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ADVANCES IN PHOTOMETRIC DISPERSION ANALYZER WITH DUAL WAVELENGTH LIGHT

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ABSTRACT

A new dual-wavelength photometric dispersion analyzer is described which can be applied in the monitoring of coagulation/flocculation processes.

KEYWORDS

Flocculation, instrumentation, photometric, dispersion analysis.

Introduction

J.Gregory has demonstrated that the measurement of fluctuations in the transmitted light near infrared light through a floc suspension in a flow cell enables detection of coagulation conditions[1]. His theory has been expanded to include the simultaneous measurement of the extinction of two wavelengths in the ultraviolet and near infrared regions, and has shown that the absorbance of residual soluble colored organics and floc size and settling velocity can be determined using several derived statistical values regarding the fluctuating absorbance of dual wavelengths[2,3,4].

This paper describes newly developed dual wavelength photometric dispersion analyzers (DPDA) based on our theory and some experiments for calibration and checks of accuracy.

Details of equipment and data processing procedure.

Figure 1 shows a schematic diagram of the newly developed equipment for laboratory use. The equipment consists of an optical unit and a data processing unit. The optical unit consists only of a flow cell. The other electrical circuits including the light sources are assembled on the data processing unit. The optical unit and the data processing unit are connected by optical fiber cables. Flow cell is made of acrylic block which houses fiber-optic probes in which 125 µm quartz glass fibers are bundled. The bundled fibers are separated (50:50) and connected to a sweet spot light-emitting diode and a low pressure mercury lamp for light sources, respectively. Receivers consist of the same fibers connected to individually wavelength matched detectors which are a Si photo-diode (PD) for near infrared light and a photo-multiplier-tube (PMT) for ultraviolet light. With this method, fluctuating absorbance at near infrared and ultraviolet light can be measured simultaneously at the same space. Interference filters of 860nm and 253.7nm

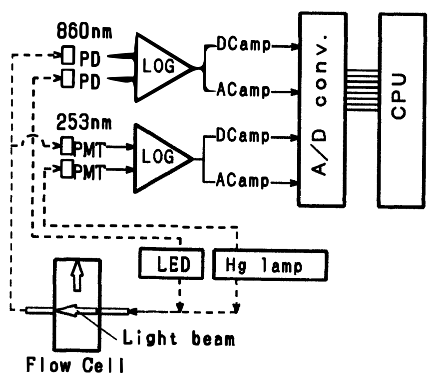

Fig. 1 Block diagram of DPDA
—— : electrical line
---- : optical fiber

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placed at the ends of the each fiber are used to get sharp absorption bands. The signals from the photodetectors are passed through logarithmic amplifiers in order to obtain signals corresponding to absorbance, expressed as follows:

$$E = K\log(V_0/V) \qquad (1)$$

The signals transformed into logarithms have an advantage that they are hardly affected by drift or random fluctuation in emitting intensity of light sources.
Instantaneous absorbance consists of average and fluctuating components scattered or absorbed by particles passing through the light beam.

$$E = E_M + e \qquad (2)$$

The fluctuating components are isolated by ac-coupling circuits. The average(DC) and the fluctuating(AC) components are respectively A/D converted and saved in memories. These stored data are calculated on digital CPU to obtain various statistical values, such as standard deviations of fluctuating absorbance. The calculation is also performed regarding to coagulation/flocculation properties such as floc size, settling velocity and absorbance of residual colored organics, based on authors' algorithms of DPDA.

Continuous in-situ monitoring with an optical method in a streaming system at a field application inevitably suffers from fouling of surfaces of fiber optic probe by adhering particles and microorganisms. From the theoretical consideration, fluctuating components of absorbance are almost entirely unaffected by contamination of the optical surfaces. However, the average components cannot be free from contamination. This difficulty has provided an incentive to devise a technique to diminish the effect of contamination of optical surfaces. An optical unit of a double beam type DPDA (DDPDA) recently developed for a field application is fitted with a reference light path parallel to and in the vicinity of the sample light path, and an ultra-sonic irradiator as shown in figure 2.

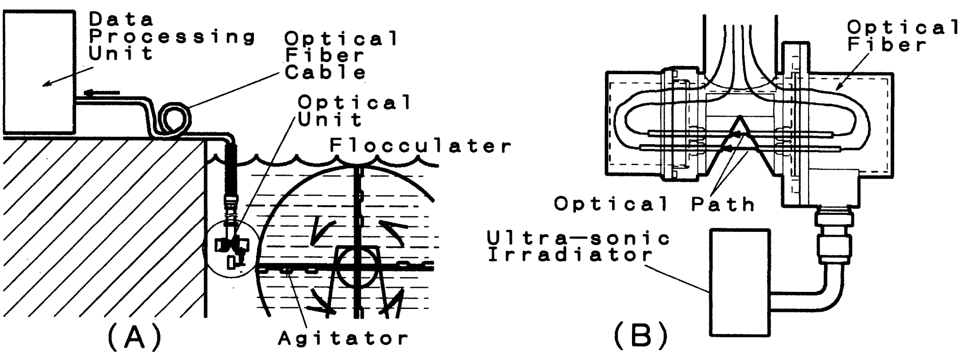

Fig. 2 Schematic diagram of the double beam type DPDA
(A); whole view of in-line monitoring, (B); structure of optical unit

Light absorbance indicating sample concentration can be obtained by subtracting the absorbance of a reference light path from the sample light absorbance as shown in equation (3).

$$E_M = E_{MR} - E_{MS} - (E_{FR} - E_{FS}) = E_{MR} - E_{MS} \qquad (3)$$

By assuming the fiber-optic probes of reference light path are similarly contaminated to that of the sample light path, extinctions caused by fouling of the optical surfaces of the sample and reference light are the same.

Experiments

Standard particles of polystyrene latex (PSL) of a known particles sizes and number concentration were measured with the developed DPDA for checks of accuracy, using theoretical equations (4) to (6)[4].

$$D_1 = \sqrt{\frac{4AE^2_{RMS1}}{\pi Q_1 E_{M1}}} \qquad (4)$$

$$D_2 = \sqrt{\frac{4AE_{RMS1}E_{RMS2}}{\pi Q_2 E_{M1}}} \qquad (5)$$

$$N = V_S\left(\frac{E_{M1}}{E_{RMS1}}\right)^2 \qquad (6)$$

The output particle size obtained is plotted against the nominal size in Figure 3. In this experiment, PSL particles of 2 to 41μm were suspended in membrane filtered water with the concentration of 0.003, 0.0067, 0.01% by weight. Meanwhile, light scattering coefficients Q_1 and Q_2 were tentatively set at 1. The plot shows that the relationship is well represented by a straight line, irrespective of number concentration of PSL. The coefficient Q_1 and Q_2 were determined to be 0.633 and 0.508 respectively, by the slopes of the regression lines. These coefficients were used to determine the particle size of Sephadex G15 (Pharmacia) suspended in water, as the spherical particle of a material other than PSL. As a result, D_1=52.7μm and D_2=50.8μm were obtained, which matched well with the microscopic observation (average size:47.9μm, std.dev.16μm).

The output number concentration is plotted against the nominal number concentration in Figure 4. Fairly good linear relationship was obtained within a concentration ranging from 10^2 to 10^7/ml, independent of the particle size. The detection sensitivity for number concentration was measured to be 10^4/ml for PSL particle of 2μm and 5×10^2/ml for 41μm.

Furthermore, we tried to apply the DDPDA to an actual water purification plant in Yokohama Japan.

Figure 5 shows a relationship on floc size between outputs of DDPDA (x-axis) and the data observed with photograph(y-axis). Scattering coefficient(Q_2=0.31) is comparable with the result experimentally obtained with kaolin and peat water(Q_2=0.24).[4]
Figure 6 shows the changes of floc size(A), settling velocity(B) measured with DDPDA at the 1st flocculator and turbidity removal efficiency of flocculation/sedimentation process at the plant(C). Settling velocity of floc is calculated with following equation(7):

$$W_f = K_W\sqrt{\frac{E_{RMS1}}{E_1}} \qquad (7)$$

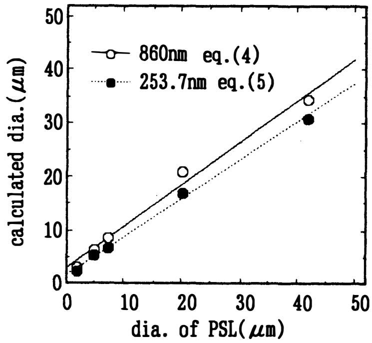

Fig. 3 Plots of diameter calculated by eq.(4) and (5) against the nominal size for PSL.
$(4A/\pi Q_1)=(4A/\pi Q_2)= 1$

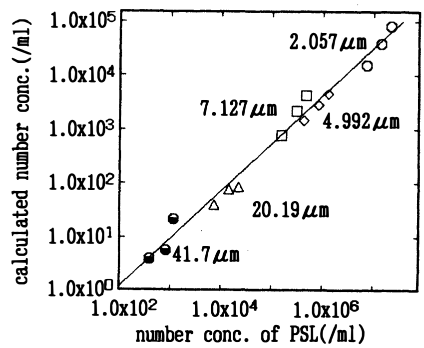

Fig. 4 Plots number concentration calculated by eq.(6) against the nominal value for various size of PSL.
$V_S = 1$

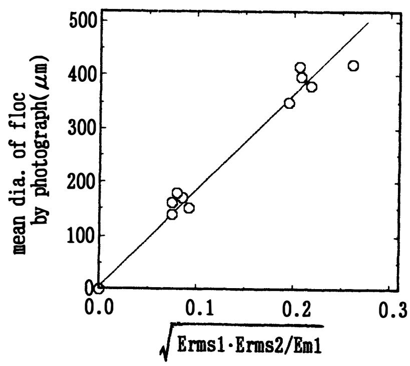

Fig. 5 Plots of floc size output of DDPDA against the photographically measured mean size of floc.
$(4A/\pi Q_2)=1$

where the coefficient K_W is 0.26, experimentally obtained[4].

Conclusion

The equipment (DPDA and DDPDA) which can make simultaneous measurement of dual wavelength absorbance including fluctuating components was developed in order to evaluate the coagulation/flocculation process. Accuracy of the developed equipment was confirmed using various sizes of PSL standard particles, and was sufficient for deriving values relating to coagulation/flocculation properties, such as floc size and settling velocity, based on the authors' theory.

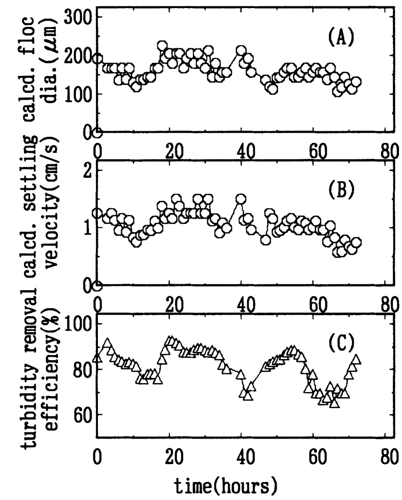

Fig. 6 The changes of floc size(A) and settling velocity(B) measured by DDPDA, with the change of turbidity removal efficiency(C) at actual plant.

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Nomenclatures

e : fluctuating component of light absorbance(-)
A : cross sectional area of a light beam(cm^2)
D_1, D_2 : particle diameter(cm)
E : light absorbance(-)
E_M : average light absorbance(-)
E_{MR} : average light absorbance of a reference light path(-)
E_{MS} : average light absorbance of a sample light path(-)
E_{FR} : extinction caused by fouling of optical surfaces of a reference light path(-)
E_{FS} : extinction caused by fouling of optical surfaces of a sample light path(-)
E_{M1} : average light absorbance for near infrared light(-)
E_{RMS1} : root mean square of fluctuating absorbance around mean for near infrared light(-)
E_{RMS2} : root mean square of fluctuating absorbance around mean for ultraviolet light(-)
K : scale factor of logarithmic amplifier(-)
N : particle number concentration(cm^{-3})
Q_1 : scattering coefficient of a particle for near infrared light(-)
Q_2 : scattering coefficient of a particle for ultraviolet light(-)
V : voltage corresponding to the intensity of light after passing through a flow cell(volt)
V_0 : voltage corresponding to the intensity of light sources (volt)
V_S : sample volume of a light beam(cm^3)
W_f : settling velocity of floc(cm/sec)
K_W : coefficient of settling velocity(-)