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Research Article

Effect of sludge recirculation on sewage sludge anaerobic digester performance

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Abstract

Anaerobic digestion is an effective process for sewage sludge reduction. The production of sludge is increasing worldwide and anaerobic digestion presents limitations in terms of solid destruction and long sludge retention time. This study investigates the possibility of reducing the sludge retention time via increasing the Solid Retention Time (SRT). The effect of sludge recirculation rate on digester performance operated at 20 day Hydraulic Retention Time (HRT) was evaluated. Three different SRTs (20, 35, and 48 days) were evaluated. The experimental set up consists of three similar pilot scale mesophilic (37^{o}C) anaerobic digesters with a capacity of 0.24 m^3. The digesters were fed with thickened sludge (mixed primary and trickling filter humus) once daily. Also the effect of sludge recirculation at different HRTs was evaluated. The experimental results showed that for reactors operated at 20 day HRT; the chemical oxygen demand (COD) mass balance indicated; removal ratio increased from 43% to 60% as the SRT increased from 20 to 48 days. Also the methane generation increased as SRT increased. At lower HRTs the digester performance was decreased for all different SRTs. Results also showed that at high SRT the digester could be operated with higher loading rates (more than double) without affecting the efficiency. Finally the process showed stability for all operating conditions. Sludge recirculation is an easy, simple and reliable method for increasing anaerobic digester performance.

Keywords: *Anaerobic digestion, mesophilic, sludge recirculation, solid retention time, hydraulic retention time.*

1. Introduction

Municipal wastewater treatment plants produce huge quantities of sewage sludge that need to be treated before disposal into the environment. Thus, the treatment of sewage sludge is one of the most important processes in wastewater treatment plants. It accounts for nearly 50 % of the total cost of the plant, as reported by Nghiem et al. (2017). There are several technologies for sludge treatment such as anaerobic digestion (AD) which is one of the most widely used technologies. The main byproducts of the digestion process are biogas that can be used as a fuel and digested sludge that can be used as a fertilizer (Bridgeman, 2012). Anaerobic digestion has several advantages, which were summarized by Yeneneh et al. (2015) as follows: (i) energy generation. It can be considered as a source of renewable energy. (ii) Reduction of greenhouse gas emissions. The sources of greenhouse gases in wastewater treatment plants include CH_4 that is emitted directly from sludge degradation and CO_2 that is indirectly emitted due to the electric power consumed by the treatment processes, i.e. electricity is generated from the combustion of fossil fuel that releases CO_2. It is worth mentioning that each ton of CH_4 emissions has an impact on global warming equivalent to the impact of 25 ton of CO_2 emissions (Dong, et al. 2013). (iii) High organic removal, (iv) low biomass production, (v) capacity to produce solids suitable for use as soil conditioner, (vi) high decay rate of pathogenic microorganisms. In conclusion, anaerobic digestion can help reduce the energy consumption in wastewater treatment plants. Previous studies have found that biogas production can generate 60 to 100% of the energy needs to operate wastewater treatment facilities (EPA, 2000).

Owing to the abovementioned advantages, many researchers investigated the effect of several parameters on the performance of the anaerobic digester. Yeneneh et al. (2015) studied the effect of combined microwave-ultrasonic pretreatment on the performance of anaerobic digester. They reported significant enhancements in the biogas production and

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COD reduction. The specific biogas production increased by about 30%, while the COD removal ratio was increased by 20%.

Various technologies for sludge pretreatment, including the thermal hydrolysis, ultrasonic homogenizer, enzymatic hydrolysis, and ozonation have been evaluated for digester performance enhancement. Wilson et al. showed that the thermal hydrolysis pretreatment of combined primary sludge and WAS at 150 ^{0}C and 170 ^{0}C increased the biogas by 24% and 59%, respectively. Despite the significant positive impact of thermal pretreatment it is also known that the process has many drawbacks such as the production of inhibitive compounds, and high energy consumption (Mehari, et. al. 2018).

The AD process is applied as an alternative method for the treatment of animal manure, organic waste from households, urban areas and industries. In the AD process, the bacteria decompose the organic matter in order to produce the energy necessary for their metabolism. The rate of biogas production and efficiency of the digestion process is affected by several factors such as the type of substrates being digested, the total solid (TS) and volatile solid concentration (VS), the temperature (T), the presence of toxic materials, the pH value, the hydraulic retention time (HRT), and the solids retention time (SRT) (Ejiroghene et al., 2017). For example, reducing the HRT can make the volumetric production rate of methane higher. However, the removal of the organic matter declines as a result of the reduction in the extent of hydrolysis process. Furthermore, shortening the HRT too much can lead to washout of biomass from the digester. To prevent the washout of biomass from the reactor, the HRT should be maintained above a minimum value (Lee et al., 2012). This also could be achieved by biomass recirculation to the digester. Ratanatamskul & Saleart; 2016 developed a prototype single-stage anaerobic digestion system for energy recovery from food wastes, and concluded that anaerobic digester with sludge recirculation could enhance reliable organic and solid reduction efficiencies better than the digester without sludge recirculation.

In the Continuous Stirred Tank Reactors (CSTRs), the microbial population is washed out with the effluent from the reactor when the system operated at HRT equals the SRT. When Increasing the SRT, the biomass concentration in the reactor will be greater and consequently, the digestion process becomes much more efficient. Thus, to enhance the digestion process, the biomass from the effluent stream of the digester is separated in a settling tank and is recycled back into the digester. It is worth mentioning that the performance of the digester depends mainly on the efficiency with which the micro-organisms and suspended solids settle. (Abbasi et al., 2012).

The above discussion demonstrates that there is still a big challenge in improving the performance of anaerobic digesters. This could be accomplished by understanding the effect of the different operating conditions on the overall performance of the digester. To the best of the author knowledge, an important factor was not studied extensively in the literature. This factor is the effect of sludge recycling and SRT on the digester efficiency and stability. Accordingly, the current study aims to investigate the effect of sludge recirculation rate on the efficiency and stability of the anaerobic digestion process using a pilot plant treating sewage sludge at varying hydraulic loading rates.

Materials and Methods

Pilot plant description

Figure 1 depicts a schematic illustration of the pilot plant anaerobic digester reactor. The experimental work was carried out using three pilot plants anaerobic digesters. The pilot plants were operated at El kinayat WWTP, Zagazig, Sharkia, Egypt. Each reactor (Anaerobic digester) is fitted with a feed tank (not shown in Fig. 1) and a settling tank. The biogas volume was measured by the liquid displacement system similar to that used by Kalloum, et al, 2012. The digester was a cylindrical shape tank with a working volume of 240 liters. Each digester is followed by a cylindrical settling tank with a working volume of 50 L. The sludge feed and withdrawn process was achieved manually once a day. The digester contents were mixed using sludge circulation pump. The digester contents could be mixed via different methods include external pumped recirculation, internal mechanical mixing, and internal biogas mixing. The external pumped recirculation observed to increase the biogas production more than other methods (Ratanatamskul & Saleart; 2016).

The digested slurry is fed into the sedimentation tank where the sludge and water are separated. In the sedimentation tank, the sludge was divided into two parts: concentrated and diluted sludge. The concentrated sludge was returned to the digester while the diluted sludge was wasted. The reactors were operated under different SRTs. Data were collected after the system reached steady state condition in terms of volume of biogas production and stable system performance. The effect of the SRT on the digester performance was evaluated at different hydraulic loading rates.

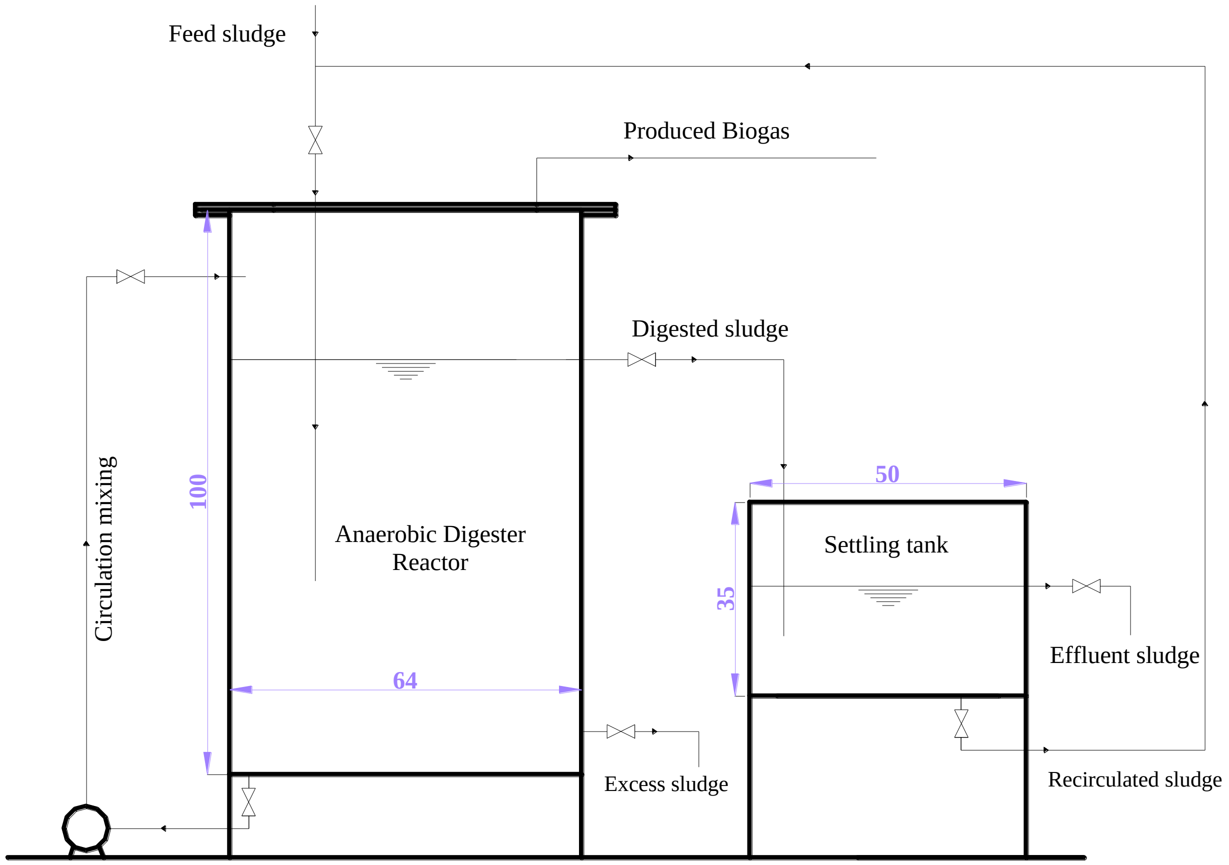


Figure 1 Schematic diagram of the experimental system

Anaerobic Digester Operation

The three digesters (D1, D2 and D3) were operated at 37±0.5 ^{0}C in a mesophilic mode. Each digester was fitted with an external heating system with a temperature control. During the experimental work that extended up to five months; the three digesters were operated at the same conditions. The digesters were fed with thickened sludge (mixture of primary and humus trickling filter sludge) which has the characteristics summarized in Table 1.

Table 1 Characteristics of the feed Sludge

Parameter	TS g/L	COD g/l	VS g/L	Alkalinity mg/L	PH	VFA mg/L
Range	42-50	50-55	29-32	1000-2000	6.4-7	450-870

It is worth mentioning that, the feed sludge was screened to prevent clogging problems (Young et. al., 2004). The three digesters were fed and the digested sludge was withdrawn once a day in a semi-batch mode (WEF, 2008, Lee et al., 2012). To isolate the effect of the ambient conditions, the three digesters were operated in parallel to evaluate the effect of sludge recirculation from the settling tank at different Hydraulic Retention Times. The digester D1 was operated without sludge recirculation (zero recirculation rate), the digester D2 was operated with sludge recirculation rate of 6 l/d and the digester D3 was operated with sludge recirculation rate of 4 l/d. The solid retention time of the digester was calculated according to the following equation (Tawfik et al. 2008):

$$SRT = \frac{V_{digester} \times X_{inside\ digester}}{Q_{Excess} \times X_{Excess} + Q_{effluent} X_{effluent}}$$

where $V_{digester}$ is the reactor volume (l), $X_{inside\ digester}$ is the average sludge concentration in the reactor (gTS/l), Q_{Excess} is the excess sludge (l/d), X_{Excess} is the concentration of the excess sludge (gTS/l), $Q_{effluent.}$ is the effluent sludge flow rate (l/d), $X_{effluent}$ the effluent concentration (gTS/l).

The calculated SRTs using Eq. (1) above were 20, 35, and 48 days for D1, D2, and D3 respectively at 20 day HRT. . The HRT was reduced from 20 to 10 days and then to 5 days and the effect of increasing the SRT was examined for each value of the HRT.

System performance

The influent sludge to the digester was characterized with the flow rate Q_{in} and the solid concentration X_{in}. The digested sludge at the outlet was passed through the settler, in which the diluted sludge separated ($Q_{effluent}$, $X_{effluent}$) and the concentrated sludge was circulated to the digester ($Q_{recirculaed}$, $X_{recirculaed}$). To control the SRT in the digester; the excess sludge was withdrawn from the digester (Q_{Excess}, X_{Excess}). Figure 2 illustrates a flowchart (control volume), which can help calculate the equivalent effluent concentration for the system using Eq. (2) below. The system removal efficiency was determined by the mass balance concept over the control volume depicted in Fig. 2.

$$X_{\text{equivalent effluent}} = \frac{Q_{Excess} \times X_{Excess} + Q_{effluent} X_{effluent}}{Q_{Excess} + Q_{effluent}}$$

As mentioned above, the digester D1 was operated at SRT equals to the HRT. Thus, with no sludge recirculation, the system effluent concentration is the same as that inside the digester, i.e. Q_{Excess} = 12, 24, 48 l/d at HRT of 20, 10 and 5 days. Additionally, $Q_{effluent}$=0, because all the sludge was removed from the digester. The second digester D2 was operated at sludge recirculation rate of 6 l/d and at HRT of 20, 10 and 5 days; Q_{Excess} = 6 l/d, and $Q_{effluent}$= 6, 18 and 42 l/d respectively. Finally, digester D3 was operated at sludge recirculation rate of 4 l/d, and at HRT of 20, 10 and 5 days; the value of Q_{Excess} was 4 l/d, $Q_{effluent}$=8, 20 and 44 l/d respectively.

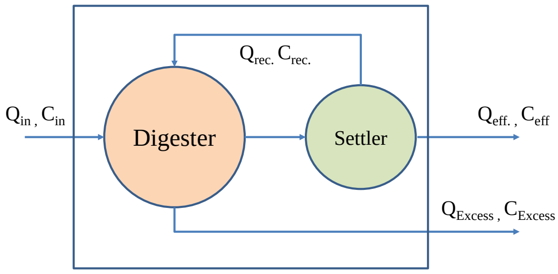


Figure 2: Schematic of the reactor flow with recycle.

Analysis and Measurement

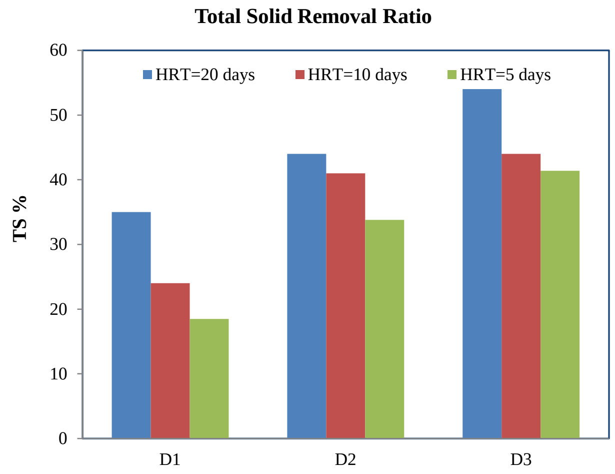
The influent and effluent samples were analyzed by measuring the chemical oxygen demand (COD), the total solids (TS), the volatile solid (VS), and the alkalinity, according to the standard methods for the examination of water and wastewater (APHA, 1999). Volatile Fatty Acids (VFA) was measured by the titration method proposed by Kappa (Buchauer, 1998). For the Alkalinity and VFA, the samples were centrifuged, and filtered through a 0.45 µm filter membrane (Yan et. al., 2012).

Results and Discussion

Effect of Sludge Recirculation on System Performance

Table 2 - Experimental measurements of TS at different HRTs

			HRT = 20 day			
	Inlet	D1 inside	D2 inside	D3 inside	D2 effluent	D3 effluent
TS (g/l)	46.6	30.3	45.8	50.7	6.7	6.6
TS equivalent		30.3	26.2	21.3		
Removal ratio %		35.1	43.8	54.3		
SRT (days)		20	33	42		
			HRT = 10 day			
	Inlet	D1 inside	D2 inside	D3 inside	D2 effluent	D3 effluent
TS (g/l)	48.5	37	50	51.1	21.5	22.5
TS equivalent		37	29.1	27.2		
Removal ratio %		23.8	41	43.9		
SRT (days)		10	17.5	19		
			HRT = 5 day			
	Inlet	D1 inside	D2 inside	D3 inside	D2 effluent	D3 effluent
TS (g/l)	42	34.3	47.5	49.9	25	22.3
TS equivalent		34.3	27.8	24.6		
Removal ratio %		18.5	33.8	41.4		
SRT (days)		5	8.5	10		



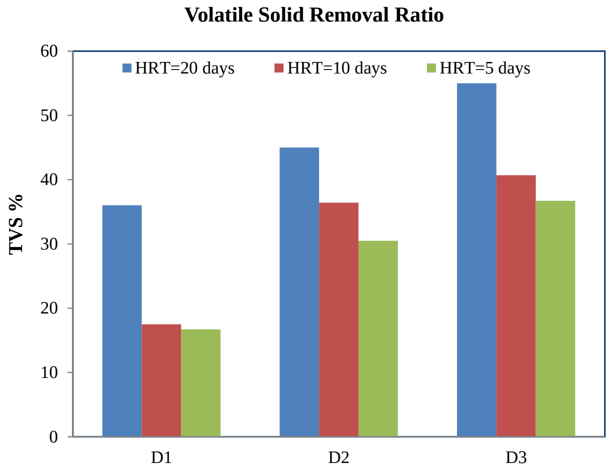


Figure 3 Effect of Sludge Recirculation on Solid Removal

Table 3 - Experimental measurements of COD at different HRTs

			HRT = 20 day			
	Inlet	D1 inside	D2 inside	D3 inside	D2 effluent	D3 effluent
COD (mg/l)	53380	30605	46870	45435	9955	9585
COD equivalent		30605	28415	21535		
Removal ratio %		43	47	60		
			HRT = 10 day			
	Inlet	D1 inside	D2 inside	D3 inside	D2 effluent	D3 effluent
COD (mg/l)	53640	37675	53000	51970	22580	22290
COD equivalent		37675	30185	27240		
Removal ratio %		30	44	49		
			HRT = 5 day			
	Inlet	D1 inside	D2 inside	D3 inside	D2 effluent	D3 effluent
COD (mg/l)	49735	40485	49285	53700	30600	28430
COD equivalent		40485	32935	30535		
Removal ratio %		19	34	39		

The system performance of the three examined digesters was evaluated using the removal of total solids (TS), volatile solids (VS), COD and the biogas production. Table 2 and Figure 3 show the effect of sludge recirculation on the total and volatile solid removal. As summarized in the table, for HRT = 20 d, the influent TS to the three digesters is 46.6 g/L and the solid removal ratio was 35 %, 44 %, and 54 % for D1, D2, and D3 respectively. Reducing the HRT to 10 resulted in a reduction in the removal ratio where the values were 24 %, 41 %, and 44 %, respectively for D1, D2 and D3. Finally, at HRT equals 5d, the removal ratio were decreased further to 19 %, 34 %, and 41 %, respectively. Additionally, Fig. 3 and Table 2 indicate that increasing the SRT enhanced the removal efficiency which could be attributed to the increase in biomass concentration caused by sludge recirculation (Rathnasiri P.G. 2016).

Figure 4 and table 3 show the effect of sludge recirculation on the COD removal efficiency. At HRT of 20 d, the average value of the influent COD to the three digesters is 53385 mg/L and the removal ratio was 43 %, 47 % and 60 % for D1, D2, and D3, respectively. The system achieved 43% COD removal at 20 days without sludge recirculation, the removal reached 49% at half the HRT (10 days) with sludge recirculation, so the hydraulic loading rate could be increased to more than double achieving the same efficiency. These results are comparable with the results of Hallaji et al. (2018), who enhanced the anaerobic digester performance through pretreatment. In their study, combination of free nitrous acid and Fenton pre-treatment of mixed primary and waste activated sludge were implemented prior to anaerobic digestion process. The amount of COD was reduced by 59% in the pre-treated reactors compared to 34% reduction the control reactor.

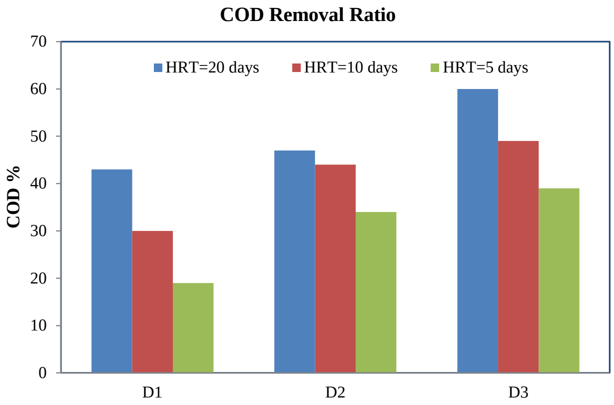


Figure 4 Effect of Sludge Recirculation on COD Removal

The main and most important parameter of the anaerobic digestion process is the produced biogas, which normally contains 60-65 % methane CH_4 and 35-40% carbon dioxide CO_2 (WEF, 2008). Figure 5 shows the effect of sludge recirculation on the biogas production.

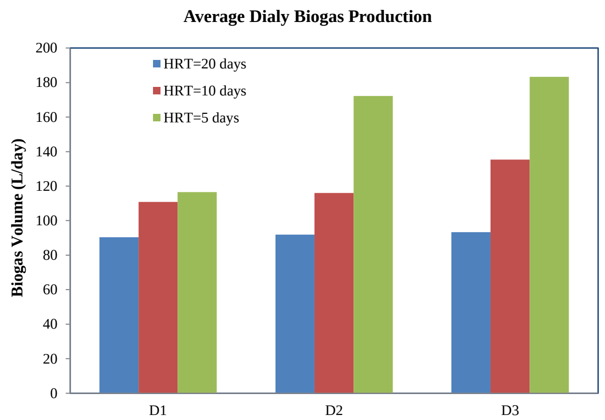


Figure 5 Effect of Sludge Recirculation on biogas production

It is worth mentioning that each increment of the HRT (5 to 10 and 10 to 20) is corresponding to doubling the reactor volume in order to treat the same volume of sludge. Accordingly, as expected, the results indicated that the solid destruction increased as the HRT was increased. These results are in consistence with that reported by Kaosol and Sohgrathok, 2012. They attempted to improve the biogas production in an anaerobic co-digestion using decanter cake from palm oil mill industry and concluded that decreasing the HRT from 20 to 10 days reduced the TS removal efficiency from 37.5 to 16.5%. In the present study, the TS removal efficiency at HRT of 5 days reached 41% with sludge recirculation.

The results of the present study demonstrated also that the removal ratio of the VS exhibited the same trend as the TS removal ratio. The VS removal ratio reached 37 % at 5 days HRT which is higher than that reported by Yue, (1997) who conducted experimental work using mesophilic digester. In his experiment, the VS concentration in the influent was 29.2 g/l, while the volatile solid removal ratio was 32.5%. Additionally, the VS removal efficiency in the current study decreased as the HRT decreased from 20 to 5 days indicating a smaller extent of hydrolysis. This result agree with the results reported by Lee et al., 2012 who operated a bench-scale digester fed with thickened mixed sludge over HRT range of 4–20 days. The maximum VS removal ration achieved in the present study was 55% at 20 days HRT and 42 day SRT. This ratio was higher than that observed by Nghiem et al. (2017) who studied the implementation of acid phase digestion pretreatment and stated that the maximum achievable VS removal according to bio-methane potential assessment was 49%.

The COD removal ratio achieved in the present experimental work is in consistence with the results published by Cacho (2005), who conducted experimental work on meshophilic digester, operated at 20 day HRT, and influent COD was 56 g/l. That digester achieved 46% COD removal ratio. Parkin and Owen conducted a theoretical study and simulated the digestion of a mixture of primary and waste activated sludge (1:1) with an influent COD value of 10 g/L. They reported that the COD removal percentage was 30 %, 43 % and 48.5 % for HRTs of 10, 20 and 40 days, respectively (Cacho, 2005). Although these values are lower than the ones obtained in the present study, it follow the same trend. The present results also matched with the experimental results of Lee et al., 2012; who concluded that as the HRT decreased from 20 to 4 days, the COD removal decreased from 49 % to 32 %. The results of the present work indicated also that when the SRT increases, the COD removal ratio increases. This improvement in COD removal ratio could be due to the fact that when the SRT increased, the acetic acid concentration further reduced, finally improving anaerobic reactor performance (Rathnasiri P.G. 2016)

The results of the present study indicated also that the biogas production increased as the HRT decreased, which agrees with the results reported by Lee et al., 2012. At HRT of 20 days, the average daily biogas production was enhanced by little values when the SRT was increased. At HRT of 10 days, increasing the SRT has increased the biogas production by about 20%. Finally, at 5 days HRT, the biogas production has increased by about 55 % when the SRT was increased from 5 to 10 days. This is matches with the results of Ratanatamskul & Saleart; 2016, who concluded that the anaerobic digester can achieve higher biogas production with increasing the sludge recirculation rate. The increase in the biogas production rate found in the present study may be attributed to the improvement of both the acetic acid conversion and the active concentrations of methenogens caused by sludge recirculation (Rathnasiri P.G. 2016).

It is important to mention that the effect of sludge recirculation on the biogas production per COD removal decreased when the SRT was increased. At HRT value of 20 day, the biogas volume was 0.33, 0.31

and 0.24 m^3/kgCOD per day for D1, D2, and D3 respectively. These values were 0.29, 0.21 and 0.21 respectively at 10 days HRT. Finally, the biogas volumes were 0.26, 0.21, and 0.2 m^3/kgCOD per day at 5 days HRT. The ratio of the methane produced per gram of VSS removed is related to the characteristics of the influent sludge and the degree of digestion along the process. This ratio reflects the performance of the process. A gas production of 0.75 to 1.12 m^3/kg VS destroyed is an indication of proper digestion (Cacho, 2005). The value obtained in the current study was 0.65 m^3/kg VS destroyed which is nearly approach the lower border of the aforementioned range at HRT of 20 day. Decreasing the HRT reduced this value to about 0.5 at HRT of 10 days, while this value was about 0.35 m^3/kg VS destroyed at HRT of5 days.

Effect of sludge recirculation on digester stability

Figure 6 shows the effect of sludge recirculation rate on the VFA concentration. The influent VFA to the digesters was 740, 870, and 450 mg/L at 20, 10, and 5 days HRT respectively. The figure demonstrates that sludge recirculation has minor effects on the effluent VFA as well as the alkalinity at constant HRT. The effluent VFA ranges from 250 to 900 mg/L, these values were lower than 1500 mg/L, which is considered to be the limit for allowing stable operation of the digester (Ratanatamskul & Saleart; 2016).

Fig 6 shows also the values of VFA-to-alkalinity ratio in the three digesters. These values are 0.22, 0.27, and 0.25 for D1, D2, and D3 respectively at HRT of 20 d. As shown in the figure, increasing the rate of sludge recirculation has little effects on the digester stability.

Biogas production was consistently high in the three digesters. It appears that there was enough alkalinity to provide buffering capacity and the pH did not decrease significantly despite the production of VFAs. The pH and alkalinity values during the operation were within the range favorable to methanogens. The recommended VFA-to-alkalinity ratio is 0.1–0.2, with a ratio greater than 0.5 causing complete system failures (Kinyua et al., 2014). All the investigated digesters were approximately within this recommended VFA-to-alkalinity ratio. The pH measurements indicated that changing sludge recirculation rate did not affect the pH values; pH for effluent of the three reactors was maintained at 7.2 - 7.5, which are in the range for normal operation of anaerobic digestion process (Ratanatamskul & Saleart; 2016).

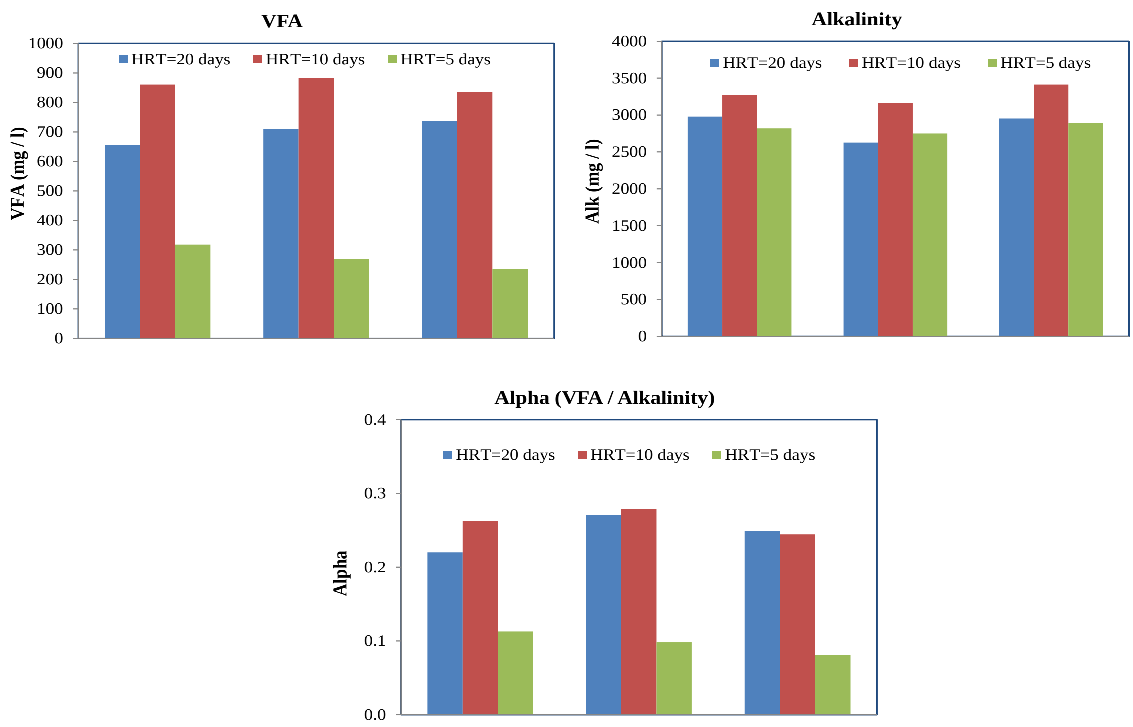


Figure 6 Effect of Sludge Recirculation on VFA Removal

Conclusions

The effect of recycling biomass into anaerobic reactor was studied under varying solid retention times. It was found that the increase of biomass recycling enhances the digester performance and stability. This is due to the increase of active biomass in the reactor. Three pilot scale anaerobic digesters were operated at different sludge recirculation rates. The results indicated that; the sludge recirculation enhanced both the total solid and COD removal ratios by about 20% at different HRTs. The hydraulic loading rate could be increased more than double achieving the same efficiency. The main and most important parameter of the anaerobic digestion process is the produced biogas. At HRT equals 20 days the average daily biogas production enhanced by little values by increasing SRT. At HRT of 10 days increasing SRT increased biogas production by about 20%, finally at 5days HRT the biogas production increased by about 55% when increasing SRT from 5 to 10 days.

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References

Abbasi T., Tauseef S.M. Abbasi S.A., 2012., "Biogas Energy", Springer Briefs in Environmental Science 2. Springer New York Dordrecht Heidelberg London.

American Public Health Association (APHA).(1999). Standard Methods for the Examination of Water and Wastewater.20th ed. APHA, AWWA, WEF, Washington, DC.

Bridgeman J., 2012, "Computational Fluid Dynamics Modeling of Sewage Sludge Mixing in an Anaerobic Digester". Advances in Engineering Software Vol. 44, pp 54–62

Buchauer, (1998). A comparison of two simple titration procedures to determine volatile fatty acids in influents to waste-water and sludge treatment processes "Water SA. 24(1).

Cacho, R. (2005). "Anaerobic Digestion of Excess Municipal Sludge Optimization for Increased Solid Destruction" Ph.D dissertation, Division of Research and Advanced Studies of the University of Cincinnati.

Dong J. N., Hui H., Xiao H. D., and You C. Z., 2013, "Greenhouse gases emissions accounting for typical sewage sludge digestion with energy utilization and residue land application in China" Waste Management Vol. 33, pp 123–128.

Environment Protection Authority, 2000, "Environmental Guidelines for Reducing Greenhouse Gas Emissions from Landfills and Wastewater Treatment Facilities" Environment Protection Authority, Southbank Victoria 3006, Australia.

Ejiroghene Kelly Orhorhoro, Patrick Okechukwu Ebunilo, Godwin Ejuvwedia Sadjere. (2017) Experimental Determination of Effect of Total Solid (TS) and Volatile Solid (VS) on Biogas Yield. American Journal of Modern Energy. Vol. 3, No. 6, pp. 131-135. doi: 10.11648/j.ajme.20170306.13.

Kalloum S., M. Khelafi, M. Djaafri, A. Tahri, K. Kaïdi and A. Touzi. 2012 "Study of start-up of a continuous digester on a laboratory scale treating the sludge issued from wastewater treatment plant in Adrar city (south west of Algeria)" Revue des Energies Renouvelables Vol. 15, No 2, pp 229 – 234.

Kaosol T and Sohgrathok N, 2012 " Influence of Hydraulic Retention Time on Biogas Production from Frozen Seafood Wastewater using Decanter Cake as Anaerobic Co-digestion" Environmental and Ecological Engineering Vol:6, No:5, waset.org/Publication/9213.

Kinyua N. M., Jeffrey Cunningham. and Sarina, J. E. (2014). "Effect of solids retention time on the bioavailability of organic carbon in anaerobically digested swine waste", Bioresource Technology, 162, 14–20

Hallaji S. M., Ali Torabian1, Behnoush Aminzadeh1, Soraya Zahedi and Nicky Eshtiaghi (2018) Improvement of anaerobic digestion of sewage mixed sludge using free nitrous acid and Fenton pre-treatment. Biotechnology for Biofuels11:233.

Lee I. S. , Parameswaran P, Bruce E. Rittmann, 2012 " Effects of solids retention time on methanogenesis in anaerobic digestion of thickened mixed sludge" Bioresource Technology 102 (2011) 10266–10272.

Mehari B. B, Sheng Chang, Youngseck Hong and Han Chen (2018) Temperature-Phased Biological Hydrolysis and Thermal Hydrolysis Pretreatment for Anaerobic Digestion Performance Enhancement. Water, 10, 1812.

Nghiem L. D., Richard Wickham, Dieudonne-Guy Ohandja, 2017. " Enhanced biogas production and performance assessment of a full scale anaerobic digester with acid phase digestion" International Biodeterioration & Biodegradation 124, 162-168.

Rathnasiri P.G. 2016, "Dynamic Modelling and Simulation of Pilot Scale Anaerobic Digestion Plant Treating Source Separated Food Waste And Effect of Recycling Sludge" International Conference On Solid Waste Management, 5iconswm 2015, Procedia Environmental Sciences 35, 740 – 748.

Ratanatamskul C. & Saleart T., (2016) Effects of sludge recirculation rate and mixing time on performance of a prototype single-stage anaerobic digester for conversion of food wastes to biogas and energy recovery. Environ Sci Pollut Res 23:7092–7098.

Ryan Grant, 2011, "Enhanced Biogas Production through the Optimization of the Anaerobic Digestion of Sewage Sludge" Master Thesis, Tuscaloosa, Alabama.

Tawfik A. , M. Sobheyb, M. Badawya 2008 "Treatment of a combined dairy and domestic wastewater in an up-flow anaerobic sludge blanket (UASB) reactor followed by activated sludge (AS system)" , Desalination 227 (2008) 167–177.

Water Environment Federation, (2008) "Operation of Municipal Wastewater Treatment Plants" The McGraw-Hill Companies.

Yan C., Bo F. , Yan W., Qian J., and He L., 2012, "Reactor Performance and Bacterial Pathogen Removal in Response to Sludge Retention Time in A Mesophilic Anaerobic Digester Treating Sewage Sludge" Bioresource Technology Vol. 106, pp 20–26.

Young C. S., Sang J. K., and Jung H. W., 2004, "Mesophilic and Thermophilic Temperature Co-Phase Anaerobic Digestion Compared with Single-Stage Mesophilic- and Thermophilic Digestion of Sewage Sludge" Water Research Vol. 38, pp 1653–1662.

Yue H. 1997. "Laboratory studies on the temperature-phased anaerobic digestion of mixtures of primary and waste activated sludge" PhD dissertation, Iowa State University, Ames, Iowa.

Yeneneh A. M. , Ahmet Kayaalp , Tushar Kanti Sen and Ha Ming Ang, 2015 " Effect of Combined Microwave-Ultrasonic Pretreatment of Real Mixed Sludge on the Enhancement of Anaerobic Digester Performance" Water Air Soil Pollut 226- 314.