Lamella settlers for treatment of urban storm runoff: Experience with model and prototype tests

Décanteurs lamellaires pour le traitement de débits pluviaux : expériences avec des analyses hydrauliques d'un modèle et d'un prototype

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RÉSUMÉ

Depuis quelques années, les décanteurs lamellaires de traitement des eaux pluviales sont utilisés sur plusieurs projets. Ils produisent une bonne efficacité de sédimentation des matières en suspension (MES). Quelques investigations, à l'inverse, utilisent des sédiments artificiels, donnant des résultats contradictoires. Le présent document décrit des résultats de comparaison.
Des essais avec de petites perles en plastique utilisées comme sédiment artificiel montrent une efficacité de séparation en fonction de la charge superficielle dimensionnelle, comme dans la théorie bien connue de Hazen. Les résultats peuvent être transposés aux MES quand on connaît la répartition de vitesse de chute. Ils indiquent une efficacité faible en regard des investigations aux MES mesurées dans les eaux pluviales.
Les essais aux sédiments artificiels ont montré que la surface de sédimentation des lamelles a une influence majeure, ainsi que celle du réservoir de l'installation. Généralement, il ne suffit pas d'étudier uniquement la sédimentation (comme évoqué dans la majorité des cas). Chaque particule de sédiment peut glisser et être ré-entrainée. Les MES sont plus « collantes », elles glissent moins facilement. Enfin, une floculation spontanée apparaît comme un effet essentiel en modifiant la distribution de vitesse de chute.

ABSTRACT

For a couple of years, lamella settlers for urban runoff treatment are used successfully in an increasing number of projects. Good settling efficiencies for total suspended solids (TSS) are claimed. In some investigations, however, model tests led to somewhat contradictory results. The present paper describes some comparative findings.
Model tests using 0.5 mm plastic beads yielded dimensionless data on the settling efficiency as a function of surficial load divided by settling velocity, as in the well-known Hazen theory. The results can be transferred to real TSS of known settling velocity distribution by fractioned computation, revealing, however, a rather feeble settling performance. Prototype TSS sampling campaigns showed much higher settling efficiencies.
In the model tests, a big influence of the settling surface of the lamellae was found, but as well of the vessel in which they were located. Generally, it is insufficient to investigate only the settling process (as in most of the literature). The fate of the sediment settled on the inclined lamella surface will dominate the overall efficiency. Single grains can slide down and may even be re-entrained while "sticky" real sewer sediment is trapped – it will slide down less easily. Spontaneous flocculation may be another important process because it will alter the settling velocity distribution.

KEYWORDS

Lamella settler, model tests, sedimentation, settling efficiency, total suspended solids

1 INTRODUCTION

In the past years, several pilot projects have been conducted using lamella settlers for treatment of urban storm runoff, as well in separate as in combined sewer systems. The goal is to improve the sedimentation performance of treatment structures such as sedimentation tanks. It is well known that many pollutants such as heavy metals are bound especially to the very fine particle fractions, so lamella settlers may extend the applicability of sedimentation as an efficient treatment step also to this material. In Germany, the design guideline DWA-M 176 (2013) shows the use of upflow lamella settlers (Figure 1) retrofitted in a sedimentation basin and recommends some data on the hydraulic design, such as a maximum surficial loading of $q_A \leq 4$ m/h at a given design inflow, 45°-60° inclination angle and a lamella distance of 80 mm. An innovative approach on the operation of a lamella settler in a separate sewer system was shown in Weiss (2014a).

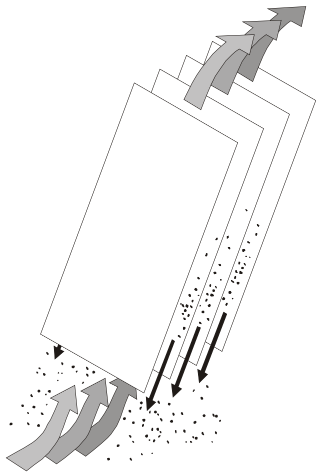


Figure 1 : Upflow lamella separator

The current literature on lamella settlers comprises numerous theoretical work which focused mainly on the sedimentation process, see e.g. Kowalski (2004). There are some approaches similar to the well-known Hazen theory which describe the sedimentation efficiency, η, as a function of mean surficial loading $q_A = Q / A_{proj}$ (flow divided by the projected settling surface) for a given settling velocity, v_s. A decisive assumption is smooth and evenly distributed throughflow, which is consequently also a topic in literature on the subject.

Some other papers describe performance evaluations of lamella settlers for real sewage sediments, e.g. Fuchs et al. (2014). Kemper et al. (2014b) have conducted measurements of settling efficiency in combined sewage using a pump-fed upflow lamella settler in a test container. They claim surprisingly high separation efficiencies of 40-50 %, depending on the surficial loading. Boogaard et al. (2010) report on investigations on a cross-flow lamella settler where also good efficiencies are claimed for small surficial loadings. They used quartz flour as model sediment.

2 MODEL TESTS AND DIMENSIONLESS EVALUATION

The author has participated in a project specifically approaching the applicability of lamella settlers for combined sewage. It was granted by the German federal state of Northrhine-Westphalia (see Kemper et al. 2014b) and investigated an upflow-type settler. Reports are under preparation. The project has made a double approach: First, model tests in the hydraulic laboratory have been conducted. Second, a test container has been built which could be operated at an existing stormwater tank. Using a pump with flowmeter, a constant inflow could be achieved during storm events so that the hydraulic conditions are known. Moreover, the flow could also be varied in different tests.

The model tests operated basically with the same type and geometry of lamella settlers used also in the container tests. Uniform 0.5 mm polystyrene beads were used as model sediment. The settling velocity could be measured; it was low, steep-graded and could even be reduced by adding salt to the water. A given quantity of sediment was added in one charge to the inflow. After a defined test time, e.g. 1 hour, the volume of sediment V_{over} which had collected in a fine sieve at the overflow was determined and also the volume of sediment V_{Sed} settled in the experimental tank after cleaning the lamellae carefully. The settling efficiency was then determined as $\eta = V_{sed} / (V_{sed} + V_{over})$.

To make the model results comparable, they were shown in dimensionless form according to the well-known Hazen theory for settling tanks. If it is assumed that the projection area A_{proj} of the lamellae is the most decisive parameter, it can be expected that a relation such as $\eta = f\left(\frac{q_A}{v_s}\right)$ where $q_A = Q / A_{proj}$ would yield an unique curve for tests with different yet constant inflow Q, different settling velocity v_s and also a different settling surface A_{proj}, the latter given by tests with different lamella spacing.

The results showed the expected unique curve for tests where flow and settling velocity were varied. However, as soon as the geometry of the lamella settler was changed, e.g. by using 40 mm and 80 mm lamella spacing, the curves were significantly different, indicating a seemingly “better” behaviour of the 80 mm lamellae (Figure 2), in spite of the fact that their smaller settling surface is accounted for by the dimensionless notation. A closer investigation revealed that this was in particular due to the vessel in which the lamellae are located which acted itself also as a sedimentation tank. Moreover, it could even be concluded that the effect of the lamellae was comparatively feeble. A mechanism was suspected where the plastic beads already settled on a lamella surface are sliding down to the sump immediately. When dropping from the lower edge of the lamella, however, they are re-entrained by the inflow. Only a small amount of material will finally reach the tank bottom and is settled. On the other hand, a considerable number of beads is settled directly in the vessel before entering the lamella module. Under this assumption the vessel geometry has a rather large influence and thus there are large differences between efficiency curves for lamellae of varied spacing. Moreover, the idea also explains the rather feeble overall settling efficiency.

It was also observed that numerous particles either stayed in suspension or were directly re-entrained by the flow over the lamella surfaces. Even without the supposed rolling-down and/or re-entrainment mechanisms, however, a sedimentation effect in the vessel or tank is still present. It is not sufficient to consider only the sedimentation surface of the lamellae.

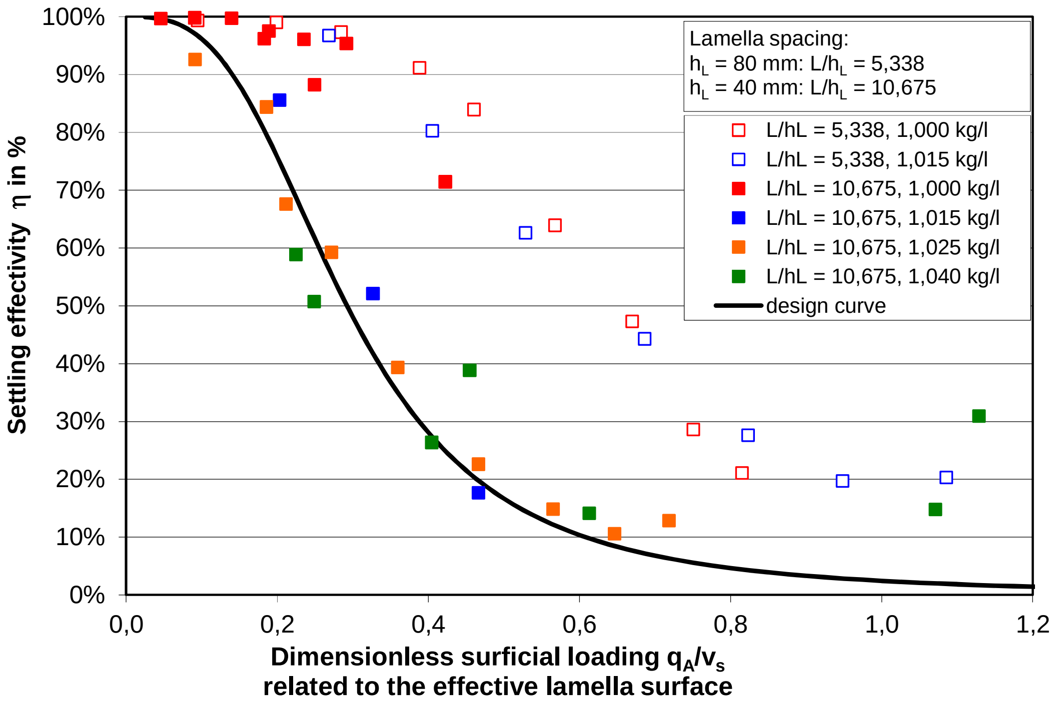


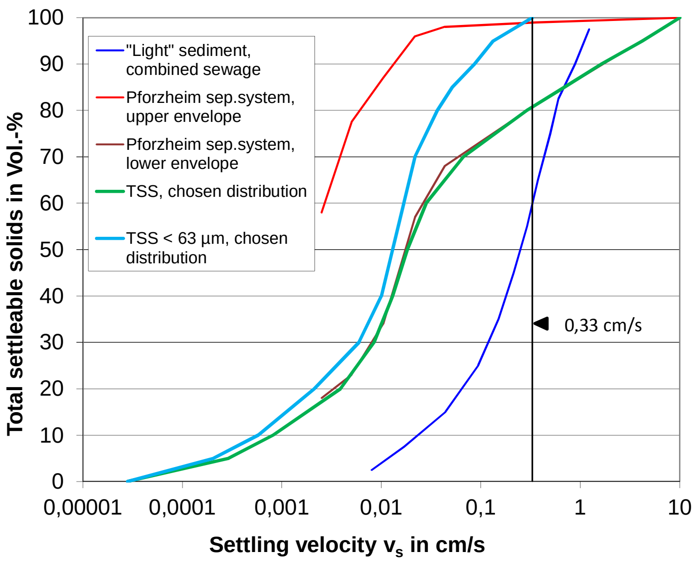
Figure 2 : Dimensionless results of model tests for 40 mm and 80 mm lamella spacing (see Kemper et al. 2014b)

3 TRANSFER TO SEDIMENTS HAVING AN ARBITRARY SETTLING VELOCITY DISTRIBUTION

From the model test results, a worst-case “design” curve $\eta = \frac{1}{40\left(\frac{q_A}{v_S}\right)^3+1}$ also shown in Figure 2 was defined. Of course, this curve includes the mentioned influence of rolling-down and re-entrainment of particles; it is not possible to separate the effects to gain the result of sedimentation only. Consequently, a dimensionless curve $\eta = f\left(\frac{q_A}{v_S}\right)$ of this kind allows prediction of the total settling efficiency for “real” sediment by computation of different sediment fractions only under the following assumptions:

- The distribution of settling velocity is known; it describes the settling properties uniquely.
- It is assumed that any sediment fraction behaves during the settling process as well as on the lamella surfaces (e.g. sliding down) like the model sediment.
- Effects caused by temporal variation of flow are neglected.

The distribution of settling velocity in the sediment found in the container tests is unknown and could not be obtained reliably in the course of the project. From Weiss (2014b), an approximate settling velocity distribution for very fine material (TSS with grain diameter < 63 µm) is taken, see Figure 3.



Settling velocity distribution, TSS < 63 µm		
Fraction i	Percent of sample α_i in %	Mean settling velocity $v_{s,i}$ in cm/s
95-100	5	0,23168
90-95	5	0,10997
80-90	10	0,06156
70-80	10	0,02913
60-70	10	0,01927
50-60	10	0,01487
40-50	10	0,01148
30-40	10	0,00798
20-30	10	0,00404
10-20	10	0,00135
5-10	5	0,00039
0-5	5	0,00012

Figure 3 : Distribution of settling velocity v_s for very fine TSS in surface runoff of separate systems, Weiss (2014b)

It is assumed that this curve will also represent fine fractions of combined sewage sediments (there could be some differences by different content of organic material). Now the following steps are performed:

- Consideration of 12 grain fractions with a typical mean settling velocity $v_{s,i}$ and volume percentage α_i each (see table in Figure 3)
- For a given inflow and known settling surface, q_A/v_s is calculated for each fraction. From the above equation $\eta = \frac{1}{40\left(\frac{q_A}{v_s}\right)^3+1}$, we get the efficiency η_i for each fraction.
- The overall efficiency is computed finally from $\eta = \sum_{i=1}^{n}(\alpha_i \cdot \eta_i)$.
- This is repeated for arbitrary values of Q or q_A, respectively, finally yielding the red “computed results” curve $\eta = f(q_A)$ shown in Figure 4.

4 COMPARISON WITH MEASURED SETTLING EFFICIENCIES OF REAL SEWER SEDIMENTS

In the cited project, the settling efficiency was determined in the following way: The test container was located immediately downstream of the headworks screen of a wastewater treatment plant so that gross solids were kept off. During storm events with increased inflow, a feed pump was started which was operated at constant flow by feedback control. This was an essential feature since the flow – and so also the surficial loading – could be arbitrarily chosen. The samples taken at the inflow and simultaneously at the overflow of the container were very large-volume 1 m³ mixed samples so that sufficient sludge for the subsequent analyses was available. The samples were taken by peristaltic pumps. After settling and discarding the supernatant, the sludge was wet-sieved by 63 µm in order to separate the fine material. Drying of the sludge finally allowed determining the inflow and overflow mass concentrations C_{in} and C_{over} and also the settling efficiency $\eta = 1 - C_{over} / C_{in}$. Details are described in Fuchs et al. 2014a).

The overall result $\eta = f(q_A)$ is shown in Figure 4. It was found that there was a significant correlation in the expected way that the larger the surficial loading q_A, the smaller the efficiency η and vice-versa. Of course, considerable experimental scatter is inevitable in sampling campaigns such as these.

It can immediately be seen that the measured settling efficiencies of „real" sewage sediment exceed the computed values from the model tests by far. Consequently, model tests of this kind and the transfer of results by the described scaling procedure are inappropriate to make any forecast of the performance of lamella settlers in the sewer system. The calculated efficiency would be much too low and too far on the safe side. (Note, however, that the steady-flow results of Figure **4** do not resemble achievable overall annual sediment removal efficiencies. This subject is not investigated here.)

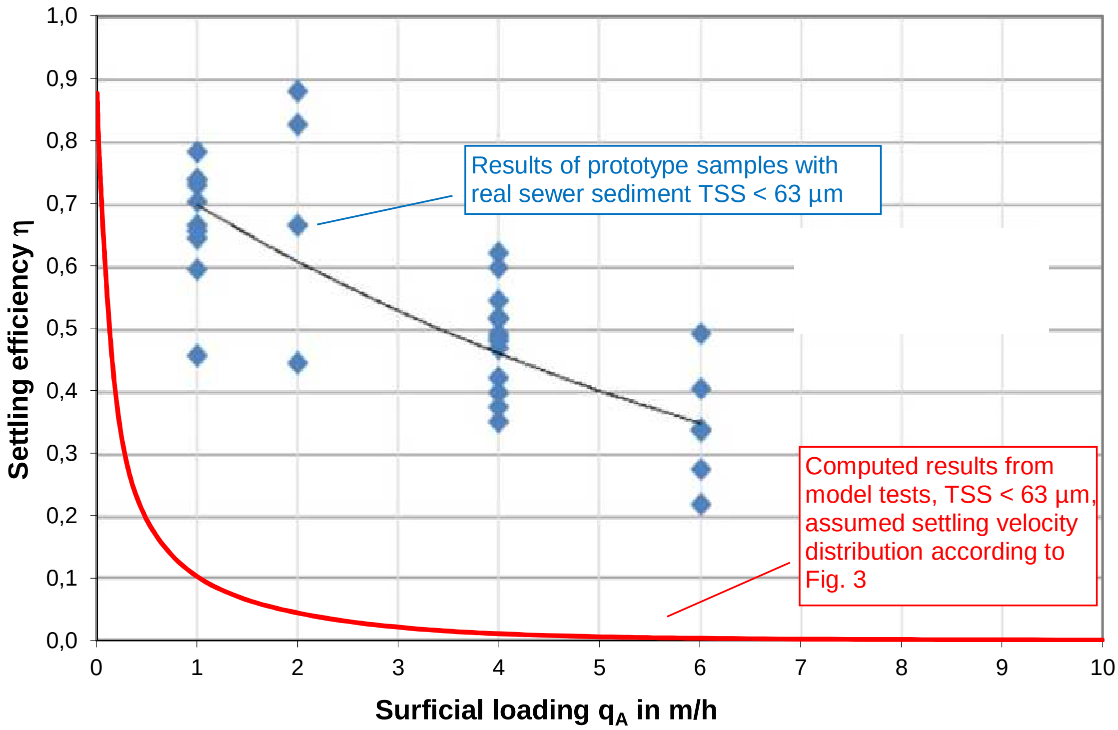


Figure 4 : Comparison of measured settling efficiencies of real sewer sediment (TSS < 63 µm) to computed values form model tests

Which reasons might cause these discrepancies? The first suspicion of non-uniform flow distribution was discarded because it could be shown that the influence of this effect is much less (see Kemper et al. 2014b) and since excessive backflow could not be observed in the model tests. There are, however, some other strong hypotheses with some evidence:

Hypothesis 1: The settling velocity distribution as assumed above is not typical for "real" sediment and, moreover, it is not unique. A common approach is that any grain size of a sample (which could be identified by wet sieving) has a distinct settling velocity, e.g. given by the well-known Stokes formula. This would yield a v_s distribution in the same order of magnitude as in Figure 3. This approach, however, is questionable since it does not account for the effects of flocculation and coagulation of fine organic material. Flocs will frequently show a larger settling velocity than very small single grains; they even may be "ballasted" by heavier larger grains included in the flocs. This will increase the measured settling efficiency while the coarser particles are removed again by the wet-sieving process. The effect of flocculation is used elsewhere by adding chemical agents, but it may also occur spontaneously.

Hypothesis 2: On the lamella surfaces, real sediment does not behave like the model sediment. It has already be stated that easy-rolling model particles may slide down and be re-entrained; the settling efficiency will be low. If real sewer sediments are more "sticky" (such as flocs probably may be), they will not slide down immediately. Consequently, re-entrainment will be less pronounced. From time to time, sediment aggregates may slide down, too, but they are re-mixed to a smaller degree than individual model sediment beads, so a larger overall settling efficiency may be expected. The research project did not provide any data on sludge accumulation on the lamellae or in the sump. Visual inspection was not possible due to the turbidity of real sewage.

However, note that it is not appropriate, either, to regard the "prototype samples" results from Fig. 4 as typical (or even universally valid) steady-flow efficiency curves for any "real" TSS < 63 µm. Results of another current project which are not yet published indicate that there may be even more scatter in η than shown already in Fig. 4, dependent e.g. on the nature of the medium (sewage or storm water with possibly different TSS content and behaviour). This may again be explained by Hypothesis 1.

5 CONCLUSIONS

The following conclusions can be drawn:

- Tests using idealized model sediments are usually not suitable to predict the settling efficiency of lamella settlers for real sewage sediments. For such forecast, solely efficiency data gained by sampling of real sewer sediments are recommended. Even then, large scatter must be expected.
- The overall settling efficiency of lamella settlers for sewage-borne sediments is fairly good, particularly if the surficial loading may be kept low. In general, lamella technology can improve sedimentation treatment of urban storm runoff considerably with small-footprint structures.
- Good sedimentation efficiency is probably also due to sedimentation in the tank itself in which the lamellae are located, particularly where the ratio of lamella surface to tank bottom surface is not too large.
- The sedimentation efficiency of lamella settlers is influenced much more by the fate of the sediment which has already settled on the lamella surfaces than by the sedimentation process itself (including a more or less even flow distribution over the lamellae). There is general lack of knowledge on the performance and properties of sediment such as “stickiness”, ability to slide down etc., and on the mechanisms of re-mixing and re-entrainment, either, which play an important role. In order to improve the performance of lamella settlers of different types, basic research on these topics is recommended.
- Good settling performance of lamella settlers is associated with sticking of the sediments to the lamella surfaces. The assumption that steeply inclined lamellae will be self-cleaning is contradictory and will thus not always be valid. It is thus necessary to provide effective cleaning, either manually – which requires easy access – or automatically, e.g. by a pivoting mechanism so that the lamella surfaces may be swayed into vertical position after the storm event.

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