Innovative use of lamella clarifiers for central stormwater treatment in separate sewer systems

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ABSTRACT

Lamella settlers have been used in the past few years for the sedimentation of particles in wastewater and stormwater applications. A new and very innovative approach for the treatment of stormwater flows is proposed which extends the portfolio of solutions beyond traditional settling tanks. Surface runoff is stored in a sewer or a basin and finally treated in a small but continuously operated lamella clarifier. The low throughput flow will yield good treatment efficiency at a small footprint. The possibilities of using existing storage volume in a storm sewer, as well as the structural flexibility of the arrangement are decisive benefits. As a large operational advantage, the lamellae may be cleaned mechanically, e.g. by pivoting under water. Finally, the flow and the sludge which will be sent to the downstream treatment plant will be minimized. A new comparative simulation method is proposed in order to assess an equivalent degree of stormwater treatment, either by achieving an equal annual volume of treated stormwater or, more directly, an equal amount of spilled pollutant load. The new solution is compared with a traditional settling tank according to current German design rules. Additionally, a case study from a real installation will be presented.

Key words | lamella clarifier, sedimentation tank, settling efficiency, separate sewer system

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INTRODUCTION

The 'classic' separate sewer system has a long tradition and is primarily used in current urban drainage masterplans in many European communities and abroad, even though alternative solutions involving local infiltration are preferred today. Numerous investigations have shown that stormwater may be considerably polluted, thus, some treatment is required. Standard treatment structures include concrete sedimentation basins or tanks with or without permanent water filling. For very sensitive receiving waters, soil filters are preferred.

In the present paper, we try to expand the stormwater treatment solutions portfolio using the lamella clarifier as an innovative technique. In process engineering, lamella clarifiers are well-known sedimentation devices; cf. e.g. Schade & Sapulak (1984). Several types are commercially available, such as tilted-plate or tube settlers; see Figure 1. Most clarifiers of this kind are of counter-flow type, i.e. the water passes upward through the inclined plates (lamellae) or honeycomb modules, while the particles collect on the surface beneath and settle to the bottom of the sedimentation tank due to gravity. Cross-flow settlers are also used; see e.g. Vasquez *et al.* (2010). In the following paper, the terms 'lamella clarifier' or 'lamella settler' are used regardless of the type.

There have been some applications for stormwater treatment in separate and also in combined systems; see e.g. Takayanagi *et al.* (1996), Andritschke (2010), Fuchs *et al.* (2013) and Boogaard *et al.* (2010). Schaffner *et al.* (2013) assessed the performance of lamella settlers by hydrological simulation, but using a quite different approach than in the present paper. The use of flocculation agents for enhancement of sedimentation is not investigated in the following paper.

It is a straightforward approach to equip or retrofit sedimentation tanks of traditional design with lamella clarifiers in order to enhance their efficiency and/or to minimize the necessary structure volume. In many cases, this requires considerable lamella settler volume and hence considerable costs with respect to the comparatively high design throughflow of the tank. A more economic approach would be not to treat all storm inflow 'as it comes', but to use storage to keep the treatment flow low. This idea is not new; see e.g.

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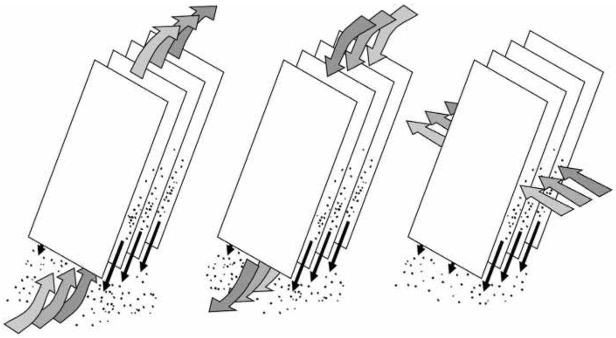

Figure 1 | Lamella settlers of counter-flow, parallel flow and cross-flow type.

Ruscassier *et al.* (1998) where the combined effects of storage and treatment are investigated.

A decisive new approach in the present paper is comparative hydrological simulation. A traditional sedimentation tank designed according to the generally accepted code of practice and the innovative solution using the lamella clarifier are simultaneously simulated with the same assumptions to show equivalence. This proof of equivalence may be a decisive argument to ease the acceptance of such an innovation by a water authority. Moreover, in a comparative approach of this kind, possible errors due to intrinsic 'sensitive' assumptions are made twice and their effect may thus cancel out.

METHODS

Design of traditional sedimentation tanks

The sizing procedure of sedimentation structures depends on the code of practice in the considered country. The present study is based on the standards in Germany. In other countries, different sizing rules may be applicable.

The current German design of a rectangular sedimentation basin is discussed in greater detail in section A of the supplementary material to this paper (available online at http://www.iwaponline.com/wst/069/791.pdf). Usually, it results in a rather bulky concrete structure of several 100 m^3 of volume with considerable construction costs. Current design rules do not provide for alternative cost-effective solutions. It is interesting to note that the volume of the sedimentation tank is derived from a steady-flow sedimentation criterion (i.e. a necessary plan-view surface of the tank), while the effect of storage is totally neglected. The tank features include an emergency overflow for strong inflows to avoid remobilization of the settled sludge. Tanks which are emptied after each storm event are preferred to those with a permanent water level.

The German dimensioning procedure has a few important flaws, namely:

- Small catchments with only a few hectares of impervious surface. The design criteria (under strict compliance) would require a minimum volume of nearly 200 m^3, which would hardly be economical.
- The guidelines do not make any recommendations on how to empty a sedimentation tank. If the whole volume is sent to the treatment plant after each storm event, this would be a rather great share of the annual runoff volume – equivalent to the runoff volume relations in a combined sewer system. This is not desirable in a separate system.
- A very big disadvantage is the fact that the storage effect of stormwater in the tank (and also possibly in a large storm sewer system) is utterly disregarded, even if this effect will greatly reduce the frequency of overflow events and also the annual pollutant loads spilled into the river.

Innovative combination of storage and lamella clarifier

The proposed approach uses a high-rate lamella settler as a small and compact treatment unit in combination with storage volume. The concept has the following features, see Figure 2 (bottom):

- Storage volume, either in a stormwater tank or in the storm sewer, which is filled up during a rain event. In contrast to a conventional sedimentation tank which has to keep certain geometric proportions, the shape of the volume is irrelevant. Oversized sewers or cheap-to-build open ponds are applicable.
- A lamella clarifier is serving as a treatment unit, located in a separate small manhole. It is designed for a rather small, yet continuous, throughflow. The lamella clarifier could be made from commercial honeycomb modules. It may be equipped with a mechanism for automatic cleaning as an additional feature.
- Pump feeding allows for a flexible arrangement on any project, although gravity feeding may also be used.

In many cases, additional storage at no extra cost is available in the storm sewer itself. In long sewers with low slopes, up to several 100 m^3 of storage is available. Basement drains are typically not connected to storm sewers; therefore backing-up of the storm water will rarely cause any problems. An emergency overflow to the receiving

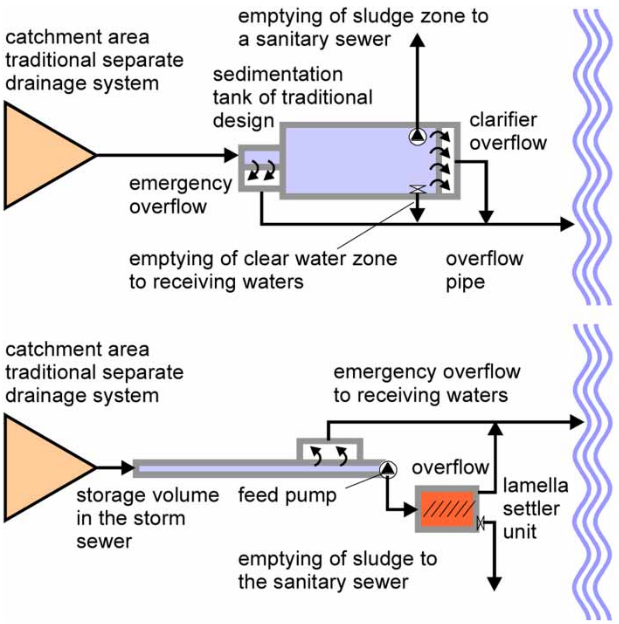

Figure 2 | Top: traditional sedimentation tank which is emptied after each storm event. Bottom: alternative concept where the storm sewer is used as a storage volume, plus a lamella settler as treatment device.

waters allows release of very strong inflows during storms. The settled sludge from the clarifier structure finally may be drained to a sanitary sewer by a shutoff valve or by a second pump.

Sedimentation efficiency of the lamella clarifier is governed mainly by the size of the lamellae surface, in relation to the chosen throughflow. Lamellae feature a large sedimentation area in a small volume, so the surface loading q_A (see below) may be chosen rather low, 4 m/h (cf. Fuchs *et al*. 2013) compared with 10 m/h in a traditional sedimentation tank. Since the water is pumped, no overcharge can take place, even during strong storms.

Comparative quantity–quality simulation

The new concept is not yet regulated or governed by technical rules. Proper sizing of the components will require a method to compare the equivalence to a conventional solution. A comparative numerical quantity–quality simulation has been applied which automatically accounts for storage effects in both cases of Figure 2. To show an equivalent level of water protection, the following approaches may be used:

- Proof of an equal annual water volume which is treated by the lamella clarifier or in a conventional sedimentation tank. This approach assumes that the treatment process is equally effective in both structures.
- Proof of an equal pollutant load per year which is spilled from both systems into the receiving waters in kilograms of total suspended solids (TSS). This approach needs some additional assumptions, such as the concentration of TSS and the sedimentation efficiency for this material.

There are some commercially available quantity–quality simulation tools, e.g. KOSIM by the German supplier itwh Hannover, which are widely used for optimization of combined sewer systems. This software has also been applied here. It allows the use of synthetic 30-year storm series in 5-minute intervals. The following effects are accounted for in order to simulate the annual flow volumes properly:

- The storm runoff in an 'ideal' separate system: no dry weather flow is modelled. Both systems receive the same input.
- For correct volume calculation, the hydraulics of the overflow weirs (clarifier and emergency overflow) must be simulated in detailed form (proper head-discharge relationships and weir levels included). This is essential since the water passing the settling tank by the clarifier overflow is regarded as treated while water spilled by the emergency overflow is not.
- Emptying of both the conventional sedimentation tank and the lamella clarifier must be simulated correctly. This requires some creative thinking since the simulation model normally does not allow for discontinuous emptying of structures. Additionally, filling and emptying of the lamella clarifier volume and also emptying of sludge from the storage volume are accounted for.

As direct simulation results, only the water volumes and flows are taken into account since KOSIM does not calculate TSS as a standard pollutant parameter. This allows a volume balance for both systems. The storage volume and the steady lamella settler throughflow are the key properties sought. By performing several simulation runs, these may be sized such that the simulation yields the desired equal annual volume of treated water compared with a conventional sedimentation tank.

Steady-state sedimentation efficiency of a lamella settler

For the desired determination of TSS loads, an important part of the model is to describe the steady-flow separation efficiency η of the lamella settler. Term η is defined as a concentration ratio, $\eta = 1 - C_{over}/C_{in}$ where C_{over} is the overflow and C_{in} the inflow TSS concentration. If we assume ideal sediment with a uniform settling velocity v_s, η will increase with increasing v_s and with decreasing surface loading $q_A = Q/A_{proj}$, which is calculated from the flow Q and the vertical plan-view projection area A_{proj} of the inclined surface of the lamella settler.

Since few comparable values of η could be found in the literature, we performed our own model investigations which are described in greater detail in the supplementary material to the present paper, section B (available online at http://www.iwaponline.com/wst/069/791.pdf). The following functional relationship was obtained:

$$\eta = \frac{1}{40(q_A/v_s)^3+1} \quad (1)$$

Equation (1) is a 'robust' approach which deliberately tends to underestimate the settling efficiency, accounting for effects like backmixing of already settled sludge sliding down in a counter-flow lamella clarifier and mixing again with the inflow, as well as irregular throughflow.

To achieve a valid comparison of the simulation methods, we need a similar formula valid for the conventional settling basin. Since the sedimentation process follows the same physical conditions and theory in a basin as in a lamella settler, Equation (1) is applied for both devices. This essential issue cannot be elaborated further here for brevity. It was verified using literature data on steady-flow efficiency of sedimentation tanks (also rather scarce and not shown here). For a rectangular tank of length L and width B, the surface loading is computed as $q_A = Q/(L \times B)$. Equation (1) is 'conservative' and accounts for non-parallel flow, backwater zones and oscillating flow patterns in many settling basins. Moreover, thanks to the comparison approach, possible errors in the assumed functional relationships may compensate for each other, at least partially.

Balance of TSS

For determination of the TSS load, some additional assumptions had to be made:

- The storm runoff from the catchment has a constant TSS concentration of $C_{in} = 141$ mg/l, a median value cited in Fuchs *et al.* (2004), which seems reasonable for a comparison.
- Settleable solids in stormwater are characterized by a range of their settling velocity v_s. Lacking a 'typical' distribution curve for sediments in a storm sewer, a v_s distribution for 'light' sediments derived from data on combined sewer overflows was used, shown in more detail in the supplementary material (section C) of this paper (available online at http://www.iwaponline.com/wst/069/791.pdf).
- The overflow TSS concentration C_{over} of any sediment fraction is determined using the steady-flow settling efficiency η determined from Equation (1) by $C_{over} = C_{in} \times (1–\eta)$ where C_{in} is the inflow TSS concentration of this fraction.

The TSS load evaluation routine, finally, combines all these approaches with the simulation results, both for the settling basin and for the lamella settler. From the simulated inflow $Q_{in}(t)$, $q_A(t)$ is computed, yielding q_A/v_s for each sediment fraction and $\eta(t)$ from Equation (1). Weighing over the fractions and integration over time finally allows computation of the overflow TSS load. The difference between inflow load and outflow load is the settled portion of TSS which is removed from the system during tank emptying. Applying this procedure, it is possible to choose the storage volume and the lamella settler throughflow such that the desired equal spilled annual TSS load can be obtained, indicating a technical solution equivalent to a conventionally sized settling tank.

RESULTS AND DISCUSSION

General results

Some simulation results are shown more in detail in the supplementary material (section D) of the present paper (available online at http://www.iwaponline.com/wst/069/791.pdf). The general observations are as follows.

The criterion 'equivalent spilled TSS load' which accounts for the settling effect requires a smaller lamella throughflow than the criterion 'equivalent annual treated storm water volume'. A larger storage volume requires a smaller treatment flow, and vice-versa. A curve of this relationship is shown in the supplementary material.

If the storage volume in the storm sewer is chosen as equal to the standard sedimentation tank (a typical figure in Germany is e.g. $V_S = 10.8$ m³/ha), a lamella clarifier should be operated with a specific design flow of around 12.3 l/(s ha) if the criterion 'equivalent treated water volume' should be kept, while around 4.6 l/(s ha) or even 3.1 l/(s ha) are sufficient if 'equivalent spilled TSS load' is applied, when the surface loading is chosen as $q_A = 4$ m/h or 3 m/h, respectively. The standard sedimentation tank has a specific throughflow of 15 l/(s ha). The lamella settler thus requires less than 1/3 of this flow. However, these figures are strongly dependent on the specific conditions of the site and particularly also on the properties of the storm series used for simulation. The cited specific flow conditions cannot be extrapolated to other projects. Individual simulations are thus required.

According to the obtained relationship (see Figure 5 in the supplementary material, available online at http://www.iwaponline.com/wst/069/791.pdf), it is advantageous to increase the lamella throughflow rather than the storage volume assuming that both parameters are flexible. Choosing a smaller surface loading q_A of the lamellae may be efficient, too, since then a considerably smaller lamella throughput may result, even if a larger settler volume is required to achieve the smaller q_A. If the criterion 'equivalent treated water volume' is applied, the chosen surface load in the lamella settler is of no influence at all – provided that an equally high settling efficiency comparable to the settling efficiency in the settling basin is reached.

The above-mentioned approach may also be beneficial in special situations, e.g. enlargement of an existing industrial area where a settling tank is already in operation and should be enlarged. Use of a lamella clarifier may make this redundant.

Case study

The project that will be described as a case study went into operation in 2011. This is a residential and commercial area drained by a traditional existing separate system: stormwater treatment was necessary due to sensitive receiving waters. Conventionally, a settling tank of around 250 m^3 would have been required following the German dimensioning procedure. The existing storm sewer system had low slopes and consequently large pipe diameters. It was thus possible to back up around 1,000 m^3 as storage volume. It could be shown that two small lamella settler units with a throughflow of 16 l/s each were sufficient. In addition, a new overflow manhole and an additional pump manhole were needed which were built close to the existing outflow sewer (Figure 3). The lamella settlers are located in two manholes of 2×2 m. All new ancillary structures were ready-made concrete shafts.

Above the lamella modules, which are arranged as six packets, an overflow gutter system ensures smooth throughflow through all modules. Since the lamella settler may permanently receive high loads of sludge, it was equipped by a mechanical cleaning mechanism. During cleaning, the inflow pump is stopped and the lamella modules are pivoted under water by a hydraulic drive to loosen up the sludge and to allow it to slide down (Figure 4). The manhole is then emptied to a sanitary sewer. For maintenance purposes, it is possible to remove and re-insert the modules manually.

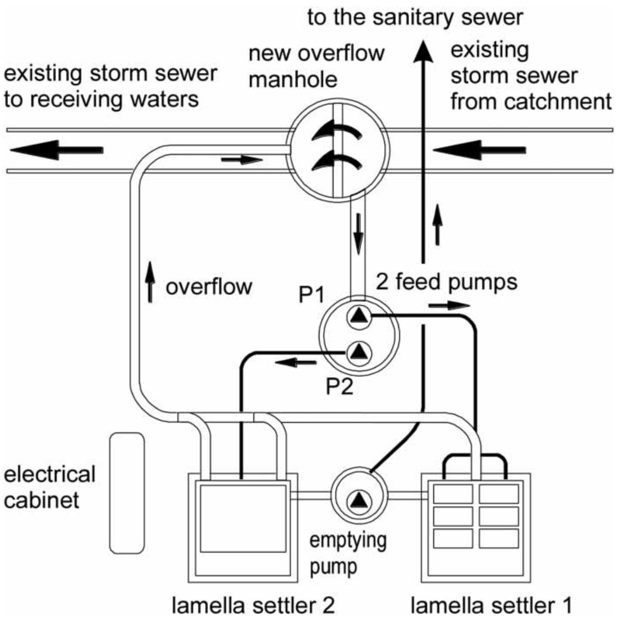

Figure 3 | Plan view of the project example.

Currently, this installation is subject to a monitoring and evaluation project in which final results are not yet available. An essential feature (not covered in the present paper) is to obtain a smooth uniform throughflow through all lamella modules since this will influence the sedimentation efficiency strongly.

CONCLUSIONS

The new innovative concept for central stormwater treatment in separate sewer systems introduced in this paper is rather flexible with regard to the necessary structures. Runoff is backed up in a storage volume of any shape, and continuously treated in a small lamella clarifier. Considerable cost savings are possible wherever, for example, existing long storm sewers or cheap-to-build open ponds may be used for storage. The lamella clarifier throughput may be chosen as considerably smaller than the design flow of a sedimentation tank. Small lamella units are sufficient, particularly where ample sewer storage volume is available. These may also be equipped with an efficient cleaning mechanism, e.g. by pivoting the lamella packs under water. This is a considerable operational benefit.

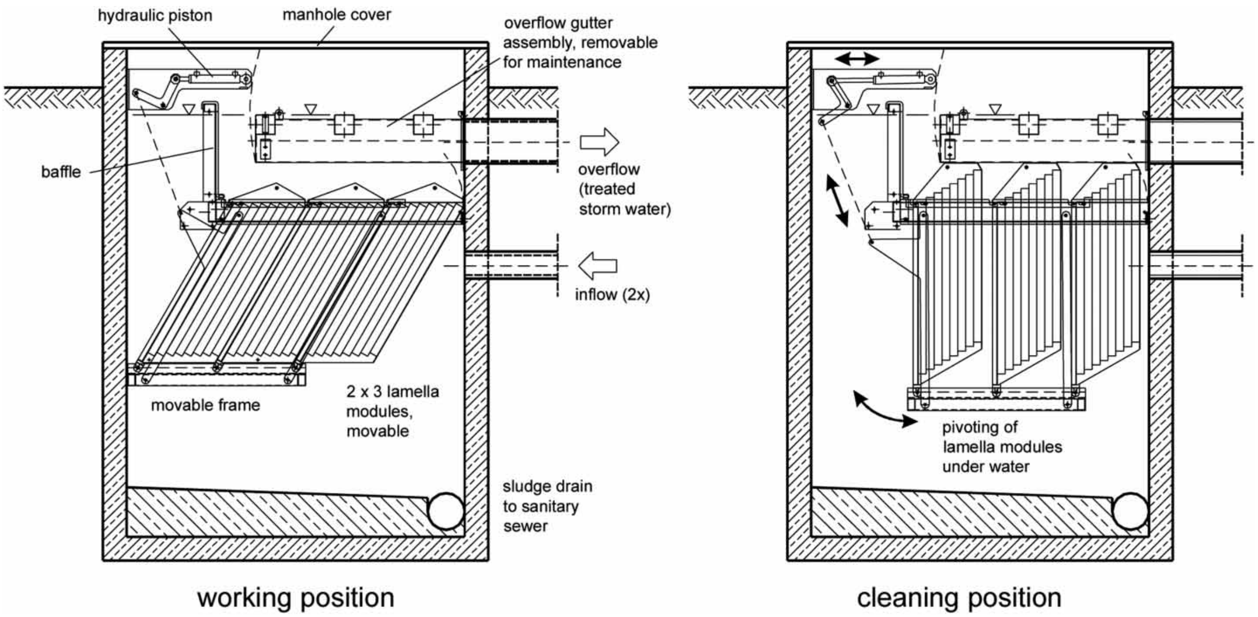

Figure 4 | For cleaning, the lamella modules are pivoting under water by a hydraulic drive. The sludge slides down and is drained to a sanitary sewer.

To prove equivalence to state-of-the-art solutions such as sedimentation tanks, a comparative simulation of equivalent treated water volumes or spilled pollutant loads is proposed. Site-specific conditions can be taken into account, e.g. the characteristics of the storm series. The water volume which is fed to the sanitary sewer while emptying the treatment units after a storm is also balanced. Solutions may be found which minimize this volume, which is again a large advantage.

A close analysis reveals that some of the intrinsic approaches and assumptions are probably sensitive, i.e. if the input data are changed slightly, the result may change significantly. This may be the case for the sedimentation approach, in particular for curves such as in Figure 4 of the supplementary material (available online at http://www.iwaponline.com/wst/069/791.pdf) where the data currently available are not very reliable. Here some basic research is still needed for the future. The approaches must be chosen carefully in order not to over-estimate the sedimentation effect. Moreover, the comparison between two similar systems is evaluated rather than taken as an absolute value. Thus, possible errors are made twice and may compensate each other.

REFERENCES

Andritschke, N. 2010 Lamellenfilter zur Regenwasserreinigung (Lamella filters for storm water treatment). *wwt-Wasserwirtschaft Wassertechnik* **2010** (2), 41–42.

Boogaard, F. C., Langeveld, J. G., Liefting, H. J. & Kluck, J. 2010 Stormwater quality and removal efficiency rates of lamella filters. *NOVATECH 2010*, Session 2.3.

Fuchs, S., Brombach, H. & Weiß, G. 2004 New database on urban runoff pollution. *NOVATECH 2004* **I**, 145–152.

Fuchs, S., Mayer, I., Haller, B. & Roth, H. 2013 Lamella settler for storm water treatment – performance and design recommendations. *NOVATECH 2013*, Session B5.

Ruscassier, G., Chebbo, G., Saget, A. & Bertrand-Krajewski, J.-L. 1998 New design method of treatment devices. Storage tanks and on-stream treatments. *NOVATECH 1998* **1**, 451–459.

Schade, H. & Sapulak, A. 1984 Parallelplattenabscheider (Tilted plate settler). *Korrespondenz Abwasser* **31** (2), 104–111.

Schaffner, J., Mayer, I., Eckhardt, H. & Steinhardt, J. 2013 Model based investigations on the pollution loads of stormwater treatment particle separators. *NOVATECH 2013*, Session B5.

Takayanagi, E., Abe, T., Taruya, T. & Fukui, S. 1996 Introduction of plate settler for combined sewer overflow treatment. *7th International Conference on Urban Storm Drainage ICUSD*, Hannover (Germany), pp. 893–898.

Vasquez, J., Morin, A., Dufresne, M. & Wertel, J. 2010 Optimisation de la forme des décanteurs lamellaires par la modélisation hydrodynamique 3D. (Shape optimization of lamella settlers by hydrodynamic 3D modelling). *NOVATECH 2010*, Session 2.3.

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