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Transient temperature effects on biofilters in recirculating systems ammonia removal rates

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ABSTRACT

Acclimation of biological filters and ammonia oxidation at transient temperature regimes was the focus of the research. A batch system of automated temperature controlled tanks was used to determine effects of temperature on biofilter response to total ammonia nitrogen utilization. Each tank contained internal biofilters loaded with synthetic chemical feedstock. The biofilters were exposed to temperature regimes of 13 °C, 20 °C and 30 °C steady state temperatures in the first experiment, and cyclical (diurnal) temperatures of 20 ± 3 °C and 30 ± 3 °C in the second experiment. A direct linear regression line method was used, with tau (τ) value from the slope of the linear regression line used to determine the biofilter substrate utilization response to varying temperature regimes.

Biofilter response was determined as the capability to utilize total ammonia nitrogen (TAN) by ammonia oxidizing bacteria (AOB). Tau (τ) values for ammonia oxidation were 40.73 day^{-1}, 58.81 day^{-1} and 159.70 day^{-1} at 13 °C, 20 °C and 30 °C respectively. Total ammonia nitrogen substrate utilization rates as indicated in a decay plot differed significantly ($P < 0.05$) between temperature regimes 20 and 30 °C. However substrate utilization between 13 and 20 °C were not different ($P > 0.05$). Ammonia oxidation tau values were 118.20 day^{-1} and 223.50 day^{-1} at (20 ± 3 °C) and (30 ± 3 °C) diurnal temperatures respectively. These were significantly different ($P < 0.05$). The data in this study can be applied to future seeded or acclimating biofilters operating within these temperature ranges.

1. Introduction

Biological water filtration systems are a significant solution to the challenges of treating wastewater to enhance water quality. The need for biological filtration is increasing in areas with high concentrations of total ammonia nitrogen content, such as aquaculture, agricultural runoff, and industrial effluent discharge [1–4]. Traditional recirculating aquaculture systems (RAS) are constantly engaged with operational challenges including, water requirements, compliance with discharge limits, demand for product of high quality, land use in coastal areas, and discharge water quality to receiving surface waters [5–7]. Systems with Recirculation technology have therefore gained wide popularity for effectively managing water reuse, waste and pollutant treatment to address water quality and disease concerns [8]. Applications of recirculating systems and biofiltration technology have continued to be widely adopted for grow-out systems, brood stock, production of larvae and fry including areas of wastewater and produced water [6,9–11].

Biofiltration systems are designed to use existing bacteria in water or seeded to accumulate micro-bacteria organisms used in water treatment, to maximize water reuse particularly in RAS systems. The process is also critical to functionality of recirculating systems to maintain water quality in sequence with other unit operations including solids capture, aeration, clarification, and circulation [3,12,13]. Bacteria presence in biofiltration process oxidize toxic soluble waste including organic carbon and total ammonia nitrogen, to a less harmful form produced in industrial wastewater and commercial RAS [14–18]. This process is also critical to the efficiency of industrial water treatment [16]. Efficiency of biofiltration in water treatment and RAS systems makes it possible for commercial RAS to compete with open ponds and net pens [19,3,4].

Commercial operations using large volumes of water including agricultural producers using RAS systems are challenged by the need to treat recirculating water for reuse. Discharge of non-treated water from such systems leads to release of water that is heavily loaded with nutrients including total ammonia nitrogen [20]. A biofilter design and function primarily impacts the efficiency of water treatment in RAS as a

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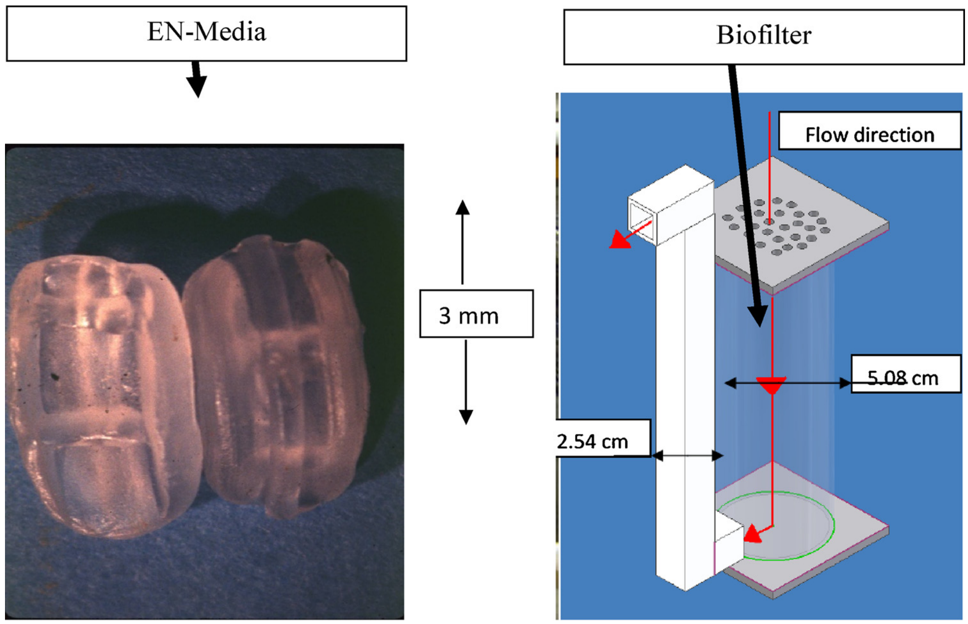

a: EN-media **b:** Biofilter and Airlift

Fig. 1. a: EN-media. b: Biofilter and Airlift.

factor of production capacity and water discharge. RAS Biofilter designs are determined by the efficiency to utilize grams of TAN per cubic meter of media volume per day ($g/m^3/d$), or milligrams of TAN per square meter of media surface area per day ($mg/m^2/day$) [6,21]. TAN utilization in the biofilm is an equilibrium process involving substrate demand for bacterial biomass growth.

However, the factors influencing ammonia oxidation in a biofiltration process, includes ammonia concentration, and temperature [22–26]. Effect of temperature in RAS specifically preferred temperature for species raised, impacts bacteria response to ammonia oxidation in the biofilter. Therefore the required temperature impacting the bacteria in oxidation of total ammonia nitrogen is significant in biofilter performance [27,28,11,4]. However, temperature studies have been viewed with a broad and varied perception of understanding the design and functionality of biofilters [29,5,4,30,6]. Temperature interactions with suspended bacteria have been reported in previous studies to follow a Van't Hoff Arrhenius exponential reaction path [5,31]. Temperature increase above optimal bacterial reaction limits is reported to disable enzymes [32,31,5].

The significance of temperature impact on bacteria process is indicated by the expression with the temperature coefficient θ in equation (1) below.

$$\mu = \mu_{20}\theta^{T-20} \tag{1}$$

Variables are defines as: μ is the rate coefficient (d^{-1}); μ_{20} is the value of μ at 20 °C (d^{-1}); θ is temperature coefficient; and T is temperature (°C). However, temperature impact on performance of biofilter over transient durations (short-term) has not been examined in detail for fixed film biofilters, especially in a phase of growth that is dynamic [33].

The process of TAN utilization in biofiltration systems are divided, into three stages. First stage requires substrate diffusion through the fluid boundary layer leading to the biofilm. The second stage requires substrate diffusion through the biofilm to the bacteria. The final stage requires availability of nutrient to the bacteria within the biofilm [34–36]. These steps are encompassed, into a single kinetic model.

Monod models are used for fixed film nitrification kinetics in biofiltration process which summarize the complex transport and enzyme reactions [37,6,38]. Stages of enzyme kinetics and reactions are also determined by the Michaelis-Menton expression. The expression is used to represent fixed film nitrification kinetics [5]:

$$R = \frac{V_{\max} S}{K_m \oplus S} \tag{2}$$

Variables are defined as: R is the substrate removal rate ($g\,m^{-3}\,day^{-1}$); $V_{\max}$ is the maximum specific rate of substrate utilization ($g\,day^{-1}$); K_m is the half saturation constant ($g\,m^{-3}$) and S is the substrate concentration ($g\,m^{-3}$). Controlled biomass systems can also be determined by equation (2). In dynamic bacteria growth systems, the reaction can be expressed by the Monod formulation [5,38,6]:

$$Rate = \frac{K\max XS}{K_m \oplus S} V_b \tag{3}$$

Variables are defined as: $K_{\max}$ is the biomass normalized maximum rate constant in (g of S converted) (g biomass)$^{-1}$ day^{-1}maximum specific growth rate (day^{-1}), X is the bacterial biomass concentration (g biomass m^{-3}) and V_b is the reactor volume in (m^3).

This study focused on the impact of transient (Short Term) temperature changes on acclimating batch biofilters. Understanding the temperature ramifications on acclimation of biofilters and the reported findings will contribute to the potential development of best management practices for commercial water treatment with high substrate loading particularly in RAS and other applications of water quality management.

The objectives were to determine: 1) Transient temperature impact on acclimating biofilter ammonia oxidation at different steady state temperatures, 2) to determine biofilter ammonia oxidation at diurnal temperature regimes mimicking daily cyclical temperature patterns.

2. Materials and methods

A direct linear regression (DLR) method proposed in prior studies [6,38] was used in this study. In an assumption of "zero order" reaction kinetics, the equation that fits the direct linear regression of the volumetric total ammonia nitrogen removal rate (*VTR*) in ($g\,m^{-3}\,day^{-1}$) is expressed as:

$$VTR = \tau(S) + C \tag{4}$$