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Influence of filter medium type, temperature and ammonia production on nitrifying trickling filters performance

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ABSTRACT

This work focuses on the achieving of optimal design and modelling of nitrifying trickling filters for closed circuit aquaculture turbot (*Psetta maxima*) farms. Several process parameters influential in nitrifying filtration were established on experimental biofilters and their efficiency was tested, based on the removal of nitrogen contained in total ammonia nitrogen (N-TAN) in a fixed time (24 h). Those process parameters were filter media types (Type A Biofill®, BactoBalls® and MECHpro® rings), temperatures (24.3 °C, 19.0 °C, 15.3 °C) and production of TAN (1.5, 3.0 and 4.5 g per day) while other process parameters values remained constant. TAN production was simulated with the addition of ammonium chloride (NH_4Cl) in the recirculation system. Constant measuring of the total ammonia nitrogen concentration in the biofilter effluent was required to perform a model of N-TAN fluctuation based on a specific feeding regime and to ascertain performance differences between biofilters.

At the end of the experiment, notable differences were observed in the ammonia removal rates depending on different process parameters. The BactoBalls® filter medium led to the highest mean N-TAN removal rates (0.24 g N-TAN removed m^{-2} day^{-1}). The N-TAN removal rate generally increased with higher temperatures, the trials with the highest mean temperature (24.3 °C) led to the highest mean N-TAN removal rate (0.26 g N-TAN removed m^{-2} day^{-1}). Similarly, the N-TAN removal rate increased with high TAN production. The trials in which production was 4.5 g per day showed the highest N-TAN mean removal rate (0.27 g N-TAN removed m^{-2} day^{-1}).

1. Introduction

Aquaculture farms in land in which the culture water is recycled are gradually increasing during the course of the current century. In those farms, water is constantly moved by pumps in closed circuits called recirculating aquaculture systems (RAS), thus assuring that the water is completely recycled expect the minimum losses caused by evaporation or management [1]. Recirculation of water in aquaculture presents an important alternative to traditional production methods, because it means independency of natural water resources and allows manipulating water characteristics [2], the temperature being the most important, because fishes have an optimal temperature on which their growth is remarkably better, as observed for different species, such as gilt-head sea bream (*Sparus aurata*) [3], European sea bass (*Dicentrarchus labrax*) [4], and white grouper (*Epinephelus aeneus*) [5]. Another important feature of the use of recycled water for inland aquaculture farms is that it allows to increase the culture water volume, thus allowing to increase the fish production [6]. Turbot (*Psetta maxima*) is an excellent candidate for production in those systems due to its benthonic nature and the capability of living under relatively high stocking densities [7]. Those characteristics properly allow to culture turbot in tanks with low water volume. In fact, stocking densities in commercial turbot aquaculture, cultured in tanks or in sea water cages, have reached 25–30 kg m^{-3} [7]. It is also a fast-growing aquatic species of great economic value [8].

A well designed RAS allows keeping water quality optimal, because all parameters are controllable and manageable by the producer. Parameters that are influential with respect to the correct operation of an RAS are oxygen (O_2) and carbon dioxide (CO_2), organic matter, pH, suspended solids (SS), alkalinity, hardness, nitrite, nitrate or total ammonia nitrogen (TAN), plus the presence of opportunistic pathogens, as they determine the survival and optimal growth of the fishes [9]. All the above mentioned water quality parameters unavoidably deteriorate with

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every recirculation cycle. Oxygen is rapidly consumed by the fishes and, depending of the feed intake and the feed properties, organic matter (both dissolved and suspended) and ammonia are produced and accumulated in the bulk water. The latter is the most threatening product [10] and the increment of a concentration beyond certain limits can be really detrimental for fish health and welfare [11] as it lowers the ammonia excretion and produces an accumulation of ammonia levels in blood, causing nervous system problems and death [12].

Fixed-film biological filters are usually installed in aquaculture facilities with the main goal of TAN removal [13]. They consist in a series of diverse solid surfaces where a population of nitrifying bacteria attaches and grows with excreted extra-cellular polymers [14]. Four kinds of biofilters are commonly used: rotating biological contactors, trickling filters, bead filters and fluidised sand biofilters [15]. Rotating biological contractors have been reported as the most efficient in TAN removal, although their cost is quite high. Among the other possibilities, trickling filters display relatively higher removal rates [16]. Besides, they have considerable advantages: low price, the oxygen transfer is provided as water cascades directly over the media [17] and degasification of CO_2 and simplicity of design, construction, operation and management [13]. Therefore, the trickling filter was used for this study.

TAN production is directly correlated to the fish production plan of aquaculture facilities and usually determines the volume of biofilters installed and the pumping requirements. Nevertheless, a wide range of process parameters apart from biofilter size affects the speed of TAN removal (and therefore the achievement of the targets in TAN concentration), meaning that the proper design and evaluation of performance is essential to avoid the construction of larger trickling filters than needed and the related expenses. A large number of process parameters affects the nitrification rate, for example influent concentration of TAN and oxygen, organic matter, nitrite, temperature, alkalinity, pH and hydraulic loading [13]. Although models have been constructed to approximate the influence of process parameters of the biofilm on TAN removal efficiency by applying the nitrification kinetics theory [18–20], the influence of several process parameters on the rates at which nitrification reactions take place still have to be assessed empirically. For example, Nijhof [19] included in his model “a” and “b” parameters depending on external factors, or internal proprieties, and presented an equation relating the value of “a” with several hydraulic loadings. Kamstra et al. [21], validated Nijhof's model and observed several variations of predicted TAN removal rates depending on the filter medium type.

Three of these process parameters were tested in this article. One of them is the influent TAN concentration, which acts as a limiting substrate. Kinetics of the nitrification reaction are described by the Monod-type expression [22–24]. Besides, experimental procedures that demonstrate a relation between the TAN concentration in the influent and biofilter performance [16,21,25,26] have also been performed. Yet Bovendeur et al. [18], noticed that the nitrification reaction is sometimes independent of the substrate when oxygen acts a limiting factor, which is not desirable for the culture. Greiner and Timmons [16] also reported 0-order reactions in their research at high TAN concentrations (above 2.5 mg L^{-1}). Nonetheless, these articles often analyse the impact of a steady TAN loading rather than analyse the effect of a fluctuating TAN concentration produced by the shifting excretion rate during the day occurring after the feeding, observed in turbot [27] as well as in other teleost species [28]. In the present research, three TAN productions are tested, and the N-TAN concentration is monitored during 24 hours.

The filter medium type was another of the process parameters tested in this study. The influence of different filter media types on the TAN removal rate of trickling filters has been studied in several articles [21,29], although the influence of the filter medium type is often discussed when analysing the performance of all kind of biofilters [15,16,30]. Characteristics of the filter media types considered to affect the performance of the nitrifying trickling filter include void ratio (volume filled with air/total filter volume when not in operation), specific surface area (biofilter surface/biofilter volume) and the type of flow that the shape of the filter media allows across the biofilter (vertical flow, random flow or cross flow) [21].

Temperature was the last factor selected for its great influence on the speed of chemical reactions (based on the Van't Hoff-Arrhenius equation) and bacterial growth and therefore the huge influence on biofilter performance. Some examples of papers analysing the impact of temperature on the TAN removal in trickling filters include the experiments of Zhu and Chen [31] and Lyssenko and Wheaton [32]. Zhu and Chen [31] discovered that the influence of temperature on nitrification speed was lower than predicted by the Van't Hoff-Arrhenius equation, but still had a considerable influence.

The aim of this study is to select the best set of these process parameters for achieving the best possible performance of nitrifying trickling filters, but also to provide information on the performance of the efficiency of biofilters under a wide range of conditions, depending on fish production plans. The three TAN productions simulated (1.5, 3.0 and 4.5 g per day) are in accordance with TAN productions estimated for turbot aquaculture facilities depending on growth state (based on the study of Dosdat et al. [27]) and in which density is 7.5, 11 and 22.5 kg m^{-3}. The three temperature values (15 °C, 19 °C and 24 °C) set were in accordance with water temperatures established in recirculating aquaculture systems to produce several species, and to mean temperatures reached in the sea at certain time periods of the year for a sea-cage aquaculture facility. With regard to the filter media, trickling filters were traditionally constructed using rocks, but today most filters use plastic media, because of their low weight, high specific surface area and high void ratio (>90%). In the present experiment, three plastic materials were selected for their positive characteristics such as availability, easy manipulation (low weight) and price. Hitherto, to our knowledge no study has been made to determine the influence of these filter media on the efficiency of trickling filters.

In summary, this paper presents a tri-factorial study where the influence of three process parameters (temperature, filter media and TAN production) on the performance of trickling filters is assessed. Influence of each one of them are determined, but also the influence of the combination of process parameters on the achievement of certain N-TAN removal rates.

2. Material and methods

2.1. Tanks and biofilters

The system was composed by six 500 L tanks connected to six trickling filters. The water flows from the drainpipe of these tanks to the top of the filter by a peristaltic pump (Oceanrunner® OR3500, Aqua-Medic®, Bissendorf, Germany). The height from the bottom of the drainpipe to the top of the filter was close to 2.5 m. At the top of the filter the water was dispersed by a series of several holes in the pipe, to ensure the soaking of the entire surface area of the filter medium, contained in a home-made cube. The base of this home-made cube had several holes, from which water was returned to the tank. Biofilters were designed to establish an equal hydraulic surface loading rate of 12 $m^3 m^{-2} h^{-1}$ in all of them. The water flow provided by the pump was 2400 L h^{-1}, minus friction and elevation losses.