REVIEW PAPER

SWINE MANURE POST-TREATMENT TECHNOLOGIES FOR PATHOGENIC ORGANISM INACTIVATION

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ABSTRACT: Swine manure agricultural use is a common practice in Brazil. Their physic-chemical characteristics favor its use as biofertilizer, but the presence of pathogens may become a risk to human health. This research presents a qualitative study of the main alternatives of pig manure disinfection, analyzing efficiency, advantages and limitations of each procedure. The disinfection studies reported in literature are based on the following treatments: alkaline, thermal, biological, chemical, and physical. The greater efficiencies are in thermal treatment (> 4 log: 60 °C), chemical treatment (3 to 4 log: 30 mg $Cl^- L^{-1}$; 3 to 4 log: 40 mg $O_3 L^{-1}$) and physical treatment (3 a 4 log: 220 mJ UV radiation cm^{-2}). The biological treatment (anaerobiosis) also promotes the pathogen reduction of swine manure, however with lower efficiency (1 to 2 log). The selection of the treatment should consider: implementation and operation cost, necessity of preliminary treatment, efficiency obtained and destination of the treated manure (agricultural use, water reuse). Brazilian regulation does not have specific guidelines for the microbiological quality of animal production effluents that is very important to be considered due to confined animal feeding operation transformation in the last years in the country.

KEYWORDS: chemical treatment, physical treatment, effluent reuse, biosecurity.

TECNOLOGIAS DE PÓS-TRATAMENTO DE DEJETOS SUÍNOS PARA INATIVAR ORGANISMOS PATOGÊNICOS

RESUMO: O uso agrícola de dejetos suínos é uma prática comum no Brasil. Suas características físico-químicas favorecem seu aproveitamento como biofertilizante, porém a presença de patógenos pode representar um risco à saúde humana. Este trabalho apresenta um estudo qualitativo das principais alternativas de desinfecção de dejetos suínos, analisando eficiência, vantagens e limitações de cada procedimento. Os estudos de desinfecção reportados na literatura são baseados nos seguintes tratamentos: alcalino, térmico, biológico, químico e físico. As maiores eficiências de redução de patógenos estão no tratamento térmico (>4 log: 60 °C), tratamento químico (3 a 4 log: 30 mg $Cl^- L^{-1}$; 3 a 4 log: 40 mg $O_3 L^{-1}$) e tratamento físico (3 a 4 log: 220 mJ radiação UV cm^{-2}). O tratamento biológico (anaerobiose) também promove a redução de patógenos em dejetos suínos, porém com menor eficiência (1 a 2 log). A seleção do tratamento deve considerar: custo de implantação e operação, necessidade de tratamento preliminar, eficiência obtida e o destino do dejeto tratado (uso agrícola, reúso de água). A legislação brasileira não define diretrizes específicas de qualidade microbiológica dos efluentes da produção animal, o que rapidamente precisa ser estabelecido devido às transformações que a atividade tem sofrido nos últimos anos no País.

PALAVRAS-CHAVE: tratamento químico, tratamento físico, reúso de efluentes, biossegurança.

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INTRODUCTION

In recent decades, the issue of treatment of waste generated in the production systems of confined animals (PSCA) has occupied a prominent part in practices of rural sanitation in Brazil and worldwide. Thus, swine production is among the activities with the greatest impacts, especially due to its high concentration of organic matter, nutrients and pathogens that can lead to contamination of soil and water resources and endanger human health and environmental quality when the waste is discarded without pretreatment (BAUMGARTNER et al., 2007; KUNZ et al., 2009; MARTINEZ et al., 2009; TOPP et al., 2009; ZIEMER et al., 2010; CHELME-AYALAA et al., 2011; TECHIO et al., 2011; BROCHIER et al., 2012; GARCIA et al., 2012; VIANCELLI et al., 2012).

The reduction of the organic load and nutrients from swine manure (liquid path) involves many steps of treatment depending on the quality of the final effluent to be reached. Generally, the steps are: primary (grating, screening and sand box - removal of gross solids and settleable solids), physical-chemical treatment (coagulation-flocculation - removal of suspended solids) and biological treatment (biodigester, stabilization ponds and biological reactor - removal of organic load, nitrogen and phosphorus) (SCHMIDT et al., 2007; KUNZ et al., 2009; KUNZ et al., 2010; VIVAN et al., 2010; ZIEMER et al., 2010; CHELME-AYALAA et al., 2011).

A complementary treatment should be used to enhance inactivation of pathogenic organisms (heat treatment, alkali treatment, chlorine and its derivatives, ozone, UV radiation, etc.). Results vary depending on the methodology used and resistance to microbial disinfectant agent, reaching levels higher than 99.99% of inactivation (MOHAIBES & HEINONEN-TANSKI, 2004; HEINONEN-TANSKI et al., 2006; MACAULEY et al., 2006 ; TOFANT et al., 2006; VINNERÅS, 2007; BERNAL et al., 2009; MARTENS & BÖHM, 2009; WONG & SELVAM, 2009; ZIEMER et. al., 2010; MASSE et al., 2011).

Application of manure in the soil for agronomic evaluation should also be careful. Pathogen survivability in soil varies according to species and environmental conditions and can survive for prolonged periods after its application (MILLNER, 2009; VENGLOVSK et al., 2009; ZIEMER et al., 2010; BROCHIER et al., 2012; GARCIA et al., 2012): *E. coli* O157, *Salmonella* and *Campylobacter* of 3-6 months, *Listeria* bacteria of up to 6 months (NICHOLSON et al., 2005; ZIEMER et al., 2010); protozoan cysts, 10 days; enteric viruses, one year and helminthes eggs, 2-7 years (SCHMIDT et al., 2007).

Thus, the need for reduction of pathogens in manure at different levels depending on its use or disposal, seeking health aspects in animal production and maintenance of human health and enabling water reuse in creative unit, to non-potable purposes (SCHMIDT et al., 2007; CHADWICK et al., 2008; MARTINEZ et al., 2009, TOPP et al., 2009; BROCHIER et al., 2012) is evident.

In this context, the discussion presented below aims at identifying and analyzing the advances in disinfection technologies of swine wastewater. The study presents a descriptive and comparative approach of the main alternatives to control pathogens in relation to the efficiency obtained, its advantages and limitations and interrelationships with the current law.

REVIEW

Alkaline and thermal treatments

VANOTTI et al. (2005) evaluated the ability to inactivate total coliform bacteria and thermotolerant coliform, *Enterococcus* and *Salmonella*, in pig manure, using a system of solid-liquid separation (flocculation and filtration), nitrification-denitrification step and phosphorus extraction with the addition of lime at 2% (m/v). The highest efficiencies have been achieved in the step of phosphorus removal (survival below 0.3 log), with increasing pH to 10 after application of lime. WONG & SEVAN (2009) found efficiency of inactivation of *Salmonella*, *Escherichia coli* O157:H7, themotolerant coliforms and *Streptococcus* in different lime combinations (2 to 4% m/v) and alkaline coal ash (25; 33 and 50% m/m), coupled with the increase in temperature during the decomposition of organic waste. The results showed that at four days mixing lime 4% (m/v) and coal 50% (m/m) promoted complete inactivation of all pathogens indicators (pH~12 and 45 °C of average temperature, after the second day). MARTENS & BÖHM (2009) reported the alkaline treatment with granular lime (10% m/v), stored in batteries (humid environment and protected from light) for a period of 10 weeks.

The effect of temperature on the inactivation of *Salmonella* in swine manure was investigated by ARRUS et al. (2006) in three conditions: 4; 25 and 37 ºC. The results show the decrease in efficiency of disinfection with decreasing temperature. To achieve the Decimal Reduction Time (DRT - time required to remove 90% of initial number of individuals) in three conditions evaluated, an average of 41, 13.5 and 1.1 days, respectively, were necessary.

VINNERAS (2007) compared three different procedures for sanitizing swine manure: composting, urea addition and storage. In composting food waste, temperature reached values close to 60 ºC, which guaranteed up to 5 log of *Salmonella*, *Enterococcus* and thermotolerant coliform in six days of treatment. In tests with urea (3% m/v), the slurry was maintained at pH 9 for 1 hour (at room temperature), resulting in DRT below 0.7 day for *Salmonella* and thermotolerant coliforms, and below three days for *Enterococcus*. Moreover, in simple storage (no heating and urea), with the slurry at 20 °C, DRT to thermotolerant coliforms and *Enterococcus* was nine and 50 days, respectively. For *Clostridium spp*. no reduction was observed in 50 days of treatment. The DRT for *Salmonella*, with the slurry at 14 °C was 25 days. Experiments with urea achieved the best results in 1 hour of reaction, possibly due to the higher toxicity of free ammonia on microorganisms.

Some studies have also reported the use of unconventional alternatives to promote the increase of temperature to inactivate pathogens. LAGUNAS-SOLAR et al. (2005) evaluated the effect of radiofrequency energy emitted to achieve adequate temperature to thermal treatment. The results showed that only 1 minute of exposure to 10 and 14 MHz was sufficient to raise the slurry temperature to 63 °C and remove 7 log of *Salmonella* sp. bacteria and 6 log of *E. coli* O157:H7 and *Mycobacterium avium* ssp. *paratuberculosis* bacteria. According to this study, the radio frequency can be used in large scale, batches or continuous process, with low power consumption required for consumption in conventional heating surface contact. MARTENS & BÖHM (2009) reported that the microwave can be efficient to raise the temperature of the manure (~80 ºC) and promote the complete inactivation of vegetative bacteria and more resistant organisms such as viruses and parasites, but this technology is not yet applied to the processing of waste in large scale, due to their operating cost.

Generally, thermal treatment has a lower cost compared to other methods (ozone and UV radiation). However, its use in cold climates requires higher energy consumption in the winter to heat and maintain the biomass at the proper temperature for disinfection, representing an additional cost to the process (MACAULEY et al., 2006).

Biological process treatment

The treatment of swine manure by biological process has as main objective the reduction of the organic load, nitrogen and phosphorus, using processes such as biodigester, stabilization ponds, composting and biological reactor, which occur both aerobically as anaerobically. Furthermore, studies have also reported the ability of the biological treatment to reduce the amount of pathogens in swine manure (HEINONEN-TANSKI et al., 2006; VENGLOVSKY et al., 2009; ORRICO et al., 2007; MARTENS & BÖHM, 2009; MASSE et al., 2011).

When aerobic biological reactors are operated under appropriate conditions (aeration, organic load, homogenization, detention time), microorganisms decompose the organic matter present in the waste. The rapid metabolism of these compounds reduces the availability of substrate, and leads to predation and elimination of pathogenic organisms (VANOTTI et al., 2005; HEINONEN-TANSKI et al., 2006; JUTEAU, 2006; MARTENS & BOHM, 2009; VENGLOVSKY et al., 2009).

MASSÉ et al. (2011) reported a 2.8 log removals for coliforms and 1.3 log for *Salmonella* in a psychrophilic anaerobic biodigester (temperature below 20 °C) after seven days. The efficiency of disinfection in mesophilic phase (30 to 40 °C) is lower than the thermophilic phase (~55 °C). As the average temperature in anaerobic digestion is close to the mesophilic range (20 to 45 ºC), its ability to sanitation is lower compared to aerobic digestion. The increased efficiency of inactivation in anaerobic digestion will mainly depend on the temperature rise to the thermophilic phase (45 to 60 ºC), which implies the additional consumption of energy, which can be provided by the energetic use of biogas generated in the process (HEINONEN-TANSKI et al., 2006; MASSÉ et al., 2011).

In biological treatment (biodigester, aerobic biological reactor and stabilization pond) the endogenous cellular degradation process also promotes the inactivation of pathogens, both aerobically as anaerobically, since the system used is properly operated. VANOTTI et al. (2005) report the removal of 2.4 log of *Salmonella* by denitrification- nitrification (sequential anoxic-aerobic reactor). This is due to the use of alternative substrates by bacteria responsible for reducing the concentration of organic matter and nutrients in the biological treatment, since it is the significant reduction of the available influent organic load (VANOTTI et al., 2005; HEINONE-TANSKI et al., 2006; MARTENS & BÖHM, 2009).

Composting (thermophilic phase) has also been reported to control pathogens, with removal of approximately 3 log (ORRICO et al., 2007). However, adequate oxygenation should be kept (optimal concentration between 15 and 20% O_2/v) for maintaining the temperature in the thermophilic phase depends on the efficiency of aeration of waste (HEINONEN-TANSKI et al., 2006; BERNAL et al., 2009; MARTENS & BÖHM, 2009). The US Environmental Protection Agency (USEPA) regulates the obligation of certain practices in the inactivation of pathogens in composting (EPA 625/4/85/014-1985). They are: maintaining compost temperature above 55 °C of at least three consecutive days in closed piles with artificial aeration and 15 days in the case of piles with manual turning of compost and natural reaeration (TURNER, 2002).

Brazilian law, however, does not regulate treatment practices aimed at controlling specific pathogens in biofertilizers from confined livestock.

Oxidizing agent treatment

Other methods of disinfection use chemical processes, which rely on the addition of oxidizing agents capable of destroying, partially or completely, cellular structures of pathogenic organisms. This is the case of the use of chlorine, ozone, hydrogen peroxide, among others.

Studies conducted by MACAULEY et al. (2006), with pig effluent collected in the stabilization pond followed by centrifugation (Oxygen Chemical Demand of 425.2 mg L^{-1}), reached removal of 3.4 log of thermotolerant coliform with hypochlorite and hypochlorous acid in dosage of 30 mg Cl^{-} L^{-1} in solution and contact time of 2.5 h. The research also showed the efficiency of chlorination on bacteria more resistant to disinfection by the action of antibiotics for veterinary use (lincomycin, chlortetracycline, sulfamethazine, and tetracycline).

However, the use of chlorination in the disinfection has been widely questioned due to the formation of by-products that may compromise the final quality of water, particularly the organochlorine compounds formed during the chemical oxidation of organic matter, such as trihalomethanes, haloacetic acids, haloaldehydes, haloketones, halophenols, halopicrin, among other by-products of high toxicity (PASCHOALATO et al., 2008). RICHARDSON (2011) points out that the direct consequences of these byproducts in human health include carcinogenic and genotoxic effects. Although the study is for the consumption of organochlorine byproducts in water supply, negative effects on indirect consumption by percolation of these compounds in soil or their dispersion in water bodies, and water dynamics in recharge aquifers and surface water sources intended for human consumption should also be considered.

In Brazil, Ordinance 2914 of the Ministry of Health, published in 2011, sets the maximum limit of 100 mg L^{-1} for trihalomethanes (THMs) on water supply, although there are other chlorination byproducts potentially harmful to human health (RICHARDSON, 2011). Therefore, in recent decades other alternatives have been studied, aiming at replacing the chlorine disinfectants by other less harmful to human health and environmental quality in terms of products generated. This is due to the fact that organochlorine compounds are formed from the chemical oxidation of organic matter remaining is the treatment of water supplies, either to treat animal waste, since no conventional therapy is able to completely remove the organic load tributary.

Hydrogen peroxide (H_2O_2) has also been reported as a disinfection agent for pig manure. TOFANT et al. (2006) reported the removal of 2.8 log of total coliforms after applying a solution of H_2O_2 at 2% (v/v) with traces of Ag^+ ions (catalyst) for 2 hours, including promoting the inactivation of spores. In the experiments, samples of liquid swine manure collected in the output of a mechanical solid-liquid separator were used.

Other technique is the use of disinfection ozone gas (O_3). MACAULEY et al. (2006) investigated the effect of ozone gas disinfectant compared to free chlorine in samples of centrifuged pig manure from stabilization ponds, considering the average consumption of the oxidizing agent and the reaction time required for inactivation desired. In the treatment with sodium hypochlorite at 30 and 50 mg L^{-1} (applied concentration) and contact time of 2.5 h the reduction found was of 3.4 and 3.6 log, respectively, while in the treatment with ozone (40 mg L^{-1}), considering the same contact time, had the reduction of 3.1 log.

Besides the disinfectant effect, chlorination, ozonation, and the use of hydrogen peroxide favor the final effluent clarification and reduction of odor due to oxidation capacity of nitrogenous and sulfurous organic compounds, although this requires a higher consumption of disinfecting agents (MACAULEY et al., 2006; TOFANT et al., 2006). The high concentration of suspended solids in manure is a limiting factor in the efficiency of chemical disinfection process. The concentration of the chemical agent used (chlorine, ozone or oxygen peroxide) must meet both the demands of chemical oxidation reactions of remaining organic matter of the treatment regarding demand of disinfection reactions (MACAULEY et al., 2006). Accordingly, to achieve efficiency above 99% is required pretreatment of the waste to promote their clarification (removal of suspended solids) prior to application of chemical disinfectant, otherwise the results will not be satisfactory.

Radiation treatment

The use of ultraviolet radiation has been widely used to disinfect wastewater (BILOTTA & DANIEL, 2010). However, few scientific studies have reported the use of this practice in the inactivation of pathogens in manure. The disinfectant effect of UV radiation occurs due to the high energy associated with the wavelength of 254 nm, whose intensity is responsible for destruction (completely or partially) DNA and cellular RNA, ensuring inactivation of the organism affected by radiation (MACAULEY et al., 2006). The main advantage of this technique is not the generation of disinfection by-products, since the emitted energy is absorbed mainly by the microbial cell (DNA and RNA), causing irreversible and lethal damage (MACAULEY et al., 2006; BILOTTA & DANIEL, 2010).

MACAULEY et al. (2006) investigated the effect of UV radiation on samples from swine manure at the output of stabilization ponds, using mercury vapor low pressure lamp with an intensity 5.4 mW cm^{-2} at 254 nm. Dosages of 220 mJ cm^{-2} and 770 mJ cm^{-2} with 10 minutes of exposure promoted reductions of 3.4 and 4.2 log of bacteria, transmittance of 0.10% and 2.19%, respectively, and complete inactivation was reached within 30 minutes. Comparatively, for the disinfection of sewage with UV radiation (effluent treatment in the anaerobic reactor and aerobic biological filter) is required dosages about 200 mJ cm^{-2} and 60 seconds of exposure to achieve reductions of 5.0 log of *E. coli* in samples with transmittance of 52% (BILOTTA & DANIEL, 2010). Comparing the efficiency of disinfection of swine manure to sewage it is possible to see that the presence of suspended solids, expressed in terms of the transmittance, is much lower in wastewater which favored, largely, the best results of inactivation achieved. This is due to the shielding effect, promoted by suspended solids, hampering (or preventing) the passage of UV radiation and restricting its germicidal action (SINGH et al., 2006; BILOTTA & DANIEL, 2010).

In practice, the high amount of suspended solids in swine manure is the main limitation of photochemical UV reactors. This implies a lower efficiency for disinfection or high energy cost (increase in exposure time) required for achieving the necessary dosages of UV radiation for inactivation above 99% (MACAULEY et al., 2006; SINGH et al., 2006). Therefore, the disinfection of swine manure is essential to implement efficient systems for removal of suspended solids prior to disinfection, through procedures such as coagulation-flocculation, stabilization ponds and biological reactors (KUNZ et al., 2009; KUNZ et al., 2010).

Brazilian law

The Ministry of Agriculture, Livestock and Supply in Normative Instruction nº 27 of July 5th , 2006 establishes maximum limits for pathogens in the production, import and marketing of bio-fertilizers, among other guidelines, as follows: fecal coliform <1,000 NPM/g of dry weight; viable helminth egg <1/4 g of total solids; absence of *Salmonella* sp in 10 g of dry mass (MAPA, 2006). However, this instrument does not establish specific criteria and procedures for the control of pathogens in pig manure biosolids for agricultural use.

The National Environment Council, by means of Resolution CONAMA 375 (2006), also establishes sanitary parameters, microbiological criteria and treatment conditions for the use of biosolids in agriculture, but it is only regarding to sludge from sewage treatment stations. Similarly, Resolution CONAMA 420 (2009) establishes criteria for the prevention of soil contamination and guidelines for the management of areas contaminated by human activities, including agricultural areas, but it refers only to chemicals. Therefore, the existing legal instruments do not regulate microbiological control criteria and conditions for use of swine manure biosolids in agriculture.

Resolution CONAMA 430 (2011) establishes standards and conditions for the disposal of human effluents on water bodies (sewage, industrial effluent, solid waste treatment effluent, etc.), but the resolution does not include microbiological criteria.

From the point of view of water reuse, the main regulatory instruments in force in Brazil are set by the National Water Resources Council (Resolution 54/2005) and the Brazilian Association of Technical Standards (NBR 15,527/2007). Resolution 54 sets guidelines for direct reuse of water (planned use) for non-potable uses, including urban activities such as landscape irrigation, aquaculture and agriculture, forestry and industrial, but this resolution does not deal with microbiological criteria. The NBR 15,527 has just reuse criteria for the use of rainwater. So there are no specific criteria for microbiological quality control for water reuse from animal production systems.

CONCLUSIONS

The importance of inactivation of pathogens in manure treatment of confined swine production is unquestionable, both for the maintenance of human health as environmental quality. It is necessary to first establish the intended destination for the treated manure (biosolids for agricultural use and reuse water for non-potable purposes), as this will determine the level of treatment required to achieve the required microbiological quality. Table I presented below summarizes the main aspects of disinfection methods of manure reported in literature.

TABLE 1. Treatments and pathogen reduction order in swine manure.

Treatment	Reduction	Advantages/Disadvantages	References
Alkaline (pH>10)	2 - 3 log	High consumption of $Ca(OH)_2$	VANOTTI et al. (2005) MARTENS & BÖHM (2009) WONG & SELVAM (2009)
Thermal ($T\sim60^{O}C$)	> 4 log	High energy consumption	LAGUNAS-SOLAR et al. (2005) VINNERAS (2007) MARTENS & BÖHM (2009)
Biodigester ($T\sim40^{O}C$)	1 - 2 log	Room temperature influence Lower cost Biogas use potential	VENGLOVSKY et al. (2009) MASSÉ et al. (2011)
Composting	2 - 3 log	Long treatment period Energy consumption after aeration	HEINONEN-TANSKI et al. (2006) ORRICO et al. (2007) BERNAL et al. (2009) MARTENS & BÖHM (2009)
Chemical (oxidizing)	3 - 4 log	Disinfection by-product formation Need of preliminary treatment High cost of chemical disinfectants	MACAULEY et al. (2006) TOFANT et al. (2006)
Physical (UV radiation)	3 - 4 log	Influence of suspended solids There is no formation of disinfection by-products Need of preliminary treatment High energy consumption	MACAULEY et al. (2006) SINGH et al. (2006)

Chemical (oxidizing agents) and physical (UV radiation) treatments require the installation of swine manure preliminary treatment steps to reduce the bulk of the effluent organic load (and nutrients), since the presence of suspended solids reduces considerably the efficiency of disinfection. In any event, regardless of the alternative chosen, the disinfection must be seen as an additional processing step and its effectiveness will depend in large part on the proper operation and function of the preliminary treatment (physical, chemical or biological).

Brazilian law does not have a regulation with specific guidelines to ensure the microbiological quality of swine manure treated, both in relation to agricultural use of biosolids as for water reuse after treatment. It is increasing the need for the establishment of a legal framework in Brazil.

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