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Removal of Volatile Solids from Greywater Using Sand Filters

Marcin Spychała, Jakub Nieć *, Paweł Zawadzki, Radosław Matz and Thanh Hung Nguyen

Department of Hydraulic and Sanitary Engineering, Poznań University of Life Sciences, 60-637 Poznań, Poland; marsp@up.poznan.pl (M.S.); pzaw@up.poznan.pl (P.Z.); rmatz@up.poznan.pl (R.M.); nthungster@gmail.com (T.H.N.)

* Correspondence: jniec@up.poznan.pl; Tel.: +48-61-848-7769

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Abstract: Sand filtration is a primary stage of treatment for reuse of greywater. This study aimed at assessing the volatile solid removal efficiency of a sand filter and imitating its performance using analytical simulation. This study used artificial greywater, medium sand as a filtering material, and nine PVC cylinders as filter columns. Samples of the sand were collected after 6, 14 and 21 days, with the aim of specific deposit determination. The vertical distribution of specific deposit (volatile solids) in the sand filters was typical for gravitationally operated sand filters. Relatively high removal efficiency of volatile solids (51–60%) was achieved at relatively low cumulative hydraulic load. The average removal efficiency of organic compounds (detected as chemical oxygen demand) was 26.8%. Maximum specific deposit was achieved for a cumulative hydraulic load of 363.6 m. The filter coefficient was identified empirically for application of the Iwasaki formula. The filter coefficient λ was corrected for a better fit of the modelled values with measured values.

Keywords: greywater; filter coefficient; modelling; sand filter; specific deposit

1. Introduction

With shrinking resources and rising costs of water treatment (for example in sand filter), the reusability of water is technologically and economically justified. According to the literature, greywater, which has a lower sanitary hazard than domestic sewage, is acceptable for research and implementation [1,2].

Population growth, industrialization, and climate change have resulted in worldwide scarcity of fresh water. This is not limited to arid or semi-arid regions, but has also surfaced in many countries in Asia, South Africa, and southern Europe [3,4]. In addition, half of the population in India and China is facing water shortage [5] and two-thirds of the world's population will face some sort of water stress by 2025 [6].

This shortage has promoted interest in finding an alternative source of water. Greywater, thus emerges, because it can be treated for non-potable reuse, such as flushing of toilets, irrigation, and washing, saving up to 30–60% of household water consumption [7,8]. Greywater, defined as wastewater generated from washing basins, baths and showers, washing machines, and the kitchen, accounts for 50–80% of the total volume of household wastewater [8,9]. Low-load greywater, which excludes kitchen sources, was found to be responsible for up to 70–75% of the total domestic wastewater volume, and shows feasibility for treatment and reuse because of its characteristics and composition [10,11]. The amount of greywater generated per person varies among countries and territories, and is dependent on several factors, e.g. 70–140 dm^3/person in developed countries, 127–151 dm^3/person in the United States, and 20–30 dm^3/person in developing countries [12–14]. Greywater contains products such as soap, shampoo, shower gel, powders, skin, hair, and pathogens, which are a result of human activities. However, the concentration of organic pollutants and nitrogen compounds in greywater is lower than that in household wastewater [7]. The particle size of greywater is in the range of 10-100 μm [15]. Moreover, the physicochemical characteristics of greywater depend on the quality of water supply, lifestyle, activities of people, material of the water supply pipe, household products used, and other factors [10]. Organic matter (soluble and particles) in greywater is an important parameter that helps assess the quality of treatment for reuse, owing to its potential risk to air, soil and plants [16].

Sand filters have been studied and applied in greywater treatment; they offer a common, low-cost technology with easy operation and maintenance, and efficient removal of total suspended solids (TSS) [17,18]. Several studies have shown that sand filters efficiently remove COD and TSS [11,16,17]. However, the efficiency of removal varies and depends on many factors—particle size, hydraulic loading rate, and height of the sand layer, among others. In addition, Chaillou et al. [11], in their study, concluded that a biofilm is formed on the sand filter, thus enhancing COD removal. Furthermore, the mean mass of organic matter in samples of filter sand was found to be basic for developing biofilms [11].

Sand filters are becoming popular and have been achieving economic efficiency in greywater treatment for reuse in households and for irrigation in regions of water shortage [18,19]. Sand filters that are used in greywater treatment need more attention, as there is a lack of research on clogging time, distribution of organic matter in the vertical column of the sand filter (potential for formation of biofilm), and loading treatment.

Slow down-flow sand filtration has low treatment efficiency, but is useful as a primary treatment stage for greywater reuse, due to its construction simplicity and ease of washing (most frequently by backwashing). Due to the relatively low cost of tap water in Poland (about 2–3 EUR m^{-3}), there is the need for easy and cheap solutions. Technically sophisticated and expensive systems (taking into consideration both investment cost and operational costs) seem to be economically inefficient.

The removal of solids from a solution can be treated as deep bed filtration, a process of deposition in filter material pores [20]. Among the many processes and mechanisms of deposition [21], the ones most commonly used in mathematical modelling are particle bridging and capture in porous media, size exclusion, gravity segregation, electrical forces (double electrical layer, London-Van der Waals forces) and transport (interception, diffusion, hydrodynamic action, sedimentation, straining, ortho-kinetic flocculation [22] (large particles), Brownian motion, electrostatic forces, surface area concentrations, bridging and coagulation [23,24] (small particles)).

The filter coefficient (sometimes called filtration coefficient) is one of the most crucial parameters in particle filtration (transport and deposition processes; it uses a filtering (porous) medium as per the classical deep bed filtration theory developed by Iwasaki [1] and modified by many authors [23,25]. The filtration coefficient is the probability of a particle to be captured during its flow over the unit distance [25].

Many hypotheses about the relationship between the filtration coefficient and specific deposit have been developed [1,26–31]. There are other approaches to filtration coefficient identification and description in deep bed filtration (macroscopic, microscopic [20,32] and probabilistic [33]. An interesting hypothesis on the mechanisms of deposition at different filter depths was made by Gitis et al. [34] using attachment and detachment rate coefficients.

Several analytical models have been developed using constant and dynamic filter coefficients [23,25].

So far, mainly conventional technologies and constructions have been investigated and used on a technical scale [18]. There are several literature reports that describe modified or alternative systems [35]. There are only a few reports related to modelling of solids removal from greywater, but most of them assume both mechanical and biological processes [36].

The aim of this study was to assess the removal efficiency of a sand filter used for mechanical greywater treatment, as the primary treatment stage, and to simulate its performance using the known Iwasaki formula. For application of this formula, a filter coefficient was empirically identified. The vertical distribution of solid in the sand filter, and maximum deposition and lifespan (clogging time) were determined with both practical (operational) and theoretical (modelling) aims. The aim of this study was to propose a model of mechanical distribution of volatile solids in sand for engineering applications.

2. Materials and Methods

2.1. Experimental set-up

Medium sand (according to a unified particle size scale, SP—poorly graded sand, according to ASTM D-2487 [37], coarse sand—in accordance with the American Association of State Highway Officials particle size scale, and coarse to very coarse sand—in accordance with the United States Department of Agriculture particle size scale) was used as a filtering material. The basic properties of the sand were as follows: d_{60} = 0.8 mm, d_{10} = 0.55 mm. These parameters were used to describe the general shape of the grain-size distribution curve. The ratio of d_{60} to d_{10} was less than 5, defining soil as uniform; bulk density (after introduction into the columns and compaction) = 1.6 g cm^{-3} and porosity equaled 30% [38].

The sand was washed with a solution of hydrogen peroxide 7.5% before it was put in the filter columns. The washing was performed by submerging the sand in the solution for approximately 1 h. It was then taken out and washed one more time with the same solution. The clean sand, in doses of same mass and volume, was filled in the filter columns. After each column was filled to 5 cm, it was lightly shaken to ensure that it was packed as densely as possible.

Nine PVC cylinders (1–9) were used as filter columns (Figure 1)—they were 60 cm long, had inner diameter of 34 mm, and were filled with 50 cm of sand. The bottom of each column was sealed with a round textile coupon. A damping sponge was used in each column to ensure a uniform stream of the dose in the cross-section surface area and to avoid disturbance of the top layer of sand. The outflowing greywater from each filter was collected into a 1.5 dm^3 volume chamber with the aim to measure outflow rate and collect samples for physico-chemical analyses.

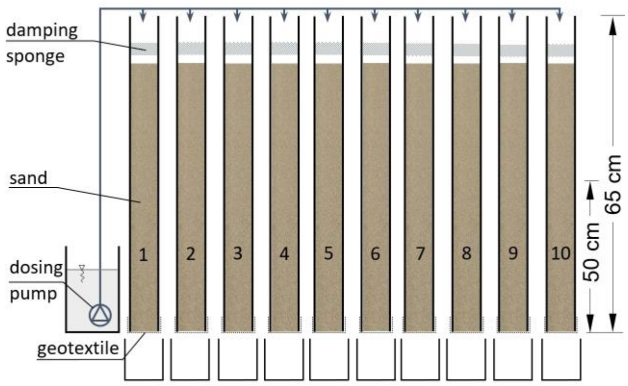


Figure 1. Scheme of experimental set-up.

2.2. Artificial greywater

The selection and proportions of ingredients used in the preparation of artificial greywater was based on properties comparable to greywater used in Polish households and that mentioned in the literature [39].

The artificial greywater solution was composed of 2.6 g of washing powder (Ariel, Procter and Gamble, Warsaw, Poland), 1 g of shampoo—Head & Shoulders (Procter and Gamble, Warsaw, Poland), 1.57 g of shower gel—Palmolive (Colgate-Palmolive, Warsaw, Poland), 0.12 g of liquid soap (Serpol-Cosmetics Ltd, Poland) and 10 dm^3 of tap water. It was prepared once a day.

Based on the above-mentioned content, the volumetric proportions of the ingredients were arranged to obtain those that are typical for natural greywater—from shower (62%), laundry (31%) and wash basin (7%)—and mentioned in the literature by other authors [7,19].

The following indicators were measured during the experiment: chemical oxygen demand (COD)—with the aim of identifying organic compound removal efficiency; volatile solids (VS)—with the aim of identifying the mechanical treatment (solids removal efficiency); pH and electrical conductivity (EC)—with the aim of defining raw greywater properties and assessing the changes of these indicators during filtration. The values of artificial greywater pollution indicators are presented in Table 1. COD was measured using a photometric procedure and VS (the sum of suspended and dissolved volatile solids) concentration was detected as ignition loss. EC was measured using an EC-3 meter.

Table 1. Artificial greywater characteristics.

Specification	Concentration	Standard Deviation/(Number of Repetitions)
Chemical oxygen demand (COD)	199.6 mg O_2 dm^{-3}	4.8/(16)
pH	9.0	0.5/(6)
Volatile solids (VS)	160.3 mg dm^{-3}	4.8/(11)
electrical conductivity (EC)	1060 S m^{-1}	60/(6)

2.3. Hydraulic loadings of filtering columns

To accelerate the accumulation process, a multiple hydraulic load was used—161.3 ± 5.5 cm d^{-1} compared to other studies, e.g. Sangeetha et al. [40]: 7.0 or 10.0 cm d^{-1}, which is comparable to the predicted cumulated hydraulic load for the advanced, but not complete clogging process. Such an approach was justified because the examined process is mechanical and time-related side-effects can be neglected.

Assuming a mechanical process of VS removal, the higher daily hydraulic load of greywater was applied. Thus, the cumulative hydraulic load (after a certain time) applied in this study can be compared to that of other studies (the time can be neglected, but total hydraulic and pollution loads are significant).

The daily hydraulic load was much higher than loads reported in the literature (Abdel-Shafy et al. [17]: 8.6 cm d^{-1}–17.3 cm d^{-1}; Ochoa et al. [19]: 16.0 cm d^{-1}), but the cumulative hydraulic load (363.6 cm after 21 days)—representative of an advanced clogging process and significant solid removal efficiency—was comparable to other studies [17,19].

The flow rates for all the filter columns were similar, but not the same (Table 2). The average flow rate for all columns was 161.3 ± 5.5 cm d^{-1}. The lowest flow rate was observed for column 8 (142.83 ± 6.8 cm d^{-1}) and the highest for column 2 (182.63 ± 10.5 cm d^{-1}).

Table 2. Hydraulic load of columns.

Column number	Hydraulic Load (cm d^{-1})	Standard Deviation (cm d^{-1})	Filter Operation Time (Day)
1	144.4	7.9	14 days
2	182.6	10.5	6 days
3	181.9	10.4	6 days
4	150.9	7.0	14 days
5	152.3	6.3	21 days
6	152.3	6.9	21 days
7	180.8	10.5	6 days
8	142.9	6.8	14 days
9	163.5	6.6	21 days

The filters were dosed every hour and can therefore be treated as intermittent sand filters (ISF). Ten pumps (brushless DC pumps, model QR30E, H_{max}: 300 cm, Q_{max}: 240 $dm^3\ h^{-1}$, input: DC 12 V, 4.2 W) controlled by a timer were used for greywater dosing.

2.4. Determination of specific deposit (VS) distribution in vertical profile of sand filter

The samples of sand were taken from the first three filter columns (2, 3, 7) and examined after 6 days of the experiment. After 14 days, the next batch of sand samples were taken from columns 1, 4, 8 and examined. The last three columns (5, 6, 9) were examined after 21 days as per VS (kg m^{-3}). The vertical profile of the filters were conventionally divided into 16 layers with the aim of determining organic matter content. The first seven layers (depths) of the filters (from which the organic matter was examined) were determined at a distance of about 2.5 cm. The next six layers were determined at a distance of about 5.0 cm. The thinner upper layers were determined according to the expected higher changeability of dry mass in depth. The experiment was conducted at room temperature (about 20 °C) in a laboratory.

The maximum specific deposit was specified using column number 10 (Figure 1). It was identified at the time of operation, when the value of the infiltration velocity dropped below the hydraulic load (greywater stagnating on the sand filter surface).

The simulation, performed on the basis of the λ filter coefficient (Equations 1–3, [41]) using the Iwasaki formulae [1], was conducted for an estimated specific deposit.

$$\frac{\partial C}{\partial h} = -\lambda C_0 \tag{1}$$

$$\frac{\partial \sigma}{\partial t} = -q \cdot \frac{\partial C}{\partial h} \tag{2}$$

where:

C = volatile solids concentration in greywater (VS, kg m^{-3});
C_0 = initial volatile solids concentration in greywater (VS, kg m^{-3});
h = filter depth (m);
σ = specific deposit of volatile solids (VS, kg m^{-3});
q = hydraulic load of greywater (m d^{-1});
λ = filter coefficient (1 m^{-1});
t = time (d).

$$\lambda = \lambda_0 \cdot \left(\frac{\sigma_{\max} - \sigma}{\sigma_{\max}} \right) \tag{3}$$

where:

σ_{max} = constant (maximum specific deposit of solids) (VS kg m^{-3}),
λ_0 = initial filter coefficient (1 m^{-1}).

The measurement of the initial filter coefficient λ_0 was taken on the filter column, considering the length of the sand filter and the difference between inflow and outflow in turbidity removals [42]. The mean value of λ_0 was 2.6 m^{-1}. The simulation performed on the basis of the obtained initial filter coefficient (Equations 1–3, [41]) did not give values comparable to measured values for a specific deposit. Additional measurements were taken considering the difference of the initial filter coefficient at depth. The filter factor was proposed for verification using data of VS depth distribution after 21 days of the experiment. The relationship of the initial filter coefficient with the filter depth is described by the exponential function $\lambda_0(h) = 0.3^{-0.5h}$.

3. Results

3.1. Volatile Solids, Turbidity and Organic Compounds' Removal Efficiency

The removal efficiency of volatile solids (VS) quickly increased (on the third day of the experiment—equivalent to about 20 days at a hydraulic load equal to 16-17 cm d^{-1}) to 62% and stabilized between 51% and 60%. From a practical point of view, it is significant that relatively high removal efficiency of VS was achieved in a short time; this information can be useful for mechanical greywater treatment or pre-treatment. VS removal efficiency is shown in Table 3.

Table 3. Volatile solids (VS) removal efficiency.

Filter Operation Time (Day)	Mean Removal Efficiency (%)
6	60
14	57
21	51

Mean inflow COD was 199.6 ± 4.8 mg O_2 dm^{-3} (n = 15). A similar value (145.8 ± 79.1 mg dm^{-3}) was reported by Zipf et al. [43] in greywater from lavatory sinks at a university campus.

After 21 days, COD removal efficiency reached 27%, an increase from 14% recorded at the beginning of the experiment (first day). This can be accepted as relatively efficient, taking into account the fact that the mechanical treatment occurred mainly during the study.

Mean inflow turbidity was 45.7 ± 1.4 FAU (n = 9) and mean outflow turbidity was 14.0 ± 0.23 FAU (n = 9). The turbidity removal efficiency (69.4% on average) was relatively high (compared to COD and TS removal).

The mean value of EC in raw greywater was 1025 ± 5 (n = 12) and after filtration, the value of EC increased to 1049 ± 1.7 (n = 69) in the outflowing greywater. A slight increase in EC during filtration through the sand was observed.

The mean pH in the inflowing greywater was 9.1 ± 0.06 (n = 12) and in the outflowing greywater was 8.8 ± 0.02 (n = 69).

In the case of both EC and pH, the changes caused by filtration were very small (2% and 3%, respectively) and can be neglected due to their statistical insignificance.

Organic matter deposit changed significantly with sand filter depth (Figure 2). As expected, the largest deposit was observed in the top layer of 4.0 cm depth: 3.2 mg of dry organic matter (d.o.m.) per cm^{-3} on average (three columns: No. 2, No. 3 and No. 7) of sand after six days of the experiment. The average daily flows of these columns were 182.6 cm d^{-1}, 181.9 cm d^{-1} and 188.8 cm d^{-1}, respectively, and the cumulative hydraulic loads of these filters were 1095.9 cm d^{-1}, 1091.7 cm d^{-1} and 1084.9 cm, respectively. After 14 days of the experiment, the detected deposition was 4.2 mg of d.o.m. per cm^{-3} on average (three columns: No. 1, No. 4 and No. 8) in the top layer of 5.0 cm depth of sand. These filters were loaded with greywater—144.4 cm d^{-1}, 151.0 cm d^{-1} and 142.8 cm d^{-1}, respectively at cumulative hydraulic loads of 2021.1 cm, 2113.6 cm and 1999.6 cm, respectively. The last part of the filter columns was dismantled after 21 days of operation and 7.3 mg d.o.m. cm^{-3} was detected on average (three columns: No. 5, No. 6 and No. 9) in the top layer of 7.5 cm depth of sand for the experiment running at hydraulic loads of 152.3 cm d^{-1}, 152.3 cm d^{-1} and 163.5 cm d^{-1}, respectively.

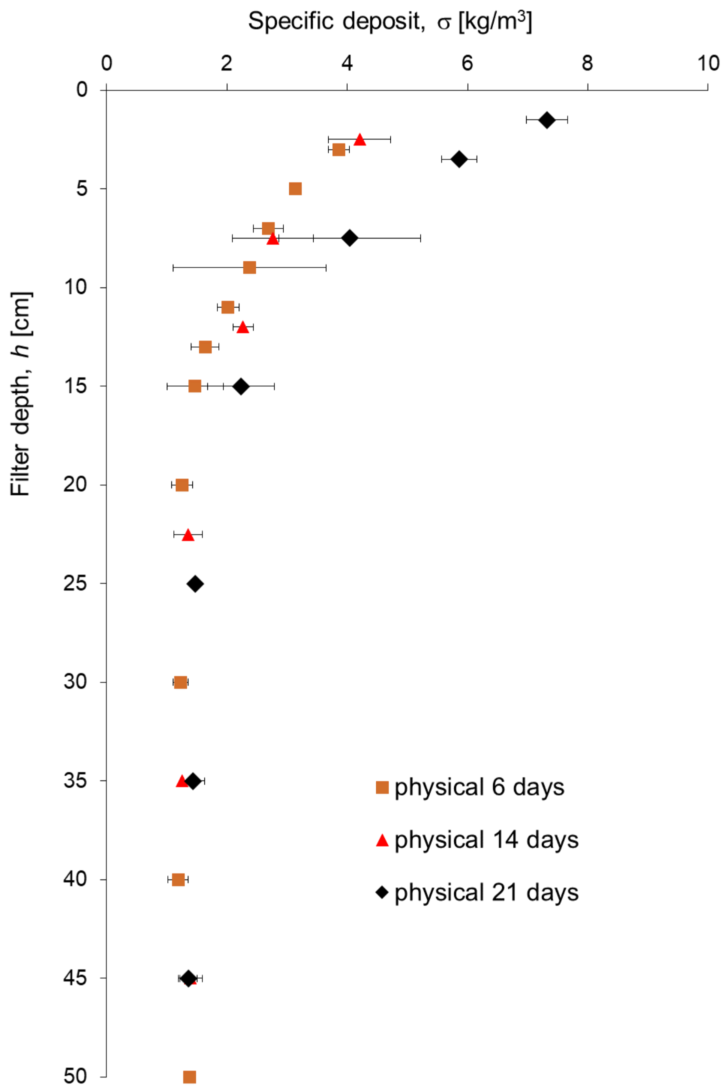


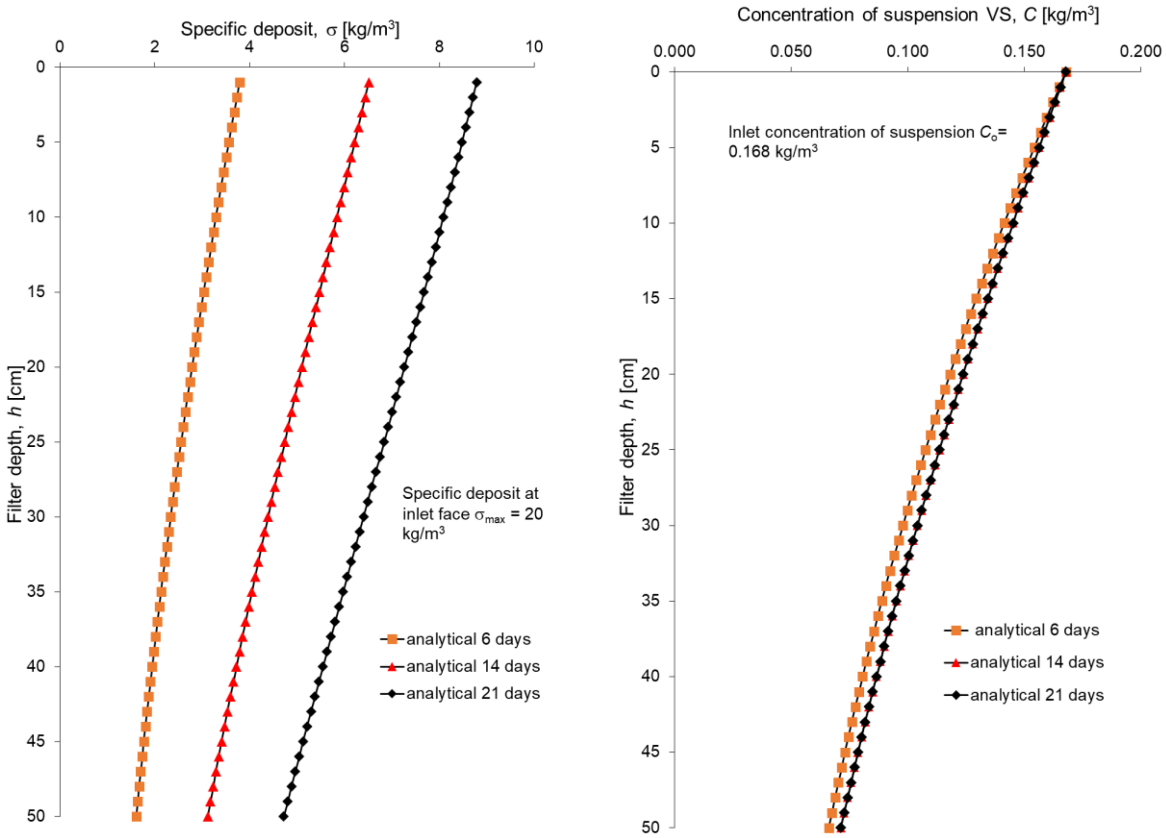
Figure 2. Vertical distribution of specific deposit.

Maximum specific deposit (8.29 ± 0.66 kg m^{-3}) was observed at the cumulative hydraulic load of 36,365 cm.

3.2. Modelling simulation

Simulation using the Iwasaki formula filter coefficient (λ) was carried out and compared with empirical data of a specific deposit detected after 14 days of conducting the experiment. The values obtained from the simulation did not give satisfactory convergence with the empirical data.

The specific deposit distribution obtained from the modelling simulation was significantly different from measured values—the modelled vertical distributions of accumulated VS (specific deposit) were much straighter than measured vertical distributions of VS in the sand filter (Figure 3a). VS measured and modelled concentration values were similar (measured average value 0.065 kg m^{-3}, independent of filtration time, for measured outflowing greywater, and about 0.066–0.071 kg m^{-3} depending on filtration time for the model simulation) (Figure 3b). The discrepancy in modelled and measured vertical distributions of accumulated VS (specific deposit) was probably related to changeability of the λ filter coefficient, with the depth of the filter being higher than that resulting from the Iwasaki [1] formula.



(**a**) (**b**)

Figure 3. Result of analytical simulations for (**a**) change of specific deposition with depth, (**b**) change of concentration with depth.

4. Discussion

The efficiency of VS removal was comparable to that obtained by Abdel-Shafy et al. [17] for a down-flow sand filter—82%. The VS removal efficiency obtained in this study was in turn much higher than results obtained by other authors: Santos et al. [44] for a study carried out using filter mesh of 0.130 mm diameter (28%), by Alsulaili [45] for sand filter (10%) and obtained by Moges et al. [46] (15-20%—for TSS).

Removal efficiency of organic compounds in this study (26.8%) was similar to that obtained by Alsulaili [45] (17%) and Moges et al. [46] (20–25%), and also comparable to results obtained by Santos et al. [44] in a study carried out using a filter mesh of 0.130 mm diameter (47%). COD removal efficiency was much lower than the removal efficiency obtained by other authors: Martikainen et al. [18]—for conventional buried sand filters (92%), and Abdel-Shafy et al. [17]—for a down-flow gravel filter (74%). Higher removal efficiency than this study was obtained by Khalaphallah [47] for commercial sand used in the filtration of swimming pools—55%. In that research work, it was found that up-flow sand filters were more efficient in removing organic compounds (COD, BOD_5) and total suspended solids (TSS).

Mean inflow turbidity was 45.7 ± 1.4 FAU and mean outflow turbidity was 14.0 ± 0.23 FAU. A similar value of turbidity was detected by Zipf et al. [43] in greywater originating from lavatory sinks at a university campus (35.8 ± 45.1 NTU). Turbidity removal efficiency (69.4% on average) was relatively high (compared to COD and VS removal).

The mean EC in the inflowing greywater was 1025 ± 5 and 1049 ± 1.7 in the outflowing greywater. A slight increase in EC during filtration through the sand was observed.

The mean pH in the inflowing greywater was 9.1 ± 0.06 and 8.8 ± 0.02 in the outflowing greywater. Both inflow and outflow values were higher than those commonly detected in greywater. The possible reason for this could be the homogenisation of the ingredients used to make the solution. A slight decrease in EC during filtration was observed.

The dismantling of the filter column after 21 days (cumulative load of 3,279 cm) was comparable in regard to the cumulative load of 3,904 cm (COD—357.4 ± 72.0, SS: 99.9 ± 14.7) for dismantling of filters in the Ochoa et al. [19] study. These authors demolished the columns with the aim of loss on ignition (LOI) determination after 60 days (the hydraulic load of 16.0 cm d^{-1}).

The vertical distribution of organic matter was typical for down-flow slow filters supplied with wastewater.

VS content in the sand filter was comparable to values reported in the literature. Similar results were obtained by Ochoa et al. [19]—the most notable difference in weight loss on ignition was observed in the top 0–2.0 cm depth (0.77%), much smaller at 5.0 cm—about 0.5% of weight loss on ignition; and between 15 and 50 cm of depth—about 0.3% of weight loss on ignition. It is worth noticing that the density of greywater could impact the amount of retained volatile solids (it also influences adsorption and mobility coefficients of constituents). However, under typical domestic (household) conditions, significant differences in density are not observed (temperature and concentrations of constituents vary to a small extent).

The maximum specific deposit (8.29 ± 0.66 mg cm^{-3}) was achieved at 36,365 cm hydraulic load, what was much higher than that used by Ochoa et al. [19] for eight months—a period during which clogging was not observed. At the very high hydraulic load used in this study, the maximum deposit of organic matter in sand was achieved at 36,365 cm, which corresponds to 238 days of operation. However, assuming a more realistic hydraulic load, comparable to values noted in the literature (16–17 cm d^{-1}, [17,19]), the predicted time of operation (before advanced clogging occurring) could be assumed as almost one more order of magnitude longer: 5.9–6.2 years. It could be comparable to natural greywater after mechanical pre-treatment (removal of suspended solids) by e.g. geotextile or another type of mesh-like filtration process.

The discrepancy in modelled and measured vertical distributions of accumulated VS (specific deposit) was probably related to changeability of the λ filter coefficient, with the depth of the filter being higher than that resulting from the Iwasaki [1] formula. Such a factor, which causes the filter coefficient λ to change with filter depth more drastically at the inlet face of the filter and the first few cm of depth (from a high value of about 100–120 to several m^{-1}) and more slightly in deeper layers (even less than one m^{-1}), is expected It is suspected that such λ filter coefficient value changeability could be related to accumulation of colloids (a specific kind of clogging process). These substances can capture particles of lower dimensions and cause the deposition to be more intensive than in the case of conventional conditions of solution filtration (without clogging).

According to the above-mentioned assumptions and terms, the λ filter coefficient value was assumed to be highly changeable with the depth of the filter, and λ (m^{-1}) filter coefficient values at the following filter depths were assumed as a function fitted to the measured specific deposit values. The relationship of the initial filter coefficient with the filter depth was described by the exponential function $\lambda_0(h) = 0.3^{-0.5h}$. The analytical results for assumed λ filter coefficient values were much closer to the measured values than the conventional λ filter coefficient based on the Iwasaki [1] formula (Equation (3)). The outflowing greywater VS concentration obtained from analytical simulation for six days of operation was 0.042 kg m^{-3} (Figure 4a). The value of the analytically simulated specific deposit (Figure 4b) was 0.989 kg m^{-3} and was comparable to values measured at 45 cm of filter depth after 6, 14 and 21 days of operation (1.26 ± 0.17 kg m^{-3}, 1.39 ± 0.20 kg m^{-3} and 1.36 ± 0.15 kg m^{-3}, respectively). The analytically simulated specific deposit using the corrected λ filter coefficient at

50 cm of filter depth after six days was much closer to the measured value than the simulated specific deposit where λ was calculated using the Iwasaki [1] formula.

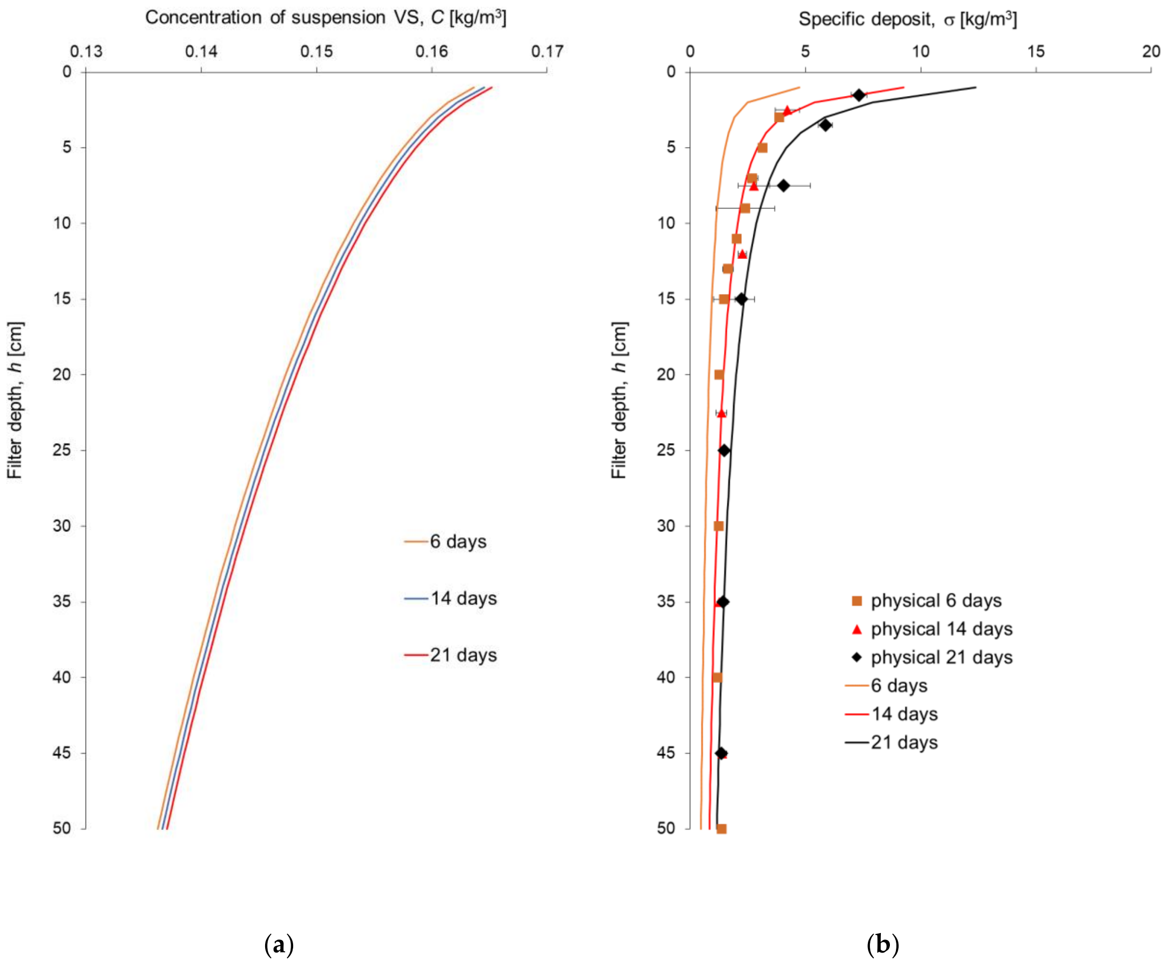


Figure 4. Result of analytical simulations with variable λ for (**a**) VS concentration and (**b**) specific deposit at filter depth.

5. Conclusions

The following conclusions can be drawn from this study:

- The vertical distribution of TS in the sand filter was typical for gravitationally operated sand filters (from 2–5 mg cm^{-3} in the top layer of the filter to about 1 mg/cm^3 at the end of the filter (50 cm of depth).
- Relatively high removal efficiency of VS (51–60%) was achieved in a short time (corresponding to hydraulic load of about 300 cm d^{-1}).
- The average removal efficiency of 26.8% for COD was observed, which is a relatively high value, considering that only mechanical (physical) processes occurred during the experiment.
- The determined maximum VS deposit value (8.29 ± 0.66 kg m^{-3}) was achieved for a cumulative hydraulic load of 363.6 m and corresponded to six years of operation (for daily hydraulic load 16–17 cm d^{-1}).
- The conventional Iwasaki model does not offer a good simulation of vertical distribution of VS; much better results can be achieved after implementation of the filter coefficient value (λ), according to the function of measured specific deposit distribution. The relationship of the initial filter coefficient with filter depth can be described by the exponential function, $\lambda_0(h) = 0.3^{-0.5h}$.

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