Membrane filtration units with integrated high frequency backpulsing

Hi-Fre

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PROJECT FINAL REPORT

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1.1 Executive Summary

Membrane filtration is an increasingly applied separation process with high relevance for industrial and environmental applications such as water and wastewater treatment. The use of porous membranes such as micro- and ultrafiltration membranes in these applications is severely hampered by the accumulation of retained material on the membrane and the interaction with the membrane material. This project aims to overcome these limits by developing a high frequency back-pulsing device, integrating it into membrane filtration systems and transferring the knowledge gained to new, more competitive products and services offered by the SMEs involved.

The applications investigated range from the treatment of liquid residues of biomass-based power generation to treatment and reuse of process fluids and wastewater, including membrane bioreactor applications. The project addresses all critical points along the value chain from membrane supply to end-use. Its outputs include insight into the hydrodynamics of high frequency back-pulsing, novel back-pulsing devices, adapted membrane/module configurations and new applications for a new technique.

To achieve the project objectives, the differential pressure between feed and permeate side of the membrane is reversed with a frequency somewhat lower than 1 Hz, by raising the permeate pressure, while an adequate cross-flow is kept on the feed side. The shape of the pressure pulse has to be controlled in a way that still guarantees a high net permeate flow. This requires backpulses that are short compared to the forward flow phases.

While in the first phase of the project the partners mainly focused on the generation of new knowledge about the effectiveness of back-pulsing systems in membrane filtration to derive appropriate design criteria for a new backpulse device, the second phase moved into constructing and designing several different prototypes of the backpulse device and integrating it in filtration systems using different kinds of membranes.

The back-pulsing systems have been tested with polymeric and ceramic membranes and feed solutions such as surface water, biomass from wastewater treatment plants and liquid residues from biogas plants (digestate).

In the testing with model solutions and with the real feed matrices the positive impact of the back-pulsing could be shown. It was confirmed that not the very high but the medium backpulsing frequencies are ideal for most of the applications. However in many applications, when the filterability of the feed solutions is very poor due to colloidal fouling and not limited by cake layer formation, the loss of permeate through back-pulsing could not be compensated by the permeability increase.

On-site tests were carried out both with the polymeric and ceramic membrane system for the sludge and digestate application respectively.

Particularly interesting results of the second project phase include a new module system for MBR application based on multi-bore membranes operated in outside-in mode and in a rotating back-pulse device.

1.2 Background

Since the first synthetic membranes became available approximately 40 years ago, the industry has grown continually[1]. Nevertheless, the membrane market growth has lagged behind expectations[2]. This is mainly due to the problem of membrane fouling, which is the deposition of contaminants inside and on the membrane surface.

Fouling is a phenomenon that is typical for membrane filtration. Contaminants that are held back by the membrane are concentrated in the boundary layer adjacent to the feed side of the membrane (Figure 1). Solid contaminants agglomerate and dissolved contaminants precipitate there and form a gel or cake layer. Trans-membrane flux (permeate flow per unit membrane area) is decreased by this layer and the filtration performance is reduced to a fraction of its value in unobstructed operation. Many attempts have been made to reduce fouling, including energy consuming high velocity cross flow on the feed side, turbulence inducing module design, gas sparging and back flushing techniques that periodically reverse the direction of flow at the membrane. Fouling can also be caused by contaminants that enter the membrane and adsorb to its porous inner structure. This type of fouling is often called irreversible because it cannot be removed by hydrodynamic measures and requires chemical cleaning.

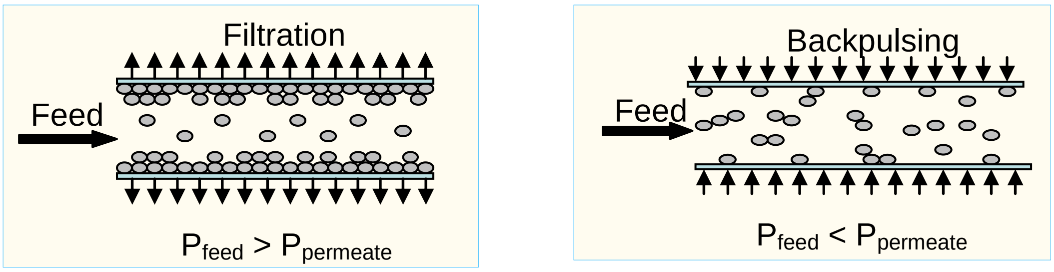


Figure 1. Membrane filtration and back-pulsing

The importance of this development has been recognised on a European level by the WSSTP[3] (Water Supply and Sanitation Technology Platform) in 2006. The WSSTP generated a Vision document and a Strategic Research Agenda (SRA) which were agreed by a wide group of European industrial stakeholders from the "water industry" being both the supplier and the user sides of the "water chain". The SRA describes the research which must be undertaken to realize the vision on the mid and the longer term. Representatives from different industrial sectors clearly recognize membrane fouling as an important technical barrier that limits the implementation of advanced water reuse. One of the topics mentioned in the SRA is the need for research on advanced treatment technologies to exploit non-

[1] Lonsdale, H.K. The growth of membrane technology, J. Membr. Sci.10, 1982, 81-181
[2] Strathmann, H. Membrane Separation Processes: Current relevance and future opportunities, AIChE, 47, 5, 2001, 1077-1087
[3] The WSSTP is one of the technology platforms supported by the EC in the ETAP (Environmental Technology Action Plan) framework. The WSSTP-members represent a wide range of water-related stakeholders; from suppliers, technology providers, consultancy and service providers, to industrial end-users.

conventional water sources (e.g. wastewater). The document specifically states the need for new concepts for low-pressure micro- and ultrafiltration described as "**New module and operation concepts for low-pressure micro- and ultrafiltration** for water and wastewater treatment incorporating **high-frequency cleaning mechanisms** (e.g. backwashing) will allow significantly increased flow rates".

1.3 Overall project objectives

The objective of the proposed project is to investigate the application of very intensive high-frequency back-pulsing concepts and to transfer this knowledge into new, more competitive products and services offered by the SMEs involved in the project Hi-Fre. A backpulsing device enabling more intensive cleaning of selected membrane processes is to be developed. Pre-selected membrane materials (polymeric and ceramic) and modules (capillary and tubular) are investigated with respect to their compatibility with the new back-pulsing concept. The membrane filtration processes considered is applied in different important applications, ranging from the treatment of liquid residues from biomass-based power stations to process and wastewater treatment.

Based on the results of the developments, the SME participants in the consortium stand to reap the economic benefits as the "first in market" providers of this technology and enhance their competitive position in the global MF/UF market. Further, in order for the SMEs to compete with the large membrane companies from the US and Japan that provide turn-key solutions to their customers, i.e. complete membrane installations with membranes, modules and other peripheries, this project involves SMEs at different parts of the value chain, i.e. membrane/module suppliers, equipment manufacturers and technology integrators.

This coordinated approach offers two advantages. Firstly, SMEs specialising in different sectors of the value chain ensure a smooth workflow without the fear of competition within the consortium. Secondly and more importantly, the approach provides the synergy for successful market introduction to compete with large membrane companies. The impact of this technology will not be as great if the innovations and developments take place in the individual SMEs due to reasons such as lack of profound knowledge on membrane processes (mainly the equipment manufacturer) or no access to market (mainly the membrane/module suppliers). Outsourcing research and developmental activities to the RTD performers with the necessary technical expertise and providing a platform for different SMEs to work together for a common interest gives added value to the concept of 'Research for SMEs'. Another characteristic of this project is the selection of the applications to pilot the developed backpulsing technology. As shown in Figure 2, the feed streams investigated vary from low organic load but very high market volume and economic potential (i.e. process and drinking water production), medium loaded streams (i.e. wastewaters to treat with UF/MF or membrane bioreactor technology), to feed streams with high organic load (in this case the treatment of liquid residues from a biomass power station).

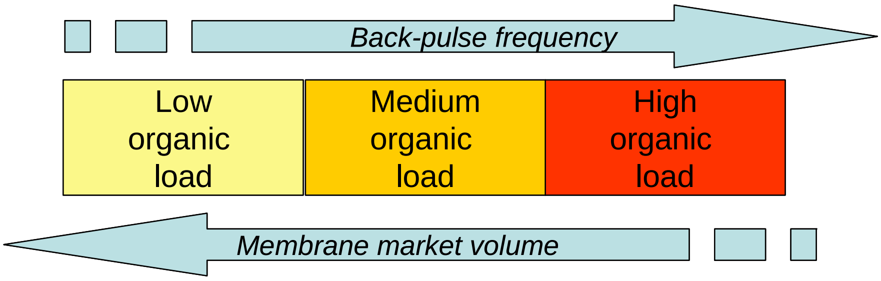


Figure 2. A summary of the technological-economic approach in the project

To achieve the objectives the project is structured in different work packages as shown in figure 3:

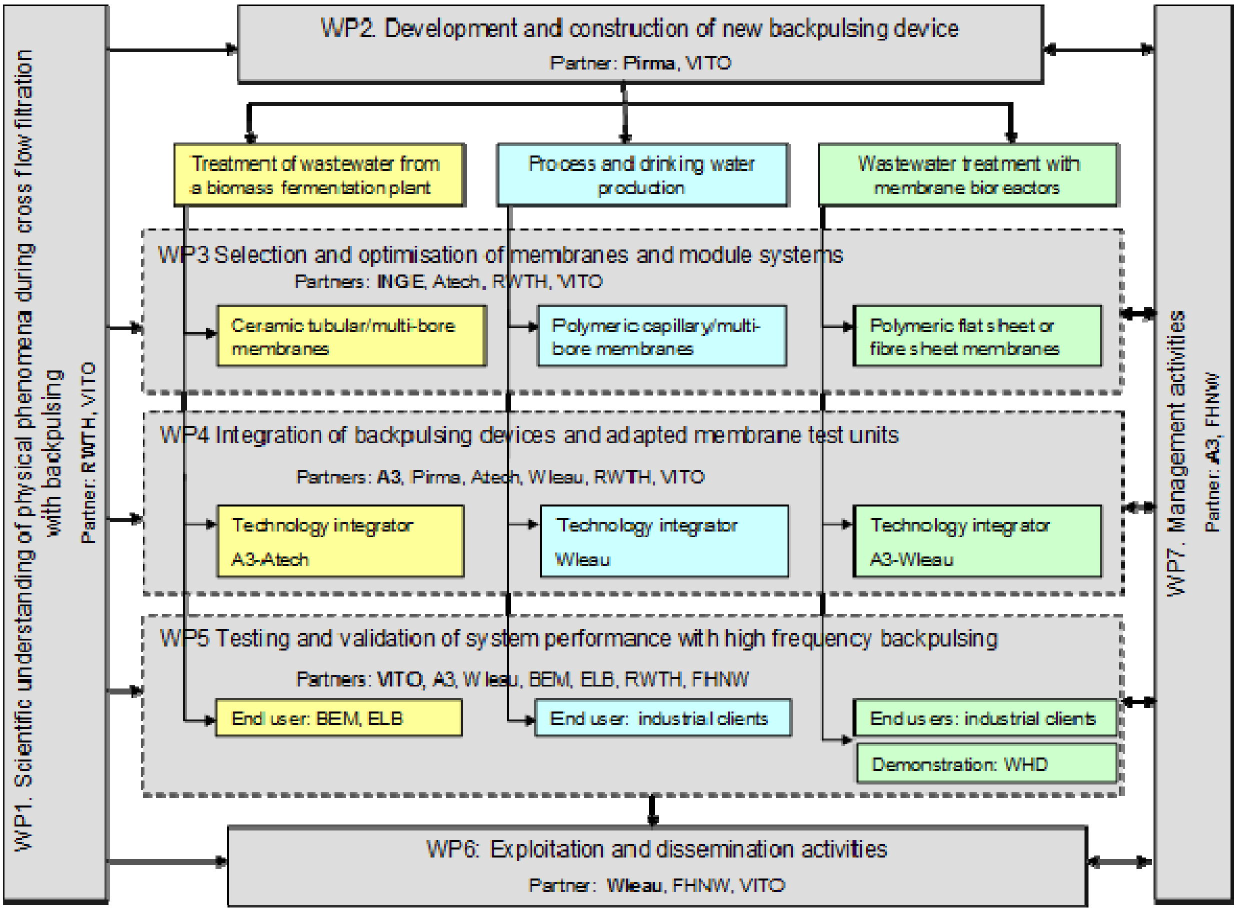


Figure 3. Work package structure of the project

The methodology and results of the different technological work packages will be summarised below.

1.4 Work package 1 Scientific understanding of the physical phenomena during crossflow filtration with backpulsing

1.4.1 Methodology

Within work package 1 the interaction between membrane properties and process parameters on the one hand with backpulsing on the other hand was investigated systematically to understand the physical phenomena involved better. The second major objective was to gain design and dimensioning criteria for a new backpulse device to be developed in the scope of the project.

To characterise the impact of the back-pulsing on crossflow filtration tests have been carried out by RWTH and VITO in lab-scale. For the experiments in work package 1, a patented backpulsing system has been used that has been provided by VITO (Belgium). This "baseline" backpulse device was the starting point for the developments and on basis of experiences with this device a new device was developed. It comprised a pneumatic cylinder with a piston that moved in a backpulsing cylinder. The cylinder has a permeate outlet (A) and an inlet (B), see Figure 4.

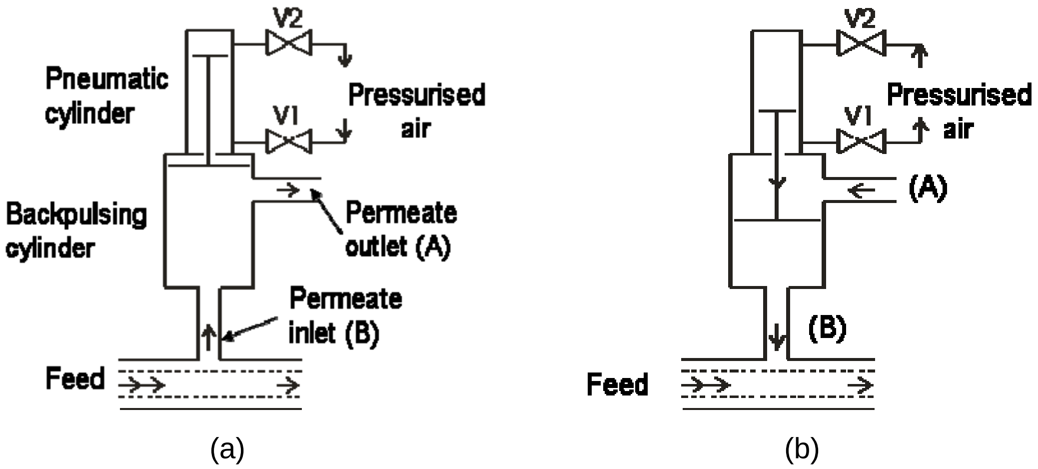


Figure 4. Schematic representation of the backpulsing apparatus. It shows the position of the piston during filtration (a) and backpulsing (b).

1.4.2 Results

The tests carried out comprised different concepts:

Characterisation of the backpulse shape

The "baseline" device showed stable backpulse profiles up to 1 Hz but not above (testing up to 2.5 Hz). With higher frequencies the backpulse strength decreased (Figure 5).

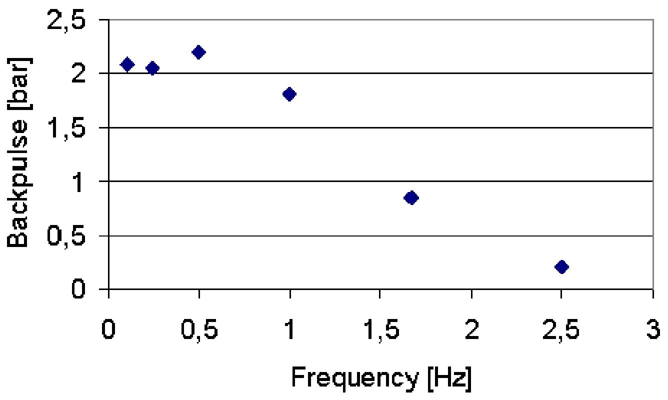


Figure 5. Influence of backpulse frequency on the backpulse strength

Also the influence of the frequency on the shape of the transmembrane pressure (TMP) curves was evaluated. As can be seen from Figure 6, no difference in the curve shape can be found between the three different backpulse intervals used. However, a pressure overshoot in the beginning of the backpulse action could be seen.

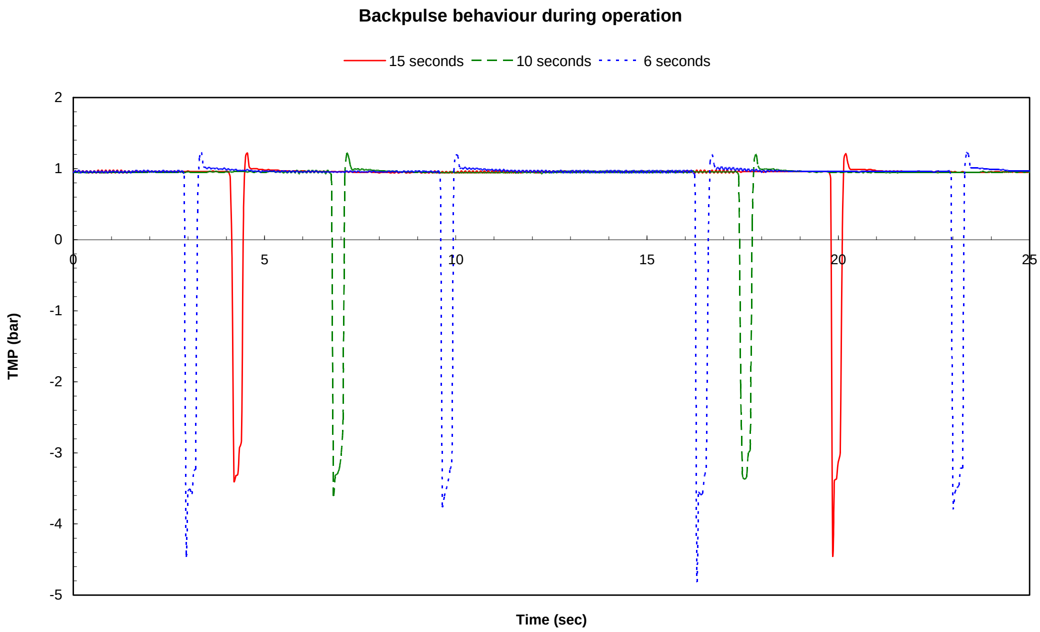


Figure 6. Transmembrane pressure profiles during backpulse for different backpulse intervals.

Testing with microfiltration membranes and yeast suspensions

A positive impact was observed for backpulsing frequencies in the area of 0.2-0.4 Hz compared to operation with no backpulse (Figure 7) while testing ceramic microfiltration membranes on yeast suspensions.

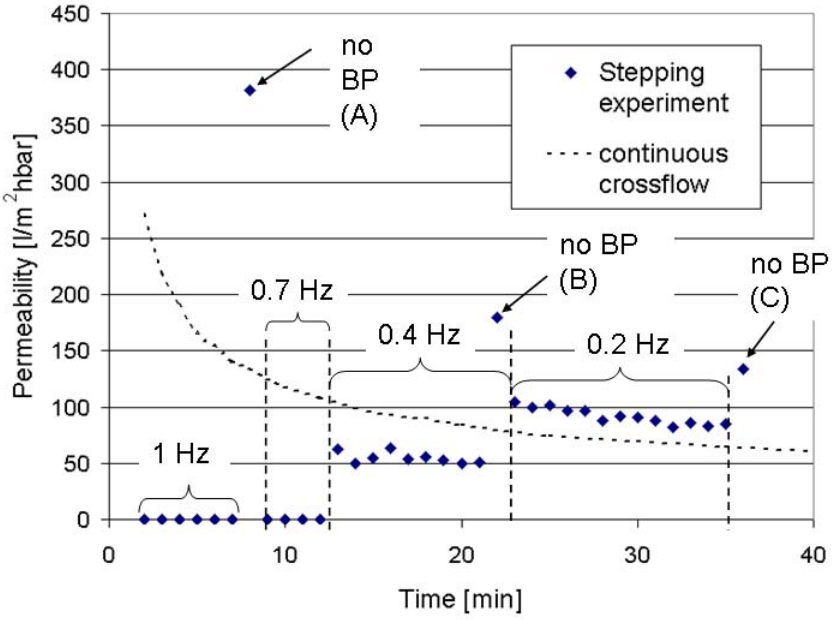
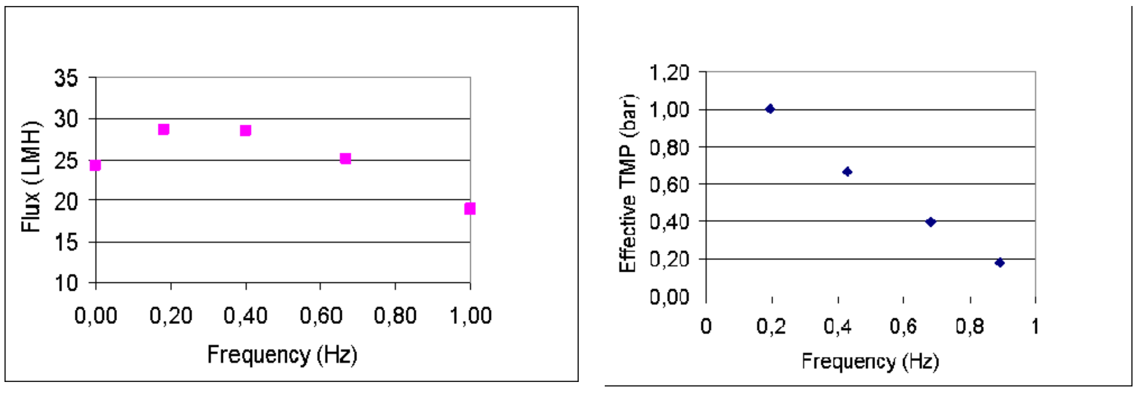


Figure 7. Effect of backpulsing frequency on permeability

Testing with ultrafiltration and dextran solutions

Experiments have been carried out with single and multi-channel ceramic membranes by ATECH. The effect of backpulsing both on permeability and separation efficiency has been investigated (Figure 8).



(a) (b)

Figure 8. Effect of backpulsing frequency on flux, transmembrane pressure and permeability. Dextran concentration 4g/l. Crossflow velocity 0.6 m/s

Optimal frequencies were found to be in the area of 0.2-0.4 Hz similar to the findings with the microfiltration membrane. The backpulsing had a clear impact on the separation efficiency as observed with chromatograms of feed and permeate dextran solutions with a broad molecular mass spectrum. It could be concluded that even with low crossflow velocities backpulsing is effective in lowering the concentration polarisation of the macromolecular solutions in a way comparable to much higher cross-flow velocities and improve the retention.

This impact of backpulsing can be a big advantage in industrial separation applications were macromolecular solutions like in the chemical or food industry have to be separated.

Based on the observations made with the "baseline" backpulse device design criteria for the new device could be defined and potential operation ranges characterised. Main improvements by the new device were required in the area of controllability of the back-pulse shape. Criteria were tight control of backpulse hub length, fast forward and slow retraction-speed. It became also obvious that the originally envisaged high back-pulsing frequencies of around 2 Hz are not relevant and beneficial for the types of membranes applied in this project as the permeate flux levels cannot be as high as e.g. with very porous and thin microsieves, which have been previously used in combination with backpulsing. Those definitions provided the input for the further developments in work package 2 as described below.

1.5 Work package 2 Development and construction of a new backpulsing device

1.5.1 Methodology

To realize backpulsing in a filtration system, it is common to implement additional valves and pressure devices (e.g. additional backpulse pump) or pressurised air. This classic approach has some disadvantages such as low frequencies, and the time delays involved with the closing and opening of the valves. Therefore, VITO introduced a novel concept which excludes the need of additional expensive valves and pressure devices (patent EP 1043053). It consists of a cylinder and piston. During filtration the piston is in its extended position, allowing the permeate from the membrane module to flow through the inside space of the cylinder and out of that cylinder through the outlet opening at the side of the cylinder. Without switching any additional valves, a backpulse can easily be introduced by forcing the piston in the backpulse cylinder during which the outlet opening of the cylinder is closed by the piston itself (see Figure 4). During the closure of the opening, the pressure starts to build up in the cylinder and the permeate will be forced back in the opposite direction. Since the movement and the force of the piston can be controlled, the amplitude and the time-interval of the backpulse can be set in a flexible way.

In the Hi-Fre project, backpulse devices had to be designed, constructed and tested. To this end, the design specifications for backpulse devices based on the valveless concept were first listed. In addition, calculations were undertaken to specify the construction of the backpulse devices intended for laboratory and pilot testing. These were performed for polymeric and ceramic membranes, for various membrane surface areas and for low to medium backpulse frequencies corresponding to pulse times down to 0.5 sec. A number of parameters were considered important and defined as follows:

- Filtration hub: volume of permeate generated during filtration (ml)
- Backpulse hub: volume of permeate sent back during backpulse (ml)
- Backpulse hub: distance over which the piston is moved in the cylinder to displace the permeate volume as specified above (mm)
- Backpulse reach: distance over which permeate is pushed back through the membrane (µm), hence, distance over which foulants and particles are removed from the membrane surface
- Pulse time: total cycle time, inverse of backpulse frequency (s)
- Tolerance: difference in diameter between cylinder and piston (mm)
- Gap velocity: liquid flow between cylinder and piston.

1.5.2 Results

Various prototypes for high frequency backpulsing were constructed:

- Prototype 1 containing a piston head in 2 parts

  A first prototype was characterized by a piston head in 2 parts and included a spring for fast retraction of the piston. During the downward movement, the two pieces acted as one piston head and pressure could build up. During the upward movement, the 2 pieces separated and permeate could flow through.

- Prototype 2 containing a single piece piston head

  For the second prototype, the piston consisted of one single piece with 3 grooves. Two versions were constructed for the ceramic and polymeric membrane testing respectively.

- Prototype 3 with an improved design of the dual piston head concept

  In the development of prototype 3 attention was paid to reduce the risk of misalignments and to avoid horizontal movements during testing. Again, two versions were constructed with different combinations of materials.

  In a final stage of the project, further improvements were implemented on the prototype 3 design concerning the top part of the backpulse set-up.

All prototypes met the design requirements. Some examples are shown in Figure 9.

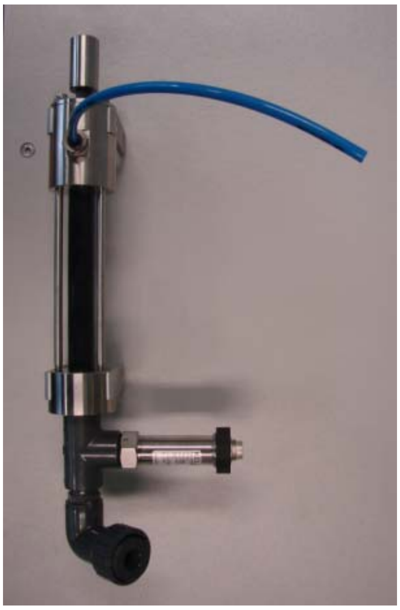


Figure 9: Pictures of backpulse prototype 3.

All prototypes were equipped with a controllable linear motor, associated software to set the conditions of the downward and upward movement of the piston and thus the pressure pulse shape, a process controller and a timer to fix the backpulse frequency.

As an alternative to the presented designs, a novel concept was also proposed and constructed. However, no details can be given for confidentiality reasons.

1.6 Work package 3
Selection and optimisation of membranes and module systems

1.6.1 Methodology

In this project the membranes will be subjected to very strong and very frequent pressure shocks. Thus, suitable membranes for application with backpulsing had to be selected and produced.

For process conditions with backpulsing it is impossible to use standard single bore polymeric membranes, but backpulsing is ideally suited to verify the qualities of the Multibore membrane from inge GmbH. The membranes used were partially chosen from the standard production membranes with a capillary size of 0.9 mm and a pore size such that viruses will be retained. Other membranes were produced specifically for the purpose of this project. These were either microfiltration membranes with larger pore sizes or ultrafiltration (UF) membranes with larger capillary diameters. A novel development was the production of specific out-to-in membranes for application in membrane bioreactors (MBRs). Different prototypes were realized for subsequent testing.

Alternatively, ceramic membranes from Atech were provided for testing:

- The **geometry** of the test membranes was as follows: constant pore size 100 nm; membrane material Al_2O_3. Expected effects were that the support wall thickness and the effectivity of the backpulse impulse in the centre channels of the multichannel elements would vary.

- The **pore size** (constant Type 19/3.3, membrane material Al_2O_3) could be changed from 60 to 100 to 400 nm. Also the 50nm TiO_2 Duratech® membrane was tested. The interest is to evaluate the effectivity of the backpulse impulse at different membrane thickness, pore sizes and porosity.

The module design had to be reconsidered for backpulsing as well. The membranes were installed in especially designed housing. The module was optimized for gas bubble free operation on the permeate site, since this is important for efficient backpulsing.

1.6.2 Results

A broad series of tests was performed. In a first stage, different backpulse prototypes were characterized and their performances compared. During pure water tests, prototype 2 seemed more promising than prototype 3. However, later tests on real feed streams did not point to any major differences in performance. Pressure build-up was in the required range.

In a second stage, fouling tests were performed with various model feed streams and backpulsing was shown to have a positive impact on the permeability level depending on the feed material. As expected, sticky foulants such as the protein BSA, were hard to remove by backpulsing, while non-sticky ones such as silica, were strongly impacted. Yeast cell and milk powder suspensions also seemed susceptible to removal by backpulsing (see Figure 10).

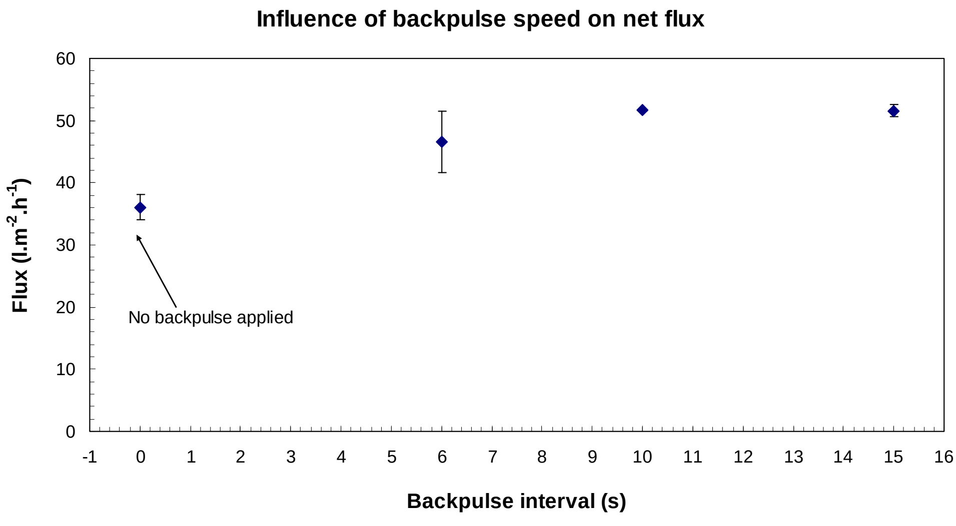


Figure 10: Influence of backpulse interval on the net flux during filtration of 0.5% milk powder.

In a final stage, tests were performed with real feed streams. Results with surface water looked very promising in terms of flux enhancement. Somewhat more difficult to filter were more complex suspensions such as activated sludge and digestate from biogas production, with the effect of the backpulsing being on occasions less pronounced and more dependent on other process parameters. Positive effects were observed both for micro- and ultrafiltration tests and both for ceramic and polymeric membranes.

Optimization of backpulse protocols was attempted on various feed streams, by varying backpulse intervals, backpulse pressure, backpulse shapes, applied crossflow velocity (CFV) and Transmembrane Pressure (TMP). For the polymeric membranes for instance, a backpulse interval of 5 to 10 s and a TMP of 0.6 bar seemed optimal. However, backpulse shapes need to be adapted to each feed stream and test configuration to avoid too high underpressures during piston retraction. The latter are undesirable because they create a higher TMP than during regular filtration and thus a temporarily higher fouling.

Figure 11 shows the influence of different backpulse intervals and of two different cross-flow speeds on filtration of digestate with ceramic membranes. The use of the backpulse device provided improved results compared to the standard filtration and higher cross-flow speeds further increased the filtration performance.

Tests performed with synthetic and real target streams such as activated sludge and digestate from biogas production showed generally better results when applying the backpulse device. The positive effect was dependent on the backpulse interval used and the type of stream being filtered. Suspensions with smaller particles tended to be more difficult to filter, due to increased pore blocking effect.

The described experiments were performed at rather small membrane surface areas and at rather short durations. These were expanded to larger surface areas and/or longer running times in the pilot phase.

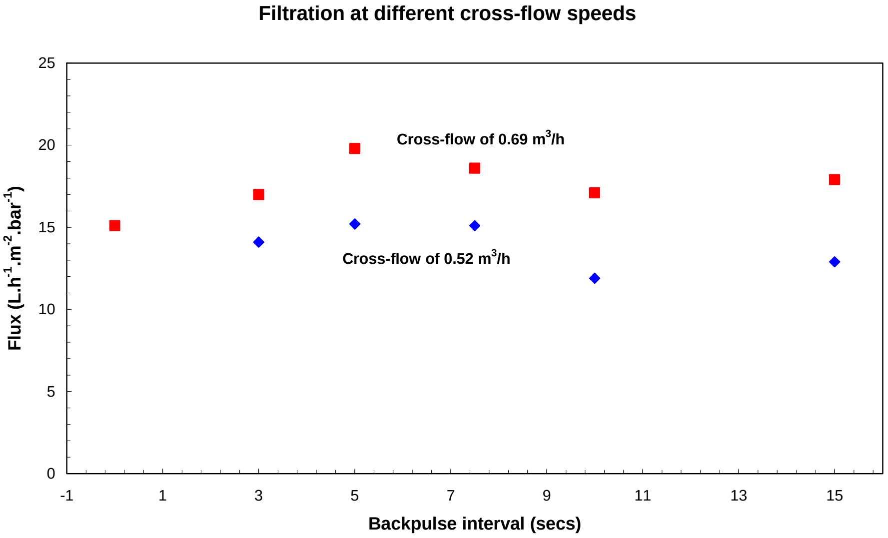


Figure 11: Filtration of digestate from biogas production at different cross-flow velocities.

1.7 Work package 4 Integration of backpulsing devices and adapted membrane test unit

1.7.1 Methodology

Pilot testing was envisaged for four different applications:

- Surface water treatment with polymeric membranes
- Tertiary effluent filtration with polymeric membranes
- Biomass filtration with polymeric membranes in a MBR
- Biogas production digestate treatment with ceramic membranes.

For the first two applications, an existing filtration unit was upgraded and equipped with all pressure, flow and temperature measurements for proper monitoring and control of the filtration and backpulse performance. The unit was controlled by VITO MEFIAS® (Membrane Filtration Assistance Software) control and steering software. The backpulse prototype was placed at the permeate side of the filtration module. Between the backpulse device and the membrane module and at the permeate side of the module, an extra pressure transmitter was placed selected for high frequency pressure measurements. Two additional sensors could be mounted at the middle and bottom of a 1.5 m long membrane module to monitor wave propagation along the module.

MBR tests were performed in a dedicated set-up, developed within the project. The novel inge membranes and modules were used for this purpose.For the digestate treatment, a detailed design of a pilot backpulse unit was performed for incorporation with the membrane filtration pilot plant from A3 (Figure 12). The unit was equipped with 4.9 m^2 of membrane area in a pressure vessel.

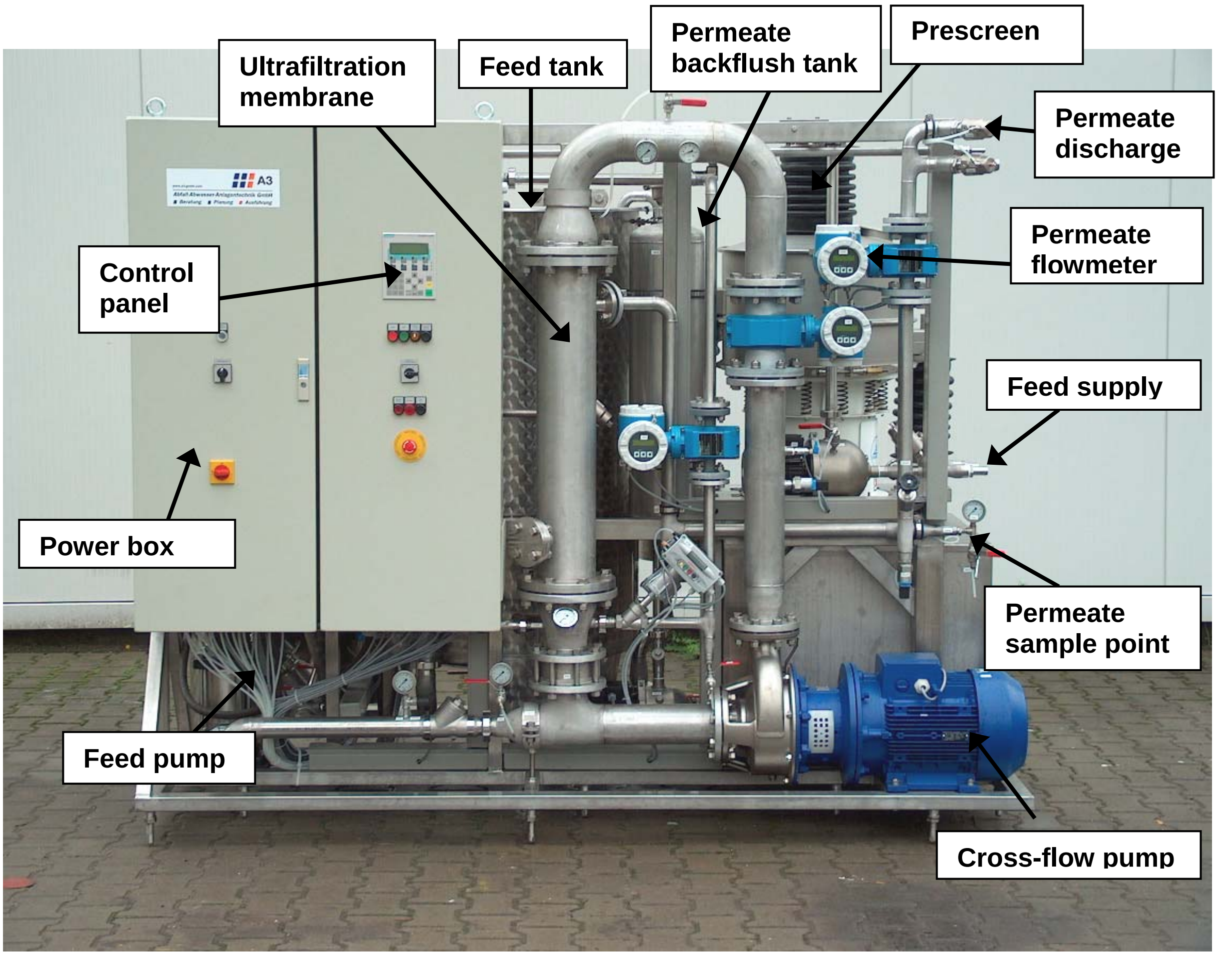


Figure 12: Existing pilot plant system at A3 water solutions GmbH.

1.7.2 Results

The dimensioning of the backpulse unit for the pilot plant of A3 was performed on base of the lab-scale testing performed at RWTH with the 3rd backpulse prototype. The dimensioning took into consideration the area used and the fluxes achieved in lab-scale digestate filtration and the ones obtained with the pilot plant as per the information supplied by A3. On the base of this information, dimensions for the pilot prototype, as well as specifications necessary for the linear motor were obtained.

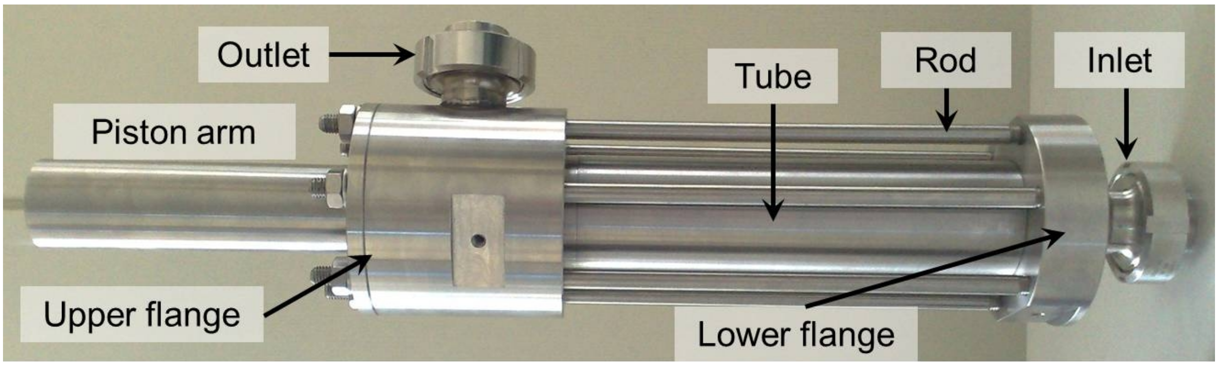


Figure 13: Assembled backpulse unit. The piston head is inside the tube (not visible).

The backpulse unit consisting of the piston and flow tube was manufactured from stainless steel. The full assembled unit can be seen in figure 13. The main characteristics of the back-pulse unit are given in Table 1.

Table 1. Main characteristics of the linear motor and backpulse unit.

Linear motor		**Backpulse unit**	
Hub length	290 mm	Piston length	300 mm
Force	3000 N	Tube length	265 mm
Speed	0.84 m/s	Piston/tube diameter	50 mm

The complete system was integrated with the pilot plant from A3.

1.8 Work package 5
Testing and validation of system performance with high frequency backpulsing

1.8.1 Methodology

For the experiments at BioEnergy Maasland, the digestate was processed through a filter-press to remove the solid content with the highest particle size. The filtration was performed at approx. 40°C, under different cross-flow velocities (CFV) and at varying backpulse intervals. The desired operational transmembrane pressure (TMP) was of 2 bar.

The feed for surface water treatment tests was taken from a river and had variable amounts of suspended solids. It was presieved at 0.5 mm, then pretreated with 3 mg/l ferric iron, conform to drinking water practice. Various short- and long-term backpulsing tests were performed at different backpulse hubs and intervals. Further variables were cross-flow velocities and TMP.

For the tests with tertiary effluent, wastewater was taken from the biological wastewater treatment of a brewery. The wastewater was presieved at 0.5 mm. Backpulsing tests were performed at various test conditions. Parameters were varied one at a time in step tests to investigate the influence of each on the flux or permeability level. Or tests consisted of periods with and without backpulsing under specific conditions.

Tests were both performed under isoconcentration conditions or at a certain volumetric concentration factor (VCF).

The MBR tests were performed with mixed liquor from two different full-scale MBR units, one of which was Heenvliet. Various membrane/module prototypes were tested under different filtration and backpulse regimes.

1.8.2 Results

1.8.2.1 Digestate treatment

The tests performed with biogas production digestate at BioEnergy Maasland were strongly conditioned by the concentration of solid material in the digestate. The digestate was then diluted in water to manageable solid concentrations about 2-6 wt %. At these concentrations it was possible to perform the filtration, but there were still many problems to overcome, namely higher pressures likely due to blockage of one or more of the membrane channels and/or accumulation of solid material at other points of the crossflow loop.

The results showed that at relatively high CFV (2.8 m/s), it may be slightly beneficial to apply a backpulse system at longer intervals (> 1 min). At low CFV (0.7 m/s) and high solid content (>5 wt. %), however, the backpulse system had a positive effect at frequent backpulsing (Figure 14). This is likely due to the disrupting effect it can have on cake layer formation. The backpulse system, therefore, seemed to be somewhat effective only in the case of filtering digestate with a very high fouling potential and in situations when using high cross-flow speeds is not possible or not desirable, e.g. due to higher energy demands.

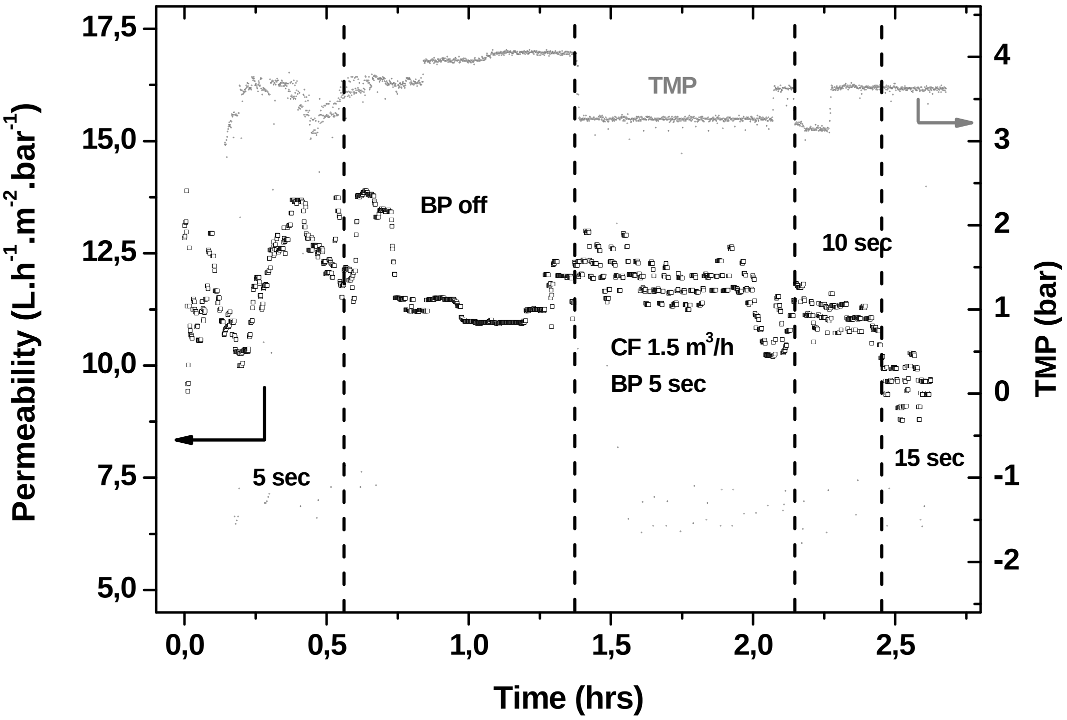


Figure 14: Filtration of a 4:1 (solid concentration of 2-3 wt. %) mixture of water digestate at an initial cross-flow of 2.0 m^3/h (2.8 m/s). The instabilities in pressure and impossibility to maintain operation at the desired 2 bar TMP are caused by the amount and type of solids in suspension.

1.8.2.2 Surface water treatment

As an example for a short-term backpulse evaluation, Figure 15 shows the evolution in permeability during a step test at decreasing backpulse interval. Intervals between 5 and 15s resulted in similar permeability levels, while at 1 s intervals the backpulsed permeate volume became too high and permeability dropped. The optimal backpulse frequency resulted in a 40-50% permeability gain compared to the situation without backpulsing. This is conform the results obtained in previous testing at smaller scale. When backpulsing was resumed, permeability levels were even higher than before. This shows the high efficacy of backpulsing, even at the low 15 s interval, to dislodge the cake of iron flocs. When backpulsing frequency was stepwise increased, the net permeability dropped. In other words the extra permeate loss was no longer compensated by permeability gains during filtration at backpulse intervals of 5 s and 1 s. The situation was however still better than in the absence of backpulsing.

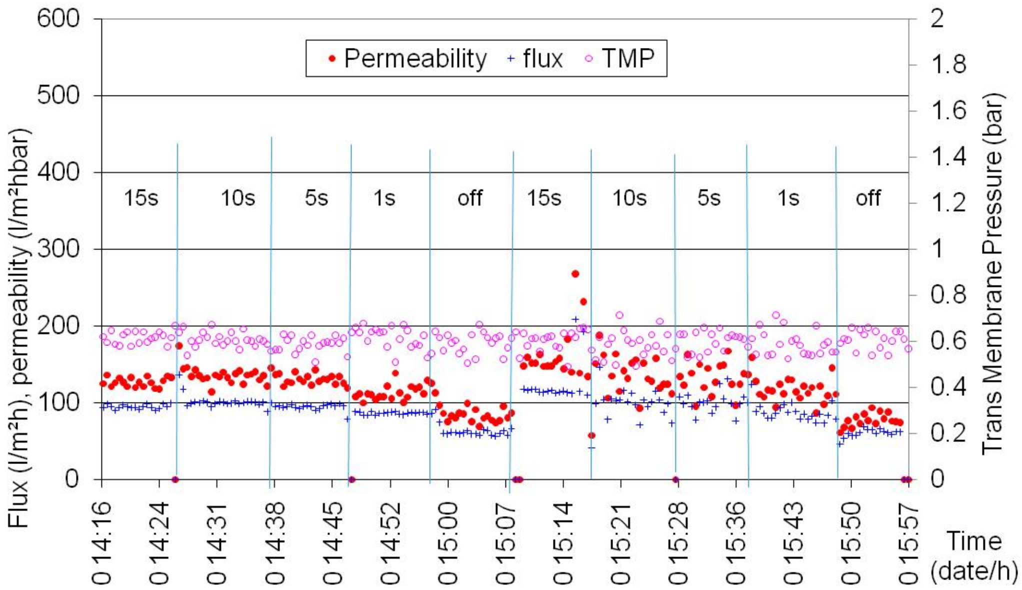


Figure 15: Permeability evolution during step test on surface water. Conditions: 0.6 bar TMP, 0.5 m/s CFV, pre-treated surface water, ultrafiltration, 100 mm piston displacement

From the whole series of short-term tests, it could be concluded that backpulsing had advantageous effects for surface water treatment. The results were variable. Even though the feed waters usually had a low initial turbidity, net permeability gains of 50-100% were obtained.

Step tests showed that a backpulse interval of 10-15 s was optimal for this application. The shorter 5 s interval created large deviations in created pressure pulses. At 1 s intervals, the permeate loss was too high to compensate for the gain in fouling reduction.

The net backpulsed volume per unit of time was important and within the tested ranges it was not so much dependent on which combination of volume and frequency was used to obtain this. However, it seems slightly preferable to pulse back a larger volume at a lower frequency than the other way around. A minimal backpulse hub is probably needed for a positive effect on foulant removal and for stability.

Long-term pilot tests were then run for several weeks applying backpulses under previously determined optimal conditions. However, they did not bring the same improvements in net permeability levels.

On the one hand, it was observed that the generated pressure peaks propagated well and uniformly through the 1.5 m long module. Values depended however on the feed water composition and fouling resistance/membrane history. In addition, the backpulse shape varied with the feed suspension composition, sometimes showing undesirable underpressure during piston retraction or leading to broad pressure peaks because of a too slow upward piston movement. It thus seems impossible to define a fixed optimal pulse shape for a certain application. Furthermore, foulants seemed to be removed from the feed and possibly sorbed to the membrane, rather than being kept in suspension.

Under optimal backpulse conditions and with membranes at sufficiently high clean water permeabilities, fluxes seemed to stabilize between 60 and 100 l/m².h, at VCFs from 1 to 8, a TMP of 0.3 bar and CFV of 0.3 m/s. This seems not too far away from the reference semidead-end filtration conditions, particularly when the sometimes high suspended solids load is taken into account.

1.8.2.3 Tertiary effluent filtration

Step tests indicated that a backpulse hub of 100 mm and intervals of 10-15 s seemed optimal for tertiary effluent treatment, similar to surface water treatment. However, the impact of backpulsing on fouling buildup was usually rather limited and manifested itself mostly through stabilization in permeability levels and not in increased permeability.

In a next step, concentration experiments were performed under low CFV (0.3 m/s) and low TMP (0.24 bar). At VCF 10, periods with and without backpulsing were alternated. Under the selected backpulsing regime, the permeability remained more stable but at a lower level than in the absence of backpulsing (Figure 16). The strong recovery in permeability after a backpulse period indicated that backpulsing led to reduced membrane fouling. During the second period with backpulsing, the permeablity gradually increased indicating that the backpulse action could dislodge some foulants from the membrane surface. When backpulsing was interrupted for a second time, the recovery in permeability was lower, pointing to some irreversible fouling.

The initial feed composition was very low in suspended solids, but dissolved organic carbon had increased from 36 mg/l in the non-concentrated feed to 283 mg/l at VCF 10. This may explain why flux levels were in general very low for this test.

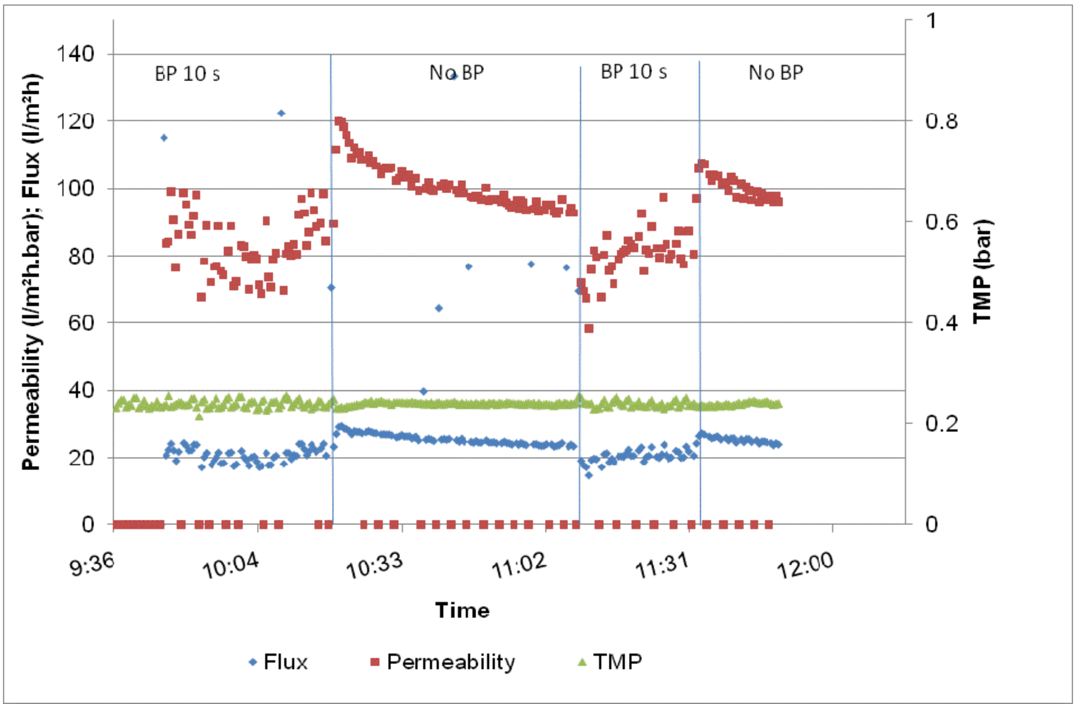


Figure 16: Permeability evolution after 10-fold concentration of tertiary effluent. Conditions: 0.24 bar TMP, CFV 0.3 m/s, 100 mm piston displacement, 10 s backpulse interval, feed (before concentrating): 2.5 NTU, 2 mg/l suspended solids.

The concentrating experiments on tertiary effluent did not show a real benefit of backpulsing, since no increased permeabilities were measured under a backpulsing regime. This may have been due to the composition of the tertiary effluent. Low levels of suspended solids and rather high levels of dissolved organics are not expected to be advantageous to achieve fouling reduction by a backpulse action.

1.8.2.4 Biomass filtration in MBR

Short-term tests showed that backflushing and backpulsing resulted in similar permeability trends when they were chosen in conditions with the same net flux. This is probably related to the fact that rather low backpulse frequencies had to be selected at the required backpulse hub.

It could be concluded that the novel membrane developed by inge GmbH could be operated in a stable manner in combination with backpulsing. Probably because of the rather low backpulse frequencies required to reduce too high permeate losses, the fluxes should remain in the subcritical zone.

Overall, longer term testing with several crossflow filtration applications did not yield big improvements in filtration performance when combined with backpulsing. The most promising application for the developed backpulse prototypes thus seems to be MBR.

1.9 Work package 6 Exploitation and dissemination activities

In the scope of this work package the commercial possibilities of using the backpusling technology have been discussed with the partners at the project meetings. It is expected that some new products, e.g. back-pulse devices and modules systems, will be derived from the project.

Also dissemination activities have been carried out. The Hi-Fre website (www.hi-fre.eu) has been launched in June 2009 and presents the projects towards the public. A screenshot is given in Figure 17. Its gives a condensed overview of the project objectives, the partners involved and the structure of the work.

Figure 17. Screenshot of Hi-Fre startpage

Due to confidentiality issues the information provided on the website is mainly quite general. However, contact points are mentioned where more information can be requested.

FHNW also issued a project leaflet to raise awareness for the project and to support dissemination activities (Figure 18).

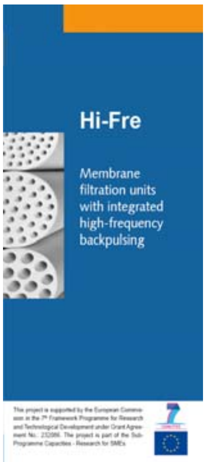


Figure 18. The Hi-Fre project leaflet

The work has been presented or will be presented at several conferences as indicated in chapter 4.

2 Partner list

Beneficiary Number *	Beneficiary name	Beneficiary short name	Country	Partner type
1(coordinator)	A3 Water Solutions GmbH	A3	Germany	SME-S
2	Pirmatech	Pirma	Belgium	SME-S
3	INGE AG	INGE	Germany	SME-S
4	Atech Innovations GmbH	Atech	Germany	SME-S
5	Waterleau	Wleau	Belgium	SME-S
6	BioEnergy- Maasland BV	BEM	The Netherlands	SME-E
7	Loick Agroservice GmbH	Loick	Germany	SME-E
8	Waterschap Hollandse Delta	WHD	The Netherlands	OTH
9	RWTH Aachen University	RWTH	Germany	RTD
10	Flemish Institute for Technological Research	VITO	Belgium	RTD
11	Fachhochschule Nordwestschweiz	FHNW	Switzerland	RTD

3 Potential impact

Innovation is one way where European membrane producers and plant manufacturing contractors can be competitive in this lucrative market by providing better products and dedicated filtration systems with enhanced performance. Depending on the success of the ongoing upscaling efforts, the expected impact is to **improve the competitive position and market share** of the project partners.

If large scale backpulse devices can be implemented in plant designs, both for surface water and tertiary effluent filtration (e.g. in municipal or brewery applications), this would enable the project partners (EPC contractors) to design their membrane plants with less membrane surface, and it would also lower the O&M costs due to reduction in energy and chemical demand.

Today, wastewater treatment is undoubtedly one of the most important themes in environmental technologies. In recent years, the emergence of membrane filtration is a predominant trend in water treatment and will continue to gain importance in the future.

This is clearly reflected in the Strategic Research Agenda of the Water Supply and Sanitation Technology Platform (WSSTP) which highlights the need for new and improved technologies for water treatment. The strong reference to membrane technology in this strategic agenda (e.g. membrane based pretreatment of wastewater, new concepts for low pressure micro- and ultrafiltration membranes, new integrated membrane system design) clearly indicates the technological growth possibilities in this area.

The MBR market in 2006 is estimated around 300 M$ worldwide with an annual growth of more than 10% (data taken from Frost and Sullivan reports). The market value of the MBR industry is predicted to be 500 M$ by 2013.

From the project results, it appears that the net permeability gain for the tested applications (digestate, surface water treatment, tertiary effluent filtration) was rather limited, particularly during long-term testing. In a literature review, it was described that backpulsing may however already become more economical than filtration without backpulsing for low flux increases of 10%. It must be noted though that this concerned high flux ranges (>200 $l/m^2.h$), and that all referenced publications on cost evaluations dated from before the year 2000. Furthermore, the review also indicated that most test work was done with non-adhesive feed suspensions such as yeast cells, oil droplets or bentonite. We therefore do not think that this conclusion is representative for our test work.

The novel MBR concept developed in Hi-Fre seemed to be most promising in terms of exploitation of the backpulse approach.

From the description of the MBR products given above, it is clear that only a limited number of membranes are compatible to backpulsing at high pressures. It must also be assumed that the novel approach with backpulsing will only be implemented on new installations and not on existing ones, because it would require a quite different design of the permeate lines to include backpulse devices.

Assuming a 10% market share of new systems in the MBR market 5 years after introducing the newly developed set-up combined with backpulsing, the total number of backpulse devices produced would amount to near 3 000.

In general, rapid backpulsing has been shown to be most effective for the treatment of feed streams containing relatively non-adhesive suspended particulates. Its effectiveness declines with increasing feed concentration. This has also been demonstrated in our tests.

In principle, smaller scale applications where high added value products are implied, or biomass filtration other than MBR, may be areas of interest as well. These may include filtration of slurries produced in the mining or metallurgical industries, as well as for recovery of valuable residues from other operations, such as in the preparation of solar panels. These applications can be especially interesting when the suspension is particularly aggressive due to pH or presence of organic solvents. However, it seems that feasibility tests are needed to check the applicability per case.

4 Use and dissemination of foreground

Section A (Public)

No	Title	Author	Periodical	Nr.	Publs	Place	Year	Pages	Open access
1	Fouling control using backpulse systems	Joao Andre, Heleen de Wever, Marcel Pirson, Matthias Wessling, Thomas Melin	ICOM Conference			Amsterdam	2011		Yes
2	Fouling control in membranes using a backpulse system	Joao Andre, Matthias Wessling, Thomas Melin	ECCE Conference			Berlin	2011		Yes
3	Fouling control using backpulse systems	Joao Andre, Eva-Lena Meyer, Thomas Melin, Matthias Wessling	IWA Specialist Conference on Membrane Technology for Water & Wastewater Treatment			Aachen	2011		Yes
4	Fouling control using backpulse systems (in preparation)	Joao Andre, Matthias Wessling, Thomas Melin	To be defined						No

Section B (confidential)

Exploitable Foreground	Products	Sectors	Timetable	Patents or other IPR	Owner & Other beneficiary
Back pulse device	Linear design Rotating design	All where UF/MF is applicable	1 year	Patent filing for rotating device under investigation	Pirmatech
Tubular membrane/module unit for improved backpulse operation	Membrane selection for use with backpulse	MF/UF filtration	Coming years	-	Atech
Multibore capillary membrane/module unit for improved backpulse operation	New module design	MBR	Coming years	Patent filing for module under investigation	INGE
Dedicated filtration system for high load (biomass) filtration	Backpulse system in pilot scale	Digestate filtration (UF)	1 year	Up-sclaing under investigation	A3
Dedicated filtration system for high fouling MBR applications	New module system	MBR for wastewater treatment	Coming years	Patentability of system under investigation	Inge
Dedicated filtration system for low organic load applications	New knowledge about system with back-pulsing	Process and drinking water treatment	Coming years	-	Waterleau