DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

www.dessin-project.eu

MS4: CONCEPT FOR THE MODEL SETUP FOR CROSS-CURRENT LAMELLA SETTLERS

Development and construction of the experimental rig

Gebhard Weiss, UFT, May 2014

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

TITLE OF THE REPORT

MS4: CONCEPT FOR THE MODEL SETUP FOR CROSS-CURRENT LAMELLA SETTLERS
Development and construction of the experimental rig

SUMMARY

This paper describes the concept for design and construction of the experimental setup for the model tests on cross-flow lamella settlers within Work Package WP 21 of DESSIN. It is planned to conduct tests with steady flow and model sediment (plastics granulate) in various configurations, including tests using salt in the water to gain a lower settling velocity. The setup is based on prior model tests in the course of another project on counter-flow lamella settlers. All model data are kept close to these prior model tests in order to allow direct comparison.

MILESTONE NUMBER	WORK PACKAGE
MS4	WP21.1
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
UFT Umwelt- und Fluid-Technik GmbH	Gebhard Weiß (UFT)
QUALITY ASSURANCE	
Dipl.-Ing. Doris Steinriede Dr Herman Helness	UFT SINTEF
PLANNED DELIVERY DATE	**ACTUAL DELIVERY DATE**
30/04/2014	25/07/2014

DISSEMINATION LEVEL	□ PU = Public ● PP = Restricted to other programme participants □ RE = Restricted to a group specified by the consortium. Please specify: ______________________________ □ CO = Confidential, only for members of the consortium

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Table of contents

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

List of Figures

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

List of Tables

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

List of Acronyms and Abbreviations

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Executive summary

This paper describes the concept for design and construction of the experimental setup for the model tests on cross-flow lamella settlers within Work Package WP 21 of DESSIN. It is planned to conduct tests with steady flow and model sediment (plastics granulate) in various configurations, including tests using salt in the water to gain a lower settling velocity. The setup is based on prior model tests in the course of another project on counter-flow lamella settlers. All model data are kept close to these prior model tests in order to allow direct comparison.

1 Cross-flow lamella settlers: General

Lamella settlers are tried-and-tested sedimentation devices in process technology (e.g. mining, quarries, etc.). The principle is used in many commercial devices. The basic idea is to feed the sediment-laden flow through narrow gaps between plates in order to provide a merely small settling distance of some cm, rather than of the whole depth of a settling tank. It can be shown that this will increase the settling efficiency considerably. Plate or honeycomb arrays made from plastics or other materials come in a variety of dimensions and shapes from different manufacturers.

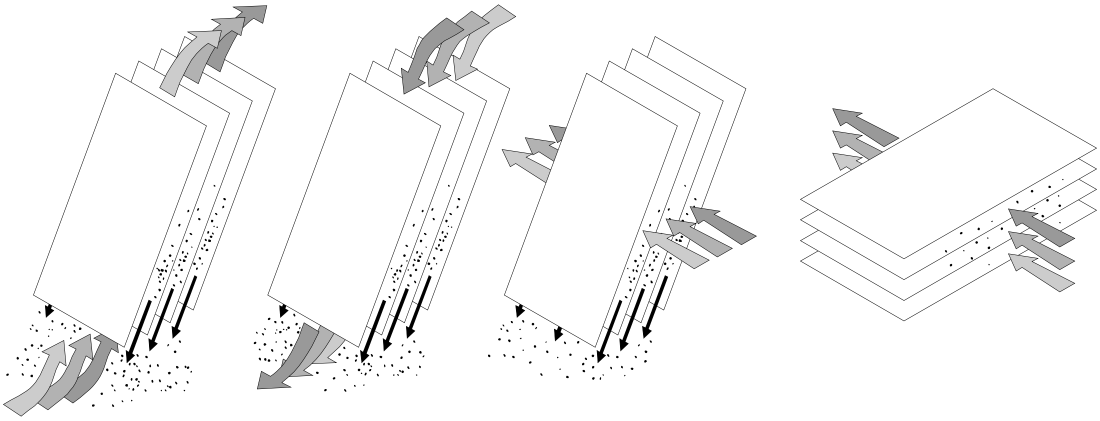

Figure 1: Upflow, downflow, cross-flow and horizontal plate settlers (from left to right)

Figure 1 shows basic arrangements for lamella settlers made from plate arrays. Except the horizontal plate settler, the plates are inclined to allow the settled sludge to slide finally down into a sludge sump from where it can be removed. Of course, there are numerous ideas and patents for cleaning the whole assembly. The details are not discussed here for brevity. Most popular are upflow settlers. In this case, also honeycomb profiles or tube arrays are used. Their common disadvantage, however, is the fact that the sediment particles slide down against the direction of inflow. When the sliding sediment grains have reached the lower plate edge, they fall down into the fluid beneath, mixing in rather efficiently. Former model tests (UFT 2013) with well-rolling spherical plastics sediment grains have shown that this effect is pronounced. For real wastewater sediment, the sludge is expected to be somewhat more coherent, so that it will slide down as “plaques” which will not disaggregate completely underneath the settling plates and thus re-mix to a lower extent. Anyhow, this is still a hypothesis. Generally, improved sedimentation efficiency could be detected, but it is not yet clear how large the influence of the effect of sliding down and re-mixing really is.

In the past years, the technology was also used for improved sedimentation treatment of overflows during storm from combined or separate sewer systems. A recent research project granted by the German Federal Country of Northrhine-Westphalia (UFT 2013, KIT 2013) has investigated the use of upflow settlers first as model tests (UFT 2013) and later also in a testing container with real wastewater, a line of action which will be followed also in the present project DESSIN. To allow direct comparison of results, it is desired that the new model tests follow quite closely the experiments in the past project. Also, the experimental setup should be rather similar.

In the present project, cross-flow plate settlers are to be investigated. The first step within Work Package WP 21 of this project is to design an experimental rig for model tests similar to the cited tests in UFT (2013). The present documentation derives the basic design parameters and shows also the final design.

2 Concept of model test rig

2.1 Experimental rig of past project

For the reason mentioned, it is necessary to document the features of the experimental rig from UFT (2013) somewhat more in detail. It is shown in Figure 2. A commercial rectangular tub (approximate dimensions 1200 x 800 mm, volume 1000 L) was used as a container to house the upflow lamella arrays. Above the lamellae, some parallel horizontal flumes were arranged to collect the treated water and to achieve a smooth even throughflow through the lamella packets.

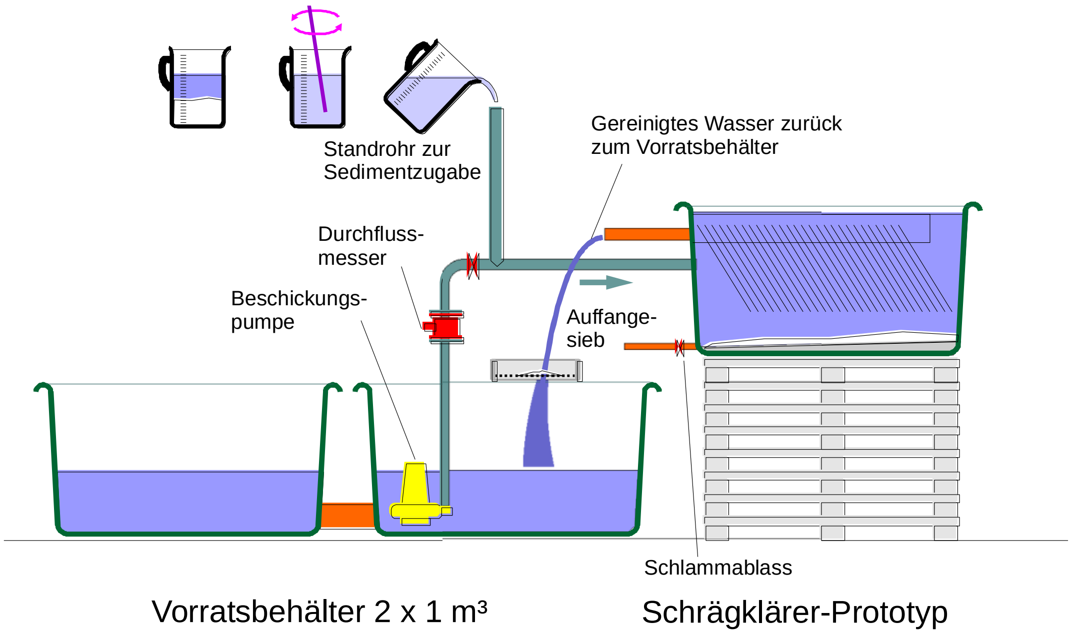

Figure 2: Model test rig of the past experiments on an upflow lamella separator (from UFT 2013)

The experimental rig featured closed-loop water circulation which allowed also the addition of salt to the water in order to increase the fluid density and, thus, to reduce the settling velocity of the particles. Two 1 m^3 tubs served as a reservoir. The model sediment – small polystyrene beads – are added to the inflow. Circulation is driven by a submergible pump (max. flow approximately 8 L/s). Flow is measured by an inductive flowmeter. The overflowing water passed a fine-meshed textile sieve which collected any escaped particles. After the end of the test, the content of the tub including the captured particles was emptied through a second sieve. Both sieves were finally emptied carefully into Imhoff cones where the sediment volume could be determined.

Figure 3 a and b: Experimental setup of the past project (UFT 2013) with Leiblein upflow honeycomb lamella modules

The upflow lamella modules used in these tests are shown in Figure 4. The first tests used honeycombs of 40 mm profile height from the German supplier Leiblein, made of polyamide. These profiles, however, would probably not be suitable for combined sewage because they would easily clog. Thus in a second test series, 80 mm-honeycombs of the same supplier were used. The cross-sectional shapes of both types were similar. Any plates of different geometry and spacing or profiles of other suppliers have not been investigated. The technical data of the experimental rig are shown in Table 1.

Table 1: Technical data of model tests from UFT (2013) with upflow lamella settlers

volume of tub	ca. 1,0 m³
dimensions of lamella packet (projected view)	L:B:H = 1200 x 800 x 370 mm
inflow (pumped)	max. 7,0 l/s
type of honeycomb modules	a) Leiblein LW 40, 40 mm height b) Leiblein LW 80, 80 mm height
Specific projected settling area of this honeycomb type at 60° inclination	a) 12,5 m²/m³ b) 6,3 m²/m³
inclination angle	60°
total projected settling area	a) 4,44 m² b) 2,22 m²
surficial loading if homogenous throughflow through all honeycombs is assumed	a) 4,1 m/h @ 5,0 l/s b) 8,2 m/h @ 5,0 l/s

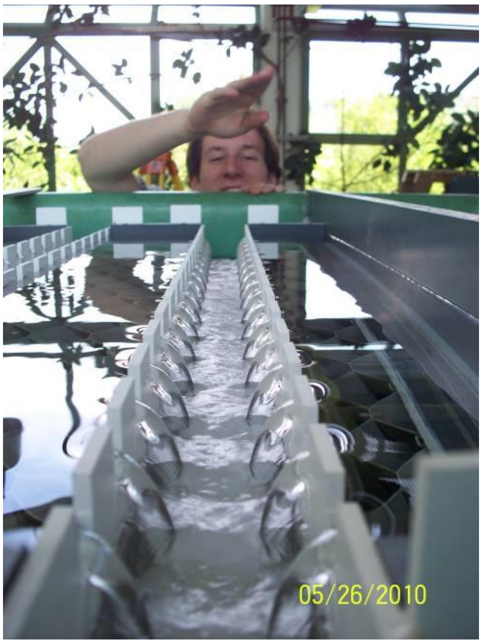

Figure 4: Final arrangement of overflow flumes (the shown camera date is wrong, the pictures are from June 2011)

Figure 5: Left: Capturing of sediment by sieving, right: Determination of sediment volume in Imhoff cones

2.2 Conception of new experimental rig

The concept of the new experimental rig is based on an idea how future structures for lamella-enhanced settling could look alike. The title of this work step is “Enhancing treatment efficiency in CSO tanks with cross-flow lamella settlers” which implies already the perception that a CSO tank is equipped or retrofitted with lamella modules. Anyhow, this need not necessarily be the only possibility. UFT has developed a concept for stormwater treatment in separate systems where only a small lamella settler chamber is serving as treatment unit which is continuously fed, while the necessary storage is within large sewers, see Weiss (2014). Possibly, a similar concept could also be used for combined sewage treatment.

In general, one would expect the biggest influence on the settling performance by the lamella geometry (total projected area, spacing). Moreover, the size and shape of the structure housing the lamella modules will also have some influence. Of course, it may contain the more lamellae modules the larger it is. If a model should investigate the sedimentation performance realistically, it had to account for both effects, which would mean a scale model of all dimensions. To give a handy model, e.g. a CSO tank with a prototype length of 20 m could be scaled in 1:10 which yields a model length of 2 m. If the same scale factor is applied to the lamellae and, say, 80 mm prototype spacing is assumed, we would have 8 mm in the model only.

Anyhow, it we make experiments with 8 mm lamellae as a model of 80 mm lamellae, we had to scale also the sediment properties (e.g. use model sediment with a smaller settling velocity than in real combined sewage, scaled down according to Froude’s model law). Since this relies on several assumptions, we expect considerable so-called scale effects so that the results would be comparable to the prototype only conditionally.

It is expected that the lamellae packets (and not the tank itself) are predominant for the settling performance of a tank – an expectation which is, by the way, not trivial at all and needs to be approved in the course of the DESSIN research project. If this assumption is made, however, results are desired which may be scaled to any lamella packet volume or projected settling area, respectively, in relation to the inflow and valid for typical sediment in combined sewage. Lamella settler theory (not shown here for brevity) accounts for this by giving a dimensionless relation settling efficiency = f(surficial loading/settling velocity). For a first approximation, the dimensions of the tank are neglected. Under these assumptions, however, we could use for the experiments a small model tank of arbitrary size, but with prototype-spaced lamella packets. The flow must be chosen such that the ratio surficial loading/settling velocity is the same value as in the prototype structure. Since we do not scale the settler, we need not scale the sediment, either. Theoretically, we could use real combined sewage in the model. We do not want to do this in our hydraulic laboratory, however, but then we can use model sediments more easily and more hygienically to handle provided that their settling velocity has the same magnitude.

This approach would account for the most essential effects. Anyhow, it must be discussed how possibly neglected parameters such as the non-prototype lamella length (regardless of their original spacing) or, as already mentioned, the tank geometry could influence the results.

There is, however, another implication which needs to be taken into account: The vessel or tank in which the lamellae are inserted has itself also some sedimentation effect, and in the model tests, we cannot distinguish which part of the measured effect is due to the vessel and which due to the lamella modules. For a given flow and sediment, sedimentation is mainly governed by the available surface – e.g. the plan view area of the vessel or the projected area of the lamella modules, respectively. Consequently, of course, the lamella settler has a dominant effect when its settling surface is large compared with that of the vessel. The essential item is: If lamellae of prototype spacing are used in reduced-scale model tests, the ratio of lamella settling area : plan view area of the vessel is always much smaller than in the prototype. Thus, we should expect that in prototype size the effect of the lamella settlers will be more pronounced than in the model, if compared with the effect of a settling tank alone. This has to be accounted for when interpreting the results with prototype lamella spacing.

The experiments should thus follow this general concept:

- Construction of a rather small, easy-to-clean flume which is equipped with some cross-flow lamella modules. The flume size need not reproduce a possible prototype CSO tank size.
- However, the size of the flume must be chosen somehow, and if we are free with that, we may design the flume proportions such as to resemble a small lamella treatment unit as a possible future prototype realization, e.g. a precast concrete tank of, say, 2 m internal width for easy road transport. The flow pattern in the model then is similar to the pattern in such a prototype. The experimental container which shall be used in further steps of the DESSIN project should also be designed keeping approximately to the model proportions.
- The flume must be designed such that the flow through the lamellae modules shows the same behaviour as it would do in a prototype structure. This requirement is met if homogenous throughflow is achieved in the model as well as in a prototype lamella settler structure. Any non-homogenous throughflow is caused by the structure shape and size only, so we would get then an effect of these properties in contradiction to the above mentioned assumption.
- Essential design parameters are the volume and projected settling area of the lamella modules used. The spacing is equal to the prototype lamella spacing. We neglect the fact that the absolute size of prototype settling module surfaces may be larger than in the model (and thus also e.g. the path length which particles must travel when sliding down).
- The flume dimensions are needed later for discussion of secondary effects.
- Under these assumptions, the model can finally be designed keeping to the dimensions of our past research project using upflow settlers where the model used the same design approach. Equal design parameters should be used, e.g. the same projected settling area of the lamellae, for easy direct comparison of cross-flow and upflow settler results. Also, the setup should be chosen similar to our past research project, in order to make use of several existing rig devices (pump, MID flowmeter, etc.). This allows also conducting the experiments and evaluating the results in the already practiced manner.

The experimental rig for the cross-flow lamella settlers in DESSIN then should have the following features:

- Construction of a new flume from waterproof-coated plywood sheets. No glass walls due to our limited budget.
- Use of two lamella packages or modules (equal constructed packages) of 600 mm length. Optionally tests with one single module are possible. Lamella spacing 40 mm or 80 mm (if needed, also other lamella spacing can be investigated). Cross-flow plates with 60° inclination made from clear methacrylate (Perspex) to allow observation of the particles and dye tests. One lamella packet or module should have a projected settling area of 2.22 m² at 40 mm lamella spacing. Using both modules, the total projected settling area is then 4.44 m², equal to the past experiments. With 80 mm lamella spacing, the values are halved.
- “Zero tests” use the flume only, without any lamellae. These tests can be compared with results from literature for settling basins.

- The proportions of the flume are chosen similar to those found in rectangular concrete detention basins; however we do not keep to the proportions width:depth = 2..4 required by the German technical rule DWA-A 166 (2013), with respect to the possible future prototype realisation as a compact precast concrete structure and also to the experimental container for later DESSIN project phases.
- As an additional feature, the cross-flow lamella settler modules should be exchangeable to such which use horizontal settlers in order to investigate the effect of sliding down of the particles. Due to geometry, horizontal settler modules of the same spacing and the same overall volume have the double projected settling area than 60° cross-flow settlers.
- The flume then has a width of approximately 75 cm and the same depth. The flume length was chosen to 2400 mm = four times the lamella packet length only, because the experimental rig should not get too large and also because the settling performance of the flume without lamellae should not be too good. In prototype size, later, it is desired to use a compact structure with minimum necessary space between the front and rear wall and the lamella packets. This is of course some contradiction to the desired homogenous flow distribution which would call for a long structure.
- If the tests visualize uneven flow distribution (e.g. much higher throughflow at the bottom than on top of the packets), additional baffles could be used to correct this. Visualisation can be achieved with dye. The design of the model could additionally be simulated numerically to get an idea of the flow pattern inside and on the degree of inhomogeneity. Calibration of the simulation model by velocity measurements would be straightforward, but velocity measurements would require a very small sensor such as thermo-film or laser-Doppler anemometers in order not to disturb the flow.

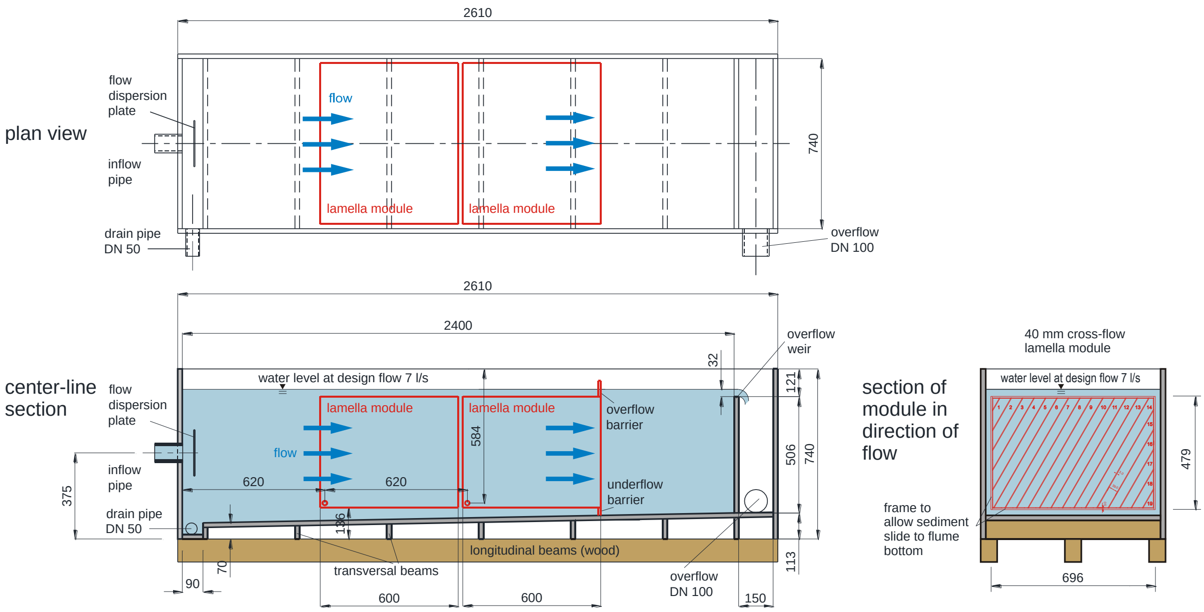

Figure 6: Final design of the experimental flume with two cross-flow lamella modules inserted

3 Experimental program

3.1 General

As mentioned, the planned experiments follow closely the runs in our past research project. After some qualitative tests mainly to get familiar with the experimental rig and to see the flow pattern, the first quantitative tests should be made with 80 mm plate spacing. Later, additional plates (already prepared) may be added in the modules to reduce the plate spacing to 40 mm. The additional plates should be cemented in for stability.

The cross-flow modules have an inclination angle of 60°. Tests with other inclination angles are probably not necessary (besides of the already mentioned horizontal settler). Such tests would require construction of new lamella modules.

Each test series (using a defined settling velocity and different, yet constant, flows) should be accompanied also by a „zero test" without modules, but with the same flow and sediment.

3.2 Qualitative tests of flow pattern

Before starting quantitative tests where settling efficiencies should be measured, the flow pattern through the test flume should be observed by dye tests. Essential for homogenous flow distribution is e.g. the inflow to the flume where the DN 75 inflow pipe ends bluntly in the wall. Without any further flow-dividing appurtenances, there is a strong free jet blowing straight through the tank. The momentum of this jet would cause a high-velocity longitudinal flow though the central part of the lamella modules, but low flow velocity or even backflow close to the flume bottom and walls. In order to avoid this undesired flow pattern, the least measure is a flow dispersion plate as shown in Figure 6. Also other flow-dispersing devices should be tested here, such as a T-shaped pipe manifold with several outflow orifices. The flow distribution should be as homogenous as possible. It should be noted that the hydraulic resistance of such devices might reduce the maximum throughflow, dependent on the power of the pump.

The flume design should be simulated numerically (by the University of Essen as DESSIN partner) in order to verify the observed flow patterns in the model. Even without a calibration by flow measurements, some statements could be made how to improve the flow distribution, e.g. using the mentioned manifold pipe or some improved bafflework.

3.3 Determination of settling efficiency

The tests of settling efficiency may use the same model sediment as in the past project. There are still some kg of "non-popped" BASF Styropor P 423 available which consists of spherical polystyrene particles of nearly uniform diameter of approximately 0.5 mm, including some tiny bubbles of a solvent. There have been investigations of the narrow-graded settling velocity of this material in "sweet" tap water (without addition of salt) as well as with different salt concentrations. In all tests, the water temperature and also the fluid density of salt water (the latter measured directly using a hydrometer) must be noted down. The handling of the model sediment in the tests will require some practice, e.g. it must be treated with some detergent to reduce surface tension and to improve the wettability. There are also tests with other sediment sorts planned, e.g. with Styropor types of still smaller sphere diameters.

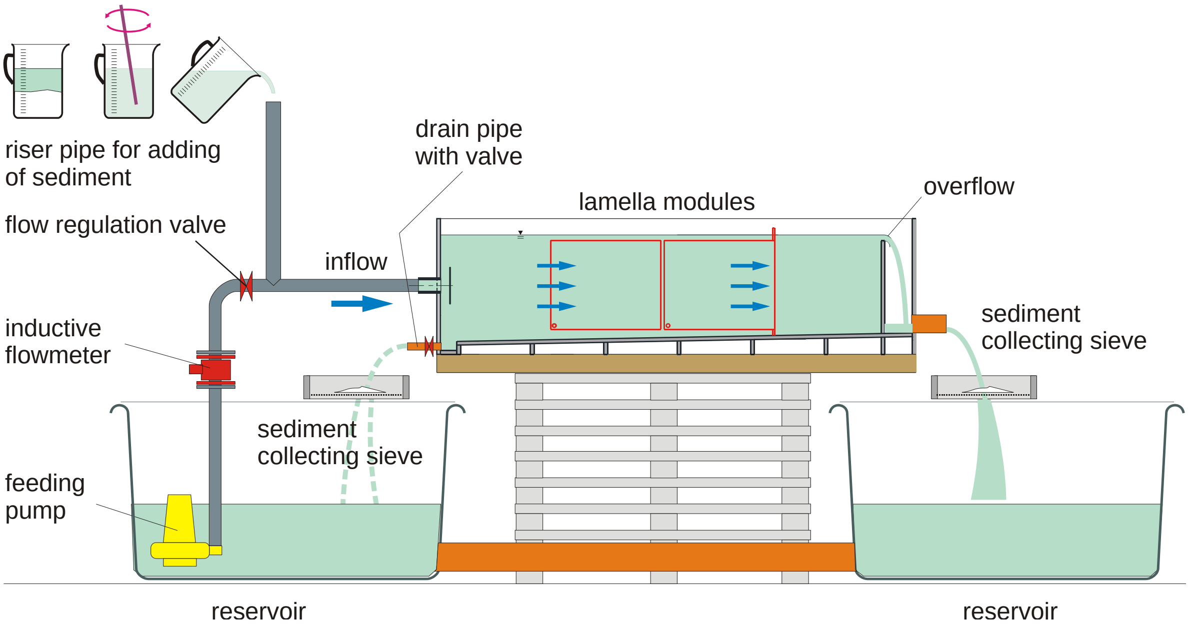

Figure 7: Schematical setup of the experiments

The schematical setup of the experiments can be seen from Figure 7. The tests are conducted mainly as described already in Chapter 2.1. The following parameters are varied:

- Geometry: 40 mm or 80 mm lamella spacing, 1 or 2 modules
- Discharge Q
- Different model sediments; additionally, the salt concentration in the water may be changed (by adding salt, thus reducing the settling velocity of the model sediment)
- additionally: tests with lamellae of different spacing and of a horizontal settler rather than a cross-flow settler (to see qualitatively any difference)

The most essential parameter in any test series is the flow Q which should be varied in at least 6-7 steps, e.g. 2,3,4,5,6,7,8 L/s. We expect large data scatter, so it is also reasonable to repeat some tests. It is most practicable to start with a large flow which is then subsequently reduced. Any subsequent test will then show an improved settling efficiency. When e.g. 95 % - 98 % efficiency is reached, it is not necessary to continue with even smaller flows.

It is necessary to take some time during the tests for simple observation of the flow and the settling process. The particles can serve as rather well visible flow tracers. Of course, observations can be recorded by a movie camera.

For the tests with salt water, table salt is added. The maximum salt concentration in the past tests was around 4 %, slightly more than sea water. To achieve this, around 100 kg of table salt are necessary for 2.5 m^3 of water volume in the experimental rig. Salt is added just like sediment and the process of dissolving can be observed. The salt concentration need not be measured; moreover it is modified unintentionally by the process of removing sediment from the flume bottom by washing and also by evaporation of water. Instead, the density of the salt solution is measured during any test using a hydrometer. – It should be noted that in the past project, tests with large salt content caused particularly large data scatter. One reason might be that a higher fluid density will make the settling velocity distribution of the sediment less steep, i.e. broader-graded, which makes it more sensitive to tiny air bubbles attaching to the beads due to possibly insufficient treatment with detergent. However, there may be also some other reasons not yet understood completely.

4 Evaluation of results

The evaluation of the tests may closely follow the procedure as in the past project, i.e. determination of the steady-flow settling efficiency as the percentage of added sediment which has settled in the flume. This efficiency η is dependent on the settling velocity, on the flow and on the geometry of the settler and is finally expressed by a set of dimensionless parameters, e.g. $\eta = f(q_A/v_s)$ where $q_A = Q/A_{settler}$. These are chosen such as to allow direct comparison to other types of lamella settlers (particularly the counter-flow settler from our past project and the horizontal settler which may optionally be investigated here, too) or also with the performance of settling basins without lamella settlers.

One important finding of the past project was that the measured settling efficiency always comprises both the effect of the flume and the effect of the settler modules while the flume had already a good efficiency. It is not possible to divide these effects directly, but some statements can be gained by comparison of different tests, e.g. such with and without lamella settler modules. Details must be worked out when some results are available.

The final outcome of the model tests should be some statements on the achievable settling efficiency, dependent on inflow, structure geometry and sediment properties, which could also be transferred to a prototype-size structure.

5 References

UFT (2013) Grundlagen zum Einsatz von Lamellenabscheidern und halbtechnische Versuche. Beitrag zum Schlussbericht „Analyse der Leistungsfähigkeit von Mischwasserbehandlungsanlagen“. Forschungsprojekt des Landes Nordrhein-Westfalen (in print)

KIT (2014) Schlussbericht „Analyse der Leistungsfähigkeit von Mischwasserbehandlungsanlagen“. Forschungsprojekt des Landes Nordrhein-Westfalen (in print)

Weiss, G. (2014): Innovative use of lamella clarifiers for central stormwater treatment in separate sewer systems. Water Science and Technology, in print

DWA-A 166 (2013): Bauwerke der zentralen Regenwasserbehandlung und –rückhaltung – Konstruktive Gestaltung und Ausrüstung. DWA-Arbeitsblatt

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

www.dessin-project.eu

DESSIN
DEMONSTRATE ECOSYSTEM
SERVICES ENABLING INNOVATION
IN THE WATER SECTOR