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Swine effluent post-treatment by alkaline control and UV radiation combined for water reuse

Patrícia Bilotta [a, *], Ricardo Luiz Radis Steinmetz [b], Airton Kunz [b], Rubia Mores [c]

[a] Positivo University, Environmental Management Post-Graduate (Master and Doctorate) Program, Professor Pedro Viriato Parigot de Souza Street, n. 5300, 81280-330, Curitiba, Paraná, Brazil

[b] Brazilian Agricultural Research Corporation – Embrapa Swine and Poultry, Br-153 Road, Km 110, 89700-000, Concórdia, Santa Catarina, Brazil

[c] Agricultural Engineering Post-Graduate Programa (UNIOESTE), Department of Agricultural Science, Universitaria Street, n. 2069, 8519-110, Cascavel, Paraná, Brazil

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A B S T R A C T

Water reuse is widely practiced by industries, including swine farms, to reduce the consumption of clean water. However, water reuse requires controlling physical and chemical parameters of quality and mainly pathogens to meet the regulation limits recommended for no potable reuse. This paper presents an exploratory evaluation of the combined disinfection use of alkaline control and ultraviolet radiation to suit the sanitary parameter of secondary effluent from a swine manure treatment plant for agricultural water reuse. The efficiency of disinfection was measured by total coliforms, *Escherichia coli* and *Salmonella* at three pH levels (7.5, 9 and 10), two settling times (30 and 60 min), and two contact times for ultraviolet radiation (0 and 60 s) at 160.5 ± 20.8 mJ/cm^2. The highest inactivation responses were 3.7 log for total coliforms, 3.8 log for *Escherichia coli* and 4.0 log for *Salmonella* at pH 10, 60 min of settling and 60 s of exposure to UV radiation. These results show an increase in the disinfection efficiency of 2.8 log for total coliforms and *Escherichia coli* and 2.4 log for *Salmonella* in comparison to pH control alone. Therefore, a previous alkaline treatment forces the sedimentation of the total suspended solids, responsible for reducing the ultraviolet light germicidal effect, and, for this reason, in the next stage of disinfection the efficiency was higher. The application of both disinfection agents sequentially yielded better results to improve biosecurity status for water reuse.

1. Introduction

Brazil is the third largest swine producer and the fourth largest exporter of swine meat. In 2012 alone, 581 thousand tons were exported to 60 countries in the world, representing 1.49 billion US $ in revenue for the Brazilian economy (EMBRAPA, 2013). However, despite the economic gains that the pork industry provides, this activity consumes a high quantity of water (water footprint = 6 m^3/kg of meat) (Palhares, 2011) and produces highly polluted effluent, considering chemical, physical and biological parameters (Steinmetz et al., 2009). Thus, managing water and wastewater is extremely important in swine farms to minimize environmental impacts on soil (Balota et al., 2014) and on stream (Chelme-Ayalaa et al., 2011) and reduce the consumption of clean water in times of water scarcity (IPCC, 2014).

Swine effluent reuse in agriculture for irrigation of crops (Vázquez et al., 2015) and in pork farms for cleaning of facilities (Viancelli et al., 2015) may be an alternative to reduce the clean water consumption. Therefore, this practice demands an efficient treatment of the effluent to remove various contaminants, as organic and inorganic matter, nitrogen, phosphorous (Kunz et al., 2009), veterinary drug residues (Widyasari-Mehta et al., 2016), and mainly pathogenic microorganisms, as *Salmonella*, *Campylobacter*, *Escherichia coli*, *Cryptosporidium*, and viruses that can cause human and animal diseases (Viancelli et al., 2015; McCarthy et al., 2013).

Traditional treatment methods are commonly used to reduce the quantity of chemical contaminants in swine effluent, such as aerobic with polymer (Kafle et al., 2016), anaerobic co-digestion (Siddique et al., 2015), composting (Vázquez et al., 2015), nitrification-denitrification (Riaño and Gárcia-González, 2015), anaerobic digestion (Gopalan et al., 2013), coagulation-

* Corresponding author.
E-mail address: pb.bilotta@gmail.com (P. Bilotta).

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flocculation-sedimentation (Chelme-Ayalaa et al., 2011), anaerobic-aerobic-sedimentation (Kunz et al., 2009), and others. However, in general, pathogens resist to traditional swine manure treatments and may survive in the environment, which demands a stage of disinfection for the effluent before its disposal or reuse (Viancelli et al., 2015).

Some conventional alternatives for swine effluent disinfection include alkaline and thermal control, chemical oxidization (ozone gas or hydrogen peroxide), and application of ultraviolet radiation with germicidal lamps (Bilotta and Kunz, 2013). Table 1 summarizes values reported for inactivating microorganisms commonly found in liquid manure by conventional disinfection methods.

Although conventional disinfection methods may demonstrate their efficiency to reduce the number of remaining microorganisms in swine effluent, some limitations have been reported.

Alkaline treatment is usually focused on the phosphorus recovery and microorganism reduction has been reported as a result (Viancelli et al., 2015). For pH 9.0 the removal of total and suspended phosphorus may be higher than 96% (Fernandes et al., 2012), but at this pH only 1 log of inactivation is reached for *Salmonella* and no *Escherichia coli* in 24 h of exposure (Viancelli et al., 2015). Therefore, alkaline treatment requires high consumption of $Ca(OH)_2$ or CaO to reach inactivation superior to 3 log, which may greatly increase the operational cost. Thermal method may carry to high inactivation of bacteria (~4 log), but it demands high-energy consumption to keep the temperature of the effluent above 60 °C during the disinfection time, and it may be unfeasible mainly to cold weather places (Lagunas-Solar et al., 2005; Martens and Böhm, 2009). Chemical oxidization involves non-selective reactions, and organic and inorganic suspended and dissolved solids present in liquid swine manure may also suffer oxidation and, thus, the consumption of chemical disinfection agent (chlorine, hydrogen peroxide, ozone, and others) will be higher, increasing the operational costs for disinfection (Macauley et al., 2006). Moreover, for chlorine, the oxidizing reactions with organic matter produce halogenated by-products associated with mutagenic, carcinogenic, and genotoxic properties (Lee et al., 2015). UV radiation is largely used to wastewater disinfection with inactivation superior to chemical disinfection agents (Couto et al., 2015; Gómez-López et al., 2009), less expensive, safer than chlorine and effective against protozoa, as *Cryptosporidium* and *Giardia* (EPA, 2004). However, the UV radiation technique may be limited by the quantity and size of suspended solids in the effluent, that blocks light passage and reduces the intensity of ultraviolet radiation effective to inactivate the microorganisms (Macauley et al., 2006; Singh et al., 2006).

Studies have also reported that combining two or more disinfectant agents may improve the sanitary quality of effluent from wastewater treatment plants (Koivunen and Heinonen-Tanski, 2005; Bilotta and Daniel, 2010), for water reuse, and reduce the consumption of disinfectant agent, but no information has been found for swine effluent.

The aim of this study was to evaluate if combining alkaline and UV radiation disinfection method reduces the number of remaining microorganisms in liquid swine manure in the way to make possible its reuse for unrestrictive agricultural reuse and for cleaning of facilities in swine farms. This combination of methods was chosen because alkaline control is a practice commonly used for swine manure sanitary control (Bilotta and Kunz, 2013) and UV radiation (at 254 nm) is a clean technology that does not generate disinfection by-products (Macauley et al., 2006). The hypothesis investigated in this study was the increasing of disinfection efficiency with UV radiation by introducing a previous stage of suspended solid sedimentation due to adjustment of pH.

The microorganisms evaluated were *Escherichia coli and* total coliforms, for their importance as sanitary parameter for water reuse, according to international standards (WHO, 2006; EPA, 2004) and Brazilian standards (NBR, 1997), and *Salmonella* sp. for its importance as a biosafety parameter in swine production (Viancelli et al., 2015).

2. Materials and methods

2.1. Sampling

For the disinfection tests, aliquots of 5 L of effluent were collected from an experimental swine manure treatment system (SMTS) (Kunz et al., 2009), located at Embrapa Swine and Poultry (Brazilian Agricultural Research Corporation) in Santa Catarina, Brazil (Fig. 1).

Table 2 shows the average measured values of the physical, chemical and sanitary parameters in the effluent from the secondary settling.

As the presence of *Salmonella* may be intermittent in the swine effluent (Viancelli et al., 2015), 10^3 MPN *Salmonella* enterica serovar *Typhimurium* (ATCC 15631) was inoculated by 100 mL of effluent to guarantee suitable quantity of microorganisms to be evaluated the combined method efficiency.

2.2. Experimental description

Table 3 presents the experimental design for the disinfection essays performed. For the tests, the influence of pH, settling time, and exposure to UV radiation were evaluated in an exploratory multivariate study using 2^3 factorial. Before the essay, to ensure the presence of a large amount of microorganisms, a spike addition of concentrated cultures of *Salmonella* was performed to obtain an initial number of individuals more than 10^5 MPN/100 mL. The effectiveness of turbidity reduction (%) and of inactivation (- log N/N_0) for total coliforms, *Escherichia coli* and *Salmonella* was evaluated as a response. All tests were performed as presented in Table 3, in which T1 was the control test.

The natural pH of the effluent was 7.8 (±0.8). For the control test, the pH was adjusted to 7.5 and for the other tests the pH was carried to 9.0 and 10.0, according to the experimental design, by adding a solution of 10% calcium hydroxide (m/v), stirring for 1 min and allowing the mixture to settle. The settling time corresponded to the period for solid sedimentation due to the alkaline treatment. After the settling time, the pH of the supernatant was adjusted to 7.5 with sulfuric acid (concentration 1 mol/L). Fig. 2 shows the sequence of steps for the combined disinfection method.

For the tests, effluent from SMTS (Fig. 1) was transferred to a reservoir (volume 500 mL) for adjustment of pH, and, after that, to a tank (volume 500 mL) for suspended solid sedimentation, following the experimental design (Table 3). Then, the supernatant was pumped from the sedimentation settling to the photo-reactor for receiving UV radiation. The experiments were carried out in a laboratory scale.

2.3. Photo-reactor

The UV photo-reactor had a volume of 270 mL, was constructed with a polyvinyl chloride (PVC) pipe and closed with a PVC cover (Fig. 3). The purpose of this construction was to evaluate the disinfection efficiency of swine effluent using an affordable material to enable its utilization on farms. For the tests in the photo-reactor, it was used a germicidal lamp of low-pressure mercury vapor (TUV - Philips) at 254 nm (ultraviolet region) and nominal power of 6.0 W, according to the manufacturer.

The average UV irradiance (Im) was calculated from the Beer-Lambert law (Equation (1)), where: "I_o" is the incident irradiance