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Daily micro particle distribution of an experimental recirculating aquaculture system—A case study

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ABSTRACT

The particle size distribution (PSD) in a recirculating aquaculture system (RAS) was investigated during a 24-h cycle. PSD was analyzed in water sampled at several locations in a recirculation loop containing a 60-μm drum filter, a submerged fixed-bed biofilter and a trickling filter.

In relation to total counts, the system was dominated by micro-particles with particles smaller than 20 μm comprising >94% of the distribution in all samples. However, the system presented a substantial volumetric influence of larger particles, reflected by a PSD derivate β-value of 3.40 ± 0.18. Overall β-values throughout the compartments ($p = 0.584$) and experimental period ($p = 0.217$) were not significantly different, although specific components seemed to marginally affect the PSD.

A high internal water turnover rate (one system passage every 50 min) promoted the rapid removal of large particles from the system. Permanent volumetric particle removal above 60 μm (31% reduction in the relative contribution from each size by the drum filter) per passage, but marginal production and removal of particles throughout the rest of the system further support the β-value stability and consequent PSD equilibrium.

The results showed a stable β-value in the mature RAS. The β-value is influenced by the contained compartments and system configuration, and may be used as a system performance-predicting tool. Mechanisms of particle influence on system and fish performance should be addressed in future studies, and are herein discussed.

1. Introduction

Particulate matter and suspended solids represent an important characteristic of the water quality in aquaculture systems (Brinker and Rösch, 2005). Removal of solids in recirculation aquaculture systems (RAS) has attained considerable attention (Summerfelt et al., 1997; Patterson and Watts, 2003; Sindilariu et al., 2009) while the abundance and distribution of micro particles has received less attention (Cripps and Bergheim, 2000). Chen et al. (1993) observed that more than 95% of particle counts in RAS were in the <20 μm fraction, a portion of which may have negative implications on fish health (Clark et al., 1985; Chapman et al., 1987; Bullock et al., 1997) or RAS performance (Michaud et al., 2006).

Rueter and Johnson (1995) introduced a universal tool to size solids in aquaculture, termed particle size distribution (PSD), with Patterson et al. (1999) demonstrating its application in RAS. This tool is based on the assumption that solids in an aqueous system fit the power law function, since they follow a near-hyperbolic size distribution characterized by continuous exponential decreases in particle counts along the abscissa (x-axis). The slope of the double logarithmic transformation of the data is termed the β-value, which is a standpoint for assessing the scattering of particles within the distribution. The β-value of aquaculture systems is generally in the range of 2–5 (Patterson et al., 1999). In practice, a β-value of 2 will characterize a system largely dominated by relatively large particles, whereas a system with a β-value of 5 will almost solely comprise fine solids. Assuming particle sphericity, the ratio of the distribution also extracts dominance of specific size classes in terms of available surface area and weight (volume), thus making the PSD comparable to classic solids characterization parameters, such as Total Suspended Solids.

For engineering and biological purposes, the solids characterization is preferably demonstrated by available surface area or particle volume. Since the β-value accounts for both – deriving this information from particle counts by size class (diameter) – it is an easier representation of the particle distribution in the system, and simplifies discrimination of potential effects of accumulated

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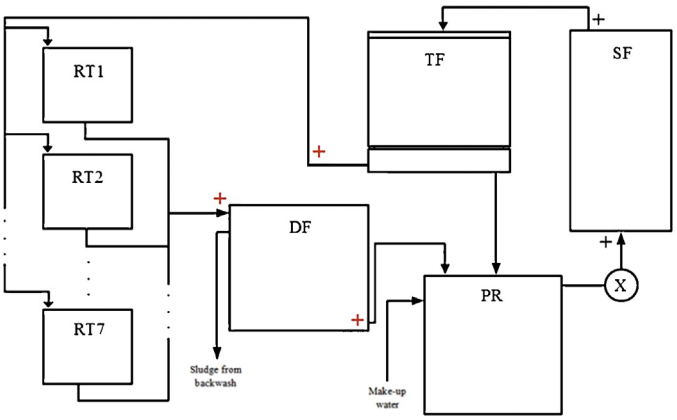

Fig. 1. Schematic representation of the experimental RAS system used in the experiment. Water movement was according to arrow directions. RT1-7 – rearing tanks; DF – drum filter; PR – pump water reservoir; X – pump; SF – submerged filter; TF – trickling filter. Samples were collected at the locations marked with a "+".

solids. Overall, the β-value conveys a simple representation of several particle factors and provides important information on several engineering aspects of the system.

By observing micro-particle distribution in RAS, Patterson and Watts (2003) concluded that the PSD-derived β-value is a constant of the system, but is still dependent on specific operational factors that can stimulate variation in this index. Solid removal units, such as sedimentation basins, hydrocyclones, drum filters or foam fractionators are some of the possible components to produce a direct effect in the β-value (e.g. Weeks et al., 1992; Langer et al., 1996; Summerfelt et al., 1997; Davidson and Summerfelt, 2005; Timmons and Ebeling, 2010; Wold et al., 2014), mostly through screening of unwanted particles. Employment of high flushing and water turnover rates (Patterson and Watts, 2003) can promote stabilization of particle concentration, while pumps and waterfalls (Langer et al., 1996; Kelly et al., 1997; Krumins et al., 2001; McMillan et al., 2003; Sindilariu et al., 2009) and feed-related factors (Patterson and Watts, 2003; Brinker and Rösch, 2005) have also been shown to qualitatively and quantitatively affect the PSD of closed aquaculture systems.

The purpose of this study was to assess the daily PSD of an experimental RAS, presumed in steady-state, during a period of constant operation conditions. Potential components affecting the β-value were examined, and a special focus was given to probable daily fluctuations of PSD in the specific RAS.

2. Materials and methods

2.1. Experimental rearing system

The particle size distribution of an experimental RAS, located at the National Institute of Aquatic Resources, Hirtshals, Denmark, was analyzed over a 24 h-period. Tanks stocked with rainbow trout (*Oncorhynchus mykiss*) at an average density of 27 kg m^{-3} were fed a fixed feed amount of 0.43 kg d^{-1} (0.5% of stocking biomass for a 12-h period (8 am–8 pm), i.e., the first 12 h of the observation period).

The experimental RAS (Fig. 1) comprised a series of compartments and rearing tanks, including seven 0.44 m^3 culture tanks (Pedersen and Pedersen, 2006). From the outlet of the tanks, water flowed through a 60 μm drum filter, from where it entered a 1 m^3 pump reservoir and was pumped into the bottom of an up-flow, fixed-bed biofilter. The water then entered the top of a trickling filter, and flowed, via a reservoir beneath the trickling filter, back to the fish tanks, while a side-stream diverted part of the water into the pump reservoir.

Total water volume in the system was 15.8 m^3. Make-up water was maintained at a steady level of 187 L h^{-1} (4.5 m^3 d^{-1}), correspondent to a feed loading of 95 g feed m^{-3} make-up water (10.5 m^3 kg feed^{-1}), and representing a complete system water change approximately every 3.5 days. Water flow through the system was maintained at 19.8 m^3 h^{-1} giving a water velocity in the pipes of 42 cm s^{-1}, while water velocity in the fish tanks was steady at 3.8 cm s^{-1}. Water temperature in the rearing tanks was 14.5 ± 0.5 °C. Experimental conditions were kept constant for weeks prior to the experimental period.

2.2. Particle size distribution sampling and analysis

Sampling started at 8:00 am and occurred every fourth hour in the subsequent 24-h period, at five locations within the RAS (N = 35). In each sampling event, three independent grab samples were collected at the same time (within 10 min) in 100 mL plastic tubes with screwable caps at the different sampling locations (marked by "+" in Fig. 1): before the drum filter (BDF); after the drum filter (ADF); after the pump reservoir (APR); after the submerged filter (ASF); and after the trickling filter (ATF). Each sampling point was placed immediately after a component (or combination of components) that might affect the PSD: the fish and fish tanks before the drum filter (BDF), the drum filter (ADF), the pump reservoir, the pump and the make-up water inlet (APR), the submerged filter (ASF) and the trickling filter (ATF). Immediately after collection (<30 min), the samples were transported to and randomly analyzed in an optical particle counter (OPC): the AccuSizer™ 780 SIS (Particle Sizing Systems, Santa Barbara, CA, USA). Any potential out-settling of particles was not specifically accounted for, but occurred in similar fashion throughout all samples.

The measuring method of the counter is based on the Single Particle Optical Sensing (SPOS) method, or the light scattering profiles of single particles passing through a narrow tube that leads to an illuminated area. The shadow size generated by each particle in stated zone creates a correspondent change in voltage measured by a sensor, which then relates the electrical pulse to particle size. The PSD of a given sample is then generated by the program using a standard calibration curve constructed with a set of uniform particles of known diameters.

The AccuSizer™ 780 SIS filter was able to detect particles ranging between 2 and 1000 μm in diameter. For this study, cut-off points were defined for the PSD analysis, and only the particles observed within the 5–300 μm range were considered for the β-value and statistical tests. The statistical representation of the particles <5 μm in all data sets was not sufficiently accurate to demonstrate reproducibility (Brinker and Rösch, 2005), while no particles were detected above 300 μm in any sample. Therefore, cutoff points were determined at these marks.

Before any analysis took place, the particle counter collecting tube was washed by running the machine twice: once with a solution of soap and milli-Q water, and a subsequent run with only milli-Q water. Every sample was gently agitated with a glass rod just before measuring. The program read each sample three times, presenting an average of the last two readings. Between each measurement, the sampler tube was externally and internally rinsed with milli-Q water.

Data obtained from the particle counter was then transferred into EXCEL spreadsheets for posterior calculations and analysis of β-value, particle counts, surface area and volume of particle size distribution from each sample. The β-value analysis was conducted according to the log–log fitted regression of the PSD power-law function, as fundamentally described in Patterson et al. (1999).