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Continuous Flocs Image Analyser (C-FIA) For Flocs Dynamics Tracking During Conventional Water Treatment

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Abstract. In this paper an image analyser termed 'Continuous Floc Image Analyser (C-FIA)' developed for tracking the dynamics of floc formation, growth and settling during conventional water-treatment (i.e. coagulation, flocculation, and settling processes) is described. The C-FIA is proposed as an alternative to light-beam scattering and signal-based analysers such as Photometric Dispersion Analyser (PDA). A primary configuration of the C-FIA was developed for collecting video recordings of flocs in a flowing suspension of water sample during the treatment process. A MATLAB script was developed to analyse the image data. A Flocculation Index (FI) based on RGB[1] data associated with video frame pixels was calculated as a measure of flocs concentration. The practicality of the C-FIA in comparison with the PDA was tested using jar testing under laboratory conditions for two different surface water samples with contrasting water qualities. The results demonstrated the C-FIA capability to track the floc dynamics during the conventional treatment process using the FI. The C-FIA showed distinct baseline, rapid mixing, flocculation, and settling stages by providing different levels of FI for each stage. The results obtained indicated impacts of light intensity and light beams radiation angle to the photography cell on the resulted FI. This through its effects on the pixels RGB values of the floc images and raw water image used for determining the background FI value. The comparison of the FI data obtained through the C-FIA with the PDA indicates similarity in FI signal trends during process time by either technique. To achieve a more reliable signal with comparable results between experiments, a more advanced configuration with higher consistency in the photography system is needed.

Keywords: Continuous Floc Image Analyser, Photometric Dispersion Analyser, Coagulation, Flocculation, Settling.

1. Introduction

In conventional surface water treatment applied for drinking water purposes, coagulation, flocculation and settling are key stages for removal of suspended solids and natural organic matter (Zouboulis and Traskas 2005). Throughout this treatment process, floc particles of different sizes and characters emerge, dependent on operational parameters (Ramphal and Sibiya 2014). The floc size and character play an important role in understanding the efficiency of the treatment process (Ramphal and Sibiya 2014). There are few techniques to determine the flocs size distributions, which includes light scattering based optical techniques, e.g. Photometric Dispersion Analyser (PDA) which is a commonly used technique. As pointed out by Ramphal and Sibiya (2014), these techniques enable users to track the flocs dynamics and to estimate flocs concentration during the treatment process. The PDA developed by Gregory and Nelson (1986) monitors the fluctuation in light scattering which is considered to be related to the floc concentration in the suspension (Rossi *et al.* 2002; Ball *et al.* 2011). More specifically, PDA measures the root mean square of the fluctuating signal (V_{rms}) and the average transmitted light intensity (d_c). The ratio of V_{rms} to d_c called Flocculation index (FI) is a measure of aggregation during the treatment process (Gregory and Nelson 1986; Ramphal and Sibiya 2014). However, in practical systems, detailed flocs size and character information cannot be derived through the FI signal obtained by PDA (Rossi *et al.* 2002). Previously, image analysis-based techniques have been proposed for either online or discrete analysis of floc size and character during the coagulation process (Gorczyca and Ganczarczyk 1996; Chakraborti *et al.* 2000; Amaral and Ferreira 2005; Liwarska-Bizukojc and Bizukojc 2005; Cheng *et al.* 2008). In this study, an image analysis based instrument termed a Continuous Floc Image Analyser (C-

[1]RGB (red, green and blue) refers to a system for representing the colours to be used on a computer display.

FIA) was developed for tracking the dynamics of the flocs' formation, growth, and settling in a flowing suspension of water sample during the conventional surface water treatment process. The C-FIA is proposed as an alternative to light-beam scattering signal-based analysers such as PDA for flocs dynamics tracking. C-FIA has potential to provide additional information on flocs dynamics including online visual control of the floc's formation process as well as digital characterization of the flocs.

2. Materials and Methods

Two water samples used in this study were collected from the Murray River (Tailem Bend, SA, Australia) and the Myponga River (Myponga, SA, Australia). The Murray River sample contained a comparatively lower level of organic matter concentration (4.3 mg L^{-1} DOC), had a lower humic character (3.3 L mg^{-1} m^{-1} $SUVA_{254}$ and 17.2 RFU fDOM[2]), and higher turbidity (41.6 FNU) than the Myponga River sample. This contained a higher concentration of organic matter (18.8 mg L^{-1} DOC), a higher level of humics (5.0 L mg^{-1} m^{-1} $SUVA_{254}$ and 112 RFU fDOM), and lower turbidity content (12.1 FNU). Samples were stored at 4°C before conducting experiments, within four weeks of the samples collection.

The experimental equipment included a 2-L jar testing instrument, a PDA (3000 model, Rank Bros Ltd., Cambridge, UK), and the developed C-FIA instrument. A peristaltic pump was used to flow the water samples with a 25 mL min^{-1} flow rate through the PDA and C-FIA during the treatment process. Compatible, clear plastic tubing (3mm internal diameter) from the PDA sample pathway was used to pass the water sample through the C-FIA system. A rectangular borosilicate cell (9 mm W × 3 mm H × 50 mm L) (Friedrich & Dimmock Inc., Millville, USA) was used as the photography cell of the C-FIA. The photocell was connected using soft tubing sealed using silicone paste. A flow-through lightbox equipped with a strip of white LED lamps (6000 K light temperature) was used as a light controlled environment during photography. A Panasonic LUMIX G100 Micro Four Thirds Camera with 12-32mm Single Lens was used to take a 4K video recording during the 1min background, 1 min rapid mixing, 14 min flocculation, and 15 min settling process times in the jar testing experiments. A schematic of the experimental configuration is shown in Figure 1a and 1b.

The videos recordings were analyzed using a develop MATLAB script for extracting the FI data based on the RGB data associated with the pixels of the video frames. The PDA FI were also collected in the concurrent experiments. The collected FI using both PDA and C-FIA were used to calculate some further parameters (i.e., FI_{1min}, Plateau, Variance, and RSF) which are previously proposed for PDA signal analysis (Staaks *et al.* 2011). The details of the parameters are presented in the Table 1 footnote.

DOC measurements were conducted by a TOC analyser (Model 820, Sievers Instruments, USA). A spectrophotometer (Model UV-120, Miostech, Australia) was used to measure UV absorbance at 254nm, A_{254} (m^{-1}) of water samples. Samples were filtered before DOC and UV absorbance analyses using 0.45μm polyether-sulfone membrane filters (Sartorius, Germany). A YSI EXO2 sonde equipped with an fDOM probe (Xylem instructions, USA) was used for fDOM analysis. Jar testing experiments were conducted using 2 litres of samples and dosing water with different amounts of alum coagulant. Four jar testing experiments using four different alum doses were conducted for each water sample. The PDA was operated concurrently with the C-FIA in some selected experiments to provide simultaneous comparison data[3].

3. Results and Discussion

A sample of photography results collected during the Middle River sample treatment process using 202 mg L^{-1} alum dose is presented in Figure 1. This indicates the capability of C-FIA for providing visual information on flocs formation/growth dynamics during the process. The obtained frames also have the potential to be further analyzed for flocs characteristics such as flocs size, flocs shape, flocs density, etc., using open source or commercially available image analysis software e.g. ImageJ. These could be considered as C-FIA advantages over the light scattering based techniques.

The results of the image analysis for FI signal extraction from the captured video frames during the process are presented in Figure 3, for selected experiments. The results indicate the capability of the proposed signal to distinguish between baseline, rapid mixing, flocculation, and settling stages. However, it was found that light intensity and light irradiation angle to the surface of the photocell can impact the C-FIA FI through its effects on the pixels RGB values in the flocs images and raw water image used for determining background FI value. Hence, to have a valid comparison between the results of different experiments, it was found that more advanced C-FIA configuration with more controlled (consistent) light irradiation intensity, light irradiation angle to the photo-cell surface, and camera position to the photography cell can provide more reliable outcomes. The comparison of the C-FIA FI versus PDA FI in Figure 3 indicates the higher reliability (lower variance in FI) of C-FIA FI (Table 1 and Figure 3). It could be considered as another C-FIA advantage over the light scattering based techniques. Also, the C-FIA distinguished the high and low organic content of samples by the corresponding high and low FI values, respectively. The FI level correlation with applied alum dose can be observed from the results as well.

Further factors of Plateau, Variance, and RSF were calculated using FI versus process time data which are shown in Table 1. The correlation observed between the C-FIA and PDA data with increase in applied alum doses for some parameters such as Baseline and Plateau should be further investigated. This using an upgraded C-FIA configuration with capability for providing a highly consistent light environment during photography.

4. Conclusion

[2]Fluorescent Dissolved Organic Matter (fDOM) content in relative fluorescence unit (RFU).

[3] Due to limited time availability of the PDA instrument during the project.

The C-FIA showed potential as an alternative to light scattering based techniques for tracking floc dynamics during the conventional water treatment. The findings of this study indicate C-FIA advantages include capability for providing detailed visual information for control of the treatment process. Also, it shows potential for providing detailed floc character information, with low noise FI background data. However, C-FIA as a novel instrument/technique should be further investigated to optimize and standardize its performance, especially for water treatment control.

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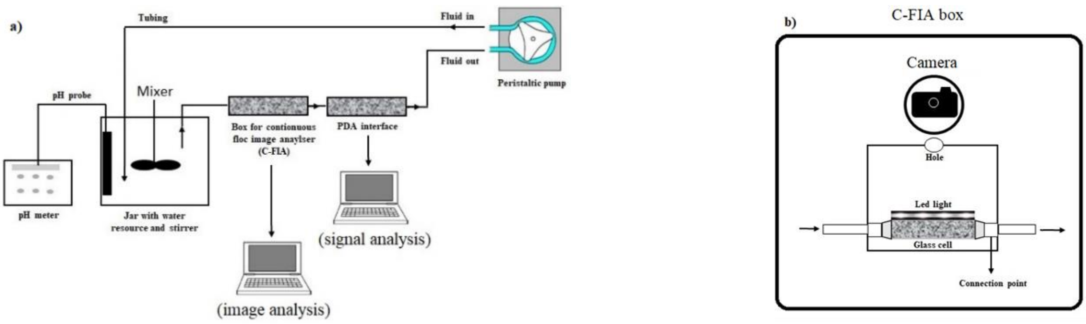

Figure 1. A schematic of the experimental configuration (a) and the details of the developed C-FIA configuration (b)

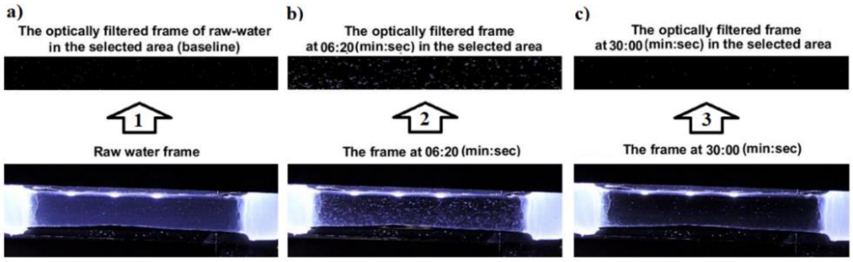

Figure 2. Video frames and their corresponding optically filtered selected pixels-area for C-FIA signal extraction in raw water (a), flocculation (b), and end of settling (c) stages of Murray River sample (156 mg L-1 alum dose)

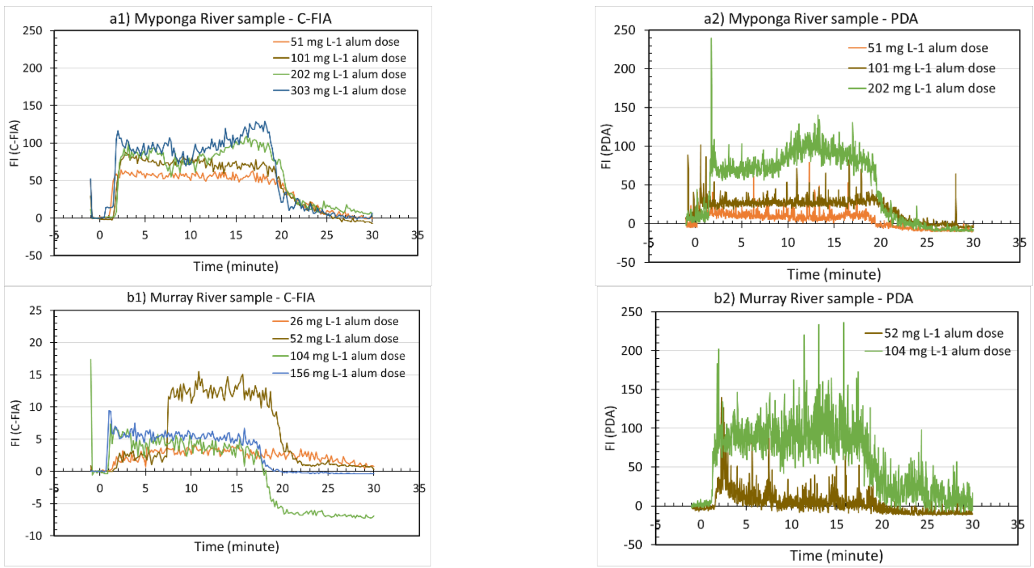

Figure 3. The comparison study between C-FIA and PDA output graphs for two studied water samples[4]

[4]The FI step observed in the C-FIA result of Murray River sample treated with 52 mg L^{-1} alum dose experiment in the time range of 7-8 minutes occurred due to the inconsistent light environment during the photography period.

Table 1. The comparison study between C-FIA and PDA output signal graphs for two different water samples

Sample	Alum dose mg L^{-1}	Baseline		FI_{1min}		Plateau		Variance		RSF	
		C-FIA	PDA	C-FIA	PDA	C-FIA	PDA	C-FIA	PDA	C-FIA	PDA
Myponga River	51	108	27	1.6	10.9	56.1	9.4	15	63	0.76	1.94
	101	106	42	-1.8	30	72.5	29	28	41	0.94	1.05
	202	97	34	1.9	13	84.3	98	92	132	0.82	1.07
	303	111		14		96.1		90		0.90	
Murray River	26	89		0.1		3.35		0.2		0.55	
	52[5]	88	25	-	-2.8	-	6.2	-	84	-	2.90
	104	108	29	1.0	3.6	3.72	99	0.6	735	2.84	1.05
	156	93		6.7		5.3		0.3		1.05	

Baseline**:** FI signal for raw water before dosing coagulant to the water, which is calculated through the average of FI signal in the range of -40 to -20 sec (when dosing time is considered as zero time). The baseline was used for signal correction during process time (i.e., 0-30 min).
FI_{1min}: FI signal at the end of rapid mixing stage, which is calculated through the average of FI signal in the range of 50-60 sec of the process time.
Plateau: This is calculated through the average FI signal in the range of 10-15 min of the process time.
Variance: This is calculated through the Variance of FI signal in the range of 10-15 min of the process time.
RSF = Relative Settling Factor (RSF) which is calculated through the following formula:

$$RSF = \frac{\text{Plateau} - \text{IS}}{\text{Plateau}}$$

where IS (Initial Settling) is the extreme value in the range of 15:00-22:30 min:sec of the process time.

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[5]The C-FIA results for the 52 mg L^{-1} experiment was removed here because of the inconsistent light during the photography period.