Fine-bubble engineering: A fresh and economic appraisal to redesigning liquids' life-line to bioprocesses

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Niall J. English, from Chemical & Bioprocess Engineering at University College Dublin, discusses how new paradigms in manipulating microbubble and nanobubble populations by novel and inventive engineering approaches have an impact on tailoring liquids for various bioprocess applications

A fundamental challenge in many unit operations in (broadly defined) biochemical engineering (such as activated-sludge processes in wastewater treatment), as well as in environmental settings (e.g., surface-water treatment), is the provision of adequate levels of dissolved oxygen (DO) in water supply – or, indeed, dissolved gases in liquids more generally.

This is limited by Henry's Law, which governs thermodynamic gas solubility in liquids. In ecosystems and the environment, lack of D.O. is a major reason for, inter alia, fish kills and water-body blight by blue-green algal blooms of cyanobacteria – especially in Summer when Henry's-Law dissolved-gas solubility is lower at higher temperatures.

Indeed, the promotion of dissolved-gas solubility extends into bioprocesses in general in liquids, which often depend on D.O. or dissolved-CO2 levels (or, indeed, other dissolved gases), e.g., for algaculture, fermentation or brewing. Dissolved-gas levels must be maintained for bioprocess productivity – a liquid's "life-line" to feed and sustain its underlying and dissolved-gas- needing biological processes, as it were.

The presence of fine-bubbles in liquids (i.e., nanobubbles (NBs) and microbubbles (MBs) offers a means by which one may manipulate liquid properties – at least in a time-dependent fashion. Given that bubbles rise by Stokes' Law (albeit with the relative exception of NBs – to be explored anon), the smaller the bubble, the more slowly these buoyancy phenomena exert themselves.

Therefore, Stokes'-Law dissipation means that bubbles rise and exit the liquid over specific characteristic timescales: for instance, seconds for carbonated water, and perhaps tens of minutes for meso-bubbles rising in champagne, prosecco or beer (with subsequent taste "flatness"), and up to hours for "foggy" liquids dissipating their light-scattering (and smaller) MBs more slowly; this is explained in a recent audio-podcast from Prof. English.

Therefore, by tailoring the bubble size, one may adapt the dispersed (bubble) phase to control the timing of supersaturation of the total dissolved-in-liquid gas accommodation. Of course, one must bear in mind the residence time of the unit operation at play to ensure that these are (somewhat) less than the "fine-bubble-engineered" dissolved-gas-saturation timescales – thereby realising canny and efficient "just-enough" gas- saturation strategies, so as also to minimise gas-supply and bubble- generation operating costs.

Enter fine-bubble engineering

NBs are tiny gas bubbles on the nanometre (nm) scale. They may be thermodynamically metastable for up to months, and have enhanced gas-transfer properties for sustaining (bio) processes taking place in the liquid. 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 podcast.

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 with enhanced longevity, e.g., long-time-maintained high dissolved gas in water. See also here.

In addition, MBs are shorter-lived in water – perhaps over no more than hours, depending on their size distribution, and novel and efficient engineering methods to generate these – both in their own right and as a pre-cursor for subsequent NB generation therefrom – are important to pursue.

AquaB Nanobubble Innovations Ltd, commercialises novel water- and fuel-gasification technologies based on its breakthrough low-energy 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 lead-invented by Company Director Prof. Niall English; he holds an ERC Advanced grant on NBs with broad applicability across disparate application areas.

Since 2020-21, AquaB has been developing TRL 4-8 NB generators, aided by its just-finished and highly successful European Innovation Council (EIC) Accelerator project, and it is now entering full commercial activity in Q1 2025 with its line of photovoltaic-enabled, TRL-9 and CE-marked, IP- and ATEX-rated NB generators – ISO-certified and witnessed independently for high NB presence and performance – with best-in-world NB-production. Indeed, the upstream engineering of meso- and MB populations, before NB generation therefrom as derivative sub-populations, is a key engineering process in determining the success of fine-bubble engineering – just one of many problems to overcome in developing the world's best NB generators.

Rising to the fine-bubble challenge of redesigning liquids for bioprocessing

Building on this fine-bubble engineering momentum, Researcher, Inventor and Chartered Chemical Engineer Niall English (FIChemE), in either or both ERC- and EIC-project capacities, has been collaborating with Turritech and Saudi Aramco recently in the R&D métier of fine-bubble engineering – in particular, to manipulate fine-bubble lifetimes, populations and oxidative potency – with a view to re-engineering the "mother liquid's" dispersed-phase fine-bubble characteristics to host bioprocesses optimally and economically within specified water- treatment residence times.

To this end, the application of longer-lived ozone NBs (compared to traditional macro-bubbling) has been optimised with a much lower need for parallel application of UV irradiation, and this has boosted the oxidative potency of shellfish-farm water – with positive implications for norovirus suppression and much less energy- intensive UV needed for ongoing oxidative-capacity boosting of the water.

In further effective and economic boosting of bioprocess-handling capacity of water, innovative Schauberger-flow vortices from Turritech have been tested and validated as being highly effective in the generation of gas MBs in water: the manipulation of components of water-flow momentum by biomimetic swirl patterns optimises eddy-current cavitation for MB formation, which also serves to enhance the "bio-friendly" oxidative-action properties of water – albeit temporarily due to Stokesian MB dissipation over a number of hours.

Working with Aramco, nano-carbonation of marine-algal species, in the guise of exposure to AquaB "electro-generated" CO_2 NBs (with effective upstream meso-bubble engineering to tailor this original population for ultimate downstream electric-field exposure) have provided, inter alia, highly beneficial biomass-yield outcomes, as English discussed in a well-received talk recently in Kyoto at the Nanobubbles 2024 conference.

AquaB believes firmly that its industrially-proven field-trials, with superior performance compared to rivals, e.g., in submersible NB generation (see also this link) is advancing its EIC-supported water- treatment agenda – tailored for boosting bioprocesses. This addresses UN Sustainable Development Goals for Man's greater good and the Earth's environment.

Contributor Details

Stakeholder Details

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