Ecological Engineering 57 (2013) 353–360

Contents lists available at SciVerse ScienceDirect

Ecological Engineering

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

Demonstration of technology to treat swine waste using geotextile bag, zeolite bed and constructed wetland

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ARTICLE INFO

Article history:
Received 11 July 2012
Received in revised form 25 February 2013
Accepted 6 April 2013
Available online 24 May 2013

Keywords:
Constructed wetland
Geotextile bag
Nitrogen removal
Phosphorus removal
Solids separation
Swine wastewater
Zeolite

ABSTRACT

A comprehensive treatment system consisting of geotextile bag, zeolite bed and constructed wetland has been devised to remove solids and nutrients from swine house waste. Alkalinity was observed to be reduced by 44% after geotextile bag and 77% after wetlands. In one day (24 h) waste flush cycle, COD was reduced by 72% after geotextile bag and further reduced by 95% after zeolite treatment followed by constructed wetland. When wastewater was passed through geotextile bag, 71% reduction of COD occurred during 96 h flush cycle and further reduction of 87% was observed after zeolite. Reductions of 94% total N, 92% NH_4^+-N, 88% total P, and 87% o-PO_4^--P were observed after the wastewater was passed through the geotextile bag, zeolite, and wetland treatment systems during 24 h flush cycle. Approximately 50% NH_4^+-N was adsorbed by the zeolite bed and 12% was presumed to be lost through NH_3 volatilization process during zeolite treatment.

1. Introduction

Manure management and its impact on environment is one of the major challenges in agriculture in USA. Swine operations in North Carolina have grown in the past 15 years, and the state ranks second in the nation after Iowa (USDA, 2007). Historically, swine waste is flushed with water from swine houses into an anaerobic lagoon or swine waste falls into the waste holding pits below the swine houses and then the plug is removed from the pit to facilitate the flow of wastewater into an anaerobic lagoon. The lagoon water is sprayed periodically on agricultural fields. Such operations with improper management can pollute surface and ground water (Ritter and Chirnside, 1990; Burkholder et al., 1997) and may pose a threat to human and animal health. In July 2000, the Attorney General of North Carolina reached an agreement with Smithfield Foods, Inc., and its subsidiaries to demonstrate environmentally superior animal waste management technologies (Vanotti et al., 2007). There were several technologies demonstrated in removing solids or nutrients or biogas production from swine wastewater. However, none of the demonstrated technologies showed a comprehensive treatment system to treat swine waste from swine houses that removed solids, nutrients, odor, and reduced air emissions except the Terra Blue (formerly Super Soil Systems) technology by Vanotti et al. (2007, 2009).

The surface flow constructed wetland research showed that nutrients can be reduced by 50% with less odor problem by using anaerobic lagoon for swine wastewater treatment (Reddy et al., 2001; Poach et al., 2004). The treatment of swine lagoon wastewater by wetlands can be a possible solution to those farmers who do not have adequate land to apply the nutrient rich wastewater. However, this technology did not eliminate the need for anaerobic lagoon usage. Swine manure is mostly in the liquid fraction having colloidal particles, dissolved solids, fine solids, coarse solids, and fiber (hair) and also contain high BOD, COD, nitrogen and phosphorus. Therefore, it is essential to separate solids from the liquid fraction of swine waste and treat the liquid portion to further reduce the nutrients. The major advantage of the solid–liquid separation is that it enables better management and utilization of both the solid and liquid fractions (Zhang and Westerman, 1997).

Several solids separation techniques have been implemented in animal wastewater, such as sedimentation (Metcalf and Eddy, 2003), centrifugation, screening, screw press filtration, belt press filtration (Burton, 2007), and bag filtration (Worley et al., 2004, 2008; Sharrer et al., 2009). These mechanical separations did not

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http://dx.doi.org/10.1016/j.ecoleng.2013.04.046

reduce potassium and ammonia which are mostly dissolved in the liquid portion (Westerman et al., 2000). Also, fine solid particles contain protein, other organic compounds, and nutrient elements that are associated with odor (Zhang and Westerman, 1997). The above techniques will not separate colloidal particles and fine solids and some dissolved solids, unless chemical coagulants and flocculants are used before the treatment. According to Singh et al. (2006), as much as 85% of the particles present in the raw and treated swine manure samples were <10 mm in size and removal of such small particles can be achieved by coagulation/flocculation, followed by sedimentation and filtration. Most common chemicals used as coagulants are alum [$Al_2(SO_4)_3 \cdot 18H_2O$], ferric chloride ($FeCl_3$), ferric sulfate [$Fe(SO_4)_3$] and hydrated lime [$Ca(OH)_2$]. Normally in swine wastewater one of these coagulants is used in combination with a flocculant agent such as polyacrylamides. Earlier studies (Sievers et al., 1994; Zhang and Lei, 1998) showed that $FeCl_3$ is more effective in removing solids and nutrients from swine wastewater than other metal salts. Vanotti et al. (2002) have tried many cationic and anionic polymers to remove solids in swine wastewater and found that cationic polymers perform better than anionic polymers. Also other scientists (Sievers et al., 1994; Jiang and Graham, 1998; Boisvert and Jolicoeur, 1999; Vanotti and Hunt, 1999; Timby et al., 2004) found that cationic polymers having high molecular weight, long chain structures, and high density were more effective in solids separation than others. Cationic flocculants are also most effective at pH higher than 7.0.

Physical, chemical and biological composition of swine wastewater is different from one swine operation to the other and it depends on feed ingredients, feeding pattern, animal age, number of animals, and waste to water ratio. Therefore, it is important to test the solids separation on a bench scale with coagulants and different cationic polymer, in order to derive an optimum concentration of coagulant and polymer and duration of mixing before starting the project on a field scale.

Even though coagulants and flocculants may be effective in removing a high percentage of solids and some nutrients (i.e. phosphorus) from the waste stream, a large portion of other nutrients (i.e. nitrogen) remain in the liquid effluent. Other separation processes can be used to remove these nutrients from the waste stream. Earlier laboratory studies have shown that high concentrations of NH_4^+-N can be removed by using zeolite (Cyrus and Reddy, 2011).

Geotextile bags have been used to separate solids from dairy wastewater (Worley et al., 2008), aquaculture wastewater (Sharrer et al., 2009), and swine wastewater (Baker et al., 2002). However, their studies used either a small size (1 m × 1 m) geotextile bag or only treated the fixed total solids concentration from the wastewater stream. Also, none of the studies dealing with solids separation has evaluated other treatment options of the liquid fraction after solids separation to further reduce nutrient concentrations. Therefore, the objective of this study was to reduce suspended solids and nutrients (nitrogen and phosphorus) in swine wastewater by 90 and 75% respectively, using coagulant, flocculant, geotextile bag, and either zeolite bed or constructed wetland.

2. Materials and methods

2.1. Screening of polymers

A total of nine polymers were tested based on recommendations from two commercial companies, Kemira Water Solutions Inc., and Hychem Inc., which were cationic polyacrylamide emulsion and cationic acrylamide copolymer emulsion, respectively. Polymers were diluted and mixed (Neptune Mixer, shaft assembly 12.7/40 cm dia. × 76.2 cm length, with 7.62 cm propeller, Neptune Mixer Co.). Two coagulants from Brenntag Southeast Inc. were also tested for efficiencies. The polymers and coagulants screened for the study and their properties are shown in Tables 1 and 2, respectively.

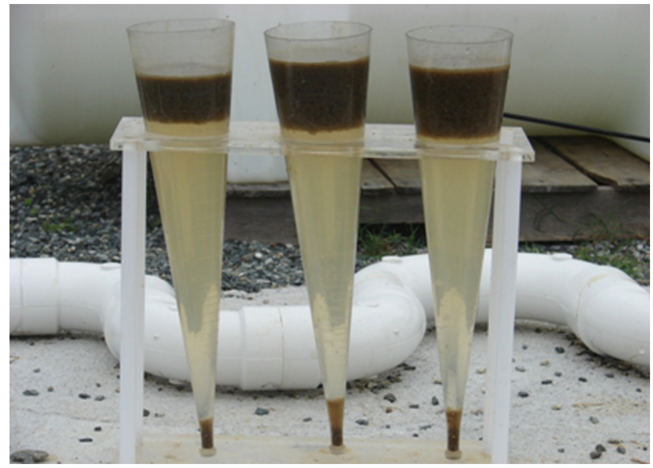

Fig. 1. Cone testing after polymer/coagulant treatment.

2.2. Jar testing

Jar testing can be done in two ways (Tencate, 2011), Geotube Dewatering Technology (GDT) and Rapid Dewatering Test (RDT). In our case, cone testing was done by adding the coagulant and polymer to the effluent in a 1 L cone and letting it stand for separation (Fig. 1). Table 3 shows the coagulant–polymer ratio, floc size and strength of the various polymers investigated.

The total solids (TS) and total phosphorus (TP) of the raw manure and the samples resulting from the polymer treatment were analyzed. The percent reduction of TS and TP was calculated using the following equation.

$$\text{Reduction}\ (\%) = \frac{\text{Concentration in raw manure} - \text{Concentration after polymer treatment}}{\text{Concentration in raw manure}} \times 100$$

2.3. Site description

This study was performed at the North Carolina Agricultural and Technical State University (NCAT) Swine Research Facility (250 sow farrow-feeder operation), located in Greensboro, NC, USA. Emphasis was placed on the 123 head finishing/nursery hogs with an average weight of 45 kg, producing higher solid content in their waste.

2.4. Geotextile bag

A high performance, high-strength, permeable, woven polypropylene geotextile bag (GT500; 9.14 m circumference × 15.24 m length) specially engineered by TenCate Geosynthetics (Commerce, Georgia) was used for containment and dewatering of high moisture content sludge and sediments. The geotextile bag was made of polypropylene yarns, which are woven into a stable network so the yarns retain their relative position and was custom fabricated using seaming techniques to withstand pressure during pumping operations. The thickness of the material was 1.8 mm and the pore size distribution ranged from 80 μm at O_{50} to 195 μm at O_{95} (Tencate, 2013). High flow rate of 813 L min^{-1} m^{-2} allows residual materials to dewater,