Testing the efficiency of decentral devices for stormwater treatment

Développement et test d'un dispositif décentralisé de traitement des eaux pluviales

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RÉSUMÉ

Le traitement décentralisé des eaux pluviales influence la conception et le dimensionnement des ouvrages de gestion des eaux pluviales. Les dispositifs industriels dédiés offrent des efficacités de traitement appropriées. Les autorités allemandes en charge des questions liées à l'eau envisagent de mettre en place une procédure normalisée concernant ces dispositifs décentralisés de gestion et de traitement des eaux pluviales.

Dans ce contexte, une procédure de test d'un nouveau dispositif décentralisé de gestion et de traitement des eaux pluviales a été mise au point. La mise en œuvre de cette procédure permet : i) de comprendre le lien entre efficacité de traitement, caractéristiques de l'écoulement et conditions d'écoulement à l'entrée ; ii) d'estimer l'efficacité de traitement pour une charge polluante à l'entrée correspondant à la charge moyenne annuelle. Cette procédure a été validée à partir des essais de répétabilité, sous différentes concentrations et débits d'entrée en régime permanent.

Les résultats relatifs à l'étude d'une dizaine de dispositifs de traitement des eaux pluviales montrent que l'efficacité de traitement peut atteindre 80% dans le cas d'une conduite de sédimentation. L'écoulement dans cette canalisation est contrôlé de façon à limiter la remise en suspension. Ces résultats ont permis d'améliorer la procédure de test et de validation du dispositif développé.

ABSTRACT

Decentral stormwater treatment contributes to low impact design in storm water management. Industrially produced devices offer a good potential for controlled treatment efficiency. Water authorities in Germany intend to implement a formal approval procedure for those devices.

For that reason a test procedure was developed. The test setup allows to study (i) the efficiency and flow characteristic as a function of the inflow and (ii) the efficiency for a total load similar to an average annual load. The test procedure was validated according to repeatability, effects of inflow concentrations and steady flow and mass transport conditions. The future formal approval procedure will base on a slightly modified annual load test.

The performance of ten devices was intensively studied. The paper reports exemplarily results for simple sedimentation pipes. The efficiency is a function of flow and residence time. Low flow enables high efficiencies and vice versa. Resuspension effects were limited. During the annual load test with three different flows efficiencies of around 80 % were observed.

KEYWORDS

Decentral systems, Efficiency, Industrially produced devices, Low impact design, Sedimentation, Separate systems, Stormwater treatment, Test procedure

1 INTRODUCTION

The pollution of storm water runoff in separate systems depends essentially on the type and the use of the catchment area and the general air pollution (e.g. Welker 2005). The main sources of pollution are mostly heterogeneously distributed within the catchment and can often not be clearly identified.

The common strategy of stormwater treatment uses central devices such as settling tanks, infiltration basins or planted soil filters. Decentral infiltration facilities are efficient in terms of watercycle and pollution control. But they are space consuming and require appropriate geohydrological conditions.

Decentral treatment strategies intend an efficient treatment of storm runoff from heavy polluted small areas. They treat at the sources of pollution aiming at low impact design and serve the polluter pays principle. During the recent years several industrially produced decentral devices were developed. They range from new gully pot devices for heavy polluted street runoff to large devices serving longer road segments or properties with heavy polluted runoff as proprietary devices.

The water authorities in Germany require a formal approval procedure for those industrial products to assure high efficiencies. After a review of existing procedures for evaluation or approval (DWA 2010) it was decided for well controlled laboratory test procedures. The Deutsche Institut für Bautechnik (DIBt), Berlin is responsible for the approvals on the german market. Guidelines do exist for the approval of pavements with treatment features (DIBt 2005) and devices for treatment of storm runoff from car traffic areas up to 2,000 m² before infiltration into the ground (DIBt 2011). An extended approval procedure for all kind of devices, types of areas and both receiving compartments groundwater and surface waters is in development.

Objectives of the study to be reported on in this paper was to (i) develop a test procedure for decentral devices for stormwater treatment, (ii) to investigate the efficiencies of three different devices and (iii) to contribute to a test protocol for a formal approval procedure for decentral devices being in development at the Deutsche Institut für Bautechnik (DIBt), Germany. The paper covers the first objective and the second objective mostly by one device as an example for simple sedimentation pipes because of the limits of a paper.

2 MATERIAL AND METHODS

2.1 Test rig

The hydraulic system of the test rig consists of a 32 m³ tank, centrifugal pumps and valves for flow control. Two magnetic flow meters (Promag 50 W DN 32, accuracy 0.2 % and Promag 53 W DN 150, accuracy 0.5 %, Endress und Hauser, Germany) serve for flow measurement and control of the pumps. The flow ranges between 0.5 $L \cdot s^{-1}$ and 70 $L \cdot s^{-1}$. For low flows (< 4 $L \cdot s^{-1}$) the DN 32 flow meter and for the other discharges the DN 150 flow meter was used.

The dye tracing tests are run with Uranin (Fluorescein) being injected as an impulse three meters before the device to be tested. Outflow signals are recorded continuously by a fluorimeter (MKT-1, Sommer Mess-Systemtechnik, Koblach, Austria) with to two redundant sensors.

The particle transport tests had to focus on fine particles as they are important for particle bound pollutant transport. Test material was a fine blend of quartz (Millisil W 4, Quarzwerke GmbH in Frechen, Germany) with grain sizes ranging from 4 µm to 200 µm (cf. Figure 8) and a specific density of 2,650 $kg \cdot m^{-3}$ The material does not agglomerate. Millisil W 4 was selected to be the best representative for solids in urban stormwater runoff (Dierschke et al. 2010).

The particles were dosed by a high precision dosing screw Typ K-MV-KT20 (K-TRON GmbH, Gelnhausen-Hailer, Germany). Accuracy tests at the beginning and the end of selected test series showed accuracies less than 2 %. At the outflow two grab samples respectively were manually taken at every sampling time (cf. chapter 2.3).

Particle analysis of one sample was done for TSS according DIN 38409-1 (1987) (membrane filters with a width of porosities 0.45 µm). Grain size distributions of the other samples were analyzed with a particle analyzer (EyeTech of Ankersmid GmbH, Düsseldorf, Germany).

2.2 Treatment devices

The treatment devices are tested in full scale. The tests were carried out with 10 devices of three companies being relevant for the german market. They are designed to serve for a range of 100 m² to 14,500 m² impervious area. All devices were filled with water before, during and between the tests.

The hydrosystem by 3P Technik, Donzdorf, Germany is a vertical vortex flow system with additional filter packages. The test was run for the subsystems HS 400 heavy traffic and HS 1,000 heavy traffic.

The sedi-pipe system by Fränkische Rohrwerke, Königsberg, Germany is a sedimentation pipe with diameters of 400 mm and 600 mm and a special sediment trap construction at the bottom to protect sediments against resuspension. The types 400/6, 400/12 and 600/12 were investigated as well as the subtype Sedi-substrator 400/6+ having a filter unit at the outflow.

The RAUSIKKO Sedimentation types M3, M9, R3 and R9 (REHAU, Erlangen, Germany) are the most simple systems consisting of a circular shaped pipe with a diameter of 1 m. Details are given in table 1. The subtypes differ in length and the type of in- and outflow constructions with scumboards at the in- and outflow (type R) or without (type M).

Table 1: Characteristics of the system RAUSIKKO

type of device		specials	lenght	diameter	volume	maximum impervious area for design
			m	m	m³	m²
REHAU RAUSIKKO sedimentation	type M3		3	1,025	2.356	1,050 – 4,200
	type M9		9	1,025	7.069	3,500 – 14,500
	type R3	scumboards	3	1,025	2.356	500
	type R9	scumboards	9	1,025	7.069	1,700

2.3 Test setup

Test series 1 investigates the maximum hydraulic capability of each treatment device. The occurrence of regular overflow or backwater defines the limit of the hydraulic capability.

Test series 2 focusses on the hydrodynamics and the sedimentation as a function on inflow. The tests were run with constant flow ranging from $0.1 \cdot Q_{max}$ to $1.0 \cdot Q_{max}$ with steps of $0.1 \cdot Q_{max}$. Dye tracer was manually dosed as a short impulse when the volume of the inflow was equal to the volume of the device ($\Phi = 1$, cf. chapter 2.4). The particle concentration at the inflow was 500 $mg \cdot L^{-1}$. The duration of each test varies with the flow ensuring an inflow volume of at least twice of the volume of the treatment device ($\Phi = 2$). Some of the tests were run longer to study the influence of inflow duration on the sedimentation processes. Grab samples at the outflow were taken at residence times between $\Phi = 1$ and $\Phi = 4$. After each test the device was cleaned to have defined initial conditions.

Test series 3 studies the sedimentation efficiency for a defined particle load. The basic idea of this test is to simulate approximately a one year particle load resulting from rainfall events of low and medium intensity and resuspension by a rainfall with high intensity. For practical reasons the time for the test should be limited. Therefore the load was applied with higher concentrations than normally occurring in urban runoff. Details are given in table 2.

The tests 3.1, 3.2.2 and 3.3 will be part of the formal approval procedure for decentral treatment devices in Germany. Test 3.3 accounts for flush out effects by resuspension of deposited materials of the previous two tests. It was run with tap water. The devices were not cleaned between the tests 3.1 and 3.3. Tests 3.2.1 and 3.2.3 were incorporated in the test series to study potential influences of particle concentrations on the sedimentation efficiency. Test 3.4 studied the repeatability of test 3.1. Before test 3.4 the devices were cleaned to get the same initial conditions as in test 3.1.

The inflow in $L \cdot s^{-1}$ of the individual treatment device is depending on the rain intensity according to table 3 and the maximum impervious area for which the manufacturer wants its device to be tested and approved. For the RAUSIKKO device data are given in table 3. The specific volume of the RAUSIKKO devices vary between 42 $m^3 \cdot ha^{-1}$ and 47 $m^3 \cdot ha^{-1}$ and are about four times larger compared to sedimentation tanks being state of the art in separate systems.

The future formal approval procedure will use a slightly modified test setup basing on test series 3 with an additional flow of 2.5 $L\cdot s^{-1}\cdot ha^{-1}$, a concentration of 3,472 $mg\cdot L^{-1}$ and a duration of 480 min.

The sampling times were defined multiples of the residence time at $\Phi = 1$, $\Phi = 1.25$, $\Phi = 1.5$, $\Phi = 1.75$ and $\Phi = 2.0$.

Table 2: Test setup data of test series 3

test no.	flow	concentration	duration	note
	$L\cdot s^{-1}\cdot ha^{-1}$	$mg\cdot L^{-1}$	min	
3.1	6	2,315	> 90 1)	
3.2.1	25	232	48	influence of concentration
3.2.2	25	1,153	48	
3.2.3	25	2,315	48	
3.3	100	-	15	resuspension, inflow: tap water
3.4	6	2,315	90	repeatability

1) duration until inflow volume is twice the volume of the device

Table 3: Test setup data for RAUSIKKO at test series 3

type of device		area	inflow at rain intensity of		
			6 $L\cdot s^{-1}\cdot ha^{-1}$	25 $L\cdot s^{-1}\cdot ha^{-1}$	100 $L\cdot s^{-1}\cdot ha^{-1}$
		m²	$L\cdot s^{-1}$	$L\cdot s^{-1}$	$L\cdot s^{-1}$
REHAU RAUSIKKO sedimentation	type M3	500	0.30	1.25	5.0
	type M9	1,700	1.02	4.25	17.0
	type R3	500	0.30	1.25	5.0
	type R9	1,700	1.02	4.25	17.0

2.4 Evaluation of dye tracer data

Dye tracer data are analyzed using the residence time distribution (e.g. Werner/Kadlec 1996). The dimensionless expression of concentration and time offers the opportunity to compare data of different hydraulic inputs and sizes of devices.

The dimensionless concentration c* is given by $c^* = c\cdot M^{-1}\cdot V_R$ with, c being the measured concentration of the dye tracer at the outflow ($mg\cdot L^{-1}$), M the mass of the dye tracer at the inflow (mg) and V_R the volume of the device (L).

The residence time is defined as the dimensionless flow weighted time $\Phi = VQ_{out}\cdot V_R^{-1}$. VQ_{out} can be obtained by $VQ_{out}(t) = \int_0^t Q(t)\cdot d(t)$ with the flow volume VQ_{out} (L) at the outflow, the time t (s) since injection of the dye tracer and the flow Q ($L\cdot s^{-1}$).

The dimensionless concentration can finally be expressed as a function of the dimensionless time by $c^*(\Phi) = c(\Phi)\cdot M^{-1}\cdot V_R$ being the residence time distribution. Integrating $c^*(\Phi)$ gives the residence time sum function $F(\Phi) = \int_0^\Phi c^*(\Phi)\,d\Phi$ describing the portion of dye tracer having passed the outflow at a certain time Φ. At $\Phi = 1$ the volume having flown through the outflow is equal to the volume of the reactor. The water volume in an ideal reactor has then being changed once.

Dye tracer time series can be described by characteristic parameters (cf. table 4) being indicators for certain characteristics of the flow (e.g. Stamou/Adams 1988). The parameter Φ_{10} can be used as an indicator for short circuit flow, the parameter Φ_{50} as indicator for the mass transport (also named as hydraulic efficiency) The parameter $\Phi_{75\text{-}25}$ is an indicator for the dispersion in the reactor.

The plug flow reactor (PFR) and the continuous stirred tank reactor (CSTR) characterize both idealized extremes of the flow behavior in a reactor. An ideal PFR is characterized by an output signal being congruent to a short input signal ($\Delta t \rightarrow 0$), passing the outflow at $\Phi = 1$ with no short circuit flow ($\Phi_{10} = 1$), equal flow in the reactor ($\Phi_{50} = 1$) and no dispersion ($\Phi_{75\text{-}25} = 0$). A CSTR shows directly after the input impulse the maximum output signal which then decreases approximately to zero. Characteristic values for a CSTR are a quick short circuit flow with $\Phi_{10} = 0.11$, a mass transport value

Φ_{50} = 1 and the dispersion Φ_{75-25} = 1.1. In addition to the above parameters the dye tracer signal can be described by the residence time of its begin Φ_i and the residence time Φ_{peak} of the occurrence of the maximum tracer signal.

Table 4: Parameters of the residence time distribution

parameter	indicator	note
Φ_{10}	short curcuit flow	residence time until 10 % of the dye tracer passed the outflow
Φ_{50}	mass transport	residence time until 50 % of the dye tracer passed the outflow
Φ_{75-25}	dispersion	residence time difference between 25 % and 75 % of the dye tracer passed the outflow
Φ_{peak}	maximum	residence time when the maximum dye tracer passed the outflow

2.5 Evaluation of Sedimentation data

The efficiency of the device was calculated (i) related to the concentration as $\eta_{c,TSS}$ and (ii) related to the particle load as $\eta_{l,TSS}$.

The concentration based efficiency $\eta_{c,TSS}$ was estimated for every sampling time calculated as a function of the concentration of TSS in the inflow $c_{TSS,in}$ and the outflow $c_{TSS,out}$. It was used for test series 2 and can be calculated by $\eta_{c,TSS} = 1-(c_{TSS,out} / c_{TSS,in})$.

The load based efficiency $\eta_{l,TSS}$ is used for test series 3 and the future formal approval procedure as well. The particle load B is calculated according to a convention which had been decided to use for the formal approval procedure. It bases on the experiments 3.1, 3.2.1 and 3.3. For every test k the flow volume VQ_k and the arithmetic mean of the concentrations $c_{m,k}$ of the five samples were calculated. The load at the outflow B_{out} is defined to $B_{out} = VQ_1 \cdot c_{m,1} + VQ_2 \cdot c_{m,2} + 0.5 \cdot VQ_3 \cdot c_{m,3}$. With the applied load at the inflow B_{in} the load specific efficiency is given with $\eta_{l,TSS} = B_{out} \cdot B_{in}^{-1}$

3 RESULTS AND DISCUSSION

3.1 Performance of the test procedure

3.1.1 Repeatability

The repeatability of the tests was investigated for three devices with two replicate tests respectively at low flows (cf. table 2 tests 3.1 and 3.4). The repeatability at low flow was considered to be important for the approval procedure because (i) most of the annual fine particle load is transported during low flow and (ii) the dosing of particles at the inflow has a higher relative error at low flow compared to that at higher flow. Figure 1 shows that the efficiencies $\eta_{c,TSS}$ of both tests are very similar. In 17 cases the differences were less than 1 percentage points. Only for RAUSIKKO R9 at Φ = 2 the difference amounts to 3 percentage points. The repeatability of the test procedure can be approved for low flow of 6 $L \cdot s^{-1} \cdot ha^{-1}$. Tests for higher flows have to be done.

3.1.2 Stationarity of the sedimentation process

The development of efficiencies during each test can be studied basing on the grab samples. Figure 5 shows the efficiencies $\eta_{c,TSS}$ depending on the residence time. Within residence times up to Φ = 2 decreasing efficiencies can be observed. It can be shown for all 10 devices that from residence times Φ > 2 the efficiencies remain to be nearly constant. The reasons for this effect will be discussed later in chapter 3.2.3. Concluding for the sampling strategy it is evident that samples in times Φ > 2 are meaningful to evaluate the efficiency under stationary conditions.

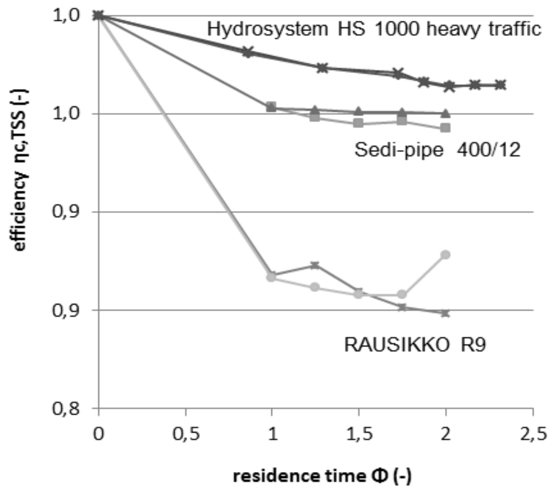

Figure 1: Results of repeatability tests

3.1.3 Influence of the inflow concentration on the efficiency

The results of the tests with different concentrations at medium flow of 25 L·s^{-1} (table 2, tests 3.2.1 to 3.2.3) are shown for three devices in figure 2. In all cases the efficiency for the concentrations of 1,153 mg·L^{-1} and 2,315 mg·L^{-1} are very similar with a maximum difference of 2 percentage points. The efficiencies for the low concentration of 232 mg·L^{-1} is systematically lower than that for higher concentrations. The maximum differences are -4 percentage points for Hydrosystem HS 1000, -8 percentage points for RAUSIKKO R9 and -6 percentage points for Sedi-pipe 400/12. Tests with high concentrations may overestimate the efficiencies of the devices a bit.

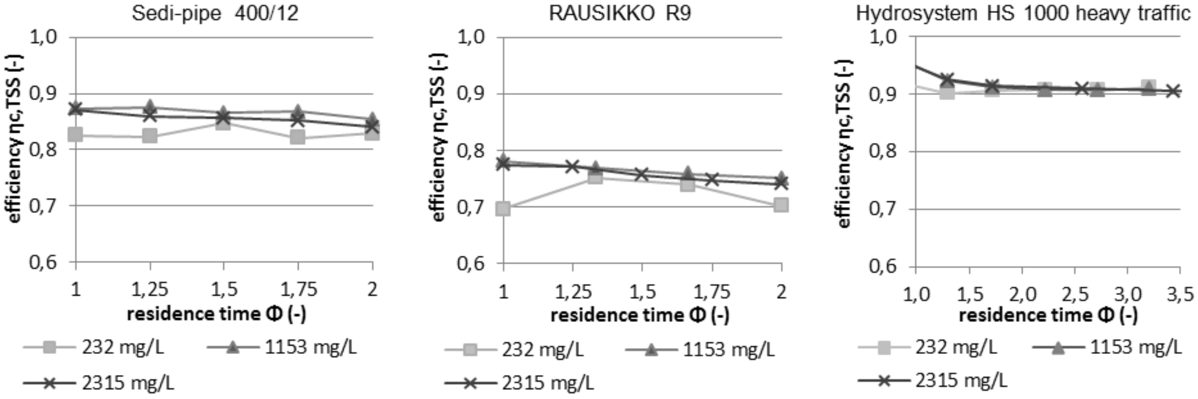

Figure 2: Influence of inflow concentration on the efficiency

3.2 Performance of treatment devices

3.2.1 Maximum flow

All sedimentation devices of the types Sedi-pipe and RAUSIKKO showed no significant flow resistance up to 60 L·s^{-1} being the maximum flow of the test rig. The Sedi-substrator 400/6+ showed considerable less hydraulic performance due to the high flow resistance of the filter units. The overflow started running at flows of approximately 3 L·s^{-1}. The Hydrosystem has less hydraulic capability due to the filter units. The maximum flows from which on the overflow spills off are limited to 1.5 L·s^{-1} for the HS 400 and to 14 L·s^{-1} for the HS 1,000.

3.2.2 Flow characteristics

The flow characteristic in the devices can be analyzed by the position and shape of the residence time distribution. In this paper results are given exemplarily for one of the simply constructed devices, the RAUSIKKO R9.

The residence time distributions are shown in figure 3 and their characteristics are given in table 5 and figure 4. At flows between 3.5 $L \cdot s^{-1}$ and 49 $L \cdot s^{-1}$ the device has quite similar behavior. The peaks occur in a range of $\Phi = 0.74$ to $\Phi = 0.93$. The higher the flow the nearer the peak is to $\Phi = 1$. The indicator for short circuit flow varies in $0.50 \leq \Phi_{10} \leq 0.82$. The mass transport indicator ranges in $0.85 \leq \Phi_{50} \leq 1.08$.The indicator for dispersion shows values of $0.24 \leq \Phi_{75\text{-}25} \leq 0.41$. All three indicators are independent of the flow in $3.5\ L \cdot s^{-1} \leq Q \leq 49\ L \cdot s^{-1}$.

The lowest flow of 1.02 $L \cdot s^{-1}$ showed a different behavior characterized by an earlier peak at $\Phi = 0.56$ and for $\Phi_{10} = 0.50$ and $\Phi_{50} = 0.85$ very low values. The value $\Phi_{75\text{-}25}$ could not be determined because of an extremely long tailing of the dye tracer signal.

At the highest flow of 56 $L \cdot s^{-1}$ the peak of the dye tracer occurs at $\Phi = 0.92$ and the three parameters $\Phi_{10} = 0.82$, $\Phi_{50} = 1.08$ and $\Phi_{75\text{-}25} = 0.41$ are the highest ones.

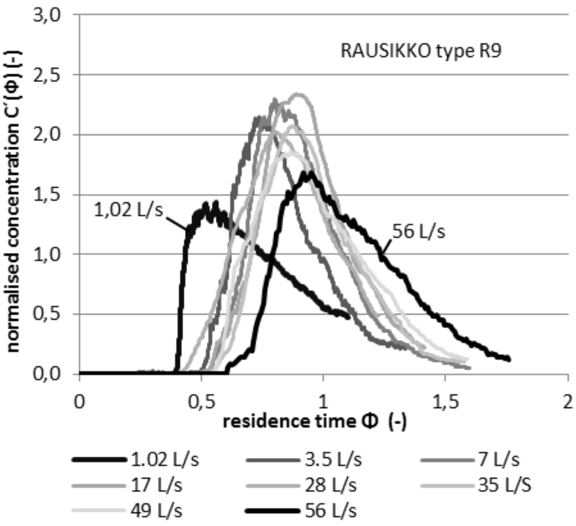

Figure 3: Residence time distributions of RAUSIKKO R9

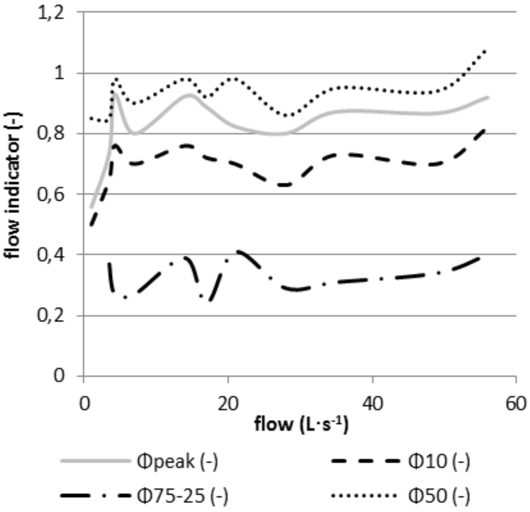

Figure 4: Characteristic parameters of the residence time distributions of RAUSIKKO R9

Table 5: Flow indicators of RAUSIKKO R9

flow	flow indicators			
Q ($L \cdot s^{-1}$)	**Φ_{peak} (-)**	**Φ_{10} (-)**	**$\Phi_{75\text{-}25}$ (-)**	**Φ_{50} (-)**
1.02	0.56	0.5		0.85
3.5	0.74	0.65	0.37	0.85
4.25	0.93	0.76	0.27	0.98
7	0.80	0.7	0.27	0.9
14	0.92	0.76	0.39	0.98
17	0.89	0.72	0.24	0.92
21	0.82	0.7	0.41	0.98
28	0.80	0.63	0.29	0.86
35	0.87	0.73	0.31	0.95
49	0.87	0.7	0.34	0.94
56	0.92	0.82	0.4	1.08

The RAUSIKKO R9 behaves in general like a non ideal plug flow reactor with peak signals and main mass transport occurring near to the residence time ($\Phi = 1$), low to medium dispersion and a low proportion of circuit flow. The highest flow ($Q = 56$ L·s^{-1}) shows the highest dispersion which may be due to higher turbulence. During low flow (1.02 L·s^{-1}) a quick peak and short circuit flow combined with high dispersion can be observed similar to a stirred reactor.

3.2.3 Efficiency during the charging

Figure 5 shows how efficiencies $\eta_{c,TSS}$ develop during the charging of a device. The efficiencies decrease from high values at the beginning to rather constant values from a residence time of $\Phi = 1.5$ to $\Phi = 2.0$. This effect occurs typically at the 10 devices which are filled with tap water at the begin. The first inflow displaces this clear water. Until then particle transport increases at the outflow according to (i) the flow pattern being observed during the tracer studies and (ii) the sedimentation process in the device.

It can be concluded that the device operates at the beginning as a plug flow reactor discharging its initial content. Thereafter it changes by and by to a fully developed reactor with stationary mass transport and constant sedimentation. Short chargings will have higher efficiencies than long chargings.

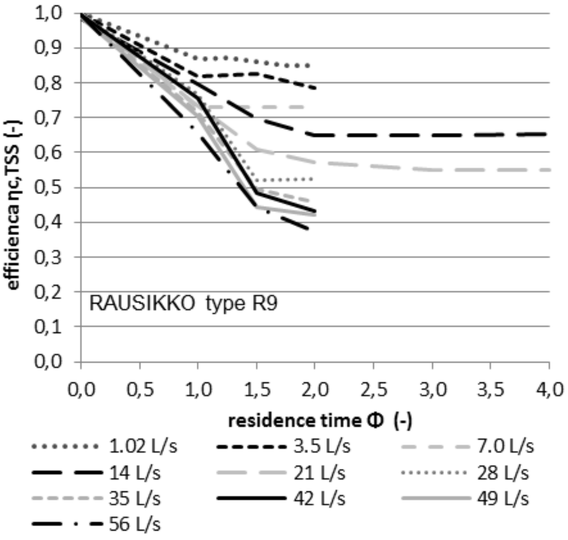

Figure 5: Efficiency depending on flow and residence time

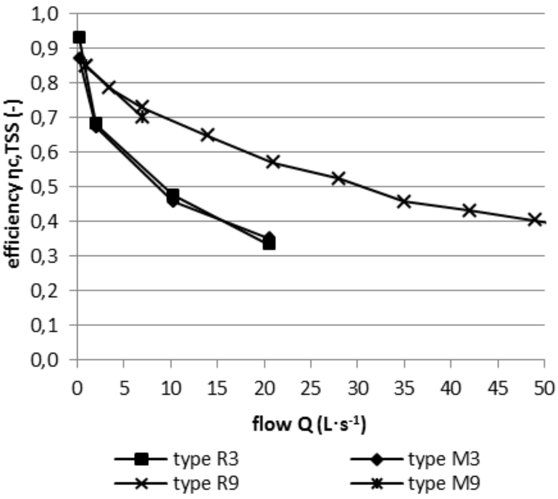

Figure 6: Efficiency of RAUSIKKO devices depending on flow

3.2.4 Efficiency depending on flow

Figure 6 shows the efficiencies of the RAUSIKKO devices as a function of flow in stationary condition at residence times $\Phi > 2$. Efficiencies decrease with increasing flow due to higher flow velocities in the sedimentation unit. The efficiencies of the RAUSIKKO R 9 device range from 0.85 at very low flow to 0.38 at the largest flow being tested. The type RAUSIKKO M9 without scumboards has similar efficiencies at low flows. Higher flows could not be tested for technical reasons of the test rig. The shorter devices RAUSIKKO R3 and M3 have similar but all in all lower efficiencies compared to the longer versions.

The efficiency can clearly be expressed as a function of flow. The length of the RAUSIKKO type sedimentation pipes influence the efficiencies whereas the scumboard does not influence the sedimentation noteworthy.

3.2.5 Resuspension

The outflow concentrations of the resuspension test (table 2, test 3.3) in figure 7 prove that resuspension occurs at all RAUSIKKO devices at 100 L·s^{-1}·ha^{-1} with outflow concentrations of up to 205 mg·L^{-1}. For RAUSIKKO M3 an additional test with 200 L·s^{-1}·ha^{-1} showed higher concentrations not exceeding 200 mg·L^{-1}. Although resuspension occurs a total flush out effect could not be observed.

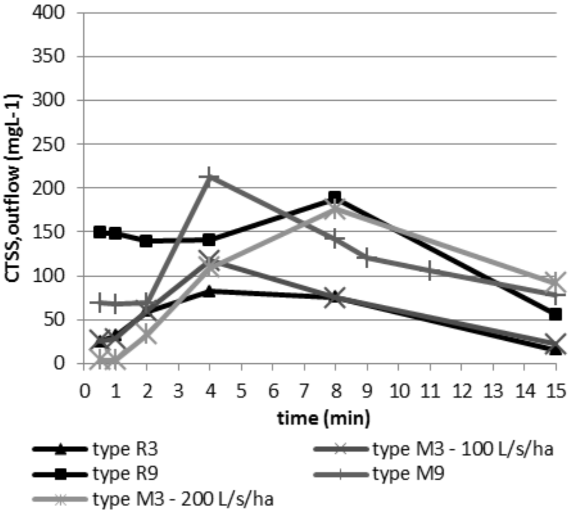

Figure 7: Pollutographs of the resuspension tests for RAUSIKKO devices

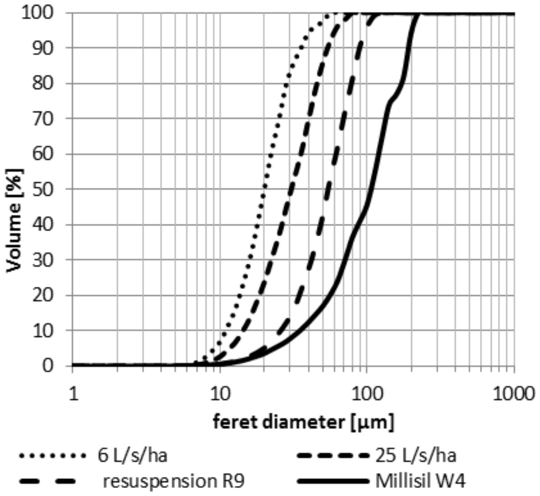

Figure 8: Grain size distributions for RAUSIKKO devices

Figure 8 shows the grain size distribution of samples during the tests 3.1, 3.2.3 and 3.3 at times with constant efficiencies at residence times Φ > 2. The results indicate that a classification process takes place depending on the flow, e.g. the flow velocities in the device. The lower the flow the finer the particles are in the outflow. At 6 $L \cdot s^{-1} \cdot ha^{-1}$ all particles larger than 60 µm were deposited in the device and 25 $L \cdot s^{-1} \cdot ha^{-1}$ this limit was 70 µm.

On the other hand the outflow contains in general fine particles less than 60 µm at low and medium flows. This finding is relevant for the treatment of particle bound substances being mostly associated with the fine particles. Further studies of the mass balances of fine particles in the devices are necessary.

During the resuspension test the particle distribution at the outflow indicates coarser material but being finer than the test blend Millisil W 4. Particles coarser than 100 µm remain in the device.

3.2.6 *Efficiency for the annual load test*

The mass balance of the annual load test consisting of test 3.1, 3.2.3 and 3.3 is given in table 6. The detention of solids is about 80 % TSS or more. During the low flow 3 % TSS to 7.3 % TSS passed the device. At medium flow 9 % TSS to 12.9 % TSS was emitted. The test with a short lasting high flow resulted in resuspension and discharge of 2 % TSS and less. Note that these values have to be doubled in reality because they are weighted by the factor 0.5 in the official mass balance formulae (cf. chapter 2.5).

Table 6: Mass balance of the approval test procedure for RAUSIKKO devices

test			**M3**	**R3**	**M9**	**R9**
3.1+3.2.3+3.3	TSS inflow	kg	16.668	16.668	5.671	56.671
3.1+3.2.3+3.3	TSS detention	%	79.3	86.2	80.3	80.6
3.1	TSS discharge at 6 $L \cdot s^{-1} \cdot ha^{-1}$	%	6.0	3.0	7.3	6.7
3.2.3	TSS discharge at 25 $L \cdot s^{-1} \cdot ha^{-1}$	%	12.8	9.0	11.4	11.6
3.3	TSS discharge by resuspension at 100 $L \cdot s^{-1} \cdot ha^{-1}$	%	2.0	1.7	1.0	1.1

4 CONCLUSIONS

A test procedure was developed to test the efficiency of devices for decentral stormwater treatment provided by the industry. The test setup allows to study (i) the efficiency and flow characteristic as a function of inflow (test series 2) and (ii) the efficiency for a total load similar to an average annual load (test series 3).

The repeatability of the test is proved for low flow conditions being the main inflow situation in practice. The test is run with higher concentrations than occurring in storm water runoff from practical reasons. The test results will overestimate the efficiencies of the devices only slightly. Steady conditions of flow and particle transport can be expected at residence times $\Phi > 2$ when the volume of inflow is twice or more of the volume of the device.

Test series 2 is elaborate but gives detailed information on how the devices work. It can be recommended especially during the development of the devices or simulation models for them. Test series 3 is simpler and was selected for practical reasons to serve for the future formal approval procedure in Germany for industrially produced decentral treatment devices.

Further investigations are recommended on (i) the reproducibility for medium and high flow conditions, (ii) the mass transport for fine particles with sizes < 63 µm, (iii) the influence of colmation of optional filter units in the treatment devices and (iv) the behaviour of particles with lower specific weights such as organic particles.

The performance of treatment devices is exemplified for a simple sedimentation pipe with four subtypes. They operate as a non ideal plug flow reactor with limited dispersion and low short circuit flow. The efficiencies are a function of flow and decrease during increasing flow. Mineral particles larger than 70 µm can surely be removed at low and medium flow. Finer particles may pass the device to a certain degree which is not yet known. Resuspension at high flow is very limited. Flush effects could not be observed. The efficiency according to an annual load (test series 3) is around 80 % for test particle blend with sizes ranging from 4 µm to 200 µm.

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