Complutense University of Madrid

Knowledge Transfer Office (OTC)

Nanobubble technology to extend the limits of water treatment removal of emerging contaminants

Brief description

Nanobubbles (<200 nm) exhibit extraordinary properties due to their negative charge, colloidal behavior, large specific surface area, high mass/gas transfer efficiency, strong adhesion capabilities, and their ability to generate free radicals. Thanks to the Brownian motion, they possess a long lifespan and a high stability, leading to a new approach in liquid-gas and solid-gas contact systems. These features highlight their technological potential across various applications, including **water treatments**. Given the current need **to extend the limits of traditional wastewater treatment plants**, nanobubble technology emerges as a promising and adaptable alternative to enhance efficiency in removing recalcitrant and emerging contaminants, without requiring major investments.

The UCM Research Group on Cellulose, Paper, and Advanced Water Treatments is developing new knowledge on the integration of nanobubbles (Figure 1) into conventional treatment systems to facilitate their optimization and industrial implementation. Nanobubbles have been shown to significantly **improve flotation processes** by removing suspended solids and dissolved/colloidal matter. They also **enhance water aeration** in **aerobic biological technologies,** improving efficiency in systems such as activated sludge, biological activated carbon, and membrane bioreactors. Moreover, nanobubbles can **generate active free radicals** that promote the oxidation of organic compounds. In addition, nanobubbles can be used in **nano-ozonation treatments**, **improving effectiveness while reducing the required ozone dosage and, consequently, the treatment costs**. Based on the knowledge generated, the group offers **targeted solutions** for the removal of specific contaminants, as well as **short-term integrated strategies** to increase the effectiveness of existing wastewater treatment plants.

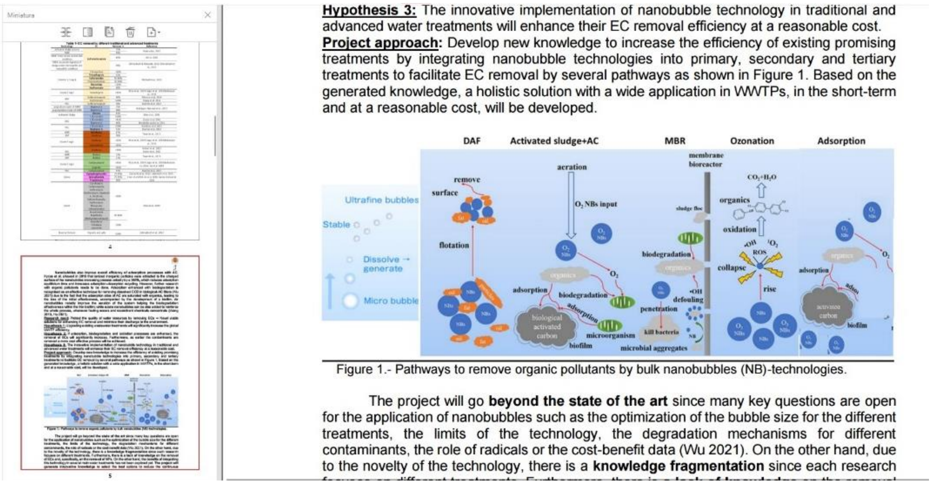
Hypothesis 3: The innovative implementation of nanobubble technology in traditional and advanced water treatments will enhance their EC removal efficiency at a reasonable cost.
Project approach: Develop new knowledge to increase the efficiency of existing promising treatments by integrating nanobubble technologies into primary, secondary and tertiary treatments to facilitate EC removal by several pathways as shown in Figure 1. Based on the generated knowledge, a holistic solution with a wide application in WWTPs, in the short-term and at a reasonable cost, will be developed.

Figure 1.- Pathways to remove organic pollutants by bulk nanobubbles (NB)-technologies.

The project will go **beyond the state of the art** since many key questions are open for the application of nanobubbles such as the optimization of the bubble size for the different treatments, the limits of the technology, the degradation mechanisms for different contaminants, the role of radicals or the cost-benefit data (Wu 2021). On the other hand, due to the novelty of the technology, there is a **knowledge fragmentation** since each research

Figure 1. *Pathways for the removal of organic contaminants using nanobubble technologies.*

How does it work?

- **Nanobubble technology** involves the generation of gas nanobubbles within a liquid medium. Thanks to their unique physicochemical properties, nanobubbles can significantly enhance the removal of contaminants.
- **Generation of oxidizing species** without the addition of chemicals: When nanobubbles collapse or interact with UV radiation or metal surfaces, they release hydroxyl radicals (•OH) and other highly reactive oxidative species. These radicals attack and degrade complex organic compounds such as pharmaceuticals, pesticides, cosmetics, endocrine-disrupting chemicals, among others, breaking down their chemical structures and improving their biodegradability.

Medicine Faculty. Entrepabellones building 7 y 8.
C/ Doctor Severo Ochoa, 7. 28040 Madrid.
comercia@ucm.es

- **Enhanced oxygenation and biological activity**: Nanobubbles possess a high surface-area-to-volume ratio and dissolve slowly, continuously releasing oxygen in an efficient manner. This enhances dissolved oxygen levels, stimulating the metabolic activity of microorganisms. As a result, they reinforce secondary biological treatment processes, facilitating the biodegradation of contaminants that are otherwise resistant to conventional methods.
- **Improved adsorption and contaminant transport mechanisms**: Due to their negatively charged surface and high surface energy, nanobubbles can attract and carry contaminants, particularly polar or ionic substances, toward reactive zones where they can be more effectively degraded or removed. In systems using adsorbents (such as activated carbon), nanobubbles enhance contaminant-sorbent contact, thereby increasing removal efficiency.
- **Removal of dissolved and colloidal material**: Nanobubbles also assist in destabilizing colloidal structures where contaminants tend to accumulate. They promote the flotation or aggregation of microplastics and nanoparticles, facilitating their separation during subsequent treatment stages.

What problem does it solve?

Nanobubble technology enhances advanced oxidation processes, biodegradation, and suspended solids removal, thereby increasing the overall efficiency of wastewater treatment plants in addressing recalcitrant and emerging contaminants, without requiring major infrastructure investments and with low operational costs.

What future products will it develop?

- Sediment and soil remediation: Facilitates *in situ* oxidation of polycyclic aromatic hydrocarbons (PAHs) and heavy metals, accelerating the recovery of degraded ecosystems.
- Oxygenation of aquatic ecosystems: Maintains oxygen levels above natural saturation, preventing fish die-offs in aquaculture and eutrophic lakes.
- Agriculture and horticulture: Irrigation with nanobubble-enriched water improves root absorption, stimulates the growth of beneficial microorganisms, and reduces fungal diseases, enhancing yields with fewer pesticides.
- Mining and selective flotation: Air or CO_2 nanobubbles act as nucleation "seeds" on fine particles, improving mineral recovery while reducing the need for chemical collectors.

Competitive advantages compared to other research

- Increases the overall effectiveness of wastewater treatment plants without requiring major upgrades.
- Enables advanced oxidation without the need for added chemical reagents.
- Increases the performance of biological treatments while reducing energy consumption.
- Enhances the removal of suspended, dissolved, and colloidal material.
- Reduces treatment costs.

Where has it been developed?

Nanobubble technology is currently being developed by the **Cellulose, Paper, and Advanced Water Treatment Research Group**. The group operates an Acniti Microstar nanobubble generator (model FS302AC-SW1, 300 W), which can be integrated into other treatment systems such as photocatalysis (Figure 2), dissolved air flotation (Figure 3), or nano-ozonation. In addition, the group is equipped with an ultrafine bubble concentration sensor (model ALT-9F17), which enables precise quantification of nanobubble presence under varying operational conditions.

Figure 2. *Photocatalysis system enhanced with nanobubbles*

Figure 3. *Dissolved air flotation (DAF) system incorporating nanobubbles.*

And moreover…

The application of nanobubbles is a **versatile** and **efficient technology** that can be easily installed within existing infrastructure, acting as a functional enhancement and complement to current treatment processes. It does not require major modifications or capital investment, and operates as a **sustainable, residue-free process with low energy consumption**. Its field of application extends beyond water treatment, including agriculture, healthcare, food processing, surface cleaning, and bioremediation.

Researcher in charge

Ángeles Blanco ablanco@ucm.es
Department: **Chemical Engineering and Materials**
Faculty: **Chemical Sciences**