

4 Strategies for Water Quality Control in Recirculating Aquaculture Systems

4.1 Mechanical and biological filtration technologies

Mechanical and biological filtration form the core treatment sequence in recirculating aquaculture systems because RAS water contains both suspended solids and dissolved metabolic wastes that must be removed continuously to maintain fish health. Reviews of RAS treatment equipment describe physical filtration units such as microscreen drum filters, foam fractionators, and other solid-liquid separation devices as the main tools for removing residual feed, feces, and fine suspended particles before they impair downstream treatment performance, while the broader water treatment unit is recognized as the central barrier against pollutant accumulation in the recirculating loop (Li et al., 2023). This front-end solids removal step is strategically important because particulate waste is one of the main hazardous fractions generated by feeding and fish excretion, and its early capture reduces organic loading on later biological processes.

Biological filtration then stabilizes water quality by converting toxic nitrogenous wastes into less harmful forms through microbially mediated nitrification. Biofilters are the defining feature of intensive RAS and operate through microbial consortia that oxidize ammonia to nitrate, with nitrifying bacteria growing either in suspension or as biofilms attached to fixed media; accordingly, technologies such as fluidized sand biofilters, moving-bed biofilm reactors, and rotating biological contactors are widely used because they provide the surfaces and hydrodynamic conditions needed for sustained microbial activity. Future optimization of these systems depends not only on reactor design but also on better management of microbial ecology, since biofilter success is ultimately determined by the structure and function of the biological community embedded within the filter matrix.

4.2 Oxygen management and gas exchange regulation

Oxygen management is a central water quality control strategy in RAS because high stocking density and continuous microbial oxidation create strong and variable oxygen demand. Artificial aeration remains essential for maintaining dissolved oxygen at suitable levels, and aerator selection must balance transfer performance with operating cost, while broader dissolved oxygen control research shows that keeping DO near a desired setpoint is important not only for fish health but also for treatment efficiency and energy use (Li et al., 2022). In practice, this means oxygen supply systems must be designed as control technologies rather than simple accessories, with sizing and operation matched to biomass, feed load, and the oxygen demand of biofilters.

Gas regulation in RAS also requires effective removal of carbon dioxide and, increasingly, more precise control architectures for oxygen delivery. Recent work on hybrid degassers shows that excessive CO₂ accumulation and oxygen depletion jointly reduce water quality and production efficiency, and that combined packing-media configurations can improve both CO₂ stripping and oxygenation performance; at the same time, control-system reviews indicate that although predictive, fuzzy, and hybrid DO controllers are being developed, PID-based approaches remain the most widely implemented in engineering practice (Li et al., 2022). Complementary methods such as hydrogen peroxide dosing can also contribute when carefully applied, because they can simultaneously increase oxygen saturation and reduce microbial load without measurable fish stress or biofilter impairment under appropriate conditions.

4.3 Nutrient and waste management approaches

Nutrient and waste management in RAS must address not only ammonia and nitrite toxicity but also the longer-term buildup of nitrate and other dissolved wastes. Conventional indoor RAS typically rely on solids capture followed by nitrification inside the recirculating loop, yet nitrification alone shifts waste from ammonia to nitrate rather than eliminating total nitrogen, which is why nitrogen accumulation remains a major challenge in sustainable high-reuse systems (Preena et al., 2021). This limitation becomes more important as water exchange is reduced, since system sustainability then depends on internal waste reduction rather than dilution.

For that reason, current nutrient management increasingly emphasizes denitrification, anammox, sludge digestion, and biological assimilation pathways that reduce waste mass rather than only transforming it. Denitrification can lower energy and water demand because it reduces the need for aeration and minimizes water exchange, while