Desalination and Water Treatment
www.deswater.com
16 (2010) 95–100
April
1944-3994/1944-3986 © 2010 Desalination Publications. All rights reserved
doi: 10.5004/dwt.2010.1048

Optimizing coagulant demand by Nephelometric Turbidimeter Monitoring System (NTMS)

Wen Po Cheng*, Ruey Fang Yu, Ying Ju Hsieh, Shu Yi Wu, Yu Wei Huang, Sin Ming Chen

Department of Safety, Health and Environmental Engineering, National United University, Miaoli, Taiwan 360
Tel. +886-3-7381764; Fax 886-3-7333187; email: cwp@nuu.edu.tw

Received 12 April 2009; Accepted 28 November 2009

ABSTRACT

In a water treatment plant, the dosage control of coagulants depends generally on the results from Jar tests. Improper coagulant and dosages may lead to an inefficient operation and may increase the quantity of chemical sludge. In this research, a Nephelometric turbidimeter coupled with a data acquisition unit was used to measure turbidity every second in Jar tests. The standard deviation (SD) of the measured turbidity values was proportional to the square root of the floc size. In addition, the image analysis (Matrox Inspector V2.2) used to measure the mean floc size confirmed whether Nephelometric Turbidimeter Monitoring System (NTMS) is suitable for directly applying to floc size analysis in Jar tests. The results indicated that the standard deviations (SD) of the turbidities during the flocculation (slow mixing) period of Jar tests really can provide direct information for the floc size formation. In addition, this on-line monitoring technique can be a simple and effective indicator to select an optimal coagulation dosage for a flocculation process.

Keywords: Nephelometric; Turbidity; Floc size; Standard deviation

1. Introduction

Recently, due to the technical progress to overcome part of the instrument limitation problem, many devices, used in control or monitoring particle aggregate in coagulation procedure [1–2], are developed for the purpose of increasing the coagulation efficiency in a water purification factory. To measure the coagulation particle characteristics including particle size, zeta potential and coagulant strength, the measuring methods are based on microscopy, light scattering, transmitted light and individual particle sensors technology [3–9]. Many apparatus such as zeta potentiometer, streaming current detector, photometric dispersion analyzer and particle size analyzer were applied for flocculation process to control the chemical coagulant dosage [10–15]. The data of the monitoring result can allow the operator in a water treatment plant to understand the coagulation particle characteristics during the coagulation processes, so that the operator may quickly adjust the coagulant dosage or operational parameter to improve the water quality and to drop the processing cost [16–18]. In this research, a probe of an ordinary scattering type optical turbidity meter (Nephelometric turbidimeter) is directly inserted into the water. The combination of a probe and a data acquisition unit formed the on-line continuous turbidity monitoring system (Nephelometric turbidimeter monitoring system, NTMS). Apart from reading the turbidity changes and precipitation analysis in the coagulation process, we developed "Turbidity amplitude of floc size measurement technology" [19–20]. The standard deviation (SD) of the measured turbidity was proportional to

*Corresponding author.

the square root of the floc size. In theory it is similar as Gregory and Nelson had indicated [3, 21]. In a Photometric Dispersion Analyzer (PDA) monitor system, it can be assumed that the ratio of the root mean square (VRMS) of the turbidity fluctuating signal is roughly proportional to the size. However, the PDA is not a commonly used instrument in water treatment plants and cannot be directly inserted into the water to obtain the floc size in flocculation process. But the VRMS or SD value does not provide quantitative information on aggregate size. Therefore, in this study a video camera (Watec Co Wat-202B) with image analysis (Matrox Inspector V2.2) was used to confirm whether NTMS is suitable for directy applying to floc size analysis in flocculation process to optimize coagulant demand.

2. Experimental equipment and methods

2.1. Nephelopmetric turbidimeter coupled with a data acquisition unit

Different size particles of the corn cob were separated by screening them with a series of different mesh size sieves. Five sets of different average particle size test water were prepared. For each size of 115, 137, 335, 460 and 920 μm in particle diameter (R_R), 0.4 g of corn cob particle was added into 1-L de-ionized water. Then, each test water was stirred at a speed of 20 rpm. The turbidity measurement from a Nephelometric turbidimeter monitoring system (NTMS) was done in every second for 10 minutes to yield 600 data points. Thus, the standard deviation (SD) of the turbidity data for each particle size was found. Fig. 1 shows the arrangement of the Nephelometric turbidimeter monitoring system (NTMS). A hole was made in the wall of the test vessel to enable the probe of the Nephelometric turbidimeter to reach into the water. A Light-Emitting Diode (LED) on the probe of Nephelometric turbidimeter was used to illuminate the solution at 90° to the path of light entering the turbidimeter. The intensity of the scattered light, which was measured with the detector at 860 nm infra red light, was converted to turbidity value. The measured turbidity was recorded with a data acquisition unit (YOKOGAWA model FX-106-0-2) and then uploaded to a computer.

2.2. Particle size analysis with images captured from cameras

A video camera CCD (Watec Co Wat-202B) was used to record the particle or floc in a free settling test (particle number more than 5000). Then the image analysis (Matrox Inspector V2.2) was used to measure the mean particle size, to confirm whether Nephelometric technology is suitable for directly applying to particle size analysis.

2.3 Jar test

In this research, poly aluminum chloride (PACl) with high basicity (b = 2.3) was used as a chemical coagulant in a jar test to perform a solid-liquid separation study. The synthesized water was prepared from the following steps. First, the high turbidity synthesized raw water was prepared by adding 1 g of kaolin into 1 L of deionized water after four hours rapid mixing and then settled for 30 min. Second, the 600 mL supernatant from the high turbidity synthesized raw water was diluted into deionized water. Third, 0.072 g/L $NaHCO_3$ and 12.244 g/L $NaClO_4$ were added to the diluted solution to control the basicity and ionic strength at 50 mg/l as $CaCO_3$ and 10^{-2} M, respectively. After mixing the supernatant, the synthesized raw water is prepared with characters of pH 8, solid concentration 89 mg/L and 100 NTU of turbidity. The average size of the particles in suspension was about to 10 μm, measured by images analysis (Matrox Inspector V2.2). One liter of the prepared 100 NTU synthetic kaolin sample was placed in the acrylic flask in Fig. 1. After adding the coagulant, the solution was mixed rapidly for 1 min at 150 rpm, slowly mixed for 10 min at 50 rpm and left for 20 min to settle. Instantaneous

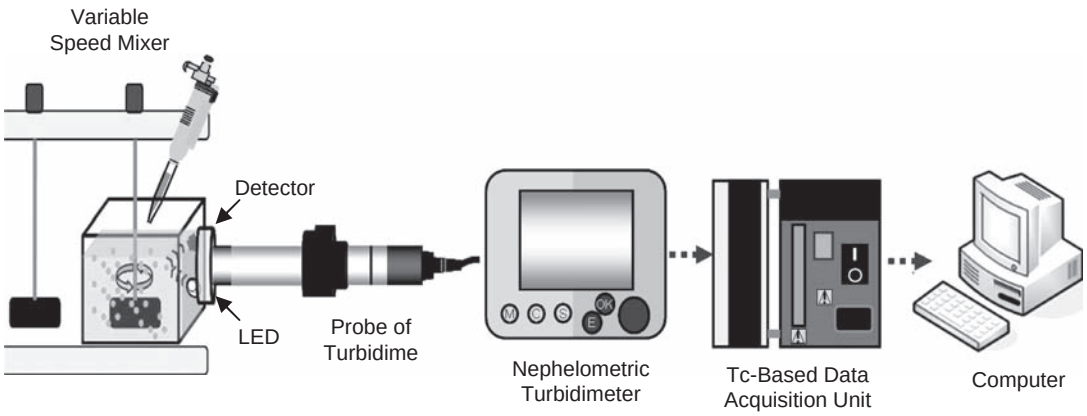

Fig. 1. Schematic diagram of the Nephelometric Turbidimeter set-up.

variations in turbidity were monitored and shown on the computer monitor. Data were processed using Microsoft Excel, and the curve of turbidity *vs*. time was plotted.

3. Results and discussion

3.1 Turbidity amplitude of floc size measurement technology

Using the NTMS shown in Fig. 1, each size of corn cob test water was stirred at a speed of 20 rpm, the turbidity measurement was done every second for 10 minutes to yield 600 data. Fig. 2 shows the relationship between the turbidity fluctuate and the size of corn cob. For small diameter corn cob particle (such as 115 μm in Fig. 2), the particle suspension in the water was uniform and the reflected turbidity values did not show much variation versus time. The resulting turbidity curve was flat and had relatively small fluctuations. For large diameter corn cob particle (such as 920 μm in Fig. 2), at the same concentration (0.4 g/L) it will greatly reduce the particle number and the total specific surface area of the suspended particles and the turbidity value will fluctuate with greater amplitude. This phenomenon is similar to the finding of Gregory and Nelson [3, 21] that for a given suspension, the root mean square (V_{RMS}) of the turbidity fluctuating signal is roughly proportional to the particle size. For a given suspension, Photometric Dispersion Analyzer (PDA) or "fluctuating turbidity" technique developed by Gregory [21] it can be assumed that larger V_{RMS} values imply larger aggregate size [22]. Therefore, the square root of each real particle diameter ($R_R^{1/2}$) of corn cob was plotted versus the standard deviation (SD) based on 600 turbidity data (Fig. 2) to demonstrate the linear relationship between these two parameters. The very good linear relationship ($R^2 = 0.995$, $R_R^{1/2} = 0.718SD5.32$) between the SD of NTU data and the square root of particle diameter shown in Fig. 3 indicate that this "Turbidity amplitude of floc size measurement technology" [17–18] can help understand the variation of particle diameter. Additionally, each size of corn cob suspension was removed with a pipette and the particle diameter derived from images captured with camera. In Fig. 3, the good linear relationship between corn cob particle diameter calculated from image analysis (Matrox Inspector V2.2) (R_I) and real particle size (R_R) shows that the values of imaged particle size (R_I) have good relationship with real particle size (R_R) ($R^2 = 0.99$, $R_I^{1/2} = 1.05\ R_R^{1/2}$-1.047). These results also indicate that the values of turbidity SD have good relationship with imaged particle size (R_I). Therefore, the "Turbidity amplitude of floc size measurement technology" can be as a tool to help understand the floc diameter variation in coagulation process.

3.2 Jar test

The data of Fig. 4 shows the results of jar tests. To conduct the jar test, 100 NTU of kaolin suspension was treated by PACl with 0 to 4 mg/L (as Al) dosages. After the PACl coagulation treatment, the supernatant turbidity variations of each second were plotted in Figure 4. The coagulation dosage range of PACl was close to the study by Lee et al., which indicate the coagulation mechanism under this dosage range was charge neutralization [23]. The final pH values after rapid mixing were decreased from 8 to 6.11, while the coagulation dosages were increased from 0 to 4 mg/L (as Al). The turbidity monitoring results in slow mixing period for each coagulation dosage was enlarged and plotted in Fig. 5 to compare the difference in turbidity amplitude. The experimental

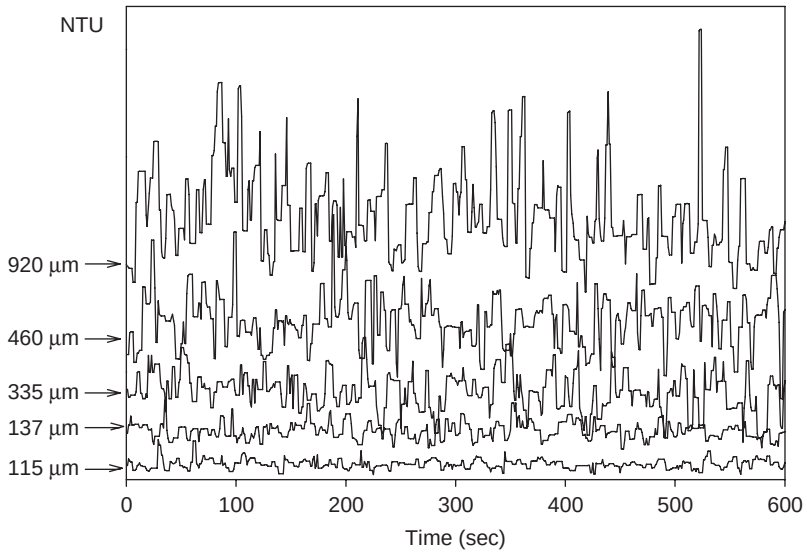

Fig. 2. Turbidity fluctuations in difference sizes of corn cob.

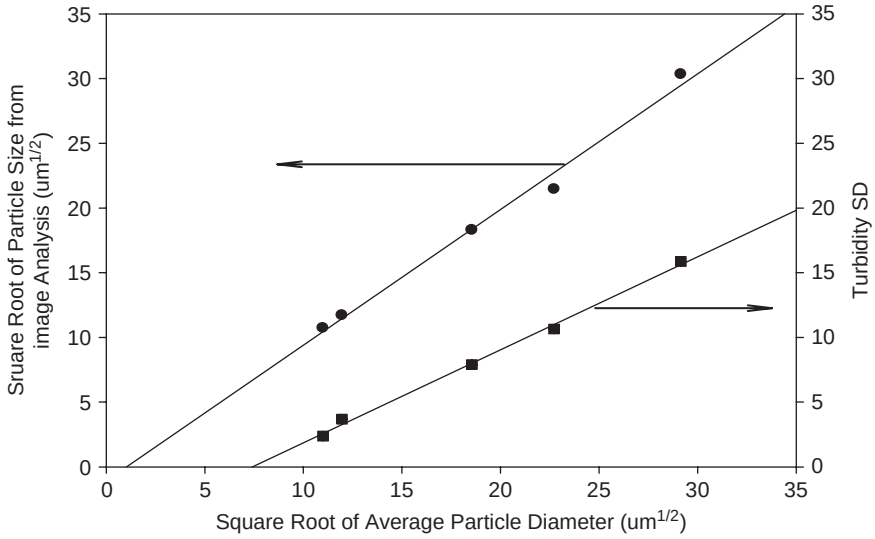

Fig. 3. Linear relationship between (■) turbidity SD, (■) square root of the imaged particle diameter and the square root of average particle diameter for corn cob suspensions.

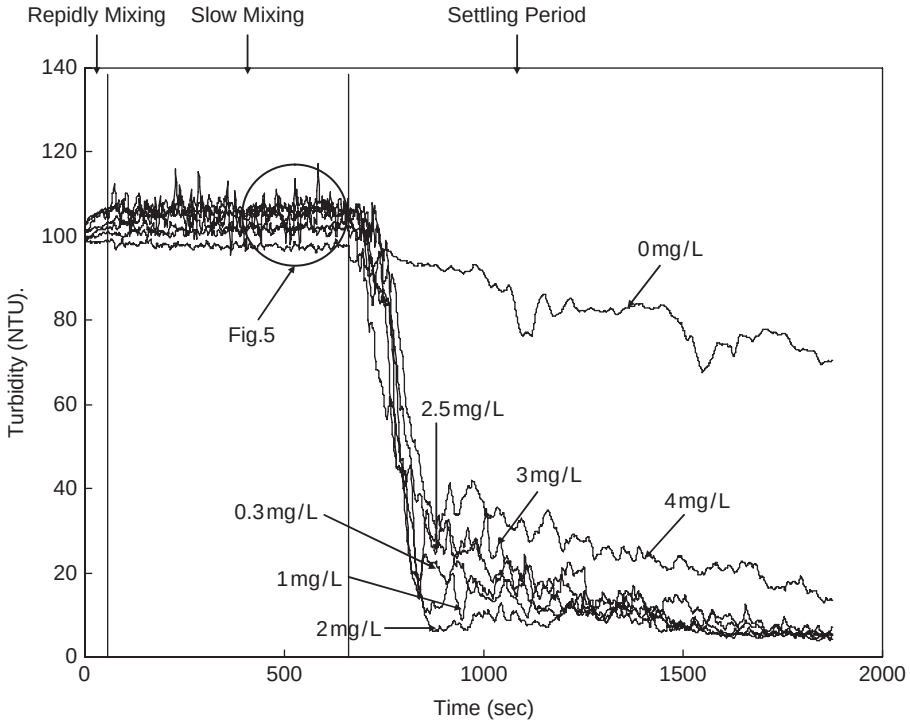

Fig. 4. Changes in turbidity with coagulation time at different PACl dosage.

results in Fig.5 show that the samples flocculated without PACl coagulant (dosage 0 mg/L) had relatively smaller fluctuations of turbidity and the coagulation dosage from 1 mg/L to 2.5 mg/L (as Al) had higher turbidity fluctuations. Using the "Turbidity amplitude of floc size measurement technology", the turbidity data collected at the last 320 seconds during the slow mixing was used for calculating the turbidity SD to study the particle size changes at each coagulant dosage. The results of Fig. 6 show that when the coagulation dosage is 2 mg/L (as Al), turbidity SD reaches the maximum. The high turbidity SD indicates a large floc size. Therefore, after 5 minutes settling, turbidity in those solutions dosed with 2 mg/L (as Al) PACl is significantly lower than the turbidities in the other solutions as shown in Fig. 6. This result indicates that for 2 mg/L (as Al) PACl dosage, the particle

size is relatively large and the particle itself can be rapidly settled out from the solution. On the other hand, lower PACl dosage may reduce the ability for solution to form flocs. Therefore, in the case of lower coagulant dosage, the turbidity SD is relative low and the residual turbidity after 5 min settling is relative higher than with 2 mg/L(as Al). When the PACl dosage is more than 2 mg/L (as Al), the turbidity SD decreases again. This result indicates that floc size in the overdosed solution is smaller than the floc size in the solutions with 2 mg/L (as Al) PACl. Therefore, the residual turbidities in most of the solutions are higher than those measured in the solutions added 2 mg/L (as Al) PACl after 5 minutes settling; however, the experimental results in Fig. 6 also indicate that the residual turbidities in the dose range from 2 mg/L (as Al) have very similar value after 20 minutes settling. According to this result, the smaller coagulation floc required takes longer time (20 minutes) to settle. Therefore, this result also indicates that in the process of determining optimum coagulation condition, other than measuring the final residual turbidity, a traditional method, turbidity SD that obtains by NTMS is another alternative to rapidly and accurately determine the floc size during the coagulation process. The results found in this study may help the further coagulation study, such as the research in a full scale drinking water treatment plant.

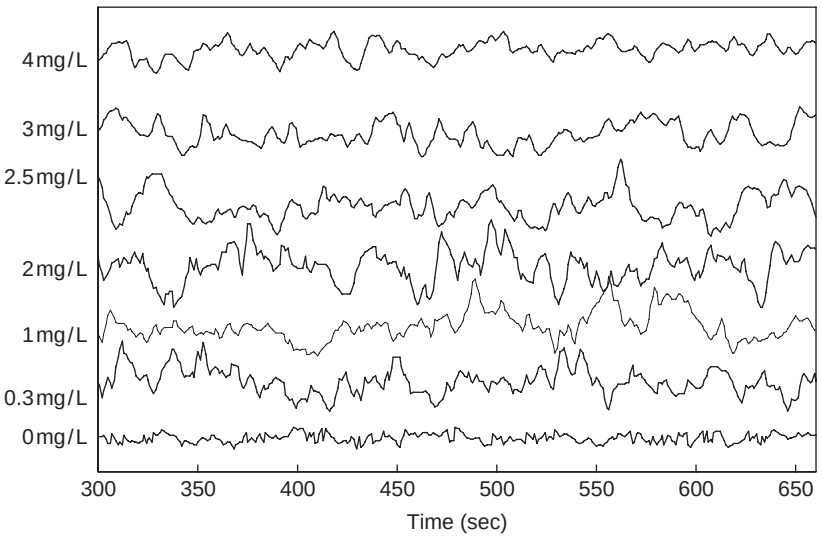

Fig. 5. Turbidity fluctuations in slow mixing period.

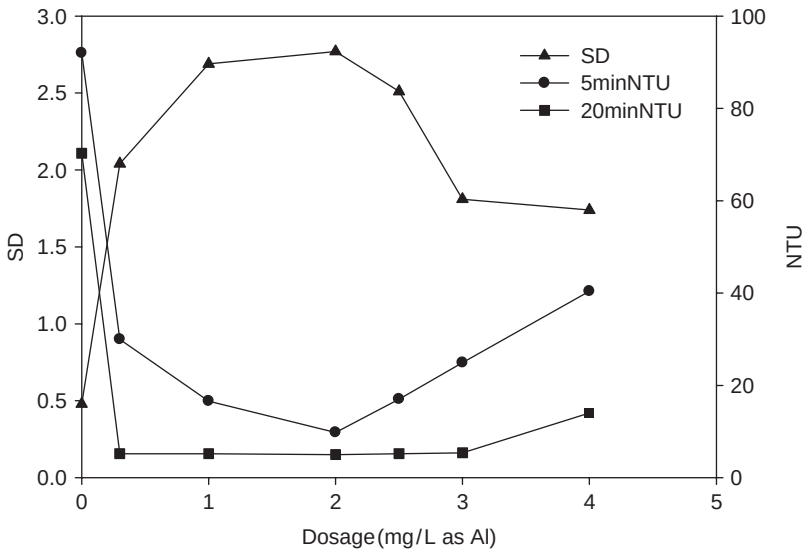

Fig. 6. The relationship of turbidity SD and the residual turbidity (5 and 20 min settling time) at different PACl dosage.

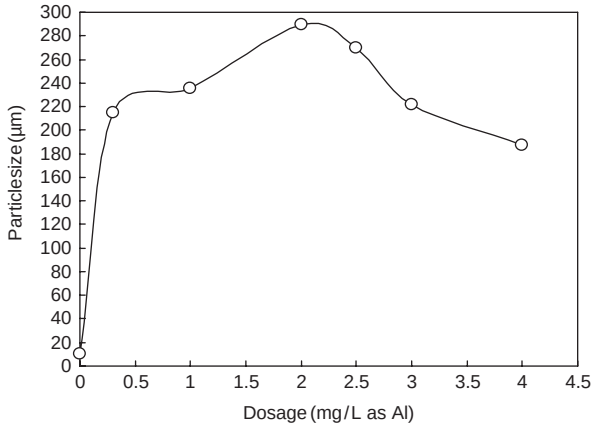

Fig. 7 Variation of calculated particle diameter (RI) from the captured image at various coagulation dosage.

In order to confirm the floc size change during the flocculation process is really correlating with the turbidity SD, a drop of the coagulation solution sample was taken in the end of flocculation or slow mixing process. These samples from the end of the slow mixing period were capturing the image of the particles by a video camera. Then use the captured image and the computer software to calculate the image particle diameter (R_I). The data of Fig. 7 shows the imaging floc diameter (R_I) changes with the coagulation dosage and has optimum particle size in coagulation dosage of 2.0mg/L. Comparing both Fig. 6 and Fig. 7, one can find a similar result that is the standard deviation (SD) of the measured turbidity in coagulation process was really proportional to the floc size.

4. Conclusion

The concept that the SD of turbidity data is linearly proportional to the square root of floc diameter will assist in predicting the variation of particle size. The results can be used to effectively determine the multiplication of particle size increase such as in flocculation process. Also, the continuous on-line turbidity monitoring using the Nephelopmetric turbidimeter (NTMS) device provides more accurate flocculation data in jar tests. The relationship between the standard deviation (SD) of measured turbidities and the resulting floc sizes assisted in understanding the influence of various conditions on the floc agglomeration and subsequent sedimentation.

Acknowledgement

The authors acknowledge the financial support of National Science Council, Taiwan, R. O. C. for this work (NSC -96-2628-E-239-001-MY2).

References

[1] J. Gregory, Monitoring particle aggregation processes, Adv. Colloid Interface Sci., 147–148 (2009) 109–123.
[2] J. Gregory, Optical monitoring of particle aggregates, J. Environ. Sci., 21 (2009) 2–7.
[3] J. Gregory and D. W. Nelson, Monitoring of aggregates in flowing suspension, Colloid and Surface A., 18 (1986) 175–188.
[4] S. Mas and C. Ghommidh, On line size measurement of yeast aggregates using image analysis, Biotechnol. Bioeng., 76 (2001) 91–98.
[5] Y.X. Huang, Simultaneous measurement on particles in solution with size ranging from nm to sub-mm by microscope light scattering spectroscopy and image analyzing system. Cur. Appl. Phy., 5 (2005) 549–552.
[6] P. Jarvis, B. Jefferson and S.A. Parsons, Measuring floc structural characteristics, Environ. Sci. and Bio/Tech., 4 (2005) 1–18.
[7] C. Rattanakawin, Aggregate size distributions in sweep flocculation, Songklanakarin J. Sci. Technol., 27 (2005) 1095–1101.
[8] M. Han, T. Kim and J. Kim, Application of image analysis to evaluate the flocculation process, J. Wat. Sup.: Research and Technology-AQUA, 55 (2006) 453–459.
[9] J. Lin, C. Huang, C. J. Chin and J. R. Pan, Coagulation dynamics of fractal flocs induced by enmeshment and electrostatic patch mechanisms, Water Res., 42 (2008) 4457–4466
[10] A. Morfesis, A.M. Jacobson, R. Frollini, M. Helgeson, J. Billica and K.R. Gertig, Role of zeta (ζ) potential in the optimization of water treatment facility operations, Ind. Eng. Chem. Res., 48 (2009) 2305–2308.
[11] A. Adgar, C.S. Cox and C. A. Jones, Enhancement of coagulation control using the streaming current detector, Bioprocess Biosyst. Eng., 27 (2005) 349–357
[12] L. Rossi, C. Lubello, E. Poggiali and O. Griffini, Analysis of a clariflocculation process with a photometric dispersion analyzer (PDA 2000), Water Science Technology: Water Supply, 2 (2002) 57–63.
[13] R.J. Chakraborti, J.F. Atkinson and J.E. Van Benschoten, Characterisation of alum floc by image analysis. Environ. Sci. Technol., 34 (2000) 3969–3976.
[14] D. Ghernaout, B. Ghernaout and A. Kellil, Natural organic matter removal and enhanced coagulation as a link between coagulation and electrocoagulation, Desalination and Water Treatment, 2 (2009) 203–222.
[15] T. Nir, E. Arkhangelsky, I. Levitsky and V. Gitis, Removal of phosphorus from secondary effluents by coagulation and ultrafiltration, Desalination and Water Treatment, 8 (2009) 24–30.
[16] H. Bai and G.B. Li, Fuzzy based auto-coagulation control through photometric dispersion analyzer, J. Harbin Institute of Technology, 11 (2004) 48–51.
[17] S.H. Kim, B.H. Moon and H.I. Lee, Effects of pH and dosage on pollutant removal and floc structure during coagulation, Microchemical Journal, 68 (2001)197–203.
[18] R.F. Critchley, E.O. Smith and P. Pettit, Automatic coagulation control at water-treatment plants in the north-west region of England,. Water and Environmental Journal, 4 (1990) 535–543
[19] W.P. Cheng, Y.P. Kao and R.F. Yu, A novel method for on-line evaluation of floc size in coagulation process, Water Research, 42 (2008) 2691–2697.
[20] W.P. Cheng, Y.P. Kao and R.F. Yu, Comparison of three coagulants by on-line turbidity monitoring, Proceedings of the Institution of Civil Engineers Journal Water Management (doi: 10.1016/j.jtice.2010.01.002).
[21] J. Gregory and D W Nelson, A new optical method for flocculation monitoring. In Solid-Liquid Separation, (J. Gregory, Ed.) Ellis Horwood, Chichester, (1984) 172–182.
[22] M.S. Burgess, J.E. Curley, N. Wiseman and H. Xiao, On-line optical determination of floc size part I: principles and techniques, J. Pulp. Pap. Sci., 28 (2002) 63–65.
[23] T. Li, Z. Zhu, D. S. Wang, C. H. Yao and H. X. Tang, Characterization of floc size, strength and structure under various coagulation mechanisms, Powder Technol., 168 (2006) 104–110.