PUBLISHABLE SUMMARY

OF FINAL REPORT

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Research for the benefit of SMEs

ConductMem

Development of a conductive membrane that generates oxidizing surface to prevent biofilm formation and fouling

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Executive summary

By its very nature, the surface of a filter is an open structure in which microorganisms can readily settle. Nutrients available in the in-feed enable them to grow. As a result biofilms develop, leading to an overall reduction of filtration efficiency, unstable processes and frequent cost intensive filter change.

A multitude of strategies has been tested to reduce membrane fouling which in itself demonstrates the urgency of the problem. Current strategies, often used in combination, are: enhanced hydrodynamic layout of modules and surface modification of membranes, cross-flow filtration, low flux, regular back flush, permeate stoppage, scouring, sparging, rinsing cycles, chemical cleaning with soda, caustic and tenside solutions.

In ConductMem a conductive membrane was developed by the project. This conductive membrane acts as electrode during the filtration process, thereby avoiding biofilm formation and surface fouling by the electrolytic production of biocidal oxidising agents on the membrane surface itself. The current flow generates substances on the membrane surface that degrade organic matter and disinfect the surface.

An automated demonstration unit was developed to prove the efficiency of the ConductMem Technology with regard to flux and pressure stability and fouling reduction. The demonstration unit was mounted on site and test runs were performed.

The partners form a strong supply chain for the ConductMem system.

The component manufacturers are:

- Polymem (France): Membranes, MBR systems
- Eilenburger Elektrolyse- und Umwelttechnik GmbH (Germany): Electrochemical reactors
- Microbac (United Kingdom): MBR systems
- ERS (Germany): Electronic control systems
- Grundfos (Denmark): Water treatment equipment

Microbac and Grundfos are responsible for sales and marketing management of the developed conductive membrane.

Summary description of the project context and the main objectives

The **ConductMem** project deals with a central problem of filtration systems and in particular of membranes: **biofilms and bio-fouling.** This is an issue which creates many problems for the global filtration market, which is estimated to €70 billion p.a. Membrane filters are a sophisticated technology within this huge filtration market. They have reasonable product costs and are used in many applications that typically have to address the separation of microbial particles. They are significantly affected by biofilm formation and biofouling. The consortium has therefore identified that the most urgent need with a customer readiness for investment to address this bio-fouling issue is in the membrane sector.

Membranes for filtration are used in a wide variety of separation applications such as in the food and water processing industries. Membranes have attractive permeate flow rates at relatively low pressure heads. In many of these applications, a primary requirement is to retain microbes to ensure hygienic pure water outputs. However, the surface of the membrane that is exposed to the in-feed will also be exposed to any kind of other particles. When the in-feed only contains hygienic pure water and inorganic suspended particles, mechanical blockages can be resolved by back flushing. However, in the majority of instances the in-feed will also contain a microbial loading.

By their very nature, the surface of a membrane is an open structure in which microorganisms can readily settle; nutrients within the in-feed permeate then enable them to grow. As a result biofilm layers are deposited. Dependent on the filtration process a variety of fouling mechanism will occur: colloidal (clays, flocks), biological (bacteria, fungi) as single organisms aggregates or biofilms, organic fouling (oils, polyelectrolytes, humic substances), often mixed with scaling (mineral precipitates). The result of this fouling is a decrease in the flux through the membrane and an increase of the hydraulic pressure head loss. In cases where the primary task of the membrane is to form a microbial barrier there is a real risk that microorganisms progressively grow into the membrane and eventually breakthrough on the permeate side, causing recontamination of the liquid output.

Whilst this issue has been well understood and characterized, no acceptable solution has been found yet to address this fouling. Biofilms occur in nearly all cases as the microorganisms in biofilms are very adaptable. Membranes suffer from the buildup of fouling layers in most filtration applications and all filter sizes: from microfiltration to reverse osmosis and in both operational options(cross-flow and dead end filtration). A wide multitude of strategies are currently used to retard or manage membrane fouling. Cross-flow filtration, low permeate flux, regular back flushing, permeate stoppage, scouring, sparging, rinsing cycles, chemical cleaning with soda, caustic or tenside solutions. These strategies, often used in combination, attempt to maintain performance and extend membrane lifetime. However none of these current approaches are able to completely refresh the membranes. There is always an irreversible remaining damage to the membrane. This results in not only operational costs, such as the use of cleaning agents and operational down-time, but also, after a certain time or refresh cycles, the membrane needs replacing which incurs additional costs.

There is therefore a clear need in all applications in which membranes are used to overcome the fouling problem in a cost efficient and sustainable way without the use of chemicals or the use of unreliable and high energy consuming mechanical processes which apply stresses on the membrane structures and shorten their operating life. No viable solution has been identified as the microorganisms in biofilms prove to be extremely adaptable. Membranes suffer from the buildup of fouling layers in all applications from microfiltration to reverse osmosis along with cross-flow as in dead end filtration.

From the beginning of the project, a team of researchers, scientific and marketing representatives of the partner companies has established a multi-national network for mutual benefit.

<u>Scientific and technical project objectives:</u>

1. To produce conductive membranes by the integration of a metal mesh or conductive particles. To then quantify the oxidative activity in the membrane. To define biofouling reduction as a function of current density and time. To then produce the conducting membrane material in sufficient amount for lab scale filtration units and demonstration units. (WP1)
2. To build an electric field simulation tool (MultiPhysics) and computational fluid dynamics (CFD) tools to enable efficient module design. (WP2)
3. To derive general design rules for the electroactive filtration modules by simulating options for electrode placement and current flow and to use the simulation tool to design and construct a laboratory scale filtration unit. (WP3)
4. To prove the efficiency of the lab scale filtration unit with regard to water flux, water flux stability in time and bio fouling reduction compared to SOA. (WP4)
5. To design a demonstration unit of permeate flux. (WP4)
6. To build demonstration units and prove the efficiency with regard to water flux stability in time and fouling reduction. (WP5)
7. To demonstrate with MBR water filtration in a MBR system running in by-pass to the end-user application. (WP6)

Description of the main S&T results/foregrounds

From the beginning of the project the partners have built a team of specialists tackling the individual tasks.

First project period

In the first period of the project membrane development, biofilm analytics and electric field simulations have been performed.

Membrane development and characterization

An electrically conductive microfiltration membrane for MBR applications was developed. For this task over 10 types of membranes were cast and characterized (porometry, flux measurement, shrinking behavior and conductivity). A multilayer membrane with the necessary conductivity and cut-off was developed in numerous optimization steps.

The membrane was tested for oxidant production at different voltages. The membrane acts as electrode during the filtration process. Good filtration characteristics are necessary regarding pore size and permeability. The membrane was produced in sufficient amount for lab scale filtration units and demonstration units.

Filtration tests and biofilm analytics

Filtration tests were performed in which electrical current was applied to the conductive membrane. The influence of the applied electrical current on the biofilm formation on the membrane surface was investigated. The tests were performed with peptone saline solution. Peptone saline solution is a growth medium for microorganisms. The biofilm formation was monitored by measuring the decrease of membrane flux during the filtration tests and by taking micrographs of the membrane surface after the filtration tests (Figure 1).

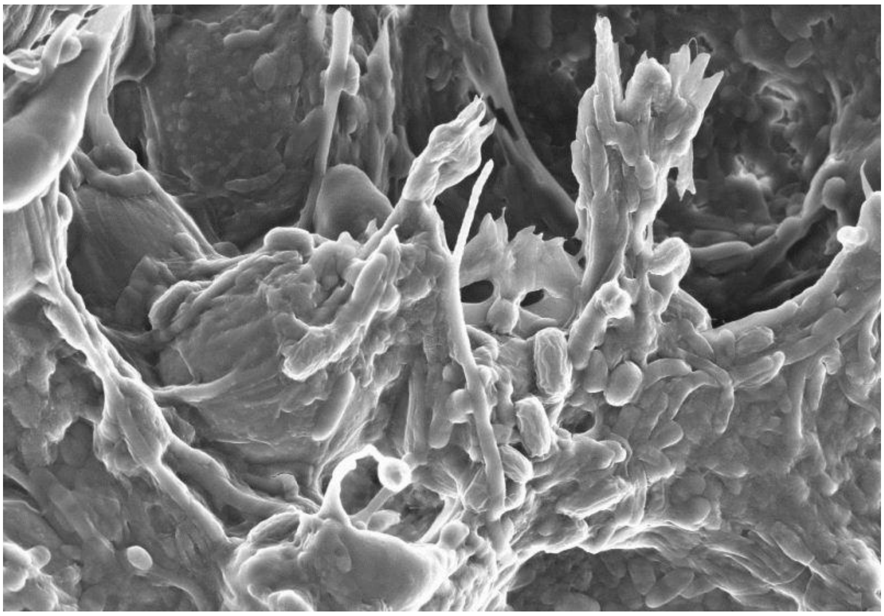

Figure 1: Biofilm on membrane surface

<u>Electric field simulations</u>

After a simplified rod model a model for the electric field distribution in a single hollow fiber was developed along with a generic electric circuit model of it.

Further a model of the lab unit with flat sheet membrane was implemented (Figure 2). The model as implemented like the others in COMSOL MULTIPHISICS (Version 4.2a). The model demonstrated the correctness of the initial assumption while at the same time highlighting the limits of the simulation, due to the simplification assumptions made, and the sensitivity of the result on input parameters.

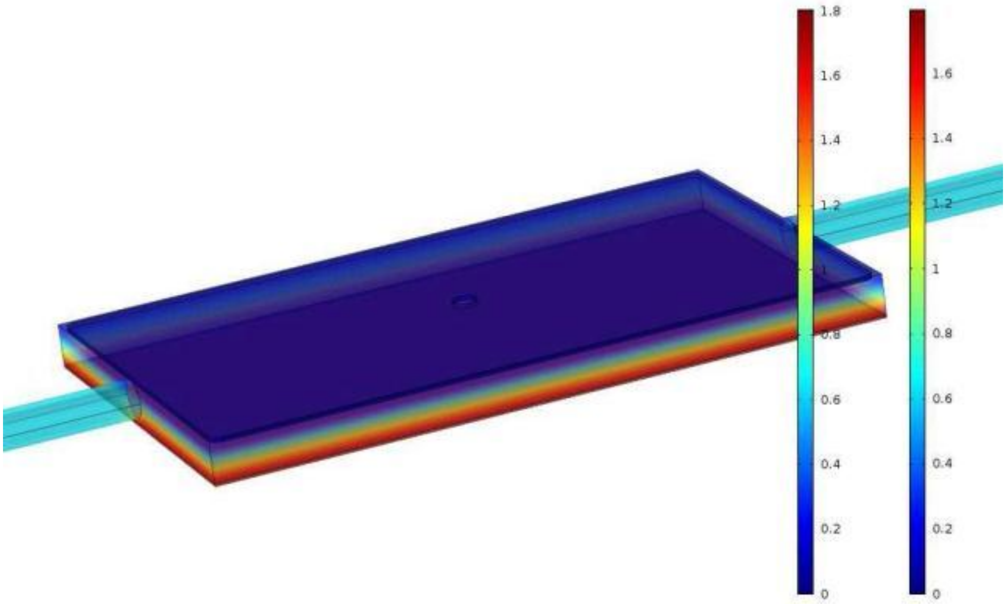

Figure 2: Electric field simulations

Second project period

In the second project period further systematic testing of the membrane was performed. Furthermore, a demonstration unit was designed, built and tested.

Membrane testing

A laboratory filtration unit with six filtration cells in parallel was designed. All filtration cells were supplied with a medium from the same tank. The performed tests allowed to compare the efficiency and differences of the biofouling avoidance with and without application of electrical current to the membrane. Different electrical current densities were applied to the conductive membrane. The results of the filtration tests showed that the biofilm formation on the membrane surface was reduced by the application of electrical current.

Demonstration unit

A demonstration unit was developed to prove the efficiency of the ConductMem technology with regard to flux and pressure stability and fouling reduction. The demonstration unit was mounted on site and test runs were performed (Figure 3).

Figure 3: Demonstration unit

A Programmable Logic Controller (PLC) was used to control the demonstration unit. The following physical and chemical parameters were measured online:

Physical parameters:

- Current applied to conductive membrane
- Voltage applied to conductive membrane
- Pressure (filtrate)
- Temperature (feed, filtrate)
- Level (Tank)

Chemical parameters:

- pH (feed, filtrate)
- ORP (feed, filtrate)
- Conductivity (feed, filtrate)

The flow rates of permeate and aeration and the pressure of the aeration were measured offline.

During the whole project partners met regularly to review the progress, align the specialist team's efforts as well as align the interests of the SME-partners.

Figure 4: Consortium meeting in May 2013 at partner VITO

Additionally bilateral technical meetings and meetings dedicated to the preparation of an exploitation agreement and subsequently a license agreement have also taken place.

Two workshops were undertaken as a knowledge transfer exercise to ensure that all relevant knowledge generated by the RDT performers was transferred to the SME participants and their staff.

Potential impact and main dissemination activities and exploitation of results

Environmental & Economic Impact

Membrane fouling is the biggest cost driver in membrane filtration, severely limiting the range of use for membrane filtration. Overcoming the disadvantages of current systems, by enabling and then implementing the ConductMem concept, could be of significant benefit to the European and global filtration markets.

The consortium generally expects that the membrane bioreactors (MBR) market will grow strongly as environmental directives, aimed at improving the quality of European water, are implemented.

In this domestic sewage will not be the only waste stream that can benefit from the technology. Down the timeline the consortium expects to convince other industries such as food production, pharmaceuticals, petrochemicals of the financial and environmental benefits of treating their waste streams using ConductMem technology.

By the use of ConductMem technology the end-users will be able to comply with environmental protection standards at comparably reduced costs. This will help small and medium sized enterprises to stay in their respective markets and helping the environment by inducing investment in waste water treatment ahead of time as a precautionary measure.

Furthermore, through the adoption of the ConductMem apparatus there could be a significant societal benefit through avoiding the use of chlorine in membrane cleaning and chlorine's inherent drawbacks. This is of benefit for both health and safety (H&S) considerations, as no harmful aggressive products need to be handled, and from environmental impact associated with chlorine disposal.

European Integration

Meetings were held at different partner locations demonstrating the trans-European character of the project and establishing long term links already branching into further cooperations between the transnational project partners.

Address of the project public website and relevant contact details

www.conductmem.eu

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