WATERSOLUTIONS
Water & Waste Water Technologies
special print
Issue 1 | 2018
Publishing House:
DIV Deutscher Industrieverlag
ISSN: 2509-2731

Carbon electrodes for low energy desalination

MIDES (for Microbial Desalination) is a 4-year project funded by the European Union Horizon 2020 program to develop an advanced reverse osmosis desalination technology with reduced energy consumption. SGL Group, as a MIDES partner, provides carbon and graphite components for the microbial desalination cell.

Reliable supplies of fresh water for drinking, industrial use and irrigation is a monumental challenge in many regions around the world, and desalination is one approach to increase freshwater resources. However, current desalination technologies require enormous amounts of thermal or electrical energy. Even with reverse osmosis, which is the most established technology with the lowest energy consumption, more than 3 kWh are required to produce 1 m^3 of fresh water.

MIDES is developing a low-energy solution through the implementation of a pre-treatment step using microbial desalination cells (MDC) as part of a reverse osmosis system (**Figure 1**). The MDC concept was first published in 2009, but to date has only been investigated at lab scale. The MIDES consortium, led by the Spanish water management company FCC Aqualia, aims to demonstrate the feasibility of this technology for large-scale desalination with an energy consumption at or below 0.5 kWh/m^3 by 2020.

How does this work? Simply put, wastewater will be used as an energy source to fuel the desalination process.

Microbial desalination

The basic principle of a microbial desalination cell is an electrodialysis process which is powered by the metabolism of so-called electroactive bacteria supported on a carbon anode (**Figure 2**). Similar to well-known microbial fuel cells (MFC), this specific type of bacteria metabolizes organic matter and converts it to electricity. Unlike MFCs, which consist of two chambers, MDCs comprise three chambers, separated by two ion exchange membranes. In the anodic chamber, wastewater is fed to the bioanode, organic matter is oxidized by the electroactive bacteria in the biofilm, and electrons are transferred to the anode material. In the cathodic chamber, a mediator redox system with high positive standard potential is used to establish a high cell potential. The middle chamber is fed with high-saline water. Driven by the electric potential gradient between anode and cathode, ions (Na^+ and Cl^-) migrate through the respective membranes and concentrate in the cathodic and anodic chamber, respectively. Based on that principle, the MDC can decrease the salinity in the middle chamber from 35 g/L to around 5 g/L.

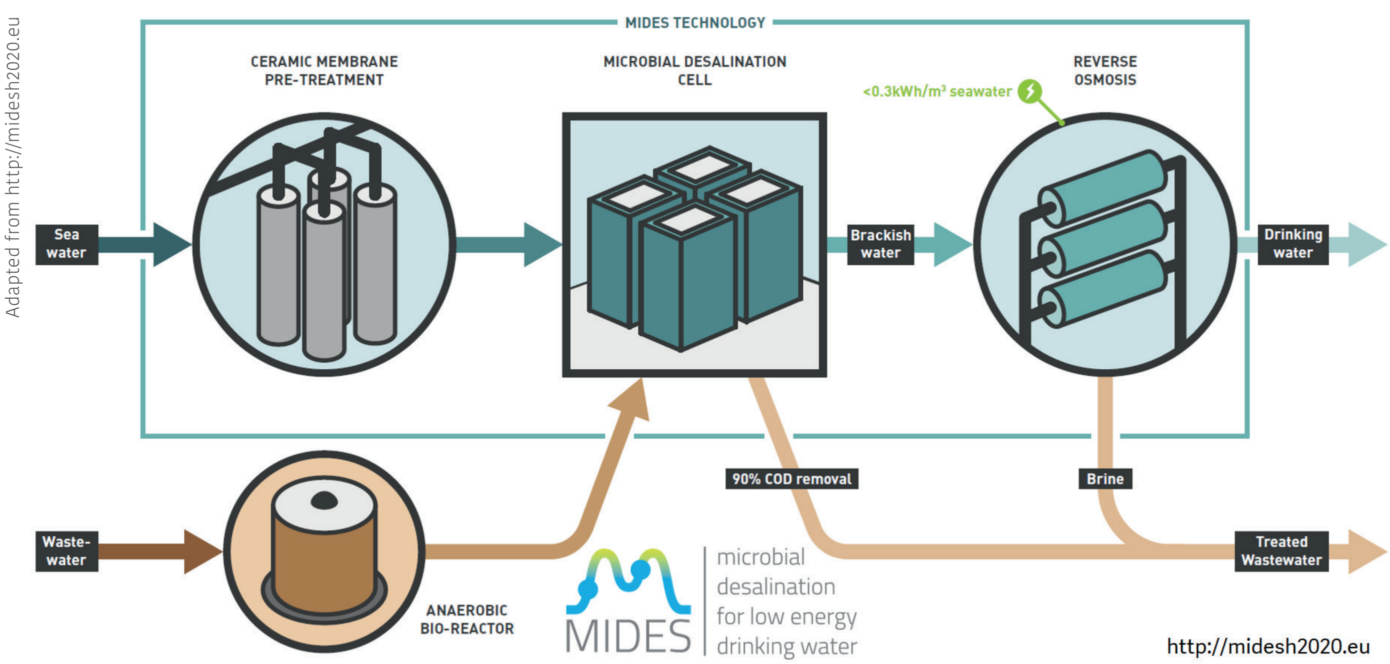

Figure 1: The MIDES approach combines wastewater treatment and desalination in a complex system with the microbial desalination cell at the heart of the process

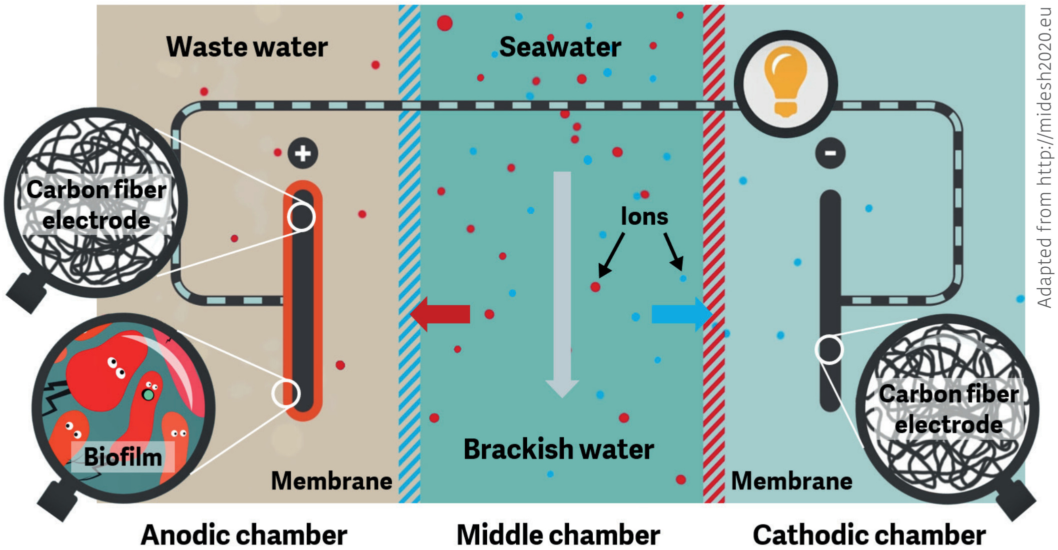

Figure 2: Schematic representation of a microbial desalination cell.

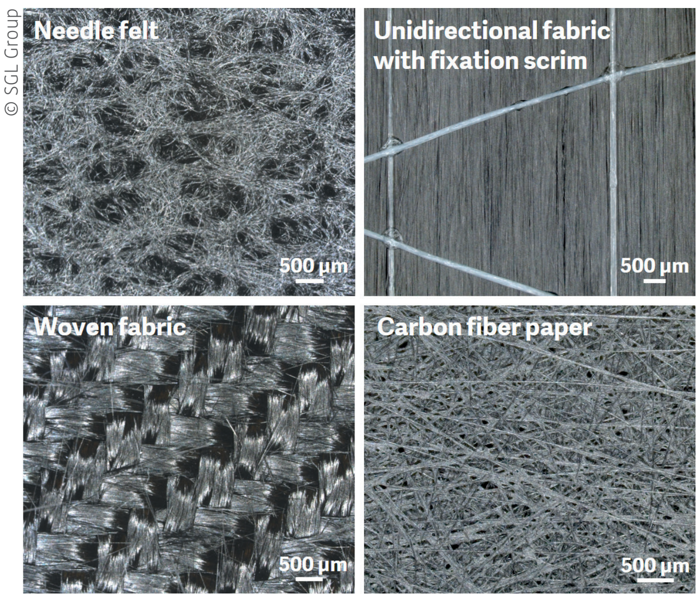

Figure 3: Optical microscopy images of various carbon fiber textiles used as electrode for MDCs.

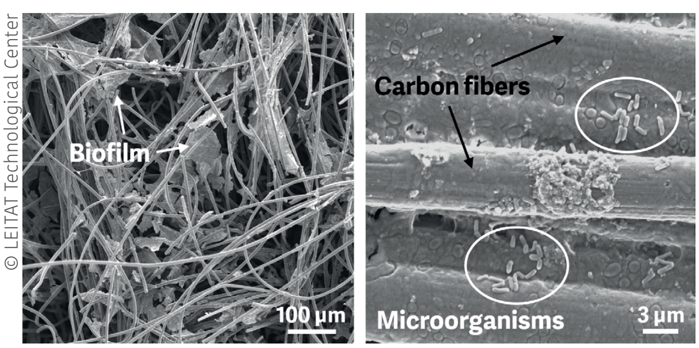

Figure 4: SEM images showing the biofilm on and in between the carbon fiber anode. At higher magnification, the individual microorganisms are visible.

Subsequently, the resulting brackish water can be completely desalinated by reverse osmosis with a significantly lower energy consumption of less than 0.5 kWh/m³.

Carbon fiber based electrodes

Carbon fibers are known mainly for their impressive mechanical properties and applications in lightweight construction. In addition, carbon materials offer promising characteristics in water treatment. For example, an anode material with a porous structure is needed to obtain a large active biofilm area in the MDC and, consequently, an efficient desalination process. Carbon fiber textiles are the perfect material to meet this requirement while also exhibiting the following favorable characteristics:

- Nontoxic and biocompatible
- Long-term resistance to corrosive media, e.g. high salinity solutions
- Good electrical conductivity which enables large current densities
- Low weight and high flexibility
- Adjustable surface morphology of individual carbon fibers allows for an increase of the active surface of the anode and improved contact to the biofilm
- Possibility to tailor the surface chemistry, e.g. introducing oxygen or nitrogen functional groups, to improve and accelerate the formation of the anodic biofilm
- Economic fabrication at large scale

SGL Group's portfolio offers various carbon fiber based textiles suitable for the application in microbial electrochemical technologies. Within the MIDES project, carbon fiber needle felts, unidirectional fabrics and woven fabrics have been identified as the most suitable base for high performance anode materials (**Figure 3**). By scanning electron microscopy (SEM), the biofilm, which forms around and in between the carbon fibers, could be investigated (**Figure 4**). At higher magnification, even individual microorganisms could be observed.

In addition to the anode, carbon fiber textiles are also the base material of choice for the cathode. Two configurations are being investigated:

- A ‘liquid cathode’ configuration (symmetric MDC), which uses water-dissolved species as redox couples, and is based on similar carbon electrodes as the anode.
- An ‘air-cathode’ configuration (breathing MDC), which is based on the oxygen-reduction reaction (ORR) and consists of gas diffusion electrodes based on carbon fiber paper (**Figure 3**).

Finally, graphite plates manufactured from expanded graphite can be employed as current collectors to establish electrical contact to the porous electrodes.

Outlook

The objectives of the MIDES project include three pilot plants with a desalination capacity of 1-3 m^3 per day. The first pre-pilot system is currently in operation at the reverse osmosis desalination plant in Denia, Spain, situated at the Costa Blanca. Furthermore, sites in Tunisia (seawater) and Chile (brackish water in a mining site) will follow to demonstrate the feasibility of low energy microbial desalination on large scale.

Acknowledgement

The MIDES project is a consortium of 10 companies and research organizations from 8 countries funded by the European Union within the Horizon 2020 NMP24-2015 program (grant agreement No. 685793). Research on electrode materials was performed in collaboration with LEITAT Technological Center, Barcelona.

Further information:

http://midesh2020.eu/
http://www.sglgroup.com/cms/international/innovation/future-carbon-technologies

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