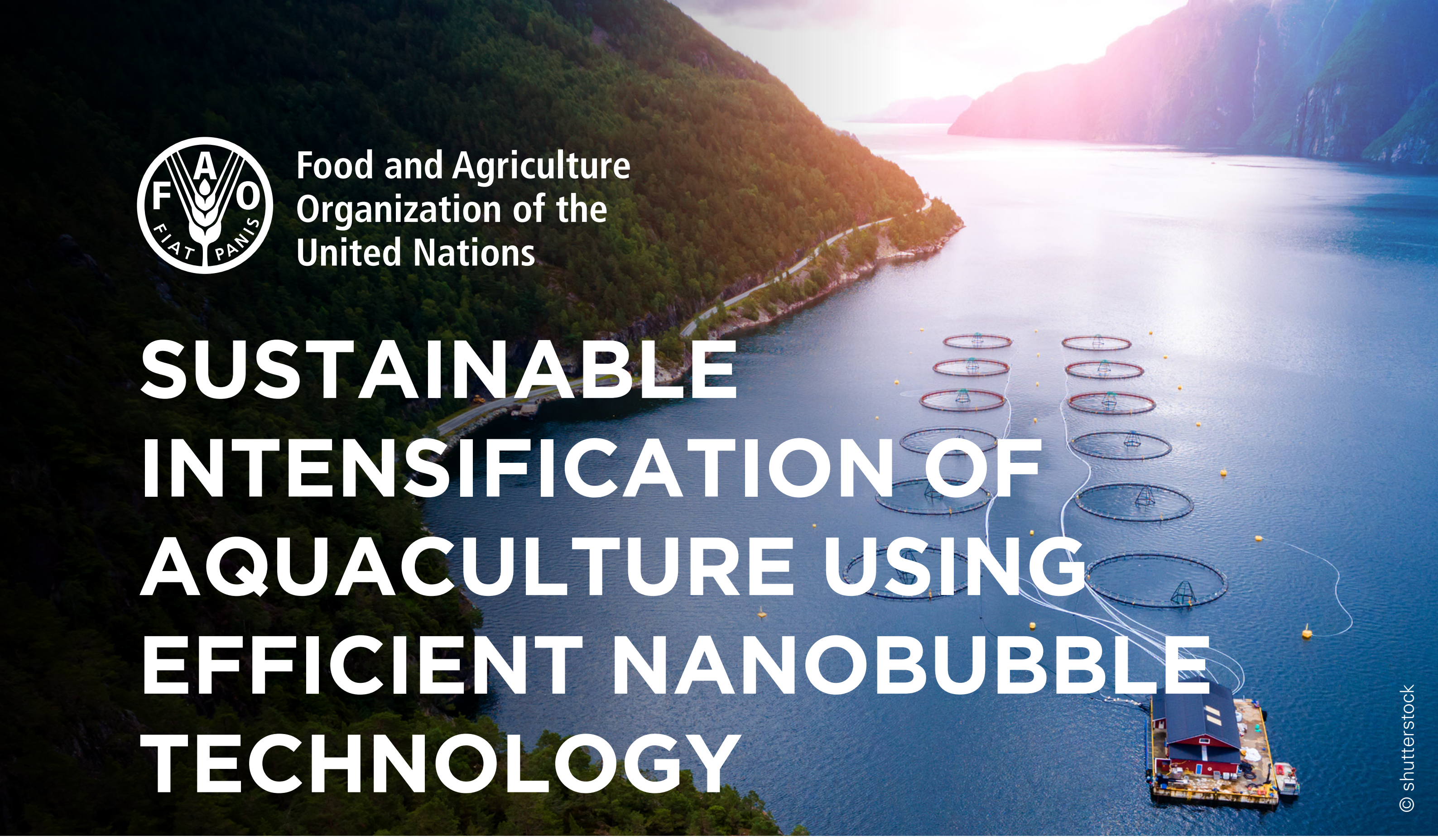


Food and Agriculture Organization of the United Nations

SUSTAINABLE INTENSIFICATION OF AQUACULTURE USING EFFICIENT NANOBUBBLE TECHNOLOGY

Devices that produce bubbles one-ten-thousandth of the size of those made by conventional aeration systems are being heralded by their developers as having a range of advantages – such as allowing increased stocking densities, reducing diseases and improving feed conversion ratios. While studies of these devices are still too few, the anecdotal evidence of their value is compelling.

Many aquaculture producers are seeking to sustainably intensify aquaculture production systems for many reasons including the constraints of finite and costly operating locations on land and water, enhancing efficiency, greater environmental control, more effective biosecurity (mainly hatcheries/broodstock) and improved system economic performance.

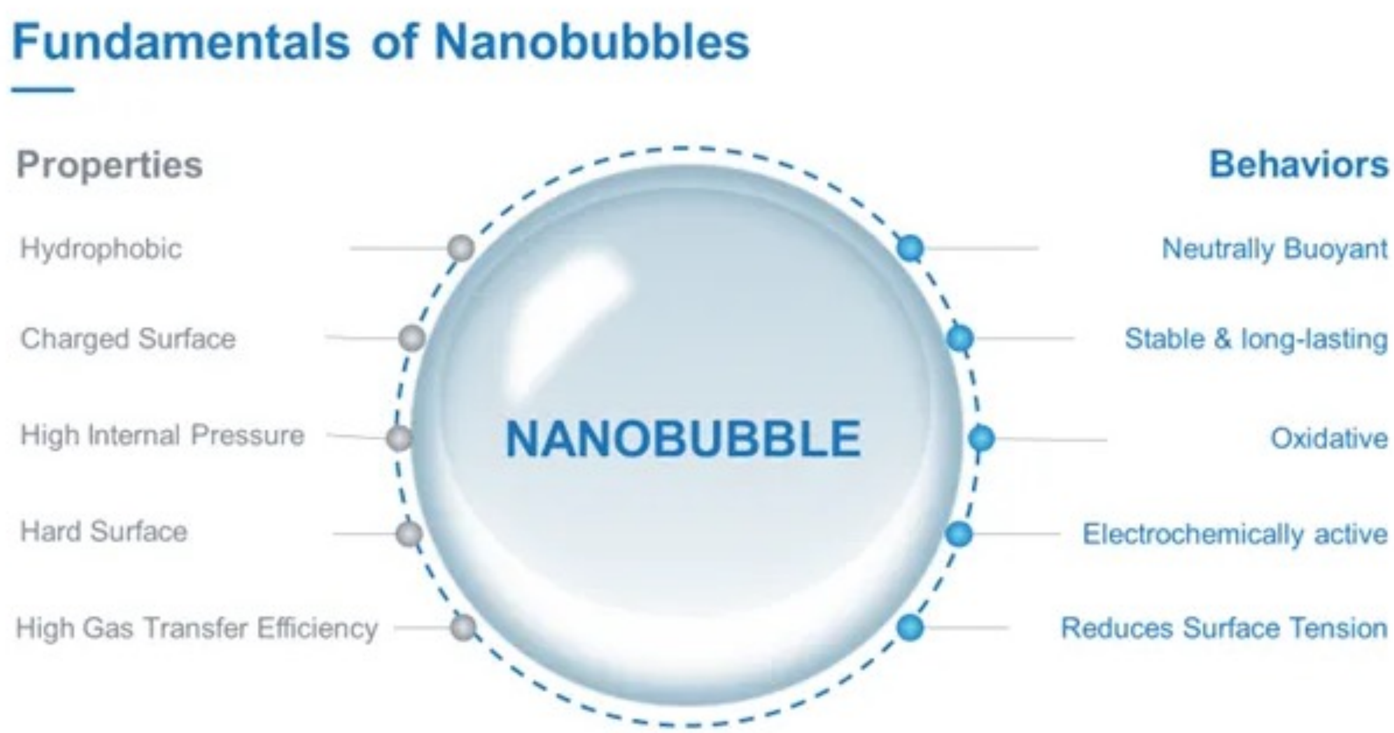
There are physical limits to doing this imposed by the carrying capacity of any aquaculture production system and the quality of water in the production unit, with dissolved oxygen (DO) being a key water quality parameter. The maximum DO levels in water are primarily limited by temperature, salinity and altitude with cold water holding more DO than warm water. DO in warm water fish ponds typically ranges from 2 mg/L to 12 mg/L of oxygen, with the DO level following a diurnal pattern that increases while sunlight drives photosynthesis and declines at night to a critical low point just before sunrise. Most aquatic species are comfortable with DO levels of 5 to 12, but many species suffer when DO is less than 4 mg/L.

The DO level in the water determines the amount of stock that can be held by a system in a low stress, healthy environment. The aquatic stock as well as breakdown of feed and excretory waste products utilize oxygen from the water in the production unit, which can be critical if the volume of stock held is high, unless water can be exchanged, or recirculated, or a heterotrophic system is operated where bacteria maintain water quality by keeping ammonia and nitrite levels low.

Low DO can cause stock crowding and stress, poor feeding and growth, as well as increased susceptibility to disease pathogens. In extreme situations, low DO can result in deaths and even complete die-off of a stock batch.

To intensify production, it is common for aquaculture producers to aerate water in aquaculture production systems using water splash boards, paddle wheels, venturi pumps, air stones, air lift pumps and so forth. The most intensive systems use direct oxygen injection. Exceptions to this are extensive culture systems for air-breathing fish like climbing perch (*Anabas testudineus*), snakeheads (*Channa* spp.) and catfishes, which can tolerate very low DO levels by breathing air at the water surface.

Most mechanical aeration systems agitate the water surface to increase oxygen levels and as a result DO levels are highest near the water surface and aquatic animals may aggregate and crowd in areas where oxygen levels are highest in the upper water layers of production units or close to aerators. Benthic (like shrimp) and sessile species (like abalone) have less ability to do this. Efficient distribution of DO in the production unit is important to avoid stress and crowding behaviour. Recognizing the importance of achieving oxygen saturation at all times and even distribution of oxygen within production systems to reduce crowding effects, commercial companies have developed and are now marketing improved oxygen supply and aeration systems which allow safer, more reliable and lower risk production system intensification.



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The key properties and behaviours of nanobubbles

TECHNIQUE AND APPROACH USED

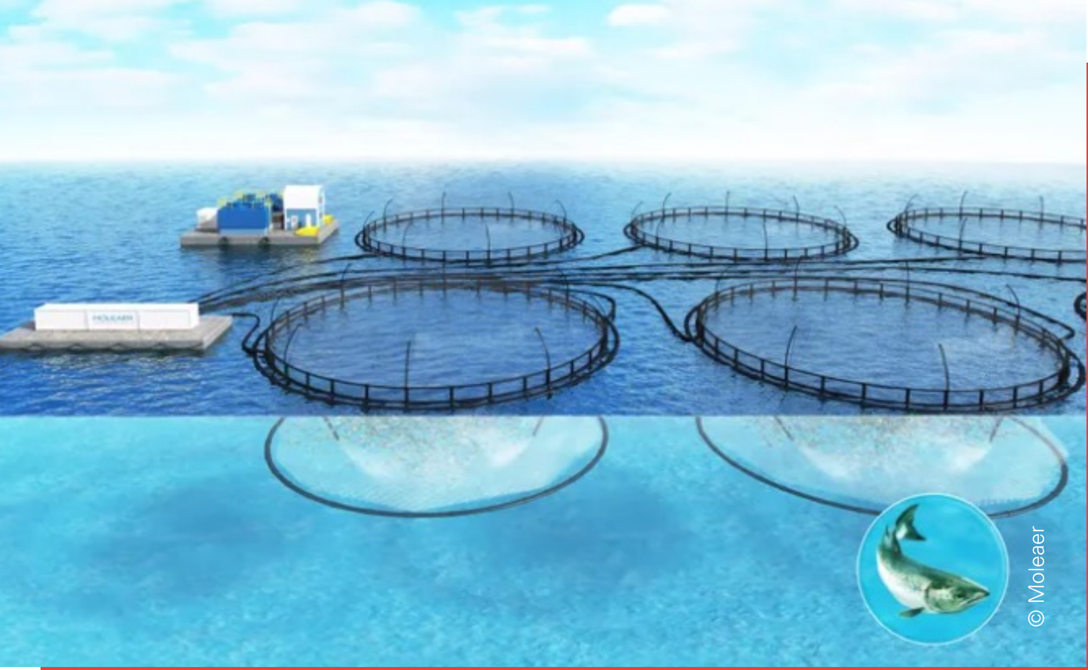
Typical mechanical aeration systems used in aquaculture production units produce large or macrobubbles of air or oxygen which are typically 3 million nanometres (0.3 cm) in diameter; because of positive buoyancy they rapidly rise to the water surface where they burst. Even when using microbubbles, which are typically 100 000 nanometres (0.01 cm) in diameter, to provide oxygen to water, the bubbles normally only last a few minutes (Tekile, Kim and Lee, 2016), meaning that the transfer of oxygen from the air to the culture water in aquaculture production systems is inefficient. Some systems may use supplemental oxygen injection to increase the oxygen concentration being delivered through the aeration system.

To improve the efficiency of oxygen transfer from air or oxygen bubbles, commercial companies have developed nanobubble technology production systems. Nanobubble generators can inject any gas into any fast-flowing liquid to create nanobubbles, but for aquaculture operations compressed air or oxygen are normally used. The air or oxygen bubbles produced have a mean diameter of less than 200 nanometres, making nanobubbles one-five-hundredth and one-ten-thousandth the size of microbubbles and macrobubbles respectively (Agarwal, Ng and Liu, 2011).

Nanobubbles are so small that they are neutrally buoyant and do not rise to the water surface, but move on Brownian motion[1] currents within the water of the production unit. The neutral buoyancy of nanobubbles gives homogeneous oxygen bubble distribution with DO levels near the surface and at the bottom of the aquaculture production unit being nearly the same, meaning that stock can be distributed and fed actively throughout the water column of the production unit. Tekile, Kim and Lee (2016) reported that air and pure oxygen nanobubbles can remain suspended in water for 10 days to 15 days respectively until dissolving and are therefore a more efficient method of increasing the DO content in water.

In addition, the collapse of nanobubbles results in chemically reactive free radicals (unpaired electrons) being produced, which oxidize organic compounds, and which may improve water quality in closed aquaculture production systems.

[1] Brownian motion is the random motion of particles suspended in a medium.



Nanobubble treatment of salmon cages results in sustainable intensification of aquaculture production and reduced feed conversion ratios.

SCOPE AND SCALE OF APPLICATION

Nanobubble generators are modular and so can be upscaled easily, with pumped capacity ranging from 50 L/minute to 4 000 L/minute.

The system is particularly relevant to salmonid species, which have higher DO requirements and lower tolerance to low DO than many cultured tropical aquatic animal species. The approach is being used with land-based recirculation aquaculture technology by salmon producers working with high stocking densities to make operations economically viable. The nanobubble system is undoubtedly more appropriate for closed production systems like hatcheries, but it can also be used effectively in semi-closed production systems like skirted salmon cages.

Despite the fact that nanobubble aeration is not as efficient in water with high suspended solids, the manufacturers report that nanobubble generators work well in biofloc pond systems for species like shrimp and tilapia. These species require vigorous aeration to keep the flocs from settling, thus preventing dead zones where anaerobic conditions can generate ammonia and methane, and allow disease pathogens to build up. Enhanced biomass kinetics using nanobubble aeration in biofloc systems, the manufacturers claim, efficiently oxidize ammonia and reduce loads of bacterial pathogens like *Vibrio* spp.

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Nanobubble generator

ACCESSIBILITY

A salmon cage system requires a considerable number of infrastructure components. These include a barge or pontoon, a power generator, the oxygen generator (or external oxygen tanks), heavy duty pumps, piping (including oxygen and water hoses), injector nozzles and possibly a back-up liquid oxygen tank.

The manufacturers report that the return on investment can be as little as 14 months, but this requires independent verification. Companies marketing nanobubble generators are offering rental leases to convince users of their efficiency and cost-effectiveness.

Analogue sensors are used to monitor DO, to automatically control the power used by each nanobubble generator and to optimize energy use efficiency. Cleaning of nanobubble nozzles typically takes 30 minutes, with some brands having self-cleaning systems. Continuously operated nanobubble generators require less cleaning compared to those that are switched off and on.

Nanobubble generators require a reliable stable electrical supply and a back-up generator system. In Asia, technical back-up and spare parts may require materials and experts being brought in from overseas, although manufacturers report that the operating and maintenance costs of nanobubble generators are low and they are less prone to technical issues.

Nanobubble generators are less efficient and effective at increasing DO levels in water with higher suspended solid loads (Tekile, Kim and Lee, 2016) and so are less efficient if used in turbid tropical ponds and even in inshore coastal waters with river runoff; but they are still a significant improvement on current aeration systems in the same environment.

There are also health and safety considerations and additional expense when using large amounts of high purity oxygen on floating cages anchored at sea.

People searching the internet for nanobubble products also need to be wary because many companies selling nanobubble equipment, which by definition are smaller than 200 nanometres or 0.0000002 metres, are actually selling equipment producing microbubbles, which do not have the same aeration properties as nanobubbles.

OUTCOME AND BENEFITS

The manufacturers of nanobubble generators claim that nanobubble aeration gives homogeneous oxygen distribution within aquaculture production units, giving better utilization of the space from the bottom to the water surface of tanks, cages and ponds, and allowing increased carrying capacity of production units without causing additional fish stress.

The homogeneous mixture of nanobubbles throughout the water column with the nanobubbles remaining in solution for days and weeks efficiently ensures that DO levels are optimal for the species and stock size being cultured in aquaculture production units. It reduces aquatic stock stress, allows sustainable intensification of aquaculture production and higher stocking densities, and results in better feeding with lower feed conversion ratios. Furthermore, the likelihood of pathogen disease outbreaks is mitigated. This all translates into greater productivity and improved aquaculture unit profitability from aquaculture production units.

Rahmawati *et al*. (2021) conducted a comparison of diffuser aeration and nanobubble aeration for whiteleg shrimp culture over 81 days in 50 m^2 indoor raceway systems stocked at 680 shrimp/m^3. The nanobubble aeration gave significantly higher DO levels and significantly ($P<0.05$) better shrimp growth with total harvest (436 kg) and productivity (8.7 kg/m^3) of the nanobubble raceway system being double that of the diffuser aeration raceway system (222 kg/m^3 and 4.4 kg/m^3) and with a lower feed conversion ratio.

Companies producing nanobubble aeration systems state that the nanobubble systems transfer oxygen with greater than 90 percent efficiency, which is 30 times greater than non-nanobubble aeration systems.

Nanobubble could be a viable technology for removing microbial biofilms from surfaces and enhancing the efficacy of conventional sanitizers (Shiroodi *et al*., 2021). Manufacturers also claim that nanobubbles can be used to cost effectively and sustainably treat sea lice, although again this claim requires independent verification.

While there are a few peer-reviewed articles to verify the claims made by the manufacturers of nanobubble generators, commercial salmon farming companies in Australia are currently piloting the technology to determine whether the best business case would be for constant use for performance or emergency use for fish health, but the companies involved are keeping the propriety results to themselves for the moment to gain competitive advantage. Hopefully more positive news will be forthcoming shortly.

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