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Design and management of conventional fluidized-sand biofilters

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Abstract

Fluidized-sand beds are an efficient, relatively compact, and cost-competitive technology for removing dissolved wastes from recirculating aquaculture systems, especially in relatively cool or coldwater applications that require maintaining consistently low levels of ammonia and nitrite. This paper describes several types of flow injection mechanisms used in commercial fluidized-sand biofilters and provides criteria for design of flow distribution mechanisms at the bottom of the fluidized bed. This paper also summarizes the most critical aspects of sand selection, as well as methods for calculating or experimentally measuring fluidization velocities and pressure drop for a given filter sand size distribution. Estimates of nitrification rate, ammonia removal efficiency, carbon dioxide production, and oxygen consumption across fluidized-sand biofilters are also provided for various conditions. Fluidized-sand biofilter operational and management practices are also described.
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Keywords: Fluidize; Biofilter; Biofiltration; Ammonia removal; Sand; Water recirculation or reuse; Aquaculture

1. Introduction

Biofilter selection influences capital and operating costs of recirculating aquaculture systems, their water quality, and even the consistency of water treatment. A perfect biofilter would remove all of the ammonia entering the unit, produce no nitrite, support dense microbial growth on an inexpensive support material that does not capture solids, require little or no water pressure or maintenance, and require a small footprint. Unfortunately, no biofilter type can meet all of these objectives, but each biofilter type has there own advantages and limitations. In addition, different factors considered in biofilter selection can shift in relative importance depending upon production system requirements. For example, in recirculating systems used to culture salmonids, which are species that are relatively sensitive to unionized ammonia- and nitrite-nitrogen, a biofilter's capacity to reliably maintain low levels of total ammonia-nitrogen and nitrite-nitrogen could be as important a consideration

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Nomenclature

A_b cross-sectional area of fluidized bed column (cm^2)
A_{orif} area of orifice (cm^2 or m^2)
A1 fluidization constant, $\frac{\varepsilon^3}{(1-\varepsilon)^2}\frac{\rho(\rho_p-\rho)g(\psi D_{eq})^3}{6^3\mu^2}$
C orifice discharge coefficient for sharp-edged, submerged orifices (0.6)
D_{eq} equivalent diameter, diameter of a sphere with the same volume as the particle of media (cm)
D_{10} effective size, size of an opening which will pass only the smallest 10% of the granular media (cm)
D_{50} mean size, sieve size which will pass 50% of the granular media (cm)
D_{60} sieve size which will pass 60% of the granular media (cm)
D_{90} calculating size, sieve size which will pass 90% of the granular media (cm)
g gravity constant (980 cm/s^2)
H_{bed} headloss due to flow through a granular bed (cm of water)
H_{orif} headloss due to flow through orifice (cm of water)
L depth of loosely-packed (static) granular-media bed (cm)
L_e depth of expanded (fluidized) granular-media bed (cm)
ΔP headloss across a bed of granular media, m of H_2O
Q_{biof} flow rate of water through biofilter (L/min)
Q_{orif} flow rate of water through orifice (cm^3/s)
Re_1 fluidization Reynolds number for expansion model, $\frac{\rho v_0 \psi D_{eq}}{6\mu(1-\varepsilon)}$
S_b bed specific surface area (cm^{-1})
SG_p specific gravity of the particle (unitless)
SG_w specific gravity of water (1.0 unitless)
T temperature (°C)
UC uniformity coefficient
v_{mf} minimum fluidization velocity (cm/s)
v_0 fluid superficial velocity (cm/s)
V_b volume of bed (cm^3)

Greek letters
ε static bed porosity of a loose packed bed, i.e., void fraction (unitless)
ε_e expanded bed void fraction (unitless)
μ fluid viscosity (g/cm/s)
ρ fluid density (g/cm^3)
ρ_p density of a particle of media (g/cm^3)
ψ sphericity, the ratio of the surface area of a sphere of equal volume to the actual surface area of the particle (unitless)

as the biofilter's capital and operating costs (Summerfelt et al., 2001).

Conventional[1] fluidized-sand biofilters (FSBs) have been widely adopted in North America, especially in recirculating systems that must reliably maintain excellent water quality to produce species such as salmon smolt (Forsythe and Hosler, 2002; Holder, 2002; Wilton, 2002), arctic char (Summerfelt and Wade, 1998; Summerfelt et al., 2004a), rainbow trout (Heinen et al., 1996; Summerfelt et al., 2004b), endangered fish (Montagne, 2004), and tropical or ornamental fish (Weaver, 2005). FSBs can typically remove 50–90% of the ammonia each pass and thus maintain total ammonia-nitrogen and nitrite-nitrogen concentrations in their discharge of 0.1–0.5 mg/L and <0.1–0.3, respectively, in cold- and cool-water aquaculture systems (Heinen et al., 1996; Summerfelt et al., 2004b). FSBs can be less expensive and more compact than other biofilter types (Table 1), even when they are sized to provide excess nitrification capacity (Summerfelt and Wade, 1998; Timmons et al., 2000). The cost of surface area in FSBs is low (i.e., \$ 0.05–0.004 m^{-2} surface area) because filter sand has a high specific surface area (i.e., 4000–20,000 m^2/m^3) and is low cost, approximately \$ 70–200 m^{-3} of sand delivered (Summerfelt et al., 2004b). Individual FSBs can treat both small or large flows, with single FSBs treating as much as 190 L/s of water flow. FSBs can be circular or rectangular in shape, can

[1] Non-conventional fluidized biofilters use an expanded or moving bed media material other than sand, such as granular activated carbon, which is operated in an upflow configuration, or various types of relatively small plastic media, which are operated in either an upflow or a downflow configuration that depends upon the specific gravity of the media.

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