Diagnosing and optimizing water treatment processes by using particle counter: a case study in Korea

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Abstract The goal of the flocculation process is to change the particle size distribution to best suit the subsequent processes. Although several methods exist to evaluate the flocculation process, no single universally accepted method has yet to be developed. The purpose of this paper is to present experiences whereby particle counting was used in the diagnosis and optimization of the flocculation process. A commercially available on-line continuous particle counter has been used in evaluating the design and the operation of this process at two conventional Water Treatment Plants. The evaluation is based on particle dynamics, i.e., the change of the number of small and large particles. Some design deficiencies in the distribution channel and flocculation process have been identified from this method, and thus some operational parameters are suggested for optimum performance. Because the optimum condition may be site-specific, the method presented in this paper will be beneficial in the evaluation of the flocculation process at other water treatment plants.

Keywords Design deficiency; flocculation process; optimum condition; particle counting; particle dynamics; water treatment plant

Introduction

The design and operation of the flocculation process and the evaluation thereof have been mainly based on the recommended detention time (t), mixing energy (G) or Gt values which can be easily found from many textbooks (AWWA, 1999; Kawamura, 2000; *Recommended Standards For Water Works*, 1992). However, their suggested ranges are too wide to find the optimum condition specific for a particular water treatment plant. Moreover, no possible mistakes in the details of design can be easily identified using such guidelines. Although some practical methods exist to find the optimum condition in flocculation for rotational direction and the speed of mixers, it is questionable whether such results are reproducible and quantifiable. Floc shape and size may be compared visually, but they are subject to the judgment of operators. Turbidity of sedimentation basin effluent or filter run time may also be used. However, turbidity itself is not a good representation of the behavior and dynamics of particles in the process due to the limitation of its measuring principle, especially for a flocculation process. Also, time delay may sometimes prevent immediate response.

The goal of the flocculation process depends on the process that follows (Han, 1999; Han *et al*., 2000). Settlable flocs are needed for sedimentation, while filterable flocs are needed for filtration. For a typical conventional water treatment plant, the number concentration of small particles should decrease by flocculation, while that of large particles should increase. Once grown, floc breakage should be avoided. To meet this goal, tapered flocculation has been preferred.

In this paper, Korean experiences of using a particle counter in evaluating the design and operation of the water treatment process at two conventional water treatment plants is presented. The evaluation is based on particle dynamics, i.e., the change of the number

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concentration of small and large particles. Some design deficiencies in the water treatment process have been identified from this method, and some operational parameters are suggested for optimum operation.

Methods

A commercially available on-line, continuous particle counter working in light obscuring principle (Chemtrac Model PC2400, USA) was used to evaluate the flocculation process at existing water treatment plants. The samples were taken at different places in the water treatment plant from a point which represents each process or before and after a point under investigation. The results are presented as the changes in the number concentration of particles at different time steps for a user selected particle size range between 2–400 μm. The flow rate of samples to the sensor was 100 mL/min which is set by the manufacturer. The measurements were taken under steady state conditions, when there is no significant change in the particle dynamics. The sampling and measuring at each point was made continuously for 15–20 minutes to obtain a steady output of the signal and the particle counts data were used for analysis and discussion. Particle counts data were presented as number concentration, that is, the number of particles of a specific size range per mL.

Results and discussions

Identifying design deficiency

A set of experiments was made at the Sungnam WTP, a conventional water treatment plant located in the southern part of Kyungki province. This plant serves several cities in the southern Kyungki area with a design capacity of 400,000 m^3/d. Figure 1 shows the schematic layout of the plant. The raw water is conveyed 40 Km by a pressure pipe from an intake and pump station at Paldang reservoir, which is in the tributary of the Han river. After arriving at a receiving well in the water treatment plant, polyaluminium chloride is added as a coagulant and is hydraulically mixed. Mechanical mixers are installed, but are used only when needed. The coagulant-mixed water is introduced to the tapered distribution channel and fed into 24 flocculation basins, as described in Figure 1. Three flocculation basins are connected to one sedimentation basin.

Design deficiencies in the flocculation basin. Figure 2 shows the change of small (2–5 μm, Part A) and large (75–100 μm, Part B) particles, at various stages in the treatment process. The number of small particles in the raw water gradually decreases after the hydraulic mixer, distribution channel, and the first and second stage of the flocculation basin. This

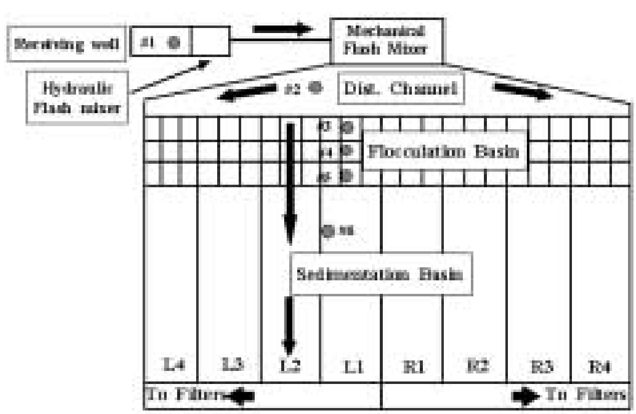

Figure 1 Layout of Sungnam WTP (not drawn to scale)

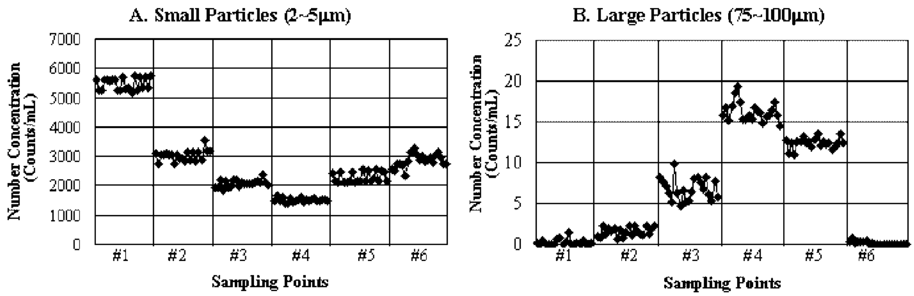

Figure 2 Number concentration of small and large particles at each process (# represents the sampling points as shown in Figure 1)

trend of decreasing small particle concentration is apparently due to flocculation. However, there is an abnormal increase in the number of small particles at the third stage flocculation basin and these small particles remained unsettled in the sedimentation basin. These small particles are carried into the filter and could possibly become the cause for inefficient operation such as frequent filter backwashing and shorter filter run time.

A similar conclusion can be drawn from the observation of large particles at each stage of the process. The number concentration of large particles gradually increases after the hydraulic mixer, and through the first and second stage of the flocculation basin, implying that flocculation does occur. However, the number concentration of large particle decreases after the opening at the second stage flocculation basin which implies that flocs are broken at this point. The reason for this floc breakage can be found in the second wall of the flocculation basins, as shown in Figure 3. The second wall has an opening (0.8 m × 0.8 m) at the top left part; this opening is only partly submerged and the water level and cross-sectional area vary with flow rate. Velocity increases at this opening because of the decreased cross-sectional area of the flow and the free surface.

The floc breakage after the opening can be observed by eye, but no quantitative measurement had been recorded previously. The measurement of particle size distribution shows clearly that the flocs are broken after the opening on the second wall. Modification in the design of the wall has been recommended based on this result, that is, to increase the opening of the second wall to avoid the floc breakup.

Design deficiency at the distribution channel. The second design deficiency is found at the distribution channel to the flocculation basins. This water treatment plant is designed with a long (72 m) distribution channel, which serves 12 flocculation basins on each side of the plant, as shown in Figure 4. Samples were taken at the inlet of each flocculation basin, and the particle counts were measured and compared.

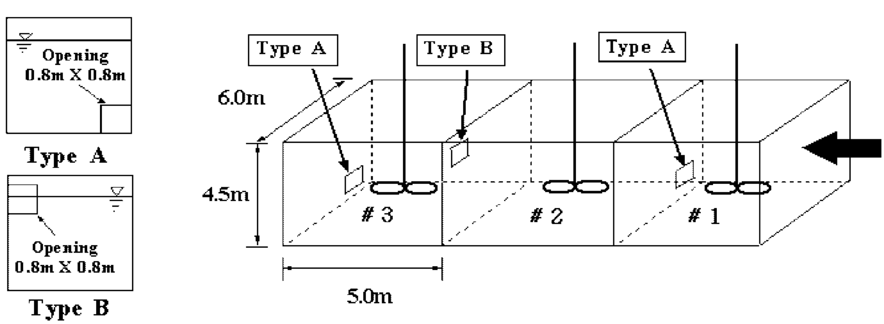

Figure 3 Flocculation basin details of Sungnam WTP

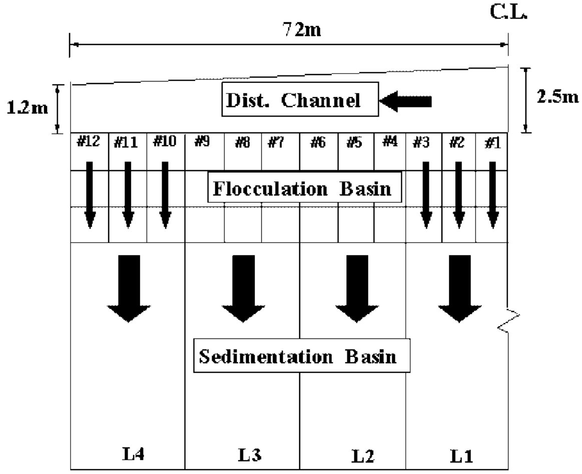

Figure 4 Layout of distribution channel

The variations of small size particles (2–15 μm) and large particles (25–50 μm) among the twelve parallel units are shown in Figure 5. The number concentration of small particles gradually decreases until the mid part of the distribution channel, which confirms that flocculation has occurred along the channel. However, after the mid-part, the number concentration of small particle remains unchanged while the number concentration of large particles decreases, which confirms that sedimentation has occurred. At the far end of the distribution channel, an increase in small particles is clearly seen.

The particle count measurement has clearly shown that it can be a good basis of evaluation. Sedimentation might result in the deposition of sludge at the bottom of distribution channel and could lead to operational problems such as odor or plant shutdown for the cleaning of sludge. Therefore, it can be concluded that the distribution channel should be as short as possible to avoid sedimentation, as recommended in *Recommended Standards For Water Works* (1992). Although narrowing the distribution channel to give a higher velocity than the scouring velocity might be thought as another option, any possible problem associated with increased velocity is unpredictable. Flocculation should occur at the flocculation basin instead of occurring at the distribution channel. Again, this is in accordance with the design guideline in *Recommended Standards For Water Works* (1992) which recommends that the rapid mix and flocculation basin should be as close together as possible.

Finding optimum operational condition

A few experiments to find the optimum operational conditions were performed at the

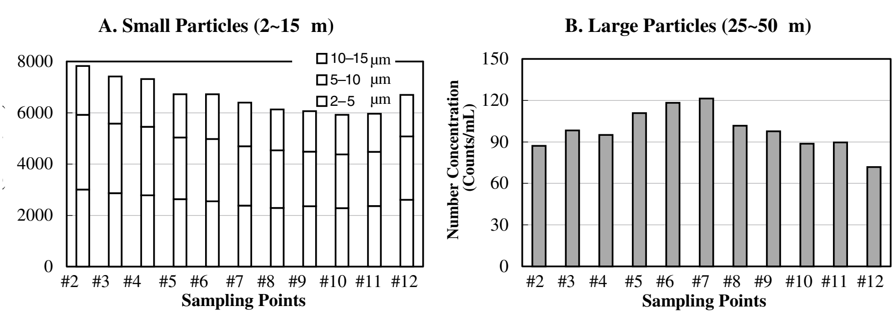

Figure 5 Number concentration of small and large particles at distribution channel (# represents the flocculation basin as shown in Figure 4)

Shaewoon plant at Donghae City. This plant is a conventional water treatment plant with a design capacity of 20,000 m^3/D. The flocculators are three-stage horizontal paddle type, and the three stages are divided by intermediate perforated walls. The schematics of this part in the water treatment plant are shown in Figure 6.

At the time this experiment was performed, the flocculator was operated under the condition which is traditionally thought optimum by the operators; i.e., the rotational directions of flocculator stages 1, 2 and 3 were counterclockwise (CCW), clockwise (CW), and clockwise, respectively. The flocculation speed was tapered with the rotational speed of 2.9, 2.2, and 0.6 rpm, respectively. In this study, two sets of experiments were conducted. First, the optimum rotational direction was determined. Second, the optimum rotational speed was determined under the optimum rotational direction.

Optimum rotational direction. In order to find the optimum rotational direction, 8 possible combinations were selected and tested. Although the order of experiment was random, the experimental results are reassembled as in the order of Table 1. All the experiments are made on the same day with other operational parameters unchanged.

For each experiment, the measurements were made after three detention times of the affected flocculation basins and after confirming that no significant changes were occurring in the particle count data. The results are presented as the number concentration of small (2–5 μm) and large (50–75 μm) particles in Figure 7.

The best rotational direction was selected that best suits the goal of the flocculation process, i.e., decrease in small particles and increase in large particles. It was found that the current operating method at Shaewoon WTP did not produce optimum results. A better method whereby all the three flocculators rotate in a clockwise direction has been recommended. The operation was modified as recommended so as to obtain the desired result.

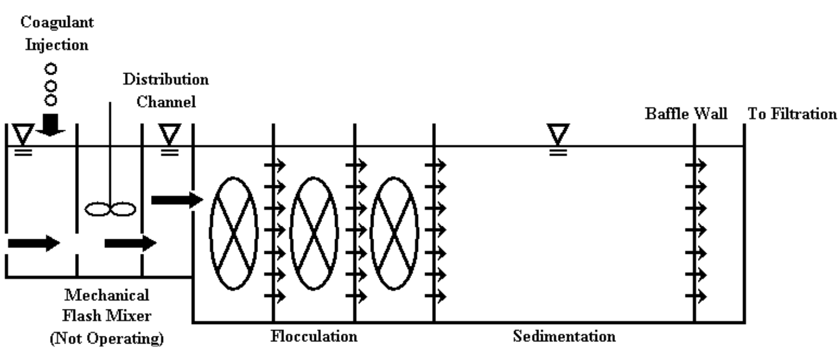

Figure 6 Schematic diagram of Shaewoon WTP

Table 1 Experimental schedule to find the optimum rotational direction (CCW: counter clockwise, CW: clockwise)

Exp. #	Floc. #1	Floc. #2	Floc. #3	
1	CCW	CCW	CCW	
2	CCW	CCW	CW	
3	CCW	CW	CCW	
4	CCW	CW	CW	Current
5	CW	CCW	CCW	
6	CW	CCW	CW	
7	CW	CW	CCW	
8	CW	CW	CW	Best

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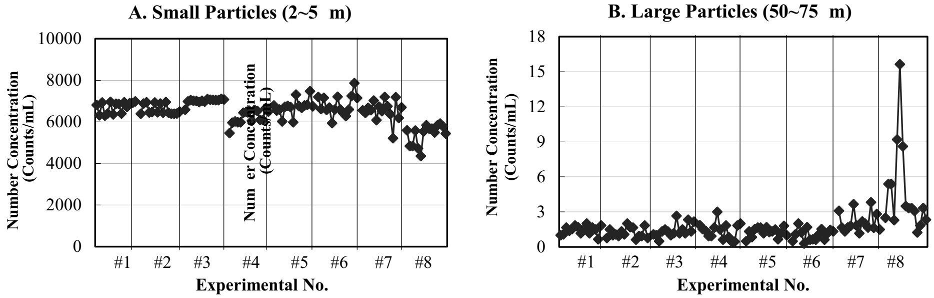

Figure 7 Variation of number of small and large particles at each experimental condition (# represents the experiment number as shown in Table 1)

Optimum rotational speed. Another set of experiments was performed to find the optimum rotational speeds of the three stages of flocculation, using the same experimental setup and the rotational direction scheme found from the first experiment. The design and the order of experiment are shown in Table 2.

The effect of rotational speed, of tapered flocculation, of partial increase of rotational speed, and finally of mixing are discussed. In order to investigate the effect of rotational speed, the current speed was increased to around 40% (Exp. 2) and 70% (Exp. 5) and compared. The speed can be changed easily by adjusting the speed gauges in the local control panel. For each experiment, measurements were made after three detention times of the affected flocculation basins and accepted after confirming no significant changes in the particle count data. The particle count data for each run is presented as in Figure 8. For each experiment, measurements were made after three detention times of the affected flocculation basins and accepted after confirming no significant changes in the particle count data.

From the observations of the change in the numbers of small and large particles, it is obvious that Exp. 2 best suits the purpose of the flocculation process, i.e., to decrease the

Table 2 Experimental schedule to find the optimum rotational speed (rpm)

Exp. #	Floc. #1	Floc. #2	Floc. #3	Remarks
1	2.9	2.2	0.6	Current
2	4.2	3.1	1.4	40% increase
3	2.9	2.2	1.4	#3 faster
4	2.2	2.2	2.2	Const. speed
5	5.1	4.2	2.2	70% increase
6	5.1	2.2	0.6	#1 faster
7	4.2	3.1	0.6	#1, 2 faster
8	–	–	–	No mixing

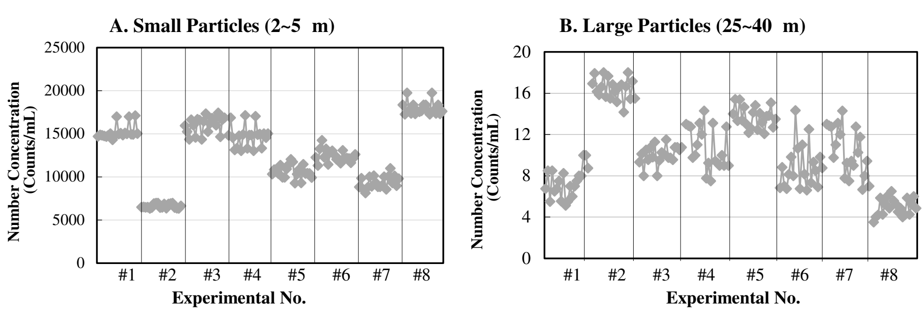

Figure 8 Variation of number of small and large particles at each experimental condition (# represents the experiment number as shown in Table 2)

number concentration of small particles and increase that of large particles. Also, it can be concluded that there is an optimum speed for the flocculator; floc is not grown fully at a slower speed, while floc may be broken at a faster speed. Experiments to investigate the effect of increased speed of some of the flocculators were also performed. The speed of the third stage flocculator only was increased in Exp. 3, the speed of the first flocculator only increased in Exp. 6, and both first and second flocculators were increased in Exp. 7, as shown in Table 2. The increase of speed at the third stage (Exp. 3) resulted in floc breakage. However, the increase in speed at the first stage (Exp. 6 and, to a lesser degree, Exp. 7) resulted in a better flocculation. Here, the advantage of tapered flocculation is reconfirmed. The effect of mixing was investigated by turning off all the flocculators (Exp. 8). Without mixing, the number concentration of small particle remains higher, while the number concentration of large particle remains lower than with mixing, which supports the necessity of mixing in this particular plant.

Discussion

It has been general practice to design and operate the flocculation process using the recommended range of G and Gt values from the design standards. Although widely used, this method is able to neither determine any design deficiencies nor account for any site-specific design and operational characteristics. Some have questioned the significance of G values from the theoretical work (Han and Lawler, 1992), and many practitioners have agreed on this point based on their experiences. Several methods have been used to evaluate the performance of flocculation including turbidity measurement, floc observation and others. However, they are not reproducible nor can they produce enough detailed information to suggest design modification or optimum operational condition.

The evaluation is aimed at testing whether the process meets its goals, i.e. flocculation is to make more large particles and less small particles. In this research, a particle-counting method has proven to be useful in the evaluation of the flocculation process. However, there are some technical drawbacks in this method. Air bubbles in the samples may result in the increase of the number of large particles. Flocs may break up when passing long sampling tube. These can be avoided by carefully adjusting the sampling method. Also, the obtained result may be different from the true particle count of a sample because of the inherent floc breakup mechanism in the sampling and measuring system. However, if we want to see the trend of particle behavior between each operational and design parameters, comparison of relative particle counts will give enough information to make decision as far as the sampling conditions are the same. From this experience, the authors believe that a particle counting method is an easy and handy method to evaluate the flocculation process and to suggest better operational alternatives to water treatment plant operators.

Conclusions

Particle counts are measured at each treatment process at existing water treatment plants by a simple set with a particle counter and the data are very much useful to evaluate the performance of each treatment process and to detect design deficiencies by considering the purpose of each process in terms of particle behavior and dynamics. That is: the purpose of flocculation process is to make large numbers of large particles by reducing the number of small particles. By investigating the change of number of large and small particles, trivial mistakes in the design and operation of WTP can be detected such as particle breakup at the opening between flocculation basins, and flocculation and sedimentation at the distribution channel.

The findings from this research can be applied to the diagnosis and optimization of the performance of existing WTPs and will be found to be very much helpful for the decision making in the rehabilitation projects of WTPs for other countries.

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