AEROBIC THERMOPHILIC TREATMENT OF SEWAGE SLUDGE WITH AND WITHOUT FOOD WASTES

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1 INTRODUCTION

The increasing prices of fuel and fertilizers together with the increasing grain growing for food and biomass form an untenable equation, and thus, the pressure to re-use organic wastes as fertilizers or soil improvers is increasing. Sewage sludge is exquisite source of nutrients and organic material. Using sewage sludge as a fertilizer would turn waste into a valuable resource according to the principles of sustainable development. High amount of heavy metals, originating mostly from the industrial wastewaters, restricted earlier the agricultural use of sewage sludge. Nowadays heavy metals are not so widespread problem in sludge products, thanks to the strict control of sources and use of heavy metals, as well as, the obligation to pre-treat wastewaters in industrial plants (Vihersaari 2002, Rantanen et al. 2008). However, sewage sludge contains pathogens, which may pose hygienic risk to land users, and therefore the sludge should be treated responsibly before application. In addition to sewage sludge, food industry wastes, such as jam residues, whey and potato peel wastes, could also be treated and recycled in agricultural practices, and thereby diminish the loading of wastewater treatment plants in some areas (Mohaibes and Heinonen-Tanski 2004, Heinonen-Tanski et al. 2005).

Thermophilic aeration has proven to be promising method in improving the hygienic quality of animal slurry together with food waste. The method has reported to have the capability of maintaining disinfection temperatures solely from the heat released from the biological oxidation of organic matter, thus requiring no supplemental heat (Svoboda and Evans 1987, Heinonen-Tanski et al. 2005). Thus the potential advantage of this method is the pathogen inactivation, which is not necessary reached using anaerobic digestion, quick liming or in-vessel composting (Vuorinen 2003). In addition, the method is much easier and the capital costs are cheaper in aerobic treatment of slurry and food wastes than methanogenesis (Mohaibes & Heinonen-Tanski 2004). However, the suitability of thermophilic aeration for the hygienisation of sewage sludge with food wastes has not been studied widely.

Our purpose was to study the suitability of thermophilic aeration for the treatment of liquid sewage sludge with and without food wastes. The aim was to improve the hygienic quality of the sludge without having negative effect on the nutrient quality of the mixture.

2 MATERIALS AND METHODS

The study was conducted in laboratory scale aeration reactors with aeration, mixing and heating. Sewage sludge (S) was composted with and without whey (W), jam residues (J) or potato peel waste (P) in thermophilic conditions (70 °C) for five days followed by post-composting in mesophilic conditions (40 °C) for five days. Three different mixtures of raw materials (% by volume) were used: 1) 100 % sludge (100S), 2) 60 % sludge 30 % whey 10 % jam residues (60S30W10J) and 3) 70 % sludge 15 % whey 15 % potato peel waste (70S15W15P). The process was carried out semi-continuously by replacing daily 20 % of the treated mixture with fresh raw material to get the retention time of 5 days.

Sewage sludge was picked up from Lehtoniemi wastewater treatment plant, which is located in the city of Kuopio. In Lehtoniemi wastewater treatment plant, the sludge is formed during the wastewater purification process (average flow was 18100 m^3/d during 2009), where sand and solid waste are removed from the wastewater mechanically, organic matter and nitrogen biologically, and phosphorus chemically. Whey was picked up from local dairy (Osuuskunta Maitomaa, Suonenjoki), jam residues from manufacturer and developer of processed berry and fruit ingredients (Nordic jam Ltd., Suonenjoki) and potato peel waste from local farmer (N. Vartiainen, Vartiala). Properties of raw materials are presented in Table 1.

TABLE 1 **Properties of sewage sludge, whey, jam residues and potato peel waste, which were used as raw materials in aerobic thermophilic treatment.**

Raw material	Total solids, g/L	Volatile solids, g/L	pH	Total nitrogen, g/L	BOD, g/L
Sewage sludge	30	21	6.7	1.3	11
Whey	60	53	4.5	1.4	51
Jam residues	185	184	3.1	0.2	179
Potato peel waste	193	182	5.9	2.2	40

The microbial hygiene of sludge mixture was determined before and after the thermophilic and mesophilic treatment. Fecal coliforms, enterococci and fecal clostridia (sulfite reducing clostridia) were determined by cultivating diluted samples with spread plate technique on Les-Endo agar (SFS 4088 1988), Slanetz-Bartley agar (SFS EN-ISO 7899-2 2000) and Clostridia agar (SFS-EN 26461-2 1993), respectively. Fecal clostridia were incubated in anaerobic jars (Heinonen-Tanski & Savolainen 2003). RNA coliphages (*Escherichia coli* ATCC 15597 as a host) was determined by using double agar technique (SFS-EN ISO 10705-1 2002).

Several physic-chemical parameters were analyzed during the treatment (temperature and pH), as well as before and after the thermophilic and mesophilic treatment (biological oxygen demand (BOD), total solids (TS), volatile solids (VS) and total nitrogen (N) content). BOD was determined by respirometric method with the OxiTop measurement system, which included addition of nitrification inhibitor (N-allyl thiourea) (WTW, Germany) (Roppola et al. 2007). TS and VS were determined by weighting the sample (V=50ml) before and after digestion for 24±4 h in 105±3 °C and 2 h in 550 °C, respectively (SFS 3008 1990). Total nitrogen was determined by Kjeldahl method.

Phytotoxicity and maturity of composted sludge mixture was evaluated by studying the effect of sludge, whey and potato peel waste mixture (70S15W15P) application on the emergence and early stages of growing of ryegrass (*Lolium perenne*), cress (*Lepidium sativum*) and radish (*Raphanus sativus*). The mixture of composted sludge and peat (*sphagnum* peat B2, Kekkilä, Finland) was prepared in three replicates by hand-mixing the components in ratio 1:4 (by volume). Growing was carried out under greenhouse lamps with an 18 h day at 20 °C and 6 h night at 18 °C. Emergence, and fresh and dry weights of each replicate were determined 14 days after sowing.

3 RESULTS AND DISCUSSION

The study showed that the addition of whey and jam residues or potato peel waste increased TS and more importantly the VS and BOD content of the sludge (Table 2). All food industry residues decreased the pH of sludge, but not too much for microbial degradation. In preliminary study, addition of 15 % whey and jam residues (% by volume) in 70S15W15J-treatment caused decrease of pH below 5 and had negative effect on microbial activity. Previously Heinonen-Tanski et al. (2005) reported that 35 % of jam residues addition to slurry causes the pH fall below 5 and thereby decreases the oxygen consumption rate. Thus, the results of this study suggest that municipal sewage sludge cannot resist pH change caused by jam residue addition as efficient as animal slurry. Therefore the additions of acidic wastes should be more sensible in sewage sludge treatments. Total nitrogen content of the mixture remained approximately the same as in pure sludge before treatment, although the potato peel waste increased the ammonium-N concentration of the mixture (data not shown).

TABLE 2 **Total solids (TS, g/L), volatile solids (VS, % of TS), total nitrogen content (N, g/L) and biological oxygen demand (BOD, g/L) in mixtures of sewage sludge (S), whey (W) and jam residues (J) or potato peel waste (P) (% by volume) before and average pH during aerobic thermophilic treatment.**

Treatment	Treatment time (days) and temperature (°C)	TS, g/L	VS, % of TS	BOD, g/L	pH	N, g/L
1. 100S	5d (70 °C) + 5d (40 °C)	29	72	11	6.7	1.4
2. 60S30W10J	5d (70 °C) + 5d (40 °C)	42	82	28	6.3	1.2
3. 70S15W15P	5d (70 °C) + 5d (40 °C)	56	85	25	5.6	1.5

VS and BOD content decreased during the process. Joined thermophilic (70 °C for 5 days) and mesophilic (40 °C for 5 days) treatment stabilized the sludge mixture most effective, and thus the addition of post-composting in mesophilic temperature was found to be advantageous (Table 3). Also the color and odor of sludge mixture revealed that the material is stabilizing.

Nitrogen content decreased 28–63 % during the process (Table 3). This was most probably due to the loss of vaporous ammonia and timely foaming, which caused some losses of solid material. The N-loss was high especially in 60S30W10J-treatment during the mesophilic post-composting period, when the pH was near 8.0. In full scale reactors, the loss of nitrogen should be prevented to sustain the nutritional value of the product as high as possible. For example peat filter on the top of the reactor absorbs easily ammonia that passes through the condenser (Skelhaugen, 1999, Juteau, 2006).

TABLE 3 **Percentage reduction of volatile solids (VS, red-%), total nitrogen (N, red-%) and biological oxygen demand (BOD, red-%) in mixtures of sewage sludge (S), whey (W) and jam residues (J) or potato peel waste (P) (% by volume) after 5 days at 70 °C or 5 days at 70 °C + 5 days at 40 °C**

Treatment	VS, red-%		N, red-%		BOD, red-%	
	5d (70°C)	+5d (40 °C)	5d (70°C)	+5d (40 °C)	5d (70°C)	+5d (40 °C)
1. 100S	6	40	9	28	66	88
2. 60S30W10J	54	71	38	63	40	47
3. 70S15W15P	13	54	10	38	40	67

Process improved clearly the hygienic quality of sludge. Fecal coliforms, enterococci and RNA coliphages were reduced over 99.4 % and fecal clostridia were reduced over 96.0 % (Table 4). Semi-continuous and other batch processes have also previously shown to give better microbe reductions than continuous processes. In continuous processes, there is a risk for formation of dead zones etc. where pathogens can survive (Juteau, 2006). However, there is a little risk for recontamination in two-step semi-continuous process during the mesophilic post-composting period, which was seen in 70S15W15P-treatment in this study. Therefore, the contamination of treated materials must be avoided during the process performance. According to Finnish Fertilizer Production Act 529/2006, the maximum permissible amount of *Escherichia coli* (belonging to the fecal coliforms) in fertilizer products is 1000 cfu/g. This limiting value was clearly reached in 100S and 60S30W10J –treatments and probably also in 70S15W15P –treatment without recontamination.

TABLE 4 **Numbers of fecal coliforms, enterococci, fecal clostridia (cfu/ml) and RNA coliphages (pfu/ml) in mixtures of sewage sludge (S), whey (W) and jam residues (J) or potato peel waste (P) (% by volume) before 5 days aerobic thermophilic treatment including 5 days mesophilic post-composting treatment.**

Treatment	Fecal coliforms		Enterococci		Fecal clostridia		RNA coliphages	
	before	after	before	after	before	after	before	after
1. 100S	1.4*10^6	<5	1.0*10^4	64	6.2*10^4	2500	8.8*10^3	<1
2. 60S30W10J	2.9*10^7	<5	4.7*10^5	<5	2.6*10^5	1656	1.4*10^4	<1
3. 70S15W15P	1.8*10^7	8400	1.1*10^5	40	1.5*10^5	180	1.3*10^4	<1

Seed germination and growth test indicated that the product from combined aerobic thermophilic and mesophilic treatment does not have major negative effect on plant growth. The germination was over 93 % in all treatments. Growth index (fresh weight, % of control) was 80, 99 and 114 % for cress, radish and ryegrass, respectively, and expressed as dry weights: 61, 80 and 111 % for cress, radish and ryegrass, respectively. Only the dry weight of cress was under the normal range (80 % of control) (Itävaara et al. 2006).

4 CONCLUSIONS

This study showed that thermophilic aeration together with mesophilic post-composting improves the hygienic quality and stabilization of sewage sludge with and without food industry wastes. After successful process the sludge can be re-used without hygienic risks and offensive odor emissions in agricultural applications. In addition, the treated sludge keeps its homogeneity and flow characteristics, which makes the application comfortable with pumping and modern slurry spreaders. Further research is needed to clarify the technical implementation of the process in large scale to avoid problems such as foaming and N-losses, and also verify the self-heating capacity of municipal sewage sludge to gain economically profitable treatment process.

ACKNOWLEDGEMENTS

We thank Lehtoniemi wastewater treatment plant (Kuopio), Osuuskunta Maitomaa (Suonenjoki), Nordic jam Ltd. (Suonenjoki) and farmer N. Vartiainen (Vartiala) for providing materials for the study. We also thank M.Sc. Kati Martikainen, Mrs. Sirpa Martikainen and Mr. Matti Pessi for their help during laboratory experiments and analyses. Financial support from Maj and Tor Nessling Foundation is gratefully acknowledged.

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