Start-up Performance of a Pilot-scale Integrated Reactor for Treating Domestic Garbage and Sewage Sludge from Treatment Plant

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Abstract: A pilot scale innovative design reactor that integrates anaerobic fermentation of domestic garbage and excess sewage sludge digestion was developed and studied. The reactor was operated continuously for 56 days, 22L of sewage sludge were treated daily and a total of 2240kg of domestic garbage were treated in the entire period of the experiment. The results show that under the conditions of sludge dosage rate of 10%, average HRT 5d, the sewage sludge water content and organic matter content (VS/TS %) fall down from 99.8% to 91% and 71% to 28% respectively. The fermentation of garbage in the integrated reactor supplied appropriate heat for digestion of sewage sludge to take place while the garbage being stabilized and reduced. The temperature in the middle sludge digestion compartment was between 25℃to 38℃ at the ambient temperature of 17℃ to 28℃. The inlet domestic garbage organic matter and moisture content were 64%~88% and 87.0%~94% respectively; while the outlet organic matter and moisture content were reduced to 36%~77% and 76.6%~93.5% respectively. The preliminary results of the reactor attain the reserved design target. It showed to be effective in reduction and stabilization of sewage sludge and domestic garbage. The integrative reactor, however, still remains to be improved.

[Mhamadi AT, Qiang H, Li J, Ntakirutimana T. **Start-up Performance of a Pilot-scale Integrated Reactor for Treating Domestic Garbage and Sewage Sludge from Treatment Plant.** J Am Sci 2012;8(5):728-732]. (ISSN: 1545-1003). http://www.americanscience.org. 80

Keywords: Start-up; pilot scale; Integrated Reactor; domestic garbage; sewage sludge digestion

1. Introduction

The upgrading and expansion of wastewater treatment plants along with development in industry, agriculture and improvement in human life have greatly increased the volume of sludge generated (Wei and Liu, 2005; Tay et al., 2000). The handling of sewage sludge is one of the most serious challenges in biological wastewater treatment plants (Davis and Masten, 2009; Egemen et al., 2001). Sewage sludge is a serious problem due to its high treatment costs and the potential risks to the environment and human health (Ghazy et al. 2009).The management costs of sewage sludge produced has been estimated to be 20% to 60% of the total expenses of the wastewater treatment plant (Marcos and Chernicharo, 2005). As sewage sludge contains organic matters, heavy metals and bacteria, it must undergo the process of reduction, stabilization and resourcing as otherwise is very likely to cause secondary pollution to the environment (Tuncal, 2011; Rughoonundun et al. 2010). On the other hand, the constantly increase in population，urbanization and the improvement of people's living standard has resulted more generation of solid waste and its disposal has become a major cause of concern for public authorities (Ajay et al., 2011). The organic part of Municipal Solid Waste (MSW) if not appropriately treated and disposed of, can lead to epidemic diseases, proliferation of foul odors and climate change (Viéitez and Ghosh, 1999).

Problem of excess sewage sludge and the organic fraction of MSW disposal are of growing concern due to their fast increase in production of which increase the threats on the environment. It is of utmost importance therefore to effectively handle and dispose excess sludge and organic fraction of municipal solid waste so as to reduce their possible impacts on the environment.

Several studies have been carried out and reported on co-processing of sewage sludge and MSW treatment. For example, co-digestion of organic fraction of municipal solid waste with: sewage sludge from WWTPs (Zupančič et al., 2008, Bolzonella et al., 2006, Gomez et al., 2006, Sosnowski, et al., 2003, Grasmug et al., 2003, Roch et al., 2003), residues from livestock farms (Angelidaki and Ellegaard, 2003, Converti et al., 1997) or more specific wastes (Bouallagui et al., 2009). However, there haven't been any reports on co-treatment of sewage sludge and organic fraction of MSW carried out by integrative of two reactors like the one we developed in our laboratory. This paper introduces the new way of co-processing sewage sludge from waste treatment works and organic fraction of MSW in particular domestic garbage. The development of this integrated reactor is based on the MSW composting principles and the integrated reactor for sludge thickening and digestion researched and developed by Qiang He and his project team (Qiang et al., 2009 a&b).

On this reactor, the sludge thickening and digestion takes place in the sludge digestion vessel and the heat required for anaerobic digestion of sewage sludge is supplied by fermentation of solid waste in the refuse bin surrounding the sludge digestion vessel. The reactor is developed to serve as a tool for minimizing and stabilizing sewage sludge produced from wastewater treatment works and domestic garbage in medium and small size urban communities. In this paper, the startup experimental study results of our own developed small scale pilot plant are reported.

2. Material and Methods

2.1 Description of the Reactor

The configuration of the pilot plant reactor is shown in Figure. 1. The reactor is composed of two main parts which are the sludge digestion vessel and the refuse bin. The sludge thickening and digestion takes place in the sludge digestion vessel at the middle of the reactor while anaerobic fermentation of refuse takes place in the refuse bin. The reactor is made of PVC with an overall diameter of 80cm and a height of 154.9cm. The reactor was provided with 8 sampling ports connected to the sludge digestion vessel to collect samples at different heights and compartments. Drain valve to collect digested sludge and an outlet to collect the gas produced were also provided. On top of the refuse bin there are three refuse-feeding holes, 10 centimeter in diameter each and at the bottom sides there are correspondingly three discharging holes with the same size. Drain valve to collect the leachate was provided at bottom of the refuse bin.

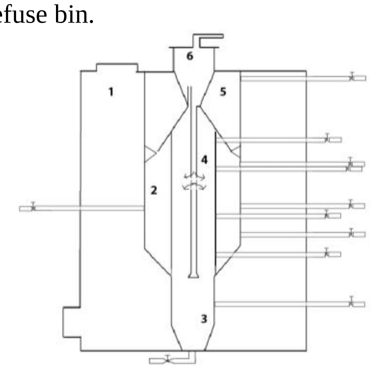


Figure 1. Schematic diagram of the reactor. 1.Refuse bin; 2. Outer sludge reaction chamber; 3. Sludge thickening area; 4. Inner sludge reaction chamber; 5. Sludge precipitation and dewatering area; 6. Gas collector chamber

Detailed information about the functions of different parts of the reactor which we designed and fabricated at our own laboratory is given in Table 1.

Table 1. Functions of different parts of the Reactor

Item		Effective Capacity((l)	Function
The Whole Reactor		440	Anaerobic fermentation of refuse and sludge thickening and digestion.
Refuse Bin		220	Anaerobic fermentation of refuse.
Sludge reaction vessel	Outer Reaction chamber	112	Thickening, digestion and acidification of sludge.
	Inner reaction chamber	50	Sludge thickening and digestion.
	Sludge thickening area.	12	Sludge thickening.
	Precipitation and dewatering area.	40	Separation of supernatant and clear effluent
	Gas collection chamber.	6	Gas collection

2. 2. Influent Sludge and refuse characteristics

Sludge used for experiments were collected from the SBR treatment system which treats sewage from students hostels at campus B of the Chongqing University. Garbage was collected at the solid waste transfer station in campus B and mainly was belonging to vegetables and fruits peels collected from the kitchen of student dining halls. Manual sorting was employed to separate the desirable material from paper, plastic and other unwanted materials.

The main characteristics of sewage sludge and organic fraction of solid waste used are as summarized in Table 2 and 3 below.

Table 2. Characteristics of influent sludge

Parameter	Mean value	Minimum value	Maximum value
pH	7.5 ± 0.24	7.0	7.98
Organic matter (VS//TS%)	55 ± 7.11	46	71
water content(%）	98 ± 0.98	98.6	99.80

Table 3. Characteristics of Inlet garbage

Parameter	Mean value	Minimum value	Maximum value
pH	6.85±0.29	6.94	7.50
Organic matter(VS//TS%)	81± 7.67	64	88
Bulk Density(kg/m^3)	600± 66	530	630
Water content(%）	91± 2	87	93.6

2.3 Experimental Procedure

The residual activated sludge were raised manually from the SBR tank into the high level sludge box and then allowed to flow by gravity into the reactor. Digestion temperature was supplied by fermentation of garbage which was taking place in the refuse chamber. The reactor was run under the sludge inflow rates of 20% that is 22ml/d of residual sludge were fed daily into the reactor replacing an equivalent amount of digested sludge and supernatant taken out in order to keep the volume constant. The time interval between two consecutive feeds was 24 h. The garbage fed into the reactor was chopped into grains 20 to 60mm and filled into the refuse bin for fermentation. In order to increase the continuity and heat generation of refuse fermentation and in consequence to ensure enough heat for sludge anaerobic digestion, new refuse grains were added daily to the refuse chamber to the top. The test process is shown in figure 2:

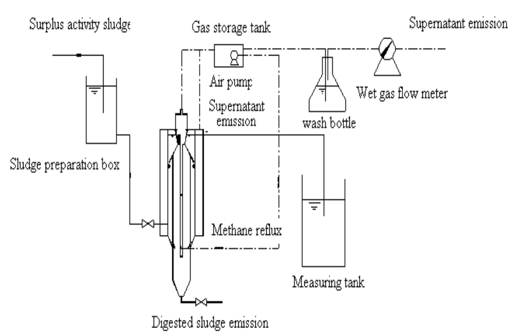


Figure 2. Experimental set-up

2.4 Analysis

The performance of the reactor was evaluated by measuring the following parameters: total solids (TS), volatile solids (VS), water content, pH, temperature and daily biogas production. Temperature was measured three times in a day using XTA-7000 temperature controller. pH, TS and VS were measured thrice in a week in accordance to standard methods (APHA, 2005). Daily biogas production was measured using a liquid displacement system that was connected to the digester.

3. Results and discussion

3.1 Variation in Temperature

Temperature is a dominant factor influencing the digestion process. In accordance with Arrhenius expression, the temperature not only influences the rate of the process but also the extent of degradation (Yavuz and Aydin, 2006). In this experiment the appropriate temperatures for anaerobic sludge digestion were provided by the heat from the fermentation of garbage, which is another feature of this integrative reactor.

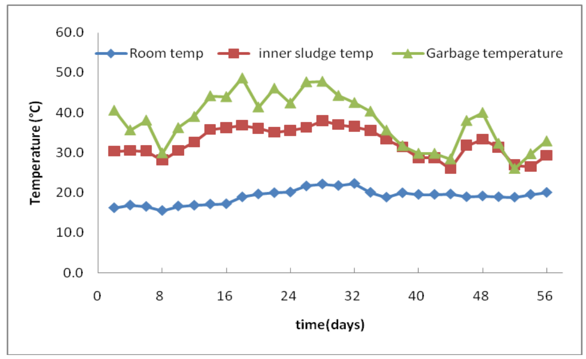
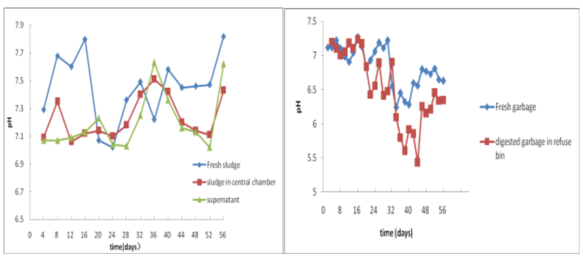


Figure3.Variation inTemperature

Figure 3 depicts the temperature variation of the inlet sludge, inner sludge digestion chamber and temperature in the refuse chamber during the experimental period. The results show that the heat generated during fermentation of garbage raised the temperature in the inner sludge to be within mesophilic range of which it ranged between 25-38^{o}C at the ambient temperature of 17- 28^{o}C while the temperature in the refuse bin was in between 26-48^{o}C. A large temperature difference between day and night was observed in the refuse bin and reached a maximum of 6℃. A maximum temperature difference between day and night in the inner sludge compartment was 3 ℃. The temperature of the inner sludge increased as the temperature in the refuse bin rose and decreased as the temperature declined. However there was a time when the temperature of inner sludge was equal to that of the garbage in the refuse bin. This might be due to the high loss of temperature from the outer surface of refuse bin to the surrounding. The low temperature in the refuse bin might also be attributed to low quantities of garbage which were added. Expansion of the refuse bin and provision of proper thermal insulation layer will result to an accumulation of much heat and maintaining temperature in the refuse bin and sludge digestion vessel as well.

3.2 Variation in pH

pH is an important indicator in anaerobic digestion stability. The pH of an anaerobic reactor in the range of 6.3-7.8 appears to be most favorable for methanogenesis (Yavuz and Aydin 2006). Figure 4 (a)&(b) below show the pH variation during the experimental period for the sludge and domestic garbage in the refuse bin. As it can be seen in Figure 4(a), the pH ranged from 7.0 - 7.9 and 7.0 - 7.6 for inlet sludge and effluent supernatant respectively. The sludge pH in the inner digestion chamber showed to be comparatively more stable and was in between 7.1 - 7.5, the range which is suitable for efficient methanogenesis and indicate that there was no accumulation of acids in the sludge digestion reactor. pH remained in this range without an addition of any chemical and this indicate that buffering capacity of the acid base system in an anaerobic digester was sufficient.



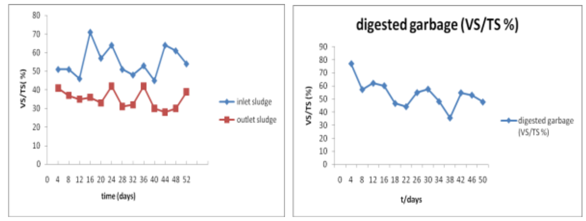
(a) (b)

Figure 4. pH variation (a) in the sludge; (b) in the garbage

As it can be observed in Figure 4(b), pH values show a declining trend in the digested garbage. The lowest pH observed in the digester during this period of study was 5.4 observed on day 42. This low pH values indicated that the digester was no longer stable, and conditions was not favorable for growth of methanogens. The pH values decrease in the refuse bin could be attributed to the VFA accumulation in the refuse bin and increase of dissolved CO_2 due to lowering of temperature. The pH drop inhibits the initiation of methane fermentation process and hence generation of gas (Kang and Jewell, 1990).

3.3 Digestion effect on Organic matter

The digestion effect of organic matter (VS/TS %) on sewage sludge and domestic garbage are shown in Figure 5 (a & b). As it can be observed, the organic matter of influent sludge varied from 46% to 71% while the organic matter of discharged sludge varied from 28% to 41%. This corresponds to the removal efficiency of 17.9% - 64.5%. The VS/TS of the effluent sludge basically shared the same variation trend as the influent sludge. On the other hand, organic matter content in the garbage was degraded with time as shown in Figure 5b. As it can be seen, minimum VS/TS of 36% were achieved after 38 days of operation. The decrease in VS/TS depicted in Figure 5 is attributed to the utilization of the organic matter by microorganisms to produce biogas.

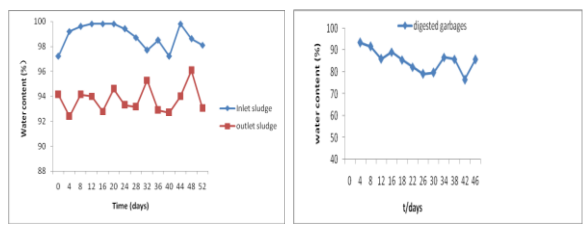


(a) (b)

Figure 5. Variations of VS/TS (%) (a) in the sludge; (b) in the digested garbage

3.4 Water content

The water content variation in influent sludge and discharged sludge is shown in Figure 6. As it can be seen, the water content of inlet sludge was 98.6% ~ 99.8% and that for effluent sludge was 91% ~ 93%. The water content in the digested garbage decreased from 91% to a minimum of 76.8%. So there was reduction in water content in the sludge and garbage.



(a) (b)

Figure. 6 Variations of Water content (a) in the sludge; (b) in the digested garbage

4 Conclusions

Co-processing of anaerobic fermentation of MSW and anaerobic digestion of sewage sludge was carried out in our self-developed pilot scale integrative reactor. The results of this study indicates that heat from fermentation of MSW can provide appropriate temperature conditions for sludge thickening and digestion, which is conducive to the stable operation of the integrative reactor. Temperature of the sludge reaction chamber during the study period ranged from 25 to 38℃ and that of the refuse bin from 26 to 48 ℃. The pH in the sludge digestion chamber was relatively stable and was in between 7.1 to 7.5, the range which is suitable for efficient methanogenesis. However, the pH in the refuse chamber was unstable and varied from 5.43 to

7.4. The organic content in the inlet sludge was decreased from the inlet of 71% to a minimum effluent organic matter of 28%. There was no obvious variation between the moisture content of influent sludge and that of the discharged sludge, but in all cases the moisture content of the discharged sludge was reduced and was below 93% from the inlet moisture content of 98.6% ~ 99.8%. The organic content of the digested garbage was reduced to a minimum of 36% after 35 days of operation. The biogas generation rate from the digestion processes could not be correctly quantified because of the gas spilling problem.

As the temperature is a dominant factor influencing anaerobic fermentation of MSW and sludge thickening and digestion, it's suggested that the capacity of refuse bin of the reactor be expanded and a thermal insulation layer be added to the outer surface of the refuse bin. This will help to reduce high temperature variation within the refuse bin and sludge digestion compartments. In addition to that, the reactor need to be sealed perfectly in order to collect more gas which is a great stirring power for sludge thickening and digestion system and also to avoid pollution to the environment caused by spilling gases. The experiment has showed that the reactor is effective in reduction and stabilization of sewage sludge and domestic garbage. Longer term running of the reactor at different Loading rates is required to assess the stability and potential of the reactor.

Acknowledgements:

This research was supported by the Major Science and Technology Program for Water Pollution Control and Treatment, 2009ZX07318-008-003 and financed by the Ministry of Science and Technology of the People's Republic of China.

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