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Application of expanded polystyrene filter for tertiary treatment of domestic waste effluent in the UK

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Abstract

The use of expanded polystyrene filters is a promising method for tertiary treatment of domestic waste effluent where biologically treated effluent is filtered through a layer of buoyant polystyrene beads. The advantage of such filters is in the absence of backwashing pumps, containers of clean washing water, while having low energy costs, high resistance of polystyrene to various chemical contaminants that may be in the effluent, easy automation of switching modes.

The article describes the features of the design and principles of the expanded polystyrene filter operation with an upward filtration flow which works in automatic mode. The article includes the comparison of operation and the structural technological characteristics of polystyrene filters with disc filters, which are usually used in practice of tertiary-treatment of effluent in the UK.

Experimental results were obtained from the operation of expanded polystyrene filters with an upward flow of filtration at two operational wastewater treatment plants. The effectiveness of the tertiary-treatment of waste effluent was evaluated by measures of BOD and COD in non-filtered and filtered samples, as well as total suspended solids during the months of the year and hours of the day. The filter demonstrated an average removal of 40% BOD, 28% of COD and 66% of TSS.

Key words: *disc filters, domestic waste effluent, effectiveness and efficiency of effluent tertiary treatment, expanded polystyrene filter, upward filtration*

INTRODUCTION

Presently, there is a growing attention being paid to the quality of water in urban areas [BARTNIK, MONIEWSKI 2016] as it is greatly affected by the impact of urban and industrial effluent [ATTOUI *et al*. 2016]. Insufficiently treated effluent leads to pollution not only of surface water but also groundwater [SHIRAZI *et al*. 2015; SMOROŃ 2016]. It causes problems not only in the developing areas of the world, but also in developed countries [MESTER *et al*. 2017].

The most common filters used for tertiary treatment of waste effluent are the filters with heavy filtration media (sand, expanded clay pellets, zeolite and other materials) which provide a high degree of biological contaminants removal [ARIMI 2017; TALVITIE *et al*. 2017; TATARI *et al*. 2016; TYAGI *et al*. 2009]. The mechanism of organic impurities removal in filters is mainly physical as opposed to biological [MURNANE *et al*. 2016]. The main disadvantage of these filters is the difficulty in carrying out the backwashing of the filter media which requires the use of backwashing pumps, compressed air for stirring the media that complicates and increases the cost of the operation of filters, requires the presence of maintenance personnel and does not always achieve the required backwashing efficiency. Recently, membrane bioreactors have come into wide use in tertiary treatment of domestic waste effluent [JUDD 2006; TRUNOV 2010] as well as disc filters [ZHANGA *et al*. 2017]. Disc filtration has found itself in the "sweet spot" between the granular media and membrane filtration technologies due to the enhanced efficiency and dirt-holding capacity of disc filter elements provided by a combination of surface and volume filtration.

More promising is the use of expanded polystyrene filters which filter effluent through a layer of buoyant beads of expanded polystyrene [FYLYPCHUK, ORLOV 2008; ORLOV *et al*. 2016; SCHÖNTAG *et al*. 2015]. The advantage of such filters is the absence of backwashing pumps and containers of clean washing water, low energy costs, high resistance of polystyrene to various chemical contaminants that may be in the effluent. The backwashing of the filter buoyant media is often carried out via hydraulic automation by using a special backwashing siphon which is activated when the water level above the filter media reaches a certain level [ORLOV *et al*. 2012]. The expanded polystyrene filters can be designed to operate in either top down or bottom up filtration flow modes.

Experimental studies in England were conducted at Thames Water Utilities sites. Thames Water Utilities is responsible for operating 351 sewage treatment works (STW) with approximately 200 serving populations of 2000 or less. Virtually all of these sites are unmanned and receive routine operator visits as inferquently as once per week or once per fortnight. Due to this high number of unmanned sites, there is a demand for tertiary treatment installations to treat the sites' effluents to meet stricter consents set by the Environment Agency without the need for frequent attention. These consents for small works which were traditionally in the region of 30–45 mg·dm^{-3} total suspended solids (TSS) and 20–30 mg·dm^{-3} biological oxygen demand – BOD (total BOD_5 with added Allyl thiourea) are increasingly being reduced to more stringent requirements with BOD consents as low as 7 mg·dm^{-3} and TSS of 15 mg·dm^{-3} applied to some sites.

Thames Water Innovation started working Biovis in 2011 at 2 small operational trickling filter sites to evaluate buoyant media filter for its suitability for application at small unmanned trickling filter sites. The technology had been developed in The National University of Water and Environmental Engineering (NUWEE, Ukr. Nacional'nyj universitet vodnogo khozyajstva i prirodopol'zovaniya) [ORLOV *et al*. 2016], where there are many units in operation. The key design concept is simplicity and the original filter had no internal moving parts.

Many sewage treatment works use disc filters for tertiary treatment of effluent, including Veolia disc filters. In these filters the effluent is filtered through rotating discs covered with mesh material. The cleaning of these filters requires periodic flushing of filter discs with a pressure jet of water and the use of sodium hypochlorite for the biological growths/deposits removal.

The high pressure pumps and spray bars require more frequent attention to ensure efficient cleaning and the 8–10 bar spray pressure for the washwater incurs moderate power costs and associated carbon impact.

A chemical clean with hypochlorite is also required typically every 3 months. This is required to remove biological growths/deposits on the back of the mesh panels which are sheltered from routine backwash. These factors combined have given rise to the scoring of the disc filters as 'reasonable' for operability.

The purpose of this work was the evaluation of the performance of the expanded polystyrene filter with an upward flow of filtration (further Biovis filter) in tertiary treatment of biologically purified effluent and a comparison of its effectiveness with disc filters within the conditions and requirements of the UK water industry.

The objective of the trials was to study the degree of TSS removal from effluent, the reduction of BOD and other indicators, determination of the filter optimal filtration rate and frequency of backwashing, as well as identification of filter media backwashing parameters in automatic filter operation conditions, without operator intervention.

MATERIALS AND METHODS

Biovis filter (upflow configuration) seen in Figure 1 and Photo 1.

In Biovis filter the filtering media bed is comprised of two layers of polystyrene. The top 400 mm layer consists of beads ranging from 4–7 mm in diameter while the bottom 900 mm layer consists of beads ranging from 1–4 mm in diameter. Thus in total, the depth of the media is 1300 mm and this gives a media volume of about 0.975 m^3 and the filtration unit has plan dimensions of 1.0 m × 0.75 m.

In upflow mode the head available for filtration is restricted to the height of the feed chamber/pipework above the overflow level of the filter. On the development unit this was a maximum of approximately 600 mm before a backwash was triggered by the ultrasonic level measurement device.

The top level required to be attained before the filter discharge commenced following backwash is 1.0 m above the holding grid and siphon break. The backwash volume is discharged through the filter media typically over a period of 90 seconds (by virtue of

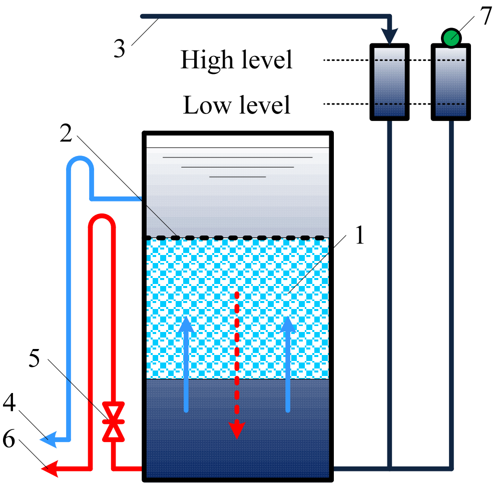

Fig. 1. Biovis filter (upflow configuration); *1* = filter media; *2* = holding grid; *3* = humus tank effluent; *4* = effluent returned to head of works; *5* = backwash valve; *6* = backwash returned to head of works; *7* = level sensor; source: own elaboration

Photo 1. Biovis unit at site 2; phot. *S. Induchny*

the sizing of the backwash siphon but depending on the headloss encountered in the media) resulting in a downflow backwash velocity of 60 m·h^{-1} sufficient to expand the media bed and flush the accumulated solids out of the media and the filter shell into the backwash line.

In the Biovis filter the backwash was linked to a level sensor in a separate stand pipe emulating the feed pipe so that backwash would be initiated by an increased head loss across the filter. When the level in the stand pipe rises to the high set point, the level sensor opens the backwash valve which initiates a siphonic backwash. When the level reaches a point just above the media containment grid the siphon is broken and the backwash is complete.

A timer was added to the system so that when the level reached low set point the valve was held open for 2 minutes, a sufficient time for a full backwash. When the level in the effluent chamber reaches the holding grid an air break stops the backwash siphon so that water does not drain below the holding grid and put the filter at risk of losing the media. The use of an actuated valve to both initiate the backwash and to isolate the backwash siphon after a preset time delivers 2 benefits. The timed closure of the backwash syphon valve acts as a safeguard against blockage of the siphon air break tube and also allows a backwash to be programmed in on a timed basis. This may be particularly useful at low solids loading when otherwise filter run times may become excessive. The siphonic backwash is designed to run for 90 seconds before the siphon is broken. The timer on the automated valve will close the valve typically 30 seconds after the siphonic backwash has completed.

The backwash level set point has been programmed to initiate a backwash once the level in the stand pipe reaches 0.6 m. This has been chosen as it gives the optimum backwash frequency of approximately two times per day.

Biovis upflow buoyant media filter was evaluated at two sites, both of which are small trickling filter sites serving populations of between 3,000 and 5,000.

The Biovis filter is the only tertiary treatment plant running at site 2, in contrast to site 1 where there is a full flow to treatment Disc Filter installation. The treatment process on site 2 can be seen in Figure 2.

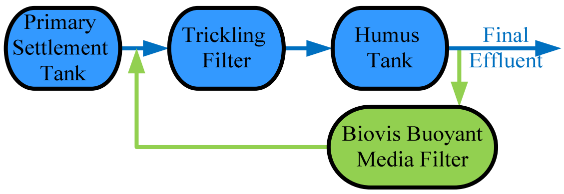

Fig. 2. Simplified diagram of effluent treatment at site 2; source: own elaboration

At site 1 the feed for the Biovis filter was sourced from the low level wet well at a rate of 3–5 m^3·h^{-1} (corresponding to a filtration rate of 4–6.7 m·h^{-1}) where the works humus tank effluent is pumped up to the disc filter. Effluent was discharged to the disc filter returns well and from there was returned to the head of the works. Feed and effluent samples were collected by autosampler normally as 24 hour composite samples.

At site 2 the filter was fed with humus tank effluent at a rate of 4–6.5 m^3·h^{-1} (corresponding to a filtration rate of 6.7–8.7 m·h^{-1}), which is taken from the final effluent sampling point; it then discharges effluent to the humus desludging tank where it is returned to the head of the works.

The samples are collected by autosampler normally collecting time weighted 24 hour composite samples. A sample the effluent samples is collected every hour and stored in a refrigerated unit. The sub samples are combined for bulk sample. Discrete sampling was also conducted comprising 2 hourly single shot samples allowing diurnal profiles of feed and effluent to be determined.

The particle size analysis (PSA) was performed by Cranfield University and samples were run on machine a Malvern Instruments 'mastersizer'. The mastersizer covers a wide particle size range (0.01–2000 µm) but output results as assumed spherical particle volumes as percentage of total volume and so will tend to very significantly bias towards large particle size – a single 100 µm particle will have the same volume as 1,000,000 1.0 µm particles so the representation of particle size by mass (volume) or count will be very substantially different.

RESULTS AND DISCUSSIONS

Whilst the Biovis filter has been running, there has been a large amount of data collected over both sites. The data from site 1 is presented as one set of 24 hour composite samples when the filter was operating in upflow mode. At site 2 there were periods of relatively high and low loading resulting from variations in upstream plant performance; Results are presented from the overall data set from the high and low loading periods as 24 hour composite samples and from a number of diurnal sampling events where samples were analysed as 2 hourly spot samples.

Table 1 shows the influent for both the Biovis filter and the site's existing disc filter. The poor humus tank performance resulted in high BOD and TSS loadings onto both tertiary treatment units.

The average effluent BOD from the Biovis filter over the course of the phase of the trial was 7.6 mg·dm^{-3} compared to 9.2 mg·dm^{-3} of the disc filter. At the 95th percentile for BOD the Biovis filter effluent was slightly lower at 13.3 mg·dm^{-3} compared with the disc filter's 14.2 mg·dm^{-3}. For solids removal, the site's effluent (disc filter effluent) was 14.1 mg·dm^{-3} on average while 36.6 mg·dm^{-3} at the 95th percentile, comparing this to the Biovis filter, the effluent was an average of 8.0 mg·dm^{-3} and 16.0 mg·dm^{-3} at the 95th percentile, showing the Biovis filter to be performing efficiently and reliably. The high average to 95th percentile ratio for both TSS and BOD seen on the disc filter effluent suggests that a small population of relatively high results.

The filtered BOD concentration in the humus tank effluent averaged 3.9 mg·dm^{-3} with a 95th percentile value of 6.0 mg·dm^{-3} which represent a non-filterable load. The filter did show a very small removal of filtered BOD probably by virtue of some biofilm development and activity on the filter media with filter effluent values of 3.2 and 4.3 mg·dm^{-3} mean and 95th percentile respectively.

Similarly a small amount of ammonia removal was observed in common with most media filters with approximately 0.5 mg·dm^{-3} removal at both mean and 95th percentile. TSS removal shows that generally effluent TSS was better than 10 mg·dm^{-3} but increased to a maximum of 23.5 mg·dm^{-3} when the feed quality was particularly poor. Feed TSS concentrations of as high as 63.5 mg·dm^{-3} were recorded and overall the feed TSS 95th percentile value was over 40 mg·dm^{-3}. During these high solids loading events the Biovis filter effluent TSS increased accordingly resulting in the effluent 95 percentile value of 16 mg·dm^{-3} compared to an average of 8 mg·dm^{-3}.

The data from the 24 hour composite samples from the Biovis trial at site 2 has been analysed in total and in 2 sections reflecting upstream plant performance. Figures 3 and 4 show graphically the entire data set for the trials for BOD and TSS.

Diurnal profiles for the Biovis filter were conducted to test whether both filters could work with short term spikes in the influent as these couldn't be shown with the 24 hour composites. The tabulated results are shown and the charts grouped in Figure 5.

The Biovis filter showed high removal percentages of 40% BOD and 66% SS removal compared to the onsite disc filter's 21% BOD and 52% SS removal. However, these figures reflect the high loadings (20 mg·dm^{-3} and 40 mg·dm^{-3} BOD and TSS 95th

Table 1. Biovis filter performance at site 1 using humus tank effluent

Unit	Parameter	95 percentile	Average	Standard deviation	Min.	Max	Average removal %
		mg·dm^{-3}					
Humus tank effluent	BOD	19.6	12.4	4.24	3.60	20.0	
	BODf	6.03	3.90	3.04	2.10	7.70	
	COD	98.9	76.8		48.3	123	
	CODf	58.4	49.0		38.0	59.6	
	TSS	39.6	23.9	11.55	11.5	64.5	
Site's effluent (disc filter)	BOD	14.19	9.19	2.73	5.20	17	21
	BODf	6.15	3.72	1.23	2.10	7.30	9
	COD	74.32	59.9		2.60	201	22
	CODf	67.62	48.57		34.70	137	5
	TSS	36.60	14.13	9.99	3.50	47.50	52
Biovis filter	BOD	13.28	7.62	3.04	3.10	17.70	40
	BODf	4.30	3.22	0.91	2.0	5.70	17
	COD	75.10	55.23		35.80	84	28
	CODf	56.60	49.43		6.28	342	8
	TSS	16.0	8.0	4.84	2.5	23.50	66

Explanations: BOD = biological oxygen demand, BODf = biological oxygen demand filtered, COD = chemical oxygen demand, CODf = chemical oxygen demand filtered, TSS = total suspended solids.
Source: own study.

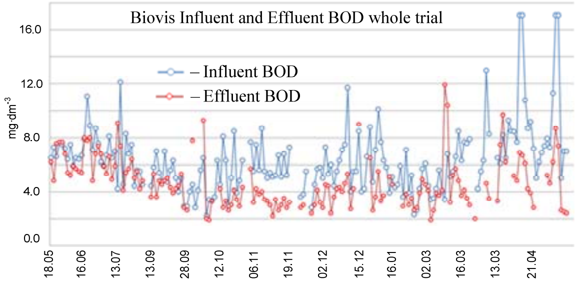

Fig. 3. Site 2 Biovis filter biological oxygen demand (BOD) removal; source: own study

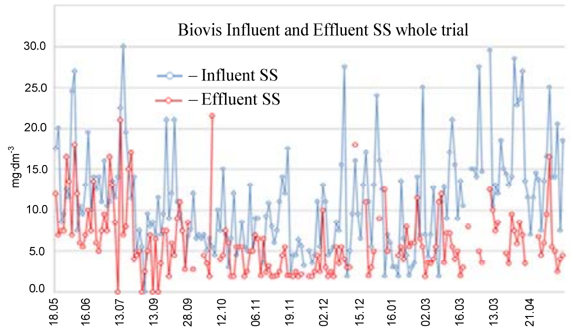

Fig. 4. Site 2 Biovis filter total suspended solids (TSS) removal; source: own study

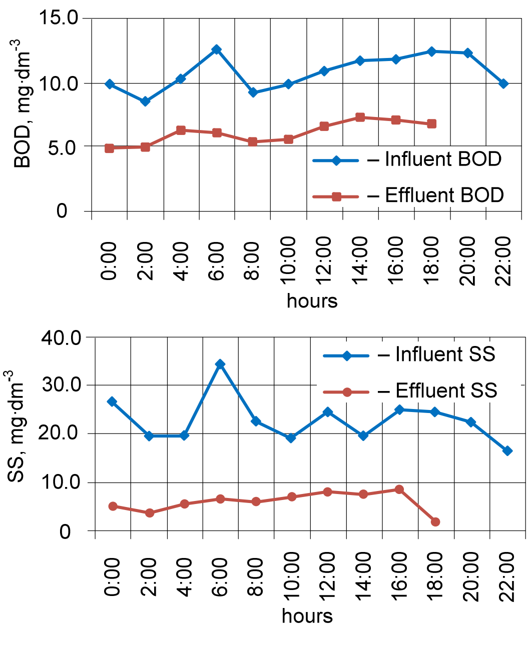

Fig. 5. Diurnal profiles sampled on the Biovis filter at Site 2 for both biological oxygen demand (BOD) and suspended solids (SS); source: own study

percentile respectively) this showed though, that the Biovis is able to cope with poor effluent while producing good results. The average BOD and SS coming off the filter during this time was 7.62 mg·dm^{-3} BOD and 8.0 mg·dm^{-3} SS compared with the disc filter's 14.13 mg·dm^{-3} BOD and 9.19 mg·dm^{-3} SS. On the 95th percentile, the Biovis was also the more effective filter.

During the high solid's loading period, the removal percentage of BOD from the Biovis is 16% with solids removal at 38%. This shows that it is able to cope sufficiently with a higher loading of solids, as the 95th percentile reading never approached the site's effluent consents, unlike the site's final effluent which got close on the 95th percentile at BOD 10.65 mg·dm^{-3} and SS 25.75 mg·dm^{-3}.

A majority of the data collected for the Biovis at site 2 was during the low solids loading period. The Biovis has higher removal efficiency, reaching removal percentages of 31% and 51% for BOD and SS respectively. With this high removal percentage, it means the average effluent BOD and TSS levels across the lower loading set of composites are 3.85 mg·dm^{-3} and 4.44 mg·dm^{-3}. With 95th percentile values at 5.46 mg·dm^{-3} BOD and 8.8 mg·dm^{-3} SS against humus tank effluent of 7.88 mg·dm^{-3} and 15.9 mg·dm^{-3} respectively show the filters ability to maintain performance at routine loadings. Throughout these trials the filter was operated at a filtration rate of 8.5 m·h^{-1}, close to its maximum design rate of 10 m·h^{-1} and above the optimal filtration rate of 7 m·h^{-1}.

Figure 6 shows one set of PSA yields for particle size analysis which are held on the filter. Mastersizer data presented for the humus and Biovis effluent at site 2 expressed as percentage total particles and corrected for absolute particle mass (as mg·dm^{-3}) shows the resultant % removal across the particle size fractions for one of the pair of samples.

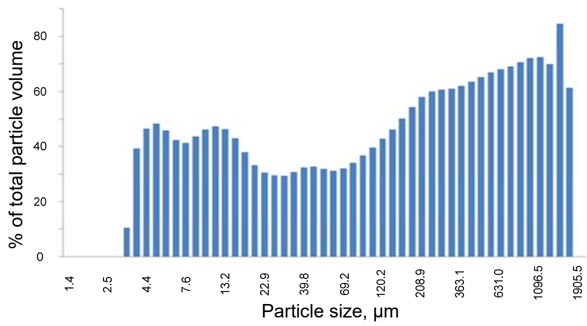

Fig. 6. Estimated % removal by size fraction: site 2 mastersizer site results for 14th Jan corrected for TSS concentrations HTE 13.5 mg·dm^{-3} TSS Biovis effluent 5.5 mg·dm^{-3} TSS; source: own study

At the time Thames Water Utilities conducted a broader evaluation of available tertiary treatment options including disc filters, heavy multimedia filters and reed beds. The Biovis filter is the simplest of the 4 units assessed in part of a wider tertiary treatment plant trial. In its configuration as used at sites 1 and 2 its performance and operation has been fairly robust. There is a crude strainer on the inlet which has required cleaning quite frequently but subsequent designs could eliminate this as the flow is introduced into an open chamber below the bed of buoyant media. A simple coarse (10 or 15 mm) open tank basket strainer located in the feed chamber would be

Table 2. Summary of operability of 2 types of tertiary treatment

Unit	Moving parts/ service items	Maintenance	Relative OpEx	Relative operability
Veolia disc filter	disc/shaft drive and seals, high pressure backwash pumps, spray nozzles, upstream effluent strainer for protection ultrasonic level sensor	3 monthly hypochlorite clean, (contract) expected membrane life – 15–20 years (life of unit)	medium/high backwash sprays pressurised at 8–10 bar	reasonable
Biovis	1 x automated valve ultrasonic level sensor potential to remove effluent strainer for protection?	6 monthly jet wash media retention grid	very low external pumping only	good

Source: own study

sufficient to prevent large items of debris (leaves, twigs dead animals etc.) entering the filter with the potential for fouling the backwash collector grid openings. This feature will allow the filter to operate without an inline strainer which would improve operability further.

At site 2 the media retention grid required cleaning with a high pressure washer at 6 month intervals. In a highly loaded environment with higher BOD concentrations in the effluent this may be required more frequently and vice versa. Other than the automated valve which is close to ground level there is an ultrasonic (or other) level sensor at the top of the unit detecting filter headloss and initiating the backwash. Access to this and to the grid for occasional cleaning are the only requirements for access to the top of the filter. Control is simply a relay output from the level sensor to trigger the backwash valve and a timer to close it after the siphon break has stopped the backwash flow.

On 2 occasions the filter has received a very high solids load due to site issues. In each case the backwash was insufficient to clean the filter but in each case the unit backwashed multiple times sequentially (with partial volume of backwash water increasing each time) and after 4 or 5 backwashes normal operation was resumed typically with a filter run time of 12 hours. This procedure occurred spontaneously with no operator intervention and was picked up from remote logging of the headloss. Overall the filter has been therefore been given a good operability rating.

CONCLUSIONS

1. The Biovis upflow buoyant media filter is mechanically a very simple unit and following development of the upflow configuration has proved to be efficient at solids removal and robust in operation. The Biovis filter is potentially a good robust option for very small sites and should be considered as an alternative to disc filters.

2. The Biovis filter trials at both sites showed performance in upflow mode to be capable of meeting tightened consents on typical small trickling filter sites and capable of meeting a 10 BOD and 15 TSS consent with reasonable upstream settlement tank performance.

3. The possibility of operation with a simplified open tank coarse strainer should be investigated. In upflow operation the media should protect the retention grid from fouling and removing the need for an inline strainer would reduce maintenance requirements significantly.

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Zastosowanie filtrów ze styropianu w trzecim stopniu oczyszczania ścieków bytowych w Wielkiej Brytanii

STRESZCZENIE

Użycie filtrów ze styropianu jest obiecującą metodą w trzecim stopniu oczyszczania ścieków bytowych. Odpływające ścieki oczyszczone biologicznie są w tej metodzie filtrowane przez warstwę pływających kulek polistyrenowych. Korzyścią takich filtrów jest brak pomp przepłukujących, zbiorników czystej wody, mały wydatek energetyczny, duża odporność polistyrenu na różne zanieczyszczenia chemiczne, które mogą być obecne w ściekach oczyszczonych biologicznie, oraz łatwa automatyzacja trybów przełączania.

W pracy przedstawiono charakterystykę i zasady funkcjonowania filtrów polistyrenowych ze wstępującym przepływem ścieków, które działają automatycznie. Porównano działanie i właściwości technologiczne filtrów polistyrenowych z właściwościami filtrów dyskowych, które są zwykle używane w trzecim stopniu oczyszczania ścieków w Wielkiej Brytanii.

Wyniki uzyskano z obsługi filtrów polistyrenowych ze wstępującą filtracją w dwóch oczyszczalniach ścieków. Wydajność trzeciego stopnia oczyszczania ścieków oceniono, mierząc BZT i ChZT w próbach filtrowanych i niefiltrowanych oraz stężenie zawiesiny w kolejnych miesiącach roku i godzinach dnia. Stosując filtr Uzyskano średnie zmniejszenie BZT na poziomie 40%, ChZT – 28% i zawiesiny całkowitej – 66%.

Słowa kluczowe: *filtracja wstępująca, filtry dyskowe, filtry styropianowe, oczyszczone ścieki bytowe, skuteczność i wydajność oczyszczania trzeciego stopnia*