Simulation of Recirculating Aquaculture Plants

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Aquaculture, the farming of fish and aquatic crops such as kelp and algae, is classically done in natural bodies of water. In land-based recirculating aquaculture systems (RAS), however, tanks or raceways contain the farmed species and the water is circulated through a treatment system. Benefits compared to traditional farming in open cages include reduced emissions of nutrients, less risk of infections, and the possibility to control water temperature, pH and so forth (Ungfors et al., 2015).

Water treatment takes place in a series of mechanical filters and biological reactors, where particulate and dissolved matter is degraded by microorganisms. The process is similar to how municipal sewage is treated. Development of recirculating aquaculture systems is hindered by the high investment cost together with their biological nature with long time constants, making experimentation costly (Wik et al., 2009). Reliable and realistic simulation of aquaculture systems is therefore very useful both in design and operation.

A working simulator for a limited number of system configurations was previously implemented in Simulink (Wik et al., 2009). This simulator accounts for material balances in the recirculating water. Its drawbacks included numerical issues from the system's high stiffness as well as lack of robustness with regard to varying configurations. A new recirculating aquaculture simulator is therefore being developed in Modelica using the same underlying models as in the existing software. The aim is to obtain a more robust simulator allowing more complex systems to be simulated, while expanding the mathematical models of the processes taking place. Modelica is a high-level object-oriented language for modeling particularly developed for dynamical systems (Modelica Association, 2012). With Modelica's component-based models, a familiar "flowsheeting" approach to plant modeling should be possible in the simulator. Since open-source Modelica tools are available, the user could avoid the costs incurred by proprietary software such as Simulink.

The energy system surrounding the RAS (pumps, heaters etc.) is a major cost and also contributes to a large part of the produced food's environmental impact. It is therefore motivated to incorporate energy balances in the model, both from an optimization point of view and to evaluate proposed or existing systems. The simulator will be extended with components that use power (pumps, heaters, coolers, UV-photoreactors reducing pathogen load etc.) and components to reduce the energy consumption, such as heat exchangers.

Furthermore, using the Optimica exension of Modelica (Åkesson et al., 2010), the plant model can be used for optimization studies. This is particularly interesting with respect to the energy system, where running expenses must be balanced against investment costs in the design of new plants. It is also of great interest when cold-water species are in focus. Cold water enhances the growth rate of certain cultured species, such as wolffish, but disrupts bacterial growth. This in turn demands larger reactor volumes to increase residence time. Another, more comprehensive, economical optimization problem therefore arises concerning the whole plant. This motivates the usefulness of a simulator with optimization capabilities.

Measurements to determine parameters included in the model are being planned at a pilot-scale marine salmon plant in Kungshamn. The simulator will also be applied to cultures of lobster and wolffish, the farming of which is the focus of the Mistra project Nomaculture aiming to introduce sustainable recirculating aquaculture of these species in Sweden.

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