Nauka Przyroda Technologie

2015
Tom 9
Zeszyt 4
#55

ISSN 1897-7820 http://www.npt.up-poznan.net DOI: 10.17306/J.NPT.2015.4.55

Dział: Melioracje i Inżynieria Środowiska

MARCIN SPYCHAŁA, ALEKSANDRA SOWIŃSKA

Department of Hydraulic and Sanitary Engineering
Poznań University of Life Sciences

FILTER CAKE IMPACT ON THE TEXTILE FILTERS FOR WASTEWATER TREATMENT HYDRAULIC CAPACITY*

WPŁYW PLACKA FILTRACYJNEGO NA WYDATEK FILTRÓW WŁÓKNINOWYCH DO OCZYSZCZANIA ŚCIEKÓW

Summary. The aim of the study was to identify the filter cake hydraulic conductivity and its impact on the hydraulic capacity of textile filters for wastewater treatment. The study was carried out using septic tank effluent filtered on four types of filters of different thickness (0.9, 1.8, 3.6 and 7.2 mm). The dry biomass content was 13.45–36.7 mg TS per 1 cm^2 at organic loading rate of 0.04–0.07 mg BOD_5 per 1 mg d.m. per day. The filter cake dry mass was related to filter thickness. The dry mass content of filter cake was about 9.7–19.1% of whole filter cross-sectional profile TS content in the long-term experiment. The filter cake had a significant impact on the hydraulic capacity reduction due to its high density and small porosity. The volumetric density of filter cake biomass was almost twice as high as the volumetric density of biomass inside the textile filter. The filter hydraulic conductivity of a one-layer filter without filter cake was over four orders of magnitude higher than the hydraulic conductivity of a one-layer filter with filter cake formed during the short-term experiment.

Key words: biomass, filter cake, hydraulic capacity, hydraulic conductivity, septic tank effluent, textile filters for wastewater treatment

Introduction

Filtration through porous materials is the one of the most common processes used for water and wastewater treatment. Although the main application of microfiltration is the separation of suspended particles from liquid, the microfiltration can also remove dissolved substances when it is supported by live biomass.

*This work was supported by the National Science Centre under Grant No. N N523 75 1540.

Unfortunately, one of the major limitations of filtration technology is filter fouling due to the clogging process. The accumulation or capturing of solids contained in inflowing wastewater is one of the disadvantages of treatment by filtration, especially in small diameter porous media. There are many factors and conditions related to accumulation and capturing in this regard.

Fouling or bio-fouling occurs when the flux decline is not reversible by changing operating conditions (Fane et al., 1991). Both in membranes and micro-filters (textile filters for wastewater treatment, TFWT), bio-fouling is a major problem due to the productivity and lifetime reduction, and outflow quality changes. Three main processes are responsible for filter and membrane fouling: precipitation of non soluble inorganic substances, adsorption of organic substances (polysaccharides, humic substances, products of microbial metabolism) and growth of microbial clusters at the filtering surface causing pore blocking and filter cake development (Ivnitsky et al., 2007; Kim et al., 2006).

Filter cake is the wetted sludge containing e.g. suspended solids, colloids, microorganisms, extracellular polymeric substances trapped on the filter as a result of the separation of these substances from the liquid (supernatant) (Żużikow, 1985).

The advantage of cross-flow filtration in comparison to the dead-end filtration is a reduction of the fouling by high velocity gradient near the filtering layer surface thanks to which the tangential flow prevents filter cake from building up through larger particles.

A special case is the liquid movement perpendicular to the filtering layer surface. This process is called dead-end filtration. Under these conditions the increase in cake thickness is theoretically unlimited (Bessiere et al., 2008; Carroll, 2001; Mourouzidis-Mourouzis and Karabelas, 2006; Santos et al., 2008). In case of vertical orientation of the filtering surface (TFWT) the gravitational force acts on the filter cake. It is expected that at low cake viscosity or a low bulk density, this force will cause a falling of certain fraction of cake particles. One of the more difficult to identify and modelling issues is the compressibility of the filter cake, the conditions upon which it depends and especially their impact on hydraulic conductivity. There are results showing the correlation between the compressibility and the tendency to the clogging of colloidal matter (Singh and Song, 2006). The filtration process involving a filter cake is very similar to the paper layer formation process (Hubbe et al., 2009). While creating layers of paper, all the fibers of cellulose are practically retained on the grid, while also containing a mixture of fine particles, which due to their very small size can be retained only by the same cellulose fiber layer (through the sieve, or by colloidal forces). Various studies on the reduction of permeability due to the pore blocking by cellulose particles were conducted, e.g. for the production of paper (Hubbe et al., 2008). The permeability of fibrous network models to simulate the filtration was presented in the literature (Higdon and Ford, 1996). In certain cases the filter cake is a fibrous mat formed of fibrous particles and its forming and compaction occurs at the same time. Several studies and tests undertook the modelling of such situations (Hubbe and Heitmann, 2007; Kumar et al., 1996).

Law et al. (2001) found more extracellular structures (extracellular matrix) in the cake (the layer formed on the border of the sand/water) produced in the mature filter than on the newly set going.

Excretion of extracellular polymeric substances (EPS) by bacteria and resulting flux decrease is related to the bio-fouling process (adhesion of microorganisms to the membrane surface) (Ramesh et al., 2007).

Bio-fouling runs in several steps: deposition of cells on the filter surface, forming a bio-cake by excreted EPS and soluble metabolic products, and the increase in hydraulic resistance (Ramesh et al., 2007). Several studies showed that the structure of the bio-cake of the fouled filter has an impact on permeability (Yun et al., 2006).

In membrane systems (aerated mainly) for the treatment of wastewater bio-fouling was investigated (Lee et al., 2008; Meng and Yang, 2007). To prevent membranes from bio-fouling the bio-cake must be controlled by shear stress, e.g. of aeration flux (in membrane aerated systems) (Psoch and Schiewer, 2008). There are no membrane reactors mentioned in the literature that do not require flushing or cleaning (Peter-Varbanets et al., 2010).

The filters investigated and presented in this paper are of a different type (no aeration, much larger pore volume). However, in relation to some aspects and processes they can be compared to former systems and discussed accordingly. Their numerous characteristics can be found in review articles (Le-Clech et al., 2006; Meng et al., 2009).

There are opposite hydrophilic (Fane et al., 1991) and hydrophobic properties believed to reduce fouling process. Some authors have suggested that a negatively charged or neutral surface can limit biomass adsorption (Shimizu et al., 1989). Nevertheless different materials are used as biomass supporting media, e.g. polypropylene or polyethylene (Kruszelnicka and Ginter-Kramarczyk, 2013).

Geo-textiles have been used for many years for different purposes. The main utilization is related to geo-techniques (Holtz et al., 1998). Other applications are related to slow sand filtration prevention from solids accumulation during rural water supply (Setlhare and Mwiinga, 2006).

Textile filters for wastewater treatment (TFWT) have been described already in relation to performance (Spychała et al., 2013), biomass structure and microbial characteristics (Spychała and Starzyk, 2015). TFWT is a system involving gravity driven microfiltration.

Studies on the TFWT showed a high efficiency in organic compounds removal and a periodically significant removal of ammonium nitrogen. One of the most important technological parameters, related to: treatment efficiency, filtering capacity and life time or fouling is filter cake impact on the textile filter's hydraulic capacity.

The clogging of non-woven geo-textile filters for wastewater treatment (TFWT) under hydrostatic pressure is a complex phenomenon affected by many processes. These are related to two main groups of matter: 1) solids originating from septic tank effluent (STE) and related processes: transport, deposition and decay, and 2) live biomass and related processes such as bacteria growth and decay. Both groups and related processes interact with each other and with fluid flow (deposition, erosion, nutrients supply).

Resistance and thickness of the filter cake reduction in certain conditions can be caused by the action of hydrodynamic forces (Bérubé and Lei, 2006).

As the filter cake thickness increases – an increase in bio-cake (filter cake) resistance is reported (Peter-Varbanets et al., 2010).

It is worth noting that the initial saturated hydraulic conductivity of the filtering media (textile, soil etc.) becomes negligible as the bio-cake develops some infiltration rate (resistance). Values between 1.4 and 7.5 cm/d were observed: 5.8–7.5 cm/d (Bouma, 1975), 1.4–2.6 cm/d (Kropf et al., 1977) and 2–3 cm/d (Beach et al., 2005). This phenomenon is rather common in the case of small pore diameter media. The capturing of the solids from liquid (wastewater) occurs mainly in the thin-top layer of filter, commonly in shallow bed filtration (clogging). This was reported for different kinds of suspension and media: sand filters (Spychała and Błażejewski, 2003) and geo-textiles filters (Spychała et al., 2013). This process was theoretically (by modelling) confirmed (article in preparation).

The aim of the study was to recognize the filter cake mass and volume and its impact on the TFWT hydraulic capacity in relation to filter thickness. Both, the filter cake and the textile layers dry mass impact on the hydraulic capacity of TFWT at changeable wastewater level has been hypothesised. TFWT filter cake development description gives important information related to TFWT operation in practice (technical scale) and basic – physical and biochemical processes, and enables to complete a mathematical modelling description.

Materials and methods

Long-term experiment

The long-term experiment was conducted on three reactors (RI, RII and RIII, in each reactor four non-woven geo-textile filters were installed) fed with septic tank effluent (Fig. 1).

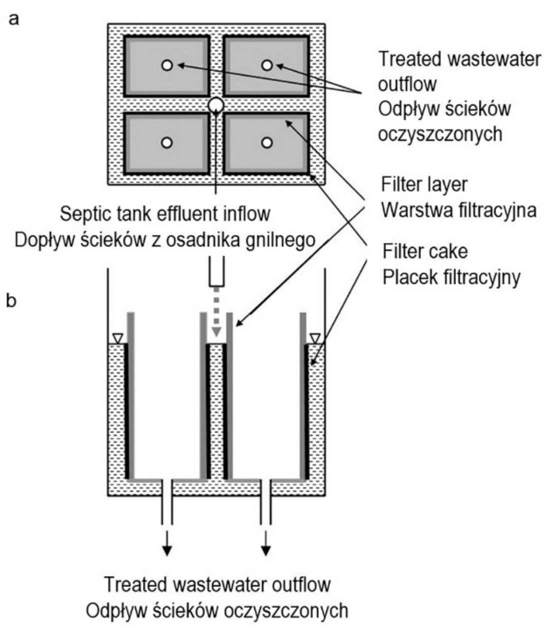

Fig. 1. Scheme of the research reactor
Rys. 1. Schemat reaktora badawczego

The study was carried out in a period of 18 months (01.2013–06.2014).

The concentrations of inflowing wastewater pollution indicators (mean values of the whole period of research) were: five-days biochemical oxygen demand (BOD_5): RI – 259 ±22.3 g/m^3, RII – 328 ±42.2 g/m^3, RIII – 313 ±29.6 g/m^3; chemical oxygen demand (COD): RI – 500 ±29.0 g/m^3, RII – 557 ±42.4 g/m^3, RIII – 539 ±30.8 g/m^3; ammonium nitrogen (N-NH_4): RI – 108 ±5.3 g/m^3, RII – 121 ±6.1 g/m^3, RIII – 121 ±8.0 g/m^3; total phosphorus: RI – 18 ±1.2 g/m^3, RII – 21 ±3.0 g/m^3, RIII – 22 ±2.8 g/m^3; total suspended solids (TSS): RI – 80 ±8.2 g/m^3, RII – 208 ±45.4 g/m^3, RIII – 191 ±35.3 g/m^3; pH: RI – 7.77 ±0.08, RII – 7.73 ±0.07, RIII – 7.75 ±0.09.

The filters were fed every 4 h daily at a dose volume corresponding to the reactor volume – from 740 to 800 cm^3, for the working height of wastewater level surface, i.e. 25–30 cm and surface area corresponding to the single filter circuit (30–32 cm).

The research was carried out on three filter types of varying thickness (1.8 mm, 3.6 mm and 7.2 mm – two, four and eight layers of 0.9 mm thickness non-woven TS20 textile, respectively). The set of 2–8 thin layers simulating thicker layers enabled cross--sectional analyses performance and has been earlier performed by Ren et al. (2010).

The non-woven TS20 geo-textile general properties were as follows: opening size O_{90} (EN ISO 12956:1999, 1999): 0.105 mm, permeability vertical 2 kPa (EN ISO 11058:2010, 2010; h = 50 mm): 115 dm^3/(m^2·s) and mass per unit area (EN ISO 9864: 2005, 2005): 125 g/m^2.

The filter's hydraulic capacity (average for four of the same type filters in one reactor) for initial period of the research (May-August 2013) was calculated as the daily volume of wastewater, divided by the lateral surface of the filter (the product of the average depth of the filter and its wetted perimeter).

The reactors operated at changeable wastewater surface levels as a result of intermittent dosing. The minimum/maximum wastewater surface levels (average of last 15 weeks of experiment) were respectively: 5.0/13.0 cm for two-layer filter reactor, 12.9/25.9 cm for four-layer filter reactor and 25.4/33.2 for eight-layer filter reactor.

Short-term experiment

The short-term experiment was aimed to verify the impact (short-term – several hours and long-term – several months of operation time) on filter cake hydraulic conductivity and filter performance under various conditions.

The short-term experiment was performed using a one-layer geo-textile in two series: 19 and 27 h duration experiments. Three replications were carried out in each experiment – using transparent pipes made of organic glass 2.5 cm diameter, 4.9 cm^2 inner cross-sectional surface area and 30 cm length.

The inflow wastewater TSS concentration during the first series was 203.9 ±30.5 g/m^3 and at the volume of filtered wastewater 2600 ±230.7 cm^3 (2860 cm^3 for filter "one", 2140 cm^3 for filter "two" and 2800 cm^3 for filter "three"). The inflow wastewater TSS concentration during the second series was 375.2 ±16.11 g/m^3 and at the volume of filtered wastewater 952 ±78 cm^3 (1085 cm^3 for filter "one", 815 cm^3 for filter "two" and 955 cm^3 for filter "three"). The cumulative mass loading was 530.1 g on average for the first series (583.2 g for filter "one", 436.3 g for filter "two" and 570.9 g for filter "three") and 357.1 g on average for the second series (407.1 g for filter "one", 305.8 g for filter "two" and 358.3 g for filter "three").

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

Filter layer sample hydraulic capacity determination

Filtering material samples (coupons) taken from long- and short-term experiments were investigated using falling water surface level methods for hydraulic capacity estimation (Fig. 2). The method used corresponds to the one described by Li et al. (2005). Additional experiment showed practically no difference between septic tank effluent and water hydraulic capacity rate.

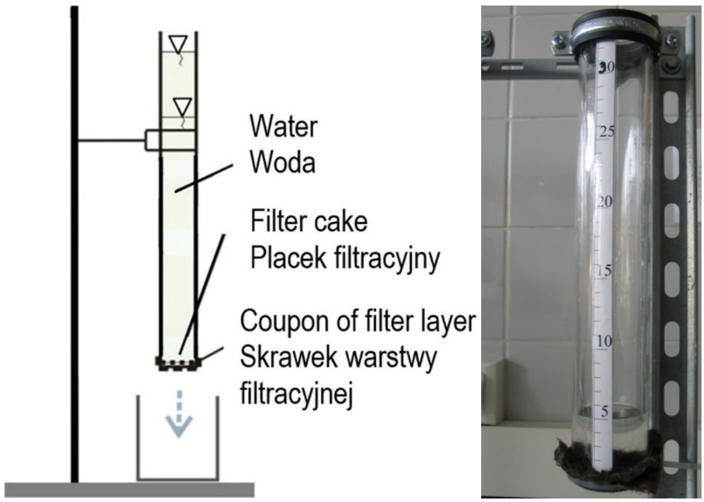

Fig. 2. Stand of the falling surface level method
Rys. 2. Stanowisko pomiarów metodą opadającego zwierciadła wody

The transparent cylinders of internal diameters: 1.8 cm, 2.5 cm and 5.0 cm and of 32.0 cm length were used. Three measurements of hydraulic capacity were made for textile with filter cake (FC) and three – for textile without filter cake at initial water level height of 30 cm.

Samples of textiles (cut as coupons) were taken from filter height of 3.0–9.0 cm. The region between 0 and 10 cm of height was assumed to be representative for filter cake development and its impact on filter hydraulic capacity.

The textile coupons corresponding to measurement cylinder diameter, enlarged by additional value that enabled the collapse of the cylinder with the compressing band (6.0 × 6.0 cm for cylinders of 2.6 cm diameter and 8.0 × 8.0 cm for cylinders of 5.0 cm diameter), were cut out for hydraulic capacity and dry mass (determined as total solids, TS) examination.

The hydraulic conductivity of filter covered by filter cake developed during long- and short-term experiment was determined without filter cake (after filter cake removal).

For both long- and short-term experiments the average value of filter cake thickness was used for hydraulic conductivity calculation.

Dry mass (indicated as TS) examination was made using coupons which had been used earlier for hydraulic capacity determination (located between cylinder wall, corresponding with internal cylinder cross-section area).

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

Additional textile coupons of a surface area of 0.9–1.8 cm^2 were cut out from filters and used for dry mass (TS) examination. Samples of textile for the purposes of TS determination were pressed, washed and subsequently heated at 105°C to a stable mass. Samples for dry mass identification were taken from a continuously saturated (CS) wastewater region (below minimum wastewater level: 10 cm).

The volume of filter cake after its scraping was measured by micropipette. The thickness of filter cake was calculated by dividing the measured volume by filter surface, from which the cake was taken.

The average particle size of filter cake was calculated, based on image analysis using open-access ImageJ software. For each long-term two-layer filter and short-term one-layer filter experiment was performed and analysed with the aid of five microscopy pictures that were taken.

As the conditions in the region of filters intermittently saturated (IS) with wastewater between 10 and 20 cm of height from reactor bottom were less stable than in those continuously saturated with wastewater (below minimum – 10 cm wastewater level from reactor bottom), the filter region continuously saturated with wastewater was chosen to determine filter cake impact on filter hydraulic capacity. This is due to the more stable flow and microbiological growth conditions in continuously saturated with wastewater region in comparison with that intermittently saturated with wastewater (between minimum and maximum wastewater surface level: 5.0–13.0 cm, 12.9–25.9 cm and 25.4–33.2 cm for two-, four- and eight-layer filter, respectively).

Results and discussion

Long-term experiment

Hydraulic capacity of filters at the start of the experiment (after the end of the start--up period) was between 12 and 20 cm/d (unstable, depended on the thickness of the filter). Average hydraulic capacity during initial period of the research (May-August 2013) was related to filter thickness – for two-layer filters (RI): 8.1 ±1.22 ($n = 25$), for four-layer filters (RII): 6.4 ±0.43 ($n = 31$) and for eight-layer filters (RIII): 5.8 ±0.34 ($n = 35$). Hydraulic capacity of filters will be described and discussed in another paper (*opus in progressu*).

The biological start-up period for COD and BOD_5 removal was about 3 to 4 months and for ammonium nitrogen – about 4 to 5 months (arbitrarily determined – assuming the treatment efficiency higher than 50% for COD and BOD_5).

Beside the TSS removal efficiency for all other pollution indicators (COD, BOD_5, for ammonium nitrogen and total phosphorus) the following relation was observed: the thicker the filter layer – the higher the removal efficiency. The efficiencies were as follows: COD – 48.3–64.3%, BOD_5 – 63.3–78.9%, ammonium nitrogen – 7.7–28.8% and phosphorus – 21.4–40.3%. In all these cases the lowest value was achieved by the thinner filter and the highest – by the thicker filter, and four-layer filters showed intermediate efficiencies.

Hydraulic capacity and total solids content of filter samples (coupons) with and without filter cake were analysed in relation to different thickness (Tables 1, 2, Fig. 3).

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

Table 1. Dry mass content of filtering media coupons with and without filter cake during long-term experiment
Tabela 1. Zawartość suchej masy w skrawkach materiału filtracyjnego pokrytego i niepokrytego plackiem filtracyjnym podczas testu długoterminowego

Filter type Rodzaj filtra	Sample taking height Wysokość poboru próbki (cm)	Filter cake dry mass (mg TS per 1 cm²) Sucha masa placka filtracyjnego (mg TS na 1 cm²)	First layer dry mass without filter cake (mg TS per 1 cm²) Sucha masa pierwszej warstwy bez placka filtracyjnego (mg TS na 1 cm²)	All layers dry mass without filter cake (mg TS per 1 cm²) Sucha masa wszystkich warstw bez placka filtracyjnego (mg TS na 1 cm²) (A)	All layers dry mass with filter cake (mg TS per 1 cm²) Sucha masa wszystkich warstw z plackiem filtracyjnym (mg TS na 1 cm²) (B)	Difference between B and A Różnica między B i A (%)
Two-layer Dwu-warstwowy	–	2.57 ±0.78	6.97 ±0.87	10.88	13.45	19.1
Four-layer Cztero-warstwowy	7.5–15.0	3.20 ±1.50	7.72 ±0.53	14.25	17.45	18.3
Eight-layer Ośmio-warstwowy	6.0–9.0	3.43 ±1.16	6.26 ±0.42	25.34	28.77	11.9

Table 2. Hydraulic capacity of filtering media coupons with and without filter cake and solids content during long-term experiment
Tabela 2. Wydatek hydrauliczny skrawków materiału filtracyjnego pokrytego i niepokrytego plackiem filtracyjnym i zawartość w nim substancji stałych podczas testu długoterminowego

Filter layers number Liczba warstw filtra	Filter cake dry mass Sucha masa placka filtracyjnego (mg/cm²)	Filter cake thickness Grubość placka filtracyjnego (mm)	All layers dry mass Sucha masa wszystkich warstw (mg/cm²)	Capacity +FC* Wydatek +FC* (cm/h)	Capacity –FC* Wydatek –FC* (cm/h)	Capacity rate –FC/+FC Stosunek wydatku –FC/+FC	TS content rate +FC/–FC Stosunek zawartości suchej masy +FC/–FC
2	2.57	0.28	13.45	1.70	3.78	2.22	1.24
4	3.20	0.50	17.45	0.14	0.24	1.71	1.11
8	3.43	0.30	28.77	0.19	0.55	2.89	1.14
Average Średnia	3.07	0.36				2.28	1.16

*Average of 150 min.
+FC – with filter cake, –FC – without filter cake.
*Średnia ze 150 min.
+FC – z plackiem filtracyjnym, –FC – bez placka filtracyjnego.

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

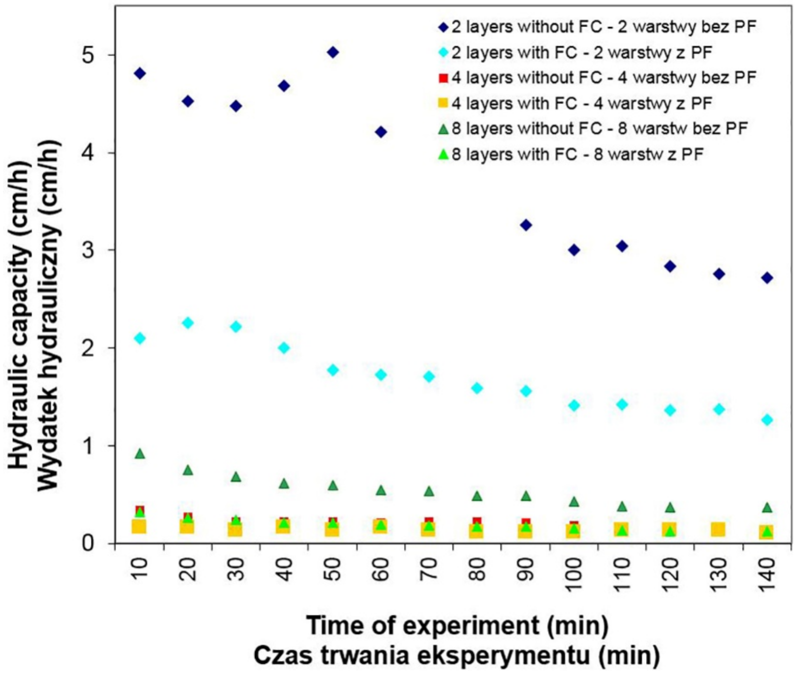

Fig. 3. Hydraulic capacity of filtering media coupons with and without filter cake (FC) during long-term experiment
Rys. 3. Wydatek hydrauliczny skrawków materiału filtracyjnego pokrytego i niepokrytego plackiem filtracyjnym (PF) podczas testu długoterminowego

The dry total mass of all filter layers (whole cross-sectional profile) of filter samples (coupons) was correlated with their thickness (13.45 mg/cm^2 for two-layer filter, 17.45 mg/cm^2 for four-layer filter and 28.77 mg/cm^2 for eight-layer filter).

Similar but a little bit higher values were observed for coupons taken from the filters in initial period of the research (May-August 2013): 13.4 mg/cm^2, 26.9 mg/cm^2 and 36.7 mg/cm^2 for two-, four- and eight-layer filters, respectively.

The filter cake dry mass was related to filter sample thickness. However, the higher difference was between two- and four-layer filters: 0.63 mg TS per 1 cm^2 than between four- and eight-layer filters: 0.23 mg TS per 1 cm^2. TS content in filter with filter cake to TS content in filter without filter cake rate was 1.16 on average for all filter thicknesses (the range between 1.11 for two-layer filters and 1.24 – for four-layer filters). It means that TS content in filter cake amounted to several percent of whole filter cross--sectional profile TS content. The impact of FC mass on different thickness samples hydraulic capacity was much higher than TS in whole cross-sectional profile content.

The hydraulic capacity of filter with filter cake in relation to hydraulic capacity of filter without filter cake rate was 2.28 on average for all filter thicknesses (between 1.71 for four-layer filters and 2.89 for eight-layer filters). Measurement of filter hydraulic capacity with and without filter cake showed the decisive influence of filter cake occurrence on the filter hydraulic capacity.

The filter cake had a decisive impact on the hydraulic capacity reduction due to high density and small porosity (relatively high TS content despite low thickness). The volumetric density of filter cake biomass (90 mg/cm^3 on average for all filter thicknesses) was almost twice higher than the volumetric density of biomass inside the textile filter (52.8 mg/cm^3 on average for all filter thicknesses excluding volume of textile fibres – about 12% of textile layer volume).

The hydraulic conductivity of two-, four- and eight-layer filters, which functioned during a long-term experiment was with filter cake 6.1×10^{-6} m/d, 4.0×10^{-6} m/d and 1.7×10^{-5} m/d, respectively and without filter cake: 1.3×10^{-5} m/d, 6.4×10^{-6} m/d and 4.9×10^{-5} m/d, respectively. The values of the hydraulic conductivity of two-, four- and eight-layer filters, which functioned during a long-term experiment with and without filter cake were presented in Figure 4.

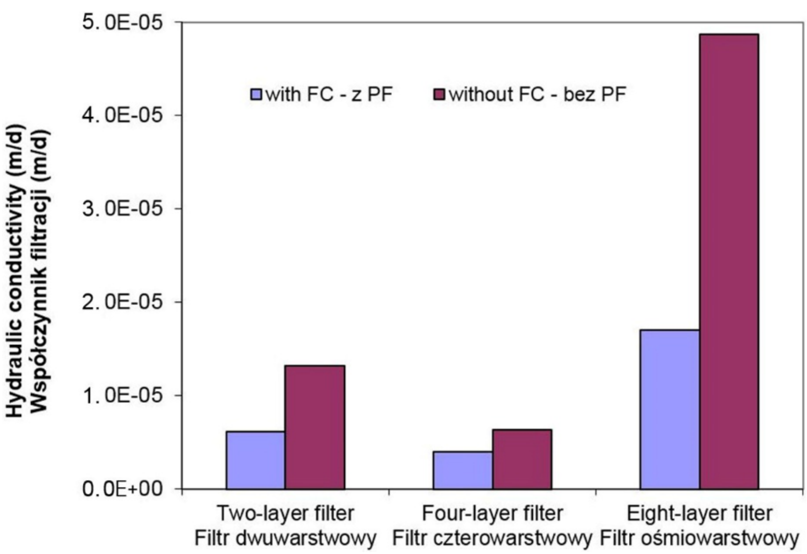

Fig. 4. Hydraulic conductivity of filtering media coupons with and without filter cake (FC) during long-term experiment
Rys. 4. Współczynnik filtracji skrawków materiału filtracyjnego pokrytego i niepokrytego plackiem filtracyjnym (PF) podczas testu długoterminowego

The differences between coupons with and without filter cake were confirmed statistically for two- and eight-layer filters, using a small-sample test of hypothesis for the difference in means (Łomnicki, 1999) and statistics was: 31.9 (statistical t-test for difference of means, $\alpha = 0.05$, *df* = 5, critical value: 2.6) and 17.3 (statistical t-test for difference of means, $\alpha = 0.05$, *df* = 4, critical value: 2.8), respectively. The difference for four-layer filter was not confirmed statistically probably due to the small number of replications (statistics: 5.2, $\alpha = 0.05$, *df* = 1, critical value: 12.7).

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

Although the hydraulic capacity values corresponded with filter thickness, and filter cake presence and absence (Fig. 3), the values of hydraulic conductivity did not fully correspond with filter thickness (Fig. 4). The eight-layer filter showed a higher hydraulic conductivity than the two- and four-layer filters, both for filter with and without filter cake. This could be the consequence of a longer period of hydraulic conductivity determination, which was related to the lower filtration velocity of eight-layer filters compared to the two- and four-layer filters. During a longer period in this context some biochemical processes may become more intensive and accordingly, increase the determined hydraulic conductivity value. Moreover, the hydraulic conductivity determination could be burdened with some error related to the precision of filtering layer (the sum of geo-textile layer and filter cake thickness) determination.

It is worth noting that although the filter layer during long-term experiment was not aerated, the access to the wastewater side of filter and filter cake was sufficient for preventing the filter layer and filter cake from fermentation processes, which was demonstrated by oxygen concentration measurements and filter cake grey-brown colour (Fig. 5). The ammonium nitrogen removal (confirmed directly by measurements and indirectly – by ammonia oxidizing bacteria observation) (Spychała and Starzyk, 2015; Spychała et al., 2013) and absence of anaerobic processes (fermentation) was proof that the low oxygen concentration, thanks to the natural aeration and diffusion from the atmospheric air, can be sufficient for organic compounds and ammonium nitrogen removal through live biomass from wastewater.

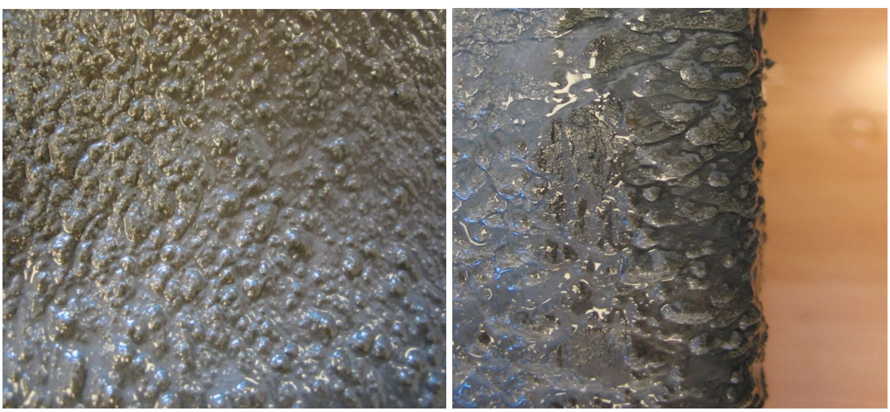

Fig. 5. Filter cake surface observed during long-term experiment (digital camera photography)
Rys. 5. Powierzchnia placka filtracyjnego obserwowana podczas testu długoterminowego (zdjęcie aparatem cyfrowym)

Short-term experiment

The hydraulic conductivity of one-layer filter with filter cake, which operated during the short-term experiment was 1.11×10^{-3} m/d on average (from 5.77×10^{-4} m/d to 1.66×10^{-3} m/d). So the hydraulic conductivity of the filter cake formed in the short period was about two orders of magnitude higher than filter cake formed during the long-term experiment. This was related to the difference observed in filter cake structure: long--term filter cake structure was more homogeneous and viscous in nature (see Fig. 5), when the structure of filter cake formed during short-time period was more porous, a greater number of coarse and separate particles could be seen by the naked eye.

The hydraulic conductivity of the sediment-geo-textile system (sediment formed by fly ash) observed by Kutay and Aydilek (2005) was from 2×10^{-8} m/s to 2×10^{-7} m/s and proved to be comparable to the value observed in this study for the short-term experiment (1.28×10^{-8} m/s on average for three experiments in the two series).

At the end of the first series the filter cake mass (detected as TS) was 6.54 ±1.12 mg/cm^2, inside the geo-textile: 4.23 ±0.58 mg/cm^2 and 10.78 ±0.69 mg/cm^2 as a sum of filter cake and biomass inside the geo-textile layer. The mass accumulated as filter cake during the first series of the short-term experiment was on average 1.25 ±0.20% of cumulative loading of TSS. The sum of mass accumulated as filter cake and inside the geo-textile layer during the first series of the short-term experiment was on average 2.05 ±0.14% of cumulative loading of TSS.

At the end of the second series the filter cake mass was 4.82 ±0.91 mg TS per 1 cm^2, inside the geo-textile: 7.58 ±0.37 mg TS per 1 cm^2 and 12.40 ±0.54 mg TS per 1 cm^2 as a sum of filter cake and biomass inside the geo-textile layer. The mass accumulated as filter cake during the second series of the short-term experiment was on average 1.40 ±0.37% of cumulative loading of TSS. The sum of mass accumulated as filter cake and inside the geo-textile layer during the second series of short-term experiment was on average 3.54 ±0.43% of cumulative loading of TSS.

Such relatively low ratios of accumulated TSS loading (2.05 ±0.14% for first series and 3.54 ±0.43% for second series) in the short-term experiment were related to the significant difference in filter average pore size: 12 μm and 100 μm of cellulose filter for TSS determination and geo-textile (TS 20), respectively.

The hydraulic conductivity of filtering layer without filter cake developed during the short-term experiment (after removal of filter cake) was over four orders of magnitude higher than the hydraulic conductivity of filtering layer with filter cake (37.3 m/d and 1.48×10^{-3} m/d on average, respectively).

The difference was confirmed statistically (small-sample test of hypothesis for the difference in means, statistical t-test) and the statistics was: 5.05 ($\alpha = 0.05$, $df = 2$, critical value – 4.3).

This was the result of a much lower mass and its concentration inside the geo-textile layer compared to filter cake, corresponding to results reported by Vyrides and Stuckey (2011). They observed that the resistance of cake layer in the form of biofilm was about 25 times higher that of the biomass strongly attached to the membrane surface (7.35×10^{10} 1/m and 0.28×10^{10} 1/m, respectively).

The observed number of filamentous particles accumulated during the short-term experiment ($2.2 \times 10^4 - 3.0 \times 10^4$ particles per 1.0 cm^2 of filter cake surface area) was relatively high in comparison to the number of filamentous particles observed in filter cake developed during the long-term experiment (four-layer filter): $5 \times 10^2 - 1 \times 10^3$ particles per 1.0 cm^2 of filter cake surface area. The significant difference in experiment conditions was probably the cause of difference in results. During the long-term experiment some part of filamentous particles (easy biodegradable) was decomposed and a significant fraction of particles supplied with septic tank effluent settled down into the

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

bottom under the gravitational force, which was made possible due to the vertical orientation of the filtering layer. The higher hydraulic conductivity of short-term experiment filter cake than hydraulic conductivity of long-term filter cake was probably related to the much higher number of filamentous particles observed in the former than the number of filamentous particles observed in the latter.

No significant difference was observed in average particles size of long- and short-term experiment: 4.17 ±0.19 μm and 2.58 ±0.03 μm, respectively. However the evident difference was observed in filter cake structure (long-term filter cake structure – more homogeneous and viscous, short-term filter cake structure – more porous).

The comparison of hydraulic capacity of filter cake developed under different conditions (long and short period of time, one- and two-layer thickness, occurrence or absence of filter cake) showed that hydraulic capacity was related to the accumulated total mass.

Conclusions

1. The dry mass of all filter layers was related to filter sample thickness.
2. The dry mass of filter cake developed during the long-term experiment was related to filter sample thickness, however the greater difference was between two- and four-layer filters: 0.63 mg TS per 1 cm^2 than between four- and eight-layer filters: 0.23 mg TS per 1 cm^2.
3. The dry mass of filter cake (developed during the long-term experiment) was about 10–20% of whole filter cross-section TS content.
4. The volumetric density of filter cake created during the long-term experiment was almost twice as high as the volumetric density of biomass inside the textile filter.
5. Both the filter cake developed during long- and short-term experiments had a decisive impact on the filter hydraulic conductivity reduction due to its high density and low porosity; during the long-term experiment the ratio of hydraulic conductivity without filter cake to hydraulic conductivity with filter cake was 2.17, 1.60 and 2.87 for two-, four- and eight-layer filter, respectively, and the differences were confirmed statistically; the filter hydraulic conductivity of a one-layer filter without filter cake was over four orders of magnitude higher than the hydraulic conductivity of a one-layer filter with filter cake developed during the short-term experiment.
6. The hydraulic conductivity of a one-layer filter with filter cake, which operated during the short-term experiment was about two orders of magnitude higher than filter cake formed during the long-term experiment. This was related to a much more compact and viscous long-term filter cake structure.

References

Beach, D., McCray, J., Lowe, K., Siegrist, R. (2005). Temporal changes in hydraulic conductivity of sand porous media biofilters during wastewater infiltration due to biomat formation. J. Hydrol. (Amst.), 311, 230–243.

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

Bérubé, P. R., Lei, E. (2006). The effect of hydrodynamic conditions and system configurations on the permeate flux in a submerged hollow fiber membrane system. J. Membr. Sci., 271, 1–2, 29–37.
Bessiere, Y., Fletcher, D. F., Bacchin, P. (2008). Numerical simulation of colloid dead-end filtration: effect of membrane characteristics and operating conditions on matter accumulation. J. Membr. Sci., 313, 1, 52–59.
Bouma, J. (1975). Unsaturated flow during soil treatment of STE. J. Environ. Eng., 101, 967–983.
Carroll, T. (2001). The effect of cake and fibre properties on flux declines in hollow-fibre microfiltration membranes. J. Membr. Sci., 189, 2, 167–178.
EN ISO 12956:1999. (1999). Geotextiles and geotextile-related products – Determination of the characteristic opening size. Genève, Switzerland: International Organization for Standardization.
EN ISO 9864:2005. (2005). Geosynthetics – Test method for the determination of mass per unit area of geotextiles and geotextile-related products. Genève, Switzerland: International Organization for Standardization.
EN ISO 11058:2010. (2010). Geotextiles and geotextile-related products – Determination of water permeability characteristics normal to the plane, without load. Genève, Switzerland: International Organization for Standardization.
Fane, A. G., Fell, C. J. D., Hodgson, P. H., Leslie, G., Marshall, K. C. (1991). Microfiltration of biomass and biofluids: effects of membrane morphology and operating conditions. Filtr. Separ., 28, 5, 332–340, 331.
Higdon, J. J. L., Ford, G. D. (1996). Permeability of three-dimensional models of fibrous porous media. J. Fluid Mech., 308, 341–361.
Holtz, R. D., Christopher, B. R., Berg, R. R. (1998). Geosynthetic design and construction guidelines. Report (Grant No. DTFH61-93-C-00120). Woodbury, MN: Berg & Assoc.
Hubbe, M. A., Chen, H., Heitmann, J. A. (2009). Permeability reduction phenomena in packed beds, fiber mats, and wet webs of paper exposed to flow of liquids and suspensions: a review. BioResources, 4, 1, 405–451.
Hubbe, M. A., Heitmann, J. A. (2007). Review of factors affecting the release of water from cellulosic fibers during paper manufacture. BioResources, 2, 3, 500–533.
Hubbe, M. A., Heitmann, J. A., Cole, C. A. (2008). Water release from fractionated stock suspensions. 2. Effects of consistency, flocculants, shear, and order of mixing. TAPPI J., 7, 8, 14–19.
Ivnitsky, H., Katz, I., Minz, D., Volvovic, G., Shimoni, E., Kesselman, E., Semiat, R., Dosoretz, C. G. (2007). Bacterial community composition and structure of biofilms developing on nanofiltration membranes applied to wastewater treatment. Water Res., 41, 17, 3924–3935.
Kim, A. S., Chen, H., Yuan, R. (2006). EPS biofouling in membrane filtration: an analytic modeling study. J. Colloid Interface Sci., 303, 243–249.
Kropf, F. W., Laak, R., Healey, K. A. (1977). Equilibrium operation of subsurface absorption systems. J. Water Pollut. Control. Fed., 49, 9, 2007–2016.
Kruszelnicka, I., Ginter-Kramarczyk, D. (2013). Biofilmowe oczyszczanie. Ochr. Środ., 35, 2, 50–53.
Kumar, P., Wei, H. L., Ramarao, B. V. (1996). A model for freeness measurement of papermaking suspensions. Chem. Eng. Commun., 152–153, 287–306.
Kutay, M. E., Aydilek, A. H. (2005). Filtration performance of two-layer geotextile systems. Geotech. Test. J., 28, 1, 1–13.
Law, S. P., Melvin, M. M. A. L., Lamb, A. J. (2001). Visualisation of the establishment of a heterotrophic biofilm within the schmutzdecke of a slow sand filter using scanning electron microscopy. Biofilm J., 6, 1.
Le-Clech, P., Chen, V., Fane, T. A. (2006). Fouling in membrane bioreactors used in wastewater treatment. J. Membr. Sci., 284, 1, 17–53.

Lee, C. H., Park, P. K., Lee, W. N., Hwang, B. K., Hong, S. H., Yeon, K. M., Oh, H. S., Chang, I. S. (2008). Correlation of biofouling with the bio-cake architecture in an MBR. Desalination, 231, 1–3, 115–123.

Li, W., Kiser, C., Richard, Q. (2005). Development of a filter cake permeability test methodology. In: American Filtration and Separations Society, International Topical Conferences and Exposition, Ann Arbor, Michigan, USA, September 19–22 (paper 5, pp. 1–8). Ann Arbor, MI: AFSS.

Łomnicki, A. (1999). Wstęp do statystyki dla biologów. Warszawa: Wyd. Nauk. PWN.

Meng, F., Chae, S. R., Drews, A., Kraume, M., Shin, H. S., Yang, F. (2009). Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material. Water Res., 43, 6, 1489–1512.

Meng, F., Yang, F. (2007). Fouling mechanisms of deflocculated sludge, normal sludge, and bulking sludge in membrane bioreactor. J. Membr. Sci., 305, 1–2, 48–56.

Mourouzidis-Mourouzis, S. A., Karabelas, A. J. (2006). Whey protein fouling of microfiltration ceramic membranes – pressure effects. J. Membr. Sci., 282, 1–2, 124–132.

Peter-Varbanets, M., Hammes, F., Vital, M., Pronk, W. (2010). Stabilization of flux during dead--end ultra-low pressure ultrafiltration. Water Res., 44, 12, 3607–3616.

Psoch, C., Schiewer, S. (2008). Long-term flux improvement by air sparging and backflushing for a membrane bioreactor, and modeling permeability decline. Desalination, 230, 1–3, 193–204.

Ramesh, A., Lee, D. J., Lai, J. Y. (2007). Membrane biofouling by extracellular polymeric substances or soluble microbial products from membrane bioreactor sludge. Appl. Microbiol. Biotechnol., 74, 699–707.

Ren, X., Shon, H. K., Jang, N., Lee, Y. G., Bae, M., Lee, J., Cho, K., Kim, I. S. (2010). Novel membrane bioreactor (MBR) coupled with a nonwoven fabric filter for household wastewater treatment. Water Res., 44, 3, 751–760.

Santos, A., Bedrikovetsky, P., Fontoura, S. (2008). Analytical *micro* model for size exclusion: pore blocking and permeability reduction. J. Membr. Sci., 308, 1–2, 115–127.

Setlhare, B., Mwiinga, G. (2006). Impact of fabric material on slow sand filtration for small and rural water supply in South Africa. In: Proceedings of the Water Institute of Southern Africa Biennial Conference (WISA 2006), 21–25th May, Durban, South Africa. Durban: WISA.

Shimizu, Y., Rokudai, M., Tohya, S., Kayawake, E., Yazawa, T., Tanaka, H., Eguchi, K. (1989). Filtration characteristics of charged alumina membranes for methanogenic waste. J. Chem. Eng. Jpn., 22, 6, 635–641.

Singh, G., Song, L. F. (2006). Cake compressibility of silica colloids in membrane filtration processes. Ind. Eng. Chem. Res., 45, 22, 7633–7638.

Spychała, M., Błażejewski, R. (2003). Sand filter clogging by septic tank effluent. Water Sci. Technol., 48, 11, 153–159.

Spychała, M., Błażejewski, R., Nawrot, T. (2013). Performance of innovative textile biofilters for domestic wastewater treatment. Environ. Technol., 34, 2, 157–163.

Spychała, M., Starzyk, J. (2015). Bacteria in non-woven textile filters for domestic wastewater treatment. Environ. Technol., 36, 8, 937–945.

Vyrides, I., Stuckey, D. C. (2011). Fouling cake layer in a submerged anaerobic membrane bioreactor treating saline wastewaters: curse or a blessing? Water Sci. Technol., 63, 12, 2902–2908.

Yun, M. A., Yeon, K. M., Park, J. S., Lee, C. H., Chun, J., Lim, D. J. (2006). Characterization of biofilm structure and its effect on membrane permeability in MBR for dye wastewater treatment. Water Res., 40, 1, 45–52.

Żużikow, W. A. (1985). Filtracja. Teoria i praktyka rozdzielania zawiesin. Warszawa: WNT.

Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55

WPŁYW PLACKA FILTRACYJNEGO NA WYDATEK FILTRÓW WŁÓKNINOWYCH DO OCZYSZCZANIA ŚCIEKÓW

Streszczenie. Celem badań było określenie współczynnika filtracji placka filtracyjnego oraz jego wpływu na wydatek hydrauliczny filtrów włókninowych oczyszczających ścieki. Badania przeprowadzono z użyciem ścieków odpływających z osadnika gnilnego, filtrowanych przez filtry o czterech grubościach (0,9, 1,8, 3,6 i 7,2 mm). Zawartość suchej masy wynosiła 13,45–36,7 mg zawiesiny ogólnej w 1 cm^2 dla obciążenia ładunkiem związków organicznych wynoszącego 0,04–0,07 mg BZT_5 na 1 mg suchej masy osadu w ciągu doby. Sucha masa placka filtracyjnego była związana z grubością filtra. Zawartość suchej masy placka stanowiła 9,7–19,1% zawartości substancji stałych całego przekroju poprzecznego warstwy filtracyjnej w przypadku testu długoterminowego. Placek filtracyjny miał istotny wpływ na zmniejszenie wydatku za sprawą swojej dużej gęstości i małej porowatości. Gęstość objętościowa biomasy placka filtracyjnego była prawie dwukrotnie większa od gęstości objętościowej biomasy wewnątrz włókniny. Współczynnik filtracji jednowarstwowego filtra bez placka filtracyjnego, badanego w ramach testu krótkoterminowego, był o ponad cztery rzędy wielkości większy od współczynnika filtracji tego filtra pokrytego plackiem filtracyjnym.

Słowa kluczowe: biomasa, placek filtracyjny, wydatek hydrauliczny, współczynnik filtracji, odpływ z osadnika gnilnego, filtry włókninowe do oczyszczania ścieków

Corresponding address – Adres do korespondencji:
Marcin Spychała, Katedra Inżynierii Wodnej i Sanitarnej, Uniwersytet Przyrodniczy w Poznaniu, ul. Piątkowska 94, 60-649 Poznań, Poland, e-mail: marsp@up.poznan.pl

Accepted for publication – Zaakceptowano do opublikowania:
1.07.2015

For citation – Do cytowania:
Spychała, M., Sowińska, A. (2015). Filter cake impact on the textile filters for wastewater treatment hydraulic capacity. Nauka Przyr. Technol., 9, 4, #55. DOI: 10.17306/J.NPT.2015.4.55