Comparing water treatment topologies in Recirculating Aquaculture Plants

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Aquaculture, the farming of fish and aquatic crops such as kelp and algae, is traditionally carried out in natural bodies of water. An alternative is land-based farming in tanks or raceways, which is particularly attractive when coupled with water treatment to form a recirculating aquaculture system (RAS). Benefits compared to traditional farming in open cages include reduced emissions of nutrients, small or no risk of escapes, and control of pathogens (Thorarensen and Farrell, 2011).

Water treatment takes place in a series of mechanical filters and biological reactors, where particulate and dissolved matter is degraded by microorganisms similarly to how municipal sewage is treated. The biological nature of recirculating aquaculture systems makes experimental process development troublesome. Contributing factors include very long time constants, biological variations, and concerns for animal welfare. This strongly motivates the use of dynamic simulations, and for that purpose a RAS simulator – called FishSim – was developed (Wik et al., 2009). However, the capabilities of that implementation were limited by numerical problems.

Using Modelica, a high-level object-oriented language for dynamic systems modeling (Modelica Association, 2012), we have developed a new simulation tool for recirculating aquaculture. Like FishSim, it is based on Activated Sludge Model 1 (Henze et al., 2000), but this implementation is numerically well-behaved and robust which allows a much greater variety in the simulated systems. It is also significantly faster, even after the models have been expanded with many more features, such as energy balances, different feeding options, and a separation of autotrophic bacteria into ammonia-oxidizing and nitrite-oxidizing bacteria. Since open-source Modelica tools are available, the software is also free to use.

Water treatment is central in recirculating aquaculture. Fish excrete ammonia, which is toxic to them. Aerated bioreactors are typically employed to remove ammonia and ammonium via nitrifying autotrophs, which require low levels of biodegradable organics to thrive. Nitrification creates nitrite (also toxic to fish at low levels) and nitrate, the latter which is removed by water exchange or denitrification. Denitrifcation conversely requires high availability of biodegradable organics, but only progresses rapidly in the absence of oxygen. The treatment systems often further contain particle filters and UV and/or ozone treatment against pathogens.

While it is reasonably clear to the industry which components should be present in the treatment system, the order in which they are best employed is still an open question. In the literature and supplier information material there is a large number of suggested configurations, but few studies comparing them. Some guesses can be made based on elementary chemical reaction engineering, but the very complex dynamics of the biological treatment leads to high uncertainty.

Using the simulator, we have investigated and compared several treatment topologies. Through parameter optimization based on a genetic algorithm (Haupt and Haupt, 2003) the minimal reactor sizes in each configuration was found which could maintain acceptable levels of ammonia and nitrate. The resulting sizes are an indicator of which topology is the most effective.

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