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On-line optical monitoring of activated sludge floc morphology

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ABSTRACT

An on-line device for the optical monitoring of activated sludge flocs was set up and tested *in situ* at a municipal wastewater treatment plant over eight months. A charge-coupled device camera was used to image the flocs and filaments, and an automated image analysis programme was used to analyse the morphological parameters of the flocs. Results were compared to those obtained from offline laboratory analysis for water quality indicators, such as suspended solids. The results showed that the activated sludge process has produced different levels of settling quality. Large and round flocs enabled good settling, whereas small and irregularly shaped flocs, as well as the large amount of filaments, led to poor settling. The image analysis results obtained from the on-line device indicated that the poor settling was most likely caused by filamentous bulking. Such bulking was most likely due to the compositional variations in incoming wastewater; the poorly settled sludge was characterised by much lower solids content, which could have been responsible for the growth of filamentous bacteria. The image analysis results also revealed that the changes in floc morphology occurred slowly, indicating the potential for optical monitoring to control and optimise the activated sludge process.

1. Introduction

The activated sludge process (ASP) is a common and environmental-friendly approach to treating wastewaters, because almost all wastewaters contain biodegradable constituents that can be removed by using microorganisms [1]. In ASP, different bacterial species consume organic matter from wastewater and produce flocs that can be removed by settling. Dysfunctional flocculation causes settling problems, that have both environmental and economic consequences; thus, floc formation is critical to excellent ASP [2,3,4]. In addition, more stringent demands for high-quality treated water are constantly made even as wastewater loads continue to increase; this situation gives rise to the need for new sensors and monitoring tools [5,1].

The flocculation problems in ASP are often associated with the imbalance between floc-forming and filamentous bacteria; this imbalance affects floc structure and leads to settling problems in activated sludge [6,7]. In filamentous bulking, for example, an excessive amount of filamentous bacteria forms large, irregular and open flocs [8,6,9], whereas a lack of filamentous bacteria results in small, compact and roughly spherical flocs (pinpoint flocs) [4]. Similarly, an excessive amount of floc-forming bacteria overproduce extracellular polymeric substances (EPS) thereby leading to the formation of weak and buoyant flocs (zoogleal bulking) [10,11]; low amounts of floc-forming bacteria, on the other hand, form only small, dispersed flocs (dispersed growth) [8,12]. As can be seen, different disturbances in bacterial balance exert different effects on floc structure. Such differences may enable the determination of ASP status by visual observation. Apart from floc morphology and bacterial balance, EPS content [13–15], cations (such as Ca^{2+}) [6,15,16] and biomass density [17,18] influence the settling properties of activated sludge. Despite the progress made in this regard, however, the on-line measurement of the aforementioned parameters is difficult to accomplish.

Given that flocculation performance affects the quality of treated water and because biological processes are sensitive to sudden changes in wastewater composition, a necessary requirement is the real-time monitoring of floc characteristics [1,4]. An unresolved challenge in research is the lack of appropriate on-line methods for measuring floc characteristics [2,19]. The quality of treated water is often monitored by manual grab sampling, in which researchers conduct offline analysis for water quality indicators, such as biological oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SS) [1,20]. Such analysis is unlikely to provide a meaningful and accurate picture of ASP conditions. The on-line measurement of flocculation enables rapid response to disturbances in bacterial balance, thereby preventing pollutant discharge. In addition, the daily monitoring of flocs allows researchers

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to identify the relationship between flocculation and the influent operational characteristics of ASP [21].

An earlier study [22] indicated a correlation between floc morphology and the total suspended solids content in effluent. This correlation points to the possibility of examining the state of ASP by image analysis. Previous studies also revealed that digital image analysis could determine a good linear relationship between floc morphology and SS precipitation efficiency [23], and that automatic image analysis could identify filamentous bulking, pinpoint flocs formation and viscous bulking [10]. Nevertheless, although full-scale studies of ASP are valuable, most flocculation studies have been conducted in laboratory conditions or at the pilot scale [15]. None have performed the on-line monitoring of activated sludge floc morphology.

In the current work, an on-line optical monitoring device for activated sludge flocs was installed and tested *in situ* at a municipal wastewater treatment plant (WWTP) over an eight-month period. This study aimed to determine whether the developed method is suitable for on-line analysis and to identify a correlation between floc morphology and the state of ASP. In addition, the study intended to identify the short- and long-term variations in floc morphology at the full-scale activated sludge plant.

2. Materials and methods

2.1. Description of the wastewater treatment plant

The method used at the WWTP is ASP that utilises simultaneous precipitation; thus wastewater treatment at the plant uses mechanical, biological and chemical processes (Fig. 1). Phosphorus is removed by chemical precipitation with ferrous sulphate dosing at the beginning of grit removal and after aeration. In the biological process, the WWTP has eight parallel lines for activated sludge process with own sludge handling system for every line. From the secondary settling, the wastewater is led to biological filtration to enhance denitrification. The wastewater treated in the plant comes primarily from domestic sources, and the average amount of treated water is 280 000 m^3/day. The legal discharge limits at this wastewater treatment plant were for COD < 75 mg/L and for SS < 15 mg/L.

2.2. Floc imaging system

The on-line optical monitoring device consists of an imaging unit, a sample handling unit and a control PC and electronics unit (Fig. 2). The imaging unit is equipped with an industrial camera, LED light source and a cuvette. The cuvette is planar and the special design of it makes the sample flow laminar. The sensor of the charge-coupled device (CCD) camera is 4.4 mm × 3.3 mm (1296 pixels × 966 pixels), with a pixel size of 3.4 μm × 3.4 μm. Camera is focused in the centre of the cuvette and the depth of field covers the whole imaged volume. The sample is pumped from the wastewater process into a container where the sample is diluted and pumped into the cuvette of the imaging unit. The sample is pumped from the process by a large grinder pump into pipeline from where the sample is taken to the sample container. The sample is then pumped by a peristaltic pump from this container to the imaging unit. The control PC and electronics unit controls the pump and valves synchronistically with image acquisition. There is also a constant water flow between the measurement cycles and chemical cleaning is done once a month to prevent biofilm growth. Videos of the samples were saved approximately twice a day, five times a week. A single video contains about 1000 images and an image contains around 150 flocs. Almost 300 000 flocs were analysed daily; thus, sufficient data were obtained for statistically reliable results. The trial, initiated in late May 2013, lasted 8.5 months.

2.3. Image analysis

The automated image analysis programme presented in Koivuranta et al. [24] was used to calculate the different size and shape parameters of each particle in each image. In the current study, the shape parameters calculated for the activated sludge flocs, which area is over 100 μm^2, included roundness and aspect ratio. Additionally, the equivalent diameter of the flocs and the proportion of small particles (equivalent diameter between 3.6 and 25 μm) relative to all the particles were calculated. To quantify the amount of filamentous bacteria, the total filament length per total floc area ratio was calculated. The mathematical formulas for the shape factors are presented in Koivuranta et al. [24].

2.4. Offline process monitoring

The ASP was monitored twice a week for COD (SFS 5504:1988) and SS (SFS-EN 872-2005) contents. These parameters were measured by collecting grab samples from every line once an hour.

2.5. Dilution study

To determine the appropriate dilution for the on-line device and the effects of dilutions on floc morphology, samples of different dilutions were tested at the laboratory using the floc measurement environment presented in Koivuranta et al. [24]. The image sensor of CCD camera is 5.0 mm × 3.7 mm (1392 × 1040 pixels), with a pixel size of approximately 3.6 μm × 3.6 μm. All the samples were diluted with deionised water at ratios of 1:50, 1:100 and 1:200 ratios for a total volume of 2 L. After the dilution, the samples were stirred gently to avoid floc breakage. They were then processed through the imaging unit and disposed of after imaging.

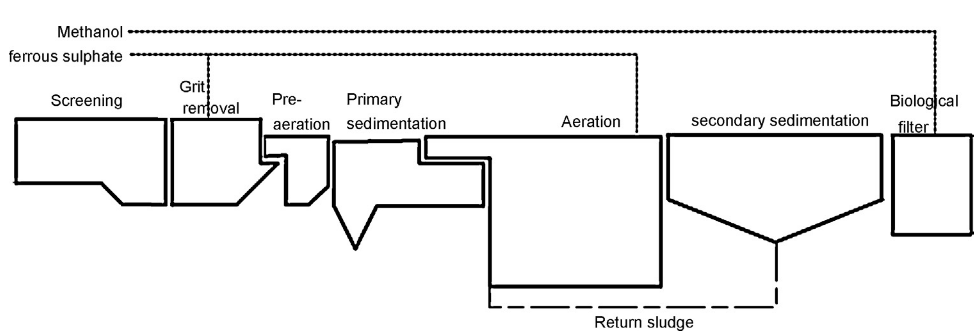

Fig. 1. Schematic of the WWTP.