NanoTheC-Aba: Micro, Nano and Ultra at your Water Service

New Integrated Prototype System for Energy Efficient Water Purification

Concentrating On the Right Things

To make the environment safer and human activities more sustainable, NanoTheC-Aba developed a prototype system with silicon carbide (SiC) membranes, advanced coating solutions and nanoparticle-based active materials. This system reduces over 99% of a wide range of contaminants of emerging concern (CECs) and antimicrobial-resistant bacteria (ARB). It also allows for the complete reuse of process effluents and the recycling of membrane materials. Our treatment setup minimizes the disposal of wastewater in the environment, reduces the water treatment cost and uses sustainable and efficient materials (Figure 1).

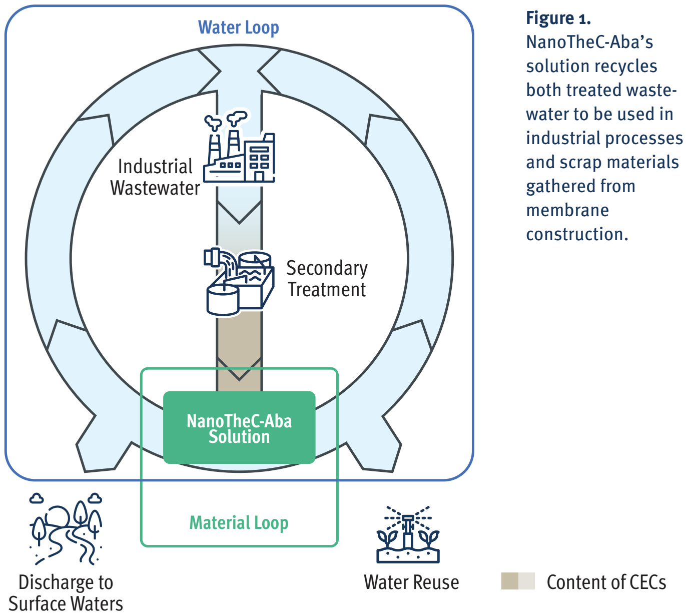


Figure 1. NanoTheC-Aba's solution recycles both treated wastewater to be used in industrial processes and scrap materials gathered from membrane construction.

Filtration, I Choose You!

Filtration is a process of removing particulate matter and contaminants from water by forcing the water through a porous media. This porous media can be natural, in the case of sand, gravel and clay, or it can be a membrane wall made of various materials. The size of substances that can be removed during filtration depends upon the filter pore size.

In the Midst of Every Crisis, Lies Great Opportunity

We are developing innovative and sustainable methods and tools for the purification of tannery, hospital, textile, and aquaculture wastewater based on membrane filtration and catalysis. The designed system is a unique solution that overcomes the current technical limitation of a mere passive filtration process, and, at the same time, does not require any modification to existing water treatment plants. Our system is made of a prefiltering microfiltration unit with antimicrobial functionality (AM-MF), an ultra/nanofiltration membrane (UF/NF) for pre-concentration of the CEC-contaminated wastewater and a thermocatalytic packed bed reactor (TPBR) for the generation of hydroxyl (•OH) radicals able to remove CECs and residues of ARB via an advanced oxidation process (AOP; Figure 2).

Similar But Not Equal

Polymeric NF membranes dominate the market but face issues like biofouling and poor resistance. Ceramic NF membranes, especially SiC-based, provide superior thermal, mechanical, and chemical resistance, with low fouling in harsh conditions.

Passively Getting Water Just Right

The integration of the four units results in increased efficiency of the system as a whole. The AM-MF based on SiC flat sheet membranes pre-concentrates the CECs, decreasing the primary energy demand necessary to supply heat for the thermocatalytic process by at least 30%. The thermocatalytic process will require mild temperatures (~50°-70°C) and no need of further chemical agents or ultraviolet (UV) or light sources to achieve AOP.

NanoTheC-Aba not only tested innovative nanoparticles in our solution, but we also considered sustainability aspects. Large amounts of SiC membrane production residues are recycled as support for the thermocatalytic active phase to make functionalized beads for the TPBR reactor. Moreover, heat for the thermocatalytic reactor can be recovered in principle through heat exchange with the pump's cooling system or from other waste sources.

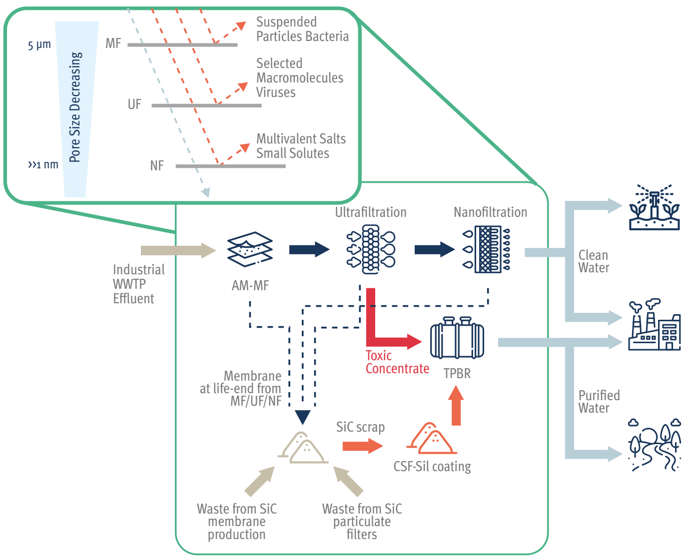


Figure 2. The NanoTheC-Aba solution includes four units: the AM-MF destroys bacteria, the UF and NF steps serve to separate particulates and concentrate contaminants, and finally, the TPBR degrades the contaminants from the UF concentrate, producing purified water. The SiC from the different membranes is recycled into scrap material and then used as a solid platform for the thermocatalyst nanoparticles and placed inside the TPBR.

Aquatic Pollutants

CECs and AMR Bacteria Pre-Concentration by Ultra-Nano Filtration and Abatement by ThermoCatalytic Nano-Powders Implementing Circular Economy Solution (NanoTheC-Aba)

Modern Problems Require Modern Solutions

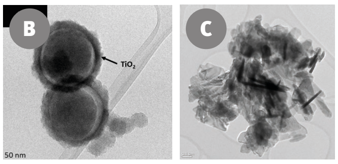
AM-MF Unit

In NanoTheC-Aba, we use a microfiltration unit with antimicrobial functionality (AM-MF), which we achieved by coating the SiC-membranes with an antimicrobial nanomaterial. The presence of antimicrobial nanoparticles on the membranes ensures that bacteria are killed or removed during the filtration process.

We tested two different nanoparticles. The first one is composed of a core of SiO_2 (silica) nanospheres, coated by a TiO_2 (titanium dioxide) layer, which has antibacterial properties.

Therefore, the TiO_2 layer helps to kill or inhibit bacteria, while the SiO_2 core is a support structure for the active layer. The second nanomaterials we tested is composed of zinc oxide (ZnO).

The SiO_2@TiO_2 core-shell antimicrobial nanoparticle was chosen over ZnO due to its higher adsorption capacity (it can interact better with bacteria) and its higher affinity for the SiC support (Figure 3, right).



	SiO_2@TiO_2	ZnO
Absorption capacity	👍	👎
Affinity with SiC support	👍	👉
Antibacterial activity	👍	👍
Citoxicity	👉	👉
Synthesis yield	n.a.	12-38%
Industrial implementation	👉	👍

Figure 3. A) The coated SiC flat membrane, core of the AM-MF unit, B) Transmission electron microscopy (TEM) image of a SiO_2 nanosphere surrounded by TiO_2 active layer and C) TEM image of a ZnO nanoflower. The table lists some important requirements of the active nanoparticles for the AM-MF unit, in a comparison between SiO_2@TiO_2 and ZnO.

TPBR Unit

To make the TPBR unit, we need a thermocatalytic material. Cerium-doped strontium ferrate ($SrFeO_3$; CSF) is a thermocatalyst that can breakdown CECs like BPA, paracetamol, caffeine, and some bacteria, after being heated at low temperatures. To provide a robust and stable support for the thermocatalyst, we used SiC scraps gathered from the production of the MF membranes. (During the membrane production process, large columns are cut down to size, resulting in leftover "scraps".) Adding amorphous silica (SiO_2) during the synthesis of CSF helps better attach the thermocatalyst to the SiC scraps' surface. This synthesis process also creates strontium silicate (Sr_2SiO_4), which somewhat lowers CSF activity but prevents excessive leaching of the catalyst, reducing the need for frequent replacement or regeneration.

We used two methods to attach the thermocatalytic material:

1. Produced the thermocatalyst first and attached it to SiC scraps using sonochemical coating
2. Dip-coated the SiC scraps directly in the „sol" step (colloidal suspension) of the synthesis process and then heated them (Figure 4).

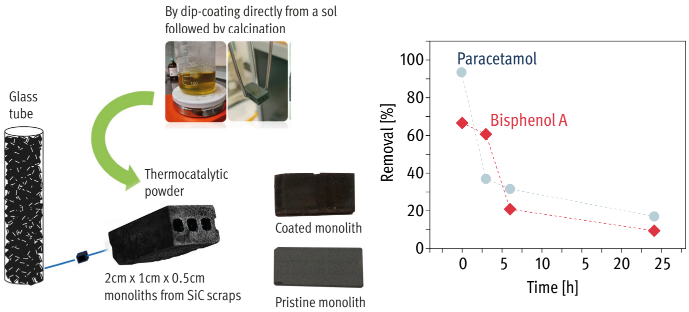


Figure 4. Left) SiC scraps from the SiC membranes are used as a support for the thermocatalytic active phase. They were dip-coated directly into the synthesis solution, a process that still needs to be scaled up to produce enough coated scraps to fill the TPBR. Right) Batch experiments to test thermocatalytical nanoparticle removal of paracetamol and bisphenol A.

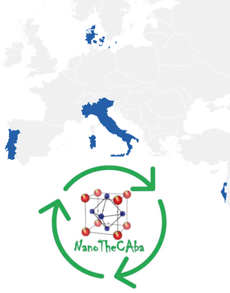
The Wheels of Ingenuity go Round and Round

A circular economy maximizes the lifespan of resources through sharing, reusing, and recycling. This principle will be applied in TPBR development by recycling ceramic scraps from membrane production, addressing economic and environmental needs from SiC membrane scrap production. Circular economy is also considered in the recycling of the water for industrial processes.

More than One Way to Improve

NanoTheC-Aba offers a comprehensive solution that integrates pre-concentration, antimicrobial properties, high filtration efficiency, CECs abatement, operational safety, simplicity, and robustness. It surpasses reverse osmosis systems, in terms of complexity and cost-effectiveness, without consuming or wasting natural resources. The integration of the four components boosts the efficiency of the wastewater treatment process and ensures safe and high-quality water by enabling a multi-circular model for water and SiC material.

Figure 5. Top Right) NanoTheC-Aba organised a PhD Day on „Facing scientific and technological challenges together: Sustainable solutions for water treatment" in collaboration with several other projects. Right) The NanoTheC-Aba project partners are located in Italy, Denmark, Israel and Portugal.



Collaboration

This factsheet was developed by AquaticPollutantsTransNet in collaboration with the NanoTheC-Aba project as part of the AquaticPollutants Cross-Cutting Issue #3 on "Mitigation Technologies for CECs and AMR".

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NanoTheC-Aba

NanoTheC-Aba Partners

1. Università degli Studi di Torino, Dipartimento di Chimica (UNITO), Italy (coordinator)
2. Consiglio Nazionale delle Ricerche, Istituto per lo studio dei materiali nanostrutturati (CNR), Italy
3. B4C ApS (B4C), Denmark - substituting Liqtech Ceramics A/S (LQT) as of 29/03/2023 – [+ BIU, Israel - Subcontractor of B4C]
4. Aalborg University, Chemistry and Bioscience Department (AAU), Denmark
5. Centro de Nanotecnologia e Materiais Técnicos, Funcionais e Inteligentes (CeNTI), Portugal

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Water JPI   JPI OCEANS   jpiamr Joint Programming Initiative on Antimicrobial Resistance

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