Removal of Hydrogen Sulfide in Biogas From Wastewater Treatment Sludge by Real Scale Biotrickling Filtration Desulfurization Process

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Abstract

High sulfur content in excess sludge impacts the production of biomethane during anaerobic digestion, meanwhile leads to hydrogen sulfide (H_2S) formation in biogas. This study aims to reveal the efficiency of the real-scale Biotrickling Filtration Process (BTF) in the removal of H_2S in the biogas formed in the anaerobic digester. The biogas was produced by stabilization of the treatment sludges formed in the processes of Urban Wastewater Treatment Plant with mesophilic anaerobic sludge digesters. It was determined that the anaerobic stabilization unit of the treatment plant was operated efficiently and the biogas with a high flow (18,123-21,383 m^3/day) was formed during the operation of the plant. The H_2S concentration in the biogas at the inlet of the BTF was 3,632 ppmv on average (2,900-4,400 ppmv) and 16 ppmv at the outlet. The elimination capacity of the system reached a maximum of 52.71 $\text{gH}_2\text{S m}^{-3}\text{h}^{-1}$. As a result, a real scale BTF unit was found to provide a sufficient removal efficiency (97.84-99.90%) for H_2S in the biogas.

1. Introduction

Anaerobic digestion (AD) is commonly used in the treatment of organic waste, such as agricultural waste, sewage sludge and organic form of municipal solid waste. During this process, approximately 95% of the organic matter and 95% of the energy present in the substrate are restrained in the biogas. (Guerrero et al. 2015). The biogas produced through anaerobic digestion is an environment friendly and important renewable energy resource (Oztürk 2007; Khoshnevisan et al. 2018). The produced biogas can be burned directly in combined heat and energy conversion plants and can be used as transportation fuel. Biogas is produced through anaerobic digestion of the treatment sludge originating from the wastewater treatment plants. The most important ingredients in the biogas produced by the digestion of the treatment sludges through anaerobic processes are: 60-70% methane (CH_4), 30-35% carbondioxide (CO_2), 1-2% hydrogen sulphide (H_2S) and 0.3-3% other gases (Al Mamun and Shuichi Torii 2015; Rulkens 2008). The components of the biogas can vary depending on the used substrate for the production (Rasi et al. 2007). If the substrate used for biogas production contains sulphur, the formation of hydrogen sulphide (H_2S) is inevitable. (Chaiprapat et al. 2015, Dumont 2015).

The concentration of H_2S in biogas varies from a few hundred to ten thousand ppm depending on the amount of bioavailable sulfur compounds in the feedstock and the outcome of the competition among sulfate-reducing bacteria, acetogens and methanogens for the organic substrates (Stams et al. 2005). The presence of high concentration of H_2S causes corrosion on the equipment and increases the maintenance costs. Especially, due to the corrosive effect on the gas engines, engine life is shortened, the service/maintenance costs increase, and the conversion of biogas to electricity decreases. (Rasi et al. 2011). For this reason, H_2S must be removed from the produced biogas. By the removal of the H_2S , higher quality biogas is produced increasing electricity production and extending the life of equipment used. In addition, H_2S should be removed in terms of health and security (Deublein and Steinhauser 2008).

Actually, H_2S is produced under anaerobic conditions because sulphate (SO_4^{4-}) acts as an electron acceptor while organic compounds are decomposed biologically. H_2S is produced by anaerobic degradation of sulfur-containing compounds (mainly proteins) and reduction of anionic species (especially SO_4^{2-}) in the

feedstock of the digester (Ramos et al. 2013). Kuenen (1975) proposed the mechanism of HS removal that occurs through a series of physico-chemical processes and biological reactions, summarized by Equation (1)-(4) below.

(a) $H_2S_{(g)}$ dissolution in water

(b) H_2S biological oxidation to SO_4^{2-}

(c) H_2S biological oxidation to $S_{(s)}$

(d) $S_{(s)}$ biological oxidation to SO_4^{2-}

All of the processes lead to changes in terms of pH, dissolved oxygen and oxidation-reduction potential (ORP), which can be used to follow and control process performance (Janssen et al. 1998). There are also other reactions that have been reported, including non-biological oxidation of H_2S to thio-sulphate and the further biological oxidation of thio-sulphate to sulphuric acid (Fortuny et al. 2011).

For the removal of H_2S in biogas; solid phase adsorption, liquid phase absorption, membrane separation, chemical, biological, and thermal methods are used (Abatzoglou and Boivin 2009; Wellinger and Linberg 2000; Rasi et al. 2011; Lin 2013; Angelidaki et al. 2018; Diaz et al. 2011; Peluso et al. 2019). The biological desulphurisation of biogas can be performed in additional units mainly using bio-filters and bio-trickling filters during digestion process and by applying microaerobic conditions directly in anaerobic digestors (Ramos et al. 2013). This biological desulphurisation treatment method for the cleaning the contaminated biogas is a relatively new trend and is of great interest. On the other hand other gas desulphurisation methods have high operation costs and produce wastes that must be disposed. Biological desulphurisation method is economically more advantageous and more environment friendly than the other methods. Biological desulphurisation of biogas takes place under low temperature and pressure and can proceed with limited reactive consumption or no reactive consumption (Alvarez 2003; Syed et al. 2006). This treatment method is also more useful because the gas stream contains biodegradable or biconvertible compounds (Gabriel and Deshusses 2003; Tomas et al. 2009).

In bioreactor systems, first hydrogen sulfide in the gas phase is dissolved into sulfur oxidizing bacteria (SOB) containing microbial media, followed by the oxidization of hydrogen sulfide by bacteria with oxygen in the liquid phase (Duan et al. 2006; Park et al. 1999). High elimination capacity and stability in the presence of severe operating conditions are required for bioreactor systems to be able to apply biological methods for the removal of high-strength hydrogen sulfide in a biogas stream. A large number of biodesulfurization processes are present, such as the biofilter processes (Rodriguez et al. 2014; Montebello et al. 2014; Ramos and Fdz-Polanco 2014), the bioscrubber processes (Hansen and Rindel 2000; Valero et al. 2019), and the process using

headspace of the digesters (headspace process) (Ramos and Fdz-Polanco 2012). The differences between these systems are the phase of the biomass (suspended or fixed), the state of the liquid phase (flowing or stationary) and the state of having or not having a carrier material (Ramirez et al. 2009). BTF, the waste air stream passes through a bed which is packed and which has pollutant-degrading organisms immobilized in the form of biofilms. The contaminant either passes from gas phase to liquid phase and later to the biofilm, or directly from gas phase to the biofilm, where it is eventually degraded biologically to harmless compounds (Gabriel and Deshusses 2003). The usage areas of BTF are large-scale gas applications to control and other odorous emissions from WWTPs and other industries (Khanongnuch et al. 2019). Its major advantages are having low operation cost, requiring low-energy and chemicals and having high removal efficiencies (REs), mostly above 99% (Aita et al. 2016). Thus, the aim of the present study is to eliminate H₂S from biogas generated in Konya advanced biological urban wastewater treatment plant sludge through anaerobic processes with the use of real scale biotrickling filtration desulphurisation method.

2. Material And Methods

2.1. Real-Scale Biotrickling Filtration (BTF) Process

This study performed at Konya advanced biological urban wastewater treatment plant with an equivalent population of 1,000,000 and a flow rate of 200 00 m³/day. BTF was used for the purification of H₂S in the biogas collected at the anaerobic digester output used for sludge stabilization. In this process, the H₂S is removed from biogas and biogas is cooled to condense the moisture in it and the condensate is disposed. Biogas collected from anaerobic sludge digesters is transferred to the feeding chamber at the bottom of the closed tower where the BTF unit is located. The biogas moves from bottom to the top and in the tower that contains layers of polypropylene media filling circles (Table 1) where desulphurisation occurs. A complexed culture of sulfur oxidizing bacteria (SOB) dominated by *Acidithiobacillus thiooxidans* acclimated from activated sludge was used as the bacterial strain and a biofilm was formed. In order to supply the substrate for the SOB, treated wastewater was feeded to the feeding chamber at the bottom of the tower. The feeding water was passed through heat exchangers to adjust the temperature to 35-36 °C and it was sprayed to the media material from the top of the tower. Some authors reported for similar sulfide-oxidizing microorganisms, an optimum growth temperature at around 30 °C (Ravichandra et al. 2006; Sanchez et al. 2014). Operation of H₂S biofiltration reactors report 100% removal efficiency at 30-50 °C, but only 20% at temperatures below 10 °C (Yang and Allen 1994). At the entrance point of the desulphurisation unit 1.5-3.5% air was added to the biogas. In this process, O₂/H₂S ratio was 2/1. The end product of oxidation, sulfate (high O₂/H₂S ratio in biofilm) or elemental sulfur (low O₂/H₂S ratio), should vary depending on the availability of oxygen for microorganisms in the bioreactor. If the oxygen is more than the stoichiometric requirement, the formation of elemental sulfur decreases (Buisman et al. 1991). The treated biogas was passed through cooling units to decrease the temperature and moisture before it was feeded into the gas conversion engines. The filtrate collected at the bottom of the unit was discharged into the sulphur fertiliser tank. The sludge layer accumulated on the polypropylene material was disposed from the system by back-washing. The flow diagram of Biotrickling Filtration process is given in Figure 1.

Table 1. BTP media material characteristics

Material	Polypropylen (PP)
Shape	Perforated rings
Size (D1-D2/L) (mm)	100-90/50-35
Colour	Black
Porosity	92%
Specific surface area (m ² /m ³)	140
Weight (gr/adet)	39
Pieces per unit volume (pieces/m ³)	2080
Density (kg/m ³)	80

2.2. BTF Operational Conditions

Real scale BDP design criteria are given in Table 2. The produced biogas consists of 65% methane (CH₄), 34% carbondioxide (CO₂), and 1% H₂S and other gasses. The process was designed for biogas average temperature to be 30 °C and the dilution water average temperature to be 15 °C.

Table 2. Biological desulphurisation process design criteria

Parameter	Unit	Value
Flow rate	Nm ³ /hour	1,500
Inlet H ₂ S concentration	ppm	5,000
Outlet H ₂ S concentration	ppm	200
Inlet biogas temperature	°C	30
Inlet biogas temperature	°C	5
Biogas pressure	mbar	15
Methane (CH ₄)	%	65
Carbondioxide (CO ₂)	%	34
Nitrogen (N ₂)	%	7
Oxygen (O ₂)	%	2

2.3 Monitoring and Analytical Methods

The pH is an important parameter affecting the process efficiency and the system was operated in the pH range of 1.5-3.5. The optimum pH should be in the range of 2-3.5 for activities of sulphate oxidising *Acidithiobacillus thiooxidans* bacteria (Syed et al. 2004; Montebello 2013; Rodriguez et al. 2014). Kim and Deshusses (2005) reported that the biological activity of microorganisms was inhibited due to the low pH and high sulfate content

(at pH 2 the sulfate content in the water was 1,900 ppm). In order to monitor and control of the environment conditions of sulphur bacteria taking active role in the system, full automation (SCADA) system was used. In this biological desulphurisation process; biogas flow meter, air flow meter, circulation liquid flow meter, pH and temperature measurement devices, dilution (addition) liquid indicators, biogas oxygen analysis system, sulphur removal tower, tank level indicator, gas detector, pressure indicator, and other instruments were used. In order to compare the ability of biofilters on the same basis, the elimination capacity (EC) was used. It represents the ability in removing pollutants in gaseous form compared to the incoming pollutant mass, expressed as the mass of pollutant removed per unit time per bed volume. The parameters used in this study to describe the operating conditions and for the determination of the removal performances are given in Table 3.

Table 3. Process control parameters used in this study

	Formula	Nomenclature
Loading rate ($\text{gH}_2\text{S m}^{-3}\text{h}^{-1}$)	$LR = \frac{Q}{V} C_{in}$	C_{in} = concentration of H_2S in gas entering biofilter (ppm_v)
Elimination capacity ($\text{gH}_2\text{S m}^{-3}\text{h}^{-1}$)	$EC = \frac{Q}{V} (C_{in} - C_{out})$	C_{out} = concentration of H_2S in gas exiting biofilter (ppm_v)
Removal efficiency (%)	$RE(\%) = \frac{(C_{in} - C_{out})}{C_{in}} \times 100$	Q: Flow rate of mixed gas entering biofilter (m^3/h)
Empty Bed Residence Time (min)	$EBRT = \frac{V}{Q}$	V: Empty packed bed volume (m^3)

H_2S removal efficiency of real scale BTF system was monitored for twelve months between January 2017 and December 2017 and the performance of the process was evaluated. During this period, the flow rate of biogas produced in the anaerobic sludge digesters, minimum, maximum, and average values of H_2S level in the biogas and at the process outlet were monitored on a monthly basis to determine the H_2S removal efficiency of the process. During this study, biogas flow was measured by flow meter (Drager) and H_2S concentration was measured by H_2S measurement tubes (Rea) and analyzed by colourmatic method (TS EN 1231: 2000).

3. Results And Discussion

3.1 Anaerobic Digester and Biogas Production

The flow rate of biogas and the H_2S concentration in the biogas were measured for the efficient process operation. The operational parameters of the mesophilic anaerobic sludge digester (pH, organic loading rate, sludge feeding rate, ambient temperature, volatile organic acid concentration, sludge retention time) during the operation of the biological desulphurisation process, were given in Table 4. The characteristics of sludge at the inlet and outlet of sludge digester (total solid material, chemical oxygen demand, protein, alkalinity) were given in Table 5. The most important indicator showing the efficient operation of the anaerobic sludge digesters is the biogas production. During the working period, the flow rate of biogas produced in anaerobic sludge digesters varied between 18,123-21,383 m^3/day and an average of 19,519 m^3/day (Table 6) (Figure 2). However, the

range of percentage composition of the biogas produced from AD processes is dependent upon several factors including the digestibility of organic matter, digestion kinetics, digester retention time, and the digestion temperature (Dobre et al. 2014).

Table 4. Anaerobic sludge digester operation parameters

Parameters	Value
pH	7.3-8.1
Organic loading ratio (OLR) (kg/gün/m ³)	1.2–1.5
Sludge feed flow (m ³ /h)	16–17
Temperature (°C)	36-41
Volatile fatty acid (VFA)/Alkalinity	0.02-0.08
Sludge Retention Time (SRT) (day)	17

Table 5. Sludge characteristics in anaerobic sludge digester

Parameters	Feed Sludge	Anaerobic sludge digester outlet
TS (mg/L)	25,100-37,500	21,000–30,100
COD (mg/L)	19,100–32,000	9,400–19,000
TKN (mg/L)	1,500–4,150	1,300–4,700
Protein (mg/L)	11,000–23,100	7,400–22,000
Alkalinity (mg/L)	720-1300	2,450–3,900
VFA (mg/L)	450-1450	60–230

3.1. Hydrogen Sulfide Removal from Biogas

The inlet H₂S concentration was routinely measured per day to assess the variation of the inlet H₂S load. H₂S concentration of biogas at the inlet of the BTF unit varied between 2,900–4,400 ppm and an average of 3,632 ppm (Table 6). The H₂S concentration in biogas is consistent with the literature (Jenicek et al. 2008; Charnnok et al. 2013; Reddy et al. 2019;). The biogas generated in anaerobic digestion facilities in WWTPs contains average concentrations of H₂S in the range from 0.1 to 0.5 vol. % (1000-5000 ppmv) (Walsh et al. 1998). At the outlet of the BTF process, H₂S concentration varied between 4-63 ppm and an average of 16 ppm. (Figure 3). No relation was determined between the biogas flow rate produced in anaerobic sludge digester and the H₂S concentration in the biogas. It is thought that H₂S is produced depending on the other factors (protein and sulphate concentrations in wastewater, etc.) completely independent from the produced biogas quantity.

Table 6. Operation parameters for BTF

Time	Biogas (m ³ /d)	Inlet [H ₂ S] _{biogas} (ppm _v)	Outlet [H ₂ S] _{biogas} (ppm _v)	H ₂ S LR (gH ₂ S m ⁻³ h ⁻¹)	EBRT (min)	EC (gH ₂ S m ⁻³ h ⁻¹)	H ₂ S removal efficiency (%)
January	19,627	2,923	63	33.47	7.34	32.74	97.84
February	19,581	3,233	14	36.93	7.35	36.77	99.57
March	19,673	3,200	23	36.72	7.32	36.46	99.28
April	19,714	2,900	12	33.35	7.30	33.21	99.59
May	19,526	3,253	17	37.05	7.37	36.86	99.48
June	18,233	4,103	6	43.64	7.90	43.58	99.85
July	18,123	4,000	20	42.29	7.95	42.08	99.50
August	18,683	3,900	4	42.50	7.71	42.46	99.90
September	20,583	4,400	10	52.83	7.00	52.71	99.77
October	21,383	4,133	4	51.55	6.73	51.50	99.90
November	18,617	3,433	11	37.28	7.73	37.16	99.68
December	20,483	4,100	12	48.99	7.03	48.85	99.71
Average	19,519	3,632	16	41.38	7.39	41.20	99.55

Since the produced biogas is used in the production of electrical energy, H₂S needs to be removed due to the corrosive effect of H₂S on gas engines and other auxiliary equipment. For this reason, H₂S concentration should be reduced up to the limit value (≤ 260 ppm) determined for gas engines before biogas is given to gas engines. The recommended level of H₂S in the produced biogas is in the range of 0.02 to 0.05% (w/w) (200 to 500 ppm) while H₂S-free biogas is more desirable (Rodriguez al. 2014). During the working period, the H₂S removal efficiency ranged between 97.84-99.90% and an average of 99.55 %. (Table 6). In January 2017, when the performance of the process started to be monitored, H₂S removal efficiency was observed to be 97.8% and increased during operation to 99% (Figure 4). It was determined that the H₂S concentration at the outlet of BTF process was well below the determined limit value.

The elimination capacity (EC) and RE as functions of the load supplied to the system were analyzed for BTF reactor. Figure 4 shows the removal efficiency and elimination capacity of H₂S monthly. EC changes as a function of EBRT and LR values. In BTF process, EBRT values were between 6.3-7.95 min, LR values were between 33.35-52.83 g H₂S m⁻³h⁻¹, EC values were between 33.21-51.71 g H₂S m⁻³h⁻¹ (Figure 4). The average H₂S removal was 99.9% at EBRT of 7.39 min (i.e., a LR of 41.38 g H₂S m⁻³h⁻¹). In addition, the elimination capacity and H₂S removal efficiency of this study BTF process performance well when compared to the previous studies (Table 7).

Table 7. Comparison of the performance of BTF reported in the literature on the treatment of biogas polluted by H₂S

Scale	Type bed	Packed Bed volume	Inlet [H ₂ S] (ppmv)	Gas residence time (EBRT)	Elimination capacity (EC) g H ₂ S m ⁻³ h ⁻¹	H ₂ S RE (%)	Reference
Lab-scale	Polypropylene pall rings	1L	170	36 s	20	100	Cox and Deshusses 2001
Lab-scale	HD-QPAC	2 L	2000	3 min	55	99	Maestre et al. 2010
Lab-scale	Polypropylene rings	1L	5415	5.5 min	89.4	100	Zhou et al. 2015
Lab-scale (bench)	Calgon AP460	6.4 L	20-100	4-16 min	22.1	90	Duan et al. 2005
Lab-scale (pilot)	Plastic pall rings	5.15 m ³	1954±454	180 min	50 ± 11	94	Rodriguez et al. 2014
Lab-scale	HD Q-PAC	2.15 L	2000-8000	180 s	50	100	Montebello et al. 2010
Lab-scale (pilot)	Metallic Pall rings (AISI 316)	2 L	2000	180 s	100-140	95-100	Montebello et al. 2012
Lab-scale	Polypropylene Pall rings	2 L	2000	131 s	50-100	35-100	Montebello et al. 2013
Lab-scale	Metallic Pall rings	2.4 L	2000-10000	130 min	100-140	70-80	Montebello et al. 2014
Lab-scale	HS- Q-PAC	2.15 L	900 - 10000	180 s	200	84	Fortuny et al. 2008
Lab-scale	HD-Q-PAC	2 L	2000	167-180	84	97 ±0.3	Fortuny et al. 2011
Lab-scale	Polypropylene pall rings	2.4 L	850-8500	2.4-3.5	99.8–130	99	Fernandez et al. 2014
Lab-scale (pilot)	Polyurethane foam	600 m ² m ⁻³ surface area	5-25	15-40 s	15-95	99	Gabriel and Deshusses 2003

			and 35 kg m ⁻³				
Lab-scale (pilot)	Ceramic granules Volcanic rocks	1177 L	2.84± 1.76 mg/m ³	5-20 s	2.82- 2.85	60- 100	Li et al. 2012
Full-scale	Polypropylene pall rings	-	3000	180 s	170	90	Tomas et al. 2009
Lab-scale (pilot)	BioSulfidEx	2.21 m ³	500- 600	84	32.3	98	Naegele et al. 2013
Lab-scale	Polyethylene (HDPE)	1 L	0-2040	120	78.57	100	Vikromvarasiri et al. 2017
Lab-scale (pilot)	Commercial polyester fibers	12 L	1000- 4000	10.29-72 min	14.58	100	Soreanu et al., 2008
Lab-scale	Schist	7.85 L	1100	300 s	30.3	100	Jabera et al. 2017
Lab-scale	3D-printed honeycomb monolith	0.2 L	2000	41 s	122	95	Qiu et al. 2017
Lab-scale	K1 packing material	0.5 L	200	40–100 s	-	92.27 ± 10.30	Zhuo et al. 2019
Lab-scale	HDPE Plastics	1 L	2000	120 s	82.98	99.5	Juntranapaporn et al. 2019
Lab-scale (Semi-pilot)	Polypropylene Pall rings	4000 L	2000	15 min	29.5	94.6- 99.6	Reddy et al. 2019
Lab-scale	Bamboo charcoal	643 L	5-20	10.9– 28.9 s	6.58	99.8	Chen et al. 2019
Lab-scale	Polyurethane foam	3 L	1246- 305	1.6 min	98	95-99	Tayar et al. 2019
Lab-scale	Polypropylene pall rings	2.8 L	2000	118 s	120	100	Lopez et al. 2019
Pilot scale	Polypropylene spheres	440 L	1.2 g/m ³	40 s	122	100	Xia et al. 2019
Lab-scale	PUF cubes	3 L	4000	3 min	113.5	97	Watsuntorn et al. (in press)

Real-scale (WWT)	Polypropylene pall rings	100,000 L	2900– 4400	6-8 min	33-53	98- 100	This study
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3.3. Microbial community

In effective removal of H₂S, microorganisms have important roles. Sulfide oxidizing bacteria (SOB) are gram negatives which can use sulfide and thiosulfate as an energy source. Due to their ability to tolerate a pH swing between 1.5 and 3.5, SOB *Acidithiobacillus thiooxidans* was found to be a major microorganism group in our biofilter in the present study. This bacterium is thought to be an ideal inoculum for the biofiltration of H₂S in biogas and it is the most acidophilic SOB (Aita et al. 2016; Ramirez et al. 2016). It has a pH range between 0.5 and 5.5 and an optimum at pH 2-3 for growth (Wang et al. 2019). In this technology, the headspace of anaerobic digesters functions as a H₂S abatement unit that causes the development of various microaerophilic SOBs such as *Acidithiobacillus sp.*, *Arcobacter sp.*, *Sulfuricuvum sp.*, *Sulfurimonas sp.*, *Thiobacillus sp.*, *Thiofaba sp.* and *Thiomonas sp.* in case of the development of limited amount of O₂ (Diaz et al. 2011; Kobayashi et al. 2012; Rodri Guez et al. 2012). This result is similar to the results of Lee et al. (2006) which showed that in degradation of H₂S, *Thiobacillus thiooxidans* proliferating between pH 2 to 0.5 and *Acidithiobacillus thiooxidans*AZ11 could grow at pH as low as 0.2. It was reported that it was still possible to reach high removal efficiencies of 99.9%, 98.0%, and 94.0%, respectively. In acidic conditions, *Acidithiobacillus sp.* was reported to reach an H₂S elimination capability (EC) of 113 (Aita et al. 2016), 150.3 (Charnnok et al. 2013) and 113.5 gH₂S/m³ /h (Chaiprapat et al. 2011). Our EC 35 gH₂S/m³/h at the condition for H₂S removal is similar to those reported in the aforementioned *Acidithiobacillus sp.* predominant experiments. pH of the recirculating fluid was found to decrease rapidly and vary between 1.5 and 3.5. It can be seen from the results that the SOB culture in the BTF reactor has already adapted to the condition of inlet H₂S concentration and eliminated H₂S in biogas.

4. Conclusion

In this study, the removal of H₂S from the biogas that was produced at real scale anaerobic sludge digester by BTF process was investigated. Average biogas flow rate produced in mesophilic anaerobic sludge digester varied between 18,123–21,383 m³/day and H₂S concentration vaeried between 2,923-4,400 ppm_v. It was observed that the H₂S concentration in the produced biogas is completely independent from the biogas flow rate. The removal of high concentrartions of H₂S in biogas was accomplished by real scale BTF process with SOB bacteria (*Acidithiobacillus Thiooxidans*) which active at acidic environment (pH 1.5-3.5.). BTF process was operated at; pH:1.5-3.5, O₂/H₂S:1/2, EBRT:6.3-7.95 minutes, LR:33.35-52.83 g H₂S/ m³h⁻¹. The H₂S removal efficiency (RE) varied in the range of %97.84-99.90 and H₂S elimination capacity (EC) varied in the range of 33.21-52.71 gH₂S m⁻³h⁻¹. The process efficiency was found to be independent of inlet H₂S concentration. The average H₂S values in biogas desulphurized by BTF process ranged between 4-63 ppm. As a result, BTF process regardless of the biogas flow and inlet H₂S concentration was found to be an effective and efficient process for the removal of H₂S from biogas produced in the real scale anaerobic sludge digester.

Declarations

Ethics approval: Not applicable

Consent of Participate: Not applicable

Availability of data and materials: Not applicable

Competing interests: We declare that they have no conflict of interest.

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Code availability (software application or custom code): Not applicable

Consent for publication: Not applicable

Authors' contributions: All authors contributed to the study conception and design. Material preparation and data collection was done by SK. The study of analysis was performed by SA. The first draft of the manuscript was written by SA and SK commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Real scale biotrickling filtration (BTF) process

Figure 2

Variation of biogas production

Figure 3

Variation of H₂S concentration at BTf inlet and outlet

Figure 4

Variation of H2S removal efficiency and elimination capacity (EC).