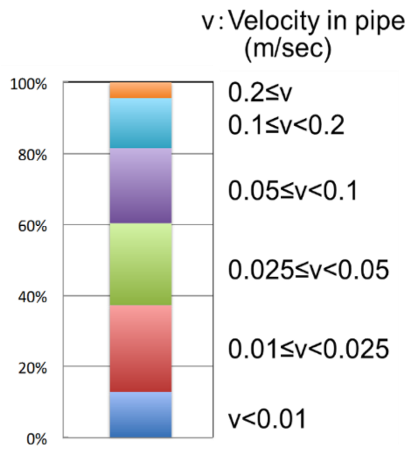
Adhesion of particles to pipe surface

We have conducted tests of adhesion of fine particles, manganese and bacteria to test pieces of ductile cast iron pipes and plastic pipes (Zhou *et al.* 2017). Materials of ductile cast iron are epoxy coated steel and cement mortar lined iron. Materials of plastic pipes are polyethylene, hard polyvinyl chloride and high intensity polyvinyl chloride. It was found that adhesion characteristics of fine particles were comparable among materials of the test pieces.

In addition, we have developed a mathematical model including initial adhesion, accumulation and steady-state, and detachment with a main parameter of water velocity. The developed model was verified by the results of the survey described in **Quantifying weight of accumulated matters**.

Control of hydraulics in distribution network

The concept of "self-cleaning" has been presented in designing water distribution network (Vreeburg, 2007). As a matter of fact, the maximum flow velocity of 0.2 - 0.25 m/sec is practically effective to keep the pipes clean (Blokker *et al.*, 2011). **Figure 1** shows a distribution of the maximum daily flow



Figue 1. Distribution of the maximum daily flow velocity in a current network of Kobe City.

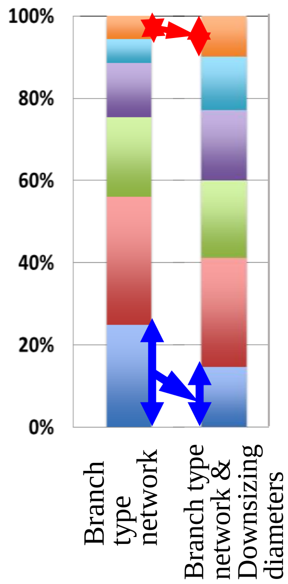


Figure 2. Distribution of the maximum daily flow velocity after redesigning the networks.

velocity in the current networks of Nada Low-Layer in Kobe City, one of the target areas of our research. It was found that distribution pipes with a velocity of 0.2 m/sec or higher are just 4.4% in the supply area. This means that most pipes doesn't have self-cleaning function. One of the countermeasures is to downsize pipe diameter, and the other is to form a branched type network. In these cases, the ratio of distribution pipes with higher than 0.2 m/sec increased as shown in **Figure 2**. In particular, downsizing improved self-cleaning function effectively. In addition, it was demonstrated that a balance between self-cleaning function, earthquake disaster resilience, and fire protection function could be achieved (Hirayama *et al.*, 2016).

Numerical simulation and control of the inside condition

As described in **Adhesion of particles to pipe surface**, we developed a mathematical model on adhesion and accumulation. **Figure 3** shows a simulated distribution of matters excluding iron in g/m^2 that can be accumulated for 20 years in a supply area of Kobe City. Based on this, it is possible to discuss the effectiveness of redesigning the network. **Table 2** shows the scenarios based on a 3-stage approach for managing particles in the distribution network (van der Kooij & van der Wielen eds., 2014; Vreeburg, 2007).

Figure 4 shows a comparison on the effect of decreasing accumulated weight (g/m^2) between the scenarios. The comments in the figure are given considering actual implementation, since downsizing the pipe diameters is not an easy work for water supply utilities.

Although the research described here has been conducted for Kobe City, a big city in Japan, the methods are now applied to small water supply systems as shown in **Photo 3**.

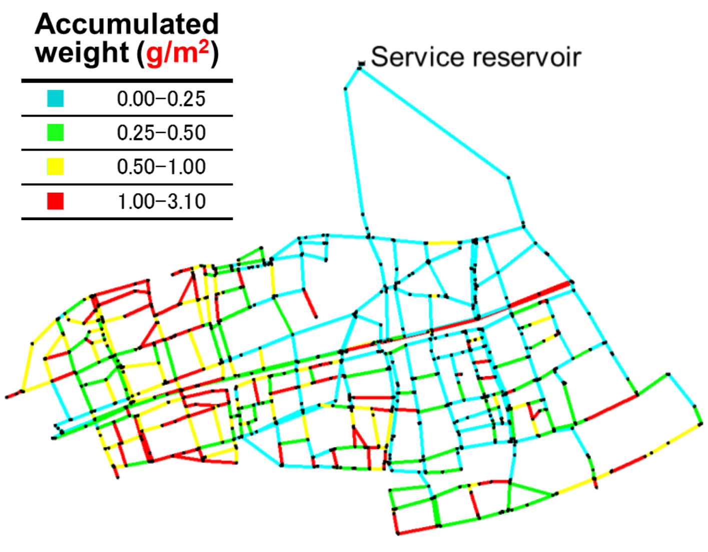


Figure 3. Simulated distribution of accumulated matters.

Table 2. Scenario setting.

Stage 1: Water treatment	Case 1	Reducing SS in finished water by 50%
	Case 2	Reducing SS in finished water by 20%
Stage 2: Downsizing the pipe diameters	Case 1	Decreasing the diameters of all the distribution pipes
	Case 2	100 mm → 75 mm 120,150 mm → 100 mm
	Case 3	120,150 mm → 100 mm
Stage 3: Pipe cleaning		The supply area was divided into ten blocks. After ten years of supplying water, pipe cleaning was performed in the block where the accumulated weight (g/m²) was the maximum. Pipe cleaning was performed in all ten blocks within 20 years with starting after ten years. Discharge efficiency was set to be 60%, based on the experiment.

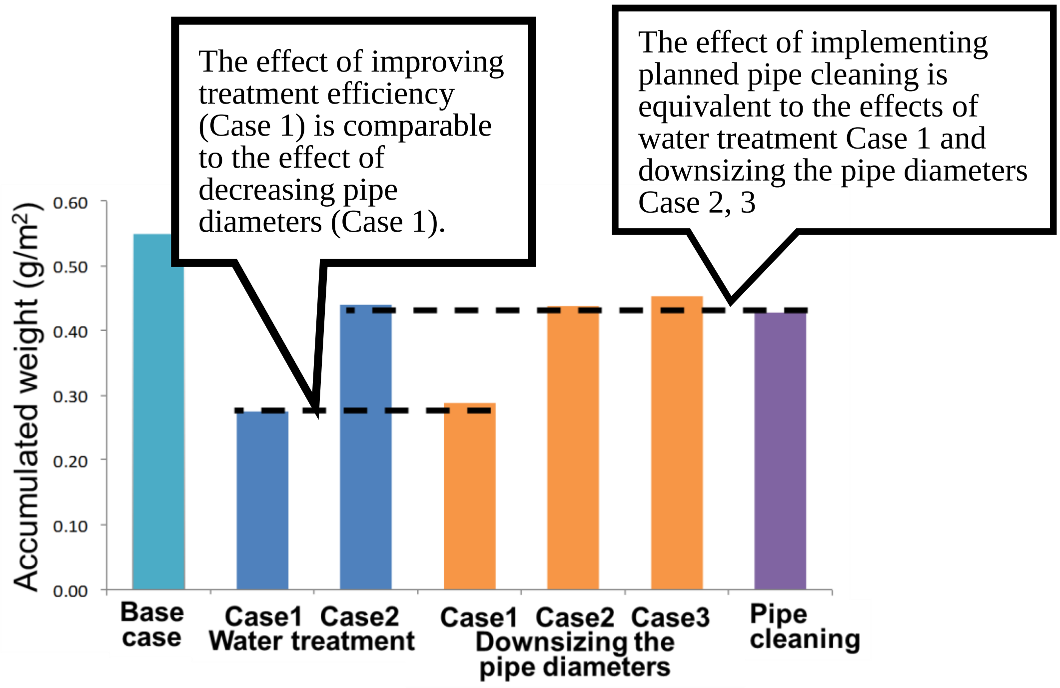


Figure 4. Comparison between the scenarios.

Photo 3. Small water treatment facilities.

ULTIMATE GOAL OF THE PROJECT

The whole aim of our project is as follows. Starting with the quality of source water, by a water treatment, what kind of water will be transferred to a distribution network? This paper emphasizes that we should focus on the quality inside the distribution network, and control it. Finally, what kind of quality of drinking water will be supplied to consumers? In this sense, an ultimate goal is to derive a total solution from source to tap toward a depopulation society in the future (see **Figure 5**).

As suggested in this report, the importance of the concept of Self Cleaning Networks can be emphasized from the viewpoint of preventing the deterioration of drinking water quality in a depopulation society.

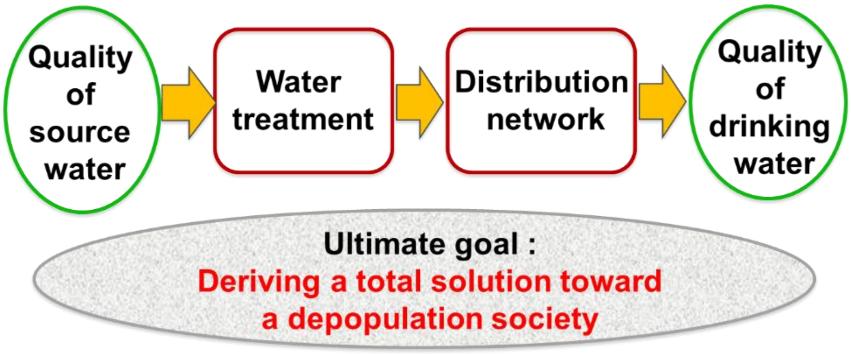


Figure 5. Concept of the project.

REFERENCES

Blokker, E. J. M., Schaap, P. G., Vreeburg, J. H. G. (2011) Comparing the fouling rate of a drinking water distribution system in two different configurations, *CCWI 2011 Urban Water Management: Challenges and Opportunities*, D. Savic, Z. Kapelan, D. Butler, eds., Centre for Water Systems, University of Exeter, Exeter, 583-588.

Hirayama, N., Yamada, T., Echigo, S., Itoh, S. (2016) A study on redesigning of water distribution system towards a depopulation society, *J. Japan Soc. of Civil Eng., Ser. G*, 72(7), Ⅲ_467-Ⅲ_474 (in Japanese).

Itoh, S., Nakanishi, T., Zhou, X., Tarui, K., Hashimoto, Y., Kitada, J., Kishimoto, J., Asada, Y., Echigo, S. (2018) Reestablishment of water supply system in a depopulation society and research needs, *IWA World Water Congress & Exhibition, 16-21 Sep. 2018, Tokyo, Japan.*

Kishimoto, J., Nakanishi, T., Zhou, X., Nishioka, H., Kitada, J., Tarui, K., Hashimoto, Y., Asada, Y., Echigo, S., Itoh, S. (2017) Survey on micro-particles adhered inside water distribution pipes and a distribution of accumulated matters in a network, *Environ. & Sanitary Eng. Res.*, 31(3), 182-185 (in Japanese).

van der Kooij, D., van der Wielen P.W.J.J. eds. (2014) Microbial Growth in Drinking-Water Supplies, 453p., IWA Publishing, London, UK.

Vreeburg J. (2007) Discolouration in drinking water systems: a particular approach, Delft University of Technology, Delft, the Netherlands, Chapter 5, 89-112.

Zhou, X., Nakanishi, T., Nishioka, H., Tarui, K., Hashimoto, Y., Kishimoto, J., Asada, Y., Echigo, S., Itoh, S. (2017) Behavior of Suspended Matters in Drinking Water Distribution System, *The 26th KAIST-KYOTO-NTU-NUS Symposium on Environ. Eng.*, 5-8 July 2017, Seoul, Korea.