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► **To cite this version:**

Yoan Pechaud, Yannick Fayolle, Camilo Duran Quintero, Sylvain Pageot, Sylvie Gillot. Biological floc size measurement for shear stress evaluation in full-scale aeration tanks. 12th International Conference on Gas-Liquid & Gas-Liquid-Solid Reactor Engineering (GLS12), Jun 2015, New York, France. pp.4. hal-01158574

HAL Id: hal-01158574

<https://hal.science/hal-01158574>

Submitted on 16 May 2020

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Biological floc size measurement for shear stress evaluation in full-scale aeration tanks

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Introduction

In a world driven towards sustainability, energy savings are nowadays a priority. In conventional activated sludge wastewater treatment plants and membrane bioreactors, the energy expenditure due to aeration, mixing, pumping or filtration is affected by viscosity of activate sludge (AS) which is a key parameter governing the bioreactors hydrodynamics and oxygen transfer efficiency in such aerobic processes (Duran et al., Submitted).

Activated sludge is a colloidal system and could be considered as a non-Newtonian fluid (Seyssiecq et al., 2003; Ratkovich et al., 2013). Its rheological behaviour is mainly controlled by the suspended solid (MLSS) concentration (Duran et al., Submitted) and the applied shear rate.

Empirical and semi-empirical correlations have been proposed to estimate average shear rate in ideal reactors such as bubble column (Sanchez Perez et al 2006). However, in activated sludge reactors, it is difficult to predict the average shear rate using these correlations due to complex geometries of full scale reactors and several operating conditions (different air flow rates, mixers configurations). Also, there is a need to propose innovative methods to estimate the average shear rate in real wastewater treatments reactors, in order to study the impact of the rheological behaviour of activated sludge on process efficiency.

The aim of this study is to propose an innovative methodology to estimate the average shear rate in full scale reactors based on the shear thinning dependence of biological flocs. This methodology is applied on a full scale wastewater treatment plant (WWTP) and the spatial and time dependencies of the shear share will be investigated.

Materials and methods

Wastewater treatment plant

The experimental set-up was installed a full scale MBR WWTP located in Briis-sous-Forges, France. The facility is designed for 17,000 PE, treat mainly domestic effluents and are operated under extended aeration (F/M ratio < 0.1 kg BOD₅ (kg VSS)⁻¹ d⁻¹). The biological treatment part is composed of one anoxic tank (equipped with mixers), one aerobic tank (equipped with one mixer and sequential aeration using fine bubble diffusion system) and three filtration zones (equipped with plane membranes of filtration and coarse bubble aeration system).

Floc size measurements

The size distributions of the flocs were determined using a particle size analyser Malvern Mastersizer 3000. It measures particle size in a liquid phase in the range 0.02 – 2000 µm. The optical index of the dispersant was set to 1.23, which corresponded to the value for the water (Wan et al., 2009). As biological aggregates are mainly composed of organic matter, the optical index was set to 1.596 (Wan et al., 2009).

In order to determine the floc size distribution just after sampling, the analyser was located in the WWTP closed to biological tanks.

Results

Influence of hydrodynamic sequencing on aggregate strength

To analyse the influence of shear forces on floc size, a first experiment has been done to study dynamically the cohesion-break mechanisms. The aim was to subject the flocs to successive different hydrodynamic stresses and to determine if the resulting aggregate structure and the floc size distributions are modified by their history. This experiment is done in a wet sample dispersion unit (Hydro-EV, Malvern) at a MLSS concentration of 0.1 g.l^{-1} to prevent from multiple diffraction during particle size determination.

The hydrodynamic sequencing is made up of twelve successive stages with rapid and slow mixing periods (Figure 1a).

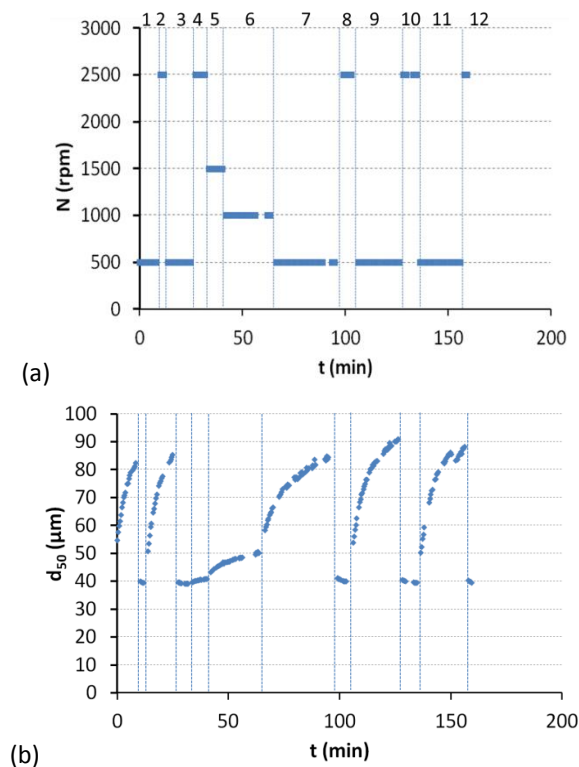


Figure 1. (a) Hydrodynamic sequencing and (b) variation of the average diameter with time during hydrodynamic sequencing

As depicted on figure 1b, the kinetics of aggregation are significantly slower than the break-up ones and seems to depend on the duration of the previous rapid mixing phases. Once the flocs have been subjected to the highest shear rate, their steady state size remains the same for rapid mixing stages.

Standard vessel to study the influence of shear rate on average floc size from a aerated tank

To go further in the understanding on the mechanisms involved and to control the average shear rate, a standard vessel has been designed. Each sample is placed in a standard cylindrical vessel equipped with a Rushton turbine or a marine propeller in order to cover a large range of shear rate (Figure 2). To characterize the influence of shear rate on the average size of flocs, two measurements have been done for each applied shear rate: (i) one after 30 minutes, (ii) the second one after 1h. It has been observed experimentally that after subjecting flocs to a constant shear rate during 30 minutes, the average size of flocs did not change.

Rheological measurements performed during this study highlight that the activated sludge liquor could be considered as Newtonian fluid only for a MLSS concentration lower or equal to 0.5 g.l^{-1} . To estimate the

average shear rate in the vessel whatever the agitation speed applied, activated sludge samples are thus diluted with WWTP effluent to a MLSS concentration of 0.5 g.l^{-1} (constant viscosity at this concentration).

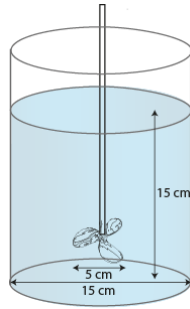


Figure 2. Standard vessel

In turbulent flow for Newtonian fluids, the shear rate level corresponding to the operating conditions induced during this experiment can be calculated using equations [1] and [2]:

$$\gamma = \left(\frac{1}{\mu} \cdot \frac{P}{V} \right)^{1/2} \quad [1]$$

$$\frac{P}{V} = \frac{4N_p \rho d_i^2}{\pi 9 \mu} N^3 \quad [2]$$

With: N_p the Power number (-), ρ the density of fluid (kg m^{-3}), d_i the diameter of the impeller (m), μ the dynamic viscosity (Pa.s) and N is the agitation speed (s^{-1}).

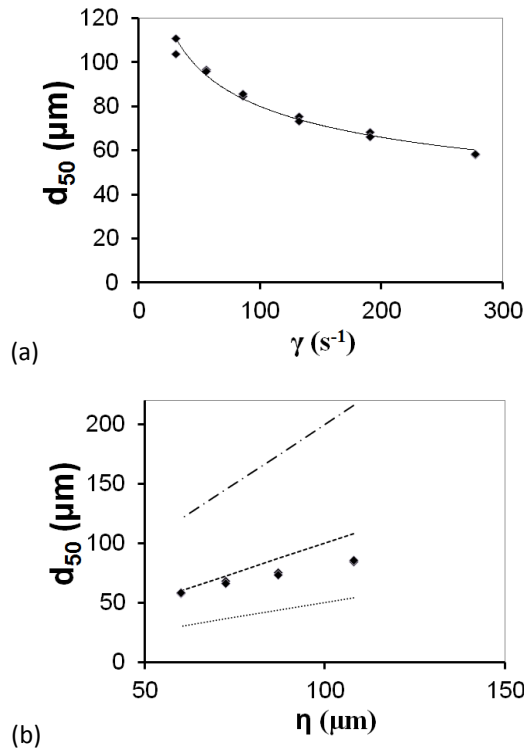


Figure 3. (a) Mean steady state floc size versus mean shear rate in the standard vessel and (b) Mean steady state floc size versus Kolmogorov microscale [♦ experiments / ---- $d_{50} = \eta$ / $d_{50} = 0.5 \times \eta$ / - · - $d_{50} = 2 \times \eta$]

Figure 3a highlights the floc size dependence to the mean shear rate. It appears that the average size of flocs decrease with the shear rates applied. For this sample, the average floc size is higher than $100 \mu\text{m}$ for shear rates around 30 s^{-1} and lower than $60 \mu\text{m}$ for shear rates higher than 250 s^{-1} .

In order to highlight the mechanisms controlling the size of flocs, the average size of flocs are compared to the Kolmogorov microscale (η) corresponding to the size of the smallest eddies during mixing (linked to the shear level in the vessel). It could be determined using equation [3].

$$\eta = \left(\frac{\nu^3}{\varepsilon} \right)^{\frac{1}{4}} \text{ with } \varepsilon = \nu \gamma^2 \quad [3]$$

With: η the Kolmogorov length scale (m), ν the kinematic viscosity of the fluid ($\text{m}^2 \text{s}^{-1}$), ε the average rate of dissipation of turbulence kinetic energy ($\text{m}^2 \text{s}^{-3}$) and the shear rate (s^{-1})

It appears that whatever the shear rate applied, the average floc size is close to the Kolmogorov microscale (ranged between 0.5η and η , see Figure 3b). Flocs are thus essentially submitted to viscous and shear effects.

Toward an indirect measure of the shear rate in aerated tank and MBR

For each samples, a specific database of floc size for different shear rate is build using the previous protocol. This database allows to evaluate the breakage mechanisms and to highlight differences in the cohesion of flocs between samples. Such differences may be linked to differences in the microstructure of flocs resulting from different feeding and hydrodynamics conditions.

In order to quantify the average shear rate in each biological tank and for each operating condition (mixing, aeration), several measurements of floc size directly taken form the AS tank were done (less than 1 minute between sample and measurement). The first results highlight that the mean floc size was $83 \mu\text{m}$ during aerated phases (with a minimal value of $70 \mu\text{m}$ and a maximal value of $87 \mu\text{m}$) corresponding to an average shear rate of 90 s^{-1} (see Figure 3a). More data are being acquiring and will be presented in the full paper. The impact of operating conditions and tank characteristics on mean floc size and associated shear rate will be investigated. These results will be compared with data from literature on bubble columns.

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