Modifications of unit processes for finished water quality improvement at the Kueui water treatment plant in Seoul

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Abstract Recently, Seoul city has tried to modify and upgrade the existing facilities and utilities and to improve the established water treatment plants, instead of application of a new treatment process. These efforts have finally lowered the turbidity of finished water below 0.1NTU. Small lab-scale and pilot-scale experiments have been conducted and they have provided optimum parameters for the design and operation of drinking water treatment plants. In addition, quantitative and/or trace analysis technologies developed for monitoring water quality of effluent from unit processes and automization of facilities, have contributed to the improvement of turbidity in drinking water. The Kueui water treatment plant, one of the drinking water treatment plants in Seoul, produces finished water with 0.08 NTU. It results from the operators' continuous endeavor to lower the turbidity in a scale of 0.01 NTU. The data for 12 months indicated that turbidity of settled water was less than 1.16 NTU and that of filtered water was less than 0.12 NTU for 95% of the period. Sedimentation basins and sand filters satisfy the recommended turbidity criteria, 2 NTU and 0.3 NTU, respectively. Also Kueui water treatment plant has focused on the control of organic matters to decrease in DBPs and on the removal of microorganisms.
Keywords Comprehensive performance evaluation (CPE); turbidity; upgrading; water treatment plant

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Introduction

Seoul totally depends on the Han river as a source for its water supply. Although source water quality has been continuously degraded with economic development since the 1960s, Seoul's waterworks system now possesses its own technologies for safe and stable water supply, without using any advanced treatment process. Specifically, turbidity of treated water has been steadily improved for last 10 years. The improvement is considered as the results of stabilization of plant operation, strict regulation of water quality, renovation of management, and continuous modification of conventional treatment plants. In this study, we introduced works of a water treatment plant which successfully control turbidity of processed water with minor process changes and elaborated operation methods (Figure 1); we then evaluated the operation performance of major unit processes and pollutant removal using the data.

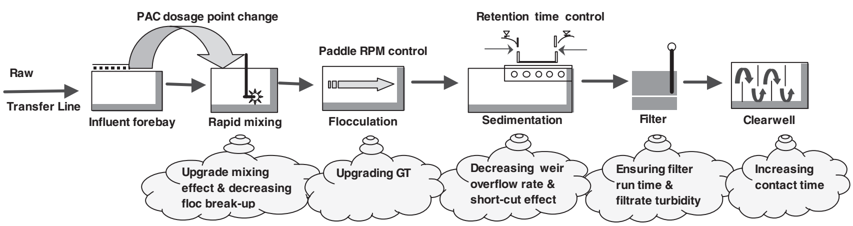

Figure 1 Plant flowchart with consideration of minor process changes

Waterworks and water quality monitoring in Seoul

Seoul city now has six water purification offices which supply water to 99.98% of the population (Table 1). To supply better water to its citizens, the city government has designated 47 standard items, and an additional 58 reference items, for monitoring water quality. The goal of turbidity for the filtered water was set at 0.1 NTU in 2000.

Criteria for evaluating the efficiency of unit operations

Seoul waterworks performed the Comprehensive Performance Evaluation (CPE) in 1999 and 2001 in order to evaluate the performance of major unit processes and performance limiting factors. This work required plenty of information and data on the plants, unit processes and operations and maintenances, and it was helpful to establish a guideline for Composite Correction Program (CCP) or diagnosis in drinking water treatment plants.

CPE consists of three major evaluations: the performance assessment, the major unit process evaluation and the performance limiting factor identification. Specific goals for assessing each unit process and correcting individual performance limiting factors are recommended. In Korea, temporary criteria on settled water and filtered water turbidity were provided in 1999. The sedimentation process is assessed based on plant capacity, such as below 4 NTU of settled water when less than 5,000 m^3/day, below 3 NTU when between 5,000–20,000 m^3/day, and below 2 NTU when greater than 20,000 m^3/day, during 95% of the operation period. Filtered water should be less than 0.3 NTU during 95th percentile of the period, less than 0.5 NTU following backwash, and below 0.3 NTU within a 30 minute period following backwashes, when the plant capacity is greater than 20,000 m^3/day.

A case study of turbidity improvement at Kueui water treatment plant

Characteristics of raw water and turbidity improvement

The Han River water inflowing to Kueui plant showed relatively moderate quality in the viewpoint of turbidity (less than 10 NTU) except during the concentrated rainy season (July and August). The highest turbidity of raw water was 200 NTU in the rainy season and another high turbidity was recorded at 140 NTU even in October (Figure 2). As shown in Figure 3, the algae counts showed seasonal variation and the temperature also showed seasonal variation and lowest value below 5°C in winter. Therefore, it is important to ensure finished water quality in this deterioration period, showing algae blooming and high pH in spring and fall, high turbidity and low pH in summer, and low temperature and low turbidity in winter. The raw water characteristics of Kueui plant are summarized in Table 2.

Table 1 Water purification offices in Seoul

Name of office	Total	Kwangam	Kueui	Tukdo	Youngdungpo	Amsa	Kangbuk
Capacity [10^3 m^3/day]	6,520	1,000	900	1,300	700	1,620	1,000

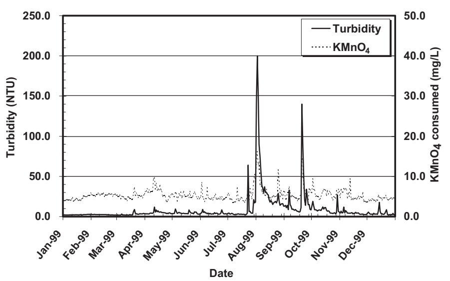

Figure 2 Variation of turbidity and $KMnO_4$ consumed

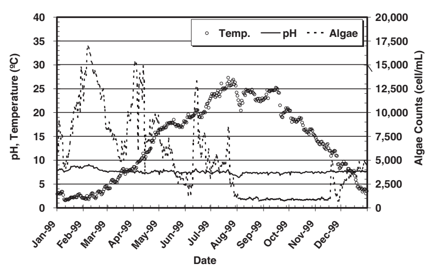

Figure 3 Variation of temperature, pH, and algae count

Table 2 Raw water characterisrics of Kueui water treatment plant

Parameter	Temperature (°C)	pH	Alkalinity (mg/L)	Turbidity (NTU)	$KMnO_4$ consumed (mg/L)	Algae counts (cell/ml)
Maximum	27.3	9.1	57	200	16.2	16,950
Minimum	0.5	6.4	13	1.8	3.5	720
Average	14.0	7.6	42	9.0	5.3	5,146

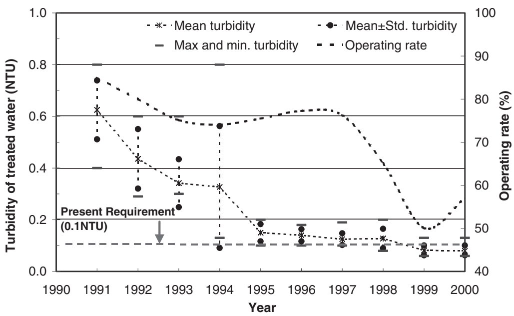

Figure 4 Improvement of filtered water turbidity at Kueui water treatment plant

Figure 4 shows that turbidity of filtered water has been continuously improved from 0.62 NTU in 1991 to 0.08 NTU in 2000. In the first half of the observed years, new purification plants were built and the Kueui plant was extended to operate 70% of production capacity. Extended capacity reduced the loading rates to each unit process. In addition, operators' continuous attention on optimization of unit operations could enhance the stability in the turbidity of filtered water.

Relocation of coagulant dosing point

The coagulant dosing point was relocated from the existing influent forebay to the narrow waterway right before mixing basins (Figure 5). This relocation provides more efficient mixing and makes flocs move shorter distances and to be protected from breaking up. As a result, the turbidity in filtered water decreased (Figure 6) and energy was saved because of no mixers.

Extension of effluent weir in sedimentation basins

From 1997 to 1998, stainless steel weirs were installed to lengthen the existing effluent weirs. It made the weir overflow rate decrease and therefore, settling efficiency increase.

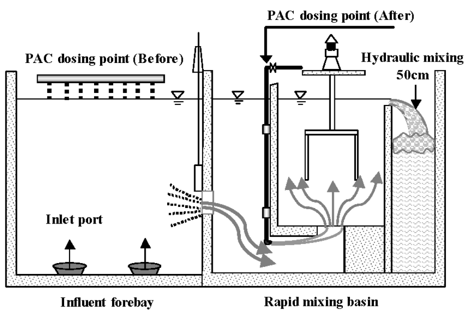

Figure 5 Relocation of coagulant dosage point

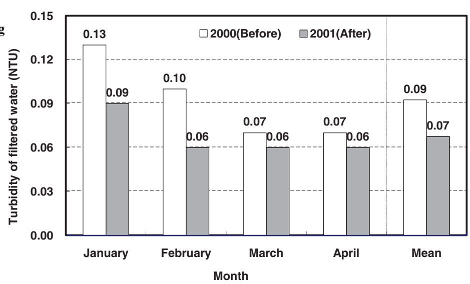

Figure 6 Turbidity improvement after relocation

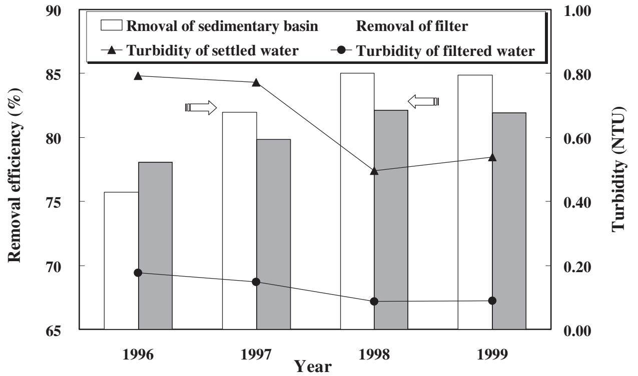

Figure 7 Turbidity improvement after extension of effluent weir

Figure 7 shows that turbidity in settled water was improved by about 0.2–0.3 NTU by extension of weirs and the turbidity in filtered water was also improved.

Replacement of underdrain system and maintenance of bed depth in filters

In 1991, a nozzle-type underdrain system replaced a Wheeler-type one which was originally constructed in 1974 and poorly shaped. As a result, the turbidity removal efficiency has improved since 1992 as was shown in Figure 4.

Figure 8 shows an instrument used to check the bed depth of filter easily and precisely. This instrument provides the benefits to keep the bed depth constant, increase filter run, and control properly filtered water quality.

Assessment of plant performance using historical data

Operation evaluation of major unit processes

Turbidity data of the raw, settled and finished water were collected from the plant operating records and the data are shown in Figure 9. The data indicated that the 95th percentile level of influent turbidity over last 12 months was less than 29 NTU. Settled water turbidities in inclined plate settlers and gravity settlers were less than 0.93 NTU and 1.4 NTU, respectively, in 95% of the samples. Both settlers meet the recommended criteria. However, performance of gravity settling basins should be more optimized in operation and design when applying the CCP performance goals of the United States Environmental Protection Agency (USEPA) (settled water turbidity less than 1 NTU at 95% of the time when raw water turbidity is less than 10 NTU).

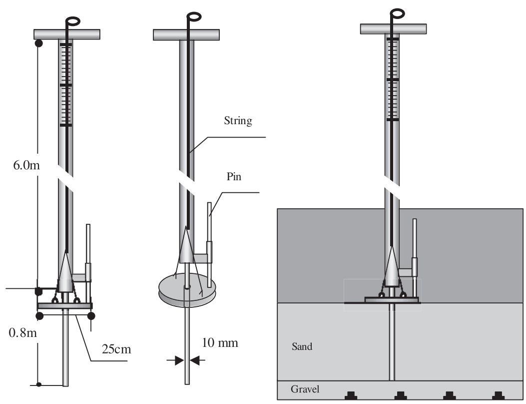

Figure 8 Schematic of filter bed depth measurement

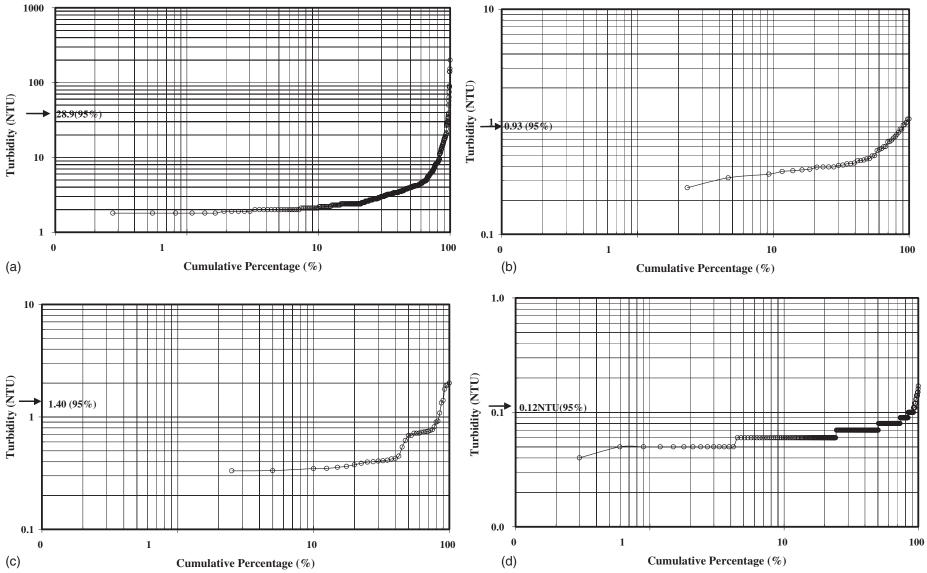

Figure 9 Percentile distribution using historical data from: (a) raw water; (b) settled water from inclined plate settlers; (c) settled water from gravity settlers; and (d) filter water

Performance of the finished water was assessed based on achieving 0.3 NTU or less in 95% of the samples and the finished water of 0.12 NTU or less in 95% of the samples could sufficiently satisfy the criteria. When comparing these data with USEPA performance goals (filtered water turbidity less than 0.1 NTU at 95% of the time based on maximum values recorded during 4 hour increments), performance of filters was not satisfactorily optimized. It is very difficult to decrease the finished water turbidity in a range of 0.01 NTU, and it is necessary to identify the causes for this less-than-optimum performance. Also, when particle count data are available, it can be used to provide a more sensitive assessment of filter performance.

Table 3 describes percentile distribution of water quality data at Kueui plant.

The settled water turbidity in both the inclined plate and the gravity rectangular settler was almost below 1 NTU during 12 months (Figure 10). However, since the raw water turbidity showed an extremely high value in August, small spikes were also evident in the settled water. The inclined plate settler was more flexible to variation of raw water quality than a rectangular settlement basin. When plants had water of low turbidities below 10 NTU, periodic spikes in the sedimentation basins appeared more than 1 NTU. It might indicated that the plant staff had to control the flow rates of unit processes, check chemical dosage, change mixing intensity, and so on.

The average turbidity of filtered water was 0.08 NTU and the filtered water turbidity was below 0.1 NTU even at the raw water spike in August. Whereas, in January and March, the filters produced water of higher turbidity than other seasons, it means that low temperature

Table 3 Percentile distribution of water quality

Percent of time less than or equal to values shown (%)	Raw waterturbidity (NTU)	Settled water turbidity (NTU)	Filtered Water Turbidity [NTU]
50	4	0.53	0.07
75	7	0.72	0.09
90	17	1.17	0.1
95.	28.9	1.39	0.12
Average	9	1.8	0.08

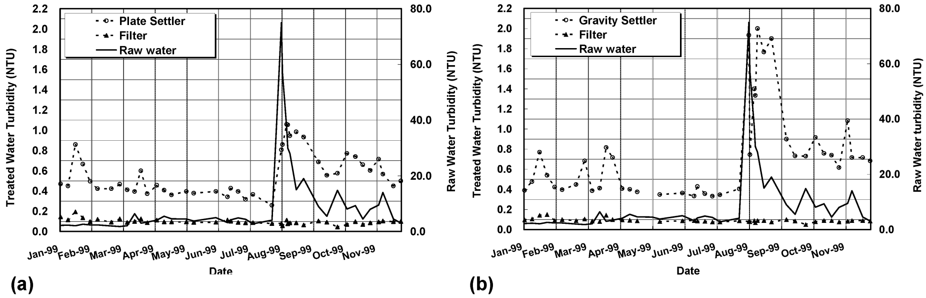

Figure 10 Performance assessment using historical data: (a) annual turbidity profile of no. 3 factory; (b) annual turbidity profile of no. 4 factory

and unsettled algae, rather than other turbidity causing particulates, might affect the performance of filtration.

Seasonal evaluation of turbidity and organic removal

The level of turbidity reduction and organic removal through each treatment process was investigated. Turbidity reduction efficiency through sedimentation and filtration was about 85% and 86%, respectively, and total reduction efficiency of turbidity was 98% during the treatment processes. Settlers and filters had lower turbidity removal efficiency during spring and winter, respectively, as shown in Figure 11. However, in this study, the sedimentation process sufficiently reduced the solids loading on the filters and contributed to filter performance enhancement.

The removal of TOC and consumed $KMnO_4$ was evaluated to characterize organic reduction through each unit process. TOC removal was 30% and 4% and consumed

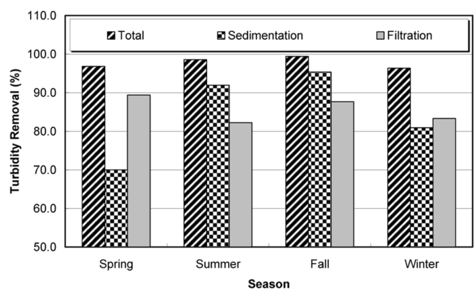

Figure 11 Turbidity removal through unit operation

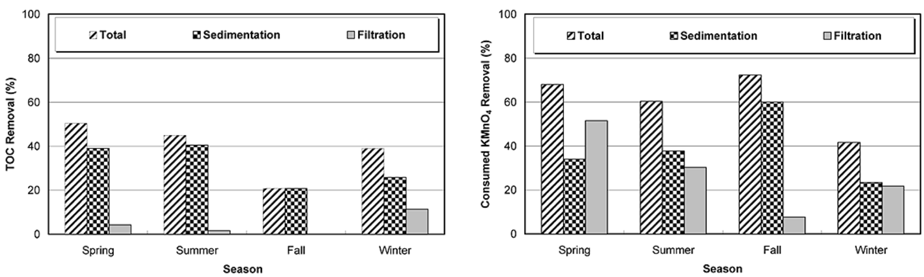

Figure 12 Organic removal through unit processes: (a) as TOC; and (b) as consumed $KMnO_4$

$KMnO_4$ was 39% and 28% through settlers and filters, respectively. Total averaged removal of organics as consumed $KMnO_4$ (61%) was higher than TOC (39%). This unit process evaluation by organics showed that flocculation and sedimentaion processes were contributed to organic removal rather than filtration process. Since operating data of consumed $KMnO_4$ are more available, but insufficient for evaluating removal of organics in each unit process compared to TOC, we have to study an approach of monitoring or obtaining organic data from each treated water, precisely and continuously.

Conclusions

Seoul city has conducted renovative policies in management, operation and maintenance. In addition to these efforts, all water purification plants are open to the public in order to enhance further public trust in tap water. Especially, Kueui plant achieved average turbidity of 0.08 NTU, 95% time of less than 0.12 NTU in finished water in yearly basis. Turbidities of settled water for 12 months were less than 1.16 NTU for 95% of the time. Both settlers and filters could produce water with the recommended turbidity criteria. However, settlers and filters need to be more optimized against deterioraton of influent water, and automatically monitored all the time. It may safely be said that Seoul waterworks has developed turbidity control technology in water treatment. This authority is on going for studies on the treatment of NOM, DBP precursors, viruses, *Giardia* and *Criptosporidium*.

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