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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Pakistan Journal of Biological Sciences

ISSN 1028-8880
DOI: 10.3923/pjbs.2017.260.266

Research Article
Evaluation of Autothermal Thermophilic Aerobic Digester Performance for the Stabilization of Municipal Wastewater Sludge

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Abstract
Background and Objective: Sludge stabilization process in terms of operational, environmental and economic indexes is the most important stage of treatment and its disposal. This study was aimed to determine the performance of Autothermal Thermophilic Aerobic Digestion (ATAD) system as one of the low-cost and biocompatible methods of sludge treatment. **Materials and Methods:** This study has been done using a laboratory scale Autothermal Thermophilic Aerobic Digestion (ATAD). The reactor was consisted of two polyethylene tanks with a final capacity of 100 L for each tank. Both tanks with all fittings were installed on a metal frame. The variables of study were temperature, dissolved oxygen, pH, volatile organic compounds, total solids, COD and the number of *Ascaris* eggs and fecal coliforms per gram of dry matter of the sludge. The temperature was measured hourly and the pH and dissolved oxygen were measured and controlled twice per day. One-way ANNOVA was applied to analyze reasults. **Results:** According to the results, the temperature of sludge increased from 11.7-61.2°C by biological reactions. Pathogen organisms were reduced from 80×10^6 to 503 in number during 72 h. After 6 days pathogen organisms and *Ascaris* eggs were removed completely. Volatile organic compounds and COD were reduced 42 and 38.3% respectively during the 6 days. **Conclusion:** It is concluded that the performance of ATAD in removing organic compounds from wastewater sludge were desirable. Resulted sludge from stabilization process were appropriate for use in agriculture as a soil supplement and met the indexes of class A sludge according to EPA's standards (CFR 40 Part 503).

Key words: Sludge stabilization, ATAD system, organic compounds, municipal waste water, sludge

Received: February 03, 2017 Accepted: March 30, 2017 Published: April 15, 2017

Citation: Reza Shokoohi, Alireza Rahmani, Ghorban Asgari, Abdollah Dargahi, Yaser Vaziri and Mohammad Attar Abbasi, 2017. Evaluation of autothermal thermophilic aerobic digester performance for the stabilization of municipal wastewater sludge. Pak. J. Biol. Sci., 20: 260-266.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Wastewater sludge is nutrients rich semisolid product which is collected from different sections of wastewater treatment plant. Sludge can be utilized in farmlands for improving the soil properties and also as the daily coverage of landfill waste[1,2]. High concentrations of pollutants in sludge revealed the necessity for its suitable management. Mismanagement in the stabilization, doping and condensation stages of sludge treatment could lead to the spread of pollution, severe damages to the environment, human health, animals and plants. Also, lack of sound management and principles regarding to wastewater sludge treatment plants cause chemical, microbial and parasitic infections in water resources, soil and agricultural crops. The biological sludge from different processes of sewage treatment, forms 0.25-12% of the total sludge weight[3,4]. Autothermal Thermophilic Aerobic Digestion (ATAD) is an aerobic method for digesting sewage treatment plant's sludge. The ATAD does not require any external energy sources, conducts the digestion process in a very short time and the output product meets the class A sludge standards of US EPA[5,6]. The advantages of the above-mentioned stabilization method are as follows: minimizing the possible time to reduce the Volatile Organic Compounds (VOCs) to the standard amount determined by US EPA, simple operation and maintenance, elimination of weed seeds that turns biological sludge into a suitable fertilizer or soil conditioner, reducing the VOCs and pathogens to class-A standards and the possibility of recycling the produced heat for heating nearby buildings at large scales[5,7]. The most significant advantage of this method is its small volume due to the low detention time compared to other stabilization methods. To better understand the aerobic sludge stabilization researchers have begun to study the chemical[5,7] and biological[5,6,8] changes during the different stages of ATAD process and some studies[5,9,10] presented comprehensive information on these variables. In most of developing countries a number of processes such as anaerobic digestion, aerobic digestion, chemical treatment, air drying, heat treatment, composting and lagoon fermentation have been typically used for stabilizing municipal wastewater sludge and converting it into an organic fertilizer. However for sufficient stabilization in these conventional methods couple of months required. Also, insufficient treatment due to low financing and capacity of facilities could lead to contamination by pathogenic microorganisms when the stabilized sludge is utilized for farming and land spread. In order to reduce the stabilization time, a cost effective and environment friendly process must be employed. The ATAD system has been considered as a reliable method for treatment of municipal wastewater sludge. Most of recent studies[9,11,12] have focused on single-stage ATAD system, while the advantages of dual-stage ATAD including quick adaption of thermophilic microorganisms and more control over the process are neglected. The purpose of this study was to stabilize sludge using the autothermal thermophilic bacteria to achieve the maximum removal of total coliform, faecal coliform, *Ascaris lumbricoides*, pathogenic organisms and *Ascaris* eggs in a very short time without energy consumption to obtain a compound with applicable standards for use in different sectors of the agriculture in alpine climate of Hamadan city to obtain a final product with applicable standards for use in agriculture.

MATERIALS AND METHODS

ATAD sludge source and sampling: This study was conducted in experimental and pilot scales which after designing and constructing, the pilot system was settled in the wastewater treatment plant location. To perform the process of sludge stabilization using ATAD method, its main components must be provided. The process was done in a batch reactor which means it did not have any Inputs or outputs during the operation[11,12]. The reactor was designed using two polyethylene tanks with a final capacity of 100 L for each tank. Both tanks and their fittings were installed on a metal frame. The tanks were insulated by a glass wool layer, a stone wool layer and two layers of polystyrene with a thickness of 1 cm to conserve heat. To prevent the heat loss from the junctions and fittings, connective pipes insulation was conducted by polystyrene coverings (Fig. 1).

Aeration methods: Aeration was conducted through openings on the plastic pipes with 2 cm diameter. To prevent loss or drop in air flow along the aeration path, the openings were designed in a way to increase the diameter along the path. Perforated aeration pipes have been installed on the floor and on the walls of tanks. Aeration was provided by a compressor with steady flow[9].

Analytical methods: The mixing process was done by a mixer with 20 rounds min^{-1} that is connected to electromotor by a slow round gearbox. In the upper part of the tank, a small insulated gate was embedded to install temperature sensor, sampling and monitoring. The variables of study were temperature, Dissolved Oxygen (DO), pH, VOCs, Total Solids

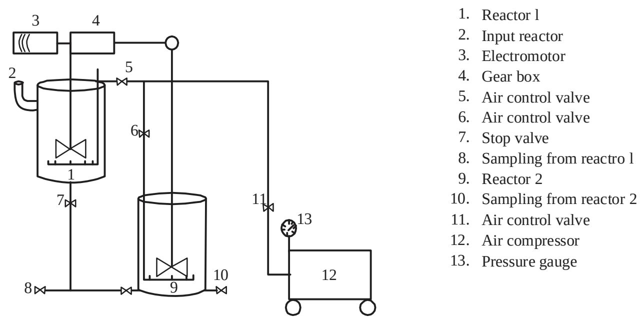

Fig.1: Schematic reactor with facilities and air compressor to do the consolidation process

(TS), Chemical Oxygen Demand (COD), the number of *Ascaris* eggs and the number of total coliform, faecal coliform, *Ascaris lumbricoides*, pathogenic organisms per gram of dry matter of the sludge. The temperature was measured hourly and also the pH and DO were measured and controlled twice per day. VOCs, TS and COD were controlled and measured daily. To control the process, realtime measurement of pH, DO and temperature have been done by HACH-HQ40d portable set. The measurement of TS and VOCs were done according to section 2540 B and section 2540 E of the "standard methods of water and wastewater experiments"[13]. The tests for determining The number of worms in the sewage and sludge were conducted according to the standards of World Health Organization[14].

Statistical analysis: In this study, descriptive statistics were used for presenting data and analytical statistics (one-way ANOVA) were applied for all parameters and comparison between them. All the statistical tests were carried out using SPSS, Ver.16, with the significance level of 0.05[15].

RESULTS AND DISCUSSION

The sludge stabilization process using ATAD method was done in two stages. The first stage that lasted for 13 days, was system launch stage and the second stage lasted from the 13-18th day (144 h), was the main stage of stabilization process. The starting temperature for stabilization process in the ATAD reactor was 11.7°C and this stage continued until the beginning of thermophilic stage. Thermophilic process started at 50°C and the stabilization process continued until the end of the final digestion. The total time of the process from the reactor loading until the end of stabilization lasted 18 days. Some studies have reported nearly identical results[7,11]. The recorded average environment temperature and relative humidity was 8.5°C and 25%, respectively. Physical and chemical properties of the primary and secondary sludge prior to stabilization process and properties of final product are presented in Table 1. The primary and secondary sludge were mixed with the ratio of 1:1 in the reactor. The percentage of TS was adjusted to 3-6% and the percentage of VOCs was adjusted in the range of 2 to 4%[10,5]. The physical and chemical properties of the mixed and dry sludge which have been fed into the reactor are presented in Table 1.

Biological properties of sludge: The number of total coliform and fecal coliform were 43×10^6 and 15×10^6 (Number/1 g of day matter) in primary sludge and 240×10^6 and 150×10^6 in secondory sludge, respectively. Also, the final count of these biological indexes in output sludge of ATAD system was zero. Similar findings were reported in previous studies[5,16,17].

Temperature changes and volatile solids removal: Temperature changes in ATAD over time (Fig. 2) show that in the primary stage of reactor launch, the increase in the temperature had a fast lift from the first day of the process until the end of the fifth day but, from the 6-9th day the trend in temperature increase slowed down to some extent which during this period the bacteria were in mesophilic stage. In the first day of the process, the psychrophile bacteria were dominant in the reactor and their activity went down till the 7th day. In 7th day the reactor entered into mesophilic stage as the temperature raised to 40°C. Most of studies have presented similar results[5,7,9,11,16,17].

The most important parameter to achieve optimal sludge stabilization in ATAD method is the concentration of VOCs in the sludge. The VOCs that determine the speed of bacteria growth at the start of the process should at least be set between 2 to 4%[9,5]. The VS changes in ATAD over time (Fig. 3) shows the consumption of VOCs in the reactor from the first day of the process. The reduction rate of VOCs concentration during the first 5 days was 7.76 % and its reduction had a slow trend up to the 13th day (16.9%). From the 13th day that the reactor entered into the thermophilic stage, the reduction in

Table 1: Physical and chemical properties of primary, secondary, mixed and effluent sludge

Parameters	pH	Temperature (°C)	VS (g L^{-1})	TS (g L^{-1})	COD (g L^{-1})
Primary sludge	6.851	10.5	42.76	90.2	79.2
Secondary sludge	6.278	17.7	19.24	63.24	62.4
Mixed sludge ratio (1:1)	6.346	11.7	22.6	63.4	67.3
Effluent sludge	7.365	61.2	11.07	29	41.545

VS: Volatile solids, TS: Total solids, COD: Chemical oxygen demand

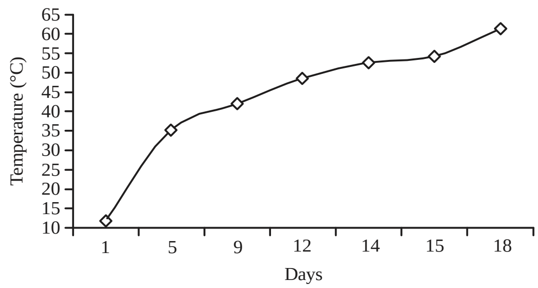

Fig. 2: Temperature changes in ATAD

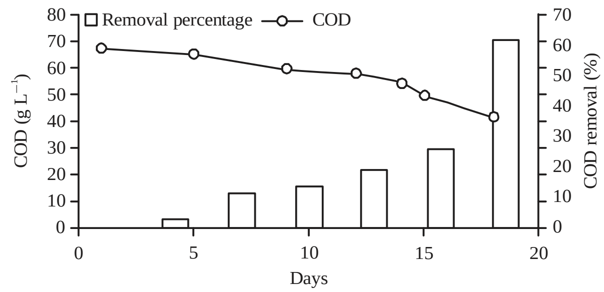

Fig. 4: Total chemical oxigen demand changes in ATAD

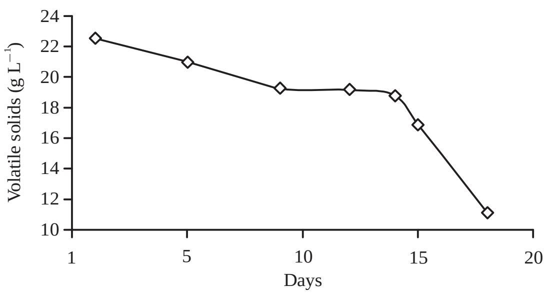

Fig. 3: Volatile solids changes in ATAD

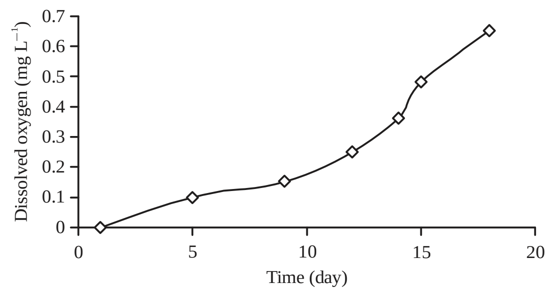

Fig. 5: Dissolve oxygen changes in ATAD

the concentration occurred at a higher speed (Fig. 3). This trend of reduction in the VOCs in thermophilic phase can be due to the activity of thermophilic bacteria and the higher growth speed. Indeed, the high speed of metabolism in bacteria in the thermophilic phase was due to high temperature[7]. The VOCs consumption in the thermophilic stage was 15.48 mg L^{-1} during 6 days. After thermophilic stabilization stage, VOCs reduction was 42% that is desirable compared to other studies (38%)[10]. Some studies have reported similar results[9,5].

COD removal efficiency and time: The initial concentration of COD in the sludge was 67300 mg L^{-1}. The BOD in mixed sludge (1:1 ratio of primary and secondary sludge) was 32000 mg L^{-1}; and COD to BOD ratio was 2.1. Piterina *et al.*[16] also have noted the same findings. This ratio showed that there is not a remarkable concentration of toxic and non-biodegrable matter in the output sludge of wastewater treatment plant of Hamadan. At the start of the process the reduction rate of COD had a mild slope until the 13th day and in mesophilic phase, this trend of gradual reduction was the same as reduction in VOCs (Fig. 4). When the system reached the thermophilic stage the COD reduction occured in higher speed and it has been reduced from 54330 mg L^{-1} at the start of thermophilic stage to 41545 mg L^{-1} at the end of stabilization stage. Also, total COD reduction in ATAD process, from the launch stage to the end of thermophilic stabilization stage was to 38.3%. Findings of Liu *et al.*[12] were the same. In ANOVA statistical comparative study, the amount of p value factor was conducted with temperature in the study of COD changes. it proved the positive relationship between these two parameters. Previous studies have presented similar results[12,17].

pH changes: During sludge stabilization process using ATAD method, the changes in pH is very important, since its changes can affect on the dominant microorganism species in the process[17]. The pH of the primary and secondary sludge were 6.851 and 6.361 (Table 1), respectively. In initial steps of the digestion process pH has been reduced with mild slope during the first 5 days. This reduction could be attributed to the production of fatty acids and acidification process. After the fifth day (Fig. 5), an increase was observed in the pH. On the 13th day and with starting the sludge stabilization process in

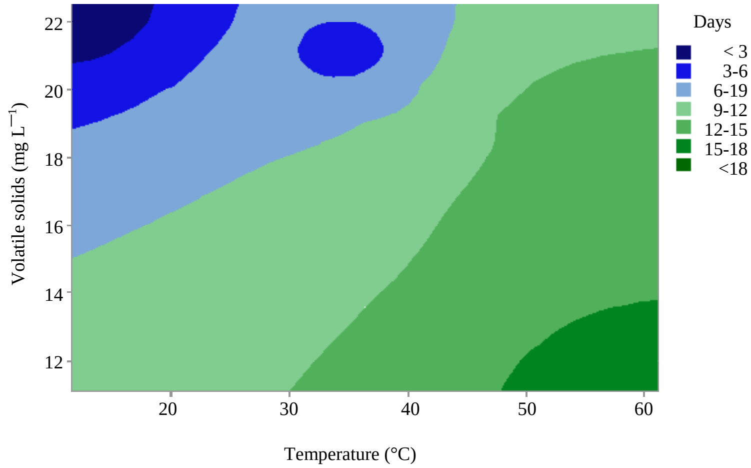

Fig. 6: Temperature and volative solid changes in ATAD

the thermophilic phase, a leap in the pH from 6.8 to 7.2 was observed and finally, it has reached to 7.4. Some studies have reported nearly identical results[11,17]. The increasing trend of pH during sludge stabilization process using ATAD method could be attributed to the biodegradation and hydrolysis of protein compounds and subsequent production of peptids and amino-acids[16]. During the sludge stabilization process, ammonia had released in the system that resulted in an increase in alkalinity and pH[18]. Due to high temperature and lack of growth of nitrifier bacteria at this temperature, the nitrification process was not done during digestion[1,2]. Thus, the only path for nitrogen reduction in the system is ammonia release[5]. Another effective factor that prevents nitrification in the ATAD reactor could be attributed to the lack of nitrifying bacteria growth, due to the short stabilization time[1]. According to ANOVA, it could be concluded that in this study there was no correlation between the temperature and pH ($p>0.05$).

Changes in dissolved oxygen: Given the fact that the ATAD process is based on aerobic stabilization, the amount of dissolved oxygen in this study was studied during the process. Initial DO concentration was zero and it gradually increased with the start of the aeration process (Fig. 5) and it had reached to maximum of 0.65 mg L^{-1} in 18th day. Some previous studies have presented similar findings[17-19].

Temperature and volatile solids: The starting temperature of reactor was 11.7°C. Temperature changes aginst (VS) changes in ATAD (Fig. 6) illustrated that at the beginning of process temperature was at its lowest and volatile solids concentration was at its max (Fig. 6). As the process continued, due to bacterial activity VS was reduced, while the temperature of the reactor started to increase gradually (Fig. 6). From the 13th day that system entered into the thermophilic phase, VS reduction occurred more intensively. whereas, during the same time temperature has increased more intensively (Fig. 6) which indicates that the stabilization process in ATAD has been done completely. Findings reported by Cheng *et al.*[20] were similar.

According to ANOVA it could be concluded that in this study there was a considerable correlation between the temperature and VS ($p<0.001$).

The process of sludge stabilization using ATAD method is known as a sludge pasteurization method for urban and industrial wastewater treatment plants. In this study in addition to removing pathogenic bacteria at a maximum temperature of 61.2°C and sludge pasteurization, VOCs has reduced 42% in 6 days. Results of his study showed that autothermal bacteria related to Ureibacillus thermosphaericus and some strains of Hydrogenophilaceae, Thermotogaceae and Clostridiaceae dominated the autothermal thermophilic aerobic stabilization process[20-23].

CONCLUSION

According to the results, it can be concluded that the autothermal thermophilic aerobic digester could stabilize the municipal wastewater sludge and turn it to a final product that met EPA's standards (CFR 40 Part 503) and "Iran's national Standards on sludge transfer, disposal/utilization". The final product was appropriate for use in agriculture as a soil supplement and its attributes put it on class A sludge classification of EPA. The ATAD compared to other conventional methods have advantages such as faster stabilization and more energy efficiency. Also, there were no limitations to operate it in alpine climate.

SIGNIFICANCE STATEMENT

This study discovers that ATAD system could achieve 100% removal of total coliforms and fecal coliforms. Also, COD and VS decreased to a desirable level. The results of this study help the researchers to know practical details on setting up an ATAD system for simultaneous treatment of primary and secondary sludge.

ACKNOWLEDGMENTS

The study extracted from a Thesis of M.Sc., Environmental Health Engineering and was supported by funds from the Hamadan University of Medical Sciences with grant No. 9406173177.

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