IN SITU PARTICLE SIZE CHARACTERIZATION ON A CIRCULAR CLARIFIER OF A WASTEWATER TREATMENT PLANT

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INTRODUCTION

The secondary clarifier, in which bioflocs are separated from the liquid effluent by gravity, is a crucial operation in activated sludge wastewater treatment systems. If this process unit does not work properly, suspended solids would be flushed out of the process into the receiving water. The consequences of this are significant. Increased turbidity may restrict plant photosynthesis, and the increased oxygen demand may be detrimental for aquatic life.

Clarifiers are typically large, open, concrete vessels, with either rectangular or circular cross sections. The biosolids are separated by gravity settling (hindered settling regime) and removed from the bottom. The properties of the biosolids are critical in determining the effectiveness of the clarifier. However, we currently know very little about which are the key properties and how they drive the settling process. It is the premise of this paper that particle size distribution (PSD) is a key variable, and this is the focus of this paper. To date, no work has studied PSD in secondary clarifiers.

To investigate the PSD of the sludge, several sizing techniques are available. In literature, methods as image analysis (14), coulter counter (6) and laser light diffraction (3) are widely applied. Unfortunately, in general, they can only be used in a lab environment and not *in situ*. It should be mentioned that an ocean application exists for a waterproof-made laser light diffraction system (1), though the practicability is questionable due to its large dimensions. Other systems than the latter are rare. One of the few is the focused beam reflectance method (FBRM). The FBRM was first applied in the field of crystallization, but to the knowledge of the authors, no applications exist in wastewater treatment.

This paper starts with a discussion of the principle of FBRM and the necessary optimization of the technique for a particular treatment plant is also presented. To show its applicability, steady-state and dynamic PSD profiling were carried out inside and outside the flocculator of a secondary clarifier. This profiling aims at demonstrating the function of the flocculator. The municipal wastewater treatment plant under study is located in Brisbane (Australia). The examined circular clarifier had a central feed, a peripheral overflow weir, a central conical sludge hopper and blade scraper. It had a maximum depth of 5.4 m and a surface area of 308 m^2.

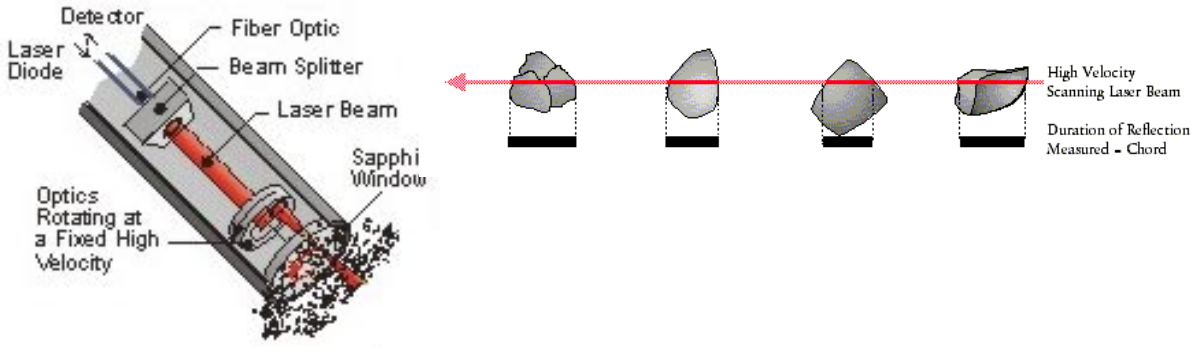
The inlet flow rate was characterized by a diurnal pattern and, during the measurement campaign, the inlet solids concentration ranged between 1,800 and 2,200 mg/l. It was concluded that the clarifier was underloaded in terms of solids. Hydraulically, the system was

within its design boundaries. Finally, it should be mentioned that the zeolite ZELflocc was dosed in order to improve the settleability of the solids. The zeolite (approximate median diameter of 20 microns) is incorporated into the bioflocs, thus increasing the density and settling velocity of the flocs. It does not affect the operation of the clarifier.

FOCUSED BEAM REFLECTANCE METHOD

PRINCIPLE

The FBRM probe used in this research was the Lasentec FBRM M500 (Lasentec, Redmond, Washington, USA). It consists of a laser that is focused in some focal plane outside the sapphire window (Figure 1a). The laser rotates at a fixed speed, i.e. 2 m/s, so that particle motion is insignificant to the measurement. As particles pass by the focal plane, the focused beam intersects the edge of a particle and begins to backscatter the laser light. The backscatter continues until the focused beam reaches the particle's opposite edge. The backscatter is collected by the FBRM optics and converted into an electronic signal. FBRM uses a discrimination circuit to isolate the time period of backscatter from one edge of an individual particle to its opposite edge. This time period is multiplied by the scan speed and the result is a distance, i.e. the *chord length* (Figure 1b). The particle size distribution measured by the FBRM is referred to as the chord length distribution (CLD).



(a) (b)

Figure 1. Principle of FBRM (a) probe layout, (b) definition of chord length (from Lasentec).

The FBRM hardware provides 1,324 primary channels of data ranging between 0 and 1,024 μm on a linear scale. This scale is split into two ranges, 0-100 μm and 100-1,024 μm. The 400 channels in the 0-100 μm range provide finer, 0.25-μm resolution, whereas the upper 924 channels provide a coarser, 1-μm resolution, covering a wider micron range (100-1,024 μm). The Lasentec software gives the user the ability to group the primary channels in a way optimal to the application. In this research, flocs were sized in the 1 to 1,000 μm range over 90 logarithmic channels.

OPTIMIZATION OF FOCAL POINT POSITION

Before starting *in situ* measurements with the FBRM, it is essential to set the focal point (5, 8, 13) of the Lasentec probe. When optimized, one obtains a calibrated probe allowing the user

to measure a statistically significant CLD in the shortest measuring time. Optimization corresponds to finding the maximal reflectance response by changing the focal point position. According to the Lasentec's FBRM M500 manual this can be achieved by maximizing the so-called *peak* value, which is the number of counts per second in the chord length range of 0.8 - 5.5 μm. This approach is also widely applied in literature (5, 8, 10, 11, 12). Still several researchers (2, 4) retain the standard setting for the probe, i.e. 20 μm inside the sapphire window. According to the manufacturer, this generally results in a maximal signal-to-noise ratio. On the other hand, others focus the beam on the window itself (9, 16). Nevertheless, for specific applications it is essential to optimize the focal point position in order to have a maximum detection of counts per second (5, 8, 10, 11, 12). This might be crucial for biological sludge in the upper layers of the clarifier where the solids concentration is very low and (very) long measurement times may be needed if the focal point is not appropriately selected. It should be mentioned that an optimal position does not exist for a polydispersed sample since it is dependent on the actual size of the flocs, and every size class would require a different focal point position (8).

As mentioned before, the search for the optimal focal point is based on the maximum *peak* value. In the context of biological sludge, one can question the use of this *peak* in the probe calibration algorithm. Indeed, the sludge covers chord lengths far beyond the predefined channel boundaries of the *peak*. For that reason, it might be more interesting to focus on the number of counts over the total measured chord length range. Both parameters are evaluated to check possible discrepancies towards probe calibration.

In view of the above, three different sludge samples were investigated that were thought to exhibit different laser reflectance responses due to their expected difference in PSD. Samples from the inlet, outlet and underflow of the clarifier were considered. The outlet only showed a solids concentration of 7 mg/l, whereas the samples from the inlet and the underflow had a concentration of 2,500 and 5,140 mg/l respectively.
In a gently stirred beaker, the focal plane of the laser was changed from 1.5 mm inside the window to 3.75 mm into the suspension and one-minute measurements were performed. Besides the number of counts over the total size range of 1 – 1,000 μm, the *peak* was measured too. Because of the chosen size range, the *peak* range was shifted to 1 – 5.84 μm.

In Figure 2 only the results for the underflow sludge and effluent are shown; the plot for the inlet sludge is comparable. For all (Table 1), the optimal focal point is located in the suspension itself (neglecting the sapphire radiation at 0 μm, see insert in Figure 2b). This is logic in view of the actual size of the flocs. From the figure, it can also be seen that the maximum for the *peak* range and the total measured chord length range coincide. The *peak* can thus be used for probe calibration.

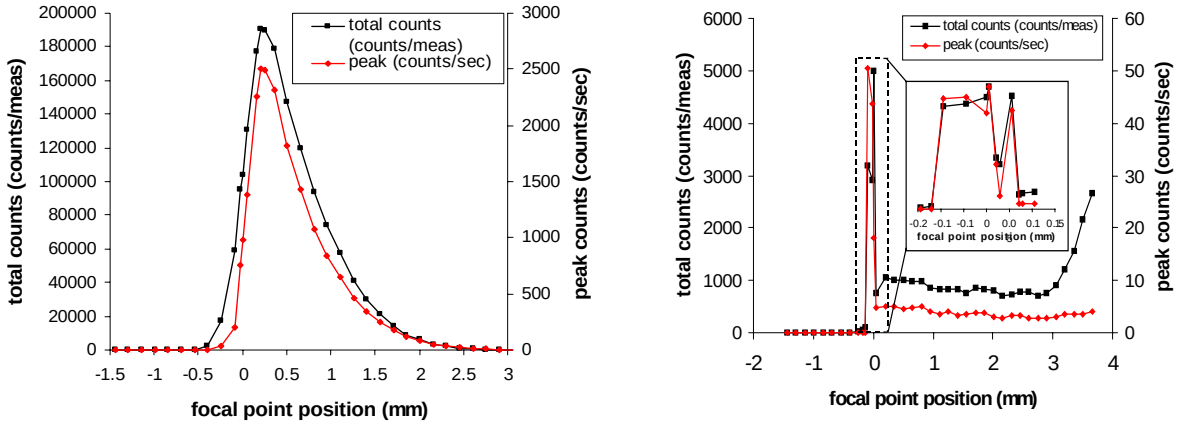
Type of suspension	**Optimal focal point position (μm)**
underflow	255
inlet	305
effluent	55

Table 1. Optimal focal point position for the different samples.

Further, it is also concluded that the particle size distribution measured with a focal point leading to the observed maximum number of counts, is characterized by the largest mean volume-weighted chord length (D[4,3]) for all focal points investigated (data not shown). On the other hand, a minimum in the mean unweighted chord length (D[1,0]) was observed by

Monnier et al. (8), but their studied range of focal point positions was more limited than the range considered in this research. In our study, no global minimum was found in the D[1,0] values, but a local minimum occurred at the same focal point position as the position where the maximum in D[4,3] was found (data not shown).

Ideally, one should adapt the focal point for every *in situ* experiment (13). For practical reasons, only two focal point positions were applied in the *in situ* experiments described below, one for measurements above the sludge blanket (55 µm), and one for below the blanket (280 µm, being the average of the positions for the underflow and inlet).



(a) (b)

Figure 2. Influence of focal point position on total number of counts per 1-minute measurement and *peak* counts for (a) underflow sludge and (b) effluent with zoom-in of 10-minute measurement.

IN SITU STEADY-STATE CLD PROFILING

Measurements were taken to obtain a profile of the particle size distribution in the studied clarifier. Different locations around the flocculator were sampled. Measurements were performed at afternoon inlet flow rates (0.147 ± 0.012 m^3/s), which were the most stable that could be obtained. Sludge blanket depth measurements confirmed that the blanket was stable in the afternoon (data not shown). Inside the flocculator five CLD's were recorded at increasing depths. Measurements outside the well and at different depths were performed as well. All locations were sampled over a 10-minutes interval, except for the four upper locations outside the flocculator. There, 30 minutes of sampling and a different focal point position were applied. The measurement periods were checked on their applicability in preliminary experiments; the total number of counts satisfactorily ranged between 400,000 and 4,000,000. To protect the probe, it was lowered into the clarifier in a tube with a seal at the bottom.

Figure 3 shows the CLDs obtained for the different sampling points. Interestingly, almost no variation was observed for the volume distribution inside either the flocculator or the sludge blanket. Therefore, only a single CLD is indicated in Figure 3 for all positions sampled inside the flocculator. A weak trimodal number distribution may be observed. The volume distribution, however, looks Gaussian. Due to this apparent invariable CLD, the role of the flocculator needs to be questioned. Presumably, most of the flocs are already formed inside the distribution pit, pipe, momentum diffuser and in the flocculator section close to the diffuser. According to Wahlberg (15), flocculation occurs very quickly, which is in accordance with the present observations.

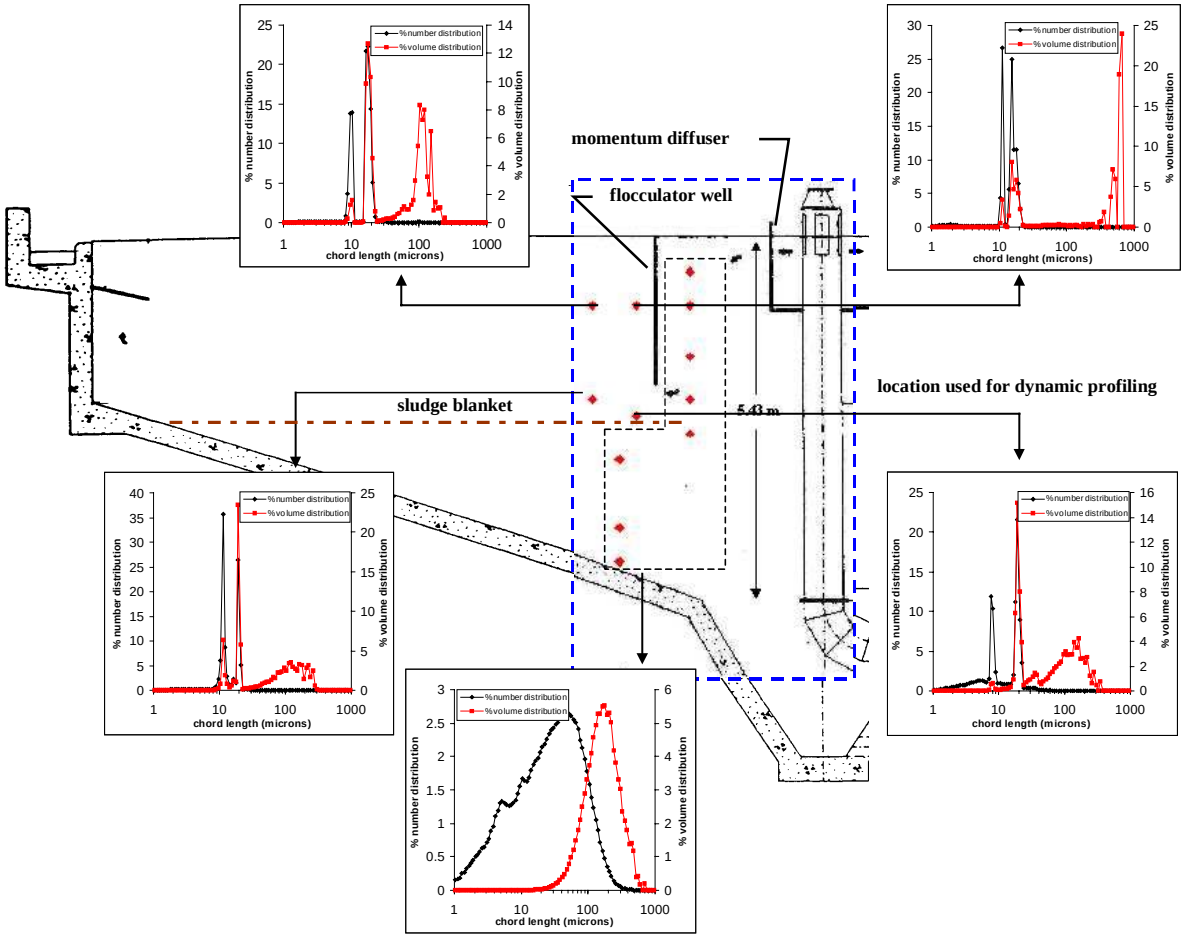


Figure 3. Steady-state CLD profiling inside and outside the flocculator.

On the other hand, above the blanket outside the flocculator one notices two pronounced peaks in the number distribution at sizes of 10 and 20 µm. Their location is comparable to the first two modi of the number distribution measured in the blanket, albeit a bit shifted to the lower end of the distribution. These two peaks can also be found in the volume distribution, but a third peak with a maximum around 100-110 µm is also observed. This peak obviously corresponds to sludge flocs.

The observation of the two peaks in the number distribution at ~10 and 20 µm, above the sludge blanket raises questions about why and where they originate from. As mentioned before, zeolite was added continuously to improve settling. For zeolite, a D[1,0] of ~20 µm was measured before. So, this inorganic fraction might explain at least one of the peaks. To investigate this qualitatively, samples were taken at the water surface from the middle of the scraper's bridge and examined *ex situ*. Images were taken with a Nikon Microphot-FXA microscope. No rigorous number distributions have been measured microscopically, but it seemed that flocs of biological and inorganic nature were equally dominant. In general, the biological flocs were of the same size or larger than the zeolite particles. The flocs could be easily detected in the images on the basis of their color and structure. From the images it was concluded that filamentous bacteria had a thickness less than 6 µm. On the other hand, the length could occasionally reach 5 mm. Single and clustered filaments could be found too. The

clusters were around 20 μm in thickness, which might explain the peak in number distribution. The two peaks remain a matter of uncertainty.

IN SITU DYNAMIC PSD PROFILING

The dynamics of the CLD profile were monitored at one spot inside the clarifier, just outside and below the flocculator well wall (as indicated in Figure 3). The probe was located approximately 20 cm above the sludge blanket to avoid any CLD invariability due to high solids concentrations. Another reason for this location was the expected higher shear rate at the lower end of the well wall, where more dynamics could be expected. As described previously, each sample of the CLD took 30 minutes because of the low velocities in the clarifier.

Figure 4 summarizes the measurements (half of the collected CLD's are shown). In general, one can observe that the fraction at the large-size end of the volume distribution increases with the flow rate. This corresponds with the sludge blanket rising above the sample point. The small particle fractions (note that again two peaks at ~10 and 20 μm are present) remain approximately constant as the flow rate changes. The D[1,0] of the number distribution is hardly influenced by these flow rate changes, just as the effluent suspended solids concentration (data not shown).

At first sight, the temporal behavior of the D[4,3] is not consistent with these observations. Indeed, due to the low velocities, large particles reside too long in front of the probe window and multiple scanning of the same particle occurs. As a consequence, due to the low flow rates at night spiky volume distributions were obtained. As the flow rate increased at 8-9am, more large particles were dragged with the flow and scanned. A more statistically significant distribution could then be collected in 30 minutes. In future experiments multiple scanning could be avoided by creating some local velocity field by installing a small mixer or pump.

CONCLUSIONS

To the knowledge of the authors, this research is a first attempt to measure *in situ* the particle sizes in a secondary clarifier of a wastewater treatment plant. Apparently, a steady-state for flocculation/deflocculation occurred in most of the clarifier. Comparison of CLD's above and below the sludge blanket clearly demonstrated the removal of the large-sized particle fractions by sedimentation. Since no change in CLD was observed inside the flocculator, its function with respect to flocculation was questioned.

This research also focused on some practical issues to consider. First, optimization of the focal point was crucial to perform statistically significant measurements in the quickest way. Different focal points resulted in other CLD's. Secondly, particle velocities should be high enough to avoid multiple scanning of the same particle residing in front of the probe window. High velocities also shorten the measurement period, which is beneficial too.
The FBRM has proved its *in situ* applicability and relative insensitivity to solids concentration. The latter is the major drawback of most particle sizers.

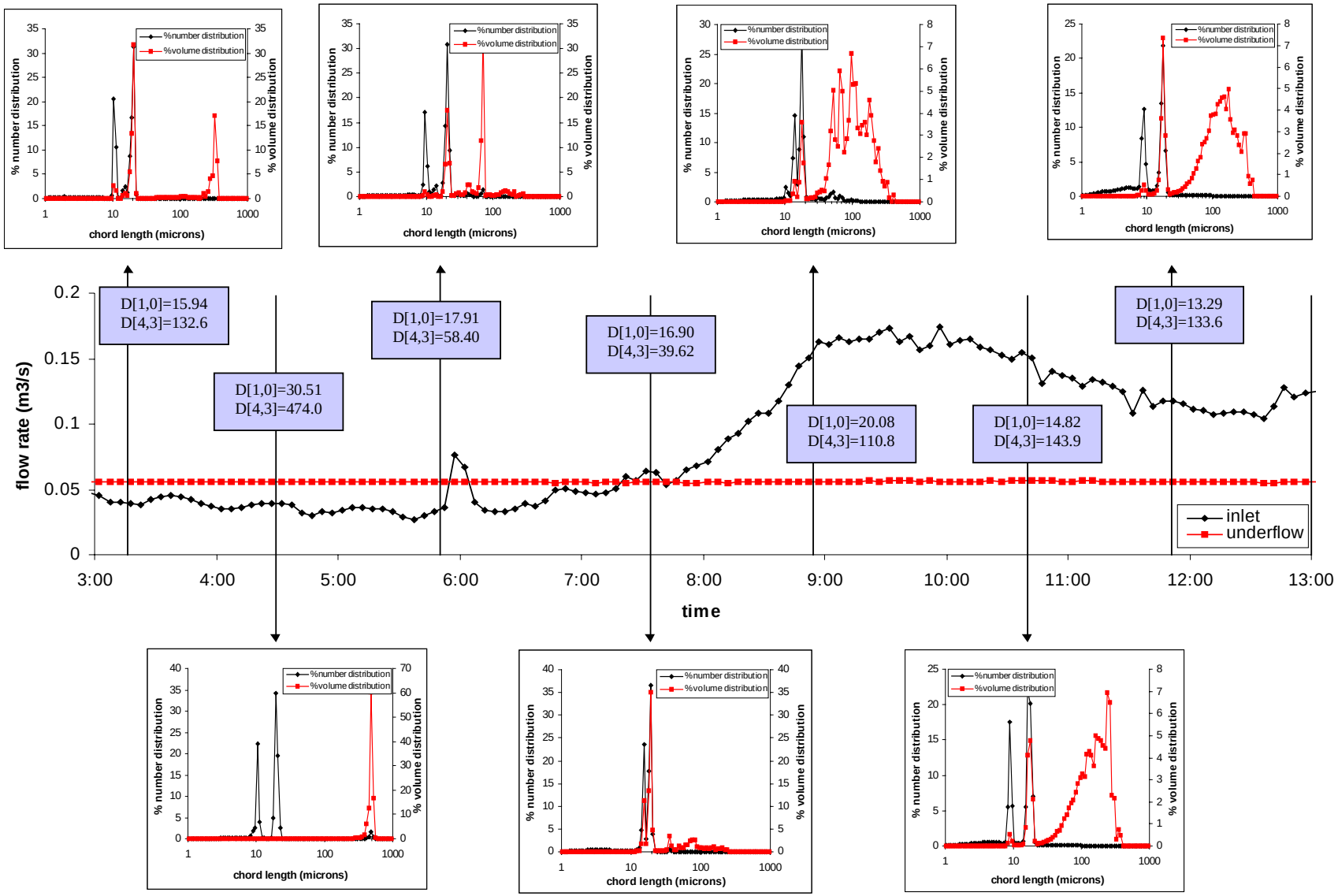


Figure 4. Dynamic monitoring of the CLD profile outside and below the flocculator well.

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