Development of testing procedures for the certification of decentralized stormwater treatment facilities – results of laboratory tests

Développement d'une méthode d'essai pour la certification des unités de traitement des eaux pluviales décentralisées – les résultats des essais de laboratoire

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RÉSUMÉ

Les émissions provenant du ruissellement de surface deviennent de plus en plus significatives pour la qualité des milieux récepteurs. Les unités de traitement décentralisées sont souvent utilisées en tant qu'alternative aux bassins de décantation primaires ou aux filtres de rétention au sol. Ces unités ne pouvant être régulièrement suivies in situ, une méthode d'essai en laboratoire doit être développée pour vérifier leur efficacité. Cette méthode d'essai sert de base aux agréments techniques nationaux en Allemagne, accordés par le Deutsches Institut für Bautechnik (DIBt, organisme allemand d'évaluation technique). Afin de garantir que les méthodes d'essai sont reproductibles, les essais sur la suppression des matières en suspension (MES) et des métaux lourds dissouts (cuivre et zinc) doivent être vérifiés en laboratoire. Cet article décrit le processus de vérification pour une unité en répétant la procédure d'essai et en en tirant une méthode d'essai finale. Pour l'essai sur les MES, une substance de silice, composée principalement de particules inférieures à 63 µm, est ajoutée à l'unité dans une installation d'essai grandeur nature. Pour l'essai sur les métaux lourds, de l'eau synthétique est pompée dans une colonne de filtration à petite échelle ou dans un segment du filtre. Les résultats ont montré que la méthode d'essai est reproductible et peut être utilisée pour les agréments techniques nationaux. Plusieurs facteurs influents sont décrits et utilisés dans la procédure de méthode d'essai.

ABSTRACT

Emissions from surface runoff are becoming increasingly significant for the quality of receiving waters. Decentralized treatment facilities are often used as an alternative to centralized sedimentation tanks or retention soil filters. As these facilities cannot be monitored regularly in situ, a laboratory test method must be developed to verify their efficiency. This test method is the basis of national technical approvals in Germany, issued by the Deutsches Institut für Bautechnik (DIBt, German technical assessment organisation). To ensure that the test methods are reproducible, the tests on the removal of total suspended solids (TSS) and dissolved heavy metals (copper and zinc) must be verified in the laboratory. This paper describes the verification process for one facility by repeating the test procedure and deriving a conclusive method of testing. For the TSS test, a silica substance, mainly consisting of particles smaller than 63 µm, is added to the facility in a full-scale test rig in the laboratory. For the heavy metal test, synthetic water is pumped into a small-scale filter column or segment of the filter. The results showed that the test method is reproducible and can be used for national technical approvals. Several influencing factors are described and used in the test method procedure.

KEYWORDS

Certification, Decentralized treatment, Lab-scale test, Surface runoff

1 INTRODUCTION

The success achieved in reducing pollution emissions from wastewater treatment plants led to the fact that emissions from surface runoff are becoming increasingly significant for receiving waters. For example, in river basins in North Rhine-Westphalia, more than 60% of the annual TOC (total organic carbon) and TP (total phosphorous) load originates from stormwater-related runoff (separate and combined sewer systems and road runoff) [MUNLV, 2010].

Therefore, measures are needed to reduce pollutant loads from stormwater runoff. This can be achieved using the following options:

- centralized treatment with sedimentation tanks and/or retention soil filter
- decentralized treatment facilities

To verify the efficiency of decentralized, stormwater treatment facilities it is important to develop a reliable method of testing. Since field monitoring of small facilities is expensive due to the large number of measuring points involved, one possible solution is to develop a suitable laboratory test method. The advantages of lab-scale tests are the lower costs involved and improved production of reproducible results. They are also used as the basis for national technical approvals, providing verified product quality assurance for design engineers and the competent authorities. In addition, other aspects such as regular maintenance must also be considered.

The different types of runoff (e.g. metal roof runoff, road runoff) and different legal situations that exist where water enters the groundwater or surface waters, a differentiation can be made between various situations in which decentralised facilities can be used efficiently (Figure 1).

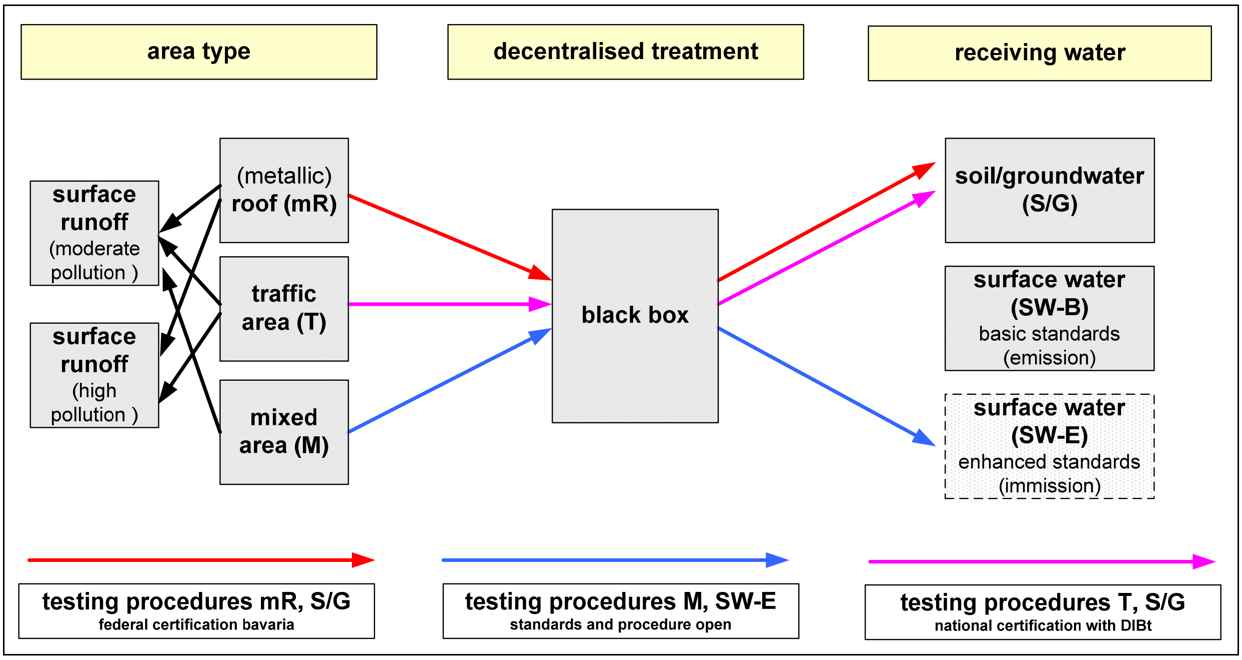

Figure 1: Illustration of typical applications for/use of decentralised treatment; mR: metallic roof; T: traffic area; M: mixed area; S/G: soil/groundwater, SW-B: surface water, basic standards, SW-E: surface water, enhanced standards, DIBt: Deutsches Institut für Bautechnik [adapted from DWA, 2010]

The DIBt procedure (pink arrow in Figure 1) is the most commonly used in Germany to verify the performance (effectiveness) of a specific decentralised facility in Germany. This approval is only valid if stormwater from hydrocarbon polluted areas infiltrates into groundwater. The surface water requirements for other pollutants are unspecified and have been the subject of recent discussions in Germany. Neither the pollutants themselves nor allowable limits have been defined (blue arrow in Figure 1).

The DIBt-certification procedure [DIBt, 2011] entails:

- tests for proving environmental compatibility of the materials used
- procedures for proving the conformity of the construction products
- notes on operation and maintenance
- testing the potential removal under laboratory conditions

Checking the hydraulic performance is not part of the test. This is ultimately the responsibility of the manufacturers and the design engineers who must design (the number of plants) to recognised good engineering practice standards.

The laboratory test procedure is used to examine the removal of total suspended solids (TSS), dissolved heavy metals (copper and zinc) and hydrocarbons. The annual load of the above-mentioned pollutants for three specific rainfall intensities (2.5; 6; 25 L/(s ha) or 0.9; 2.2; 9.0 mm/h) is applied to the treatment facility and the resulting effluents are sampled and analysed.

This procedure is similar to the approval procedure used in the US (TAPE), but does not include a field test program [Department of Ecology, Washington, 2011]. For TSS the material used is similar to Millisil, which is used in the German procedure (90 % < 63 µm, 100 % < 200 µm). While in Germany the removal rate for four different rain intensities must be at least 92 % in the US there must be 80 % reduction at the design flow rate. The German test is based on an annual load of TSS, which leads to increased inflow concentrations of approx. 2,300 mg/L TSS. The US test uses realistic TSS inflow concentrations of 100 mg/L and 200 mg/L.

Further differences between the two procedures are the pollutant parameters chosen. For example, nutrients such as phosphorous are not currently considered by the German regulations. By contrast, US systems can also obtain an approval for phosphorous reduction.

A very important requirement for the implementation of a general procedure is a method, which produces reproducible results. This is a precondition for certifying treatment systems for nationwide use. Field tests results are highly dependent on the specific conditions of the catchment area and annual climatic changes. This leads to different results when testing the facilities. The German DIBt therefore chooses laboratory testing methods. In this paper the main objectives are: to describe the conditions of the certification procedure developed in Germany and to demonstrate the verification phase by carrying out a lab-scale test series.

2 METHODS

2.1 Lab-scale test concept

The efficiency of total suspended solids (TSS) removal in treatment facilities is tested in a full-scale facility in the laboratory. The retention of heavy metals is normally tested in a filter segment or a test column of the filter element on a smaller scale to reduce the quantity of polluted wastewater required for the test [DIBt, 2011].

The material used for the TSS test is a silica substance (Milisil) that mainly contains particles smaller than 63 µm. Fine solids are a problem, because many pollutants are transported with these fine particles [Xanthopoulos and Hahn, 1990; Dierschke et al., 2010]. The annual pollution load is divided between three test rain intensities with a weight distribution of 3:2:1. These rain intensities represent the typical rainfall pattern in Germany. Following the three rain intensities an additional test is carried out with a heavy rain intensity of 100 L/(s·ha) or 36 mm/h to analyse possible washout of trapped TSS in the system. This test is carried out with no TSS load in the inflow. In the DIBt test procedure, the retention of hydrocarbons is also tested, but is not discussed in this paper.

The test to determine the retention of heavy metals is carried out in a reduced test segment. Here the annual loads for dissolved copper and zinc are evenly distributed between the three rain intensities selected. An additional test with de-icing salts completes the heavy metal test. The reason for this additional test is that the sodium (Na^+) in salt can wash out heavy metals absorbed by filters. The following table summarises the testing procedure steps.

Table 1: description of the testing procedure

Test method	Test facility	Test conditions
TSS	original size	3 test rain intensities (2.5 L/(s · ha) for 8 hours; 6 L/(s · ha) for 200 minutes and 25 L/(s · ha) for 48 minutes). with an assumed annual load : 74 mg/L TSS in 677 mm surface runoff 1 rain intensity (100 L/(s·ha) or 36 mm/h) without TSS after a waiting time of 16 h (minimum)
copper + zinc	reduced filter segment diameter = 10 cm, height = 45 cm (analogical original height)	3 test rain intensities (2.5 L/(s · ha) for 8 hours; 6 L/(s · ha) for 200 minutes and 25 L/(s · ha) for 48 minutes) with an annual load of dissolved heavy metals Basis of calculations used to estimate the annual load : 15.5 mg/m² dissolved copper and 135 mg/m² dissolved zinc produce concentrations in the inflow of 0.72 mg/L copper and 6.25 mg/L zinc

2.2 3P treatment facility

The facility tested (3P Hydrosystem heavy-traffic, 3P-Filterechnik GmbH) (Figure 2) is designed for a traffic area of 500 m². The treatment unit consists of a hydrodynamic separator with an upflow filter. In this system the water is treated by sedimentation, filtration, ion exchange and chemical precipitation [Dierkes et al. 2008]. Incoming stormwater is fed down to the base section of the filter shaft. A hydrodynamic separator facilitates the sedimentation of particles. A tangential inlet induces a radial flow pattern. A silt trap is situated below the separation chamber, so that particles cannot be remobilized by intense rain events. Above the separator there are four filter elements covering the full width of the shaft, so that the water has to flow through the filter by means of hydraulic pressure. The filter elements can be easily replaced. The treated water finally passes through an oil trap and is directed towards the receiving water or an infiltration facility. The units have a fixed central pipe. This central access is used to desilt the silt trap chamber.

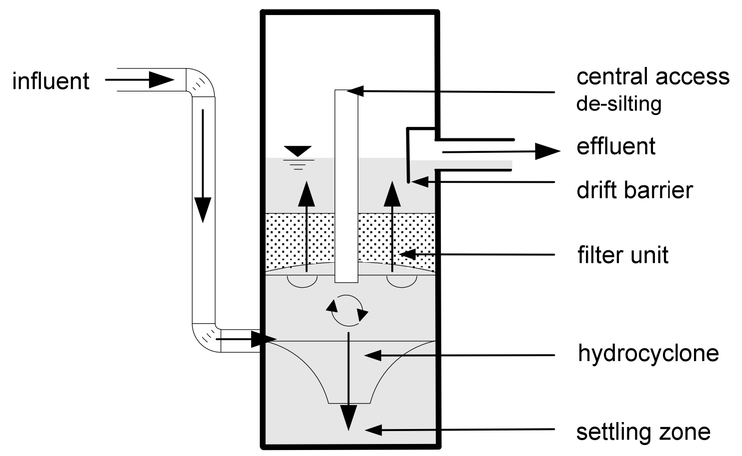

Figure 2: Schematic diagram of the 3P treatment facility

Four filter elements are installed in each unit. These can be replaced within the standard manhole. The filter elements consist of a polyethylene container with stainless steel screens. They are filled with a specific substrate in which several processes take place. It has a large inner surface area for sorption of substances. The surface itself induces ion exchange in order to trap heavy metals and other positive ions.

2.3 Lab-scale test on the removal of TSS and heavy metals

The silica matter has to be added continuously to the inflow of the facility with a tolerance of ± 5 %. Input of the TSS can begin when a stable flow exists within the facility. Following rain event 3, a period of 16 h to 24 h must pass before rain event 4 occurs.

Glass bottles with at least 1 litre capacity are used to obtain the water samples for analysis of the TSS removal. The samples are taken from the continuous flow at the outlet. Sampling starts after sufficient water has passed through the facility to exchange the water in it at least once. For rain intensities 1 to 3, five samples are taken at each rain intensity. These are then divided into two samples each for double analysis. The sampling is evenly distributed over the total test time. At rain intensity 4, 15 samples are taken at intervals of 1 minute. The first sample is taken one minute after the flow rate has been reached.

Each sample is filtered over a dried and weighed filter with a mesh size of 0.45 µm according to [DIN EN 872, 2005].

The results produced by the 5 samples are averaged for each intensity. For rain intensity 4 the average is calculated from the results of 15 samples. The test results are positive if 92 % of the TSS mass were retained by the facility.

For the heavy metal test, deionized water to which copper and zinc has been added is pumped through the reduced-size filter segment (Figure 3 and 4). A tank with a maximum volume of 200 L is filled with deionized water (electrical conductivity < 200 µS/cm), copper and zinc standards are added and the solution is mixed and adjusted to exactly pH 5.0. A peristaltic pump pumps the solution through the filter column. A flow meter checks for the correct flow rate continuously throughout the tests.

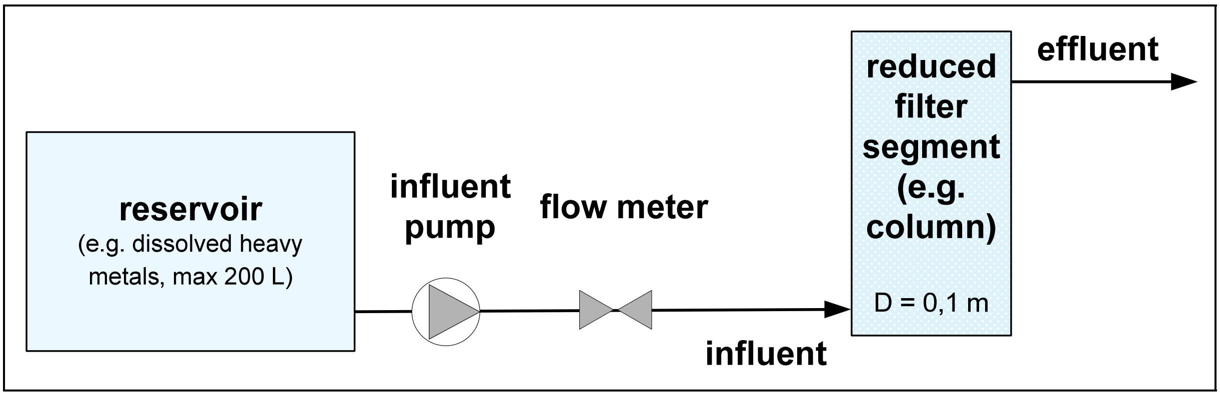

Figure 3: Schematic diagram of the heavy metal test in reduced-size filter segment (e.g. columns)

The filter segment is charged with spiked water at three flow rates and the corresponding times according to table 2. The flow rates must be within a tolerance of ± 10 %. After the water in the columns is exchanged at least once, four samples (> 100 ml) are taken at equal time intervals. All samples are analyzed to determine the zinc and copper levels according to [DIN 38406-21, 1980].

The concentration of each test is calculated using the average of the four individual samples. Samples are taken from the tank and from the effluent of the filter segment. The average of samples A and B and the average of the four samples are also calculated here. At least 80 % copper must be removed, and at least 70% zinc.

Figure 4: Photo of the heavy metal test in columns

A summary of the TSS and heavy metal test procedures is given in table 2.

Table 2: Conditions of sampling and analytical procedures

Test method	Sampling and calculation of the results	Analytical methods
TSS	Five samples (A and B samples), each sample 1 L per rain intensity, first sampling takes place after volume of the treatment facility has been exchanged once by the flow calculation of the mean for A and B sample, calculation of the mean for each rain intensity remobilization test (100 L/(s·ha)) : 15 samples (1 sample per minute, each sample 1 L volume) calculation of mean value from 15 samples	DIN 38406-21 (1980)
copper + zinc	Added to columns from bottom up using pumps per rain intensity : 4 x 2 samples (A and B samples) at equal time intervals calculation of mean result of A and B sample, calculation of mean result for each rain intensity	DIN EN 872 (2005)

3 RESULTS

3.1 Total Suspended Solids (TSS)

Figure 5 shows the results obtained from three TSS removal tests. The reproduction of TSS removal is very good and achieves the mandatory minimum limit for the DIBt approval of 92%. The results lie within 93.4 to 93.9 %. Despite the uncertainties that exist in estimating the flow rate, dosages, and in the sampling and analytical method the results show a similar behaviour in all tests carried out.

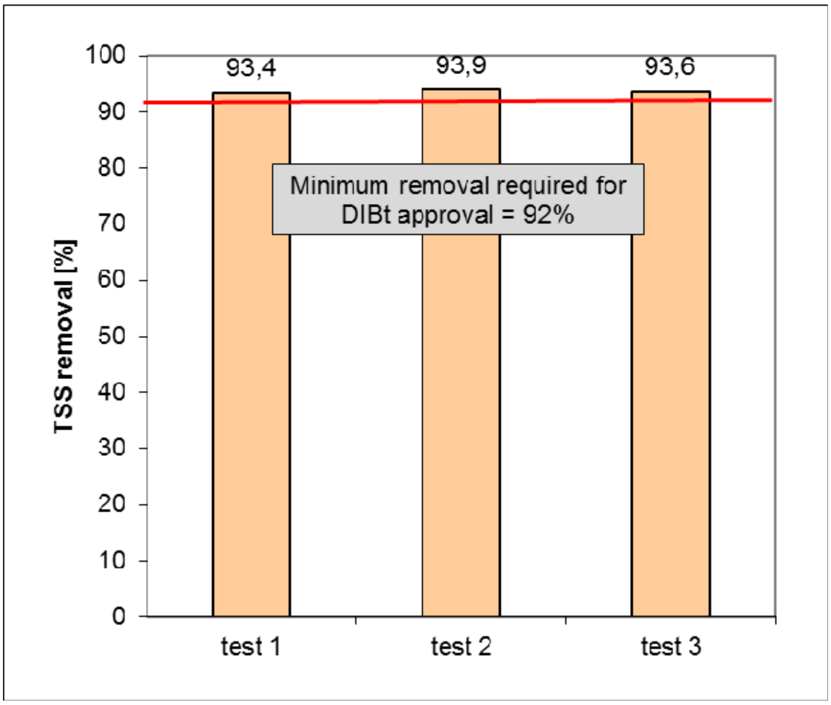

Figure 5: TSS-removal in three tests on the 3P-facility

In conclusion, the test rig and the test method are practicable and deliver reproducible results in a short time. The following specific conditions should be considered carefully:

- Presettling of TSS in the inlet should be avoided by providing sufficient slope and by visual checking. Use of a Plexiglas tube can be helpful.
- It is important that the dosing into the inlet is homogeneous. This can be ensured by using appropriate equipment, e.g. dosing screws from the pharmaceutical industry, see Figure 6.

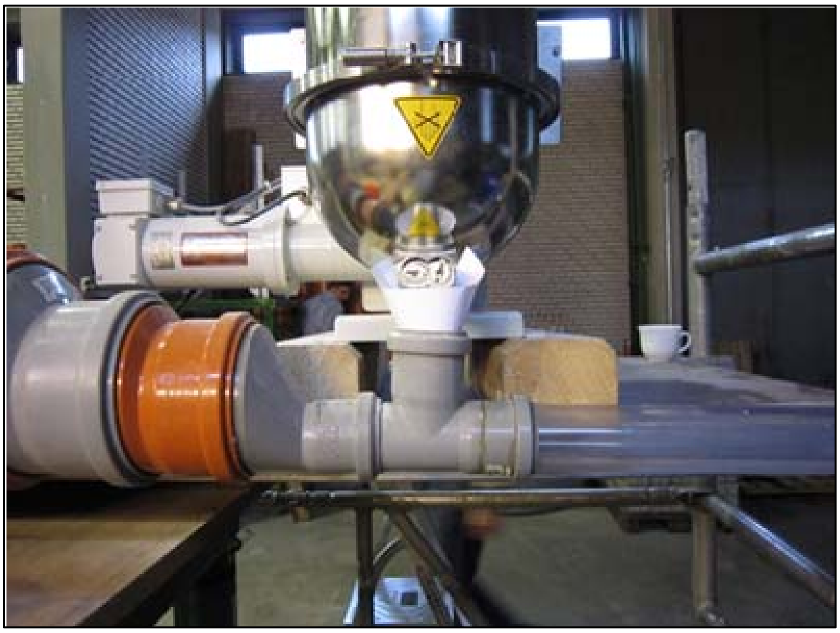

Figure 6: TSS-dosing screw

- Glass sampling bottles must be used, small particles can stick to the walls of plastic bottles
- Each sample must be at least 1L in volume. Smaller sized samples cause uncertainties in the analysis
- For the test with the purge event (100 L/(s · ha) or 36 mm/h), the test equipment should ensure that the water flow is stable within 10 seconds
- The sampling of the purge event should be started within the first minute of the test to obtain the maximum possible total amount of resuspended solids from the facility

3.2 Zinc

Figure 7 shows the results of the zinc tests (n=6). Very reproducible results can be obtained for the lower rain intensities (2.5 L/(s · ha) and 6 L/(s · ha)).

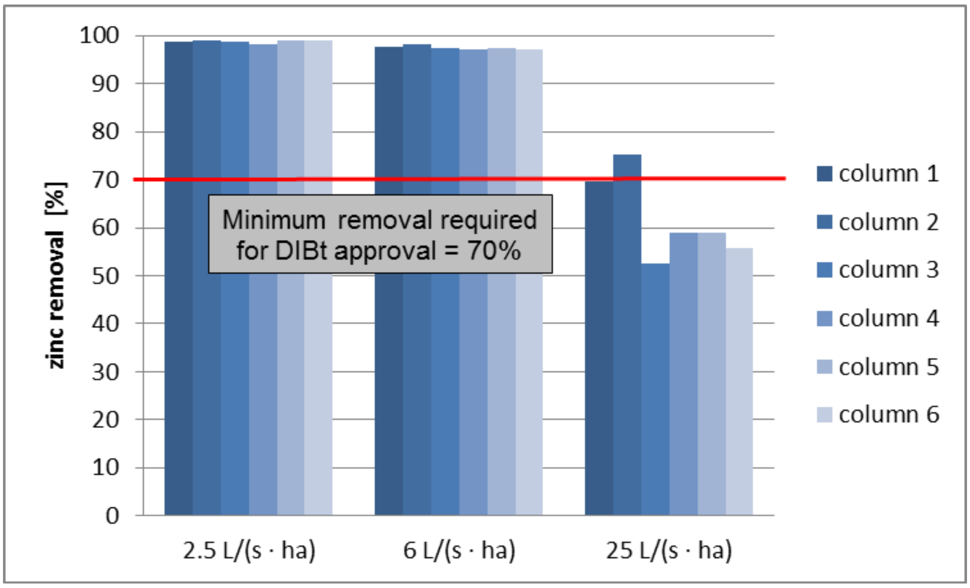

Figure 7: Removal of zinc in six filter columns and three test rain intensities

The results observed with the higher rain intensity (25 L/(s · ha)) are not consistent. Two phenomena that could cause this are discussed in the following:

The procedure used to add the filter material to the column (bulk density) is important for the test results. The filter material in columns 1 and 2 were filled by checking the volume and the material was compacted slightly. The mass of the filter material of columns 3 to 6 was added by weighing the material and it was not compacted. Therefore more filter material was added to columns 1 and 2 compared to columns 3 to 6. The removal efficiency of columns 3 to 6 is therefore significantly lower than in columns 1 and 2. One conclusion of these tests is that it is very important to clearly define the column filling procedure to ensure that each contains the same mass of filter material.

Apart from the filling procedure, generally higher inhomogeneity can be observed at higher flow rates (Figure 7). This may be due to more turbulent flows in parts of the column filter material at 25 L/(s · ha) or 9 mm/h. Therefore, the flow through the ion exchange filters is less uniform.

Total removal of zinc [%] is shown for all six columns in figure 8.

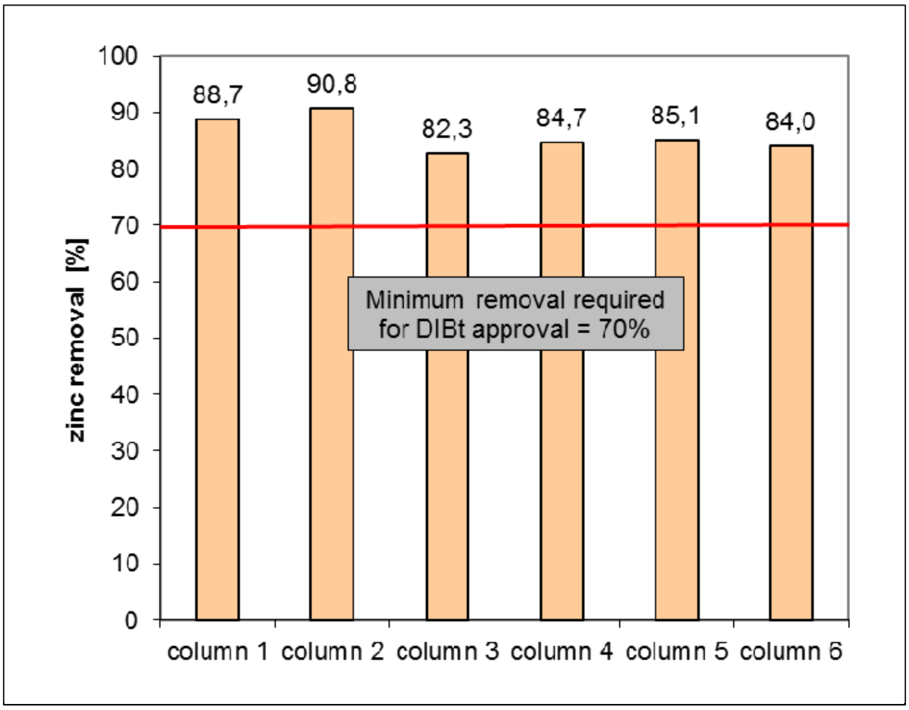

Figure 8: total removal of zinc in six filter columns

It can be seen that the results from columns 1 and 2 are similar, while although columns 3 to 6 show worse results, they are similar to each other.

Considering the different filling method (compacted / uncompacted) column 1 and 2 can be viewed as being one test and columns 3 to 6 as a further test under these conditions.

The results of the first test (column 1 and 2) differ by 5 % for copper and 2.1 % for zinc (highest and lowest value). Here it can be seen that the compaction of the filter material can cause different filter masses to occur. For the second test (columns 3 to 6) with identical mass of filter material, the results are significantly reproducible. The difference for copper was 3.8 % and for zinc it was 2.8 % (comparison of the highest and lowest single value).

Concluding, the DIBt testing procedure for heavy metals leads to reproducible results by exactly considering the following boundary conditions:

- The method used to place the filter material in the columns is important for the reproduction. The filter material should be weighed and added to the filter column according to the manufacturer's instructions. The installation instructions are part of the national technical approval, "construction" section.
- The inner diameter chosen for the columns of 10 cm was practicable.
- The pH of the heavy metal solution should be exactly pH = 5. On the one hand, the heavy metals must be 100 % dissolved in the solution, on the other, the filter material's exchange capacity should not be hindered by H+-ions in the water. This was specified in the test procedure instructions.
- A further aspect is the behaviour of the ion exchange at high flow rates through the filter media (25 L/(s · ha) or 9 mm/h). Turbulence in the filter media in parts of the filter could cause inconsistencies. Additional tracer tests (not published) showed this fact clearly.

4 CONCLUSIONS

Results of the verification phase led to the following modifications to the test method.

- Strict instructions are required for performing the test and appropriate measurement equipment must be used
- The allowable tolerances for the test equipment must be specified clearly
- The chemical composition of the synthetic runoff must be specified
- The installation of the test columns must be defined accurately (e.g. the filling conditions)

Implementation of a verified test method enables certification of different treatment facilities. This is a precondition for producing reproducible results in different places and leads to equitable conditions for the different manufacturers. At present, several nationwide approvals have been issued by the DIBt. This is a useful decision-making factor for government authorities to use when considering the installation of decentralized stormwater treatment facilities.

ACKNOWLEDGEMENT

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