SEWAGE SLUDGE APPLICATION IN AGRICULTURE: PATHOGEN REDUCTION BY TEMPERATURE-PHASED ANAEROBIC DIGESTION

Riau V[1]., de la Rubia M.A[2]., Pérez M[1].
[1]Department of Environmental Technologies, Faculty of Sea and Environmental Sciences. University of Cádiz. 11510 Puerto Real, Cádiz, Spain.
[2]Instituto de la Grasa (CSIC), Avda. Padre García Tejero 4, 41012 Sevilla (Spain)

1 INTRODUCTION

The treatment and disposal of sewage sludge generated by conventional biological wastewater treatment plants is receiving increasing attention. This is because sludge volumes are increasing as a consequence of more stringent criteria for wastewater treatment plant effluent (Council Directive 91/271/EEC, 1991).

The announcement of standards for the use or disposal of sewage sludge (40 CFR Part 503, US EPA, 1992) has provided a strong impetus for treating sludge to Class A quality in the United States of America. In addition to pathogen destruction, Class A biosolids must achieve a minimum level of vector attraction reduction (US EPA, 1999). In Europe, Council Directive 86/278/EEC (1986) considers that recycling for agricultural land is an important outlet for sewage sludge. However, the sludge must be controlled in order to obtain an agricultural benefit – whilst protecting human and animal health and the environment at large (Lang and Smith, 2008).

Despite the fact that Council Directive 86/278/EEC was developed to protect the environment, and in particular the soil when sewage sludge is used in agriculture, the directive only regulates the maximum concentration of heavy metals in sewage sludge. It does not take into account the fact that biosolids originating from wastewater treatment plants by their nature contain a wide diversity of pathogens, some of which may be present in large numbers, including *Salmonella* spp., and represent a health hazard to the general public (Sidhu et al., 2001). In fact, the concentration of *Salmonella* spp. in dewatered anaerobically digested wastewater sludge can be more than 10^5 g^{-1} of dry weight (Russ and Yanko, 1981). To eliminate this omission in Directive 86/278/EEC, the Third Draft EU Working Document on Sludge (Environment DG, EU, 2000) has been available online since 2003.

Temperature-phased anaerobic digestion (TPAD) treatment combining a thermophilic step with a short retention time and higher temperatures (55ºC) as well as mesophilic step with a longer retention time and lower temperatures (35ºC) is known to provide pathogen control and effective organic matter treatment (Huyard et al., 2000).

This study investigates how to achieve the best results from a TPAD system when handling a temperature-phased anaerobic digestion of sewage sludge in batch reactors and in continuously stirred tank reactors (CSTR) at discontinuous and semi-continuous fed conditions, respectively. To obtain a Class A sludge product in terms of pathogens destruction (Faecal coliforms and *Salmonella* spp.), the solid retention time (SRT) for each step has been optimized. To this end raw samples were subjected to dual-thermophilic–mesophilic-digestion processes at various thermophilic/mesophilic retention times (days): TPAD 2/15, TPAD 4/15 and TPAD 6/15 at discontinuous mode and TPAD 15/15, TPAD 5/15, TPAD 3/15 as well as TPAD 3/12 at semi-continuous mode.

2 MATERIALS AND METHODS

2.1 Discontinuous assays

The equipment used was specifically designed to carry out discontinuous assays for the anaerobic digestion processes over a range of temperatures. The apparatus is composed of a bank of four stirred anaerobic reactors of 3 L of the total volume and 2.5 L of the working volume, which are heated using a thermostatic bath.

Four batch reactors (R1, R2, R3 and control) were operated. The inoculum/substrate ratio (ISR) tested was achieved by keeping a constant inoculum concentration (15 g VS L^{-1}). Firstly, all digesters were filled with a mixture of thermophilic sludge (inoculum) and raw sludge (substrate). The TPAD system was subjected to three different time periods under thermophilic conditions. In addition, a fourth reactor was inoculated, as a process

control, without substrate. This control allows the inoculum activity to be confirmed. R1, R2 and R3 were operated at thermophilic conditions for 2, 4 and 6 days, respectively, in order to study the evolution of microbiological parameters at various times throughout the thermophilic stage process. Afterwards, all digesters were re-started up and inoculated with a digested mesophilic sludge, and the thermostatic bath temperature was altered to 35 ºC. The substrate in this case was the product of the thermophilic stage. The system remained under mesophilic conditions until the biodegradation process was completed, after 15 days. Therefore, the total time of the batch experiment was 17, 19 and 21 days for R1, R2 and R3, respectively. The control reactor was operated during 6 days under thermophilic conditions and 15 days under mesophilic conditions.

2.2 Semi-continuous study

The experiments were carried out using two digesters operating as completely stirred tank reactors and connected. The lab-scale system consisted of a 5 L thermophilic reactor (4.5 L of working volume) followed by a 10 L mesophilic digester (9.0 L of working volume). Both experimental digesters shared similar characteristics.

Initially, the organic loading rate (OLR) applied to the thermophilic reactor was 1.8 g VS L^{-1} d^{-1} with an SRT of 15 days, and these conditions were maintained constant until reaching steady-state conditions. The TPAD system mesophilic reactor was later fed with the effluent generated in the previous thermophilic digester. The attainment of the steady-state for all stages of the TPAD process was verified after a period equivalent to three times the SRT by checking whether constant effluent characteristic values.

Four TPAD experiments were carried out. The first-stage thermophilic (55 ºC) digester was operated at 15, 5, 3 and 3 days of retention time, respectively; and its effluent was used to provide feed for the second-stage mesophilic (35 ºC) digester. The second-stage digester was operated at SRTs of 15, 15, 15 and 12 days, respectively. Four SRT combinations were then assayed: 30 (TPAD 15/15), 20 (TPAD 5/15), 18 (TPAD 3/15) and 15 (TPAD 3/12) days. A single-stage mesophilic digester (5 L), which was operated with a 15-day SRT, was used as the control system. These conditions were chosen taking into account the results obtained for batch conditions.

2.3 Analytical methods

Salmonella spp. and Faecal coliforms densities were determined in accordance with 9221C and 9260B standard methods (APHA, 1998), respectively. The appendix F and G of EPA/625/R-92/013 (1992) has also been taken into account for pathogens analyses.

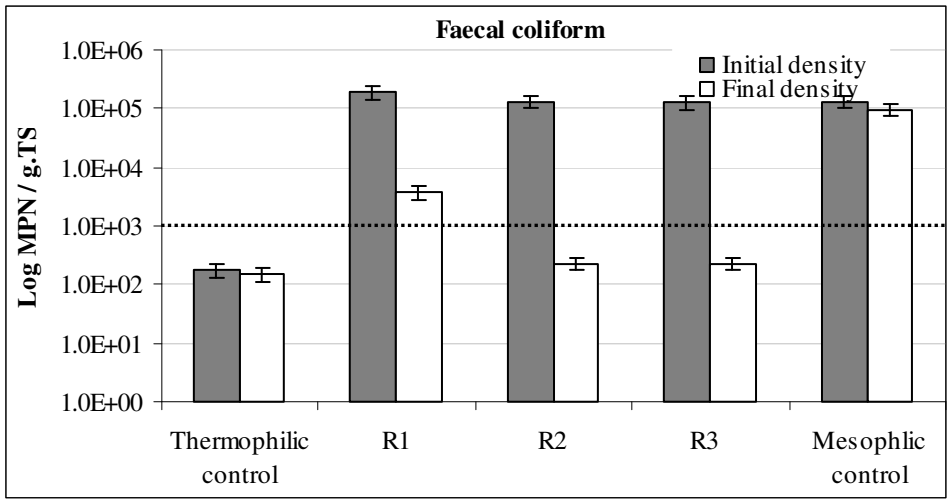
3 RESULTS AND DISCUSSION

3.1 Discontinuous study. Pathogen destruction.

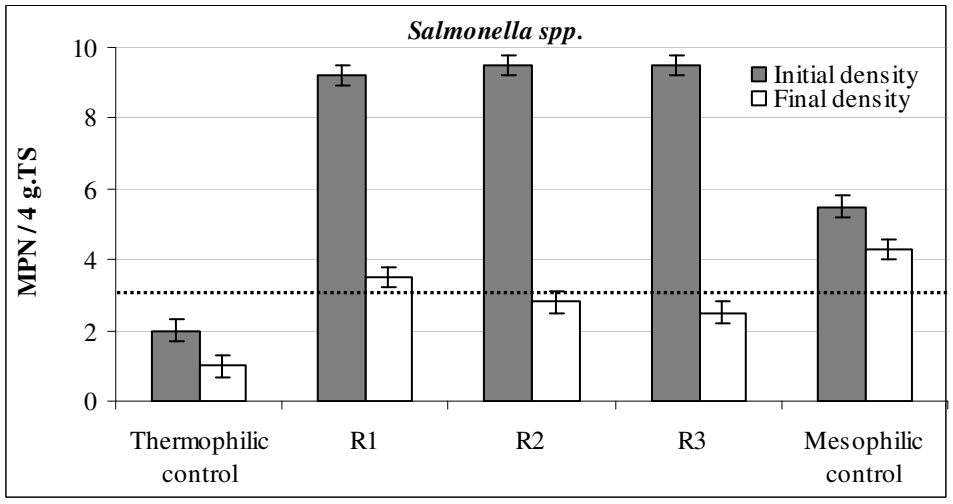
The digested solids from TPAD meet the Class A biosolids requirements laid down in 40 CFR Part 503 regulations (USEPA, 1992). Influent and effluents quality data from the TPAD system show Faecal coliform (Fig. 1a) and *Salmonella* spp. (Fig. 1b) densities in R1, R2 and R3 batch systems and mesophilic and thermophilic controls anaerobic digester product sludge.

Therefore, the Class A sludge pathogens density limit is represented. The R2 and R3 systems reduced the initial mixture faecal coliforms density from 1.3 x 10^5 MPN/g TS to $<10^3$ MPN/g TS (Class A sludge limit). Both systems achieved faecal coliforms density reductions greater than 99%, due to the high temperatures of the thermophilic stage, in comparison to the mesophilic control, which showed a reduction of 26%. Moreover, as can be seen in Fig. 1b, the R2 and R3 systems achieved *Salmonella* spp. density reductions below the Class A sludge limit (3 MPN/4 g TS) as well, showing density eliminations of 70% and 74%, respectively. Although Roberts et al. (1999) carried out TPAD experiments operating at SRT shorter than 1 day, for the pre-acidification stage of sewage sludge at thermophilic no pathogens data were reported.

Cheunbarn and Pagilla (2000) obtained Class A biosolids operating at 1 day under thermophilic conditions and 14 days at mesophilic temperature in a TPAD system. However, the results obtained in this study suggest that, if pathogen reduction is the main objective of the TPAD system, then at least 4 days of thermophilic stage is necessary in order to obtain a Class A biosolid from the sewage sludge, with the conditions studied. Four days was also the shortest thermophilic retention time used for Han et al. (1997), to produce a Class A biosolid.



(a)



(b)

FIGURE 1 **(a) Faecal coliform densities, and (b) *Salmonella* spp. densities, at the beginning and end of assay, in R1, R2 and R3 and control mesophilic and thermophilic anaerobic digester product sludge. (lines indicate EPA limits). Discontinuous conditions.**

3.2 Semi-continuous study. Pathogen destruction.

Faecal coliform densities in the TPAD system effluent sludge, at various SRTs, as well as mesophilic control anaerobic digester sludge and the Class A sludge faecal coliform density limit are shown in Fig. 2.

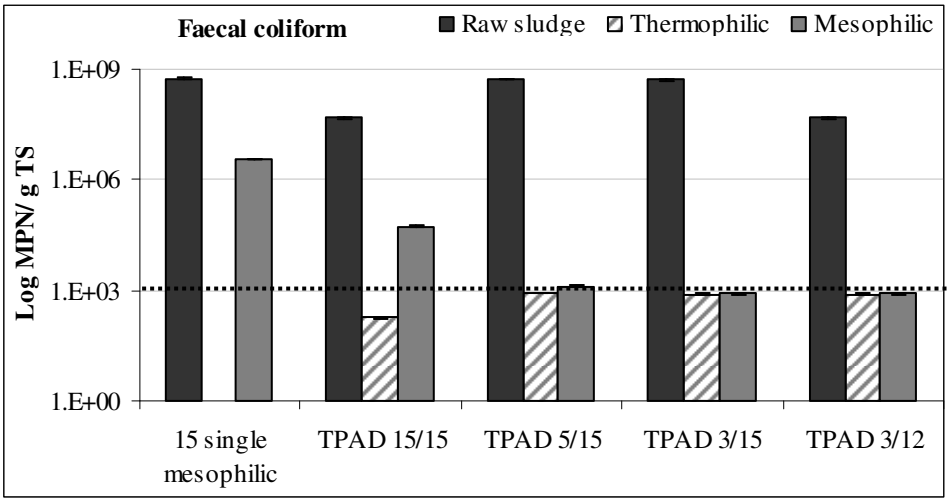
Average faecal coliform density in the feed sludge was higher than 10^8 MPN g^{-1} TS, although the initial density of faecal coliform obtained in the discontinuous study was lower: 10^6 MPN g^{-1} TS. Similar concentrations were detected by Cheunbarn and Pagilla (2000).

The thermophilic stage reduces faecal coliform density from 10^8 MPN g^{-1} TS to $<10^3$ MPN g^{-1} TS, being the limits specified by US EPA for classification as biosolids Class A (US EPA, 1999) at the four TPAD assayed, maintaining 15, 5, 3 and 3 days SRT at thermophilic conditions, respectively. However, in both TPAD 15/15 and TPAD 5/15, a recurrence of faecal coliforms was observed in the second stage (mesophilic reactor) which exceeded the Class A limit for faecal coliforms for land application. Iranpour and Huub (2006) stated that the recurrence of faecal coliforms may be related to the incomplete destruction of faecal coliform during thermophilic anaerobic digestion. But, in this case, this can be explained because the initial pathogen density was very high in the feed and the mesophilic sludge used as inoculum for the second stage of the TPAD – that is, 3.6 x 10^6 MPN g^{-1} TS for faecal coliform and 4 MPN/4 g TS for *Salmonella* spp., as shown in Fig. 2. In the mesophilic stage, the VFA concentration is too low to kill pathogens and the mesophilic temperature (30–40 ºC) that is the optimum temperature for growth and survival of enteric organisms. Therefore, mesophilic temperatures do not exert a specific thermal stress on the

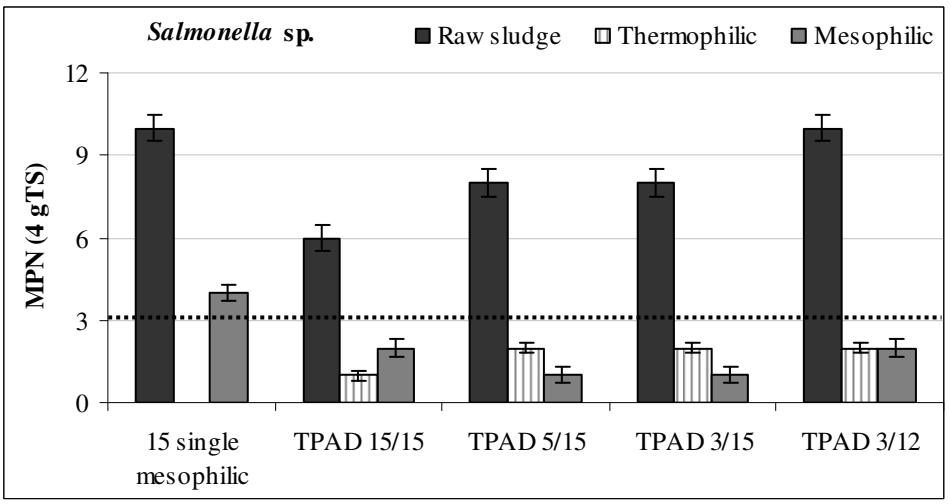
decay of faecal coliforms or *Salmonella* spp. Accordingly, an initial period to reduce the pathogen density by washing out the pathogen population from the mesophilic digester is necessary.

Salmonella density in the feed sludge during these experiments was between 6 and 10 MPN/4 g TS, whereas in the all TPAD systems effluents densities were 62 MPN/4 g TS at all solid retention times (lower than Class A limit = 3 MPN/4 g TS). Single mesophilic digestion conditions did not produce *Salmonella* spp. densities lower than 4 MPN/4 g TS. A previous thermophilic stage enhanced the final results.

These results suggest that, if pathogen reduction is the main objective of the dual-stage system, TPAD 3/15 gives a better performance than other systems studied, but is also important to take into account that initially the pathogen concentration in the mesophilic reactor could be higher than in the thermophilic digester. Therefore, an initial acclimation period is necessary for the mesophilic stage to be classified as a Class A biosolid in a TPAD system.



(a)



(b)

FIGURE 2 **(a) Faecal coliform, and (b) *Salmonella* spp. Variation in concentration in the raw sludge, after the first-stage thermophilic and at the end of the TPAD process (mesophilic). Lines indicate EPA limits to consider a biosolid as Class A. Semi-continuous conditions.**

4 CONCLUSIONS

The sewage sludge anaerobic thermophilic pretreatment followed by mesophilic digestion can improve the process, in terms of pathogen defusing. In the discontinuous assays, the systems that were under thermophilic conditions for 4 and 6 days achieved higher faecal coliforms and *Salmonella* spp. eliminations than the EPA limits. So, the 4 day thermophilic phase, followed by a mesophilic treatment, is enough to obtain a product sludge that can be catalogued as a Class A biosolid.

Semi-continuous temperature-phased anaerobic digestion systems showed better performance and process stability at total SRT of 15 days than single-stage mesophilic or thermophilic digestion at SRT 15 days. TPAD 3/15 was found the best (this means that thermophilic digestion can be even shorter than obtained in batch experiments) with faecal coliform densities $<10^3$ MPN/g TS and *Salmonella* spp. of 1 MPN/4 g TS (Class A biosolids that can be used in agriculture without any restriction). Initially the pathogen concentration in the mesophilic reactor could be higher than in the thermophilic digester. Therefore, an initial acclimation period is necessary in this stage.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the Spanish Ministry for the Environment, Rural Affairs and Marine Policy (Project 148/PC08/3-04.3) for providing financial support, to the ‘‘Programa Junta para la Ampliación de Estudios del CSIC para la especialización de doctores” and to the Novedar_Consolider project (CSD2007-00055).

REFERENCES

APHA–AWWA–WPCF, 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. Washington, DC.

Cheunbarn T, Pagilla K 2000. Anaerobic thermophilic/mesophilic dual-stage sludge treatment. J. Environ. Eng. 126 (9), 796–801.

Council Directive 86/278/EEC, 1986. Council directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Official Journal of the European Communities, L181, 6–12.

Council Directive 91/271/EEC, 1991. Council directive concerning urban wastewater treatment. Official Journal of the European Communities, L 135, 40-52.

Environment DG, EU, 2000. Working Document on Sludge 3rd Draft, July 2003. http://ec.europa.eu/environment/waste/sludge/pdf/sludge_en.pdf.

Han Y, Sung S, Dague RR 1997. Temperature phased anaerobic digestion of wastewater sludges. Water Sci. Technol. 36 (6–7), 367–374.

Huyard A, Ferran B, Audic JM 2000. The two phase anaerobic digestion process: sludge stabilization and pathogens reduction. Water Sci. Technol. 42, 41–47.

Iranpour R, Huub HJ 2006. Recurrence of fecal coliform and *Salmonella* species in biosolids following thermophilic anaerobic digestion. Water Environ. Res. 78 (9), 1005–1012.

Lang NL, Smith SR 2008. Time and temperature inactivation kinetics of enteric bacteria relevant to sewage sludge treatment processes for agricultural use. Water Res. 42, 2229–2241.

Roberts R, Davies WJ, Forster CF 1999. Two-stage, thermophilic–mesophilic anaerobic digestion of sewage sludge. Trans. IChemE Part B 77, 93–97.

Russ CF, Yanko WA 1981. Factors affecting *Salmonellae* repopulation in composted sludges. Appl. Environ. Microbiol. 41, 597–602.

Sidhu, J., Gibbs, R.A., Ho, G.E., Unkovich, I., 2001. The role of indigenous microorganisms in suppression of salmonella regrowth in composted biosolids. Water Res. 35 (4), 913–920.

US Environmental Protection Agency 1992. Control of pathogens and vector attraction in sewage sludge (including domestic septage) under 40 CFR part 503, 625/R-92/013.

US Environmental Protection Agency 1999. Control of Pathogens and Vector Attraction in Sewage Sludge, EPA 625/R-92/013. US Environmental Protection Agency: Washington, D.C. (revised 1999).