

SUPPRESSION OF 'FILTER CAKE' WITHIN A MEDIA PRESSURE FILTER BY VORTEX SURFACE SCOURING

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The findings reported in this paper demonstrate that 'filter cake', and its associated contribution to head loss in a media pressure filter system, can be suppressed by the employment of a swirl-inducing tangential inlet without any loss in separation efficiency. The likely mechanism for this performance enhancement is the creation of a vortex-induced crossflow scouring action which prevents cake formation. Instead of being retained as a thin, dense layer at the surface of the filter, particles are believed to be either held in motion above the bed or given the opportunity to penetrate the bed and collect over a greater bed depth, thus producing a lower contribution to overall system head loss by utilising media voidage more effectively. This further improves filter performance by reducing backwash cycle frequency and therefore the overall amount of contaminated backwash water requiring disposal.

INTRODUCTION

The discharge of polluted wastewaters continues to be subject to an increasingly stringent and expanding array of legislation (e.g. EC Water Framework Directive 2000/60/EC). Furthermore, the increasing scarcity of freshwater in some regions of the world is making this essential product an evermore expensive commodity. Hence, there is a growing demand for reliable and effective water treatment technologies which operate with minimal waste output and energy consumption.

Media pressure filters are commonly used in water treatment applications and are well understood in practical terms¹. Hence, simple design innovations which could potentially improve the performance of any such devices, with regards to minimising water consumption, waste generation and energy consumption, could have important and wide-reaching implications.

Conventional media pressure filters are normally designed to avoid significant disturbance of the filter bed by incoming forward flow and thus maintain a level and uniform filtration surface²⁻⁴. This situation is achieved either through the use of appropriately located baffles and/or by directing inlet flow away from the bed surface (e.g. towards the centre of the vessel roof)^{1,5}. Both strategies are intended to suppress any swirling motion above the bed and ensure that a relatively uniform flow distribution is presented to the bed surface.

Several commercial devices have recently appeared on the market which go against this convention by intentionally incorporating inlet arrangements that promote strong swirling flow patterns above the bed surface⁶⁻⁸. One method of achieving the swirling flow is to introduce influent through a tangentially-mounted inlet thus generating a vortex within the freeboard. A

claimed advantage is the inducement of a crossflow scouring action which suppresses the build-up of 'filter cake' and therefore offsets its associated problems (i.e. large head loss, frequent backwashing, channelling, etc.). Material which would otherwise contribute to a cake layer is thought to be swept clean of the surface and held in turbulent suspension above the bed. The intended outcome is a reduction in the rate of system head loss accumulation with prolonged process operation and an accompanying reduction in backwash-cycle frequency (i.e. less water, time and energy devoted to backwashing). Figure 1 illustrates this principle.

Our own review of the literature could find no data to support or refute the advantages claimed. Ward *et al.*⁹ studied two such 'swirl flow' inlet designs, including a tangential arrangement, but did not consider either with respect to head loss. However, they did report how the tangential inlet created a vortex within the freeboard above the bed, a consequence of which was the erosion of surface sand media from the near-wall region and its deposition towards the centre. As a result, the bed surface was formed into a positive cone shape. With respect to the test conditions applied by Ward *et al.*⁹, the effect was shown to have a significant negative influence on filter efficiency for particles less than 15 µm. Surface erosion in the near-wall region was found to strip away the finer fractions of the filter sand (raised to the surface by grading during backwashing) and expose the coarser material beneath. As a result, this thinned/coarse region of the bed will have attracted a greater proportion of the flow and reduced the filtration efficiency, particularly for smaller particles.

Although Ward *et al.*⁹ identified this potential disadvantage, the tangential inlet approach may still be of practical advantage if a positive performance

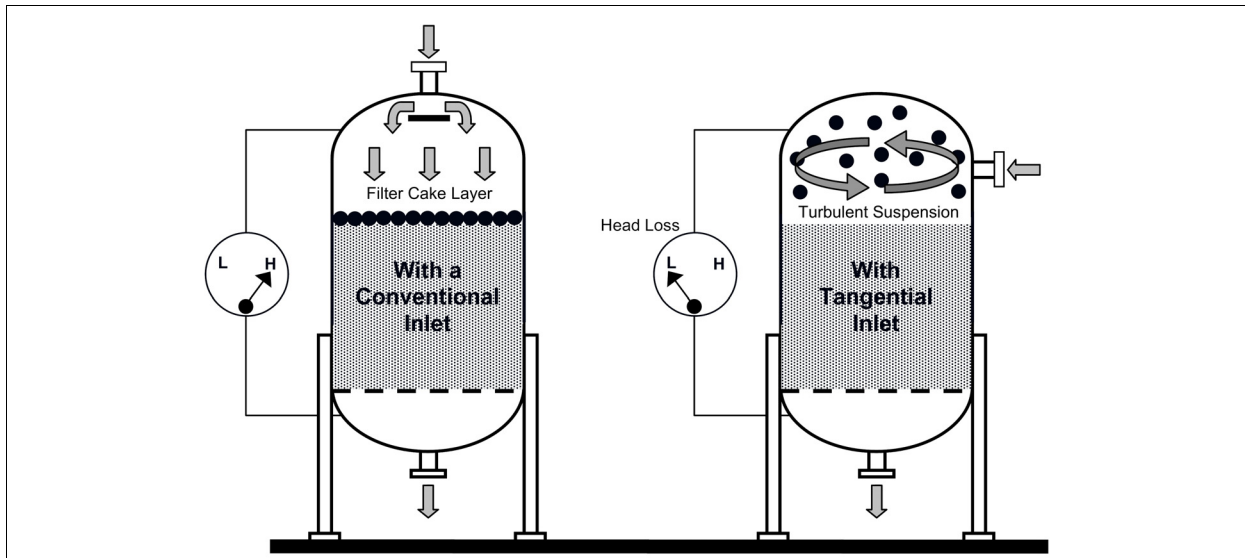


Figure 1: Effect of inlet configuration on cake formation and head loss.

influence can be demonstrated with respect to head loss. Hence, the objective of the investigation reported here was to determine the impact of a tangential inlet with respect to filter bed head loss accumulation and separation efficiency, and to compare the results with those obtained using a conventional inlet design.

METHODOLOGY

The investigation was carried out using a laboratory-based pilot-scale media pressure filter. A schematic of the test filtration system is shown in Figure 2. The

filter vessel had a diameter (D) ~ 0.5 m and was connected to a water tank approximately 4 m^3 in capacity. The water supply to the filter was fed via a centrifugal pump and metered by a bank of rotameters. Continuous pressure monitoring was achieved using transducers (0-4 bar) (PMC131, Endress & Hauser, Germany) installed immediately upstream and downstream of the filter vessel. Pressures were recorded using a data logger and PC software (U12 Labjack supplied by Audon Electronics, UK). Control valves enabled the flow to be reversed through the filter for backwashing. Viewing ports fitted to the side

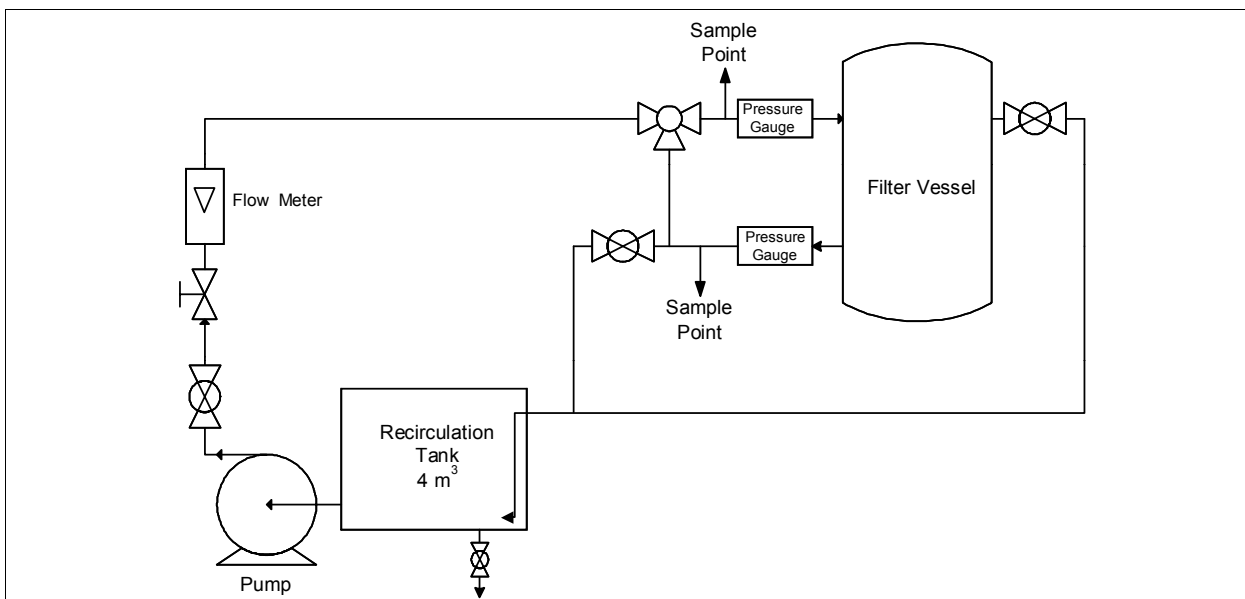


Figure 2: Schematic of the test filter recirculation loop system.

and lid of the filter allowed the bed surface and flow within the freeboard to be observed.

The bed structure used for all tests consisted of a 28 cm deep layer of glass derived filter media (0.25–2 mm size range, Industrial Purification Systems, UK) mounted above a 42 cm deep gravel support layer (3–20 mm size range, Universal Mineral Supplies, UK). The bed surface was set 20 cm below the filter inlet.

As already discussed, two inlet arrangements of approximately 38 mm inner diameter were investigated in the current study; (a) a conventional 'non-swirl' design (typically used in industry⁵) and (b) a tangential swirl-inducing inlet design (shown schematically in Figure 3).

Identical tests were conducted for each of the two inlets (Table 1 documents the exact test conditions). The applied flux rate was similar to that used by commercial swirl-inducing filters⁶⁻⁸ and also in our recent related investigation⁹. System backwashing was performed for 4 mins. at $8 \text{ m}^3 \text{ h}^{-1}$ prior to each test (flux rate $40 \text{ m}^3 \text{ h}^{-1} \text{ m}^{-2}$). Following each backwash operation, the system returned to its clean-bed head loss of 0.3 bar, suggesting that this flux rate was sufficient to achieve adequate bed cleaning.

Prior to each test the recirculation tank was dosed to approximately 50 parts per million by volume (PPMv) using a standard test dust (0–80 μm mineral flour, ISO 12103 Pt1. A2 Fine - Particle Technology, UK). To achieve this concentration, 575 g of test dust was added to the tank (total system volume 4.4 m^3 and dust SG 2.65). In order to promote a homogenous mixture, the tank was then agitated for 10 mins. by re-circulating the contents with the filter isolated. Water supplied to the tank/system was fed from the main laboratory water supply with a background

particle load of just a few PPMv.

Sampling ports, from which water could be collected for particle size analysis, were provided immediately upstream and downstream of the filter vessel (as shown in Figure 2). To avoid sample biasing effects, samples were extracted using internally mounted nozzles. Each nozzle consisted of a 5 mm diameter tube extending to the pipe centre and open to the direction of flow via a 90° bend. The collected samples were prepared and analysed using a Spectrex PC-2200 laser particle counter (Spectrex, California, USA) to determine both the size and concentration of particles in the 1–100 μm range (counts/mL). Preparation involved sample dilution to reduce the total particle concentration to within the specified limits of the instrument (i.e. 500–800 counts/mL). Dilution was achieved using ultra-clean water (<30 counts/mL). Each sample was prepared in duplicate and then each preparation analysed in triplicate (the final result was determined as an overall ensemble average – the resulting standard deviation was less than 6% total counts/mL in all cases).

The PPMv load was estimated by calculation based on particle size/count data. Calculations assumed all particles were spherical and possessed a specific gravity of 2.65 (i.e. specific gravity of the test dust). Samples were also subjected to turbidity analysis using a HACH[®] 2100P Turbidity Meter (Hach Lange, UK) conforming to US EPA method 180.1.

RESULTS AND DISCUSSION

In all cases the duplicate tests yielded very similar results. From the system capacity and flow rates it was estimated that over the course of each 24 h test, the system contents were recycled approximately 70 times.

Figure 4 compares the decline in particle concentration experienced by the system when using inlet A and inlet B (based on samples collected upstream of the filter). The rates of decline were almost identical for each inlet, suggesting similar removal efficiencies. The effect is also mirrored in the turbidity results shown in Figure 5. Visual observation of water clarity within the open tank confirmed this behaviour. At the beginning of each test the tank water was observed to possess a dense, 'milky-white' appearance. By the end of the run, the water had visibly improved to a 'crystal-clear' appearance with no significant evidence of settled material at the base of the tank – thus suggesting practically all the dust material had been retained within the filter bed.

The similar rates of solids and turbidity decline in Figures 4 and 5 show that similar filter efficiencies were obtained regardless of the inlet design. This result was also confirmed by comparison of particle

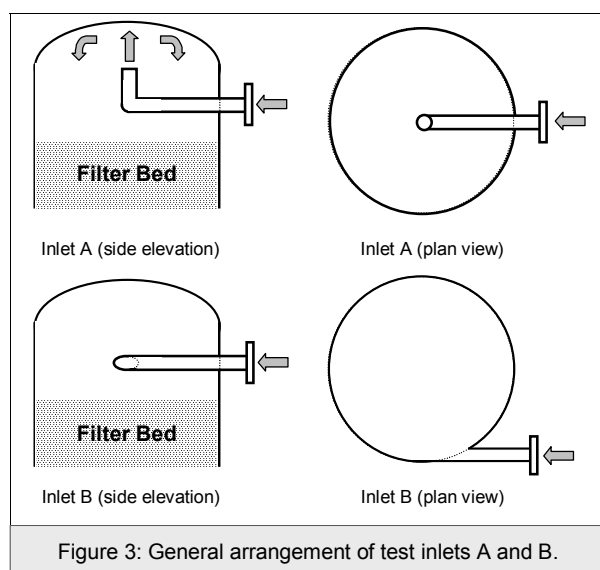


Figure 3: General arrangement of test inlets A and B.

Filtration Solutions

Parameter	
Filter vessel diameter	0.5 m
Inlet diameter - nominal bore	38 mm (1.5 inch)
Recirculation tank volume	4.4 m ³
Initial tank load	50 PPMv
Flow rate	12 m ³ h ⁻¹
Flux rate	60 m ³ h ⁻¹ m ⁻²
Test duration	24 h
Clean system head loss	0.3 bar

Table 1: Operating conditions for tests.

size/count results obtained for samples collected from the inlet and outlet of the filter throughout each test. As an example, Figure 6 compares the grade efficiencies obtained 20 mins. into inlet A and B tests. The similarity in efficiency is contrary to that reported by Ward *et al.*⁹ who concluded that the tangential inlet (inlet B) caused a significant loss in efficiency for particles <15 µm. The most likely explanation for the discrepancy is the different filter media and bed structure employed in the respective studies. In their earlier study Ward *et al.*⁹ used a filter sand media

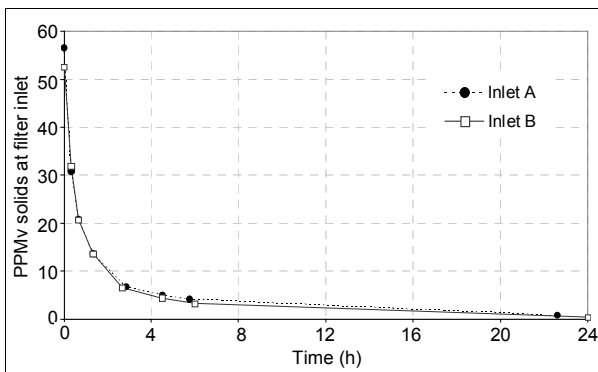


Figure 4: Comparison of PPMv load behaviour during tests involving inlet A and B.

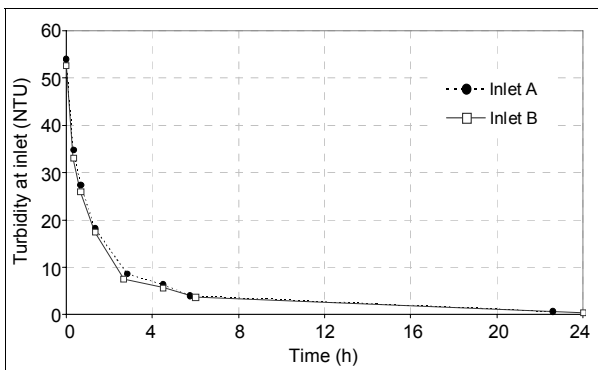


Figure 5: Comparison of turbidity behaviour during tests involving inlet A and B.

which graded on backwashing to form a thin layer of fine surface material. As discussed above, when operating with a tangential inlet, they reported that the vortex in the freeboard was seen to strip away this thin layer of fines from the near-wall regions of the bed surface and expose coarser underlying material. As it is the fine surface material that plays the more crucial role in the filtration of smaller particles, its removal was deemed to account for the reported loss in efficiency.

Visual observation of the freeboard during inlet B test operation confirmed the presence of a vortex above the bed and the formation of a positive cone shaped bed surface (as described by Ward *et al.*⁹). However, examination of the glass filter layer after backwashing revealed the upper 14 cm of bed to contain a mixture of material within the 0.25–0.5 mm size range. Despite erosion of this layer at the near-wall surface region, a depth of a few centimetres was still found to remain after tangential operation. The results suggest that the depth of this upper layer of finer media was adequate to maintain filtration efficiency despite undergoing some localised erosion.

A comparison of filter head loss behaviour between inlets A and B is shown in Figure 7. As can be seen, when using inlet A, system head loss increases to almost 1.2 bar by the end of the 24 h period: a five-fold increase compared with the initial state. In contrast, no discernable increase was observed throughout inlet B operation, despite the filter bed having retained the same mass of dust material. Visual observation of the flat bed surface during inlet A operation revealed the build-up of a thin cake layer of white test dust (approximately 2–3 mm thick). Similar observation of the conical bed surface which is formed during inlet B operation could discern no such surface build-up. The induced vortex-flow pattern above the bed was clearly seen to produce a surface scouring action about the cone peak. Furthermore, relatively large-sized solids were observed to be held in turbulent suspension above the bed or rolling about its surface in concentric

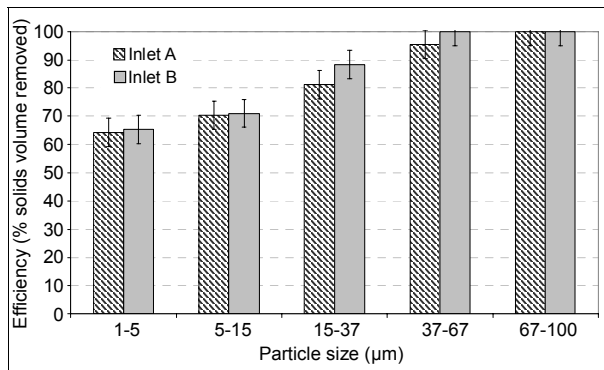


Figure 6: Comparison of filter efficiencies experienced at T = 20 mins. during tests involving inlet A and B.

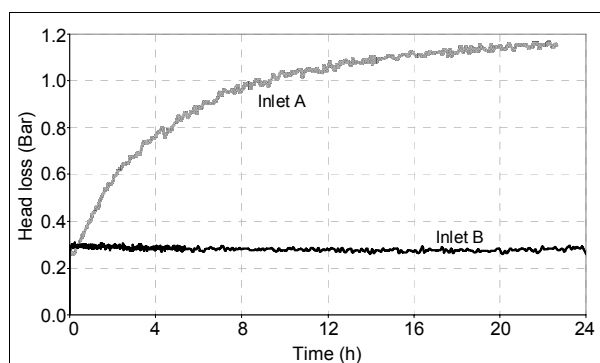


Figure 7: Comparison of head loss behaviour during tests with inlets A and B.

fashion (>1 mm by visual estimation and thought to originate from the laboratory water supply background load).

As described, no increase in head loss was recorded during inlet B operation. This is perhaps due to an improvement in the effectiveness with which the retained particles use the available bed voidage. If prevented from collecting at the surface, particles would be encouraged to penetrate the filter bed and thus become trapped over a greater depth (i.e. collected within a bed depth of possibly a few centimetres rather than as dense surface cake of a few millimetres). As such, a more efficient use of media voidage would be achieved, and hence a much lower contribution to head loss per unit volume of solids retained.

CONCLUSIONS

With respect to media pressure filtration, the findings of this investigation demonstrate that 'filter cake', and its associated contribution to overall system head loss, can be suppressed by the employment of a swirl-inducing tangential inlet. The mechanism of performance enhancement is the creation of a vortex-induced crossflow scouring action which prevents cake formation. Instead of being retained as a thin, dense layer at the surface of the filter, particles are believed to be either held in motion above the bed or given the opportunity to penetrate the bed and collect over a greater bed depth – thus producing a lower contribution to overall system head loss by utilising media voidage more effectively.

To avoid compromising filtration efficiency when using a tangential inlet (i.e. by vortex erosion of fine media from the near wall regions of the bed surface), the bed should contain an adequately deep upper layer of finer media. Such a layer will ensure sufficient surface coverage is maintained despite some degree of bed-

surface redistribution.

This investigation therefore recommends that media pressure filter designers consider employing the tangential inlet when developing new equipment or modifying existing plant. Its ability to suppress the development of filter cake should improve performance by: i) lessening the required frequency of backwashing (i.e. less time offline and less energy devoted to backwashing), ii) reducing the overall volume of backwash water requiring disposal, and iii) eliminating the occurrence of filter failure by cake-related channelling. Furthermore, designers would be free to consider optimising filtration efficiency by employing finer grades of filter media hitherto dismissed due to the consequences of rapid cake build-up and related head loss.

Work continues in an effort to determine the inevitable limits of the technique. Although under the conditions of this investigation no increase in head loss was recorded when operating via the tangential inlet, it is reasonable to assume that with increased retention such behaviour cannot continue indefinitely. Hence, further investigation is required to quantify the additional load retained before warranting backwashing (to avoid either an intolerable system head loss or solids breakthrough) and the expected reduction in backwash frequency and water consumed.

Further work is also required to determine upper and lower inlet flow limits. Vortex scouring may become too weak to prevent cake formation when flow rates are too low; conversely, filtration efficiency may be reduced by excessive surface erosion when flow rates are too high.

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INNOVATIVE TECHNOLOGIES IN WATER TREATMENT BASED ON ULTRAFILTRATION

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Even though important innovations have been created in the last two decades that contributed to the realisation of a great variety of membrane-based solutions and industrial processes, there can still be further optimisation and important improvement in different areas of membrane technology. One of the areas is water treatment or purification with ultrafiltration, including drinking water, process water and waste water. Due to the different spectra of components or degrees of contamination in these liquids, a wide range of possibilities regarding the design, manufacturing and operation of related plants has had to be developed.

At one extreme are waters with a low level of contamination, that can be processed with the deadend operation mode. At the other are waste waters or process waters with a high burden of components or contaminants, that can only be treated with the crossflow operation mode. One example for an innovation in low contaminated applications is a module with capillary membranes with a much higher membrane area than usual and improved internal hydraulics based on flow dynamic calculation. At the other extreme a new system has been developed where the crossflow velocity of the liquid over the membrane is realized by pumping this liquid through nozzles into the open channel formed between two disc membrane cushions fixed as a disc cartridge.

INTRODUCTION

Membrane processes have become important instruments in water management, environmental engineering and industrial production, because their efficiency has been proven from technical and economical, as well as ecological points of view¹. This results from:

- the reliable properties of the membranes that are available today on the market
- their combination with an appropriate module configuration, and
- a plant design or manufacturing process, that has been strictly adapted to the needs of each specific application.

However, even if in the last two decades important innovations have been made that contributed to the realisation of a great variety of membrane-based solutions and industrial processes, further optimisation and important improvements in different areas of mem-

brane technology can still be found^{2,3}. Water treatment or purification with ultrafiltration is one of these areas, including drinking water, process water, and waste water. Due to the differing spectra of components or degrees of contamination of these liquids, a wide range of possibilities regarding the design, manufacturing, and operation of related plants had to be developed.

Water with a low level of contamination, that can be processed with the deadend operation mode, is one extreme. At the other extreme are waste waters or process waters with a high burden of components or contaminants, that can be treated only with the crossflow operation mode.

One example of innovation for the treatment of lowly contaminated applications is a module containing capillary membranes with a high packing density. An example of the application of membrane technology for the treatment of heavily contaminated water is a sys-