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Comparison of Aerobic and Lime Stabilization Methods for Evaluation of Sewage Sludge Reuse

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ABSTRACT

The main objective of this research was the examination of effectiveness of lime dose in order to stabilization of sewage sludge and comparison of lime stabilized sludge reuse with aerobic digested sludge reuse. Lime and aerobic stabilization were carried out in two laboratory reactor with 40 L capacity. The sludge samples were taken from the return activated sludge line in four times. Lime was used at various ratios and the mixture was stabilized for 30 days. During the lime hydrated stabilization pH values were significantly increased from 7 to 12.5. Also, aerobic digester was loaded with raw sludge and mixed by sufficient amount of air for 30 days. The results indicate that the lime addition with the dose of 0.4 g Ca(OH)₂ g⁻¹ DS could completely inactive a high amount of fecal coliforms within 1 h and in all of the times was lower than 1000 MPN g⁻¹ DS after 30 days (p<0.01). But after 30 days, fecal coliforms density in aerobic digested sludge could not achieve to Class A of USEPA category. In two stabilization methods, density of viable helminths ova could not reduce to 1 ova/4 g DS and could not achieve to Class A of USEPA category. Therefore, these methods could be achieved the reduction requirement set by USEPA for class B (p<0.01) and the products could be well used as a landfill cover or a soil conditioner. Finally, our study confirmed that lime sludge stabilization has a higher hygienic effect and more cost-effective than aerobic stabilization, specially, when such sludge is used to dung and modify acid soils.

Key words: Biosolids, stabilization, aerobic digester, lime addition

INTRODUCTION

Biological treatment is the most used technology in wastewater purification (Zhang *et al.*, 2007). As a biological technology, activated sludge system has been employed to treat a wide variety of wastewater and over 90% of municipal wastewater treatment plants use it or one of it's modification as the core part of the treatment process (Liu, 2003). Extended aeration activated sludge process is the most common for wastewater treatment in small communities (Metcalf and Eddy, 2003). This method was choosing for many of municipal and industrial wastewater treatment plants in Iran (Farzadkia and Mahvi, 2004). High capital and annual cost and the lack of well-stabilized biosolids in many cases of exiting plants are two basic problems for this method (Metcalf and Eddy, 2003).

Therefore, many scientists classified the waste activated sludge from extended aeration activated sludge process in raw sludge categories (Benefield and Randall, 1980). Therefore the produced sludge need to be deal with carefully and should be stabilize before reuse or disposal (Alidadi *et al.*, 2007).

The improvement of sewage sludge management is a key objective for the development of an integrated strategy for wastewater treatment plants management (Samaras *et al.*, 2008). Processing and disposal of excess sludge is one of the most serious problem encountered in wastewater treatment in terms of environment, finance and technology (Cui and Jahng, 2004). Sludge stabilization has been practiced for over 100 years and the associated cost represents a major part of the total cost in any wastewater treatment plant (Azeem and Magram, 2008), So that it accounts for 50-60% of the total expense of wastewater treatment plant (Saby *et al.*, 2002; Oh *et al.*, 2007).

Sludge arising during treatment of municipal wastewaters presents a valuable source of organic matter, nitrogen, phosphorus, potassium and some trace elements. The fact that the Wastewater Treatment Plants (WTP) are localized in the suburbs of towns and villages in close vicinity of intensively used soil offers an optimum solution for utilizing surplus sludge in agriculture. Besides these positive aspects there are, however, certain risk factors as well. One of the most significant risk aspects is the presence of viruses, bacteria and parasites which are important from the viewpoint of hygiene, epidemiology and epizootiology (Bitton, 2005; Varadyova *et al.*, 2001; Jensen *et al.*, 2006). Sludge may contain a variety of pathogenic microorganisms, i.e., bacteria such as *Salmonella* species, *Campylobacter jejuni* and *Escherichia coli* O157:H7, parasites such as *Cryptosporidium parvum* and viruses such as enteroviruses (Vanotti *et al.*, 2005). The recycling of these wastes to agricultural land creates the risk of pathogens contaminating the environment, entering the food chain or infecting livestock (Martinez and Burton, 2003).

In order to eliminate these risk factors different technologies are used, such as alkaline stabilization, usually with lime (Metcalf and Eddy, 2003), anaerobic digestion, aerobic digestion or aerobic thermophilic stabilization with a subsequent anaerobic process, composting (Metcalf and Eddy, 2003; Tiquia *et al.*, 2002; Garcia-Gomez *et al.*, 2003) and ozone stabilization (Moussavi *et al.*, 2008).

A conventional treatment to stabilize excess activated sludge is the aerobic digestion process; however, due to the complicated, non-homogeneous nature of sludge, it requires long retention time to meet sludge reduction efficiencies as well as large construction cost (Hwang *et al.*, 2006).

The main disadvantage of using chemical disinfectants is the negative effect of these agents upon the living environment, their price and the demand on the technology of application. An exception can be found in those substances used to disinfect sludge which do not load the environment, are accessible and even capable of improving the fertilizing quality of sludge (Burton and Turner, 2003). All these criteria are met by lime hydrated of sludge. For this purpose lime in the form of lime hydrated (calcium hydroxide) or quicklime (calcium oxide) is used (Placha *et al.*, 2008).

In the lime stabilization process, lime is added to untreated sludge to raise the pH to 12 or higher. The lime dosage required varies with the type of sludge and solids concentration. The high pH creates an environment that halts or substantially retards the microbial reactions that can otherwise lead to odor production and vector attraction. The biosolids will not putrefy, create odors, or pose a health hazard so long as the pH is maintained at this level. The process can also inactivated virus, bacteria and other microorganisms present (Mc-Farland, 2000), as well as the

availability of heavy metals, enhancing the agricultural benefits and lowering the respective environmental risks (Wong and Selvam, 2006).

Most lime treatment facilities have the flexibility to produce either Class A or class B regulations recommended by United state Environmental Protection Agency (USEPA) (Lue-Hing *et al.*, 1998). To meet class B requirements using lime stabilization, the pH of the biosolids must be elevated to more than 12 for 2 h and subsequently maintained at more than 11.5 for 22 h. To meet class A, the class B elevated pH requirements are combined with elevated temperatures (70°C for 30 min) (Boost and Poon, 1998). Based on the classes of lime-stabilized biosolids achievement, which could be reused as a landfill cover, commercial fertilizer or soil conditioner (U.S. Environmental Protection Agency, 1995).

The main purpose of this study was investigating effectiveness of lime dose and stabilization time on the properties of produced mixtures for the stabilization of sewage sludge and inactivation of the sludge microbial content in a laboratory scale system and comparison of lime stabilized sludge reuse with aerobic digested sludge reuse.

MATERIALS AND METHODS

Characteristics of waste activated sludge: Sewage sludge samples were collected from the sewage treatment plant of serkan, in Hamadan, Iran (from April 2002 until March 2003). In addition, lime was supplied by a local production plant. The serkan wastewater treatment plant serves around 5000 inhabitants with an influent flow rate of about 10000 m³ day⁻¹. The treatment plant consists of an extended aeration activated sludge process. Treated effluent is disinfected by chlorination and is discharged to a river. Excess sludge from the secondary clarifier is thickened and dewatered in sludge drying beds and finally disposed in a landfill site. The sludge samples were taken from the return activated sludge line in four times. The sample bulk was stored at 4°C to prevent from changing the characteristics. The main characteristic of the tested waste activated sludge is given in Table 1.

Experimental apparatus and procedure: In lime addition method, the experimental set up consisted of a glass reactor with 40 L capacity and an electrical mixer with variable round. In this research, the reactor was loaded by raw sludge in four times. In each run 30 L sludge was poured into reactor and then depends on the mass of sludge dry solids, lime was added to untreated sludge in sufficient quantity.

The lime optimum ratio was the amount of lime that able to raise the pH of mixture above 12 for about 2 h 12.5 for 0.5 h and held it over 11 for 4 week. Table 2 show Activated degree and

Table 1: Average of main characteristic of the investigated waste activated sludge

Parameters	Average value in four steps			
	1	2	3	4
VS/TS	0.76	0.78	0.75	0.73
SOUR (mgO ₂ /g.VS)	3.12	3.85	3.4	3.22
pH	7.43	7.88	7.8	7.15
Temperature (°C)	25.8	21	18.2	11.5
FC (MPN g ⁻¹ DS)	8.2×10 ⁷	1.27×10 ⁸	1.17×10 ⁷	5.5×10 ⁸
Viable helminths ova (ova/4 g DS)	2333	992	873	203

Table 2: Activated degree and ratio of lime added to the waste activated sludge

Parameters	Steps			
	1	2	3	4
Activated degree of $\text{Ca}(\text{OH})_2$ (%)	46.00	77.0	77.00	77.0
g $\text{Ca}(\text{OH})_2$ g ⁻¹ DS	0.75	0.6	0.21	0.4

ratio of lime added to the waste activated sludge, in the first step, activated degree of lime added was low (46%), therefore, in next steps lime with high activated degree (77%) used for increase of sludge stabilization efficiency. The raw materials were added in the reactor and mixed for 30 min, in order to achieve complete homogenization of the mixtures. After mixing, the samples were placed into open reactor for 30 days. Also, a diffused-air system inside of a glass reactor with 40 L capacity was used as an aerobic digester. This reactor was loaded with 30 L of raw sludge and mixed by sufficient amount of air for 30 days.

Analytical methods: In order to study the performance of the lime addition process and aerobic digestion on stabilization of sewage sludge, samples were collected from each mixture at specific time intervals. Samples were analyzed for VS, pH, fecal coliform and viable helminths ova densities and compared to biosolids stabilized criteria. All these measurements were carried out on samples, according to Standard methods for the examination of water and wastewater (APHA, AWWA and WEF 1995), except for viable helminths ova density, that was done by the methods out lined in USEPA (USEPA, 1999). The SPSS software was used to perform statistical analysis.

RESULTS AND DISCUSSION

Stability and reuse potential of disposal sludge: The characteristics of disposal sludge from Serkan WWTP showed that, the minimum amounts of VS/TS, SOUR, FC and viable helminths ova densities in this sludge were 0.73, 3.12 mg O_2 /g.vs.h, 1.17×10^7 MPN g⁻¹ DS and 203 ova/4 g DS, respectively. While, the maximum amounts of these criteria for stabilized sludge are 0.6, 2 mg O_2 /g.vs.h, 1000 MPN g⁻¹ DS for Class A or 2×10^6 MPN g⁻¹ DS for Class B and 1ova/4 g DS, respectively (Metcalf and Eddy, 2003). Based on this results, difference between these parameters in samples with stabilized sludge criteria's were significant ($p < 0.01$). Therefore, these biosolids are raw and destabilized. Also, comparison of the microbial quality of disposal sludge and USEPA criteria showed that the biosolids was not in class A or B and it should not be disposed to environment or reused for any purposes (Christie *et al.*, 2001). Thus, stabilization of these sludge should be intensively noted before reuse or disposal.

Lime hydrated stabilization of sludge: In lime stabilization of sludge, the most pronounced changes were obtained in the pH values. After the application of $\text{Ca}(\text{OH})_2$ sludge pH significantly increased from about 7 to above 12.5 in the 0.5 h of the experiment ($p < 0.01$) and this value remained up for several days. Figure 1 shows the pH variation in lime-stabilized sludge during 4 times of reactor loading. The temperature and the dry matter values did not change markedly. The result that obtained in this study is in accordance with the literature (Samaras *et al.*, 2008; Placha *et al.*, 2008; Boost and Poon, 1998).

In the 1st step, for lime stabilization of sludge, 0.4 g of hydrated lime was added per gram of dry solids. Due to the low activated degree of hydrate lime (46.2%) for keeping the pH over than

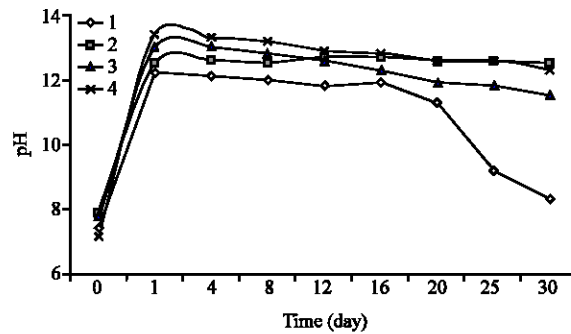


Fig. 1: pH variation in lime-stabilized sludge during 4 times of reactor loading

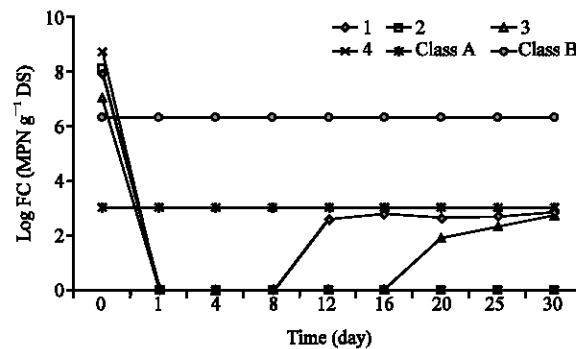


Fig. 2: FC reduction in lime-stabilized sludge during 4 times of reactor loading

12, this ratio was increased to $0.75 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$ during the reactor operation time. In this step, pH dropped under 12 after 8 days and under 11 after 20 days and FC was growing from 8th day and increased to $980 \text{ MPN g}^{-1} \text{ DS}$ after 30 days. Figure 2 shows the FC reduction in lime-stabilized sludge during 4 times of reactor loading.

For removing this problem in the second time, hydrated lime with high activated degree (77%) was chosen and added to biosolids with ratio of $0.6 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$. In this step, pH did not drop under 12 and FC wasn't growing after 30 days.

In order to reduce the cost and obtain cost-effective conditions in the third step, $0.21 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$ was added. In this time, pH dropped under 12 after 20 day and under 11.5 after 30 days; also FC was growing from 16th day and increased to $900 \text{ MPN g}^{-1} \text{ DS}$ after 30 days. Therefore, lime addition with ratio of $0.21 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$ is proper for short time storage of sludge, but in order to increase the storage time the ratio of lime addition should be enhanced.

Thus in the 4th step, for optimization lime ratio and improvement the last results, $0.4 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$ was added to sludge. In this step, pH did not drop under 12.5 after 22 days and under 12 after 30 days, also FC was not growing after 30 days. Also, these results showed that in this step, we are able to store sludge for 60 days easily.

As indicated in Fig. 1 and 2, in the lime addition reactor, pH amounts and FC removal efficiency increases with increasing the lime dosage from 0.2 to $0.6 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$. However, there is a little benefit in operating the reactor at $0.4 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$. Therefore, this amount can be considered as an optimum ratio of lime addition for sewage sludge stabilization specific for Serkan WWTP.

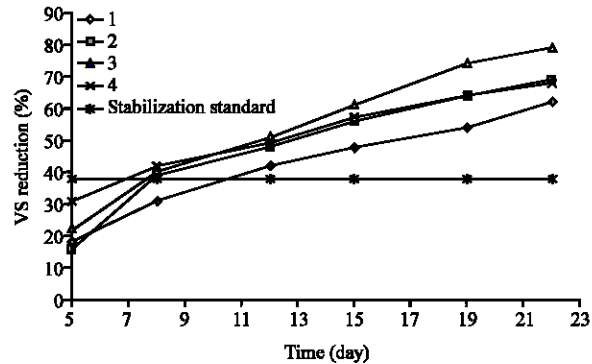


Fig. 3: Variation of volatile solids reduction versus aeration time during 4 times of reactor loading

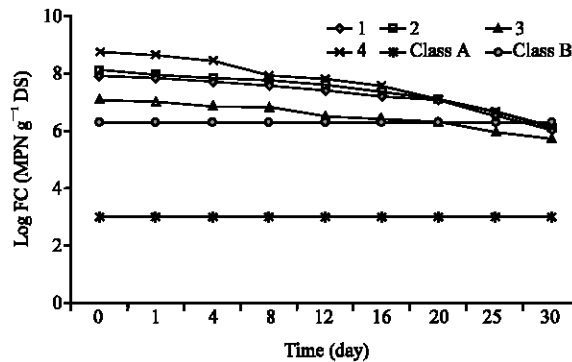


Fig. 4: FC reduction in aerobic digested sludge during 4 times of reactor loading

Aerobic stabilization of sludge: The relationship between variation of volatile solids reduction of sludge and aeration time during 4 times of reactor loading was shown in Fig. 3. Volatile solids reduction is an important indication in vector attraction reduction requirements promulgated by the EPA. EPA states that for proper vector attraction reduction, the volatile solids should be reduced by 38% (Metcalf and Eddy, 2003). According to Fig. 3, this parameter was received to acceptable amount (38%) in all of times after 6-11 days from starting the reactor operation ($p < 0.01$).

Figure 4 shows the variation of FC density in aerobic digest sludge versus aeration time. FC density was decrease under 2×10^6 MPN g^{-1} DS in all of times after 22 days ($p < 0.01$). After 4 weeks, this parameter was not achieved to 1000 MPN g^{-1} Ds in all of times.

Investigation of stabilized sludge reuse: Lime hydrated stabilization is a process which consists of the addition of lime to liquid manure in order to elevate the pH over 12. If stabilization is to be effective pH should reach the value of 12 within 2 h. Such conditions bring about the reduction of indicator bacteria by 3-6 log₁₀ (Jepsen *et al.*, 1997) compared the effects of three methods of reducing pathogenic bacteria: lime hydrated stabilization, aerobic thermophilic stabilization and composting. During lime hydrated stabilization pH values about 12.3 were reached and indicator microorganisms were devitalized within 24 h after liming. In our experiments a similar increase in pH occurred and FC completely inactivated within 1 h and in all of steps was lower than 1000 MPN g^{-1} DS after 30 days ($p < 0.01$). But after 30 days, FC density in aerobic digested sludge could not achieve to Class A of USEPA category.

The result of the viable helminths ova analyze in lime stabilized sludge showed that the density of this parameter was 295, 314, 443 and 122 ova/4 g DS in 1st to 4th steps after 30 days, respectively ($p < 0.01$). Also, the viable helminths ova density in aerobic digested sludge were 1866, 852, 765 and 501 ova/4 g DS in 4 times after 30 days, respectively ($p < 0.01$). Based on this results lime stabilized sludge and aerobic digested sludge were classified on class B of USEPA category in all of reactor operation. But lime sludge stabilization is more effectiveness than aerobic stabilization for reduction of fecal coliform and viable helminths ova.

Based on the studies conducted by Leffler *et al.* (2000) these stabilized biosolids could be beneficially reused as landfill cover material, poor soil reconditioner and co-composting material. If fertilizer using of disposal biosolids would be noted the microbial quality of biosolids must be improved up to Class A of USEPA category (Farzadkia *et al.*, 2009). For finding the class A condition in lime-stabilized biosolids, National Lime Association recommends to use of quicklime with exothermic reaction could be noted (Farzadkia *et al.*, 2009).

CONCLUSION

During the lime hydrated stabilization we obtained a highly alkalic product and thus this method may be recommended for effective inactivation of pathogenic microorganisms. It has been found that lime addition with the dose of $0.4 \text{ g Ca(OH)}_2 \text{ g}^{-1} \text{ DS}$ could inactive a high amount of FC and thus achieve the reduction requirement set by USEPA for class B. Therefore, the process is economically more acceptable when such sludge is used to dung and modify acid soils. From this aspect liming at the recommended dosage is effective since it causes stabilization of sludge, inactivation of microbes, it also increases the fertilizing quality of sludge and makes up for periodical liming of soil. Application of sludge with an alkalic pH significantly decreases heavy metal intake by plants which is an effective measure of preventing heavy metals from entering the food chain (Mihalikov *et al.*, 2005). However, evaluating the advantage of aerobic stabilization such as easy manipulation and production of a stabilized sludge without odor should be mentioned. The process, also, reveals disadvantage as well, among them the high energy demand needed for aeration and weather dependence. Our study confirmed that lime sludge stabilization has a higher hygienic effect and more cost-effective than aerobic stabilization.

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