MOLEAER

ADVANCING NANOBUBBLE TECHNOLOGY

NANOBUBBLES BOOST OXYGENATION AND BIOFILTER EFFICIENCY, SUPPORTING IMPROVED FISH GROWTH AT NORWEGIAN RAS AQUACULTURE FACILITY

Client Case Study: Lødingen Fisk, Norway

Dates:	Location:	Unit:
December, 2023 - March, 2024	**Vestbygda, Norway**	**Trinity L2**

Key Results:

- **Improved Oxygen Usage:**
  - Oxygen Transfer Efficiency (OTE): 94% (71% higher compared to cones)
  - Dissolved Oxygen (DO) increased 23%
  - Oxidation-Reduction Potential (ORP) increased 6.2%
- **Improved Biofilter Efficiency:**
  - Nitrite accumulation reduced by 70%
  - Ammonia Nitrification Rates increased >60%
- **Improved Fish Welfare and Growth**
  - Reduced Feed Conversion Rate (FCR)
  - Increased Relative Growth Index (RGI)
- **Improved Biofilm Removal and Water Clarity**
  - Water turbidity Reduced by 30%
  - Ozone usage reduced by 67%

Lødingen Fisk: Advanced Facility Supporting 1.7 Million Atlantic Salmon in Freshwater Environment

Lødingen Fisk is a well-established aquaculture facility. In part of their facility they have a RAS start-feeding department with a total treatment volume of 1100 m^3, housing 1 730 000 Atlantic salmon. The system has a maximum capacity of approximately 35 tons. The stocking density was maintained at 11 kg/m^3, with a total biomass of approximately 3,870 kg. The facility included 14 circular tanks, each with a capacity of 50 m^3, operating in a freshwater environment.

The RAS process is composed of mechanical filtration stage via drum filters (mesh size: 40 micrometers), a biofilter for the biological removal of ammonia, protein skimmers with ozonation, a degassing tower, UV disinfection and oxygenation. Oxygenation is provided by two separate systems: the main source of oxygenation is supplied by a Moleaer Trinity L2 Nanobubble Generator (***Figure 1***), while the backup oxygenation is supplied by two cones, operating on demand based on the DO in the fish tanks.

Enhancing RAS Water Quality and Efficiency Through Nanobubble Technology

In Recirculating Aquaculture Systems (RAS), maintaining optimal water quality is paramount for ensuring the health, growth, and productivity of fish. Water quality directly affects fish metabolism, disease resistance, and feed conversion efficiency. Poor water conditions can lead to increased stress, susceptibility to diseases, and inefficient nutrient utilization, resulting in higher operational costs and lower yields. Dissolved oxygen (DO) and ammonia (N-NH4) are two of the key factors that affect water quality and fish welfare. Therefore, efficient water oxygenation and biological nitrification are crucial for fish growers and constitute some of the most important operational challenges and costs.

Moleaer nanobubbles (NBs) are exceptionally small gas bubbles, typically less than 200 nanometers in diameter, that exhibit unique properties making them highly effective for various applications. Due to their size, these NBs have a much higher surface area to volume ratio compared to larger bubbles, which enhances their ability to dissolve gases like oxygen into liquids efficiently. One of their key features is their stability; unlike larger bubbles that tend to rise and burst quickly, NBs can remain suspended in liquid for extended periods, allowing for more efficient, prolonged and uniform oxygenation. This stability is attributed to the high internal pressure within the NBs, which counteracts the tendency for gas to escape and the bubbles to coalesce. Nanobubbles in aquaculture can significantly improve water quality by enhancing oxygen transfer and supporting crucial biological processes. In fact, nanobubbles can boost the activity of beneficial bacteria that turn harmful ammonia and nitrite into less harmful nitrate by ensuring these bacteria get enough

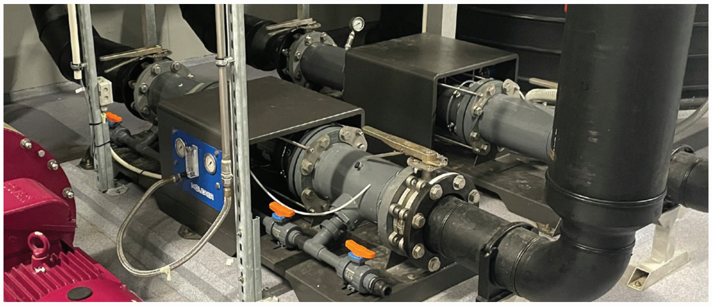

Figure 1. *Installation of Moleaer Trinity L2 nanobubble generators for main oxygenation at Lødingen Fisk RAS facility. The L2 Trinity units have a liquid flow capacity of 230 m³/hr (1000 gallons per minute) each and an Oxygen injection rate of 5 to 50 SLPM. They were installed recirculating the water from the biofilter into the header tanks.*

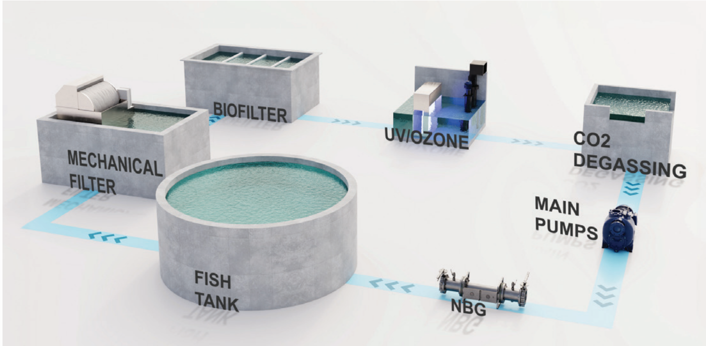

***Figure 2**. Typical configuration of a Moleaer Nanobubble Generator (NBG) on a RAS system.*

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oxygen. This is especially useful in high-biomass systems, and can enhance the breakdown of organic matter. Their introduction in RAS not only promotes the health and growth of fish but also reduces operational costs by optimizing oxygen use and enhancing the efficiency of the biological filtration process, allowing for higher stocking densities and increase productivity of the plant.

The goal of the study was to quantify how the introduction of oxygen nanobubbles can improve water quality, reduce energy, and water consumption by means of improved oxygenation, improved particulate removal, improved nitrification rates and biofilm prevention, when compared to traditional oxygenation systems.

This case study examines the implementation of nanobubble technology to complement the traditional cone oxygenation system to enhance overall system performance at the Lødingen Fisk's RAS facility in Norway.

Evaluating Nanobubble Impact: Oxygen Transfer, Water Quality, and Biofilm Control

The test was designed to evaluate the effect of oxygen nanobubbles (NBs) on four main aspects of the process:

1) Oxygen transfer efficiency

2) Solid removal performances in drum filter and water turbidity

3) Ammonia conversion (nitrification) in biofilter and

4) Biofilm growth and scaling in the pipes and other surfaces.

Water quality characteristics (DO, ORP, pH, turbidity, total suspended solids, and concentration of contaminants in the recirculating water) and NB concentration measurements were performed at several points of the RAS loopduring 4 consecutive days (2 days before start up of theTrinity nanobubble generator (NBG), 2 days after NBG startup), 4 times a day, while the plant was operating under comparable organic load conditions and biomass characteristics (fish size, total biomass, feed rate, water temperature, etc.). All measurements were repeated after 50 days of operations of the NBG, as the fish grew from 2 to 12 grams, resulting in higher oxygen demand, higher feed rate and organic loading to the RAS process.

Immediate Impact: Enhanced Oxygenation, Nitrification, and Biofilm Removal with Nanobubbles

The introduction of nanobubbles led to a significant increase in nanoparticle concentration by 61 million/mL on average, with a size of less than 200nm, within 3 hours of operation of the nanobubble generator (***Figure 3***) in each stage of the RAS process. The increase in nanoparticles can be translated as the concentration of oxygen nanobubbles. There was also a rapid significant rise in both DO and ORP (Oxidation Reduction Potential) as a result of the injection of oxygen nanobubbles. The initial 48 hours also showed pronounced scouring and cleaning effects (***Figure 4***), indicating improved biofilm removal and better disinfection. The efficiency of biological nitrification improved significantly, with a 70% reduction in nitrite accumulation in the biofilter.

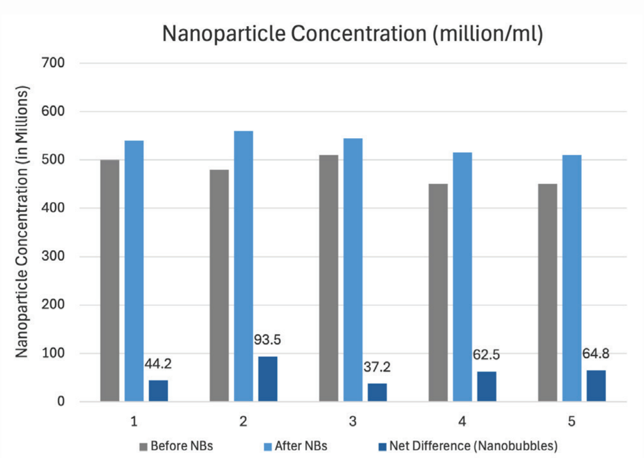

Figure 3. *Nanoparticle average concentration at different sampling points, measured before and after the startup of the Moleaer Trinity L2. The net difference between the two sampling campaigns is indicated in the Figure and assumed to represent the number of stable oxygen nanobubbles present in the water.*

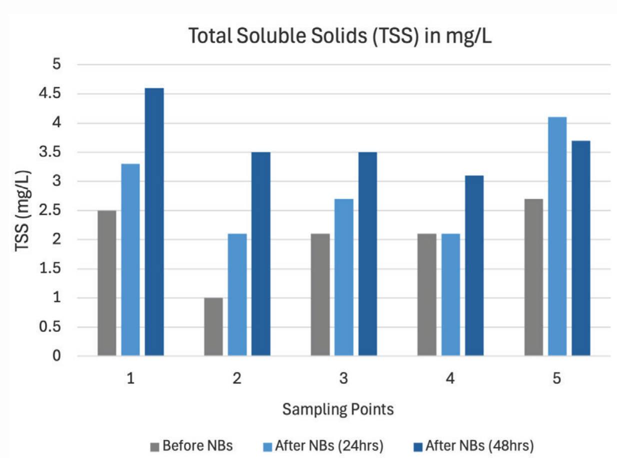

Figure 4. *Concentration of total suspended solids before the start-up of the NBG and after 24 and 48 hours of operations. The concentration of TSS linearly increased as effect of the cleaning and scouring effect on pipes and hard surfaces of the plant in all sampling points.*

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Long term Impact: Sustained Improvements in Oxygen Efficiency, Water Quality, and Fish Growth with nanobubbles

Water Quality. After 50 days of operations of the Trinity L2, the DO influent to the fish tanks was 12% to 23% higher (***Figure 5***), oxidation rates of ammonia and carbon in the biofilter increased by 68% (***Table 1***).

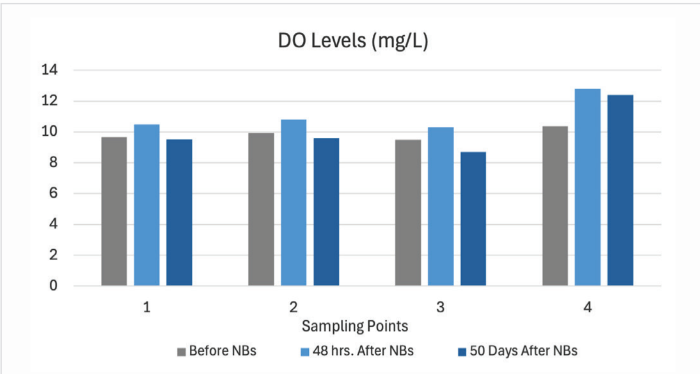

Figure 5. *Average DO at each sampling point before startup of the Moleaer Trinity L2, at 48 hours after starting up and after 50 days of operations, expressed in milligrams per liter.*

	Ammonia Removal Rate [kg N-NH4 removed/day]	Oxygen Usage in Biofilter [kg O2/day]
Before NBs	3.6	31.2
48 hrs. After NBs	5.3	40.8
50 days After NBs	7.9	86.4

Table 1. *Daily ammonia removal rate and oxygen usage in biofilter. The increase in nitrification kinetics allows to increase feeding rate to the fish as the presence of NBs results in higher treatment capacity in the biofilter.*

The concentration of harmful compounds such as ammonia and carbon dioxide, were reduced by 82.8% and 91.6%, respectively (***Figure 6***), while the accumulation of nitrites effluent from the biofilter reduced by 22.4% (***Figure 7***). Additionally, the turbidity in the fish tanks was 30% lower, when compared to the period without nanobubbles, despite significantly higher loading conditions. As a result of lower biofilm formation and scouring effects observed within 48 hours of operations, the ozone specific dosage (in g/h/ton) applied decreased by 67.5%.

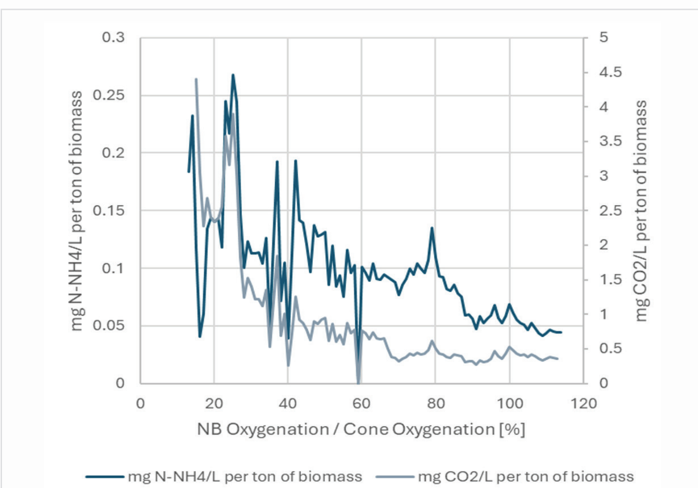

Figure 6. *Specific ammonia and carbon dioxide concentration in the influent to the biofilter and header tank, respectively, expressed in milligram per liter per ton of biomass as a function of the rate of "nanobubble oxygenation" versus "cone oxygenation."*

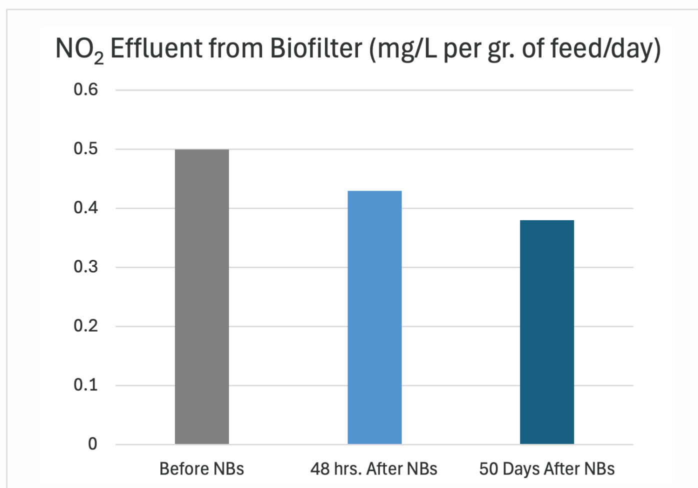

Figure 7. *Specific nitrite (N-NO2) in biofilter effluent, before and after Moleaer Trinity L2 start up (48 hours and after 50 days of NBG operations, expressed in milligrams per liter per gram of feed per day.*

Oxygen Usage. The Oxygen Transfer Efficiency (OTE) for the Trinity L2 continued to be over 85%, or 71% higher compared to the traditional cone systems (441 m^3 O_2 gas/ton O_2 dissolved for NBG, 1499 m^3 O_2 gas/ ton O_2 dissolved for cones). This hyper-efficient oxygen transfer translates into lower oxygen and energy use and costs for fish growers, and lower emissions from energy and diesel consumption.

Fish Growth. As a result of the higher DO, reduced biofilm, increased nitrification kinetic and overall improved water quality, fish can grow healthier and quicker, as suggested by the quick and sustained reduction in Feed Conversion Rate (FCR) when oxygen NBs were first introduced in the process (with the same type of feed), and was significantly lower throughout the remaining testing period, irrespective of the type of feed (0.75 ± 0.05) as

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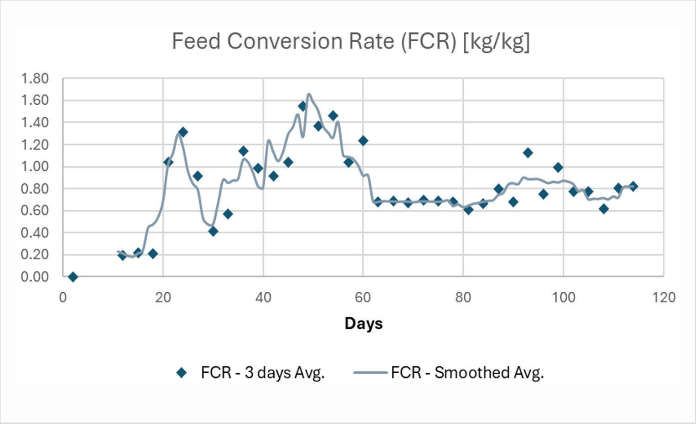

Figure 8. *Feed conversion rate (FCR) over 104 days of operations, during which the average body weight increased from 0.05 grams to 14.1 grams and total biomass from 0.06 tons to approximately 20 tons. The start-up date of the Trinity L2 NBG is shown in the Figure.*

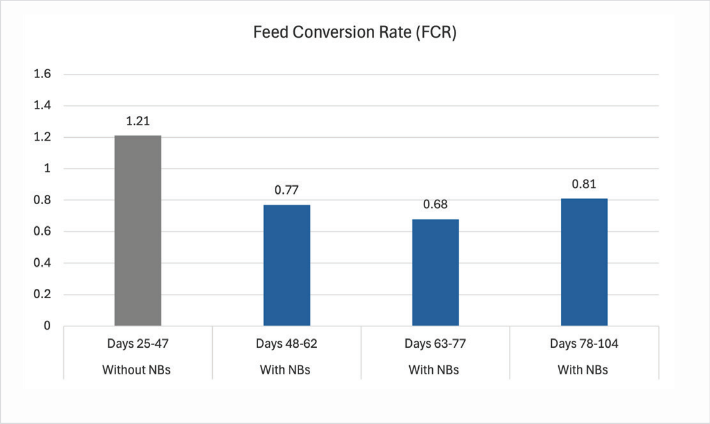

Figure 9. *Average Feed conversion rates (FCR) during four different periods of operations according to fish stage and type of feed.*

shown in ***Figures 8*** and ***9***. Having a lower FCR means it takes less food to achieve the same growth, translating into additional cost savings on food. Additionally, the Specific Growth Rate (SGR), or percentage increase in fish weight per day, was higher when compared to the previous batch produced with intermittent NB oxygenation (i.e., less than 4 hours per day of operations of the Trinity L2).

Conclusions: Nanobubbles Improve RAS Aquaculture with Enhanced Water Quality, Growth, and Efficiency

In comparison to fine bubbles and traditional aeration or oxygenation systems, Moleaer's Nanobubble Technology offers several additional benefits. Their enhanced gas transfer efficiency means that they can achieve higher levels of dissolved oxygen with less gas input, making them more energy-efficient and cost-effective. Furthermore, the unique properties of nanobubbles facilitate the removal of contaminants and impurities from water and improve water clarity.

The implementation of nanobubble technology in Lødingen Fisk's RAS demonstrated several key benefits:

- Significantly enhanced water quality, in terms of DO, ORP and turbidity, crucial for fish health.
- Improved fish metabolism and growth, as suggested by the reduction in terms of in Feed Conversion Rate (FCR) and the increase in (Specific Growth Rate (SGR), likely due to the superior water conditions in presence of nanobubbles.
- Reduced biofilm and improved biofilter performance, leading to lower concentrations of ammonia and nitrites and reduced use of ozone for sanitization.

Overall, the study confirmed that nanobubbles significantly enhance the performance of RAS, leading to higher water quality, more efficient oxygen usage, and improved fish growth and health. Supporting research from Virginia Tech and benchtop studies further validated the disruptive effect of nanobubbles on biofilm and enhanced microbial oxygen utilization.

Although the effect of additional variables such as the genetic characteristics of the fish need to be further investigated to isolate the effect of NBs on the process, the reduction in FCR and the improved oxygen usage strongly support the potential of Moleaer's nanobubble technology as a cost-effective solution to improve economic and environmental sustainability of aquaculture processes.

Do you want to know how nanobubbles can help improve efficiency at your RAS facility? Contact an expert:
info.moleaer.com/moleaer-background-information