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Experimental study of activated sludge batch settling velocity profile

Pierre François*, Florent Locatelli, Julien Laurent, Karim Bekkour

Strasbourg University, Icube, Department of Mechanics, France

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ABSTRACT

The last step of activated sludge wastewater treatment consists in separating the residual particulate matter from water. This separation process takes place in a clarifier: a large tank in which sludge particles settle while clear water overflows. In order to improve numerical models of clarifiers, a better understanding of activated sludge settling mechanism is required. Laboratory batch settling experiments involving acoustic Doppler velocity measurement methods have thus been developed. The raw Doppler signal was recorded over durations of up to 22hours and then post treated. At the very beginning of the sedimentation process 3D turbulence produced by the initial stirring generates a high velocity standard deviation. 3D turbulence dissipates after a few minutes. Low amplitude fluctuations of the vertical velocity remain, whereas the average velocity decreases at any vertical location. Vertical velocity profiles exhibit two areas: an area of rising velocity in the lower part of the blanket and an area in which velocity fluctuates around a uniform settling velocity in the upper part. This last area decreases constantly and disappears completely after some minutes. A change in concavity of the rising velocity profiles after three hours rest indicates a change in the physical mechanism of consolidation.

1. Introduction

Activated sludge is a widespread wastewater treatment method: the influent is mixed with a bacterial suspension in a biological reactor. The bacteria consume and degrade the pollution, which results in the formation of particulate aggregates called flocs the individual particle having a characteristic dimension of about 100 µm. They are made of bacteria, mineral and residual organic matter. The resulting suspension (mixed liquor) is sent to a secondary settling tank, also called clarifier, in which the flocs can settle in quiescent conditions while the supernatant overflows at the top and concentrated sludge is pumped at the bottom. The optimization of clarifiers, in term of geometry as well as in term of conditions of use, requires reliable numerical simulation since building real scale prototypes is obviously difficult in practice. Numerical simulations require themselves realistic models of sludge physical behavior. That's why activated sludge settling has been extensively studied [1–3]. It is a complex process, influenced by many parameters, such as the size, fractal dimension and porosity of flocs, suspension concentration, carrier fluid viscosity, temperature, nutrient and oxygen concentrations, pH, conductivity and the hydrodynamics of the system. Several physical models have been developed in order to describe it [1-21,27-29]. These models aim at evaluating the concentration and settling velocity of an activated sludge suspension dispersed in water on the basis of the aforementioned parameters. They require detailed experimental calibra- tion and validation, particularly regarding the inner behavior of the sludge blanket. However, most measurement systems allow only monitoring the position of the interface between the sludge and the supernatant by the use of turbidimeters, and are rarely usable in actual treatment plants. In consequence some of the assumptions about sludge's physical behavior have never been confirmed by direct velocity measurements in the core of the sludge blanket. The present paper focuses on the development and testing of an experimental procedure aiming at measuring simultaneously the height and settling velocity profile within the sludge blanket by the use of an ultrasonic Doppler profiler. We demonstrate the feasibility of accurate velocity measurements threw at least one meter of highly concentrated sludge. We proof in this way that real time monitoring of clarifiers by the use of Doppler profiler is possible. We carried out velocity profiles measurements during sludge settlement in a settling tank of simple cylindrical geometry in order to verify some of the hypothesis about sludge's physical behavior underling most of the existing models. We highlight some aspects of sludge mechanical properties that had been neglected until now and which should be taken into account for a more realistic modeling of sludge settling.

2. Materials and methods

2.1. Experimental settling column

The main body of the experimental setup is a settling column 0.4 m in diameter and 1.0 m high (Fig. 1). The column is made of

* Corresponding author.

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transparent Plexiglas® in order to allow visual observations. The suspension can be stirred by the mean of a reversible pumping system in close loop. Once the sludge is poured in the tank the liquid is pumped at the bottom of the tank and injected at the top at low rate in order to remove all the bubbles from the pumping loop. In a second stage the liquid is pumped at high rate through four inlets located at the top of the column and injected back through four outlets at the bottom creating a high level of turbulence and an upward flow of about 1 cm/s sufficient to suspend the particles.

A homogeneous concentration can thus be achieved. Stirring the suspension is also a mean of simulating the hydrodynamic conditions through which an activated sludge suspension has to go in an actual treatment plant before its arrival in the clarifier.

The ultrasonic Doppler profiler used in the present study was developed in ICube laboratory [22]. The transducer is 1 cm in diameter and has a central frequency of 1.9 MHz. 40 waves are emitted per pulse representing a length of the measurement volume of 1.5 cm. The transducer was installed above the column in order to perform vertical measurements.

2.1.1. Velocity measurements

One of the main problems in measuring velocity profiles lies in the huge range of velocities during the settling process. At the very beginning of the experiment stirring induced turbulence generates velocity fluctuations of about 1–3 cm/s. This initial turbulence decays rapidly allowing the flocculation process to take place producing flocs about 5 mm in size settling freely in the suspending liquid. During this phase average velocities are of the order of 1 mm/s while velocity fluctuations still remain probably due to concentration heterogeneities. In the meantime, a layer of settled particles thickened progressively from the bottom of the tank. At the contrary to rigid bodies, flocs slide, compress and deform depending on the balance between weight, adverse pressure gradient due to water migration in the porous medium and solid stress. During this phase the largest velocity in the profile, at the top of the blanket, decreases constantly from 0.4 mm/s to 1 μm/s after 24 h rest. A good understanding of this complex process requires velocity measurements down to 0.1 μm/s. At this average velocity and for an ultrasonic frequency of 1.9 MHz floc displacement of half a wave length takes about one hour during which velocity change to a large extend. In consequence conventional fast Fourrier transform (FFT) of the Doppler signal cannot provide fine temporal resolution of velocity in reason of time averaging over the necessarily long time of signal required for FFT analysis [23-25]. Therefore a direct phase measurement was tested allowing measuring the individual displacement of each floc or group of flocs as proved by the discontinuities in the velocity profiles. Velocity field is obtained by derivation of floc displacement. A better temporal resolution is obtained at the expense of profile smoothing. Velocity profiles presented in chapter 3.1 were obtained by FFT analysis for the sake of a better understanding of the graphs. Raw Doppler signal is recorded and post treated. As an experiment lasts 22 h the pulse repetition frequency (PRF) is reduced incrementally from 25 to 0.05 Hz in order to save disk space and computation time during post treatment. In this way the minimum measurable velocity by FFT is 10^{-8} m/s and has no lower limit by phase measurement.

2.1.2. Concentration measurements

Theoretically, concentration profiles can be obtained by an appropriate analyze of the backscattered intensity profiles. In the present case this method cannot be applied due to the very small particles displacement during the tests. In consequence, it is not possible to get sufficient independent intensity samples in order to obtain an accurate average. Therefore concentration was estimated by computing the trajectories of virtual tracers distributed uniformly over the column at the beginning of the test when concentration is known and uniform. Particle velocity was set in the settling zone at the mean settling velocity to prevent a random spatial distribution of the tracers at the beginning of the compression phase in reason of the velocity fluctuations. The density of tracer at a given height and a given time during compression is afterward proportional to concentration.

2.1.3. Sludge blanket height and velocity measurement accuracy

The velocity measurement accuracy is somehow difficult to estimate due to the lack of alternative measuring systems. Nevertheless an estimation of the velocity uncertainty could be obtained by comparing the sludge blanket height measured by two totally different signal analysis methods with the same ultrasonic device. The sludge blanket height was firstly estimated by a simple threshold applied to the backscattered intensity level to detect the sharp intensity jump at the supernatant sludge interface. This height evolution is thereafter compared Fig. 2 to the trajectory of a particle placed initially 1 cm below the free surface. As can be seen the two curves are quite similar the particle trajectory joining the interface with time in reason of concentration increase. Since interface height measurements could easily be visually validated (See Fig. 3) the velocity measurement accuracy can be estimated in the following way. The error made on particle trajectory being less than 1 cm for a total displacement of 1 m the systematic error on velocity measurement is lower than than 1%.

2.2. Experimental procedure

The sludge samples have been taken in the biological reactor

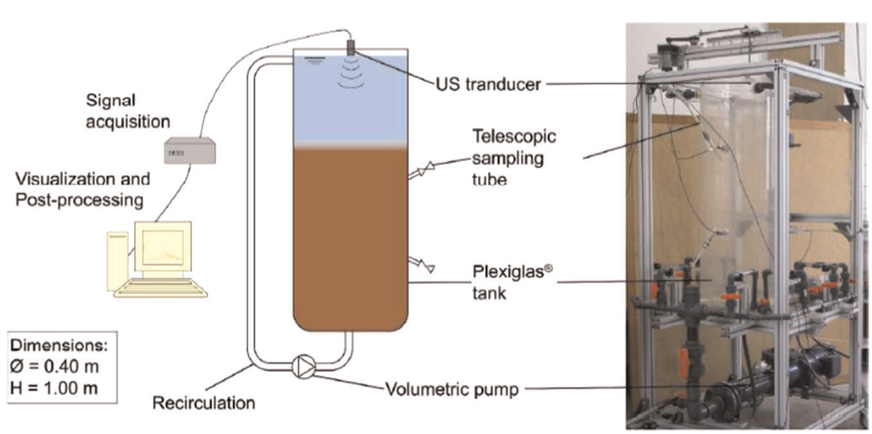

Fig. 1. Experimental setup.