

NIR Observation of Activated Sludge Decantation Indicates Correlation with the Effluent Suspended Solids of Four Different Wastewater Treatment Plant Situations

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Abstract

The results of previous near-infrared (NIR) measurements on activated sludge (AS) are used to compare the performances of effluent suspended solids (ESS) from different activated sludge waste water treatment plants (WWTPs). It is very likely that the plants with activated sludge (AS) that have presented the "transmittance overshoot" aberration actually have less ESS than do the others. This observation would provide, on a theoretical level, a better understanding of hindered settling, and, on a practical level, valuable information to the managers of WWTPs.

After a validation phase, this observation, which is based on a simple, robust and cheap technology, will likely lead to many applications.

Keywords: Near infrared; Transmittance overshoot; Management of activated sludge wastewater treatment plant; Effluent suspended solids

Abbreviations: AS: Activated sludge; EPS: Extra Polymeric Substances; ESS: Effluent Suspended solids; Jump: sharp increase in TV after a sort of latency period; STEP: Station d'EPuration; MLSS: Mixed Liquor Suspended Solids; WWTP: Waste Water Treatment Plant

Introduction

There have been many breakthroughs in water treatment, with the so-called "activated sludge", which was by "far the most widely used type of plant in the world" [1], finally being surpassed in 1995. The activated sludge process still remains a very widely used method [2], especially for municipal wastewater treatment. The reasons for this vary (economy, stability, and so on) and are beyond the scope of this paper [3].

Activated sludge (AS) wastewater treatment plants (WWTP) uses microorganisms, mainly bacteria (more than 80%) [4]. But other organisms such as viruses, protozoans, insect larvae, worms, yeasts, and fungi [5] are also present in lesser proportion. Additionally physical processes are also used, especially for solid/liquid separation [6].

Pollutants (solids and liquids) are metabolized or simply entrapped by microorganisms in a unit that is sometimes referred to as the aeration tank. Activated sludge develops in this basin and forms flocs, an aggregate of microorganisms embedded in a complex, slimy conglomerate of floc-forming bacteria [7]. Microbial Extracellular Polymeric Substances (EPS) are to be added to the list of this complicated composite [8]. Although it is not exactly physically correct, what we just described is considered the solid phase; however, all this material is immersed in water and forms mixed liquid suspended solids (MLSS).

Once at this stage of the process, we have a two-phase medium, consisting of bacterial flocs (solid phase) and water (liquid phase). The problem then becomes how to separate the two phases to discharge water that is as pure as possible into the environment. The solid phase (sludge) is retained and possibly treated to best enhance its value.

For economic reasons (especially for large WWTPs), solid settling is used to separate the two phases. In this method, the AS will "simply" sink to the bottom of the secondary settler, where it is eliminated. Sears

et al. [9] estimated from 1.038 to 1.065 g/mL the specific weight for flocs in "usual" conditions. These values are greater than one and allow settling, but they are also very close to one, which can cause problems.

We are currently faced with the situation of a WWTP without a tertiary stage (so-called "polishing", e.g., additional filtration) and the MLVSS must be treated by use of a sole secondary settler before the discharge of water into the environment. In fact, floc settling is a very complicated and subtle problem. We created mathematical simulations of the problem and obtained unexpected results [10]. In addition, floc structure involves multiple species (comparable to a stable consortium) and most likely has a fractal dimension [11,12].

Finally, the efficiency (technical and financial) of a WWTP depends to a large extent on the proper functioning of the secondary clarifier (or secondary settling tank, SST). Paraphrasing [13], "The SST is a vital component of the activated sludge system". Of course, a WWTP cannot eliminate 100% of pollutants. For example, soluble, non-biodegradable compounds pass through the system, and some of them can be hazardous. Ekama et al. [13] assessed retention of more than 90% of the solids greater than 1 µm in size (approximately the size of a bacterium). Approximately, 60% of the other solids escape the settler, which is to say 5.4% (0.9×0.6) of the total solids escape the SST and constitute the effluent suspended solids (ESS).

ESS is formed from biological and non-biological materials. In a good plant, they do not exceed a few milligrams per litre, but they can be very harmful to the environment, so this concentration has to

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be reduced as far as possible. This ESS contains bacteria, including potential pathogens (AS WWTP removes more than 98% of pathogens, and from this point of view, is a very good process). ESS may also engulf hazardous solids and other such materials. The WWTP water with this ESS is used for agronomy (e.g., irrigating fields and water for cattle) and can infiltrate groundwater.

There have been typical findings (Results in this paper and [1]), and attempts have been made to apply these discoveries to improve and generate methods devoted to ESS reduction and, consequently, improve process respect for environmental protection and public health [14].

Material and Methods

Transparency

The most important measurements are based on the transparency obtained via an ASAN (Activated Sludge Analyser) small apparatus created in the laboratory (Figure 1).

We use the term “transparency” instead of transmittance because it is an electrical intensity ratio rather a light ratio, but the two measurements have the same meaning.

The transparency is defined as

$$TY = \frac{I - I_b}{I_o - I_b} \times 100 \quad (1)$$

and expressed in per cent (%), where I_o is the blank intensity (pure water) and I_b corresponds to the intensity of the black light.

Practically, as $I_b \approx 0$, and $\ll I$ and I_o

$$TY = \frac{I}{I_o} \times 100 \quad (2)$$

was used as practical measure. When $TY > 100\%$, we say that there is a transparency overshoot.

Effluent suspended solids (ESS)

ESS is one of the most important parameters for the environment, for the evaluation of the performance of an AS wastewater treatment plant, and especially for the payment of penalties for plant failures.

The ESS data presented here has not been measured by us. They were provided by the analyst in charge at the analytical lab of each WWTP. Therefore, they are official data. Evidently, the methods for obtaining the results are different from each plant, but it is known that the data were obtained by well-trained technicians and engineers. We do not know the statistics of the data, but at this stage of our research, only the magnitude of this parameter is really significant. Theoretically, this ESS must be obtained by legal methods imposed by the Government.

Dry weight (DW) of mixed liquor suspended solids (MLSS): MES

The MLSS is the total weight of solids in suspension in the liquid flowing through the plant, and in this case, the values correspond to those of the aeration tank, where the samples were taken. Although these data are not used except for comparisons of plant performances, a very short description is provided of the method, which is perhaps not completely official but provides excellent results and are both easily reproduced.

An aluminum dish and a 0.45-microfilter were placed in a

desiccator, for several days, at the same temperature as the balance. The system (tare) was weighed at ± 1 mg. A volume of 50 ml of sludge was vacuum filtered using a 0.45-micron filter from the tare. The dish and the filter were then placed on the pan of a thermal balance and dried to constant weight less than or equal to 2% for at least a 20-minute period. The whole procedure takes approximately 40 minutes. The dish and its contents were then placed in a desiccator and cooled to the balance temperature and weighed again (± 1 mg). The resulting difference between the two weights (tare and final weight), calculated per litre, and is the dry weight (DW) of the AS.

Results

Table 1 shows in one table all the results of the main measurements. Samples were obtained approximately at the same time in 2012 (September-November). All WWTPs have a comparable MES (the two first plants having perhaps values higher than usual). All present “bulking”, except for STEP0. The difference in STEP2a and STEP2b was that polymeric flocculants were used in sampling 2b, but the samples are from the same plant (2a and 2b). Finally, the three WWTPs are fairly similar except for ESS and overshoot in TY, and it appears that the two are inversely correlated.

We now will examine the kinetics corresponding to each situation (Figure 2).

The phenomenon may be observed in visible light as shown in Figure 3. TY kinetics without overshoot is seen in Figure 4. The sludge appeared to cohere badly and contained small bubbles that were not a product of degassing. Some sludge remained above the tube, whereas some sank to the bottom. In another paradox, the bubbles are located in the sinking part of the sludge (Figure 5).

Under these conditions, no consistent kinetics was observed. This case led to the highest ESS in our observations. The next case is very interesting because of the addition of flocculants absent from the other situation. In other words, STEP2a didn't contain additional flocculants, while a flocculent compound was added in 2b: in unique plant in two different situations. With the addition of polymeric flocculants to the plant, the kinetics is as follows in Figure 6.

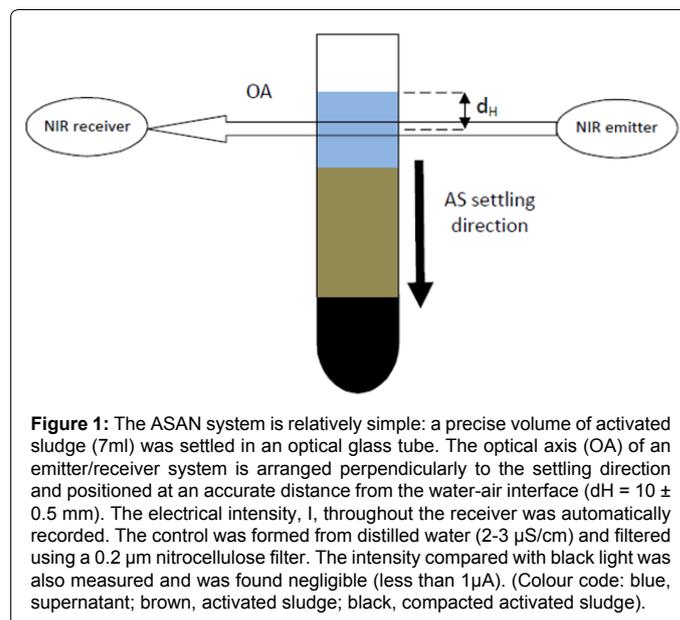


Figure 1: The ASAN system is relatively simple: a precise volume of activated sludge (7ml) was settled in an optical glass tube. The optical axis (OA) of an emitter/receiver system is arranged perpendicularly to the settling direction and positioned at an accurate distance from the water-air interface ($dH = 10 \pm 0.5$ mm). The electrical intensity, I , throughout the receiver was automatically recorded. The control was formed from distilled water ($2-3 \mu\text{S}/\text{cm}$) and filtered using a $0.2 \mu\text{m}$ nitrocellulose filter. The intensity compared with black light was also measured and was found negligible (less than $1 \mu\text{A}$). (Colour code: blue, supernatant; brown, activated sludge; black, compacted activated sludge).

Again, we observed hindered settling (Figure 7) that was very close to that seen in Figure 3. For the sake of simplicity, we will refer to Figure 8 with its various complete parts as “ideal kinetics”.

Starting at time=0 (a), we encountered a lag phase, always followed by a compaction zone (b) (here, the transparency slightly decreased). Phase 2 is the transition phase, which corresponds to the passing of the clear settling zone (the transition phase is sometimes called: jump).

Then, if the conditions were suitable, overshoot was observed (a) where TY were > 100%, followed by a gentle decrease in the transparency up to Phase 3, and the final plateau (b) was observed (Figure 8).

Thus, transparency was the unit used for the measurement of the equivalence of transmittance, and overshoot is a nonstandard phenomenon where there was greater than 100% transmittance with ultra-pure water (Figure 9).

Discussion

It might appear that there are very little data to initiate a strong and compelling discussion. The readers must remember that there is a collection of several hundred more kinetic analyses similar to those presented here and that the overall results are reproducible and consistent. For sake of simplicity and coherence, only the four situations (and the three WWTPs) described here are used to compare some properties of very comparable systems with some external and internal conditions (e.g., seasons and MLSS).

First, we have a comparison of the “overshoot time” of the situations presenting this phenomenon:

$$T(\text{overshoot, STEP0}) = 900 \text{ sec (MES} = 4.7 \text{ g/L)}$$

$$T(\text{overshoot, STEP2b}) = 1380 \text{ sec (MES} = 4.4 \text{ g/L)}$$

In all the cases encountered earlier, the overshoot time is strongly dependent on the MLSS. It can be admitted that in the situation considered above, the MES are quasi-equal, but the STEP2b time is almost twice that of STEP0. Thus, the qualities of ESS were greatly enhanced, but the settling time of the process was significantly disturbed.

This observation is not focused any further, but it should be noted that the addition of flocculants may cause unpredictable and possibly harmful consequences.

Note: It seems that durations before jumps in Figure 10 and in comparison between STEP0 and STEP2b are inconsistent. This is due to the fact that, in one case we compare two different WWTPs, while in the other case it is a dilution of the same sludge.

Another interesting observation is the MLSS concentration before and after the overshoot. The difference may be observed in Figure 2 (STEP0) and Figure 4 (STEP1 and STEP2b). Table 2 indicates that the STEP2b sample is clearly more transparent than STEP0.

These results may indicate that the coherence of the flocs was lower in STEP2b. The most striking result is that STEP0 had a post-overshoot situation involving quasi-pure water, which was not the case with STEP2b, and nevertheless, the ESS of the two cases are similar, yet STEP2b displayed superior reduction ($7.6 < 8 \text{ mg/L}$). This last result must nevertheless be viewed with caution given the way the results were acquired.

However, it is tempting to conclude that the presence of an overshoot situation is extremely favorable to the reduction of ESS. The question of the possible mechanism is then raised. Consider Figure 11, we have plotted all the significant points in a plan $TY = f(ESS)$. We indeed observed a negative correlation between the two variables. The adjustment curves were an attempt to see if it exist two clear cut domains or a smooth variation.

As the fittings diverge, it cannot be decided whether there are two domains that are more or less clearly separated (as in the “sigmoid” hypothesis) or if a continuous variation exists (as in the “exponential” hypothesis). To date, the most important fact is that ESS and overshoot are linked. It is thus important to understand this strange phenomenon and to manage it in the most efficient way.

Applications

The correlation between the TY overshoot and ESS could serve for measuring the ESS, but it would only be a superfluous complication of standard methods used to evaluate the ESS (filtering large volumes followed by a precision weighing, for example.). But our work it is not the development of a protocol for the determination of the ESS using NIR. The overshoot and the aura (see Annex) are so far unsolved phenomena and deserve a theoretical study. However, we want to present a concrete application of our correlation in activated sludge wastewater treatment plants.

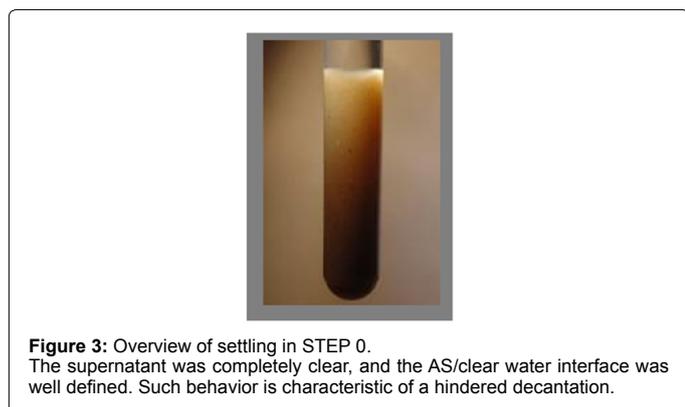
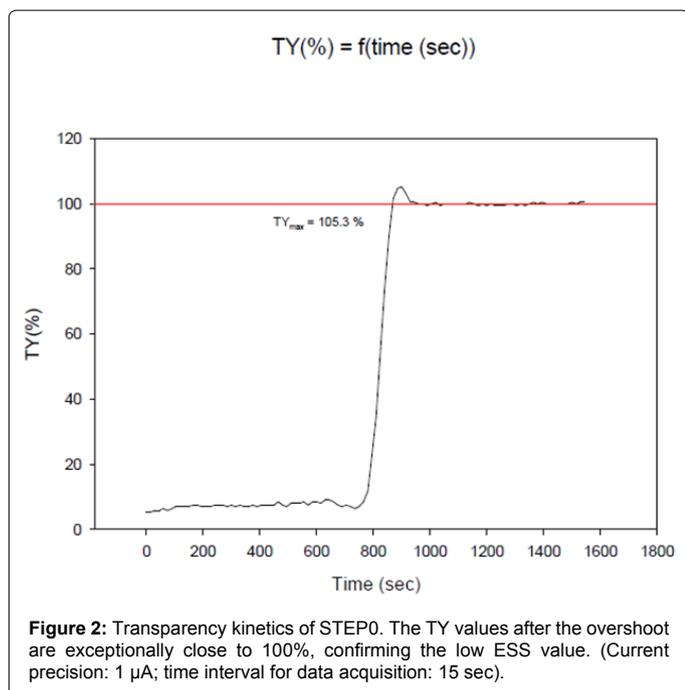
Decrease the ESS is not only a requirement to improve the quality of discharges into the environment, but also ways to escape the penalties applied when standards discharge are exceeded. To avoid these punishments, expensive compounds, such as coagulants / flocculants, are often used. They are added to the MLSS to modify the quality of sludge settling. The question is then what sort of compound (polyelectrolytes, etc.) and in what quantity should be added. In general, one proceeds to a full scale test, which are long and expensive and involves laboratory personnel, implicates construction

WWTP	DATE	ESS (mg/L)	MES (g/L)	Bulking (*)	FLOCCULANT	TY (%) overshoot
STEP 0	22-11-2012	8	4.7	NO	NO	5.3
STEP 1	06-10-2012	10.3	5.0	YES	NO	0
STEP 2a	11-09-2012	13.4	4.5	YES	NO	0
STEP 2b	26-09-2012	7.6	4.4	YES	YES	1.4

Table 1: For reasons of confidentiality, the names of the treatment plants were encrypted. “Bulking” indicates any type of floating material (foaming, filamentous bacteria, etc.). All the WWTPs are located in central Belgium. STEP2a and STEP2b are the same plant, under two different working conditions.

STEP 0		STEP 1		STEP 2b	
TY (%) before overshoot	TY (%) after overshoot	TY (%) before overshoot	TY (%) after overshoot	TY (%) before overshoot	TY (%) after overshoot
7.2 ± 0.8	99.7 ± 0.4	-	-	4.9 ± 0.4	94.5 ± 4.5

Table 2: The value of TY is a mean value obtained over a more or less random period of time, approximately comparable (in an allometric sense) from one figure to the other.



of temporary structures (like scaffoldings, pumps), etc. With the correlation OVERSHOOT / ESS, all these adjustments can be made in the laboratory and with small volumes (say, of the order of a litre). Our TY measure requires 7 mL of MLSS, mixed or not with coagulants under study. The goal is to obtain the highest TY overshoot possible while maintaining a reasonable compound cost. We should then expect to get low ESS.

Traditional measures of settling (static, agitated, etc.) that provide a SVI (Sludge Volume Index), or measurement via the Imhoff cone are obviously not useless, but these tests provide absolutely no indication of the ESS. Good settling ($SVI_{max} = 150$ mL/g, for example) is desirable but does not indicate the magnitude of the ESS. Our measure of overshoot is giving a simple and inexpensive way to obtain the significant parameter on the solid disposal of the plant.

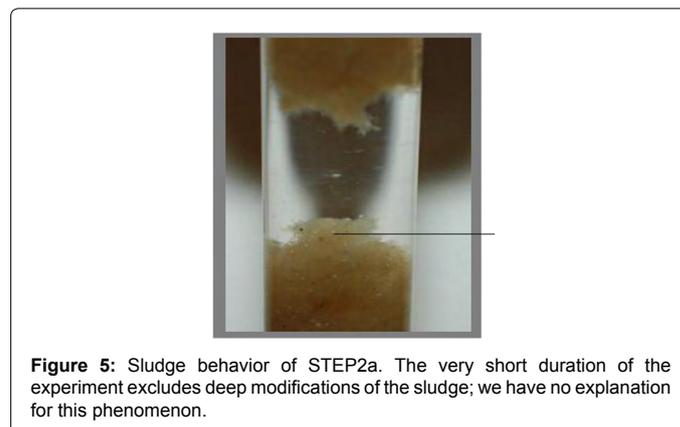
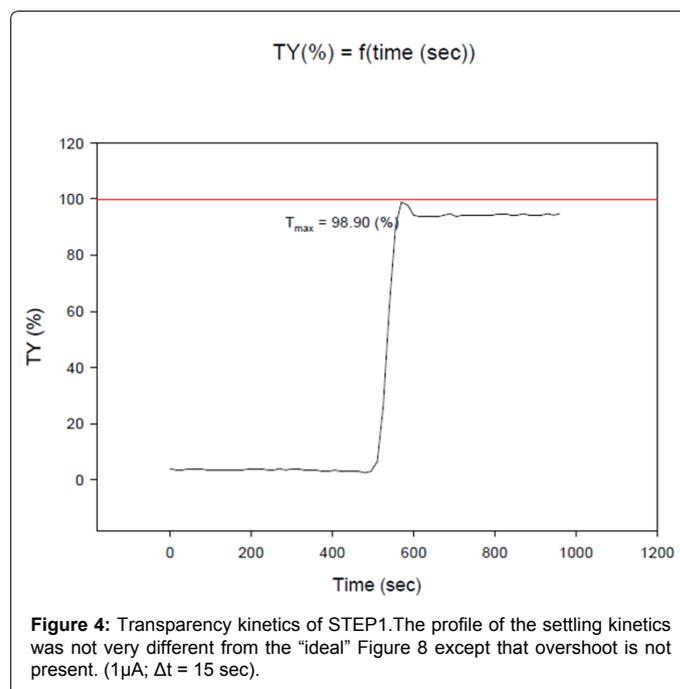
In the same vein, systematically monitoring the maximum of TY can give an indication of the change in the amount of ESS. The decrease in maximum allows anticipating deterioration in the discharges quality and conversely, maximum increase permits to envisage a reduction of additives (coagulants) and thus reduces the plant operating costs.

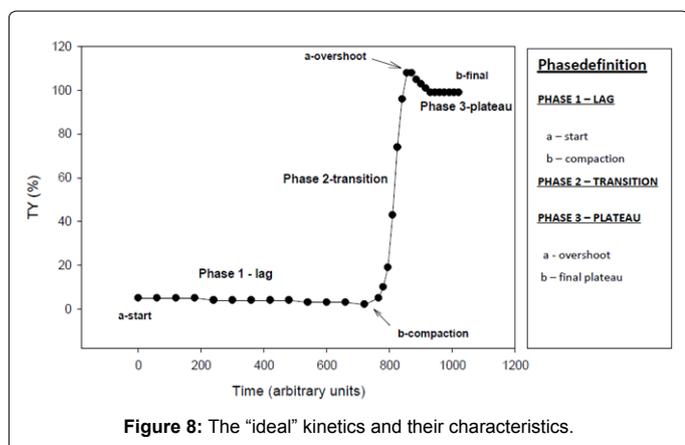
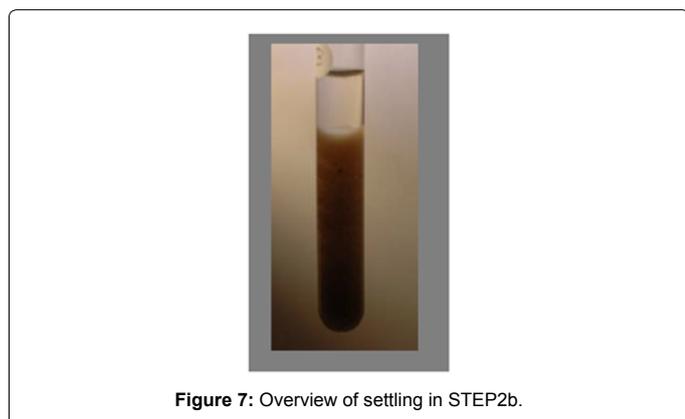
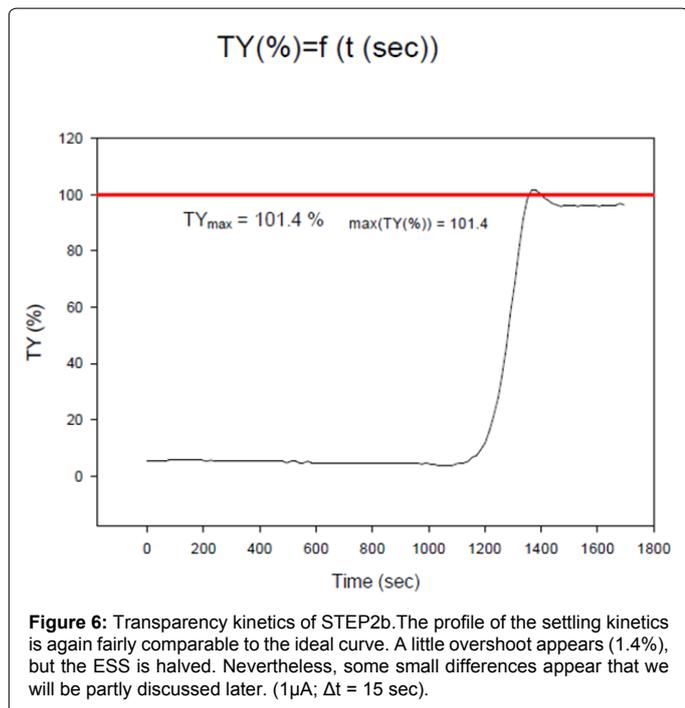
Depending on the results, we can expect to take preventive measures rather than reacting a posteriori

Annex

The “aura” phenomenon. We do not resist presenting another spectacular effect we have also observed we call “aura”. To date, essentially electrical current has been measured. In the preceding paper [1], it was assumed that the overshoot was due to an increase in the transmission of light due to a reduction of the movements of some water molecules, perhaps vibrational movements. It was intended that some extended NIR spectroscopy would be performed, but it was irresistibly tempting to observe what occurs during settling in NIR. Some photo cameras are not protected against NIR, such as the Nikon D70. We used such a camera and a 950-nm filter to photograph the supernatant/AS interface zone.

During settling, a photo of the sludge / supernatant interface was taken in NIR. A little above the mud, we were surprised to observe a very fine (quasi evanescent) ring of unknown nature. This ring is even more apparent when the near infrared image is artificially converted





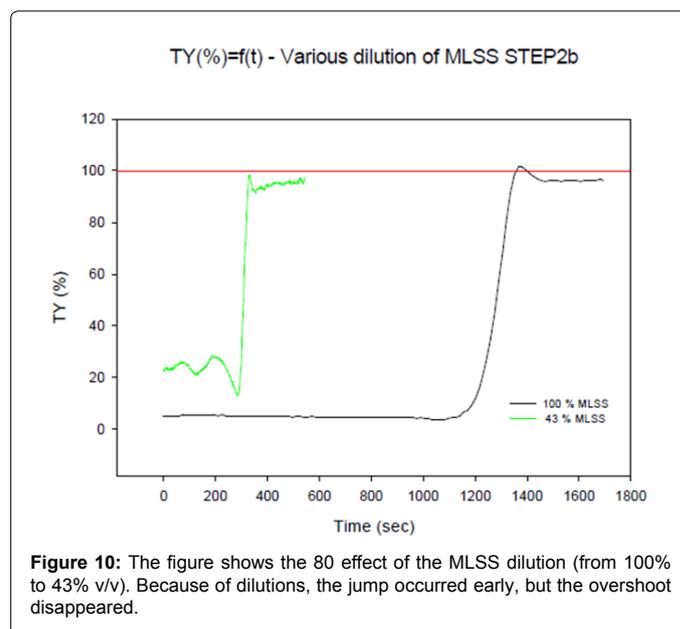
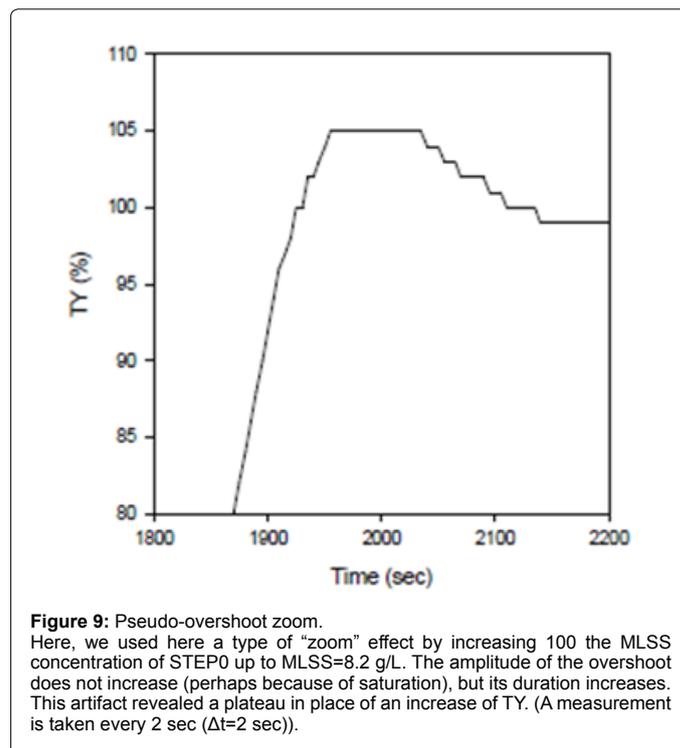
(software) in black and white (Figure 12). The ring then looks transparent.

In visible light (Figure 13), the phenomenon is also observed,

but the ring activated resembles the sludge (opaque brown color). Transparency in the NIR makes us think that it is the ring that is responsible for the overshoot, but we have no proof.

In fact, if it is not an artifact, the transparent ring seems more clear than the supernatant.

If the two shadows are actually the same phenomenon, then the aura absorbs visible light (Figure 13), but is transparent at approximately 940-950 nm. We suspect that this phenomenon is connected to the overshoot, but its nature remains yet completely unexplained and requires further elucidation.



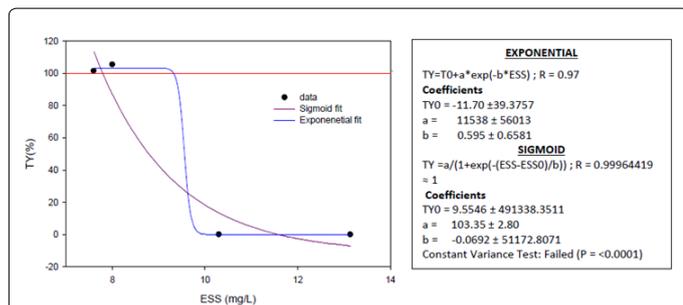


Figure 11: Various acceptable fittings indicating that correlation between ESS and overshoot is such that a domain of separation cannot be determined. Note that the fittings diverge. They are just examples of curves.

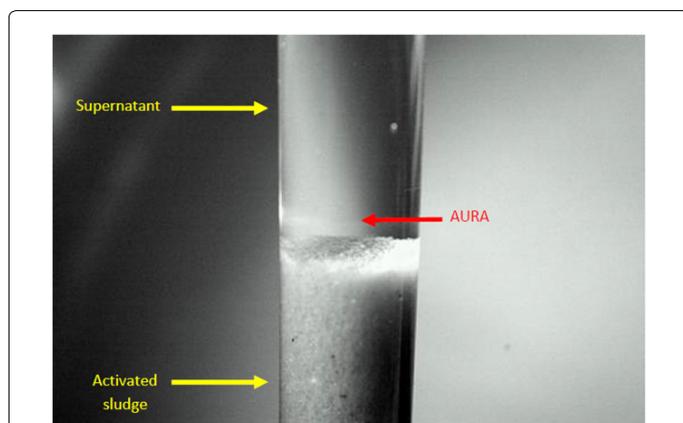


Figure 12: Picture at 950 nm (filter) showing the settling interface zone of the STEPO. It appears clearly that the aura is more transparent than the supernatant. (Notes: Camera Nikon D70; objective: 40-40 mm f/2.8-2.8; focal length 40 mm; pause time: 1/320; the violet color of the initial photo was changed to black and white artificially (software); tube diameter: 1 cm).

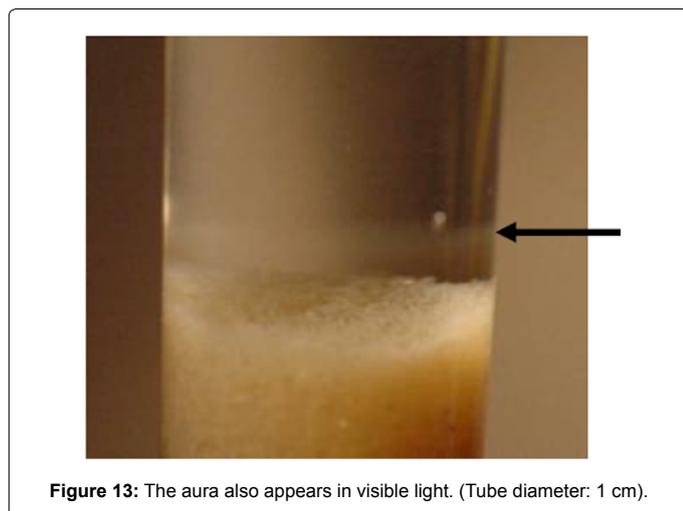


Figure 13: The aura also appears in visible light. (Tube diameter: 1 cm).

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