Electric-field nanobubbles: A step change in nanobubble engineering, and its “coming of age”

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Niall J. English, from Chemical Engineering at University College Dublin, discusses how electric-field nanobubbles have displaced their mechanically-generated counterparts in performance and sustainability

Limited solubility of gases in water, such as oxygen, is a fundamental challenge. In ecosystems and the environment, lack of dissolved oxygen (DO) is a major reason for fish kills and water bodies being blighted by algal blooms, in addition to lack of effectiveness of activated-sludge processes in water treatment or poorer-than-hoped results in irrigation.

Nanobubbles (NBs) are tiny gas bubbles on the nanometre (nm) scale. They may be thermodynamically metastable for up to many months, or sometimes even longer, and have enhanced gas-transfer properties and substantial industrial potential. The concept of NBs versus traditional, coarser bubbles – with the latter subject to buoyancy phenomena, while NBs are relatively impervious to rising – in essence, “subverts” Stokes’ Law of bubble rising – and have an excellent area-to-volume ratio. If NBs are generated well – indeed, the art of “nanobubble engineering”, as it were – NBs lead to important and useful applications.

In terms of the *status quo* (ante) vis-à-vis industrial NB generation, wherein traditional (mechanical) generation methods mainly rely on hydrodynamic, acoustic, particle and optical cavitation – in tandem with injecting pressurised gases through a tubular ceramic membrane lined by nanopores – these, inevitably, just get bio-fouled in short order. These NB-generation processes raise issues such as, *inter alia,* high energy consumption and complexity – to mention nothing of high ongoing maintenance and unscheduled process downtime.

In stark contrast, in the case of the disruptive electric-field invention lead-invented by Prof English and developed further by AquaB, the application of static electric fields via sheathed electrodes to liquid-gas systems promotes the instant and low-energy formation and build-up of ultra-dense gas NBs inside the liquid phase, by enhancing metastable gas solubility through electrostrictive action. [1] In particular, the low-energy and static, DC nature of the applied electric field allows, for the first time, solar energy as a viable approach for “passive” NB generation. In any event, this novel approach allows for thus-generated “thick-skinned” NBs to have unique environmental and industrial applications. [2,3,4]

AquaB (AquaB Nanobubble Innovations Ltd), commercialises novel water-gasification technologies based upon its breakthrough low-energy nanobubble (NB)-generation approaches. It was set up in 2020 as a spin-out company from UCD Chemical Engineering to commercialise the patented platform NB-generation technology [5] lead-invented by Company Director Prof Niall English; he holds an ERC Advanced grant on NBs with broad applicability across disparate application areas. [6] Since 2020-21, AquaB has been developing TRL 4-8 NB generators, aided by its European Innovation Council (EIC) Accelerator Grant – and has been performing many field trials in a variety of nanobubble-engineering settings.

Enter electric-field nanobubbles

As part of the urgency in addressing environmental sustainability and water-treatment concerns across a wide variety of sectors, ranging from municipal, agri-, aqua-, alga-cultural, industrial and surface water to oil-and-gas, NBs have emerged as one prominent subject of R&D. These NBs – shorter than the wavelength of light – are not visible to the naked eye, and are orders of magnitude smaller in dimension than a human hair's width, as discussed in Prof English's recent audio-podcast course on NBs.

AquaB's method of generating NBs is based on static electric fields and electrostriction-based "sucking in" phenomena of gases into liquids – making "thick-skinned", or ultra-dense, NBs [7] with enhanced longevity, e.g., long-time-maintained high dissolved- gas levels, for example, O_2 or CO_2 in water, and, indeed, in other liquids – such as calorific fuels for, *inter alia*, substantially enhanced thermodynamic-cycle combustion efficiency. Therefore, the comparison of electric-field and traditional mechanical NB-generation approaches is of interest.

Electric-field nanobubbles: A cut above the rest

To compare various types of commercially available NB-generation approaches for NB generation in water, as a starting point, five commercial liquid-flow-based NB generators were compared by UCD, as well as two commercial submersible NB generators – submerged either partly or fully in water, including from AquaB http://aqua-bubble.com/products. These units were not run for more than a few hours, given that the study was not focused on longer-term use, biofouling, or maintenance issues; instead, the focus was on absolute and comparative NB-generation efficiencies.

It was found that the electric-field approach of NB generation surpasses traditional mechanical approaches for clean-water NB generation, especially when considering the energy running cost. In particular, more passive electric-field approaches are very operationally attractive for NB generation, where water and gas flow can be handled at little to no cost to the end operator, and/or submersible NB generators can be deployed, allowing for the use of photovoltaic approaches with backup batteries for night-time and "low-sun" scenarios and air-/ CO_2-pumping paraphernalia.

The UCD study also showed dramatic levels of shore-/floating-mounted solar-powered cyanobacteria suppression on blue-green-algae-blighted ponds – the ultimate byword in passive and low-maintenance "breathing life" into water-body aquaculture and combatting ecosphere- threatening eutrophication.

Electric-field approaches are even greater in superiority vis-à-vis mechanical-generation approaches for wastewater treatment, where porous-membrane blockages become an insurmountable problem – never mind the impractically high operating- energy cost.

This study has also called into question the level of bubble generation that is actually on the nanoscale in mechanically-based commercially available generators that putatively produce NBs. It has also sought to challenge the oft-prevailing industrial mindset of (traditionally-) dissolved-gas level as being characteristic of the effectiveness, or otherwise, of NB generation.

Other metrics in water following fine-bubble aeration, such as ORP and the relaxation thereof, or the time-resolved trajectory of DO (as opposed to the absolute value thereof in the immediate aftermath of fine-bubble generation), are more relevant to (putative) NB generation per se: hydrodynamically effective macrobubble generation can, and does, boost dissolved-gas levels temporarily, for periods of tens of minutes until Stokes'-Law dissipation (and/or chemical/biological gas demand) serves to reduce that. Therefore, actual and would-be NB-generator operators would do well to take note of these "cautionary tales" in their operational assessment of the (in)effectiveness of their nano-/fine-bubble-generation strategies.

AquaB firmly believes that its industrially-proven NB generators, with superior performance compared to rivals, are advancing its EIC-supported water-management mission. This addresses UN Sustainable Development Goals and the EU Green Deal for Man's greater good and the Earth's environment.

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