Chemosphere 169 (2017) 69–77

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Combined adsorption and degradation of the off-flavor compound 2-methylisoborneol in sludge derived from a recirculating aquaculture system

Snir Azaria [a], Shlomo Nir [b], Jaap van Rijn [a,*]

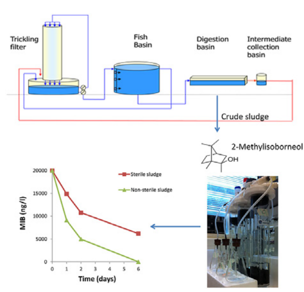
[a] Department of Animal Sciences, The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot, 76100, Israel

[b] Department of Soil and Water Sciences, The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot, 76100, Israel

HIGHLIGHTS

- Removal of 2-methylisoborneol (MIB) by sludge derived from an aquaculture system was examined.
- MIB removal in the sludge was driven by combined adsorption and biodegradation.
- Biodegradation of MIB enabled regeneration of the adsorption sites within sludge.
- A model was developed which accurately described MIB removal by the sludge.
- At steady state operation of the reactors, MIB removal was mainly driven by biodegradation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form
9 November 2016
Accepted 10 November 2016
Available online 15 November 2016

Handling Editor: A Adalberto Noyola

Keywords:
2-methylisoborneol
Sludge
Langmuir
Adsorption
Biodegradation
Recirculating aquaculture systems

ABSTRACT

Off-flavor in fish poses a serious threat for the aquaculture industry. In the present study, removal of 2-methylisoborneol (MIB), an off-flavor causing compound, was found to be mediated by adsorption and bacterial degradation in sludge derived from an aquaculture system. A numerical model was developed which augmented Langmuir equations of kinetics of adsorption/desorption of MIB with first order degradation kinetics. When laboratory-scale reactors, containing sludge from the aquaculture system, were operated in a recirculating mode, MIB in solution was depleted to undetectable levels within 6 days in reactors with untreated sludge, while its depletion was incomplete in reactors with sterilized sludge. When operated in an open flow mode, removal of MIB was significantly faster in reactors with untreated sludge. Efficient MIB removal was evident under various conditions, including ambient MIB levels, flow velocities and sludge loads. When operated in an open flow mode, the model successfully predicted steady MIB removal rates with time. During steady state conditions, most of the MIB removal was found to be due to microbial degradation of the adsorbed MIB. Findings obtained in this study can be used in the design of reactors for removal of off-flavor compounds from recirculating aquaculture systems.

* Corresponding author.
E-mail address: jaap.vanrijn@mail.huji.ac.il (J. van Rijn).

http://dx.doi.org/10.1016/j.chemosphere.2016.11.051
0045-6535/

1. Introduction

Aquaculture is a rapid growing industry and now accounts for nearly 50 percent of the worlds fish supply (FAO, 2016). In aquaculture, the problem of off-flavor in fish cultured in conventional, earthen-bottom fish ponds is well documented (Persson, 1983; Engle et al., 1995; Schrader and Dennis, 2005). Also in recirculating aquaculture systems (RAS), this problem has been reported to affect fish (Guttman and van Rijn, 2008; Schrader et al., 2010; Houle et al., 2011). The secondary metabolites geosmin and 2-methylisoborneol (MIB) are most commonly associated with off-flavor of fish. These hydrophobic compounds (log K_{ow} is 3.57 and 3.31 for geosmin and MIB, respectively; Howgate, 2004) are produced by certain species of cyanobacteria (blue-green algae), actinomycetes and fungi (Mattheis and Roberts, 1992; Martin et al., 1991; Klausen et al., 2005) and, when present in water, may enter the blood stream of fish via the gills and accumulate in the fatty tissues. Once assimilated, they impart a highly potent, musty-muddy taste to fish and render them unmarketable (Howgate, 2004). Threshold geosmin and MIB concentrations in water which may affect fish are as low as 20 ng/l (Petersen et al., 2011).

Several methods for removal of geosmin and MIB from water are presently employed. One such method is based on geosmin and MIB adsorption on hydrophobic media. In the drinking water supply industry, where the problem of flavor-tainted water has caused severe financial burdens and consumer complaints (Watson, 2004), activated carbon (powdered and granular) is widely used for this purpose. Although effective in treating water with low concentrations of organic matter (Graham et al., 2000; Cook et al., 2001; Matsui et al., 2012), this method is less efficient in aquaculture systems where, like in the treatment of other organic-rich water bodies (Ridal et al., 2001), filters may become ineffective as a result of biofilm formation on the adsorbent. Oxidation with strong oxidizing agents such as ozone and chlorine is an additional method for removal of these compounds. These oxidation methods, mainly used in the drinking water industry (Nerenberg et al., 2000), are less appropriate for aquaculture systems. In their study on ozonation in RAS, Schrader et al. (2010) concluded that ozone doses, routinely applied to improve water quality parameters in RAS, were not sufficiently high for removal of geosmin and MIB from the culture water. Use of higher doses, besides being costly, would increase the risk of a breakthrough of ozone in the culture water and thereby endanger fish and potentially damage critical bacterial biofilms within the systems' filtration units (Gonçalves and Gagnon, 2011). In the absence of effective means for prevention of geosmin and MIB accumulation in RAS, purging of marketable fish is currently the most common abatement method (Johnsen et al., 1996; Robertson et al., 2005). Depending on the type of fish, purging with clean water, free of geosmin and MIB, may last up to 15 days. In addition to being a time-consuming process, this method requires relatively large quantities of water and, as fish are usually not fed during the purging period, it results in weight loss and deterioration of the fish meat quality (Palmeri et al., 2009; Burr et al., 2012).

In a study on a zero-discharge aquaculture system it was found that geosmin and MIB were produced as well as removed in several system compartments (Guttman and van Rijn, 2008). The system was operated according to a novel treatment concept, which, in addition to commonly used treatment procedures in RAS, is based on a combination of sludge digestion and denitrification under anaerobic conditions (Shnel et al., 2002; Gelfand et al., 2003; Neori et al., 2007; Krom et al., 2014). While production took place in the aerobic, organic-rich compartments, removal of these compounds took place in the anaerobic digestion basin of this system. Chemical/physical sorption on sludge particles and biodegradation were found to underlie the removal of these compounds in this basin (Guttman and van Rijn, 2009). Long-term monitoring of this zero-discharge system revealed that MIB concentrations in the culture water were consistently higher than those of geosmin (Azaria, 2015). A possible explanation for this observation is that MIB production is higher than geosmin production in this particular system. Alternatively, with MIB being the least hydrophobic and volatile of the two compounds, more MIB accumulates in the culture water than geosmin, which is adsorbed more efficiently by the sludge.

The goal of this study was to develop a prediction tool for MIB removal by sludge accumulating in the treatment compartment of a zero-discharge aquaculture system. For this purpose, laboratory scale reactors, either filled with sterilized sludge or untreated sludge, were employed to be able to differentiate between adsorption and biodegradation of MIB by the sludge. MIB removal characteristics were then described in a numerical model, which augmented Langmuir equations of kinetics of adsorption/desorption of MIB with first order degradation kinetics. Model verification was performed under various operational conditions of the reactors aimed at examining the practical significance of the model.

2. Materials and methods

2.1. Sludge collection and preparation

Sludge was collected from a digestion basin of a pilot-scale recirculating aquaculture system situated on-campus (Faculty of Agriculture, Rehovot). Details of the system were previously described (Krom et al., 2014). Sludge from the digestion basin of the system was centrifuged for 5 min at 10,000 rpm, the supernatant was decanted and the weight of the concentrated sludge was determined. Sterilization of the sludge was conducted by autoclaving (20 min at 121 °C, at a pressure of 1.2 psi (8270 Pa)). Dry weight of the sludge was determined by drying of the sludge for 24 h at 105 °C and its organic matter content was determined after combustion at 450 °C for 2 h (APHA, 1998).

2.2. Bench-scale upflow reactors

The bench scale system was comprised of 1300 ml up-flow reactors (AE-FR40, Aqua Excell, Guangzhou, China), which were filled with sludge derived from the digestion basin. Sterile, double-distilled water, spiked with MIB (100 μg/ml in methanol, Sigma-Aldrich, Israel), was pumped (ISM 833, Ismatec, Wertheim, Germany) from a supply Erlenmeyer flask into the reactor via Tygon tubes (ID 2.79 mm, Ismatec, Wertheim, Germany) at a flow rate of 5.0 ml/min. The reactors were either operated in an open-flow or in a closed mode. In the open-flow mode, MIB in the inlet was maintained at fixed concentrations while effluent water was discharged. In the closed mode, water was recirculated so that inlet MIB concentrations decreased with time. Prevention of MIB volatilization was accomplished by sealing the systems from the air. Samples were collected by diverting 75 ml of effluent water into air-tight, sterile collection vessels followed by immediate analysis of MIB (see Section 2.3).

Additional batch adsorption equilibrium tests were performed in Erlenmeyer flasks with sludge suspended in double distilled water and spiked with MIB. Sludge (50 g, 9% dry weight) was kept in suspension by placing the Erlenmeyer flasks on a magnetic stirrer. Model parameters were derived (see below) by determination of the MIB removal over 24 h at different ambient MIB concentrations (0.5, 1.5, 7.5, 18.2, 69.2, 167.2, 367.2 μg/l).