Bioresource Technology 144 (2013) 350–359

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Process design and dynamics of a series of continuously fed aerated tank reactors treating dairy manure

Anni Alitalo[a,*], Laura Alakukku[b], Erkki Aura[c]

[a] MTT Agrifood Research Finland, Koetilantie 5, 00790 Helsinki, Finland
[b] Department of Agricultural Sciences, University of Helsinki, 00790 Helsinki, Finland
[c] Biotaito, Killintie 14, 31300 Tammela, Finland

HIGHLIGHTS

- The serial aeration treatment was designed to be part of an overall treatment scheme.
- The results confirmed the dynamic nature of the serial system.
- Process failure was easily predictable and thus easy to control.
- The feedback of slurry increased treatment efficiency via a number of mechanisms.
- MgO addition increased the slurry pH and ammonia reduction due to stripping.

ARTICLE INFO

Article history:
Received 8 May 2013
Received in revised form 26 June 2013
Accepted 29 June 2013
Available online 4 July 2013

Keywords:
Aerobic treatment
Dairy
Cow
Manure
Slurry

ABSTRACT

A 6-month trial was carried out to study operational conditions and process dynamics in a system of six continuously fed aerated tank bioreactors grouped by serial connection. Feedback was with NH_3-stripped solution after biological treatment, with the purpose of lowering the NH_3 content of the feedback solution in order to improve the process. The fate of carbon and nutrients during treatment were determined, as well as the ammonia stripping performance of the biological treatment. The results of the study confirmed the dynamic nature of the serial system and indicated its resistance to process disturbances. The feedback of slurry resulted in a dilution effect and significantly reduced the carbon and nutrients concentrations in the first tank, increasing the treatment efficiency. Overall, after mechanical separation, low intensity aeration treatment and ammonia stripping, up to 61%, 67%, 79% and 83% average reductions of TS, Ntot, NH_4^+-N and Ptot, respectively, were reached.

1. Introduction

Dairy cows produce about 16–24 tons of fresh manure (feces and urine) per year. According to Finnish manure nutrient content determinations, this material includes up to 12 kg of phosphorus (P), 72 kg of nitrogen (N), 70 kg of potassium (K) and 12 kg of magnesium (Mg) per year (Viljavuuspalvelu, 2012). In loose housing systems, approximately 35–40 m^3 of liquid manure per cow may accumulate in a year. Based on these figures, dairy cows serve as a significant source of waste (in terms of volume), nutrients and organic matter, both in environmental and economic scales.

The majority of the dairy manure is produced as slurry manure containing only 3–8% dry matter (DM) (Viljavuuspalvelu, 2012). Low DM and high water content causes considerable transport and spreading costs. To reduce the nutrient load, N and P use has been legislatively controlled. As a consequence, some farmers are obliged to transfer the nutrients over long distances. Furthermore, difficulties in determining the fertilization value of organic N fraction (Van Kessel and Reeves, 2002), as well as gaseous emissions during storage and during and after spreading (e.g., Amon and Zechmeister-Boltenstern, 2006), complicate the use of manure as fertilizer and thus increase the risk of environmental pollution. Contamination by enteric bacteria may also result. This is particularly a concern with dairy manure (Uusi-Kämppä and Heinonen-Tanski, 2008), which is often surface applied on ley.

Different treatment methods have been developed in order to address these problems. The treatment process may be designed to solve odor problems (Alitalo et al., 2013; Evans et al., 1986; Ndegwa, 2003; Zhu et al., 2008) or to recover nutrients or energy from the manure (Alitalo et al., 2012; Rico et al., 2011; Vanotti et al., 2005, 2007), to increase the fertilizer value or reduce its volume (Vanotti et al., 2007), to decrease the pollution potential of the manure (Amon and Zechmeister-Boltenstern, 2006), and/or to kill

* Corresponding author. Address: MTT Agrifood Research Finland, Koetilantie 5, PL 28, 4th floor, Room 410, FI-00790 Helsinki, Finland. Tel.: +358 29 5317124.
E-mail address: anni.alitalo@mtt.fi (A. Alitalo).

0960-8524/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2013.06.123

pathogens (Vanotti et al., 2005) and weed seeds. Biological processes have commonly been applied for treating manure. Both aerobic and anaerobic treatment methods have been applied, or combinations of the two e.g. by using alternate anoxic and aerobic phases, as in sequential batch reactors (Bernet and Béline, 2009). In these process schemes, the goal is to achieve carbon (C), as well as N and P removals (Chang et al., 2000). Generally, the goal has been attained by releasing C to the atmosphere as carbon dioxide (CO_2), by nitrification–denitrification release of N to the atmosphere and by effectively binding P to e.g. iron compounds, in which form it is unavailable to plants. This is a common treatment scheme e.g. in activated sludge treatment systems (Thistleton et al., 2001).

In the case of manure treatment, the aim should be rather a recovery process than a releasing process from the point of view of nutrient recycling, and should avoid gaseous emissions into the atmosphere. This could be achieved by a treatment scheme in which the goal is an effective recycling of manure nutrients. In the process scheme introduced by Kokkonen and Aura (2007), manure solid fraction is first separated by mechanical means, followed by a biological aeration treatment in a series of continuously fed aerated tank reactors, which reduces the odor of the slurry (Alitalo et al., 2013) and enables further fractionation of manure effluent: N separation with air stripping (after the reduction of manure solid matter and biological pH increase, Alitalo et al., 2012), and subsequent water separation (Kokkonen and Aura, 2007) with reduced amounts of conventional iron or aluminum salts. Conventional chemicals used for coagulation are mainly aluminum or iron-based salts. When added to water, Al/Fe(III) ions hydrolyze to form soluble monomeric and polymeric species and solid precipitates (Jiang and Graham, 1998). Al/Fe(III) hydrolysis products may adsorb to colloidal surfaces to neutralize the charge or may chemically interact with dissolved components thereby causing flocculation. Due to high pH and a highly buffered system, too rapid polymerization occurs, creating insoluble precipitated Al and iron polymers, wherein Al/Fe(III) is surrounded and thereby neutralized by negatively charged oxygen atoms/hydroxides and flocculation/coagulation function is lost.

The overall treatment scheme presented above is highly dependent on the efficiency of the biological treatment. However, little research has been conducted on aeration treatment in a serial system. In the present study, mechanically separated cow slurry treatment was conducted in series of continuously fed aerated tank reactors. The objectives were to examine operational conditions, dynamics and stability of this kind of treatment system, to study process efficiency, and to evaluate ammonia (NH_3) stripping of the biologically treated liquid manure and the effect of magnesium oxide (MgO) treatment on stripping performance.

In order to improve the treatment process NH_3-reduced feedback was used. This was expected to improve the process e.g. by improved odor reduction and reduced hydraulic retention time (HRT) and by allowing an increased process loading due to a reduced NH_3 inhibition effect.

2. Methods

2.1. Equipment

Experimental studies were conducted in pilot scale in a series of continuously fed aerated tank reactors consisting of six 600 l treatment tanks connected in series by polyvinyl tubing (Fig. 1). The hydraulic volume of the total system was 2.4 m^3 (loading 400 l per tank). The feed-in flow in each tank was to the bottom of the tank and outflow through the crosswise upper corner in relation to the input flow. The surface liquid level remained constant when liquid manure ran gravitationally from one tank to another. The technical details of the system are described in more detail elsewhere (Alitalo et al., 2013). Unlike in the previous study, feedback was with NH_3-stripped solution after biological treatment, with the purpose of lowering the NH_3 content of the feedback solution.

Aeration was performed using membrane diffusers and air flow produced by a high pressure blower and adjusted by manual rotameters: was 25–27 l min^{-1} in tank 1, 15–20 l min^{-1} in tank 2 and 10–15 l min^{-1} in tanks 3–6. The treatment tanks were equipped with mechanical foam breakers, and gases released during processing were collected separately from each tank via an outlet duct. Slurry was transferred from the sixth process tank by gravitation to an additional overflow container, from which it was transferred with a submersible pump to a 1 m^3 plastic container. From this container the slurry was then transferred with a hose pump into a stripping tower (Alitalo et al., 2012). After stripping, effluent was transferred to a container from which a part was continuously fed into the first treatment tank (feedback). Ammonia

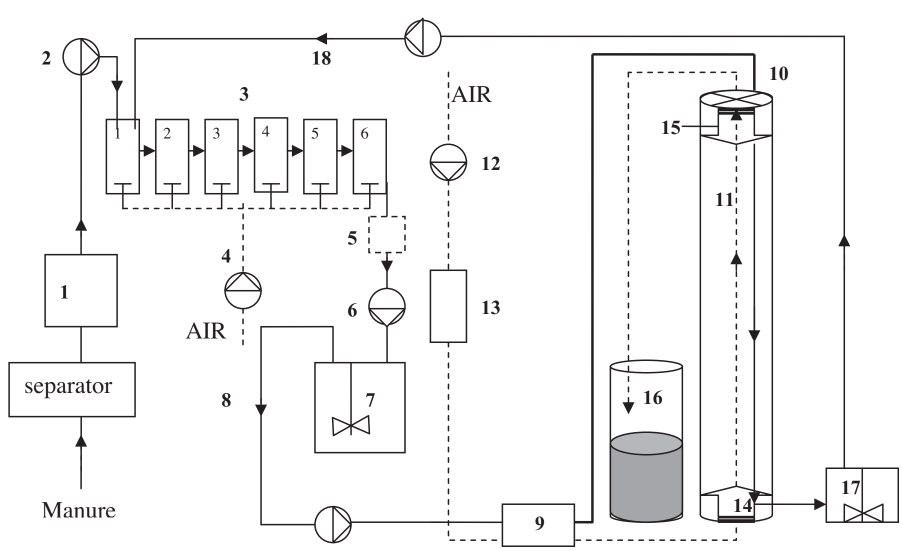

Fig. 1. Schematic representation of the treatment system. 1. Separated slurry storage tank, 2. feed-in pump, 3. serial tank system, 4. blower, 5.overflow container, 6. pump, 7. intermediate container (MgO addition), 8. effluent to the stripping tower, 9.thermostatic path, 10. liquid distributer, 11. stripping tower, 12. blower, 13. flow meter, 14. air flow, 15. liquid flow, 16. ammonia wet washer, 17. stripped effluent storage tank and 18. feedback.