On-site water recycling systems in Japan


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Abstract
Non-potable urban water reuse is Japan’s main water reuse practice, which includes water for environmental uses, in-stream flow augmentation, toilet flushing, and industrial reuse. On-site water recycling systems reclaim wastewater on site as well as harvest rainwater in one or more large buildings and distributing the reclaimed water within the buildings for non-potable reuse. Based on our survey conducted in 1999 on current status of on-site water recycling systems in 23 wards of the Tokyo Metropolitan Government District, the following findings are reported in this paper: (1) on the average, 61% of non-potable water demand is met by reclaimed water, and the deficit is made up by tap water from city water supply, (2) biological treatment or ultrafiltration processes can provide reliable treatment and suitable water quality. Some technical problems such as odor from on-site treatment facilities have occurred in a few buildings, (3) there has been no serious accident involving human health by accidentally ingesting reclaimed water, and (4) there is a scale merit in the construction cost of on-site water recycling systems. An on-site wastewater recycling system larger than 100 m³/d is more economically justifiable when compared to a conventional domestic water supply system. An on-site water recycling system can provide an effective, safe, and economical urban water resource for non-potable water reuse applications.

Keywords Economy; on-site water recycling system; public health; water quality; water reuse; water saving

Introduction
Although the majority of reclaimed wastewater reuse in the world is for agricultural and landscape irrigation, Japan’s water reuse is mainly for non-potable urban applications, which include water for environmental uses, in-stream flow augmentation, toilet flushing, and industrial reuse. Large-scale wastewater reclamation and reuse systems from publicly owned treatment works (POTW) have been reported previously (Ogoshi et al., 2001). In addition to undertaking large-scale wastewater reclamation and reuse systems from POTW, national and local governments have promoted the installation of on-site wastewater reclamation and recycling systems and rainwater recovery and detention facilities by setting new regulations and subsidizing these installations. The purpose of these actions has been to (1) cope with water supply shortages, (2) reduce wastewater load on sewerage systems and treatment facilities, and (3) prevent flooding of urban rivers from stormwater flows. An on-site wastewater recycling system is a water reuse system that treats and recclaims wastewater on site from one or more large buildings as well as collecting and detaining rainwater, and distributes the reclaimed water within or in the vicinity of the buildings for non-potable reuse applications.

Installation of on-site water recycling systems started in the early 1960s, and the number grew in the 1980s with the rapid expansion of Japan’s economy. About 130 on-site water recycling systems are currently installed each year. In 1996, there were about 2,100 buildings with on-site water recycling systems or connected to a large-area water recycling system. The volume of reclaimed water used was about 324,000 m³/day, which was about
0.8% of Japan’s domestic water use (National Land Agency, 2000). On-site water recycling systems were mainly located in urban areas, such as the Tokyo metropolitan areas and Fukuoka City.

A sequel to our previous paper which discussed large-scale regional water recycling systems from POTWs (Ogoshi et al., 2001), this paper focuses on the “on-site water recycling and reuse systems” as practiced in Japan with special reference to our survey conducted in 1999 on the current status of on-site water recycling systems in the 23 wards of the Tokyo Metropolitan Government District.

**Water recycling regulations and the 1999 on-site water recycling system survey**

Water quantity and quality requirements related to water recycling regulations are discussed, followed by the description of the on-site water recycling system survey we conducted in 1999.

**Water quantity requirements**

The Tokyo Metropolitan Government established a regulation in 1984 requiring newly constructed large buildings to install on-site water recycling system or take reclaimed wastewater from the regional water recycling system if floor space exceeds 30,000 m² or using more than 100 m³/day of non-potable water. The purpose of this regulation was to encourage efficient water use and reduce the discharge of wastewater into the public sewerage system and treatment plants due to their capacity limitations. Furthermore, in 1993, the Tokyo Metropolitan Government promulgated regulation to install on-site rainwater recovery and detention systems for buildings having a floor area exceeding 10,000 m² or having a building area exceeding 3,000 m² to conserve rainwater and prevent flooding of drainage systems.

**Water quality requirements**

The applicable water quality requirements for reclaimed water by various agencies in Japan for toilet flushing are summarized in Table 1. It is noted in Table 1 that the coliform criterion, 10 per 1 mL or 1,000 per 100 mL, is numerically equivalent to that for public waters in which bathing is allowed. Recently promulgated comprehensive water recycling requirements in several states in the United States and other countries generally require total coliform or fecal coliform density of less than 2.2 per 100 ML or non-detect.

**Table 1** Reclaimed water quality criteria for toilet flushing use

<table>
<thead>
<tr>
<th>Ministry of Construction</th>
<th>Ministry of Health and Welfare</th>
<th>Tokyo Metropolitan Government</th>
<th>Fukuoka City Government</th>
<th>Fukuoka Prefecture Government</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Not unpleasant</td>
<td>Not unpleasant</td>
<td>Not unpleasant</td>
<td>Not unpleasant</td>
</tr>
<tr>
<td>Color</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Odor</td>
<td>Not unpleasant</td>
<td>Not unpleasant</td>
<td>Not unpleasant</td>
<td>Not unpleasant</td>
</tr>
<tr>
<td>pH</td>
<td>5.8–8.6</td>
<td>5.8–8.6</td>
<td>5.8–8.6</td>
<td>5.8–8.6</td>
</tr>
<tr>
<td>Chlorine residual (mg/l)</td>
<td>Trace amount</td>
<td>Trace amount</td>
<td>Trace amount</td>
<td>Trace amount</td>
</tr>
<tr>
<td>BOD (mg/l)</td>
<td>20*</td>
<td>–</td>
<td>–</td>
<td>20</td>
</tr>
<tr>
<td>CODₘₐ (mg/l)</td>
<td>30**</td>
<td>–</td>
<td>–</td>
<td>30</td>
</tr>
<tr>
<td>Coliform organisms</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>(number/ml)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS (mg/l)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>30</td>
</tr>
</tbody>
</table>

Note:
* For reclaimed water of biological treatment process
** For reclaimed water of ultrafiltration or microfiltration process
On-site water recycling system survey

We carried out in 1999 a questionnaire survey of 325 buildings in the Tokyo Metropolitan Government District which were reported to have on-site water recycling systems or use reclaimed water from large-area water recycling systems from POTWs. We received completed questionnaires from 125 buildings, of which 109 were connected to on-site water recycling systems and 16 buildings were connected to large-scale area wide water recycling systems from POTWs. These buildings were used for offices, hotels, city halls, schools and commercial activities, but no residential uses were reported. The salient findings are summarized and discussed in the following sections.

Water savings due to on-site water recycling

Based on the survey we have conducted, the effect of on-site water recycling systems on saving water was estimated to be 30% on the average. The water recycling ratio is used in this survey and defined as the supply of reclaimed water divided by the total water usage of the subject building. Reclaimed water is used only for non-potable uses in these buildings, mainly for toilet flushing. On the other hand, the non-potable water use ratio, which is the non-potable water usage divided by the total water usage in the buildings, is about 39%. As always, the supply gap with reclaimed water is made up of tap water from the city water supply.

On-site water recycling systems can be classified according to the sources of reclaimed water. Figure 1 shows a breakdown of various sources of reclaimed water: lavatory, drinking, bath, heating and cooling wastewaters (gray water A), kitchen wastewater (gray water B), toilet wastewater (black water), rainwater, and reclaimed water supplied from POTWs.

Figure 2 shows the ratio of specific source of reclaimed water in non-potable water uses (water replenishment ratio). Figure 3 shows water recycling ratio in comparison with various sources of water. As can be seen from Figures 2 and 3, if the source is only gray water A, the water replenishment ratio is 79% and the water recycling ratio is 18% on average. If the source of water is a combination of gray water A and B, the water replenishment ratio becomes higher (82%) and the water recycling ratio becomes higher (26%). Even if rainwater is added to these sources, supplemental tap water from city water supply is needed. However, if black water is added to these sources, supplemental tap water is not needed because water demand can be satisfied with these sources and the water recycling ratio is about 33%. In the same way, if reclaimed water supplied from POTW is used, the demand for reclaimed water is satisfied and the water recycling ratio remains relatively high.

On the other hand, relatively few on-site water recycling systems use both gray waters A and B and black water or reclaimed water supplied from POTW (see Figure 1), even though this combination is more effective for saving tap water. One of the reasons is that reclaimed water supplied from POTW can only be economically justified in relatively
close proximity to POTW or where reclaimed water distribution system from POTW has already been built.

**On-site wastewater treatment processes**

Figure 4 shows four types of on-site wastewater treatment processes which are recommended to meet the reclaimed water quality criteria (Government Buildings Department, Ministry of Construction, 1997).

The on-site wastewater treatment process is designed under a trade-off between cost, reliability and safety; it is particularly important to reduce the footprint of the treatment facility in order to reduce the cost.

Conventional activated sludge process (No. 1) is widely used. In addition, biofiltration processes such as the biological contact aeration process and rotary disk process after biological treatment (No. 2) are often adopted for treating wastewater with a large pollution load such as gray water B or black water. The coagulation process is often included for effective removal of SS.

Due to recent technological development in membrane technology, the membrane separation bioreactor process is often used for its smaller footprint. A microfiltration or ultrafiltration process without biological treatment (No. 4) is also adopted for wastewater with a relatively small pollution load such as gray water A. Also, simpler treatment processes such as sedimentation and filtration are often used where pollution loads are smaller, such as rainwater. In addition to these processes, post-treatment processes such as ozonation or activated carbon treatment are sometimes used to remove color and odor for the benefit of users.

**Figure 4** On-site wastewater treatment process flow sheet
Safety of on-site water recycling systems

Our survey showed that some problems such as odor from on-site wastewater treatment facilities and deterioration of water quality have occurred in a few buildings. Figure 5 summarizes problems reported in the survey.

No serious accidents related to human health due to accidentally ingesting reclaimed water have been reported. The reclaimed water supply pipes must be inspected for possible cross-connection before operation and one month after commencing operation by monitoring the tap water quality.

Economic evaluation of on-site water recycling systems

The lifecycle cost of on-site water recycling systems, including construction cost and operation and maintenance (O&M) cost, is aggregated using the survey data. The construction cost mainly consists of that of the on-site wastewater treatment facility and reclaimed water distribution system (pipes and tanks only for reclaimed water). The O&M cost consists of personnel expenses, chemical costs, electricity, sludge disposal expenses and expendable supplies (especially for replacement of microfilters or ultrafilters).

Figure 6 shows unit construction cost. Scale merits are more significant than the effects of different sources of reclaimed water, although wastewaters with a larger pollution load need more expensive treatment processes. The unit construction cost per capacity of producing reclaimed water is reduced by producing a larger volume of reclaimed water even if kitchen wastewater with large pollution load is used as one of the sources.

Figure 7 shows unit O&M cost. The facilities only using rainwater for reclaimed water are more economical than the others. This is because O&M of rainwater treatment facilities with sedimentation and filtration is less than the other facilities with biological treatment processes.

Figure 8 compares lifecycle cost of on-site water recycling systems with the cost in the case of using tap water from city water supply. The unit cost of reclaimed water is calculated by summing the annual O&M cost and annual repayment fee of construction cost (if
there is no representative value, a repayment period of 15 years and interest rate of 6% is used). The cost of producing reclaimed water, which consists of the construction and operation costs for the treatment facility and water distribution system, is lower than the price of tap water and public sewerage system fees, if the capacity is larger than 100 m³/day.

Conclusions
The following conclusions are reached based on our survey conducted in 1999 on the current status of on-site water recycling systems in the 23 wards of the Tokyo Metropolitan Government District.

1. On average about 61% of non-potable water demands were met with reclaimed water and the rest was supplemented by tap water from the municipal water supply.
2. Biological treatment and other treatment processes shown in Figure 4 can provide reliable treatment and suitable water quality. Some technical problems such as odor from on-site treatment facilities have occurred in a few buildings.
3. There has been no serious accident involving human health by accidentally ingesting reclaimed water.
4. There is a scale merit in the construction cost of on-site water recycling systems. An on-site wastewater recycling system larger than 100 m³/d is more economically justifiable when compared to a conventional domestic water supply system. An on-site water recycling system can provide an effective, safe, and economical urban water resource for non-potable water reuse applications.
5. In light of recently promulgated comprehensive water recycling requirements in several states in the United States and other countries, Japan’s wastewater reuse regulations should be reexamined, particularly with respect to reliability of operation, monitoring, and health risk assessment based on reliable water quality monitoring data.

References