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MARCIN SPYCHAŁA[1], JAKUB NIEĆ[1]

IMPACT OF SEPTIC TANK SLUDGE ON FILTER PERMEABILITY

The aim of the study was to determine the filter cake permeability. The research was carried out on the excessive sludge flushed out from a septic tank. Two types of laboratory filters: filled with fine sand and made of geotextiles were used. The permeability of the filter cake was inversely correlated linearly to the accumulated organic solids. Based on applied organic solids, the related filter cake permeability time of filter failure can be predicted. The shortest failure time, not exceeding two years, may be recorded when filter cake development and clogging processes simultaneously take place in small-pore diameter filters and when the concentration of volatile solids is high.

1. INTRODUCTION

The septic tank (ST) is a device used for primary treatment of household wastewater. The biggest advantage of a septic tank is simply service, but it has also disadvantages, e.g. instability in volume and quality of effluent. Usually wastewater treated in a septic tank is directed to secondary treatment units such as soil absorption systems, sand filters or geotextile filters. Due to small porosity, these systems are very sensitive to solids outflow from a septic tank. In the case of a septic tank at a high rate filled with sludge, the risk of clogging of secondary treatment units dramatically increases. Some examples of data for concentration of total suspended solids (TSS) in a septic tank effluent (STE) are presented in Table 1. Large differences in presented concentrations are probably correlated with the high volume of accumulated sludge.

Specific conditions in septic tanks cause both suspended and settled solids (sludge) to result in an outflow. In conditions of high flow rates and especially when the volume of accumulated sludge is high, a significant amount of settled sludge can be flushed from the tank. This sludge can influence the permeability of second stage treatment filters. When the filter is made of relatively small grain diameter soil (fine

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[1] Poznan University of Life Sciences, Department of Hydraulic and Sanitary Engineering, 60-649 Poznań, ul. Piątkowska 94A, Poland; e-mail addresses: marsp@up.poznan.pl, jniec@up.poznan.pl

sand) or of geotextiles, the sludge outflow from the septic tank covers the surface of the filter in the form of a filter cake and subsequently causes clogging. It is well known that the filter cake has low porosity and often causes high resistance of the whole filter as a system [14].

Table 1

Concentration of total suspended solids in a septic tank effluent

Average concentration [g/m^3]	Comment	Reference
123	double chamber	[1]
64	single chamber	[2]
20–55		[3]
87 ± 91		[4]
180		[5]
84		[6]
170–475		[7]
43.7 ± 5.1		[8]
162		[9]
173 ± 67		[10]
32 ± 6.77		[11]
61 (median)		[12]
392.9 ± 259.8	three-chamber settlement tank (two day retention time)	[13]

The analyses of data referred by several authors [15–17] showed that the mass of accumulated organic solids in the filter cake or in a clogged layer in soil filters was similar to the mass of applied organic solids (difference lower than 10%). These results are shown in Table 2.

Table 2

Applied (VS) and accumulated (VS_A) of organic mass in a clogging layer

VS [mg/cm^3]	Time [d]	Hydraulic loading [cm/d]	VS [mg/cm^2]	VS_A [mg/cm^2]	$\frac{VS_A - VS}{VS_A}\times100\%$	Reference
0.038	1	100	6,8	7.8	13.0	[15]
0.04	2130	5.2	177.2	155	14.3	[16]
0.028	500	8.2	22.4	23	2.6	[17]
Average value of $\frac{VS_A - VS}{VS_A}\times100\%$ 10						

Thus for the approximated clogging time it can be assumed that a decrease in organic solids due to decay is balanced by an increase in mass due to biomass growth. Some authors, including Goonetilleke et al. [7] confirm wide variation in the effluent quality obtained in a review of 12 systems on combined grey and black water. The reason for such big differences in effluent quality is the large number of variables.

Not only total suspended solids but also total solids (TS) (due to the much higher concentration in septic tank effluent) should be taken into consideration in relation to filter cake development and permeability. Philippi et al. [5] demonstrated that total concentration of solids in septic tank effluent treating domestic and industrial sewage was equal to 771 ± 90 g/m^3.

Goonetilleke et al. [7] stated that the removal of total suspended solids equalled 33%, only, for relatively low sludge depth: 22–43% of a septic tank height. Over 62% of all septic tanks were filled with sludge in more than 80% (in many cases in 100%)!

The aim of the study was to identify filter cake permeability and its relation to accumulated organic solids. It was assumed that based on applied organic solids and organic solid-related filter cake permeability and its failure (due to filter cake forming or clogging) can be predicted.

2. EXPERIMENTAL PROCEDURES

Characteristics of a septic tank and septic tank effluent. The effluent samples of solids were collected from a single chamber septic tank of 3.0 m^3 in volume (length – 1.85 m, width – 1.34 m) equipped with an outflow filter. The wastewater originated from a household of four people (two adults and two children). The tank was filled with sludge up to 65% (1.0 m of 1.53 m tank height). The concentration of sludge in septic tank effluent was measured as total solids, volatile solids, total suspended solids and volatile suspended solids, being in a relatively wide range from 1498 to 2259 g/m^3, 551–633 g/m^3, 395–498 g/m^3 and 183–216 g/m^3, respectively (Table 2). Concentrations of the total suspended solids and volatile suspended solids calculated based on the measurement of dry mass of filtered solids (after drying at 105 °C until steady mass and after burning at 550 °C, respectively). Similarly the weight of filter cakes and matter accumulated on the surfaces of geotextile layers were determined. This matter was washed out from the geotextiles with distilled water under elevated pressure.

Identification of the sludge filter cake permeability. Three porous materials were investigated and two methods for permeability estimation were used (Table 3).

Table 3

Experimental and measurements conditions

Property	FC + SC	FC-G	FC-S
Porous material			
type	fine sand	geotextile TS20 (4 layers)	fine sand
thickness, cm	1.0	0.36 (4 × 0.09)	0.2
average pore diameter, μm	85	105	85
Method of permeability estimation			
falling down level of water surface for saturated conditions	+	+	+
Steady level of water surface at continuous flow for saturated conditions	–	+	+
STE solids concentration, g/m^3			
TS	2259	1907	1498
VS	633	551	615
TSS	not measured	395	498
*V*SS	not measured	183	216

Methods of estimation of the permeability: Falling level of water surface for saturated conditions. This procedure corresponded with the test method described by Li et al. [18]. The studies were based on the measurement of falling water table rate through the filter cake already formed. Based on the above measurements, the infiltration rate of water has been estimated. Hydraulic permeability was calculated from the equation [19]:

$$K_{us} = 2.3\frac{L}{t}\log\left(\frac{H_0}{H_t}\right) \tag{1}$$

where: K_{us} – permeability estimated on unsteady state flow, m/d, L – thickness of filtration layer, m, t – time of falling water surface level from H_0 to H_t, d, H_0 – height of the water surface level at the beginning of measurement, m, H_t – height of the water surface level at the end of measurement, m.

Stable level of water surface at continuous flow for saturated conditions. Filter cake permeability was calculated using the Darcy law equation referred by Lambe [19]:

$$K_s = \frac{QL}{thA} \tag{2}$$

where: K_s – permeability estimated on a steady state flow, m/d, Q – stable flow volume, m^3, L – thickness of the filtering material layer, m, t – time of flow, d, h – stable water level, m, A – cross section of the column, m^2.

Experiments were carried out using 3–8 pipes made of organic glass of 50 cm long and 2.5 cm in diameter (Fig. 1).

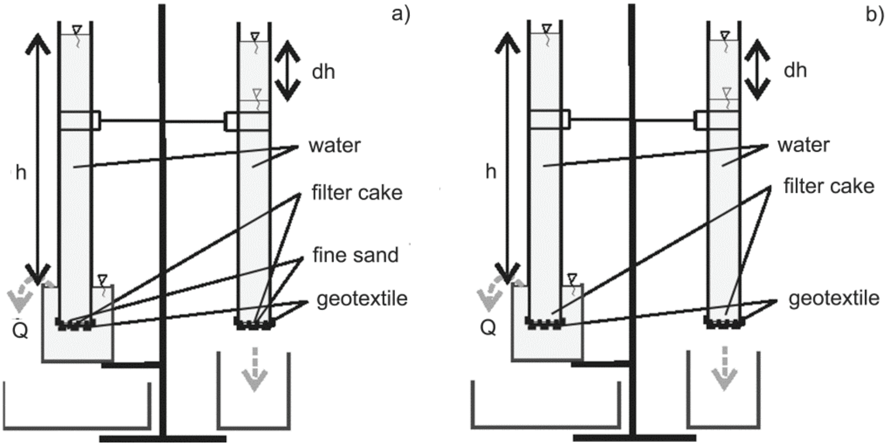

Fig. 1. Device for estimation of permeability at stable water surface level and for falling water surface level for (a) fine sand and (b) geotextiles

To estimate the permeability of the filter cake and sand clogging layer (FC + SC), three pipes were filled with fine sand in a layer 1 cm high. The bottoms of pipes were protected from the outflow of sand grains with a thin one-layer geotextile. Three doses of septic tank effluent (100, 300 and 400 cm^3) to pipes 1, 2 and 3 were applied, respectively. The method was used to assess the infiltration rate for the most probable terms in field conditions (technical scale) – for filter cake and sand clogging layer development at the same time. This was verified at the maximum water table layer, which is assumed to lie at about 30 cm above the sand surface.

To estimate permeability of the filter cake formed on the geotextile surface (FC-G), eight pipes with four layers (sheets) of geotextile (TS 20; each 0.9 mm thick) as a bottom were used. The pipes were filled with a one-dose volume of wastewater (three pipes with 2500 cm^3, two pipes with 4000 cm^3 and three pipes with 5000 cm^3 of the septic tank effluent).

To estimate permeability of the filter cake formed on the sand surface (FC-S), three pipes were filled with a fine sand layer 0.2 cm thick. Three doses of septic tank effluent: 550 cm^3, 950 cm^3 and 1350 cm^3 to pipes 1, 2 and 3 were dosed, respectively. The bottoms of pipes were protected from outflow of sand grain with a thin one-layer geotextile.

The permeability was estimated by the methods of stable and falling water level. The measurements were conducted for initial conditions (sand and geotextile before filter cake formation) and for final conditions (sand and geotextile after filter cake formation). The pipes were supplied with septic tank effluent using a peristaltic pump.

Filter cake volatile solids (VS_A) were detected as volatile solids accumulated on the surface of the top of four geotextile layers. Some proportion (10–20%) was accumulated on the surfaces of deeper layers (second, third and fourth). This organic mass obviously influenced some negligible decrease in permeability. The permeability for filter cakes and clogging mass in sand were estimated with a subtraction of clean porous material permeability.

Samples of all filtering materials were stored between filter cake development and permeability measurements in a refrigerator at 7 °C but the storage (infiltration) time for 1.0 cm fine sand layer was much longer (several days) than the storage time for geotextile and 0.2 cm fine sand layer (several hours). The samples with 1.0 cm fine sand layer were not disinfected and samples of the geotextile and 0.2 cm fine sand layer were disinfected with NaClO (dose volume fivefold higher than those suggested for tap water disinfection).

3. RESULTS AND DISCUSSION

The concentration of volatile solids in the septic tank effluent was ca. threefold higher than that of volatile suspended solids. Both volatile solids and volatile suspended solids should be taken into consideration in terms of description of the filter cake development. It was observed that the filter cake consisted mainly of filamentous particles, most of which should be treated as suspended solids. On the other hand, for the weight of the filter cake, the solids not suspended or very small ones should be taken into consideration due to the high probability of capture between larger (filamentous) particles inside filter cake pores.

The rates of accumulated organic mass (detected as VS_A) to applied volatile solids were different for particular conditions (type and thickness of porous material). The highest VS_A/VS ratios were detected for fine sand layer 1.0 cm thick: ca. 19% on average. Significantly lower values were observed for the fine sand layer 0.2 cm thick: about 13% on average. The lowest values were detected for geotextiles: ca. 2% only. These results are presented in Fig. 2. This phenomenon could be related to the initial and average time of dosing velocity. The velocities were the lowest for the 1.0 cm fine sand layer and for these conditions the higher VS_A/VS ratios were observed. At lower filtration velocities, more complex processes occur (not only filtering but also sedimentation, adsorption and others) and probably smaller particles of solids may be captured in the pores of filtering material or on its surface. Observed VS_A/VS values were significantly different from the cited results (Table 2), which can be explained by different conditions in this and previous research because the latter was carried out using relatively high filtering columns (several centimetres to almost one meter), which meant it was a clogging rather than a filter cake forming process.

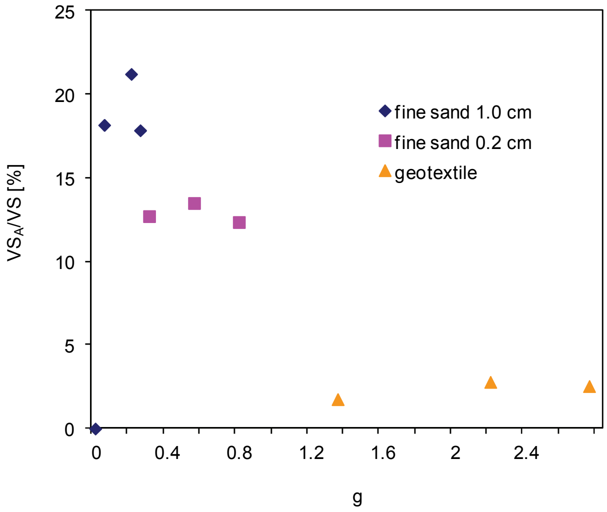

Fig. 2. Accumulated volatile solids (VS_A) to applied VS rates

Almost 80% of VS_A was blocked on the surface of the top geotextile layer (layer 1). These results are presented in Fig. 3.

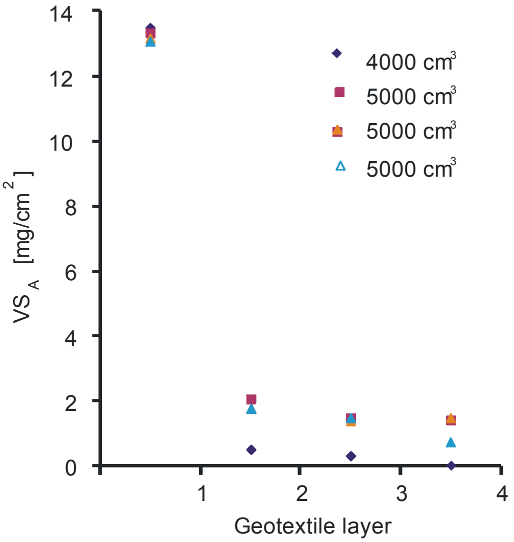

Fig. 3. Organic mass accumulated on geotextile layers

The weight of volatile solids accumulated inside the 0.2 cm fine sand layer was found to be negligible as a relatively low comparing to the weight accumulated on the sand surface (several per cent). On the other hand, the weight of volatile solids accumulated inside the 1.0 cm fine sand layer were relatively high comparing to the mass of volatile solids accumulated (VS_A) on the sand layer surface (34%, 118% and 111% for 100, 300 and 400 cm^3 doses, respectively).

A crucial role for blocking of solid particles is played by the pore dimensions. For sand (medium and fine sand), the ratio of pore dimension to particle diameter can be approximated, based on the data presented by Crisp and Williams [20]. It was estimated that the particle diameter (spherical) equalled 490–525 µm, and pore dimension – 128–156 µm, thus the ratio of the average pore diameter to the average grain diameter could be assumed to be 0.28. Assuming this ratio for the fine sand, d_{60} equalled to 300 µm – the pore size is equal to about 80–90 µm (85 µm on average). This is a significantly smaller value than the geotextile average pore size (105 µm).

Permeabilities of clean porous material (sand layer of 0.2 cm, sand layer of 1.0 cm and four layers of geotextiles) were comparable to values reported by Weggel and Dortch [21]: for plasti-grit filter cake: 54–126 cm/h (density: 1.2 g/cm^3, d_{10} – ca. 70 µm, d_{60} ca. 200 µm).

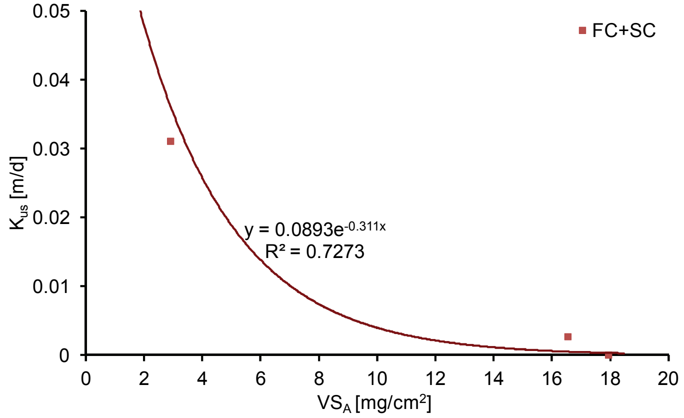

Fig. 4. Permeability of the 1.0 cm fine sand layer estimated at a falling water surface level (K_{US})

Finding the trends of correlation proved to be difficult due to the significant changeability of values. The correlations are presented in Figs. 4–6. The exponential lines were fitted with a relatively high rate of conformity (except the 1.0 cm fine sand layer, R^2 was close to or higher than 0.9). Fitting straight lines was also checked and gave relatively good results (R^2 equalled 0.7–0.9). Significant differences were found between the values obtained by various methods of estimation of permeability and between analysed conditions (sand layers of 1.0 cm, 0.2 cm and geotextile). The lowest values of permeability with respect to accumulated volatile solids were found for the 1.0 cm fine sand layer: 0.0001 m/d (at 8.5 mg/cm^2 of VS_A) and the highest values –

for the 0.2 cm fine sand layer: 0.217 m/d (at 18.5 mg/cm^2 of VS_A), intermediate values were observed for geotextiles of 0.36 cm thick: 0.057 m/d (at 13.2 mg/cm^2 of VS_A).

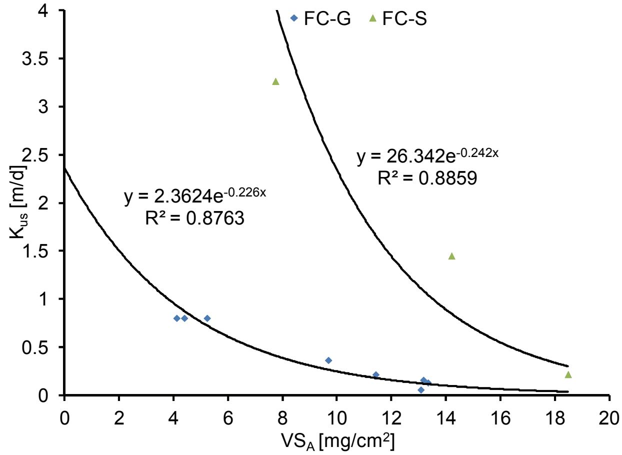

Fig. 5. Permeability of the 0.2 cm fine sand layer (FC-S) and geotextile FC-G) estimated at falling water surface level (K_{US})

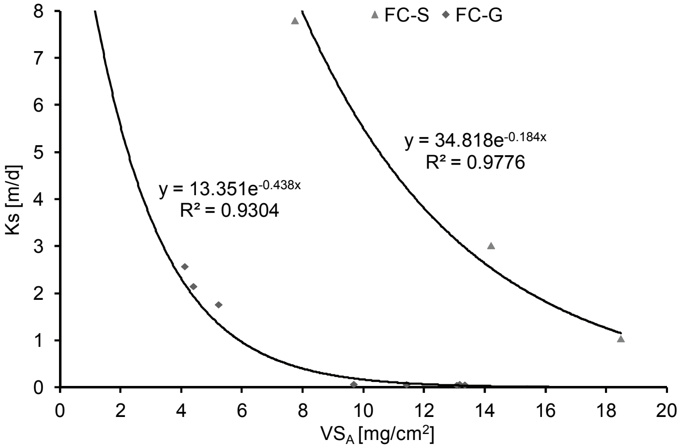

Fig. 6. Permeability of the 0.2 cm fine sand layer (FC-S) and geotextile (FC-G) estimated at stable water surface level (K_S)

A similar study was carried out by Beal et al. [10] on the biomat zones developing on the surface of soils of contrasting textures. All the soil types (coarse sand, clay loam and medium-heavy clay) were different from those used in this study. The results of this study are comparable only to those for Vertisol filters. For this soil, the hydraulic conductivity of biomat was equal to 0.0008 m/d for total septic tank effluent load equal to 198 cm. In this study for the concentration of the total suspended solids ca.

threefold higher and for a 1.0 cm fine sand layer, the permeability was equal to 0.003 m/d and 0.0005 m/d for the total septic tank effluent load equal to 57 cm and 75 cm, respectively. Taking into consideration the difference in concentrations of total suspended solids (to compensate threefold lower concentration of total suspended solids in [10]) threefold higher hydraulic load rate in this study gives almost the same value: 195 cm.

The procedure of estimation of the permeability at the falling level of water surface is preferred for soils of high permeability [19]. Despite relatively high permeability of clear fine sand after accumulation of solids on the surface and inside sand layer, the permeability decreased drastically, finally the conclusion can be drown that this procedure is not suitable for clogged fine sand.

Microscopic analyses indicated that the main content of filter cake was in the form of filamentous particles (fibres). The comparison of these pictures and pictures of waste toilet paper [22] indicated (based on diameters, colour and other features) that these were the toilet paper fibres (Figs. 7 and 8). It is possible that during the operation time of a septic tank the rate of toilet paper fibres increases due to the lower decomposition velocity compared to other organic solids of sludge accumulated in the septic tank. There is therefore a danger of rapid filter failure due to formation of a filter cake or clogging as a result of high concentration of fibre of toilet paper in septic tank effluent.

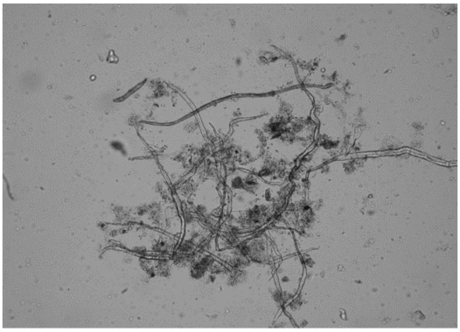

Fig. 7. Filamentous particles (toilet paper fibres) – the main content of filter cake

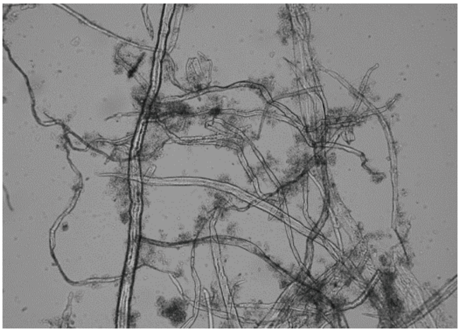

Fig. 8. Toilet paper fibres [22]

Based on the results of this study, the time of filter failure can be predicted (Table 4). For the same long term acceptance rate (LTAR), approved value (for fine sand) the failure time values are correlated to K_S and K_{US}. The values are significantly different for different material. The shortest filter failure time, lower than two years, was estimated for the development of a filter cake and clogging process occurring simultaneously in the fine sand layer 1.0 cm thick. For a lower thickness of filter layers, the accumulation of organic mass is slower in general, thus the duration until failure occurs is longer – ca. 5 years for geotextiles and a fine sand layer 0.2 cm thick.

Both values (two and five years) are very short compared to the assumed filter operation time: 20–25 years.

Table 4

Predicted clogging time for various conditions
and for various methods of estimation of permeability

Property	FC + SC	FC-G	FC-S
Permeability			
steady water surface level (K_s), m/d	–	0.047	1.039
falling down water surface level (K_{us}, m/d)	0.027[2]	0.057	0.217[2]
Accumulated volatile solids (VS_A), mg/cm^2	7.5	13.2	18.5
STE VS, g/dm^3	633	551	615
LTAR, cm/d	1.7	1.7[3]	1.7
Time to filter failure for K_S, year	–	4.2	25.1
Time to filter failure for K_{US}, year	0.14	5.1	5.2

[1] FC + SC – filter cake and sand clogging layer, FC-G – filter cake formed on the geotextile surface, FC-S – filter cake formed on the sand surface.

[2] Procedure not suitable for clogged fine sand.

[3] Not standardised, assumed the same as for fine sand (similar pores diameters).

4. CONCLUSIONS

- When the septic tank is filled at a high rate with sludge, the concentration of effluent solids can dramatically increase.
- A significant part or even main content of solid particles in a septic tank effluent can be made up of toilet paper fibres.
- In the above conditions, the failure of a secondary treatment filter may appear as the result of accumulation of solids in the form of a filter cake or simultaneous formation of a filter cake and clogging layer.
- The time of filter failure can be predicted based on total volatile solids loading and filtering of material type and its layer thickness. The predictions for various materials are significantly different. The shortest failure time probably may occur when the filter cake development and clogging process appear simultaneously in small pore diameter (e.g. fine sand) filters. For high concentrations of volatile solids (excessive sludge in septic tank effluent due to high amount of sludge in a septic tank) time of filter failure can be very short – shorter than two years,
- Decrease of the geotextile permeability was less intense (compared to the 1.0 cm fine sand layer) for the same loading of total volatile solids due to the lower thickness of the filtering layer but the decrease was much more intense when the filter cake became denser (higher values of loading of total volatile solids).

- Over 80% of VS_A was accumulated on the surface of geotextiles, 20% – inside or on deeper layers (when several geotextile layers were used),
- The VS_A/VS ratios differed significantly for different types and layer thicknesses of filtering materials (2–19%). This could be related to many factors, e.g. time of application of septic tank effluent, rate of toilet paper fibres to volatile solids in the septic tank effluent, soil density and dissolved organic compounds 5-days biochemical oxygen demand (BOD_5) concentration of the septic tank effluent.
- More attention should be paid to the research and practice in respect to qualitative content of septic tank effluent and toilet paper fibre impact on the performance of a secondary treatment filter.
- The procedure of estimation of permeability at the falling level of water surface is not recommended for clogged fine sand.

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