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Membrane performance and fouling behavior of membrane bioreactors installed in marine recirculating aquaculture systems

A.B. Holan[a,*], P.-A. Wold[a,b], T.O. Leiknes[a]

[a] NTNU Department of Hydraulic and Environmental Engineering, N-7491 Trondheim, Norway
[b] NTNU Department of Biology, N-7491 Trondheim, Norway

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ABSTRACT

Accumulation of fine suspended solids and colloids in a recirculating aquaculture system (RAS) can be avoided by integrating a membrane filtration unit into the system, where the inclusion of a membrane bioreactor (MBR) may be an alternative. The main purpose of the study was to identify how the feeding regime affected membrane performance and fouling phenomena caused by dissolved and submicron colloidal particles in the system, and how the membrane impacted general water quality and particle characterization. To be able to evaluate membrane performance and fouling behavior, transmembrane pressure (TMP) was monitored and assessed in relation to changes in rearing conditions and different water quality parameters observed. From this study the positive influence on the chosen water quality parameters was apparent, where an improved water quality was observed when including a membrane filtration in RAS. Selected water quality parameters and TMP changed during the experimental period in response to the feeding regime, where algae paste, decaying rotifers and dry feed seemed to contribute the most to membrane fouling. Analysis of the concentration of submicron particles and particle size distribution (PSD) (particles < 1 μm) showed both a higher concentration and a more spread distribution in the rotifer/algae paste and dry feed period compared to the Artemia period, which might explain the observed increase in fouling. This study also showed that adapted procedures for concentrate removal are important to prevent hydrolysis of retained particles in the concentrate and leakage of nutrients and organic matter back to the system.

1. Introduction

1.1. Particle production in RAS

Constructing recirculating aquaculture systems (RAS) to replace flow through aquaculture systems (FAS) is becoming a more common alternative in aquaculture production. Controlling the water quality is essential for successful production in RAS (Masser, 1999; Hjeltnes et al., 2012). One aspect of water treatment in RAS is the removal of particles produced from decomposing food and excreted waste. In general, 25% of the feed applied to a system will end up as suspended solids (*i.e.* mass of particles > 1 μm) (Timmons and Ebeling, 2007). Efforts are made to remove solids immediately and in a gentle manner with the aim to keep the particles intact thereby avoiding break-up into smaller components and potential mineralization of these. The non-settleable suspended solid fraction (*i.e.* particles < 100 μm) is hard to remove and is known to create several challenges for the farmer. Chen et al. (1993) characterized the suspended solids in RAS and reported that 95% of the particles by number will be included in a range up to 20 μm, and 80–90% of the total weight of solids (pre-filtered to remove particles > 130 μm) include sizes up to 35 μm. Quemeneur et al. (2001) showed that over 90% (by volume) of the particles in a semi-closed aqua farming system were smaller than 30 μm for on-growing basins. However, in the nursery a significant amount of particles (by volume) were larger than 200 μm because of difficulties of the fish in swallowing such large particles. Several particle removal techniques are common in conventional RAS, *e.g.* mechanical filtration in a disk, belt or sand filter, and gravity separation in a swirl separator/hydro-cyclone. Optional treatment are foam fractionators which can potentially remove particles smaller than 30 μm by flotation (Timmons and Ebeling, 2007; Brambilla et al., 2008; Barrut et al., 2013), which can be enhanced combined with ozone treatment (Park et al., 2011). However flotation is not a substitute for effective primary particle removal (Timmons and Ebeling, 2007). Conventional particle removal systems only manage to remove particles larger than about 40 μm. Consequently, the fine suspended solids (<35 μm) and colloidal particles (<1 μm) will accumulate in the system. When particles accumulate and mineralize, there will be an increased release of bacteria substrate in the system resulting in heterotrophic bacteria growth and oxygen consumption which

* Corresponding author at: NTNU Department of Hydraulic and Environmental Engineering, N-7491 Trondheim, Norway. Tel.: +47 91683316.
E-mail addresses: astrid.buran@ntnu.no, terje-holan@ntebb.no (A.B. Holan).

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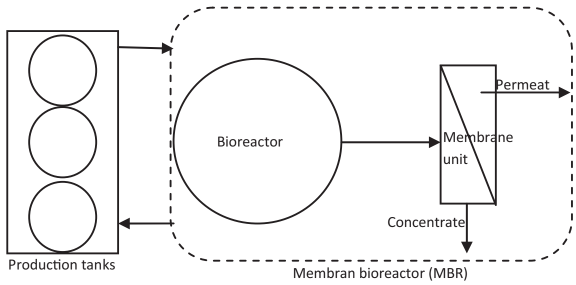

Figure 1 Membrane bioreactor (MBR)

Fig. 1. Membrane bioreactor (MBR).

may out-compete the slow growing nitrifying autotrophic bacteria oxidizing toxic ammonia and nitrite in the biofilter (Chen et al., 2006; Michaud et al., 2006; Lackner et al., 2008; Pellegrin et al., 2009). This can further lead to undesired biofouling of the rearing equipment. Formulated diet may experience rapid leakage of nutrients when immersed in water (Baskerville-Bridges and Kling, 2000; Kvale et al., 2006) and the accumulation of particles may result in increased nitrogen concentrations in the system. Particles can also reduce the effect of disinfection by providing shelter for bacteria and viruses (Hess-Erga et al., 2008; Hess-Erga, 2010).

Accumulation of fine suspended solids and colloids in RAS can be avoided by integrating a membrane filtration unit into the system, where the inclusion of a membrane bioreactor (MBR) may be an alternative.

1.2. *Membrane bioreactor (MBR) design and operation*

Commercial membrane bioreactors (MBRs) are commonly understood as a combination of biological treatment in a bioreactor (activated sludge, AS) for heterotrophic and autotrophic growth combined with a semi-permeable membrane for removal of particles (Fig. 1), defined as AS-MBR (Leiknes and Ødegaard, 2007). Low pressure systems where the membrane unit is submerged in the activated sludge bioreactor are typically used, and are often operated in an outside-in mode where vacuum is applied to transport clean water through the membrane. The treated water (permeate) can potentially be recycled back to the system while the particulates removed (concentrate) are collected and discharged to appropriate facilities for further treatment and disposal. Depending on the choice of membrane, the pore sizes vary from a few nanometers to some micrometers. The conventional MBR systems use micro-porous microfiltration (MF, pore size of 0.1–10 μm) or ultrafiltration (UF, pore size of 0.001–0.1 μm) membranes to retain the mixed liquor from the bioreactor (concentrate), and delivers particle-free treated effluent (permeate) which can be recycled back to the system. MBR is a fully commercialized product for drinking water and waste water treatment, and several suppliers of MBR systems exist worldwide (Judd, 2008; Lesjean and Huisjes, 2008).

A challenge of MBR filtration is the decrease in filtration flux caused by fouling and clogging of the membrane unit. The main forms are solids deposition as cake layer, pore clogging by colloidal particles, adsorption of soluble compounds and biofouling (Leiknes and Ødegaard, 2007; Sun et al., 2011). From the reports found in the literature, fouling caused by dissolved and submicron colloidal particles contribution is extensive (Wisniewski and Grasmick, 1998; Defrance et al., 2000; Bouhabila et al., 2001; Judd, 2004; Bae and Tak, 2005; Ahl et al., 2006; Leiknes and Ødegaard, 2007). Holan et al., 2013a,b suggested that algae paste, which is micro algae added in intensive rearing systems to enhance growth and survival of marine larvae (Reitan et al., 1993, 1997), is probably more readily subjected to hydrolysis and release of submicron organic material compared to live algae, which consists of whole intact live cells. Furthermore, Holan et al. (2013b) showed that a change in feed, from live feed (*Artemia*) to formulated diet (dry feed), in a RAS production of Atlantic cod larvae resulted in an extensive bacteria bloom. This was suggested to be due to increased amount of dissolved and submicron organic material (bacteria substrate) originating from hydrolyzed dry feed. Membrane fouling and clogging can be controlled by operation below critical flux, periodic backwashing and relaxation techniques, and air-scouring (Judd, 2006; Wu et al., 2008). However, fouling that is not readily removed by physical cleaning takes place at even low operational fluxes and can only be controlled by chemical cleaning of the membrane (Judd, 2004). Monitoring the transmembrane pressure (TMP) will give information about the membrane permeability and performance and will indicate how the membrane responds to the suspended solids composition and give information about time for chemical cleaning.

1.3. *MBR in RAS*

Despite the increasing commercial use of MBR systems throughout the world, the use of this technology in RAS has been very limited. To some extent AS-MBR has showed great potentials for use in aquaculture applications (Viadero and Noblet, 2002; Sharrer et al., 2007; Pulefou et al., 2008; Sharrer et al., 2010) creating an effluent with turbidity of less than 0.5 NTU, nearly complete removal of $cBOD_5$, TSS and bacteria, consistent removal of total nitrogen, and the permeate flow was found suited to be reclaimed in fish cultures to recycle alkalinity, salts, heat and water under biosecure conditions. However, in recent years the development of a hybrid biofilm MBR (BF-MBR) combining a moving-bed-biofilm reactor (MBBR), instead of activated sludge as the bioreactor unit, and a submerged membrane reactor has been developed and assessed for wastewater treatment (Leiknes et al., 2006; Leiknes and Ødegaard, 2007; Ivanovic and Leiknes, 2008; Sun et al., 2010). This process design is probably more suited and easier adaptable for use in aquaculture. BF-MBR has the potential of utilizing the best characteristics of the MBBR process and membrane separation resulting in a compact and efficient particle removal system (Leiknes and Ødegaard, 2007). Since MBBR is the bioreactor often applied in conventional water treatment systems in RAS, this alternative could facilitate the incorporation of membrane separation in already existing water treatment systems.

To avoid mineralization and hydrolysis of retained particles, removal of the concentrate is not only critical for the membrane performance, but also important as to avoid leakage of soluble components into the recirculating system through the membrane pores.

The aim of this project was to assess the use of membrane filtration in a marine recirculating aquaculture system (RAS) by placing a membrane bioreactor (MBR) concept in a pilot recirculating system for start feeding of cod larvae (*Gadus morhua*). Membrane performance can potentially be affected by change in feed due to increased fouling caused by dissolved and submicron colloidal particles in the system. The main purpose of the project was to identify how different feeding regimes affected the membrane performance and fouling phenomena, and to identify the possible effect from membrane filtration on water quality in RAS. This study also evaluated two different procedures for concentrate removal.

2. Methodology

2.1. *Pilot plant configuration and components*

Investigations were conducted on a pilot plant recirculating aquaculture system (RAS) for cultivation of Atlantic cod larvae (*G. morhua*). The pilot plant configuration and different components are shown in Fig. 2. A flow of 12.7 L min^{-1} was directed from a